Water Management Implications of Restoring Meso-scale Watershed Features

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Abstract:

The need to provide adequate, clean water to the 6 billion+ people worldwide has led to extensive, highly complex water storage and distribution systems in virtually every corner of the globe. The oft-concurrent use of this water as a renewable, clean source of energy is also crucial to maintaining healthy regional and national economies. Recognizing the fluvially-evolved functions of meso-scale basin features as natural management mechanisms of water and sediment will be fundamental in ensuring the optimum performance of water development infrastructure while avoiding future development related impacts in developing countries.

Stream channels with adjustable bed and banks have been proven to develop predictable features of pattern, form and profile centered around the dynamic equilibrium of available sediment and available discharge. Drainage basins of all sizes develop equivalent features that provide the same functions at the basin scale. The mountainous, western United States has historically been a region where water, its location, quantity and time of availability, has determined the character of settlement and growth. A region with distinct wet and dry seasons, this landscape has fluvially-evolved landscape features that buffer the effects of hydrologic extremes on the ecosystems of the region.

The origin of much of this water is the rainfall and snowpack of the numerous mountain ranges, extending from the Sierra Nevada and Cascade Mountain chain eastward through the Great Basin ranges in Nevada to the Rocky Mountains. These water- producing areas are often hundreds of miles from the urban and agricultural consumers, resulting in the development of some of the most complex water detention and conveyance systems in the world. Concurrent with this extensive water development, a little recognized but increasingly important phenomenon has occurred; the entrenchment of stream channels in the alluvial fans, meadows and valleys of the watersheds. Channel entrenchment disconnected streams from naturally developed floodplains and subsurface reservoirs, reducing the sediment and water storage capacity of the landscape.

The author, as staff to the Feather River Coordinated Resource Management (FRCRM) group, has been integrally involved in a nearly two decade-long watershed restoration program in the Feather River watershed of California. This effort has led to the recognition of the critical importance of restoring the meso-watershed functions in improving water quality, timing of flows, sediment reduction, and aquatic and riparian habitat. Quantitative data and qualitative observations from a number of watershed projects undertaken in the Feather River watershed illustrate these concepts.

Key Words: fluvially-evolved functions, meso-scale features, cumulative land use impacts, macro-hyporheic

Introduction:

The need to provide adequate, clean water to the more than 6 billion people world-wide has led to extensive, highly complex water storage and distribution systems in virtually every corner of the globe. The often concurrent use of this water as a renewable, clean source of energy is crucial to maintaining healthy regional and national economies. Additionally, the watersheds that deliver this water have undergone hundreds of years of local land use that has altered the fluvial function of the landscape. Road building, grazing, logging, mining and urbanization frequently have fundamentally altered the naturally-evolved buffering mechanisms and features of the landscape. These features had evolved synergistically from the sediment, nutrient and discharge inputs of thousands of years, including extreme drought and flood events. Understanding the function of drainage basin features as fluvially-evolved natural management mechanisms of water and sediment will be fundamental in ensuring the optimum performance of water development infrastructure under ever growing demands. Avoiding similar impacts to these features as developing countries implement water, transportation, municipal infrastructure will be crucial in sustaining future water supplies.

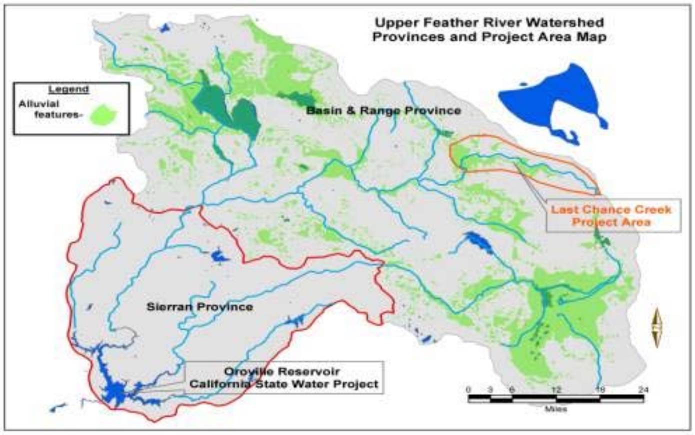
These landscape scale features include alluvial fans, meadows and valleys, generally regarded as floodplains. River system segments are often characterized simplistically as transport and depositional reaches. It is the depositional reaches that develop the above stated features. Depositional reaches are typically characterized by lower gradients and a more expansive fluvial setting. These landscape attributes, in conjunction with the type and quantity of sediment, debris and nutrients, are what provide for the development and evolution of meso-scale ‘sinks’, for the hydrologic products of the basin. Viewed as a macro-hyporheic corridor (Harvey and Wagner, 2000; Boulton, et.al., 1998; Stanford and Ward, 1993) these features are crucial as landscape zone of active mass and energy transfer as well as an active storage reservoir for water, sediment and nutrients. The long-term recruitment and evolution of these features involve physical, biological and chemical synthesis with the natural variability of fluvial disturbance.

Watershed Location/Characteristics:

The upper Feather River watershed is located in northeastern California encompassing 3,222 square miles (8342 km^2) of land base that drains west from east of the Sierra crest into Oroville Reservoir and thence to the Sacramento River. Annual runoff produced from this watershed provides over 1,400 MW of hydroelectric power, and represents a significant component of the California State Water Project, annually providing 2.3 million-acre feet (2.84^{10} m^3) of water for urban, industrial and agricultural consumers downstream

The Feather River watershed is primarily comprised of two distinct geologies, the Sierra Nevada granitic batholith of the western third and Basin and Range faulted meta-volcanics, meta-sedimentary and recent basalts in the east two-thirds. The attached map (Fig. 1) delineates these zones and their relationship to the system. It is the Basin and Range zone (Diamond Mtns.) of the watershed that has been the primary area of restoration. The Diamond Mtns. predate the adjacent Sierran and Cascade provinces by millions of years (Durrell, 1987). This geologic mélange of faulted and weathered rock has resulted in expansive meadows and valleys comprised of deep fine grained alluvium.

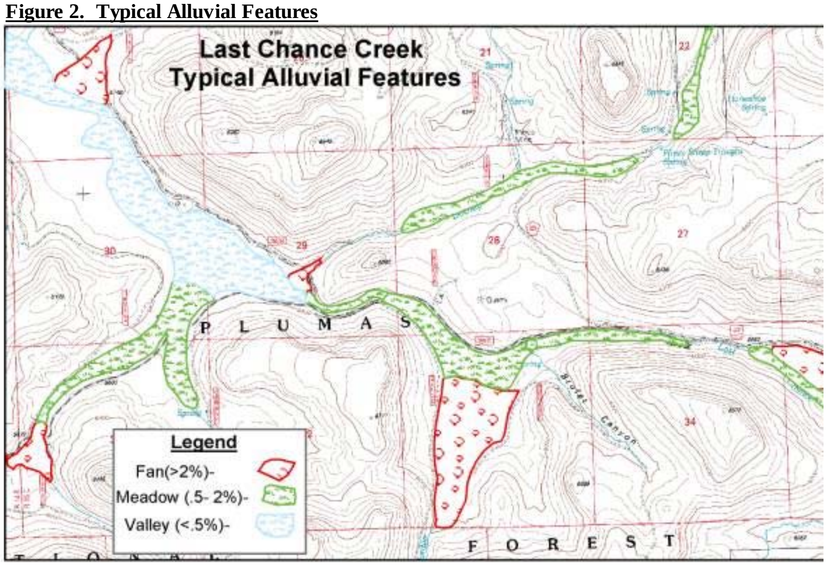
Figure 1. Upper Feather River Watershed



These upper watershed features (Fig. 2), often dozens of miles in length, supported a rich ecosystem of meadow and riparian habitats. The meadows, in turn, provided key refugia for wildlife and indigenous peoples during the dry summers typical of California's Mediterranean climate. The lush, densely rooted vegetation community, cohesive soils and expansive floodplains all contributed to the sustainability of these meso-scale features which in turn provided clear, cold water and elevated summer flows to the larger watershed downstream.

Euro-American settlement of the watershed began in 1850 with gold mining in the western portions of the watershed and, soon thereafter, agricultural production in these lush meadows to support the mining communities. Dairy farming, horses (for cavalry mounts), sheep and beef cattle were early intensive disturbances to the equilibrium of these valleys. Localized channel incision, and resultant lowering of shallow groundwater elevations began to alter and weaken the vegetative structure of the system. Soon, near the burgeoning communities in the mid-elevation valleys, a permanent road system was established with frequent channel manipulation/relocation efforts to simplify drainage. Again, localized incision began to occur. In the early 1900's both an intercontinental and numerous local railroad systems were constructed throughout the watershed. The local systems, for the purpose of both mining and logging, were routed through the long low-gradient valleys for ease of construction. These valleys were still relatively wet at that time so elevated grades were constructed using adjacent borrow ditches.

Figure 2. Typical Alluvial Features



By 1940 the severe morphological changes imposed by the railroad grades, in conjunction with the above referenced land use impacts resulted in a rapid, severe systemic incision process on many upper watershed meadow systems (Fig.3.).

The mid 1980's brought a simultaneous realization by numerous watershed stakeholders that this cumulative degradation was beginning to severely impact hydroelectric, agricultural, forestry and local government operations. Yet none of these interests had the political, financial or technical capability to address these issues, individually. The stakeholders, while often in conflict over particular issues, found a common goal in reversing the degradational trend of the watershed. Adopting a statutory authority that allowed for Coordinated Resource Management and Planning (CRMP), 23 Federal, state and local, public and private entities have formed the Feather River Coordinated Resource Management (FRCRM) group to adopt, support and implement a watershed-wide restoration program.

Figure 3- Typical Incision Cross-section

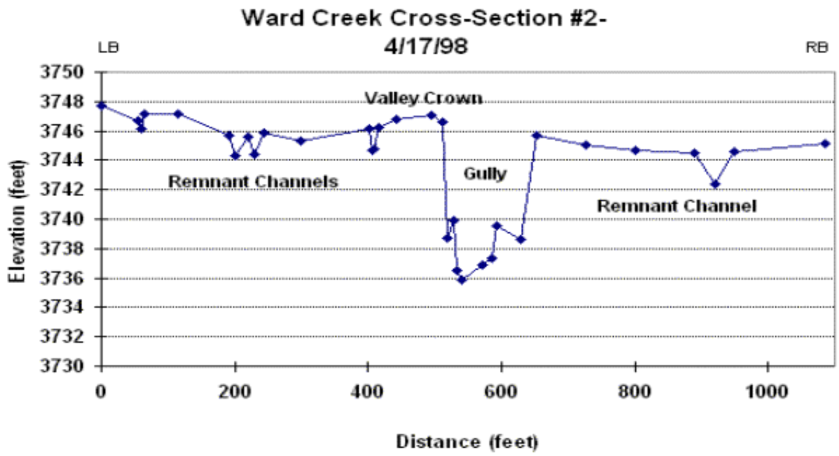


Photo 1a- Ward Comparative- Ground

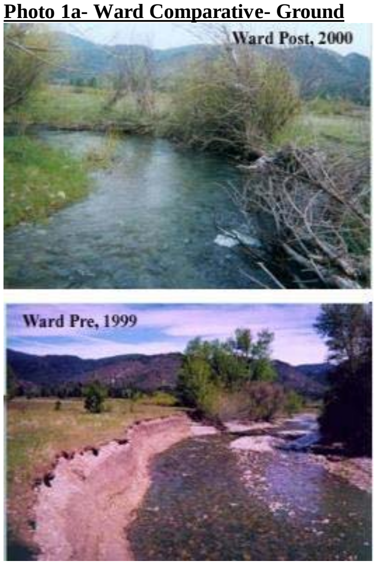
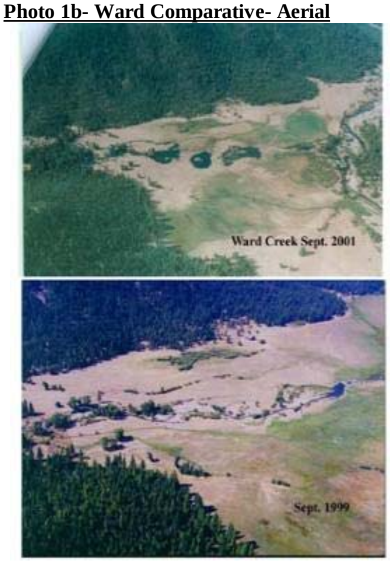


Photo 1b- Ward Comparative- Aerial



Restoration Approach:

The FRCRM began an ongoing implementation program to address these watershed issues in 1990. Initially, these projects focused on geomorphic restoration techniques (Rosgen, 1996) to stabilize incised stream channels. While overall success was encouraging, the projects illustrated the concept that any restoration work in the incised channels was subject to elevated stresses even in moderate flood events (5-10 year RI). Concurrently, the benefits from this approach were localized and limited to reduced erosion, incremental improvement of aquatic habitats and water quality. Little overall improvement of watershed conditions was being realized (Wilcox, et.al.,. 2001). This led to re-evaluating our restoration approach to encompass the entire historic fluvially-evolved landscape setting.

In 1992 the FRCRM was introduced to a new restoration concept, pioneered by Wildland Hydrology (Rosgen, pers. comm., 1992) and implemented initially on Maggie Creek, near Elko Nevada. Variously called meadow re-watering or 'pond and plug', this approach entails returning the incised stream channel to the remnant channel(s) on the historic floodplain feature and eliminating the incised (gully) channel as a feature in the landscape. Simultaneously, the FRCRM had received a project assistance request from the United States Forest Service, Plumas National Forest (PNF) to develop restoration alternatives for Cottonwood Creek in the Big Flat Meadow. FRCRM staff, led by the author, began conducting surveys and data collection that included the entire relic meadow from hillslope to hillslope. This data collection effort quickly identified the nascent meadow re-watering technology as a likely restoration alternative.

Implemented in 1995, this project quickly validated the fundamental soundness of this approach. The 1-mile long (1.7 km.), 47 acre (19 ha.) project produced elevated shallow groundwater levels, eliminated gully wall erosion, filtered sediments delivered from the upper watershed, extended and increased summer baseflows, reversed the xeric vegetation trends resulting in improved terrestrial, avian and aquatic habitats. These benefits persisted despite withstanding a 100-year RI flood in 1997.

The success of this initial project led to the implementation of an additional 15 projects utilizing this technology (Table 1.). Varying in scale and watershed characteristics these projects have restored another 14 miles (22.4 km.) of channel and 3,000 acres (1214 ha.) of meadow/floodplain.

Table 1. Meadow Re-watering Projects

Project Name/Year	Project Length/Area	Primary Monitoring/Research	Project Cost (US)
Big Flat (1995)[1]	4600'/47 acres	streamflow, groundwater, vegetation	$189,000
Willow Cr. (1996)	3300'/16 acres	project effectiveness (failed in 1/97 flood)	$100,000
Bagley Cr. (1996)	1500'/15 acres	project effectiveness	$18,000
Boulder Cr. (1997)	3000'/25 acres	sediment	$50,000
Bear Cr. (1999)[3]	10,000/600 acres	groundwater, vegetation, streamflow, fish	$400,000
Ward Cr. (1999)[1]	4800'/165 acres	project effectiveness	$220,000
Clarks Cr. (2001)	4800'/56 acres	groundwater, vegetation, wildlife	$125,000
Carman Cr. (2001-04)	9700'/200 acres	groundwater, vegetation, wildlife	$200,000

Stone Dairy (2001)	2200'/15 acres	project effectiveness	$65,000
Hosselkus Cr. (2002)[2]	1500'/20 acres	groundwater, vegetation	$155,000
West Ranch (2002)[2]	800'/15 acres	vegetation	$30,000
Last Chance Cr.-private (2002-04)[2]	6800'/800 acres	groundwater, vegetation, streamflow/temperature	$300,000
Last Chance Cr.-public (2003-04)[1]	31,000'/1600 acres	groundwater, vegetation, evapo-transpiration, streamflow/temp.	$600,000
Humbug/Charles (2004)	3000'/100 acres	project effectiveness	$155,000
Poplar Creek (2004)[2]	800'/20 acres	project effectiveness	$90,000

[1] Projects with data contributing to this paper [2] Projects with road/culvert modifications

[3] Projects outside Feather River watershed w/FRCRM assistance

Initial Results:

These projects have been monitored at a variety of intensities depending on resources/interest. To date, the monitoring results have indicated a significant change in the hydrologic regime at least at the project level. Currently, the scale of restoration is just attaining the spatial breadth necessary to effect measurable change at the watershed scale. The following data illustrate the magnitude of change being quantified at the project level as well as the various metrics being monitored at specific projects.

Hydrologic Response:

Detention- Figure 4 illustrates the change in shallow meadow water table that translate into augmented late season baseflow. Analysis of this data reveals that the time of meadow soil saturation within 1' (.3 m.) of ground level increased from an average of 8 days pre-project to 223 days post-project annually. Gross recharge water available post-project over pre-project conditions in the 56 acre meadow totals 49 acre-feet (60,441 m^3) , using a field capacity coefficient of .25 for sandy loam soils (USDA, 1955).

Figure 4. Clarks Creek Groundwater Levels

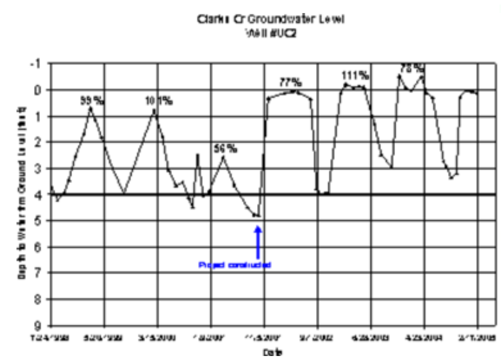


Photo #2 Clarks Creek

Baseflow Augmentation- Fig 5 is derived from continuous recording streamflow gages on the Big Flat/Cottonwood Creek Project. The project area demonstrated an immediate response in detaining and releasing flows and continued to improve in efficiency as the mesic vegetation root systems thickened and deepened in response to prolonged moisture. These root systems provide extensive macropores for efficient infiltration and release of soil water. Within 3 years stream channel flows reached near perennial conditions. Calculations of the total volume of stream flow extended beyond pre-project conditions ranged from 18 to 34 acre-feet released from the 47 acre meadow.

Table #2. Summary of Flow Day Extension- Big FlatCottonwood Creek (Sagraves, 1998 w/add)

Water Year & Precipitation % of Normal	1994 73%	1995 259%	1996 189%	1997 191%	1998 150%	1999 130%
Flow Days	214	207	250	260	365	344

Figure 5. Big Flat Timing of Flow

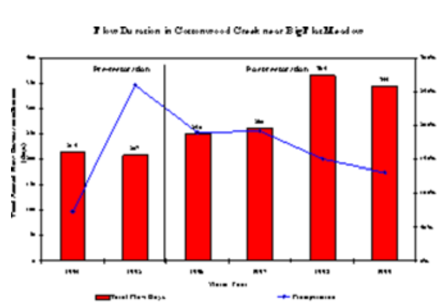
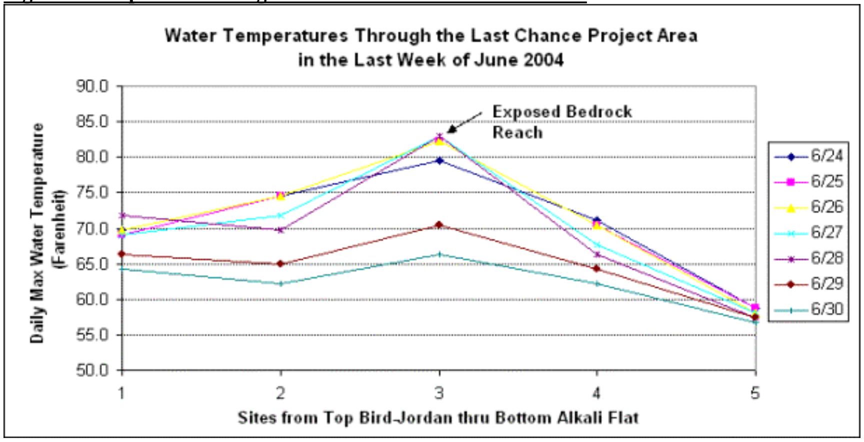


Photo #3- Big Flat

Ecosystem Response:

Temperature- Figure 6 illustrates the role of meadow groundwater in maintaining or decreasing stream water temperatures for the benefit of cold-water aquatic species. Bank recharge affected an average 10^0 F. (5.5 C^o) decrease in surface water temperature through the five-mile long study reach that underwent meadow restoration work in 2003.

Figure 6. Temperature Changes thru 5 miles of Last Chance- PNF



Vegetation- Photo #4 illustrates the reversal of xeric-trending vegetation communities with restoration of the pre-degradation moisture regime. The left photo shows a predominately sagebrush pre-project condition with minimal herbaceous cover (Note the incised channel wall (shadow) in the middle left of the June 2001 pre-project photo). The center photo is after one summer season, with some residual sagebrush (gray) trying to survive. By Year 2 on the right, the herbaceous community has become dominant.

Photo #4. Clarks Creek Project

Fisheries- Photo #5 and Table 2 document the re-establishment of a fishery in the Big Flat/Cottonwood Creek project. As the oldest meadow re-watering project in the watershed, Big Flat was selected for fishery monitoring in 2000. The pre-project channel was devoid of fish with streamflow cessation in early June each year. Anecdotal information from the four-generation, local ranching family indicated an excellent fishery before 1900. The adjacent Clarks Creek Project was sampled concurrently as pre-project monitoring for 2001 construction and as a control reach (Bogener, 2000).

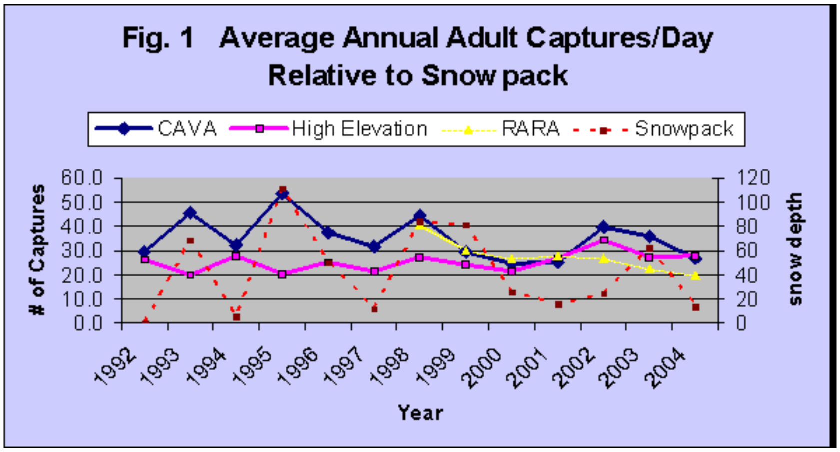
Photo #5- Big Flat Fish Monitoring

Table #3- Big Flat/Clarks Creek Fish Monitoring, 2000

Sample Date	Name/Length of Stream Sampled	Species	Total Catch	Population Estimate/mile	Biomass/mile
5/23/2000	**Big Flat**-100 feet	Rainbow Trout	60	1,126	45,700 m/L
5/24/2000	**Clarks Creek**-100 feet	Rainbow Trout	14	352	9,700 m/L

Avian Response- The Carman Valley watershed project was initiated based on the results of long-term avian research (Steele, 2004) that determined a trend of usage/nesting success relative to annual meadow moisture regime. This research was conducted in a variety of montane meadow systems in the northern Sierra Nevada Mountains and focused on neo-tropical migrant species, several of which have Federal or state designations for protection. The following information and figures are excerpted from the Carman Valley Restoration Project Final Report, November, 2004. The premise for the continuing research is that insectivorous bird and bat species would respond rapidly to ecosystem changes that would prolong insect production in the summer. Figure 7 illustrates that avian populations in CAVA (the project area) and RARA (the control meadow) closely paralleled snowpack depths and thence seasonal moisture retention through the 2001 project implementation. Post project data indicates that populations were less affected by snowpack variability in CAVA in part due to the restored meadow attenuating moisture fluctuations.

Figure 7. Avian Monitoring Trends



Bat Response- Changes in bat populations and species diversity immediately following project implementation are displayed in Table #4 below. Twelve species were captured and identified prior to restoration of which six (6) are Federal/State Species of Concern. After the restoration, two additional species were detected. These species also have protected status. Restoring mesic meadow features appears to be benefiting species that are particularly susceptible to the significant loss of riparian/floodplain habitats in the western United States.

Table#4. Bat Sampling Summary Data

Sampling Period	Water Habitat (passes/hour)	Willow Habitat (passes/hour)	Scrub Sage Habitat (passes/hour)
1997-2001 pre-proj.	31.5 ± 2.5	2.84 ± 0.37	2.28 ± 0.30
2002-2004 post-proj.	76.8 ± 8.1	17.7 ± 2.1	25.2 ± 2.0

Conclusions, Future Restoration and Research Direction:

The FRCRM, its partners and other watershed groups in the region are strongly encouraged by both the hydrologic and ecosystem response to this restoration technology. Consequently, additional large meadow restoration projects are underway or in the project development stage in major subwatersheds throughout the upper Feather River drainage. The specific ongoing project effort in the Last Chance Creek watershed is approaching a spatial threshold that should begin producing quantifiable changes in baseflow and summer water temperatures. Current project direction is to complete restoration of all meadow systems in the 100 mi^2. (259 km^2) Last Chance Creek watershed above the Doyle Crossing gage station by 2009.

The FRCRM restoration program has partnered with several research institutions, including the University of California, Davis, Stanford University and the University of Nevada, Desert Research Institute. These partnerships are applying innovative research, modeling and monitoring technologies to the FRCRM restoration projects in order to more fully understand the complex interactions of these hydrologic systems and the effect of restoration at varying spatial and temporal scales.

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