Report for 2005MT49B: Using paleoecology and paleoflood hydrology to assess the long-term ecological response of Montana's riparian and aquatic ecosystems to small natural and human dam features -- a pilot study

Publications

- Water Resources Research Institute Reports:
    - Schmitz, Denine, Selita Ammondt, Matt Blank, and Duncan Patten. 2006. Using historic aerial photography and paleoflood hydrology to assess long-term ecological response to two Montana dam removals. USGS Water Resources Research Program.
- Conference Proceedings:
    - Schmitz, Denine, Selita Ammondt, Matt Blank, and Duncan Patten. 2005. Long-term hydrogeomorphic effects of dam failure/removal – a pilot study. Floodplains and rivers: connections and reconnections. Center for Riverine Science and Stream Re-naturalization. September 22 and 23, 2005. Missoula, Montana.
    - Ammondt, Selita, Denine Schmitz, and Duncan Patten. 2005. Studying the effects of small dam removal on woody riparian species in Montana using aerial photo interpretation and field surveys. Floodplains and rivers: connections and reconnections. Center for Riverine Science and Stream Re-naturalization. September 22 and 23, 2005. Missoula, Montana.
- Other Publications:
    - Schmitz, Denine, Selita Ammondt, Matt Blank, and Duncan Patten. 2005. Long-term hydrogeomorphic effects of dam failure/removal – a pilot study. Surface Water/ Groundwater: One resource. Montana American Water Resources Association. October 2005. Bozeman, Montana.
    - Ammondt, Selita, Denine Schmitz, and Duncan Patten. 2005. The effects of small dam removal on woody riparian species in Montana. Surface Water/ Groundwater: One resource. Montana American Water Resources Association. October 2005. Bozeman, Montana.

- Schmitz, Denine, Selita Ammondt, Matt Blank, and Duncan Patten. in prep. Assessing ecological response to small dam removal using historic ecological techniques. Wetlands.

Report Follows

USING HISTORIC AERIAL PHOTOGRAPHY AND PALEOFLOOD HYDROLOGY TO ASSESS LONG-TERM ECOLOGICAL RESPONSE TO TWO MONTANA DAM REMOVALS

Denine Schmitz[1], Selita Ammondt[2], Matt Blank[3], and Duncan T. Patten[1]
[1]*Land Resources and Environmental Sciences, Montana State University*
Bozeman, Montana 59717
dschmitz@montana.edu

[2]*Earth Sciences, Montana State University*
Bozeman, Montana 59717

[3]*Western Transportation Institute, Montana State University*
Bozeman, Montana 59717

ABSTRACT
The restorative potential of dam removal on ecosystem function depends on the reversibility of the hydrogeomorphic effects of a dam and its operations. While dam removal is an established engineering practice, the long-term ecological response remains speculative. We used paleoflood hydrology, topographic surveys, hydrologic modeling (HEC-RAS), and aerial photograph interpretation to investigate the long-term hydrogeomorphic and ecologic responses to dam failure and removal. We compared downstream hydroecological responses of a controlled dam removal, which used natural sediment removal (Mystic Lake Dam in 1985), with that of a dam failure (Pattengail Dam in 1927). Our data showed greater geomorphic response at Pattengail compared to Mystic. Very few flood stage indicators were observed at Mystic and indicated muted hydrogeomorphic and ecologic responses. In contrast, the size of the flood following the Pattengail dam breach initiated a series of channel adjustments and reworked over 0.2 km^2 of floodplain immediately downstream of the dam. Floodplain vegetation responded similarly. Nearly 100 vegetation points below Mystic Lake Dam showed no statistically significant changes in canopy type in the 20 years since dam removal. However, 165 vegetation points downstream of Pattengail dam indicated active floodplain succession during the first 70 years. Our results suggest that 1) hydrogeomorphic and ecologic responses to dam removal depends on the sizes and timing of high flow events during and following removal. 2) Dam removal effects on channel evolution and floodplain development depend on reach types and their responsiveness to flow regime change. We developed these ideas into testable hypotheses as the basis of a multiyear, interdisciplinary research proposal. Further investigation into the long-term hydrogeomorphic and ecologic response to dam removal/failure will advance the knowledge of dam removal methods and their effects, leading to healthier ecosystems and associated human communities.

INTRODUCTION

The decision whether to repair, augment, or remove a dam is presented to dam owners more and more each year. Nationally, we are faced with an aging population of Dams. In Montana, 76% of our dams are over 40 years old (National Inventory of Dams 2003). As dams age, reservoirs fill with sediment. Increased sedimentation means less storage volume for irrigation, municipal water supplies, and flood control potential. Further, human populations downstream of dams are increasing. The higher potential for loss to life and property downstream of dams increases the hazard rating and, therefore, liability. Thus, dam owners are faced with increasing maintenance costs to address decreased functionality, increased construction costs to meet new hazard ratings, or, in many cases, removing the dam all together. Ecologists are interested the restoration potential of using dam removal as a restoration tool. Our project aimed to identify the long-term ecological responses to two Montana dam removals.

The need for long-term understanding of ecological responses to dam removal is far-reaching. As Montana's population grows, community development downstream of unregulated dams becomes an issue. Communities are faced with making decisions about dams without sufficient information. The result is a series of short-sighted decisions or alarmist responses. Knowledge of the long-term ecological responses to dam removal will give community stakeholders a science-based foundation from which to make well-informed decisions regarding dam operations, their potential removal and the associated ecosystem services afforded to humans in regulated and unregulated river systems.

Early dam removals were done with little pre-removal environmental assessment which resulted in great impacts on downstream infrastructure (Shuman 1995). As a result, current dam removal methods are often over-engineered (The Aspen Institute 2002). The Montana State Dam Safety dam removal guidelines currently require a full engineering report describing methods for drainage, disposal or stabilization of sediment and dam materials, reclamation applied to the dam and impoundment area, and prevention of future impoundments ([DNRC] Department of Natural Resources and Conservation 1989). These guidelines target the short-term issues of sedimentation and downstream flooding, yet make no provisions for long-term ecological responses to a restored dynamic sediment regime. Long-term data on the responses to dam removal will accelerate the evolution of dam removal methods (Bednarek 2001) and allow the pendulum to swing toward a moderate, comprehensive approach.

The issue of dam removal affects multiple facets of Montana's population. Of the 2,863 dams in Montana, 87% are privately owned (National Inventory of Dams 2003) and Montana Department of Natural Resources and Conservation (DNRC) estimates more than 2,000 additional unregistered dams. Given the agricultural base of Montana's population, it is no surprise that the primary purpose of Montana dams is irrigation and water supply for livestock. However, the 6% of Montana's dams that provide electricity and water supply to municipalities and support recreational activities affect a disproportionately large, non-agricultural component of the population. Thus, dams in Montana affect those in need of water in an arid environment, electricity in a modern world, and ecosystem processes in agriculture and ecotourism economies. Because Montana's dams are becoming increasingly obsolete due to decreased storage capacity, unsafe due to age and, liabilities due maintenance costs outweighing benefits, dam removal is becoming viable, attractive, and necessary. With region-specific knowledge of the long-term ecological effects of dam failure and removal Montana can make informed decisions regarding the alternative of dam removal.

The potential for river restoration using dam removal is great (Hart and others 2002). The most immediate ecological effect of dam removal is the restoration of the river's flow regime. Aquatic species migration, water quality and temperature regime are often rapidly improved. Changes in water quality and thermal regime drastically alter nutrient cycling and sediment dynamics affecting riparian plant communities (Shafroth and others 2003), biogeochemistry (Stanley and Doyle 2002), and channel and floodplain evolution. By reversing the effects of dam, longitudinal and lateral connectivity is restored to the system on a watershed scale. Thus, dam removal coupled with other restorative and protective practices can be an integral part of watershed plans (Stanford and others 1996).

However, the long-term responses are unknown. We expect that floodplain erosion and deposition will be restored, but we don't to what extent? We expect there will be more fish habitat area, but we don't know the quality of that habitat? We expect that riparian vegetation recruitment will return to areas with restored floodplain erosional and depositional processes, but we don't know how long it will take for successional trajectories to reestablish. For now, these questions are unanswered and provide fruitful ground upon which landowners, natural resource agencies, dam management officials, and researchers can coordinate efforts when making dam removal decisions.

Our goal was to assess long-term downstream ecological responses to failed and removed dams. Specifically, we asked two questions. 1) Are paleoflood hydrology and aerial photography methods sensitive enough to detect ecological responses to dam failures and removals? 2) Can we detect the reversal of dam impacts on downstream riparian areas?

MATERIALS AND METHODS

Site Description

Mystic Lake Dam is located approximately 10 miles south of Bozeman, Montana on Bozeman Creek (Figure 1 and Figure 2). It was built in 1901 and removed in 1985. This 43 ft tall dam augmented a lake formed naturally from an active landslide (pers. comm. Steve Custer). Once dammed, the reservoir volume was 1200 acre feet. Due to many structural integrity issues and an increasing human population downstream, the dam was removed at low flow in April 1985 (City of Bozeman documents). The reservoir sediment was left untouched. Approximately 100 m of stream channel and riparian area below the removed dam was restored.

Directly downstream of the breached Mystic Lake Dam was a narrow canyon with limited or no floodplain area. We located our 1.5 km Mystic Dam study reach (Mystic) just downstream of this canyon where the valley widened and allowed floodplain development. This study reach was constrained in a narrow valley with cascade and plane-bed channel types (following Montgomery and Buffington (1997)).

Pattengail Dam is located in the Pioneer Mountains forty miles southwest of Butte, Montana on Pattengail Creek (Figure 1 and Figure 2). The dam is 1.5 km upstream of Pattengail Creek's confluence with Wise River. Pattengail Dam was built in 1903 and burst during a rain on snow event in 1927. When in operation, the reservoir stored 12,000 acre feet of water which created a reservoir over 2 miles long. Below the breached dam, the creek flows through a wide valley along an unconstrained reach in plane-bed and riffle-pool channel types.

Much of the 40+ ft original structure exists today. There has been no channel restoration, removal of remaining dam structures, or treatment of reservoir sediments since the breach. We located our 1.5 km Pattengail study reach (Pattengail) immediately downstream of the dam and upstream of the bridge of Forest Road 484.

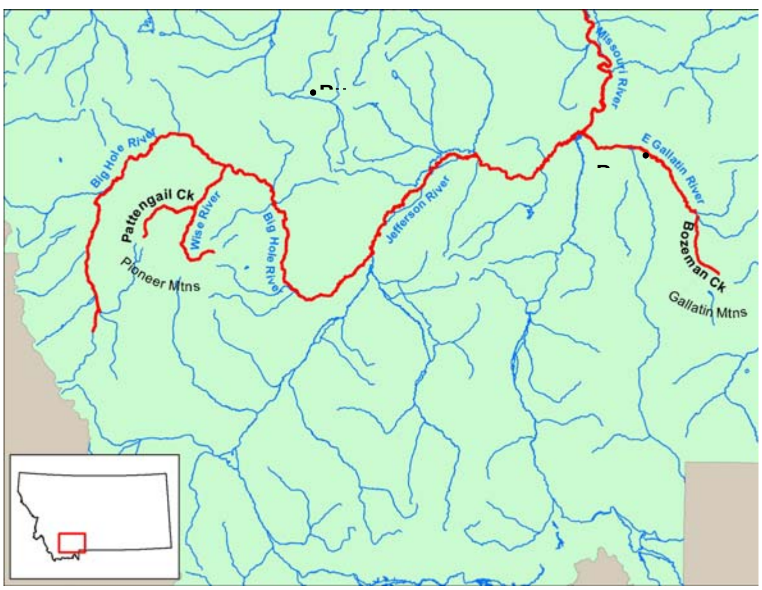

Figure 1. Regional map of study area.

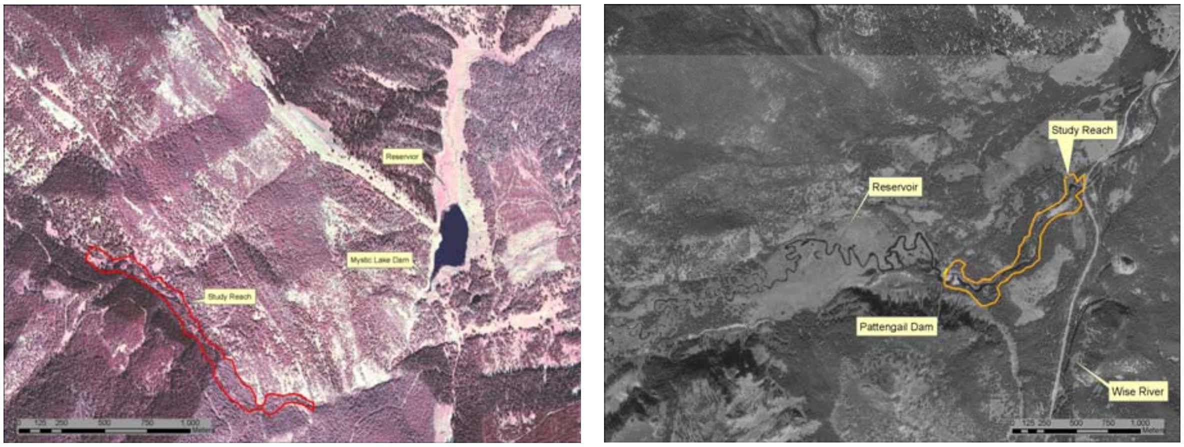

Figure 2. Study reaches for Mystic Lake and Pattengail Dams.

Aerial Photo Interpretation

Aerial photos showing the Mystic site included 1971, 1989, 1995, and 2001 (Table 1). Those for Pattengail were from 1942, 1955, and 1995. The Mystic and Pattengail 1995 digital orthophoto quadrangles (DOQ) were accessed from the Montana NRIS web site. The Mystic 2001 color infrared images were made available by the Gallatin Local Water Quality District. The 1995 and 2001 images were orthorectified. Mystic photos from 1971 and 1989 and Pattengail images from 1942 and 1955 were scanned with high resolution from hard copies and georeferenced to the 1995s using the georeferencing tool in ArcView 9.1. Fifteen control points were used in each image and produced maximum root mean square values of 3.5 and 2.6 for Mystic and Pattengail, respectively.

Table 1.

Mystic		Pattengail	
Photo Year	**# Years Post Removal**	**Photo Year**	**# Years Post Removal**
1971	Pre-removal	1942	15
1989	4	1979	52
1995	10	1995	78
2001	16		
2005*	20	2005*	88
**Field Observation*			

Floodplain Delineation

Floodplains were identified for 2 km study reaches downstream of dams. The Pattengail Creek floodplain was delineated visually using aerial photos and field reconnaissance. A 1995 Digital Elevation Model (DEM) in a Geographic Information System (GIS) was used to topographically define the floodplain of Bozeman Creek. Floodplains for each photo year were interpreted and classified into five landcover types: coniferous, deciduous, herbaceous, bare ground, and water, based on texture, color, shape, size, pattern, and association. Canopy woody vegetation was used in interpretation since it is visible on all aerial photos and is indicative of major changes to the riparian landscape. While understory vegetation is disturbance-dependent, its analysis was not possible using the historic aerial photos.

Vegetation Response

We identified eight valley-wide transects perpendicular to floodplains on both sites, spaced 100m apart close to dams, and 500m apart further down the study reaches (Figure 3). We expected more biotic change to occur near the dams, as sediment stored behind the impoundment and released along with the dam breach initially deposits close to its source. Each transect was consequently divided into points ten meters apart to facilitate statistical analysis, and landcover of each point was identified for each photo year.

The vegetation transect points were assessed in the field in summer 2005 and mapped using a Trimble GeoXT Global Positioning System (GPS) receiver, completing a time series of 1971-2005 for Mystic and 1942-2005 for Pattengail. This data was used to determine long term vegetation changes due to dam failure/removal.

Vegetation Response Analysis

Statistical analysis of change in landcover type for each transect point allowed interpretation of riparian vegetation response. A Wilcoxon Rank-Sum test was completed to detect significant differences in vegetation at observed points between years. An Analysis of Variance (ANOVA) test was performed to ascertain significant changes in landcover as a function of distance to thalweg, distance to dam, and elevation above mean sea level.

Hydrologic Characterization

Historic peak flows were estimated using three independent approaches - 1) modeled flow using paleohydrology, 2) empirically derived regional models (Parrett and others 1994), and 3) hydrograph records. Hydrology transects for input into models were placed at points of floodplain constriction and expansion along the length of each study reach (Figure 3). At each transect, we surveyed breaks in slope, banks, channel margins, and channel thalwegs. Flood stage indicators (FSI) were surveyed and used to model flood characteristics following the paleohydrologic methods of Cenderelli and Wohl (Cenderelli and Wohl 2001). They included fluvial sediment deposits and woody debris piles, and scour zones. In Pattengail, we used a Leica survey grade GPS system with sub-centimeter vertical accuracy. We used an autolevel and stadia rod in Mystic because the narrow valley and dense vegetation blocked satellite signals. The equipment yielded sub-meter vertical accuracy. These estimates were evaluated as a group to determine the best possible peak flow estimate.

Paleohydrology. Peak stage determination is a critical component to estimating historic peak discharge (Pruess and others 1998). Yet the accuracy of flood stage indicators is susceptible to several uncertainties (Jarrett and Tomlinson 2000). Paleodischarge estimates are particularly sensitive to flow resistance coefficients because vegetation can only be estimated, channel change, and identifying maximum flood stage. To address these issues we estimated channel roughness using aerial photos, chose bedrock controlled channels whenever possible, and used multiple indicators to determine peak flood stage.

We estimated peak discharge by combining paleoflood hydrologic techniques with a step-backwater hydrology model (Cenderelli and Wohl 2001). This approach combines two independent data sources to arrive at the best possible estimate of the historic flood environment – flood stage indicators (FSI) and nonflooded surfaces. Nonflooded surfaces such as undisturbed vegetation and changes in substrate tend to overestimate discharge. FSIs such as boulder bars, scour lines, and woody debris accumulations tend to underestimate them. High water marks tend to accurately indicate peak stage however, are rather ephemeral (Jarrett and Tomlinson 2000). We estimated a range of flood stages by bracketing the upper and lower limits of the flood environment. The lower elevations of nonflooded surfaces and high water marks served as the upper limits and the upper elevations of FSIs served as the lower limits. We narrowed the range of potential peak discharges using mean square error.

Regional Estimates. Empirically derived, regional estimates were used as a second estimate of peak discharge. Based on channel geometry, Parrett, Omang, and Hull (1994) developed regression models for the region with correlation coefficients of 0.733. Using the active channel width and Equation 1 we estimated peak discharge for a 100-year flood at both Mystic and Pattengail.

$$Q_{100} = 21.2\ \text{Channel width}^{1.193} \qquad \text{Equation 1}$$

Hydrograph Records. Hydrograph records for Mystic are discontinuous and represent 1967-1969 and 1975-1980 (Figure 4). Pattengail Creek is not gauged. The hydrograph for the Big Hole River at Maiden Rock near Divide is continuous since 1923 and shows the flow spike from the Pattengail dam breach over 50 river miles upstream (Figure 5). Because the hydrograph records are not specific to Pattengail Creek, we estimated flows from the time required for the reservoir (12,000 acre feet) to drain over 24 and 48 hours.

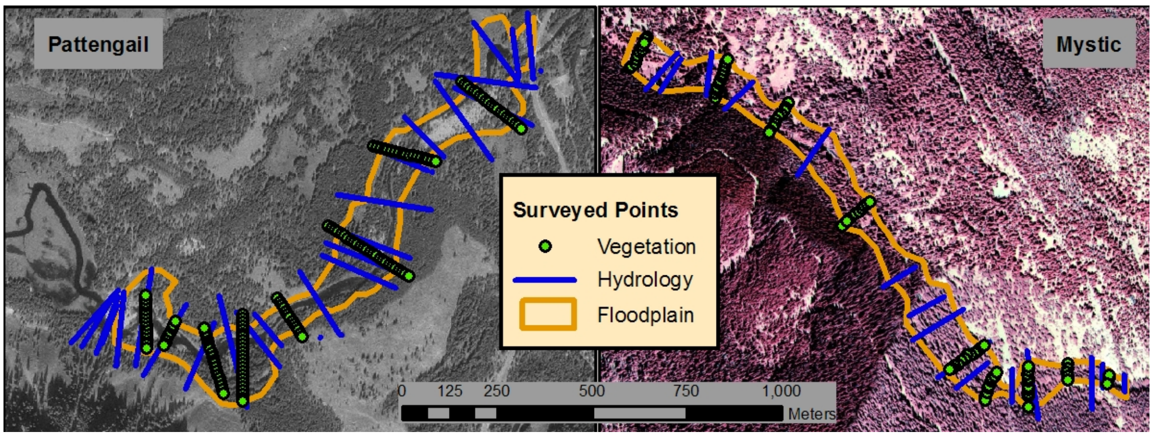

Figure 3. Pattengail and Mystic vegetation and hydrology transects used to characterize historic landcover and estimate peak flows.

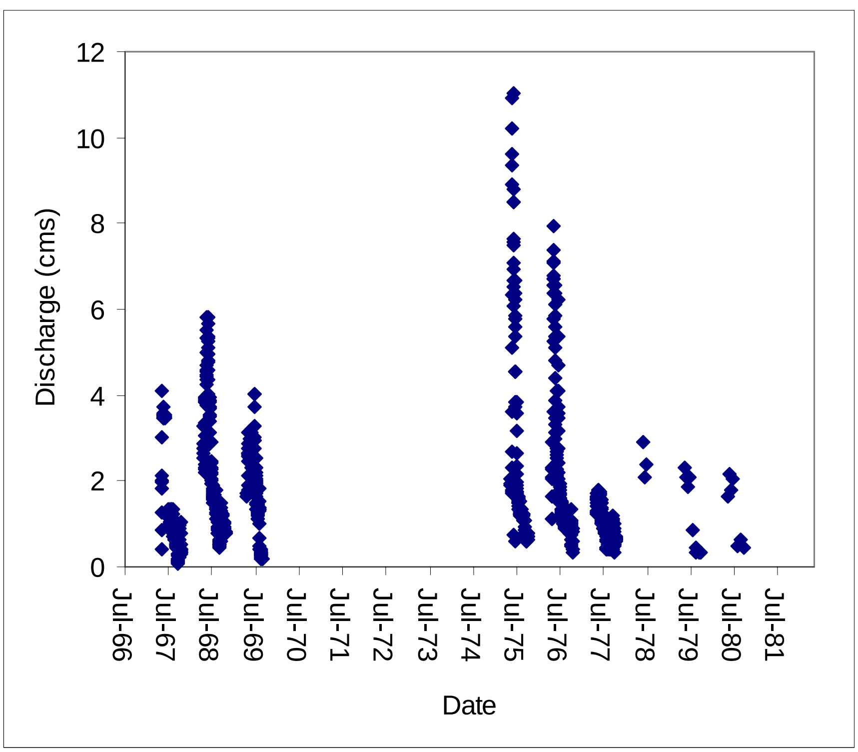

Figure 4. Historic discharge data for Bozeman Creek from 1967 to 1980.

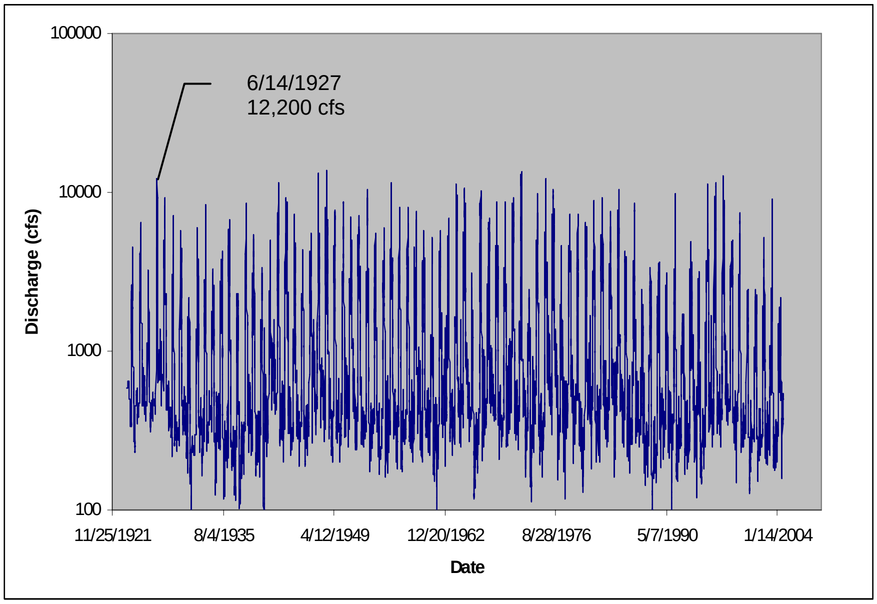

Figure 5. Hydrograph for Big Hole River near Melrose 1923-2004.

RESULTS

Hydrology

Estimates for peak discharge prior to and following removal of Mystic Lake Dam were estimated based on modeling, regional estimates, and gage records. Discharges modeled based on surveyed flood stage indicators yielded incomprehensible numbers. Alternatively, the discharge required for overbank flow from surveyed bank elevations and channel cross sections was between 141-211 cfs. The hydrograph records for Bozeman Creek are spotty despite that fact that Bozeman Creek provides a significant volume of municipal water to over 35,000 people (Figure 4). The largest discharge on record for Bozeman Creek was 388 cfs in June 1975, prior to dam removal in 1985. Over bank flows occurred in three of nine years of record, based on data presented here. An estimate of 671 cfs for a 100-yr flood was determined by applying the empirically derived, regional estimate based on the active channel width (Parrett and others 1983).

The regional estimate based on active channel width for Pattengail (Parrett and others 1985) is 4450 cfs. The estimate based on reservoir drainage time in 24 hours is 6000 cfs. Our modeled flow with the lowest average error (0.31) was 2650 cfs.

Landcover Changes

In Mystic, 99 common points were assessed for landcover (Figure 6). Minimal changes in landcover between photo years were detected (Table 2). No change was detected in 80-97% of observed points. Analysis of Variance (ANOVA) showed minor (if any) effects of environmental variables on land cover types for each photo year as well as for each photo period (Table 3). Elevation (mean sea level) showed significant effects on each landcover ($\alpha = 0.05$). Distance to the Dam showed no significant effects on landcover ($\alpha = 0.1$). Distance to the thalweg showed significant effects on land cover types for 1995 ($\alpha = 0.1$), 2001, 1989-1995, 1995-2001, and 2001-2005. Figure 7 illustrates that no vegetative landcover responds to increasing distance from the dam.

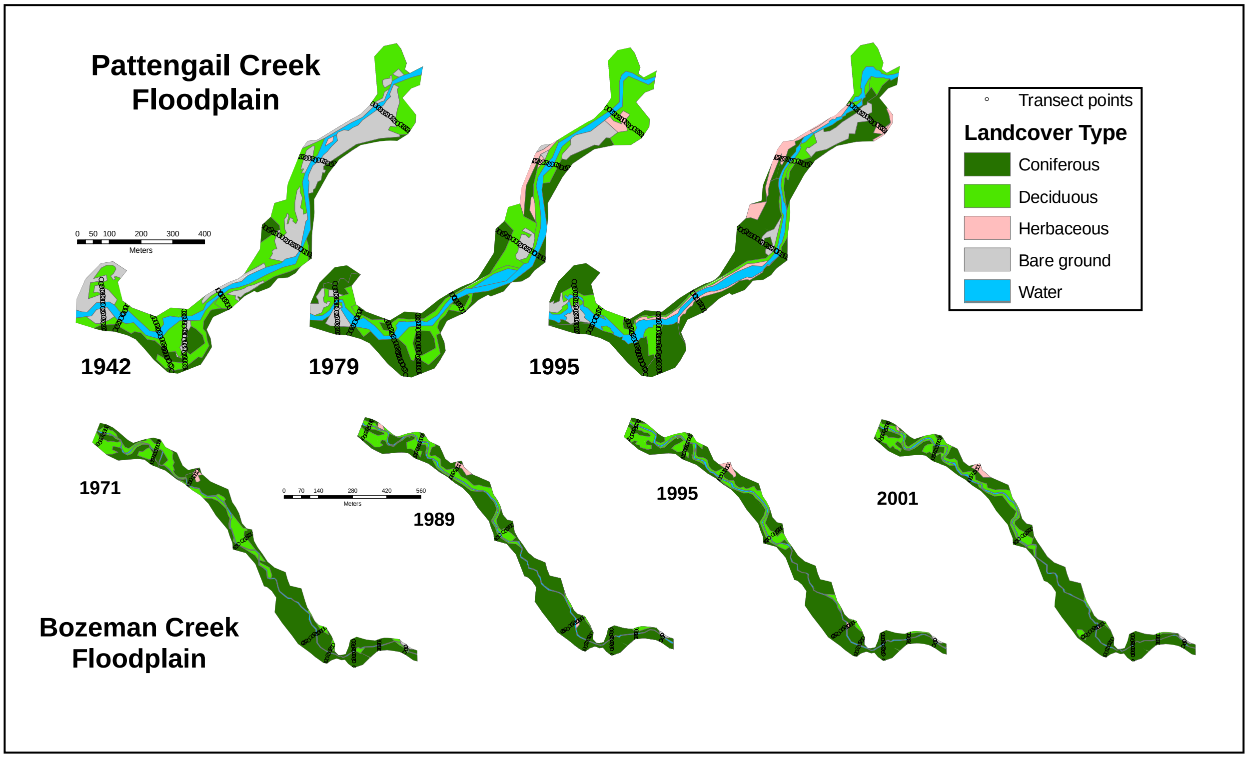

Figure 6. Vegetation changes in Mystic and Pattengail.

Table 2. Mystic Lake Dam study reach landcover changes for each photo period. Landcover changes not observed were excluded.

	Photo Period				
Land Cover Type	**1971-1989** %	**1989-1995** %	**1995-2001** %	**2001-2005** %	**1971-2005** %
Coniferous-Coniferous	62.9	67.7	64.3	61.6	56.7
Coniferous-Deciduous	6.2	0.0	4.1	1.0	10.3
Coniferous-Water	0.0	2.0	0.0	2.0	2.1
Coniferous-Herbaceous	2.1	1.0	0.0	0.0	2.1
Deciduous-Water	14.4	20.2	18.4	21.2	14.4
Deciduous-Herbaceous	0.0	0.0	2.0	0.0	0.0
Water-Deciduous	4.1	0.0	0.0	1.0	4.1
Water-Water	0.0	0.0	0.0	2.0	0.0
Water-Herbaceous	3.1	3.0	4.1	4.0	5.2
Water-Bareground	0.0	0.0	0.0	1.0	0.0
Herbaceous-Herbaceous	2.1	0.0	0.0	0.0	0.0
Herbaceous-Deciduous	2.1	4.0	4.1	3.0	2.1
Herbaceous-Bareground	0.0	0.0	1.0	0.0	0.0
Bare ground-Bareground	1.0	0.0	0.0	1.0	1.0
Bare ground-Deciduous	2.1	2.0	2.0	2.0	2.1
Coniferous-Deciduous	62.9	67.7	64.3	61.6	56.7
Coniferous-Water	6.2	0.0	4.1	1.0	10.3
Coniferous-Herbaceous	0.0	2.0	0.0	2.0	2.1
No Change	85	97	93	92	80

Table 3. ANOVA results for Mystic Lake Dam study reach landcover changes.

	Photo Year		
	Distance to Thalweg	Distance to Dam	Elevation (MSL)
1971	NS	NS	+
1989	NS	NS	+
1995	+*	NS	+
2001	+	NS	+
2005	NS	NS	+
	Photo Period		
1971-1989	NS	NS	+
1989-1995	+	NS	+
1995-2001	+	NS	+
2001-2005	+	NS	+
1971-2005	NS	NS	+
*α = 0.05 *α = 0.1*	*+ Significant*	*NS Not Significant*	

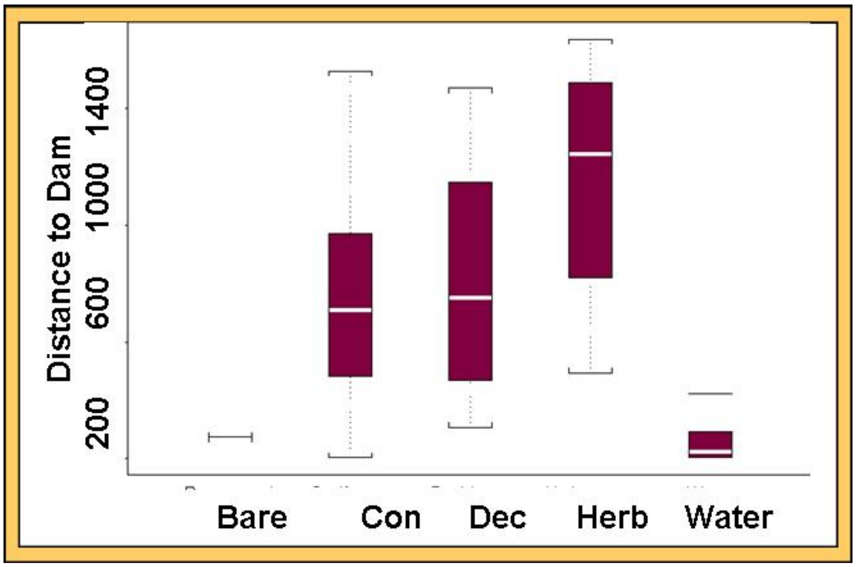

Figure 7. Mystic ANOVA results indicating that no vegetative cover responds to increasing distance from dam.

In Pattengail, 142 common points were assessed for landcover for each photo year. Changes in landcover for each photo period appear in Table 4. There was detectible vegetation change since the 1927 dam breach, particularly along the newly established channel (Figure 6). ANOVA results showed significant effects of distance to the thalweg on landcover type (α = 0.05) for each photo year and photo period (Table 5 and Figure 8). Distance to dam and elevation (mean sea level) also showed significant effects on landcover types (Table 5 and Figure 9).

Table 4. Pattengail Creek Dam study reach landcover changes for each photo period. Landcover changes not observed were excluded.

	Photo Period			
	1942-1979	1979-1995	1995-2005	1942-2005
Land Cover Type	%	%	%	%
Coniferous-Coniferous	60.6	60.6	65.1	42.3
Coniferous-Deciduous	0.0	0.0	0.7	0.7
Coniferous-Water	1.3	1.3	2.0	0.0
Coniferous-Herbaceous	3.2	3.2	0.0	0.0
Coniferous-Bare ground	0.0	0.0	1.3	1.4
Deciduous-Deciduous	8.4	8.4	7.2	5.6
Deciduous-Water	1.9	1.9	2.0	2.8
Deciduous-Herbaceous	1.3	1.3	0.7	2.1
Deciduous-Bare ground	0.6	0.6	0.0	0.0
Deciduous-Coniferous	7.7	7.7	1.3	14.8
Water-Deciduous	1.9	1.9	2.0	2.1
Water-Water	7.1	7.1	7.9	9.2
Water-Coniferous	0.6	0.6	0.7	1.4
Herbaceous-Herbaceous	1.3	1.3	2.6	0.0
Herbaceous-Bare ground	0.0	0.0	0.7	0.0
Herbaceous-Coniferous	0.0	0.0	2.0	0.0
Bare ground-Bare ground	3.2	3.2	2.6	3.5
Bare ground-Deciduous	0.0	0.0	0.7	2.8
Bare ground-Water	0.0	0.0	0.0	0.7
Bare ground-Herbaceous	0.0	0.0	0.0	1.4
Bare ground-Coniferous	0.6	0.6	0.7	9.2
No Change	80.6	80.6	85.5	60.6

Table 5. ANOVA results for Pattengail Creek Dam study reach.

	Photo Year		
	Distance to Thalweg	Distance to Dam	Elevation (MSL)
1942	+	NS	+
1979	+	+	+
1995	+	+	+
2005	+	+	+
	Photo Period		
1942-1979	+	+	+
1979-1995	+	+	+
1995-2005	+	+	+
α = 0.05	*+ Significant*	*NS Not Significant*	

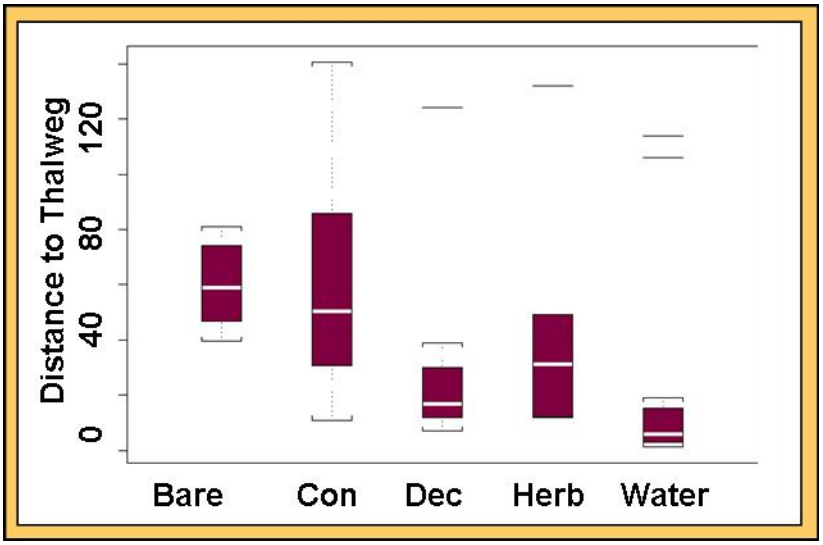

Figure 8. ANOVA results for Pattengail Creek Dam study reach showing the effects of distance to thalweg on landcover.

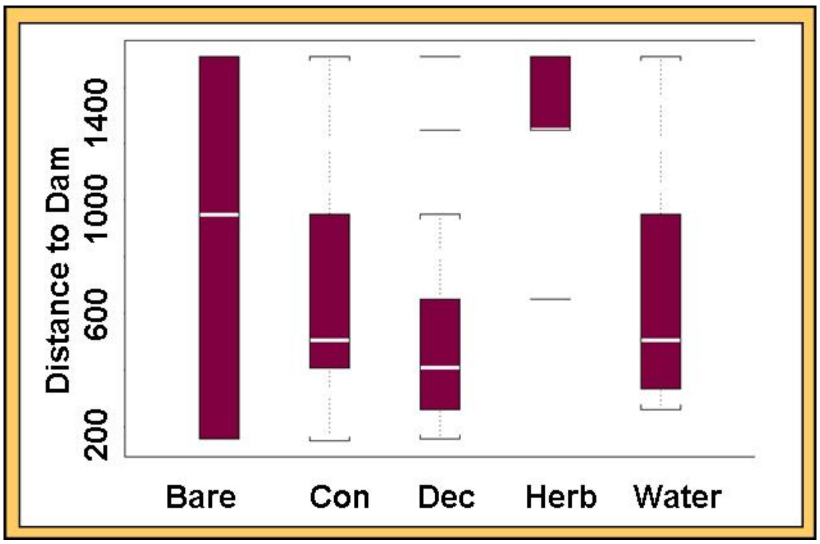

Figure 9. ANOVA results for Pattengail Creek Dam study reach showing the effects of distance to the dam on landcover.

DISCUSSION

Mystic

Modeled flow estimates based on flood stage indicators (FSIs) were used to estimate flood paths following dam removal. The flow estimates for each study site were variable but were especially wide ranging for Mystic. Although coarse, the modeled flood paths lay a foundation for estimating floodplain vegetation response.

The historic flood path for Mystic (based on a modeled flow of 141-211 cfs does not exceed its banks. Even the highest flow estimate (388 cfs from 1976 gage records) does not provide energy for deposition or erosion of sediments beyond 10 m from the channel. The Mystic valley floor width averaged 100+ meters with coniferous vegetation (*Picea engelmannii*) as the dominate landcover. Floodplain vegetation free of disturbance continues along a successional trajectory toward an upland community. Our landcover results show an overwhelming dominance of *Picea engelmannii,* a typical upland species. The lack of floodplain landcover change and modeled flows within surveyed banks suggest that flows since the dam removal have had little influence on riparian vegetation.

Historically, Mystic Lake Dam did not operate much of the time due to poor spillway design, instability, and a partial failure in 1978 (City of Bozeman records). The constrained, narrow valley with cascade and plane-bed channel types are known to be unresponsive to all but the most catastrophic flows (Montgomery and Buffington 1997). The channel and valley characteristics combined with dam operations strongly suggest that the dam had little effect on downstream riparian vegetation. Following the same reasoning, the lack of riparian response following a controlled dam removal at low flow is to be expected, also. Thus, paleohydrologic methods combined with aerial photography accurately showed no change to the downstream system following the removal of Mystic Lake Dam in 1985.

Pattengail

The Pattengail Creek Dam break substantially differs from the Mystic Lake Dam removal in both hydrology and ecology. The modeled flood path (at 2650 cfs) resulting from the break covers the valley floor and was likely very energetic. We were only able to assess vegetation response post-dam break due to the lack of ecological information prior to dam construction in 1927. However, starting with aerials from 1942, we were able to quantify vegetation response along the modeled flow path for the last 65 years (15-78 years following dam failure).

While most vegetation survey points were unchanged between photo years, those that illustrated changes suggest classic riparian successional trajectories. From a freshly disturbed site with coarse sand or fine gravel (bare ground), colonizers such as cottonwood or willow species, tap-rooted annuals, and other ruderal established in dense nurseries. These species are typically poor competitors and fast growing with low survivorship resulting in self-thinning and few mature individuals. Willow thickets and cottonwood groves, if left undisturbed, will give way to upland species such as *Artimesia* spp. (sage brush), *Pinus contorta*, and *Picea engelmannii*. These areas are represented by the change from deciduous to coniferous. In areas with high organic matter and wet soils, *Carex* spp. and *Juncus* spp. dominate and only give way to facultative wetland species if the site progressively becomes drier (Figure 6 and Table 4).

In contrast to Bozeman Creek, the dam failure of 1927 on Pattengail Creek (built in 1901) yielded catastrophic stream flows, produced marked channel change, and evoked substantial floodplain vegetation response. The plane bed and pool riffle channel types of Pattengail Creek wind through a wide, glaciated, unconsolidated valley (Figure 11). Based on relict channels detected during field reconnaissance, local interviews, and aerial photo interpretation, we found there was a meandering channel prior to dam failure. The current channel has low sinuosity. It is in a state of high flux. And, it grades from a series of scour ponds near the dam break to glides, braids, and riffle/pool sequences about a mile downstream. Flow estimates (modeled from flood stage indicators, computed from reservoir drainage times, and calculated using a regional regression equation) ranged from 120 to 170 cubic meters second – catastrophic by all measures for a stream this size. Such flows greatly exceeded the creek banks and reworked 19 hectares of floodplain compared to the current four hectares. Near the dam the flows downcut the channel nearly three meters. 40% of riparian vegetation cover changed over the 78 years since the dam failed (Table 4). The high degree of channel change, catastrophic flows, and major amount of floodplain vegetation change indicated a high degree of ecological change at this site. Further, the loss of sinuosity, shrunken floodplain area, and intense downcutting showed that very high energy flows can leave long-term scars on a river ecosystem.

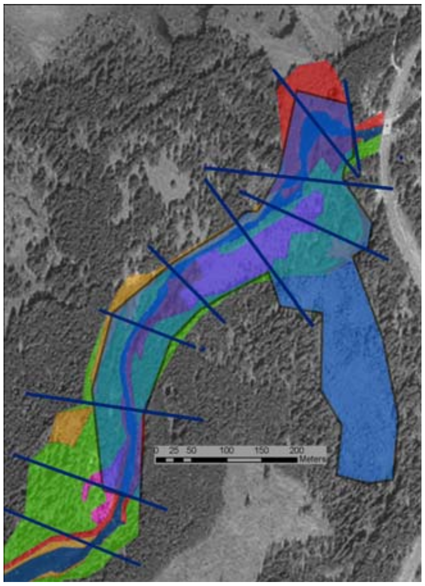

Figure 10. Modeled flow path for Pattengail Creek following 1927 breach.

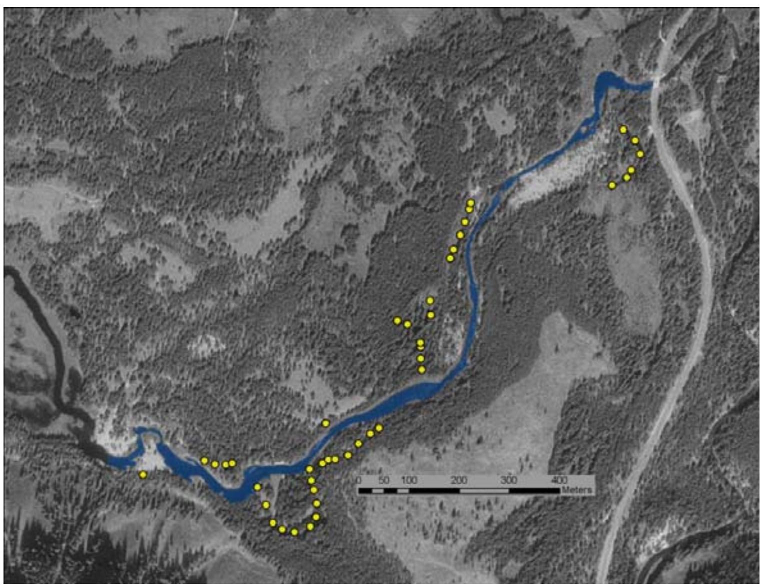

Figure 11. Flood stage indicators for Pattengail suggest a historic meandering channel once flowed through the valley.

CONCLUSIONS

The study sites represented two extremes a along gradient of channel type responsiveness and flow energy. Responsive channel types such as gravel beds and plane beds perpetually create, tear down, and recreate floodplain landforms (Montgomery and Buffington 1997). Energetic, overbank flows are required to rework floodplain sediment and create topographic heterogeneity. Floodplain landform heterogeneity (Poole 2002; Tabacchi and others 1998) and flow regime (Poff and others 1997) drive riparian vegetation establishment, community associations, and redirect successional trajectories. However, past a certain point, high energy flows can do more harm than good in terms of restoring a dam-altered river ecosystem. Through paleohydrology and aerial photo interpretation we were able to detect ecological response to dam removal and failure. We were unable to detect reversal of dam impacts due to the lack of dam impacts on Mystic and the high energy impacts of the dam breach flood in Pattengail. Our initial results suggest that channel type and stream flow magnitude played a significant role in the long term ecological response to the dam removal at these sites.

ACKNOWLEDGEMENTS

This research was supported by the USGS 104b Water Resources Research Program administered by the Montana Water Center. The City of Bozeman, NRCS in Dillon and Bozeman, Gallatin and Beaverhead-Deer Lodge National Forests and Gallatin Local Water Quality District provided access to aerial photos, hydrograph data, and access to study sites. Private land owners in the Wise River area provided anecdotal information and permission to access study sites. Wise River Merchantile provided equipment support. Steve Custer and Joel Cahoon provided technical assistance during the planning phase of the project. And Selby's ESSCO of Bozeman provided assistance with GPS.

LITERATURE CITED

Department of Natural Resources and Conservation. 1989. Dam Safety.

Bednarek AT. 2001. Undamming rivers: A review of the ecological impacts of dam removal. Environmental Management 27(6):803-814.

Cenderelli DA, Wohl EE. 2001. Peak discharge estimates of glacial-lake outburst floods and "normal" climatic floods in the Mount Everest region, Nepal. Geomorphology 40(1-2):57-90.

Hart DD, Johnson TE, Suchaw-Newton KL, Horwitz RJ, Bednarek AT, Charles DF, Kreeger DA, Velinsky DJ. 2002. Dam removal: challenges and opportunities for ecological research and river restoration. Bioscience 52(8):669-681.

Jarrett RD, Tomlinson EM. 2000. Regional interdisciplinary paleoflood approach to assess extreme flood potential. Water Resources Research 36(10):2957-2984.

Montgomery DR, Buffington JM. 1993. Channel Classification, Prediction of Channel Response, and Assessment of Channel Condition. Olympia: Washington State Department of Natural Resources. Report nr Report TFW-SH10-93-002. 86 p.

Montgomery DR, Buffington JM. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 109(5):596-611.

National Inventory of Dams. 2003. http://crunch.tec.army.mil/mid/webpages/nid.cfm.

Parrett C, Hull JA, Corp Author: Montana, Dept. of Natural Resources and Conservation, Geological Survey. 1985. Streamflow characteristics of mountain streams in western Montana. Reston, Va.?: U.S. Dept. of the Interior Geological Survey ; Alexandria VA : For sale by Distribution Branch USGS. iv, 58 p. : ill., maps ; 28 cm. p.

Parrett C, Omang RJ, Hull JACAGS, United States, Bureau of Land Management, United States, Forest Service, Montana, Dept. of Natural Resources and Conservation. 1983. Mean annual runoff and peak flow estimates based on channel geometry of streams in northeastern and western Montana. Helena, Mont.: U.S. Dept. of the Interior Geological Survey ; Lakewood CO : Open-File Services Section Western Distribution Branch. iv, 53 p. : ill., maps ; 28 cm. p.

Parrett C, Omang RJ, Hull JACAGS, United States, Bureau of Land Management, United States, Forest Service, Montana, Dept. of Natural Resources and Conservation. 1994. Mean annual runoff and peak flow estimates based on channel geometry of streams in northeastern and western Montana. Helena, Mont.: U.S. Dept. of the Interior Geological Survey ; Lakewood CO : Open-File Services Section Western Distribution Branch. iv, 53 p. : ill., maps ; 28 cm. p.

Poff NL, Allan JD, Bain MB, Karr JR, Prestegaard KL, Richter BD, Sparks RE, Stromberg JC. 1997. The natural flow regime. Bioscience 47(11):769784.

Poole GC. 2002. Fluvial landscape ecology: addressing uniqueness within the river discontinuum. Freshwater Biology 47(4):641-660.

Pruess J, Wohl EE, Jarrett RD. 1998. Methodology and implications of maximum paleodischarge estimates for mountain channels, upper Animas River basin, Colorado, USA. Arctic and Alpine Research 30(1):40-50.

Shafroth PB, Friedman JM, Auble GT, Scott ML, Braatne JH. 2003. Potential responses of riparian vegetation to dam removal. Bioscience 52(8):703-712.
Shuman JR. 1995. Environmental considerations for assessing dam removal alternatives for river restoration. Regulated Rivers-Research & Management 11:249-261.
Stanford JA, Ward JV, Liss WJ, Frissell CA, Williams RN, Lichatowich JA, Coutant CC. 1996. A general protocol for restoration of regulated rivers. Regulated Rivers-Research & Management 12(4-5):391-413.
Stanley EH, Doyle MW. 2002. A geomophic perspective on nutrient retention following dam removal. Bioscience 52(8):693-701.
Tabacchi E, Correll DL, Hauer R, Planty-Tabacchi A-M, WISSMAR R. 1998. Development, maintenance and role of riparian vegetation in the river landscape. Freshwater Biology 40(3):497-516.
The Aspen Institute. 2002. Dam Removal: A New Option for a New Century. Queenstown: The Aspen Institute. 68 p.

The presentations and proposals were made based on the project funded by the USGS 104b Water Resources Research Program administered through the Montana Water Center.

Citations

Schmitz, Denine, Selita Ammondt, Matt Blank, and Duncan Patten. 2006. Using historic aerial photography and paleoflood hydrology to assess long-term ecological response to two Montana dam removals. USGS Water Resources Research Program.

Schmitz, Denine, Selita Ammondt, Matt Blank, and Duncan Patten. 2005. Long-term hydrogeomorphic effects of dam failure/removal – a pilot study. Floodplains and rivers: connections and reconnections. Center for Riverine Science and Stream Re-naturalization. September 22 and 23, 2005. Missoula, Montana.

Ammondt, Selita, Denine Schmitz, and Duncan Patten. 2005. Studying the effects of small dam removal on woody riparian species in Montana using aerial photo interpretation and field surveys. Floodplains and rivers: connections and reconnections. Center for Riverine Science and Stream Re-naturalization. September 22 and 23, 2005. Missoula, Montana.

Schmitz, Denine, Selita Ammondt, Matt Blank, and Duncan Patten. 2005. Long-term hydrogeomorphic effects of dam failure/removal – a pilot study. Surface Water/ Groundwater: One resource. Montana American Water Resources Association. October 2005. Bozeman, Montana.

Ammondt, Selita, Denine Schmitz, and Duncan Patten. 2005. The effects of small dam removal on woody riparian species in Montana. Surface Water/ Groundwater: One resource. Montana American Water Resources Association. October 2005. Bozeman, Montana.

Schmitz, Denine, Selita Ammondt, Matt Blank, and Duncan Patten. in prep. Assessing ecological response to small dam removal using historic ecological techniques. Wetlands.

Student support

Selita Ammondt conducted ecological research into the effects of dam removal on riparian woody vegetation. She completed the entire research process including literature review, methods assessment, data collection, analysis, and presentation. Ammondt presented her work at the 2005 Center for Riverine Science and Stream Re-naturalization, 2005 Montana American Water Resources Association and 2006 Montana State University Undergraduate Scholar’s Conference. She is currently assisting in the preparation of this work for submission to the journal Wetlands.

Steve Jay is currently conducting research into the effects of dam removal on the geomorphology of stream channels. He has completed preliminary analyses of the historic changes to the Upper Blackfoot River prior to the hazard reduction of Mike Horse Dam. He has presented his findings at the 2006 Montana State University Undergraduate Scholar’s Conference and plans to present his final results at the 2006 Montana American Water Resources Association conference.

Ongoing work

The findings ascertained during this pilot study laid the foundation for submission of two proposals for further funding to the Sigma Delta Epsilon Graduate Women in Science Fellowship and the Montana DNRC Renewable Resources Grant and Loan program. The following summary describes the ongoing research.

Channel response assessment for the Upper Blackfoot – How to maximize development and preservation of water quality, riparian function, and fish habitat

Denine Schmitz[1], Joel Cahoon[2], and Matt Blank[3]
Montana State University
[1]Land Resources and Environmental Sciences
[2]Civil Engineering
[3]Western Transportation Institute

Proposal Abstract

Helena National Forest (HNF) has committed to fully restoring ecosystem function to the floodplains in the Upper Blackfoot Mining Complex. As the focus now turns to concerns over the fate of Mike Horse Dam and the ensuing restoration, it is more important than ever to fully understand the nature of the stream system. Up and downstream from Mike Horse Dam floodplain ecosystem function is the product of centuries of natural variation in hydrology followed by decades of human changes in flow regime. ***The goal of this project is to assess the ecological response potential of floodplains associated with Mike Horse Dam***. Two questions pertain to the Upper Blackfoot. 1) How can stream ecosystem restoration be maximized? And, 2) how can risk of further contamination be minimized? We will use the temporal and spatial contexts of the stream reaches to classify their potential ecological response to changes in flow regime induced by dam construction, breach, and hazard reduction. Historic aerial photographs from 1938 (pre-construction), 1961 (post-construction), 1966 (pre-breach), 1979 (post-breach), 1995 (post-breach), and 2005 (pre-reduction) will be used to track channel, floodplain, and riparian vegetation cover. Topographic surveys of flood stage indicators (flood scars and deposits) and valley wide cross sections will be used to model (HEC-RAS) past hydrologic events with step backwater and time varying techniques. From the historic ecological response classification we will predict responses to the proposed dam hazard reduction. To test this prediction we will collect topographic, hydrologic, and biological data at the same locations before and after action on Mike Horse Dam. An evaluation of floodplain ecological response based on its spatial and temporal context within the watershed will distinguish dynamic reaches from stable. Armed with this information decision makers can maximize restoration potential and minimize risk to contaminated sediment.

Goals

Helena National Forest (HNF) has committed to fully restoring ecosystem function to the floodplains in the Upper Blackfoot Mining Complex (**Error! Reference source not found.**). 1) How can stream ecosystem restoration be maximized? And, 2) how can risk of further contamination be minimized? Floodplain ecosystems are dependent on a natural flow regime— natural variability in flood size, frequency, rate of change, timing, and duration of flow (Poff and others 1997). Floodplain ecosystem function up and downstream from Mike Horse Dam is the product of centuries of natural variation in hydrology followed by decades of human changes in flow regime. Because recorded history extends over a century for the Mike Horse Mine area, there is an opportunity to assess floodplain topographic and riparian vegetation responses to past changes in flow regime. Through this assessment, changes in floodplain topography and riparian vegetation distribution may be attributed to specific events through an investigation of historical aerial photos and relicts of past floods. This information can be used to characterize the response potential of each reach in the floodplain area and inform a site specific, process-based restoration strategy. To achieve the long-term goal of a fully-functioning riparian system in the Upper Blackfoot watershed, an assessment of past ecological response is needed. ***The goal of this project is to assess the ecological response potential of floodplains associated with Mike Horse Dam***.

Objectives

1. Determine the geomorphic response potential of stream reaches.
2. Determine the vegetative response potential of riparian communities along stream reaches.
3. Predict areas of high and low risk to impacts of dam hazard reduction for use in a monitoring program.
4. Determine the effect of past, current, and predicted geomorphic response potential of stream reaches on aquatic organism habitat and mobility.

Expected Results

1. Pool riffle and plane bed channel types (following Montgomery and Buffington 1997) will show greater response in channel morphometrics (width: depth, planform) and plant community structure (riparian overstory and understory extents) than cascade and colluvial channel types to:
   - a change from a natural to a dam altered flow regime.
   - dam breach.
   - dam hazard reduction.
2. Intermediate (based on hydrograph records and flow estimates) flood sizes following dam hazard reduction have higher restoration potential than small or high flood sizes for a given channel type (following Montgomery and Buffington 1997).
3. Aquatic organism habitat and mobility will be improved due to watershed approach to stream restoration.

Expected Products

1. Full descriptions of location, morphology, fluvial processes, and riparian plant communities for each reach between the Pass Creek/Blackfoot River confluence (study area) for 1938, 1961, 1966, 1979, 1995, 2005, and 2006 (study period).
2. Maps of channel type and riparian community distributions for each year in the study period.
3. Ranking of reaches (and specific locations if possible) on a relative scale of responsiveness.
4. Descriptions of reaches in terms of their risk for retaining or aggrading contaminated sediments over the next 10 years.
5. Considerations for restoration strategies for each reach based on the known and expected processes acting on each reach over time.

Project Implementation

Tasks

1. Objective 1 – Determine the geomorphic response potential of stream reaches.
    a. Classify stream reaches and valley segments according to Montgomery and Buffington (Montgomery and Buffington 1993).
        i. Using survey-grade GPS, topographically survey the entire floodplain of the study area and the channels of all tributaries before and after the dam hazard reduction. Attribute descriptive data for each landform and flood stage indicator with a mapping grade GPS unit.
            1. Map with centimeter precision channel and floodplain landforms.
            2. Map with centimeter precision channel cross sections.
            3. Map with centimeter precision indicators of past channel locations, flood stages, and relict landforms.
        ii. Using survey-grade GPS, topographically survey the channel centerlines of all tributaries above the Pass Creek-Upper Blackfoot River confluence.
        iii. Topographically assess watershed scale distributions in drainage area, channel slope, and upland slope using digital elevation model (dem) analysis.
    b. Determine geomorphic response to past changes in flow regime.
        i. Acquire and georeference aerial photos (1938, 1961, 1966, 1979, 1995, 2005).
        ii. Map channel type and floodplain landform distributions based on aerial photos (1938, 1961, 1966, 1979, 1995, 2005) and ground surveys (2007 and 2008).
        iii. Assess historic peak flows required to produce mapped flood stage indicators.
            1. Input cross section and flood stage indicator data into HEC-RAS hydrologic modeling software.
            2. Use a combination of step backwater and time varying techniques to model flow conditions at each flood stage indicator.
        iv. Apply trend analysis to changes in classification between photo years.
        v. Document events which may alter flow regime, floodplain geomorphology, or riparian vegetation.
        vi. Evaluate channel response to dam construction (1941), dam breach (1975) and dam hazard reduction (2007).
2. Objective 2 – Determine the vegetative response of riparian communities along stream reaches.
    a. Assess riparian community composition and structure in each reach type before and after dam hazard reduction.
    b. Determine riparian vegetation response to past changes in flow regime.
        i. Map riparian vegetation distributions based on aerial photos (1938, 1961, 1966, 1979, 1995, 2005) and ground surveys (2007 and 2008) before and after dam hazard reduction.

ii. Apply trend analysis to changes in riparian canopy cover distribution between photo years.
iii. Evaluate riparian response to dam construction (1941), dam breach (1975) and dam hazard reduction (2007).

3. Objective 3 – Determine the effect of past, current, and predicted geomorphic response potential of stream reaches on aquatic organism habitat and mobility.
   a. Inspect the system for man-made barriers (bridges, culverts, weirs, diversions, pipelines.
   b. Make recommendations for enhancing aquatic organism habitat and mobility.
4. Objective 4 – Predict areas of high and low risk to impacts of dam hazard reduction for use in a monitoring program.
   a. Forecast spring peak discharge and flow stages for each cross section for 2008.
   b. Extrapolate future changes in channel morphology to predict short and long term geomorphic response to hazard reduction of Mike Horse Dam
   c. Extrapolate future changes in riparian vegetation distribution to predict short and long term riparian vegetation response to hazard reduction of Mike Horse Dam

Schedule

Jul 2007	Survey and map watershed channel slopes, cross sections, and flood stage indicators before dam hazard reduction with survey-grade GPS Assess riparian community composition and structure in each reach type before dam hazard reduction
Sep-Nov 2007	Assess historic peak flows
Sep 2007	Acquire and georeference aerial photos
Nov 2007	Map channel type, visible landforms, and riparian vegetation distribution along stream reaches in each aerial photo
Jan 2008	Apply trend analysis to changes in channel type, floodplain landforms, and riparian vegetation distribution between photo years
Feb 2008	Conduct dem analysis of drainage area, channel slope, and upland slope distributions
Mar 2008	Document events which may alter flow regime, floodplain geomorphology, or riparian vegetation
Apr 2008	Extrapolate changes in channel morphology and riparian vegetation distribution to predict short term ecologic response to hazard reduction of Mike Horse Dam
May 2008	Forecast spring peak discharge and flow stages for each cross section for 2008
Jul 2007	Survey and map watershed channel slopes, cross sections, and flood stage indicators after dam hazard reduction with survey-grade GPS Assess riparian community composition and structure in each reach type after dam hazard reduction
Aug-Oct 2008	Extrapolate changes in channel morphology and riparian vegetation distribution to predict long term ecologic response to hazard reduction of Mike Horse Dam