Lake Tahoe Basin Management Unit

Riverine Restoration Program

2003—2014

An overview of ecosystem benefits achieved and lessons learned

March 2015

Acknowledgments

This document is written from my perspective as the Riverine Restoration Program Leader at the LTBMU since 2008. Although I was the primary author for many of our effectiveness monitoring reports, during implementation I served as the mid-level manager providing office support and running interference as needed for my staff in the field. This document could not have been produced without the efforts of the actual on the ground project leaders; Theresa Cody, Stephanie Heller and Craig Oehrli. They were the ones who put in the long and often difficult hours overcoming the day to day challenges of getting a successful restoration project in the ground. I pulled much of the information in this document from their experiences, and they provided valuable review and input.

I also would like to acknowledge Jeff Reiner, the visionary who proceeded me in this position and laid the groundwork for the program of work described in this document.

Being a part of the dedication and passion displayed by the many individuals involved in planning, designing, building, and monitoring these projects has been one the most rewarding experiences of my Forest Service career. It is an honor to be a part of the legacy this work will leave on the Lake Tahoe landscape for the decades to come.

Sue Norman, Hydrologist

Introduction

The science of riverine restoration, determining how to best address past land management practices that have resulted in disrupting the natural resiliency and stability of stream channels, is still an evolving field. Natural channels exist in a state of dynamic equilibrium, in which channel forms evolve relatively slowly in response to natural variability in weather and geologic events, while maintaining characteristics that support healthy aquatic and riparian habitat. Degraded channels and associated floodplains are typically the result of decades of human actions that have stressed the system beyond its carrying capacity (such as over grazing, or rapid urbanization including road building). While there are patterns in the nature of impacts from legacy land use practices, the land use history and watershed setting of each system is unique, and both need to be considered in determining the appropriate restoration approach.

The key in determining the appropriate restoration approach is clearly identifying the desired outcome. Meaning based on the streams history and current condition, what actions should be taken to set the system on a trajectory that restores ecological function, stability, and resiliency over time. Some ecosystem components may be restored very quickly as a result of restoration actions, but in severely degraded systems full restoration of ecological function as measured by biological indicators may take many years to be achieved. Restoration actions will not be static, the stream channel and floodplain will continue to evolve in response to natural stressors including large floods, and climate change effects on precipitation regimes. Sometimes success will be measured by achieving full restoration of multiple ecosystem functions in less then two decades, as opposed to over 50 years or longer if the system is left on its own. What is important is the long view, seeking restoration approaches that not only demonstrate success in the short term, but will also be judged as a success by the next generation of geomorphologists, hydrologist and biologists. Riverine systems provide some of the most valuable and diverse ecological habitats in our landscapes, and as such are important areas for investment by land management agencies.

The LTBMU does not purport to have all the answers. But over the past two decades, our organization has had the opportunity to apply the most current restoration principles to the art and science of stream channel restoration, including rigorous post project monitoring. From sharing our experiences we can contribute to advancing learning in this field, through both our successes as well as those efforts that fell short. The purpose of this document is to provide an overview of those efforts, including a narrative summary describing the degree to which our restoration goals have been achieved, as well as lessons learned. This document does not attempt to synthesize our quantitative monitoring data results because of the inherent complexity of that analyses. But we encourage current and would be practitioners to dive into those specifics within the monitoring reports cited at the end of this document, easily obtained on the LTBMU website. We hope our experiences will help others who are endeavoring this extremely challenging, and rewarding area of ecosystem restoration.

LTBMU Ecosystem Services Restoration Goals

At the outset for each project a set of specific restoration goals were identified during the planning process, based on the restoration potential determined for the site. This helped not only guide the development of the restoration approach, but was also useful for providing the framework for project effectiveness monitoring. Although specific restoration objectives differed somewhat between projects, the following summarizes the restoration goals that apply to the LTBMU riverine restoration program as a whole.

- ***Raise elevation of incised channels relative to the floodplain surface to restore hydrologic connectively to the floodplain, increasing frequency and duration of floodplain inundation, and groundwater levels.***
    - ◊ Resulting in reduced /attenuated peak flows and filtering of sediment and nutrients onto the floodplain.
    - ◊ Resulting in increased plant available water, late in the summer.
    - ◊ Resulting in transformation of floodplain vegetation and wildlife communities to wet meadow flora and fauna.

- ***Construct/reconstruct channels with appropriate geomorphology, gradient, sinuosity, and structural components to provide dynamically resilient channels with high quality aquatic habitat features.***
    - ◊ Resulting in overall reduction in stream channel erosion (and reducing fine sediment affecting Lake Tahoe clarity).
    - ◊ Providing high quality habitat for desired aquatic species, including potential future reintroduction of native species, like Lahontan Cutthroat Trout.

All stream channels within the LTBMU were extensively inventoried during the 1980's through the 1990's, utilizing a variety of protocols including Watershed Improvement Needs (WIN) Inventories, Fish Habitat Surveys, and Geomorphic Condition surveys. These inventories documented a variety of metrics evaluating channel stability and aquatic and adjacent meadow/ floodplain habitat quality.

From these data, LTBMU staff identified a number of watersheds in the Basin that exhibited severely degraded channels. The most degraded streams and associated riverine floodplain and meadow systems were prioritized for more detailed ecosystem assessments to identify restoration opportunities. Although various attempts at stream channel restoration had been attempted during the 1980's and early 90's, we still lacked the expertise to fully understand the ecosystem processes at risk. While these efforts did result in net benefits in terms of channel stabilization, the effectiveness of these earlier restorations to significantly improve ecosystem function was limited.

The Projects

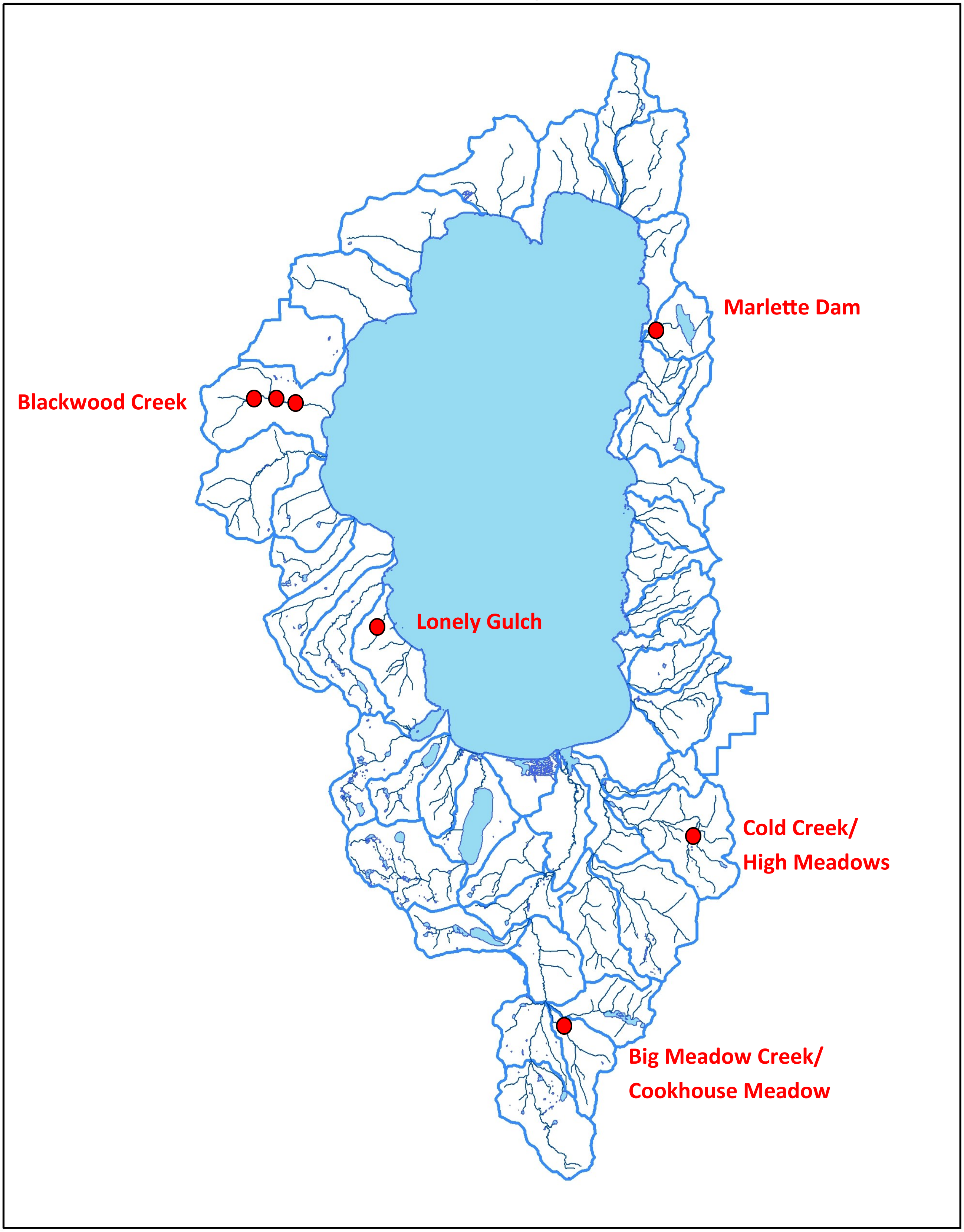
From ecosystem assessments conducted during the late 90s, a variety of stream channel and floodplain restoration opportunities were identified to restore the most degraded channel reaches and reconnect these reaches to adjacent riverine floodplains. These assessments identified reaches and floodplains in the Lake Tahoe basin that had the most potential for benefits in terms of restored ecosystem function, including reducing accelerated channel erosion to Lake Tahoe, improving aquatic habitat, and increasing wet meadow habitat. In addition it became clear that restoring geomorphic function would ultimately increase overall resiliency of these riverine systems to future high flows, which are predicted to occur more frequently due to localized impacts of climate change.

Because of the inherent risk and complexity in constructing stream channel and floodplain restoration projects, the LTBMU chose a deliberate strategy for implementation, starting with smaller scale efforts first. The restoration approaches warranted in the most degraded systems required bold action, involving large scale reconstruction of stream channel/floodplain morphology, in environmentally sensitive and technically challenging environments. As our technical and workforce capacity and efficiency increased, the LTBMU Riverine Restoration program gradually ramped up implementation efforts.

To date, the LTBMU has implemented restoration actions on 4.2 miles of stream channel, which has also improved ecosystem function on a total of 210 acres of adjacent floodplain. Fortunately the LTBMU has had funding provided through direct congressional appropriations as well as grants from the Bureau of Land Management through the Southern Nevada Public Lands Management Act. These funds have been utilized to not only construct large scale riverine restoration projects, but also implement sufficient quantitative pre and post project monitoring to determine whether the restoration approaches implemented have been successful in improving ecosystem function. The Table below provides basic information about each of the projects that are discussed in this document, and their approximate location is provided on the map on the next page.

Name	**Year Complete**	**Implementation Costs**	**Riparian Acres Restored**	**Stream Channel Stabilized(ft)**
Lonely Gulch Stream Channel Stabilization	2003	$75,000	3	400
Marlette Dam Removal and Stream Channel Stabilization *	2003	$190,000	6	500
Blackwood Creek Fish ladder removal and Culvert Replacement	2003 and 2006	$950,000	6	800
Cookhouse Meadow Restoration	2006	$600,000	20	2,500
Blackwood Creek -Reach 6 Restoration	2009	$1.75 million	40	3,500
Blackwood Creek -Reach 1 Restoration	2012	$1.1 million	35	4,000
Cold Creek/High Meadows Restoration	2012	$ 1.9 million	100	10,500
Total		$6.5 million	210	22,200

Location of LTBMU Riverine Restoration Projects in the Lake Tahoe Basin



The following briefly describes the primary cause of stream channel degradation, and the restoration approach to restore ecosystem function for each of the projects listed in the previous table.

Lonely Gulch Creek

Lonely Gulch Creek Prior to Restoration

Lonely Gulch Creek is a west shore tributary of Lake Tahoe. The contributing watershed area above the project is approximately 3mi^2. It is a high gradient forested stream bordered by a narrow willow-alder dominated riparian corridor. Common stream bed forms are step pools, high gradient riffles, and cascades. This type of channel is characteristically stable; however this pre project 2002 photo shows the combined effects of an unnaturally dense forest, and channel banks destabilized by the record January 1997 flood.

Restoration completed in 2003 was designed to arrest accelerated channel erosion in a 400 foot reach. The goal of site stabilization was to provide the structural foundation to support stream riparian vegetation recovery.

Treatments involved stream bank reshaping, strategic placement of stream bed and bank protection utilizing logs and boulders collected on-site, and planting willow and alder shrubs to initiate riparian vegetation recovery.

Marlette Creek

Marlette Dam was an un-maintained earthen dam with a large gully below the dam's spillway caused by past storm events. The gully eroded approximately 200 cubic yards of soil from one side of the valley, undermining the riparian forest and lowering the base level of the original stream channel. In addition, the reach 50 feet directly upstream from the inlet to the reservoir was experiencing active bank erosion and there was a large depositional zone where the stream dropped its sediment load as it flowed into the reservoir.

The Marlette Creek Dam Removal and Restoration Project was implemented in August of 2003, and involved the removal of the earthen dam and reconstruction of the stream channel for approximately 200 feet through the reservoir site created by the dam.

Marlette Dam and Reservoir prior to restoration.

Blackwood Creek

Research shows that Blackwood Creek has one of the highest sediment loads to Lake Tahoe. A Blackwood Creek TMDL (adopted by the EPA in 2008) supports actions to restore aquatic habitats in degraded stream segments. The Lake Tahoe TMDL (adopted by the EPA in 2011) also identifies Blackwood as one of two priority streams for stream channel restoration in the Lake Tahoe Basin.

The USFS had identified Blackwood as a priority for restoration, long before these state and federal regulatory actions. Watershed assessment identified numerous impediments to ecosystem function throughout the main stem of Blackwood creek. This included an outdated fish ladder and large road culvert crossing that were found to impede fish passage and bed load transport, as well as contribute to degradation of adjacent channel morphology.

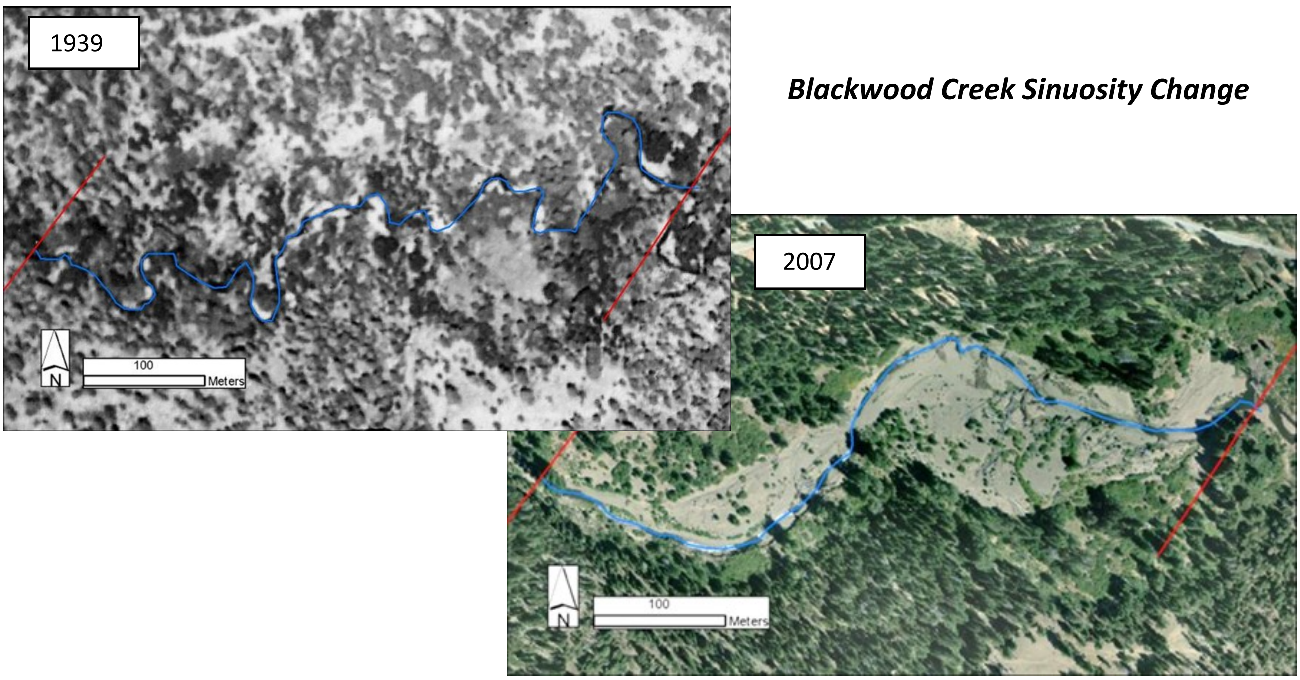
Blackwood creek fish ladder prior to removal

Blackwood Creek culvert prior to removal

In addition, cumulative impacts of historic grazing, road building, logging, and in-stream gravel mining set the stage for widespread channel and floodplain destabilization during flood events. As a result of gravel mining in the 1960s, primarily for the Squaw Valley Olympics, a 4,000 foot reach of Blackwood creek was deepened and straightened to improve gravel extraction operations, resulting in 4 to 6 feet of channel incision. This in turn caused the "drying out" of gallery cottonwood and promoted conifer invasion into the riparian areas adjacent to the channel.

As illustrated by aerial photos dating back to 1939, much of the main stem channel in the valley was historically a narrow, sinuous stream with vigorous riparian vegetation and a well-connected floodplain. By 2007, cumulative channel and floodplain destabilization resulted in a straightened channel flowing through a sparsely vegetated gravelly inset floodplain bordered by vertical cut banks. Channel erosion processes resulted in floodplain incision of up to 8 feet in depth and over 100 feet in width, with over 70 % of the channel banks in an unstable condition.

Blackwood Creek Sinuosity Change



Between 2003 and 2006, the U.S. Forest Service removed the concrete fish ladder and replaced a large culvert with a bridge, including reconstruction of adjacent stream channels at both sites. These features were replaced with a series of constructed boulder step pools to maintain a stable stream profile, while restoring function in terms of coarse bed load sediment transport and fish passage.

In 2008 and 2009, the USFS reconstructed 3,500 feet of channel within 40 acres of adjacent inset floodplain, within the most degraded reach in Blackwood Creek. To maintain flow dynamics within the reconstructed channel and floodplain, 12 rock-log flow deflection structures and 28 log-based floodplain roughness structures were installed. Existing vegetation was transplanted and augmented by riparian vegetation planting to provide a seed source for future vegetation recovery.

In 2010 and 2012, the USFS reconstructed stream channels and floodplain morphology to restore flow dynamics within another 4,000 foot reach of Blackwood Creek and hydrologic connectivity to 35 acres of adjacent floodplain. Restoration actions consisted of constructing boulder grade control weirs and sills and importing river alluvium to raise the river bed 3 feet in elevation, re-shaping stream channels and associated floodplain, and installation of wood debris/bank protection structures.

Construction of rock/log flow deflection structure in Blackwood Creek

Construction of boulder grade control weir in Blackwood Creek

Big Meadow Creek—Cookhouse

The existing Big Meadow creek channel through Cookhouse meadow, incised 8 feet over a period of 30 years, as a result of the installation of a highway culvert and over grazing (illustrated in the photo to the right, taken in 1981). This channel incision resulted in lowering the ground water table, preventing overbank flows from flooding out into the meadow resulting in a conversion to dry site meadow vegetation and degraded riparian habitat.

Big Meadow creek prior to restoration

In 2005 and 2006, the USFS constructed 2,400 feet of new channel and obliterated 1,400 feet of existing deeply incised and eroding stream channel. This was the first project implemented by the LTBMU in which it was possible to salvage and harvest native vegetation at a large scale to quickly create stable channel bank and floodplain surfaces immediately post construction. This was also the first large scale project constructed by the LTBMU utilizing only USFS staff. This significantly reduced cost, and allowed greater flexibility in implementing “field fits” when unexpected site conditions were identified during construction.

Placement of salvaged sod on newly constructed stream banks at Cookhouse

Cold Creek—High Meadows

The Forest Service acquired 1,790 acres of land in January 2003 located in the upper Cold Creek Watershed, including a 200-acre montane meadow complex known as High Meadows. This landscape was highly altered and degraded since the mid-nineteenth century by logging, and over 100 years of cattle grazing and associated diversion ditches. Like Cookhouse Meadow, this led to down cutting and widening of the stream channel, resulting in a lowered groundwater table, drying out of the meadow vegetation and lodgepole pine encroachment (illustrated in photo to right taken in 2004).

Cold creek prior to restoration

Restoration actions were similar to Cookhouse Meadow, with abandonment of the existing channels to be replaced with 3,600 feet of new channel. In addition 1,500 feet of one of the tributaries to the main channel was restored through the placement of wood debris structures. Approximately 1/3 of the wood structures were installed by equipment and the rest installed by hand. Eight acres of dead lodgepole pine that had recently suffered mortality from a large scale bark beetle infestation was removed from the meadow boundary. This project used similar sod harvest and salvage techniques utilized at Cookhouse meadow, and again was implemented completely by USFS staff. Because of the remote location of this site all rock/gravel substrate used in constructing restored stream channels was harvested on site.

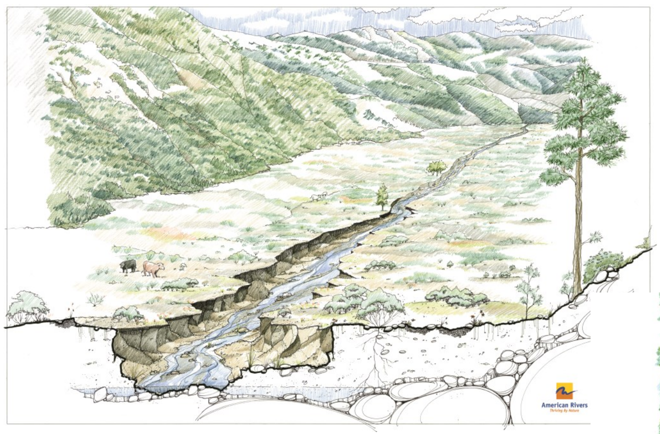
New channel construction at Cold Creek

Effectiveness Monitoring Results

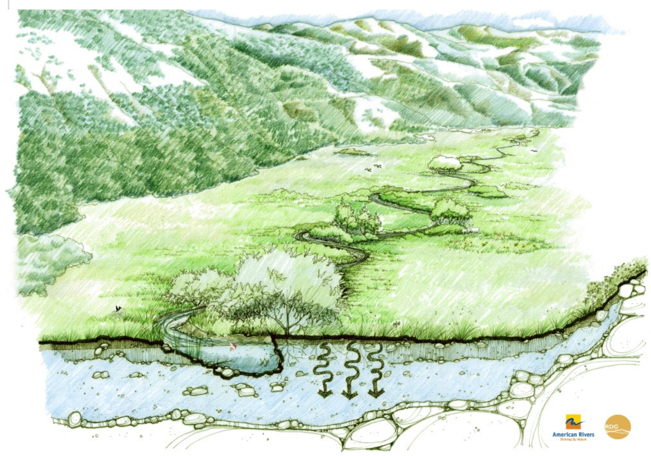
As described in the introduction, specific restoration goals were identified for each project based on the restoration potential determined for the site. These goals provided the framework for the development of the restoration approach, as well as project effectiveness monitoring. Although specific restoration goals differed somewhat between projects, the following were the overall riverine restoration program goals:

- Restoring hydrologic connectivity between stream channels and adjacent floodplains.
- Restoring dynamically resilient channel morphology

The two diagrams below provide a visual illustration of the desired outcome from riverine restoration efforts in meadow systems.



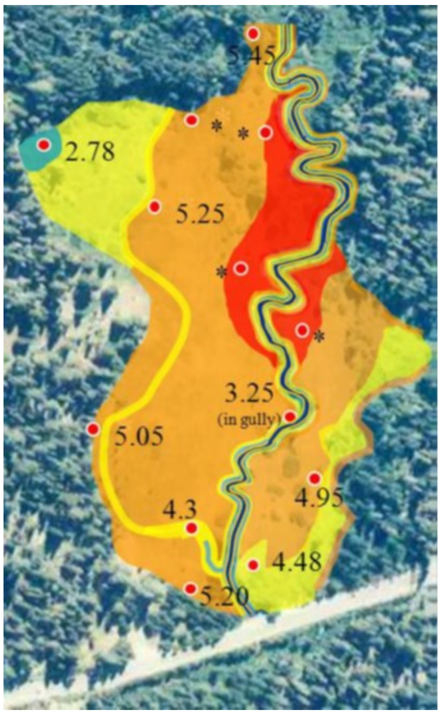
Riverine restoration in meadow systems, replacing unstable, incised streams with poor habitat (left) with resilient stream channels that provide high quality habitat, and restored natural water storage and treatment capacity (below).

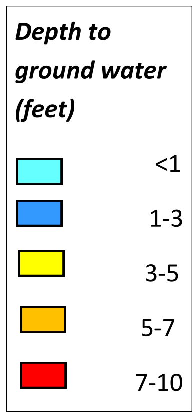


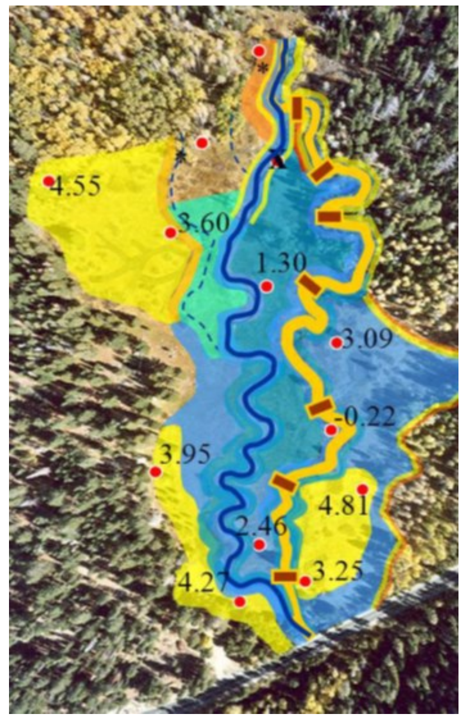
Healthy riverine systems exist in a complex state of dynamic equilibrium that is uniquely adapted to the environmental factors and constraints within that system. A system in dynamic equilibrium can be defined as one that maintains functional stability while adapting to constant change from outside sources. Determining whether restoration has helped move these systems towards this dynamic resiliency, requires long term restoration monitoring using a variety of ecosystem metrics. The following narrative and photos describe the ecosystem services benefits that are supported by project monitoring results so far, as it relates to achieving the above riverine restoration program goals.

Restoring hydrologic connectivity between stream channels and adjacent floodplains

Several of the completed projects have shown dramatic and rapid changes in restoring hydrologic connectivity to restored river channels and their adjacent floodplains and meadows. In Cookhouse Meadow and High Meadows this has been documented through groundwater monitoring, which has shown that the extent and duration of plant available ground water during the late summer has increased in much of the adjacent meadow floodplain. The figure below illustrates this change at Cookhouse Meadow.







July 2004, Cookhouse Meadow (pre-project)

July 2007, Cookhouse Meadow (post-project)

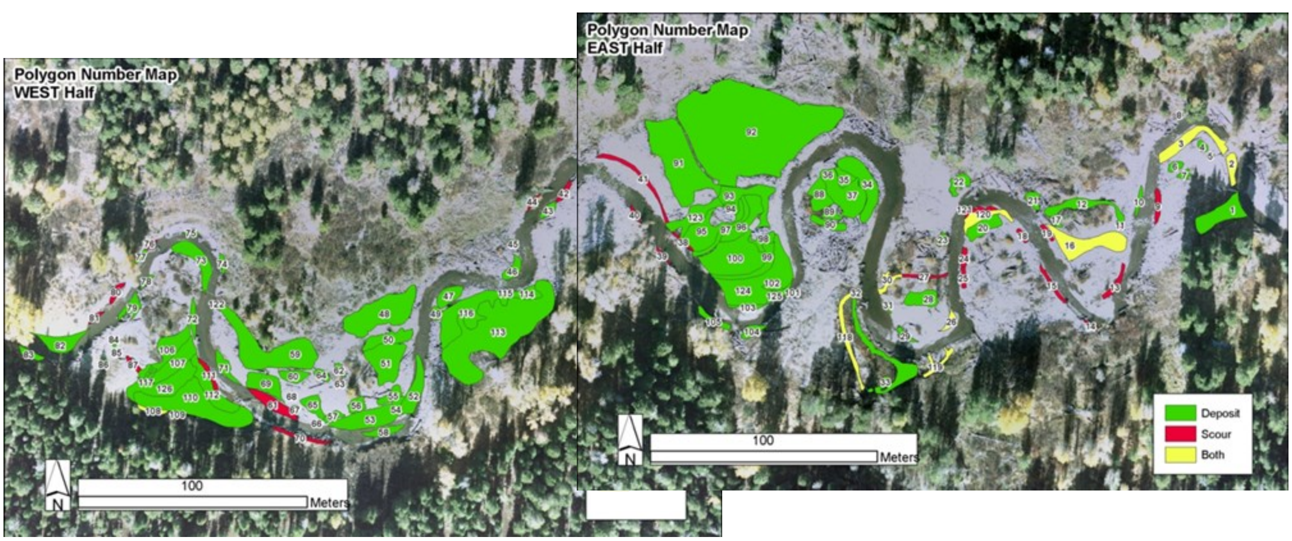
The years 2004 and 2007 were very similar water years so the difference in groundwater elevations cannot be attributed to differences in precipitation. The areas in red and orange have groundwater levels well below that which is available for plants (>5 feet depth). The areas in blue and green are well within the range available to plants (<3 feet depth), and the areas in yellow are between 3 to 5 feet in ground water depth, meaning they sometimes are within the range available to plants (approximately 4 feet).

Long term monitoring of riparian vegetation and animal species at Cookhouse meadow has documented that five years post construction the plant community has transitioned to wet meadow species. Additionally, species richness and presence of desired species has increased for three wildlife indicators (butterflies, reptiles, and birds).

The photos below illustrate the "greening" that has occurred in both of these meadows adjacent to the restored reaches, as meadow grasses have responded quickly to the increased extent and duration of plant available water.

Cookhouse Meadow, 2011 (left) and High Meadows, 2013 (below)

Blackwood Creek restoration relied on in-channel restoration techniques, and therefore the changes to vegetation in the floodplain are expected to take much longer to manifest. However, sediment deposition and flow monitoring show that high flows are able to spread out onto the adjacent floodplain to a greater extent and frequency than prior to restoration. This has resulted in substantial areas of floodplain deposition resulting in not only reducing fine sediment loading to Lake Tahoe, but also providing the substrate needed to promote natural restoration of riparian grasses, shrubs, and trees. The diagram below produced from flood plain mapping in 2010, illustrates how restoration has transformed this reach from one dominated by erosion processes to one dominated by re-building floodplains and desired in-channel depositional bars. Green illustrates areas of deposition, red denotes areas of erosion, and yellow areas experience both.



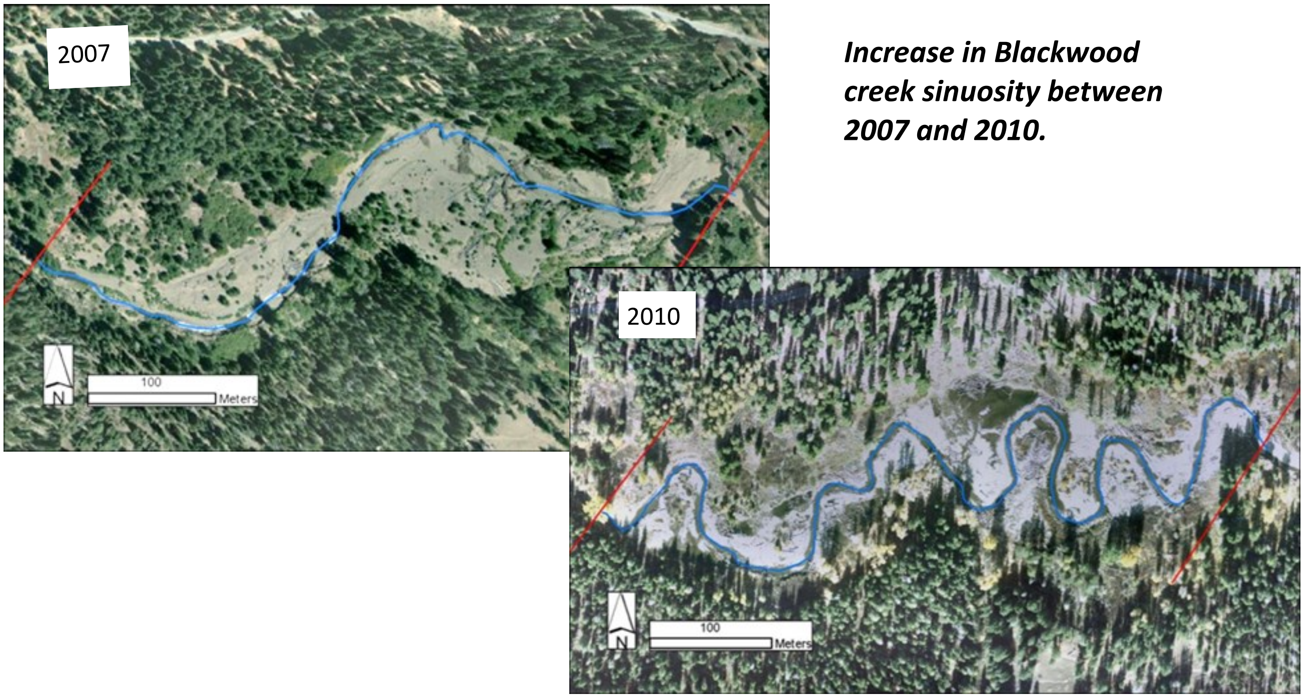
Because of the variability in annual precipitation, the period of record for project monitoring data is not yet sufficient to quantify the magnitude of changes in reduced or attenuated peak flows, however we are able to quantify substantial increases in the frequency of overbank flooding. Occurrence of flooding has increased from a return frequency of every 50 years (or more) to a two to three year frequency of occurrence at both Cookhouse and High Meadows. Although we cannot quantify the magnitude of peak flow change, we can infer that periods of overbank flooding are resulting in decreased and attenuated peak flows to some degree.

Restoring Dynamically Resilient Channel Morphology

The key to any successful riverine restoration project is to establish a dynamically stable geomorphic platform from which the river will continue to adjust to natural variations in flow regimes, while maintaining a healthy stream form and function in terms of sediment transport, water quality, and aquatic habitat. The following are monitoring highlights that illustrate the success achieved on the LTBMU in this regard. These photos taken at the same location on Lonely Gulch as the 2002 pre-project photo (on page 7) at 1 year and 8 years post implementation show that important attributes for channel resilience, riparian plant cover and large wood, are functioning as desired.

Lonely Gulch, post project

As a result of restoration of 1.3 miles of stream channel, the degraded reaches of Blackwood creek are no longer dominated by processes of channel erosion. Channel stability has been greatly improved, and floodplain connectivity and channel bar and floodplain development has been restored. Post-project measurements currently exceed the Blackwood TMDL targets for the two metrics of 1.6 sinuosity and 80% bank stability. The figures below illustrate the increase in channel sinuosity in one of the restored reaches (Reach 6) as a result of restoration.



Increase in Blackwood creek sinuosity between 2007 and 2010.

Overall measured increases in pool quality metrics (depth, frequency, and ratio of pools to riffles), lower % riffle fines, lower cross section width-depth ratios, and significantly less relative channel confinement, all suggest aquatic habitat and channel stability has been significantly improved. These habitat metrics in the restored project area are statistically comparable to established reference reaches in Blackwood creek, as well as values considered healthy in scientific literature.

Although visual observations indicate transplanted and replanted vegetation is surviving, there is not yet substantial change in the degree of riparian vegetation recovery within the project reaches in terms of its influence in providing floodplain and channel stability, riparian habitat, or channel shading. Existing post project shade measurements were only at 26%, well below the desired condition of 50 to 75 % shade. It is expected to take approximately 10 years or more before a substantial degree of riparian vegetation change occurs within the restored reaches. Positive trends in habitat metrics are expected over the longer term as woody shrub and tree vegetation recovers, providing more food, shade, and rearing habitat for all life stages of aquatic organisms.

The photos below illustrate some of the improved condition within the restored channel reaches of Blackwood Creek, Big Meadow Creek, and Cold Creek, as it relates to improved channel stability and resiliency.

December 3, 2012, rain on snow event, (two months after completion of the Blackwood Reach 1 project) estimated to be an 8 to 10 year frequency flow event (@800 cfs). Through bed load transport and deposition this event raised the base elevation of the stream channel closer to desired levels. Installed rock weirs in the stream bed and log stream bank stabilization structures were successful in maintaining channel form and stability during this event.

Blackwood pre-project, 2006.

Blackwood post project, 2014. Channel has been moved to right (off of photo), and former channel location converted to inset floodplain. Although some riparian willow stakes were planted, much of observed revegetation is occurring through natural processes of flood plain deposition during overbank flooding.

Replacement of Big Meadow creek channel with a new channel in Cookhouse Meadow successfully converted the channel type from an highly incised channel experiencing accelerated bank erosion (Rosgen F, see photo on page 11) to a stable channel form (Rosgen C), illustrated in the photo to the left.*

Big Meadow Creek post project, 2008

Cold Creek in High Meadows demonstrates improved morphology in terms of width/depth ratios, pool riffle ratios, and stream bank stability, and has increased overall stream channel length from 2,500 feet to 3,600 feet. Notice also the large area of dead conifer removal in the left side of photos below.

Change in channel location and length at Cold Creek

*The Rosgen system for classifying channels is widely used by hydrologists and geomorphologists to delineate stream channel types based on channel morphology, with D, F and G channels classified as unstable channel forms, and, C and E channels considered stable channel forms , in low gradient systems.

One of the projects discussed in the introduction, Marlette Dam restoration, is not yet exhibiting satisfactory success in terms of producing a dynamically stable channel. We believe the failure occurred in the design phase. Post project analysis determined that design specifications did not sufficiently size or key in large boulder stabilization structures, and the channel design did not specify appropriate sinuosity and channel gradient relative to valley slope. This reach is still being monitored, and recommendations for adaptive management may result if channel degradation continues.

Marlette Creek, 2011. Post project channel incision/erosion resulting in channel down cutting and widening, in 200 feet of the restored channel. Installed large boulders no longer effective as a channel stability component.

Lessons Learned—Managing Risk and Uncertainty

There is an inherent high level of risk and uncertainty when implementing management actions to alter ecosystem components and processes in riverine systems. The science and art of riverine restoration is still a relatively new field, and there is no "cookbook" for determining which restoration approach or techniques will work for any given situation. Successfully implementing large scale riverine restoration projects is primarily about effectively managing this risk and uncertainty. Through our experiences and monitoring efforts, there are number of lessons learned that we feel are important for helping others that are planning these type of restoration efforts.

Utilize/Build Workforce with High Level of Technical Capacity

This starts at the planning level. If the appropriate restoration approach is not identified during the planning and design phase, the quality of implementation will not matter. Not only may the restoration effort fall short of achieving restoration goals, it is possible restoration efforts may even make conditions worse.

Highly qualified staff are needed to develop an accurate and comprehensive understanding of the existing watershed conditions, including how watershed conditions are expressed in the existing geomorphology of the riverine system, and consequently what the site potential is for ecosystem restoration. The LTBMU had the financial resources to produce comprehensive watershed assessments for most of our projects, but in hindsight we know that many of these were not produced cost effectively. We believe the approach to conducting watershed assessments to identify restoration opportunities in the future could be much leaner and focused, to identify riverine systems in a degraded condition, current and past stressors to that system, and restoration potential with specific goals to restore ecosystem services. This could be done by utilizing regional teams of experienced and qualified practitioners comprised of forest service staff, contractors and/or other agency partners.

Once the site potential is documented through watershed assessment, qualified staff are then needed to determine the appropriate restoration approach, design, and specific techniques to achieve the restoration goals identified for that site. Again this could be accomplished utilizing a regional team approach comprised of practitioners representing a broad range of experience working in a variety of environmental constraints and settings.

A highly qualified team is also needed to successfully construct the features illustrated in design drawings and described in project specifications, including necessary field fits identified during project construction. Restoration frequently involves working in challenging conditions, under short time frames, and in sensitive environments. Mistakes or poor quality work during implementation can cause costly delays, and result in both short term adverse environmental impacts and sub-standard effectiveness over the long term. The following are specific recommendations for ensuring highly qualified staff are utilized throughout the restoration process.

- Provide high level training in advanced principles of geomorphology and restoration design to project leaders. Provide opportunities for less experienced staff to be mentored by more experienced staff on restoration projects.

- Use interdisciplinary and collaborative teams during the planning and design process, to ensure a variety of resources (physical and biological), perspectives and experience are considered.

- Use a competitive process to select the most qualified contractors for design, with proven experience and knowledge in restoration design (not necessarily the lowest bid).

- Have agency staff work in highly collaborative manner with consultants/contractors to facilitate knowledge sharing and problem solving during all phases of planning, design, and implementation.

- Utilize highly skilled equipment operators for critical work (such as channel shaping, and installation of large rock/wood grade control and bank stabilization structures). Again provide opportunities for less experienced staff to be mentored by more experienced staff.

Rapid and Effective Bank Stabilization in Meadow Systems

We have had great success in constructing almost immediately functional and stable channel banks in newly construction channels in meadow systems by harvesting sod on site as much as possible. This involves using a skilled equipment operator to “scalp” existing sod in the alignment of the new channel (as well as temporary roads), and carefully placing and stacking this material immediately on newly constructed channel banks. If sod needs to be stockpiled, prior to placement (such as when rebuilding floodplains) it should be routinely irrigated and watered. The constructed banks will need to be irrigated and allowed to “season”, before re-introducing flows. Typically a year of seasoning is adequate, but if the quality of harvested sod is high, you can get away with a couple of months of the growing season. If contracting, it is important to build flexibility in contracting specifications related to irrigation timing and performance specifications, to ensure the desired outcome is achieved. And finally we have also learned it is important to control the height of intercepted water in newly constructed channels during seasoning years, to not “drown” emerging bank vegetation. The photos on the next page illustrate successful sod harvesting techniques.

Sod harvesting

Harvested sod channel banks on Cold Creek, two years after placement.

Effective Grade control weirs

It cannot be over emphasized to not short cut the size and design of grade control structures. Materials must be of sufficient size, and keyed in deep into the channel and banks, so that they will not move as a result of future channel adjustments. In a properly designed grade control weir, you will not be able to see 80 % of the material in the weir after construction, the important “stuff”. In the photographs below, there is 6 feet of rock under the road to the right of the channel. And finally it is desirable to install grade control structure at natural valley constrictions or confined locations, particularly in meadow environments with fine grained soils.

Grade control weirs, downstream end of Cold Creek channel restoration.

Techniques for Protecting Water Quality During Construction

This particular aspect of managing for risk and uncertainty is particularly important in the Tahoe Basin where there are high standards for maintaining water quality when working around live water during implementation. Typical background turbidity levels in Tahoe Basin streams are around 1 NTU and the state regulatory standard is a no more than 10% increase in background levels. We have gotten Basin Plan prohibition exemptions that have allowed us to go up to 10 NTUs for up to 48 hours. To avoid receiving water quality violation notices we have developed practices to significantly reduce the risk of turbid water releases during construction.

<u>Stream crossings</u>

For many restoration projects that involve offline new channel construction, the highest risk to water quality occurs while constructing stream crossings for temporary access roads. Planning for adequate diversion capacity is important, which will be discussed later. But we also recommend the following techniques for easy/clean installation and removal of temporary culverts.

- At large crossings, with smooth, level channel substrate it can be effective to place the culvert into the channel first, and then sand bag flows into the culvert. If the channel substrate allows for effectively containing all flows into the culvert with sand bags, then road base material can be easily installed without resulting in turbid water releases.
- Place a 1 foot layer of straw between filter fabric and road base sediment. This creates a 3" compacted barrier to make it easier to remove the majority of road base fill when removing the stream crossing, without tearing the filter fabric.
- Use highest tensile strength fabric available, so that when you then pull up the fabric (and any remaining soil) no fine grained sediments escape into the stream channel bed.

Stream crossing installation with straw layer.

Clean Substrate, Flushing and Jetting

Before connecting flows to newly constructed channels, all fine sediments must be removed or “seated” into substrate interstices in order to meet turbidity standards. We utilize two techniques to remove or “seat” fine sediments. Flushing involves adding flows in small increments to a newly constructed channel while still offline, and pumping and spraying the resulting turbid flows onto adjacent meadow surfaces or into infiltration basins. This is done until turbidity standards are achieved (or for a maximum period of time), as negotiated with state regulatory agencies.

Jetting involves using a high pressure hose to spray the newly constructed channel surfaces, until turbid water is no longer visually evident (or for a maximum period of time) as negotiated with state regulatory agency.

In all cases, we have found it can ultimately save a lot of time and man hours if clean substrate is obtained, prior to installation. Clean substrate can either be purchased, or created using a gravel sorter to filter out fine materials in harvested or purchased material, prior to installation into newly constructed channels.

Jetting “dirty”substrate in Blackwood.

Plan for Adequate Diversion Capacity

Plan for the expected, as well as the unexpected. After calculating the surface flow volumes you will need to control, including typical storm events, you then need to plan for: equipment breakdown, theft, vandilazation, changes in intercepted groundwater as groundwater levels begin to respond quickly due to restoration actions, and unexpected problems such as beavers aggressively plugging diversion inlet pipes. We have found it necessary to have a large and varied capacity of water pumps, hose and pipes, and utilization of experienced labor crews to install and maintain diversion systems that will effectively contain and carry flow diversions. Turbidity screens will not work, so don't even try.

Beaver boulder, removed from diversion

Pumping turbid flows after rain event in Blackwood

LTBMU restoration crew ingenuity at its best, the Blackwood "Aqueduct" water diversion system.

Final Words

The following captures the "Big 3" overarching lessons learned on the LTBMU, in order to effectively manage risk and uncertainty, and to develop the capacity to successfully implement large scale riverine restoration projects.

1) Develop, train, hire - high quality staff and contractors, the stakes are high, and the field is still "young". If your agency does not have the funding to do this, then work should be conducted in partnerships with entities that can help provide this capacity. This could take the form of partnerships with other agencies, or regional teams within the agency.
2) Work collaboratively, and learn from the perspective, experience, and expertise of others at every opportunity.
3) Monitor and report – implement the DO, LEARN, ACT principles of Adaptive Management, so not only is your program utilizing the most current knowledge, but others can benefit from your experiences as well. The more project implementer experience and success (or failure) is documented, the faster the field of riverine restoration will grow.

The LTBMU is reaching the end of a decade of large scale riverine restoration projects. To date we have performed actions to restore 4.2 miles of degraded stream channels and 210 acres of adjacent floodplain.

We have two more large scale projects to complete, that are currently underway. The Upper Truckee River Reach 5 project is our most ambitious project yet; implementation began in 2013 and is scheduled to be completed in 2016. This project will restore 1.3 miles of channel and 75 acres of adjacent floodplain. The Upper Truckee River Reach 5 project is predicted to be one of the most effective projects in reducing sediment loads to Lake Tahoe from this watershed, and therefore provide a substantial contribution to achieving the Lake Tahoe TMDL (2nd Nature Report, 2014).

We will also be completing 2.0 miles of stream channel and 10 acres of floodplain restoration in Angora Creek (a tributary of the Upper Truckee River). This project will stabilize small tributary channels through restoring large wood lost as a result of the 2007 Angora wildfire, as well as reconstruct a section of destabilized stream channel resulting from legacy urban road crossing construction. Implementation began in 2014 and is scheduled to be completed in 2015.

As summarized in this document, the monitoring data we have collected to date has documented improvement in ecosystem function from our riverine restoration efforts, as measured by geomorphic stability, deposition of fine sediments on floodplain surfaces, improved aquatic habitat quality, and conversion from dry to "wet" meadow habitat.

With available funding, the LTBMU will continue to monitor both the short and long term effectiveness of our restoration efforts, with the hopes that our published reports will both confirm the success of these projects, as well as provide valuable insights and information for future project implementers.

Post project images of restored meadow on the LTBMU
Cold Creek in High Meadows, 2014 (above) , Big Meadow Creek in Cookhouse Meadow , 2010 (below)

LTBMU Restoration Reports Bibliography (all reports can be found at following link, http://www.fs.usda.gov/main/ltbmu/maps-pubs)

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