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MONITORING THE RESPONSE OF A RIPARIAN ECOSYSTEM TO HYDROLOGIC RESTORATION

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December 2005

COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH BRANCH

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16. Abstract

This study examined the effects of a stream restoration project on groundwater elevations and the population and habitat of a threatened small mammal, the Preble's meadow jumping mouse (*Zapus hudsonius preblei*). A series of nine check dams were installed on East Plum Creek in 2001 and 2002, to help restore an incised urban stream channel. This 0.54 mile section of stream is within a heavily urbanized corridor. The dams trapped considerable sediment, raised the stream bed level, and restored groundwater levels within the rooting zone of riparian vegetation.

Populations of the Preble's mouse were monitored from 1998 to 2004 in control and treatment areas before and after dam installation. Habitat vegetation cover was also measured at these sites from 2001 to 2004, and groundwater elevations in the study area were monitored. Preble's population estimates were determined for control and treatment areas through a modeling procedure. Preble's abundance increased in both treatment areas following dam installation, although treatment effects may have been different in these two areas. Positive treatment effects were localized and have been short-term to date, and the riparian system is still within a major period of adjustment. Treatment effects may have been partially due to an increase in graminoid cover in treatment areas; Preble's use graminoids for food and cover.

Implementation:
Long-term treatment effects are uncertain, but we expect additional positive responses as areas with restored riparian habitat become more favorable for Preble's.

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Monitoring the Response of a Riparian Ecosystem to Hydrologic Restoration

by

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Ensight Technical Services, Inc.

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Executive Summary

The Colorado Department of Transportation (CDOT) owns a section of East Plum Creek in Castle Rock, Colorado. During baseline environmental studies in the late 1990s, it was discovered that riparian vegetation along the creek was dying. Channel incision from increased streamflow had caused the groundwater table to be lowered below the rooting zone of riparian plants. It was also discovered that this same area harbored the Preble's meadow jumping mouse (PMJM), a federally protected small mammal. The acronym "PMJM" and the term "Preble's" are used interchangeably for the Preble's meadow jumping mouse in the remaining part of the document.

CDOT decided that the only feasible way to prevent this habitat from further degrading was to restore it. A series of nine check dams were installed in the channel bed along a 0.54 mile stretch of East Plum Creek in 2001 and 2002. It was hypothesized that if Preble's habitat was restored, that Preble's populations would increase in extent and abundance in the treatment areas.

This project looked at the responses of Preble's populations in the study area to stream restoration from the check dams. Population data had been collected in the area since 1998 with live-trapping methods, so both pre and post-dam information on these populations was available. The response of riparian foliar vegetation cover in the study area was also investigated. Groundwater elevations responded positively to the dams and led the way for additional biological changes.

Sampling sites were divided into two control and two treatment areas (the latter with check dams). Preble's population data from the control and treatment areas were analyzed in a capture/recapture model and control and treatment areas were compared. Demographic information for abundance, survival, capture/recapture rates, and temporary emigration/immigration rates were estimated.

Preble's populations in the study area may cycle on a nine-year period. There were significant increases in Preble's abundance at each of the two treatment areas following the installation of the check dams, although the factors responsible may have differed in each area. There was a significant increase in graminoid (grass) cover in the treatment areas, and this may have enhanced Preble's survival or reproduction. Both of the positive treatment effects on abundance were localized and short-term, but stream incision in the study area has been stabilized.

Groundwater elevations in monitoring wells were affected by several factors including the installation of the dams and the rate of sediment accretion behind dams , but it appeared that the installation of the first three dams during a period of high streamflow and subsequent sedimentation raised nearby groundwater elevations immediately and levels stabilized at the shallower elevations. Installation of the next set of dams likely had a two phased response: an immediate rise in groundwater levels in response to ponding behind dams, and a second response after sedimentation was complete. There is a current trend within the study area for relatively stable, shallower groundwater elevations.

This project has several potential benefits for CDOT. It shows that degrading riparian vegetation can be restored with proper ecological treatments. Eroded stream corridors are becoming common in the Colorado Front Range because of increased urban stream flows, and many potential sites could benefit from similar restoration. CDOT has encouraged this technology transfer and similar projects are springing up at other sites in the Front Range.

Secondly, this study provided baseline demographic information on the Preble's mouse that has contributed to management issues including conservation planning for roadway impacts to habitat. It also showed that degraded and urbanized Preble's habitat can be restored. This is somewhat surprising in that urbanizing factors have been associated with the decline of this species.

Finally, the collection of detailed riparian ecosystem data here were the means by which success criteria for a newly established conservation bank were measured, and credit ultimately earned.

Implementation Statement

This study was unique in that there is very little information on small mammal responses to habitat restoration. Additional information on the longer-term response to the restoration treatment and potential population cycle would be extremely helpful. The following steps are recommended:

- Continue to monitor the Preble's population in the study area. Habitat conditions in the area continue to change from the dam treatments as well as related factors such as beaver colonization. CDOT Region 1 has agreed to fund additional sampling in 2005. Monitoring of general ecological conditions will also occur.
- Control invasive weeds in the area. Initial weed control within the bank area occurred in 2005.
- Cooperate with and educate interested parties on riparian restoration. Most potential project areas will not contain Preble's habitat. But riparian areas contain important wildlife habitat, provide recreational opportunities, help control stormflows, and are aesthetically pleasing. They are prized areas in the arid west and should be managed carefully.
- The Bank Management Plan (as part of the Bank Agreement) calls for an annual monitoring report. This report should address any known changes to patterns in sediment deposition, significant storm events, and continued responses of riparian vegetation.

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I. Introduction

Riparian habitats include areas immediately adjacent to streams, lakes and other surface water bodies, as well as additional area that is influenced by shallow groundwater. In the western United States, riparian habitats are especially important to a number of plant and animal species because of the relative scarcity of these areas. It is estimated that riparian areas total approximately 3% of the area in Colorado, yet over 40% of the known plant species (1220 taxa) live in these habitats (Kittel et al., 1999).

Colorado riparian areas have experienced a number of anthropogenic changes since settlement in the early and mid-nineteenth century. Mining, forestry and agricultural practices probably had the greatest early effects on riparian zones (DeBano and Schmidt 2004). More recently, residential and commercial development has directly and indirectly affected surrounding watersheds and riparian zones (Ffolliott et al., 2004).

Urban watersheds typically show an increase in stream discharge, with both increases in peak flow and base flow. Additional urban water in stream channels provides more energy to erode the channel bed, and channel incision can result. As the channel bed lowers, the alluvial aquifer lowers to the same level. Roots from adjacent riparian vegetation can become "perched," above the water table, and water stress with dieback and eventual necrosis may result.

This problem became apparent on East Plum Creek within the Town of Castle Rock in Douglas County, Colorado. Douglas County was the fastest-growing county in the United States from 1990 to 1999, with a population increase of 160% (U.S. Census Bureau 2005). The Town of Castle Rock grew at a rate of 89% during this same time period, with a 2002 population of 25,826. The watershed area upstream of the Town was relatively undeveloped prior to 1990, but considerable residential construction and associated road building had occurred in the past decade.

East Plum Creek flows through the center of Castle Rock adjacent to Interstate 25, and much of the creek riparian area near I-25 belongs to the Colorado Department of Transportation (CDOT). CDOT riparian property was surveyed for wetlands and small mammals in the late 1990s, and two important discoveries were made. First, stream downcutting was proceeding rapidly. Based on the height of a formerly buried sewer pipe in the stream channel that was now exposed, it was estimated that the channel bed had been lowered at least 4.9 feet (ft) in the past eight years. Woody riparian vegetation along the stream was showing signs of serious decline. Visual inspection of streamside willow stands showed low-vigor plants and many dead willow patches. The cause of the decline was likely a depression of the alluvial aquifer following channel incision.

Secondly, the Preble's meadow jumping mouse (*Zapus hudsonius preblei*) was found in riparian habitat; this small mammal is listed as threatened under the Endangered Species Act (USFWS 1998). The Preble's meadow jumping mouse (PMJM) is a specialized riparian animal that also uses adjacent upland vegetation areas for feeding. Shrub-covered slopes that are slightly higher in elevation above the floodplain are used for hibernation. There was concern that if riparian vegetation disappeared along the stream, that the small PMJM population would follow. Region 1 CDOT staff were also facing the need for mitigating for future impacts to Preble's habitat from highway projects.

Concern for these issues led to the idea of stream channel restoration, Preble's habitat restoration, and subsequent mitigation credit. CDOT staff engineers and hydrologists explored the feasibility of installing a series of check structures (dams) along a 0.54 mile degraded stretch of East Plum Creek. After considerable debate and analysis, CDOT decided to install the dams. Dams were made of tongue-and-groove steel sheet pile sections that ranged from 19.7 to 24.9 ft in length. Pile was vibrated into place within sandy/gravel alluvium and adjacent upland areas with a crane-mounted vibratory hammer. Dams were variably spaced within the channel from 259 to 499 ft apart, with an average spacing of 358 ft. Three dams were installed on the upstream section of the study area as a test case in winter 2001. Based on the successful entrapment of sediment and positive response of elevated groundwater levels, six additional dams were installed at downstream locations in winter of 2002. These dams had deep driven pile, were extended across the entire floodplain in most locations, and had a low-flow notch to allow for fish passage and to help shape the channel. Additional details on dam specifications and installation can be found in CDOT's Conservation Banking Guide (2004). This study explored riparian ecosystem responses to stream restoration by quantifying Preble's populations, vegetation habitat variables, and groundwater elevations. Our hypothesis was that PMJM populations and riparian foliar cover would increase in areas affected by check dams, and that elevated groundwater levels would drive these biological changes.

The riparian ecosystem data that are discussed in this report are also discussed in relation to a crediting system that was eventually used to develop the East Plum Creek Conservation Bank. The collection and implementation of these data led to one of the only conservation banks in the United States based on ecosystem restoration, and we review how these data were used for that management process.

II. Project Area and History

The study area is located within the ecotone between two ecoregional provinces: the Great-Plains-Palouse Dry Steppe to the east, and the Southern Rocky Mountain Steppe–Open Woodland-Coniferous Forest–Alpine Meadow Province to the west (Bailey 1995). Shortgrass prairie, Gambel oak shrublands (*Quercus gambelii*), and Ponderosa pine (*Pinus ponderosa*) woodlands are the dominant vegetation types found within the East Plum Creek watershed.

The site is located at 039^{0} 22' 18.51" N, 104^{0} 51' 47.57" W. Site elevation varies from 6,121 ft at the north to 6,200 ft to the south. The average annual precipitation is 17.05 inches (433 millimeters), with the majority coming in late spring and summer thunderstorms (Western

Regional Climate Center 2005). The average maximum temperature is 63.7^0 F and the average minimum temperature is 31.9^0 F.

The study area floodplain and associated riparian vegetation are surrounded or in contract with a highway (Interstate 25), residential homes, roads, bridges, and commercial businesses. The floodplain varies in width from 111 to 394 ft., with much of the area in the narrower part of the range. There is a slightly elevated terrace about 3 ft. above the floodplain, with cut banks from 6 to 12 ft. in height above the streambed.

Soils in the East Plum Creek floodplain are classified as Sandy Wet Alluvial Land (USDA-SCS 1974). This soil classification is typified as light colored, stratified sand, loamy sand, sandy loam, and gravel, and are poorly drained, have rapid permeability/slow runoff, with low water holding capacity (USDA-SCS 1974).

East Plum Creek is a perennial, sand/gravel bed, third order stream, flowing north and northwest within the project area. The headwaters of East Plum Creek are south of Castle Rock along the Palmer Divide. The creek largely flows through rural areas and open space between the Palmer Divide and Castle Rock, and much of this area has become increasingly developed in the past decade.

Bankfull discharge of East Plum Creek is estimated to be approximately 140 cubic feet per second (cfs). Bankfull discharge is the dominant channel forming flow, and is usually considered to occur once every 1.67 years. Between 1999 and 2004 the highest average daily flow of 410 cfs was measured on April 30, 1999, and the minimum measured flow was 0.45 cfs on June 27, 2002 as measured at the USGS Gaging Station No. 06708800 (East Plum Creek below Haskins Gulch).

East Plum Creek morphology through the study area has changed from a meandering alluvial stream to one with a regular, incised channel. The current incised morphology is a result of three interdependent factors: 1) the straightening of East Plum Creek through Castle Rock in the early 1950’s in conjunction with the construction of I-25, 2) a catastrophic flood in 1965 that affected the entire watershed, and 3) the more recent urbanization of the watershed. Flow from the catastrophic flood of July 16, 1965, was estimated at 154,000 cfs (USGS 2000) at the Plum Creek gaging station near Louviers (located downstream of the current project area). This event radically altered the floodplains of all the streams in the area, including East Plum Creek. Friedman et al. (1996) state that this flood “removed most of the bottomland vegetation and transformed the single-thalweg stream (Plum Creek) into a wider, braided channel.” The incised pre-dam channel of East Plum Creek in the study area is a departure from the condition seen in much of the watershed.

III. Methods

Small Mammal Sampling

Presence/absence surveys for the PMJM were first conducted at several sites in Castle Rock in 1998. PMJM were found throughout the study area, but not at all sample locations. More extensive sampling began in 1999 on seven transects uniformly distributed within the study area. Additional transects were added at various times to provide greater coverage of the study area or because of construction disturbances from bridges and check dams. A total of eleven transects were sampled in the study area from 1998-2004. Three transects were in an upstream reference area that was not affected by dam construction or alluvial recharge (Transects 1-3 in Control Area 1), and one transect was located at a downstream reference site (Transect 7, Control Area 2). Transects 4-6 and 8-9 were combined to cover an area affected by three dams beginning in 2001 (Treatment Area 1). Transects 10-11 became a second treatment area that was affected by dams beginning in 2002 (Treatment Area 2). Thus, there were two treatment and two control areas. Each of the 11 transects was sampled a minimum of three times in separate years, and four transects were sampled every year (see Figure 1).

Fifty Sherman live-traps were placed at each transect every sampling period, with 25 traps on each side of the stream. Traplines were run for six or seven consecutive days in each session. The study area was sampled in June of every year from 1999 to 2004; an additional late season (August-September) trapping session was added in 1999 and 2003.

PMJM population estimates and movement patterns were determined by live-trapping mark/re-capture techniques. Captured PMJM were permanently marked with passive integrated transponder (PIT) tags, which were implanted in the scapular area under the skin (Schooley et al. 1993). Each tag had a unique identification number that was recorded by a reader (Mini Portable Reader, Destron-Fearing, Model HS5900L). PIT-tagged (marked) mice could be individually identified in subsequent years. The species, sex, and reproductive condition of other small mammals were also recorded. Beginning in 2001, all non-Preble's small mammals were hair clipped to determine recapture status (Johnson 2001).

In the following section, we explain how PMJM population abundance was modeled in treatment and reference areas. We also looked at the diversity of other small mammals in treatment and reference areas to see if these diversity patterns followed abundance patterns of PMJM. The minimum number of alive animals of all non-PMJM small mammals captured in June 2001-04 sessions was standardized to # animals captured/100 trap nights. These values were then used to determine a Shannon-Wiener diversity index for each trapping session. This common diversity index is a measure of both the number of species present and the relative abundance of each species (Ludwig and Reynolds 1988).

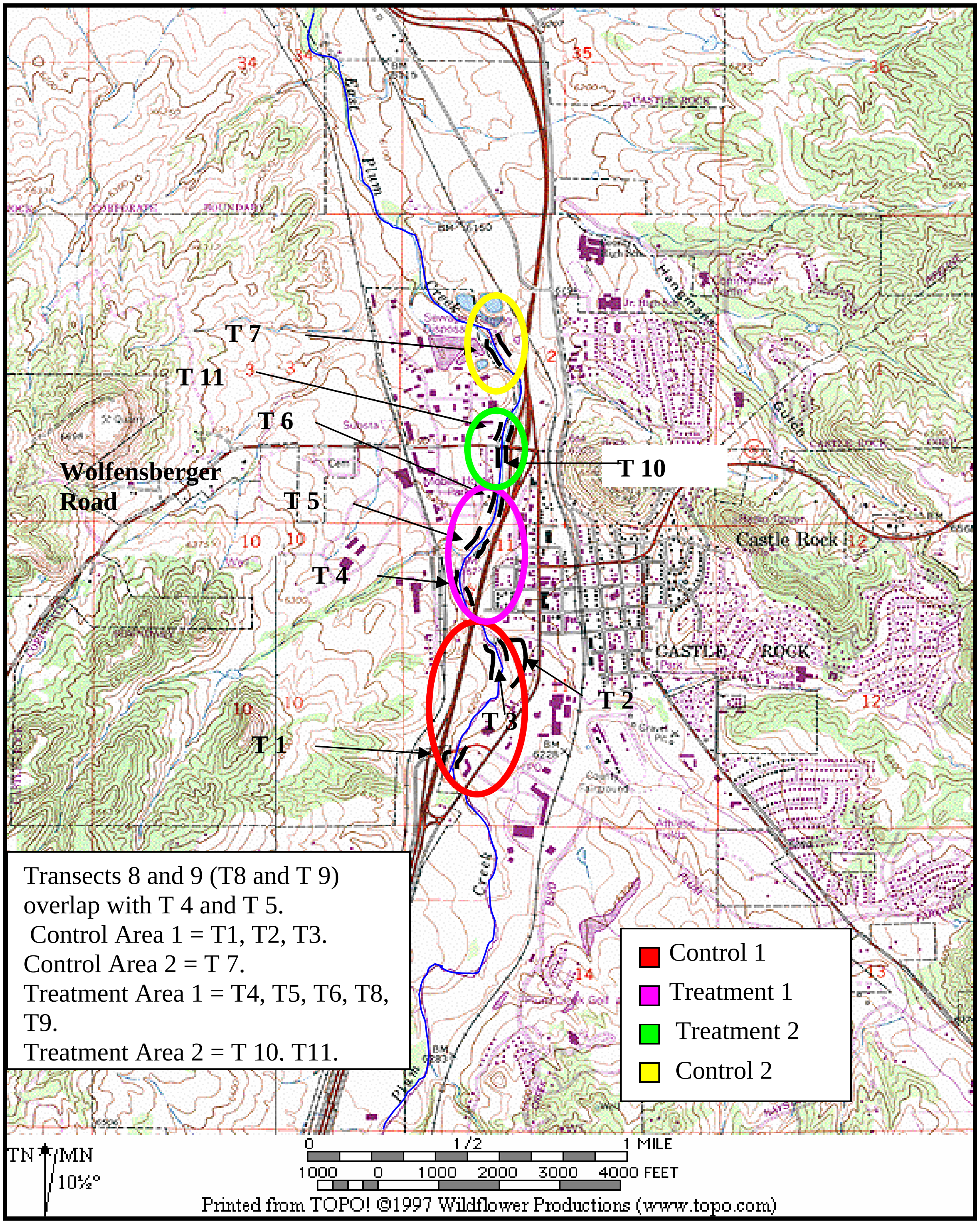


Figure 1. Preble's Meadow Jumping Mouse Sampling Sites at East Plum Creek Conservation Bank, 1998-2004, Douglas County, CO.

Analyses on PMJM mark-recapture data were completed using Program MARK with the Huggins' robust design model structure and estimator (White and Burnham 1999). This model enables estimation of population size during each trapping session and survival rate between trapping sessions. Temporary immigration and emigration in the study area can also be estimated. Sites were analyzed as treatment and control groups. Treatment Area 1 included transects associated with the first three dams installed in 2001 (transects 4, 5, 6, 8, 9); Treatment Area 2 included transects associated with subsequent dams installed in 2002 (transects 10 and 11). Control Area 1 consisted of three transects upstream from the dams (transects 1-3); Control Area 2 included one downstream transect (transect 7).

Habitat Riparian Vegetation

Habitat vegetation within the study area was field mapped in 2001 and 2002 before check dam installation. Both treatment areas and Control Area 2 were completely mapped, as well as a portion of Control Area 1. Plant communities and additional map units were defined to describe vegetation and anthropogenic conditions; vegetation map units were based on dominant plant species, distinct plant species associations, and environmental and ecological factors.

Each individual map unit was mapped as a polygon and classified by walking the perimeter with a Trimble GeoExplorer II Global Positioning System (GPS) receiver unit and marking the line every few meters with pin flags. The flags were removed as adjacent map unit boundaries were encountered. Map unit polygon data were differentially corrected, projected, and exported to ArcView shapefiles. Final coverages were cleaned and built using ArcInfo 8.1. The resulting maps were ground-truthed on subsequent site visits.

Vegetation cover values were collected in the treatment and control areas for three consecutive years from 2002-2004 (2001 measurements were taken at Treatment Area 1 to refine the field technique). A minimum of two randomly located vegetation transects were placed along East

Plum Creek at each of nine treatment and two control sites. At treatment sites, transects were randomly located within an area 98 ft downstream from a dam and 230 ft upstream from the same dam. Treatment transects were established perpendicular to the creek bed at random distances from each dam. At control areas, transects were randomly located from the southern edge of the site perpendicular to the creek. Transects ranged from 49 to 164 ft (15 to 50 meters) in length, depending on the configuration of the site.

All plant community composition and structure values were derived from species cover data collected with the point intercept method (Bonham 1989). Data were collected at each 0.5-meter interval on shorter transects (15 meter length) or 1-meter intervals on longer transects (50-meter length) along a fiberglass tape on the ground. A data point was recorded as the first plant species intercepted by a sampling rod lowered to the ground from a 1-meter height. We recorded the plant species that the rod first touched or, if a plant was not touched, whether the rod touched plant litter or bare soil at the ground surface. Each data point on the transect was assigned into one of the following classes: graminoid, forb, shrub, litter and bare ground. Sedges (*Carex sp.*) and rushes (*Juncus sp.*) were lumped into the graminoid life-form. Juvenile tree species under 20 ft in height were lumped into the shrub class to simplify data analysis. Plants were identified in the field to the lowest taxon possible. If necessary, specimens were sampled for further lab identification. Taxonomic authority for this study was Weber and Whittmann (2001).

A noxious weed inventory of the study area was also conducted during August 2003. At each weed occurrence the species, diameter of the occurrence, and the weed foliar cover (percent) was recorded. The weed occurrences were all relatively small and were therefore all mapped as points. In the office, the data were loaded into a geographic information system (GIS), and occurrences were overlain on an aerial photograph.

Vegetation point intercept transect data were summarized by computing the proportions of each ground cover type (grass, shrub, forbs, bare ground, and litter) for each year sampled. This summarization combined individual measurements at multiple locations along multiple transects at each site. The individual measurements were made at randomly selected points that were reselected each year; therefore, this does not constitute a repeated measures design. An additional response variable was constructed by summing grass, shrub, and forbs cover proportions to obtain total foliar cover for each transect. For some alternative models, the eleven sites were further combined into treatment and control sites, as with Preble's population data.

Analysis of variance (ANOVA) was conducted on these data using PROC GLM in the SAS system (SAS 1989). All response variables were first transformed using the arcsine-square root transformation. This transformation is commonly used with proportions because the transformed values are more normally distributed than the raw values, thereby more closely matching the assumptions of ANOVA. Tests for normality and visual inspection of the plotted data confirmed that the transformation reinforced assumptions regarding normality of the data. Independent (explanatory) variables considered included site effects, treatment effect, annual effects, and a linear trend over time. Akaike's Information Criteria correction (AICc)for small sample bias was used to estimate the weight of evidence supporting alternative models. Final results were computed using the weighted results of the individual models. Reverse transformation of model parameters from the arcsine-square root transformed estimates was done by parametric bootstrap using 5000 replications.

Groundwater Sampling

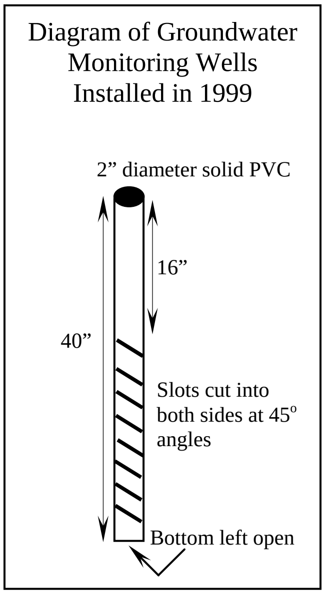
Groundwater methods are taken from the Science Applications International Corporation's (SAIC) Technical Report on alluvial groundwater at East Plum Creek prepared for CDOT Region 1 (SAIC 2001). Three sets of groundwater monitoring wells were installed within the study area. The first set of 37 shallow groundwater monitoring wells (2 more wells were added later for a total of 39) were initially installed in the area on March 24th and 25th, 1999 to aid in determining wetland hydrology within the East Plum Creek floodplain. These wells were constructed from two inch PVC pipe, and cut to forty-inch lengths. Beginning 16 inches from the top of each pipe, 45^o angle slots were cut on both sides of the pipe in three-inch increments. Each of the original 37 monitoring wells contained eight slots, approximately $^3/_{16}$ inch in width, on either side of the pipe. These slots slightly overlap to allow for movement of water into the pipe from all sides. To allow for drainage, well bottoms were left open. Wells were capped with a removable PVC cap to prevent precipitation from entering the well, and to prevent evaporation from occurring within the well.

A second set of 19 deeper groundwater monitoring wells were installed in January and February 2001 for the purpose of monitoring the effect of the first three check dams on water table elevations ("CD" wells). An additional four CD wells were installed in early May 2001. These wells were constructed from solid and slotted (10 slots per inch) two-inch diameter PVC pipe. A two-foot piece of solid PVC was used at the top of each well, with approximately three feet of slotted PVC below this. The ends of the pipes were cleaned and then permanently cemented together with a PVC coupling. The bottom ends were cleaned and permanently capped using a PVC cap and PVC cement. To allow for drainage, a quarter inch diameter hole was drilled into the center of each cap at the well bottom. In addition, a $^1/_8$ inch diameter hole was drilled into the top of the caps used to cover the exposed opening at the top of the wells. This was done to allow some movement of air, and thereby reduce cap sticking, but still prevent precipitation from entering the well.

The third set of 52 "W" wells were installed in November 2001 in the same manner as the CD wells described above.

Both types of wells were installed using a hand auger equipped with a three-inch diameter auger head. The 1999 wells were installed to an approximate depth of 2.5 feet below ground surface. The 2001 wells were installed to an approximate depth of four feet below the soil surface.

The deeper depths of the 2001 wells were necessary to adequately document the changes in the water table expected from the installation of the check dams. A two-inch thick plug of bentonite clay ($^{3}/_{8}$ inch, Hole-Plug®) was placed approximately six inches below the soil surface around each of the 2001 wells. The bentonite plug helped to stabilize the well, as well as preventing stemflow from occurring.



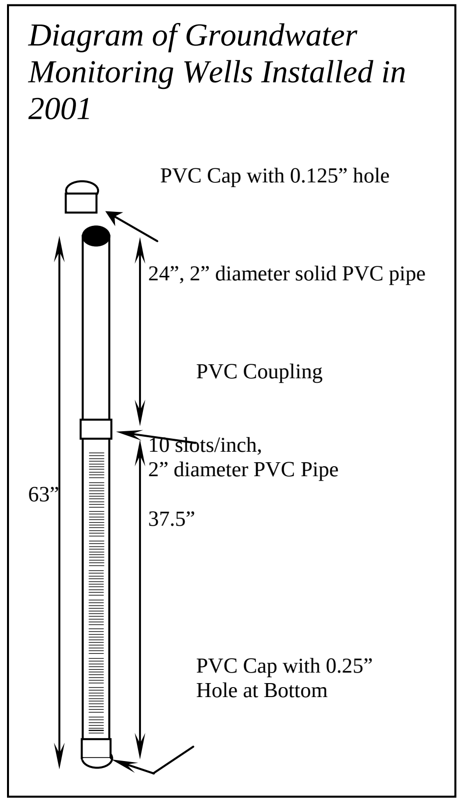


Figure 2. Diagrams Showing the Construction of Groundwater Monitoring Wells Used at East Plum Creek, Castle Rock, CO.

Monitoring of the groundwater wells was done with a Solinst-Mini water level indicator. Prior to sampling the meter's battery was tested, and the probe's sensitivity to free water was tested in the creek. Wells were sampled at various intervals depending on the objectives of the project. Sampling was always more intense during the growing season (May 9 – October 2), with daily sampling often occurring during May and June. Sampling intervals for the various wells were as follows:

MW wells: 4/3/99 to 8/27/04;
CD wells: 2/1/01 to 8/27/04; and
W wells: 11/2/01 to 8/27/04.

Note that not all wells were measured on all of the sampling dates. In particular, many of the MW wells were dropped from sampling after 2000 because they were not in proximity to the check dams, the wells were damaged, groundwater elevations were below the level of the well, or a combination of these factors.

Well monitoring involved taking the following measurements:

- Depth to water or the bottom of the well from the top of the well using the Solinst-Mini water level indicator. The measurement was verified several times by lifting and slowly lowering the probe to the water surface, or the bottom of the well, before recording in the field log. Depth to water or well bottom was recorded in feet and hundredths of feet.
- Distance from the top of the well to the ground surface (i.e., stick-up) as measured on the side of the well facing the creek with a retracting tape measurer. This distance was measured to the eighth of an inch and recorded in the field log.
- Presence/Absence of water in well.
- Other descriptive information (e.g., condition of well, condition of soil surface, etc.).

Groundwater Data Analysis

Groundwater well levels in the study area were influenced by a number of factors, including precipitation and stream discharge, elevation from nearest dam, vegetation transpiration rate, sediment fill rate behind check dams, time during growing season, local drainage features (culverts that drained into the flood plain), and local topography.

It was difficult to control the effects of these variables in order to isolate the effect of check dam installation on groundwater level. Furthermore, a complete “before and after dam” dataset was not available for comparison because: 1) the MW wells that had been installed before the dams were shallow and could not measure groundwater levels 30 inches below the soil surface, and 2) both CD and W wells that were installed before dams only had pre-dam measurements in the non-growing season.

However, general trends could be evaluated during specific time periods to see if anticipated responses were evident. We were also able to examine groundwater responses in relation to stream discharge, and reduce the number of wells analyzed to a subset that had ground surface elevations that were within 30 inches of the nearest downstream check dam – these were the wells where we expected to see responses from the dams.

Trends were evaluated by analyzing groundwater data from CD and W wells in the vicinity of the check dams. Data from some MW wells were also suitable for analysis if groundwater level did not generally exceed 30 inches in depth. Groundwater elevations were plotted over time to determine trends associated with growing season natural variability, check dam installation date, and sediment fill rate (if known). Average growing season groundwater depth was also determined for all CD and W wells from 2001-2004, as well as minimum and maximum depths during the growing season.

If water was not detected during a sampling event in a CD or W well, a value of –60 inches was assigned for that event, with the recognition that groundwater elevation may have been deeper than 60 inches.

The effects of check dam installation could be assessed over two specific periods. The first was the installation of the first three check dams, which was completed on April 30, 2001. We would expect the effect to first show in the first area of sediment accumulation, upstream of check dam 1. The second major event was the installation of check dams 4-9, completed on April 30, 2002.

IV. Results

A. General Small Mammal Results

There were 746 captures of 511 small mammals in June 2004 (capture success rate of 21.2%), a dramatic increase in capture rate from the drought and recovery years of 2002 and 2003. Total small mammal captures in previous years from the June session were 170 individuals in 2001, 151 in 2002, and 126 in 2003.

Eight species of small mammals were captured during June 2004, including the meadow vole (*Microtus pennsylvanicus*), deer mouse (*Peromyscus maniculatus*), prairie vole (*Microtus ochrogaster*), Preble's meadow jumping mouse (*Zapus hudsonius preblei*), western harvest mouse (*Reithrodontomys megalotis*), house mouse (*Mus musculus*), Norway rat (*Rattus norvegicus*) and masked shrew (*Sorex cinereus*). The Mexican wood rat (*Neotoma mexicana*) was captured at Treatment Area 2 in 2005 after the completion of this study.

The prairie vole was the most abundant species in 2004 (40.7% of the catch), followed by the meadow vole (25.3%), deer mouse (22.9%), western harvest mouse (5.7%), Preble's (2%), house mouse (1.8%), Norway rat (1.2%), and the masked shrew (0.4%). Captured Norway rats had mostly white pelage and had likely escaped from a nearby biological supply store.

Patterns of Shannon-Wiener small mammal diversity (without jumping mouse captures) at various control and treatment sites showed that Treatment Area 2 had the highest diversity from 2002-04 (this area was not sampled in 2001, see Figure 3). Control Area 1 and Treatment Area 1 had very similar diversity patterns, with Control Area 2 being similar to the former from 2002-04 (Figure 2). Controls 1 and 2 and Treatment 1 areas had very similar diversity values in 2002 (the drought year), followed by a minimum diversity value in 2003, and an increase in diversity in 2004.

B. Preble's Meadow Jumping Mouse (PMJM) Results

PMJM Abundance

From 1998 to 2004, there were 279 captures of 171 individual PMJM in the study area. Ninety-three individuals were male, and seventy-eight female. Capture/recapture records by sex are given in Table A. There were three mortalities during this period: one animal died shortly after handling; one animal died from heat stress; and the final animal died after it was captured in a trap that had been tampered with and opened during the day.

Table B presents modeled abundance for each of the four trapping areas for each of the nine trapping sessions. In control areas (Figure 4), abundance declined steeply between 1998 and 2003; however, abundance began increasing in 2004. Control areas for this modeling process included Treatment Areas 1 and 2 prior to check dam installation. The data suggest that a cyclical pattern may exist in this population, although more years of data would be required to draw definitive conclusions.

A series of alternative models—with and without different parameters for treatment and control areas—were fit to these data. This modeling approach allows for the simultaneous consideration of several plausible models with a weight measure for each model based on Akaike's Information Criteria (AIC, Burnham and Anderson 1998). The models were all based on sine functions with parameters for phase (intercept), period (frequency), and amplitude (wave height). Sine functions often are used to estimate population data because of the cyclic nature of small mammal population trends. These trends were also confirmed by reviewing the empirical data from the study area. Up to six parameters were considered for amplitude (the peak population level), one for each of the four areas without (or before) dams, plus each of the two treatment areas after dams were installed. Up to five phase and five frequency parameters were also considered (one site had only a single year of control data, so only a constant value could be estimated in the most general model). Thus, the various models tested significant similarities or differences between the length of population cycle (period of years), the peak population level (amplitude), and when these patterns occurred (phase) between control and treatment areas. Additional information on the sine models and parameter estimates are given in Appendix A.

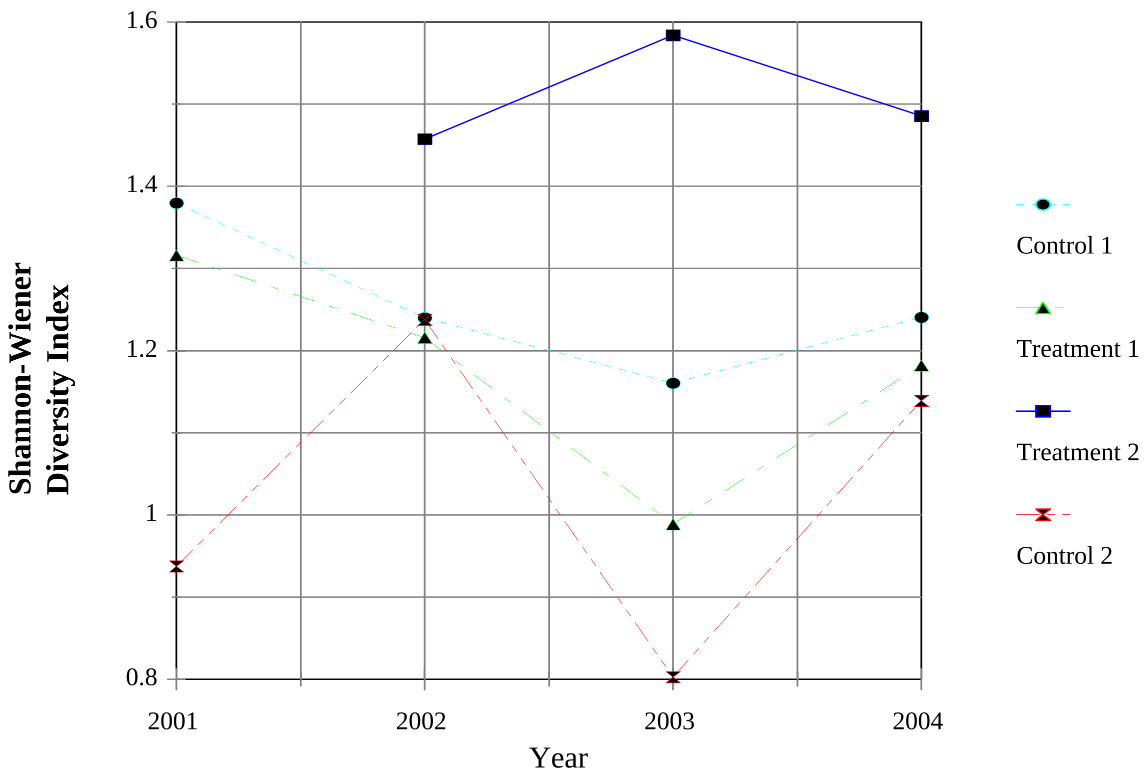


Figure 2. Small Mammal Diversity by Treatment, Castle Rock, CO.

The most strongly supported model (73% of AICc model weight) included five amplitude, two phase, and one period parameters. These data and best models are depicted in Figures 3 and 4. The period—which defines how far apart high and low points in the cycle occur—does not appear to be changed by the dams. The fitted functions suggest a period of nine years between population peaks. The study has only encompassed a little more than half of a single cycle, making inference regarding the existence of a cycle very tentative.

The purpose for fitting these models was not to offer confident projections or extrapolations of Preble's abundance to future years. They were fit for the purpose of comparing the control and treatment groups to test for the significance of the effect and confidence in it. The analysis should not be interpreted to indicate that this population actually fluctuates according to these particular sine functions -- far more data would be required to confirm such a hypothesis.

Table A. Preble's Meadow Jumping Mouse Capture Records by Sex, 1998-2004.

	Male	**Female**
Captured 1 time	55	52
Captured 2 times	23	15
Captured 3 times	9	5
Captured 4 times	3	4
Captured 5 times	2	2
Captured 6 times	1	0
Total	**93**	**78**

Table B. Preble's Meadow Jumping Mouse Population Estimates 1998-2004, Castle Rock, CO.

	Session	Start Date	Male Est.	Male SE	Male LCL	Male UCL	Female Est.	Female SE	Female LCL	Female UCL	Combined Sexes Est.	Combined Sexes SE
Control-1 (transects 1-3)	1	8/12/1998										
	2	6/12/1999	7.50	2.49	5.49	17.74	16.22	7.63	8.77	43.68	23.72	8.03
	3	9/4/1999	0.00	0.00	0.00	0.00	2.70	2.34	1.23	13.79	2.70	2.34
	4	6/24/2000	4.92	2.10	3.34	13.93	6.12	4.16	2.80	23.28	11.04	4.66
	5	6/9/2001	**3.50**	1.77	3.24	12.36	2.70	2.34	1.23	13.79	6.20	2.93
	6	6/13/2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7	6/5/2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8	8/22/2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	6/4/2004	4.28	1.63	3.19	11.78	0.00	0.00	0.00	0.00	4.28	1.63
Contorl-2 (transect 7)	1	8/12/1998	21.46	7.68	13.47	47.82	43.10	20.24	20.97	109.89	64.55	21.65
	2	6/12/1999	28.51	7.05	21.60	53.82	36.14	14.27	20.97	84.29	64.64	15.92
	3	9/4/1999	6.00	2.14	4.36	15.08	24.33	10.50	13.54	60.72	30.33	10.72
	4	6/24/2000	13.12	4.17	9.26	28.74	45.87	18.91	25.21	108.32	58.99	19.36
	5	6/9/2001	4.50	1.77	3.24	12.36	27.03	11.45	15.14	66.38	31.53	11.59
	6	6/13/2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7	6/5/2003	**3.92**	2.10	3.34	13.93	3.06	2.73	1.29	15.84	6.98	3.45
	8	8/22/2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	6/4/2004	0.00	0.00	0.00	0.00	3.06	2.73	1.29	15.84	3.06	2.73
Treatment 1-(2001) (transects 4, 5, 6, 8 & 9)	1	8/12/1998										
	2	6/12/1999	13.50	3.84	10.06	28.16	8.11	4.63	4.12	26.32	21.61	6.02
	3	9/4/1999	3.00	1.38	2.13	9.54	0.00	0.00	0.00	0.00	3.00	1.38
	4	6/24/2000	5.92	2.10	4.34	14.93	3.06	2.73	1.29	15.84	8.98	3.45
	5	6/9/2001	**7.00**	2.14	4.36	15.08	16.22	7.63	8.77	43.68	23.22	7.93
	6	6/13/2002	1.64	1.09	1.06	7.31	12.23	6.62	6.06	36.88	13.87	6.71
	7	6/5/2003	1.64	1.09	1.06	7.31	0.00	0.00	0.00	0.00	1.64	1.09
	8	8/22/2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	6/4/2004	3.28	1.63	2.19	10.78	3.06	2.73	1.29	15.84	6.34	3.18
Treatment-2 (2002) (transects 10 & 11)	1	8/12/1998	2.15	1.67	1.14	10.31	0.00	0.00	0.00	0.00	2.15	1.67
	2	6/12/1999	0.00	0.00			0.00	0.00				
	3	9/4/1999	0.00	0.00			0.00	0.00				
	4	6/24/2000	0.00	0.00			0.00	0.00				
	5	6/9/2001	0.00	0.00			0.00	0.00				
	6	6/13/2002	4.92	2.10	3.34	13.93	0.00	0.00	0.00	0.00	4.92	2.10
	7	6/5/2003	**4.28**	1.63	2.19	10.78	6.12	4.16	2.80	23.28	10.40	4.46
	8	8/22/2003	3.68	1.98	2.27	12.49	3.56	3.29	1.37	18.71	7.24	3.84
	9	6/4/2004	4.92	2.10	3.34	13.93	0.00	0.00	0.00	0.00	4.92	2.10

(*) Red indicates population affected by check dams. Bold indicates 2 male mice that moved from control to treatment areas. Both occurred within a session and were not captured again in subsequent sessions. No other movements among the 4 trapping areas were detected, however, 10 movements between grids within trapping areas were recorded. Gray cells indicate that trapping was not conducted.
Est. is population estimate, SE is standard error, LCL/UCL is lower/upper confidence limit

Data for treated areas do not appear to conform to the pattern observed in control areas (Figures 4 and 5). In Treatment Area 1, the population in 2001, the first year of check dam effects, was 23.2 ± 7.9 (1 standard error {SE}). The model (based on control data only) for that area predicted 5.9 mice. The check dams appear to have led to a much larger population than expected. Estimated population at this same treatment area declined to zero in 2003, apparently following the cyclic pattern present throughout the study area. Consequently, the amplitude of the cycle seems to have been increased, but not the period or minimum population size (Figure 3). In contrast, Treatment Area 2 did not appear to follow the cyclic pattern; rather, abundance remained high during the cyclic trough observed at all other sites (Figure 5). Again, treatment appears to have had an effect, but the pattern of this effect differs from the one observed in Treatment Area 1.

The best model contains unique parameters for either phase (Treatment Area 1) or amplitude (Treatment Area 2) of the treatment areas. Model weight supporting these differences in the treatment areas is 99.9997% of the total. Only 0.0003% of the evidence supports models with no treatment effect. This is overwhelming support for a treatment effect. The effect seems to have been different at the two treatment locations: shifting phase at Treatment Area 1 and increasing amplitude at the Treatment Area 2. However, the time periods following treatment are far too short to draw robust conclusions about the exact characteristics of the post-treatment population dynamics. Nevertheless, an unmistakable difference is clear between control and treatment areas.

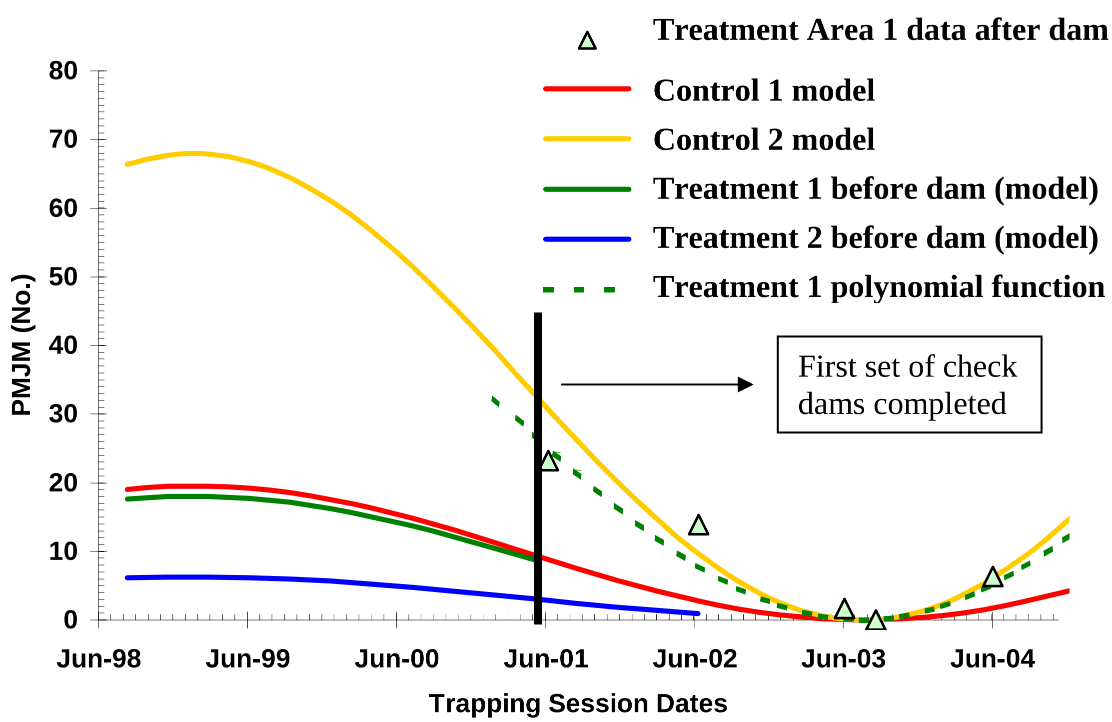


Figure 4. Control Observations of Preble's Meadow Jumping Mouse Abundance and Treatment Area 1 Effects from 1998-2004.

Data are shown for Treatment Area 1 (check dam construction in 2001); all other curves are fitted from models. Fitted models (solid lines) are sine functions with different amplitudes by area fitted to control areas and treatment areas before treatments were applied (September 1999 session was excluded from model fitting because population size at this time of year is not comparable). Dotted line represents polynomial function fitted independently to Treatment 1 series for comparison to the fitted sine-function models.

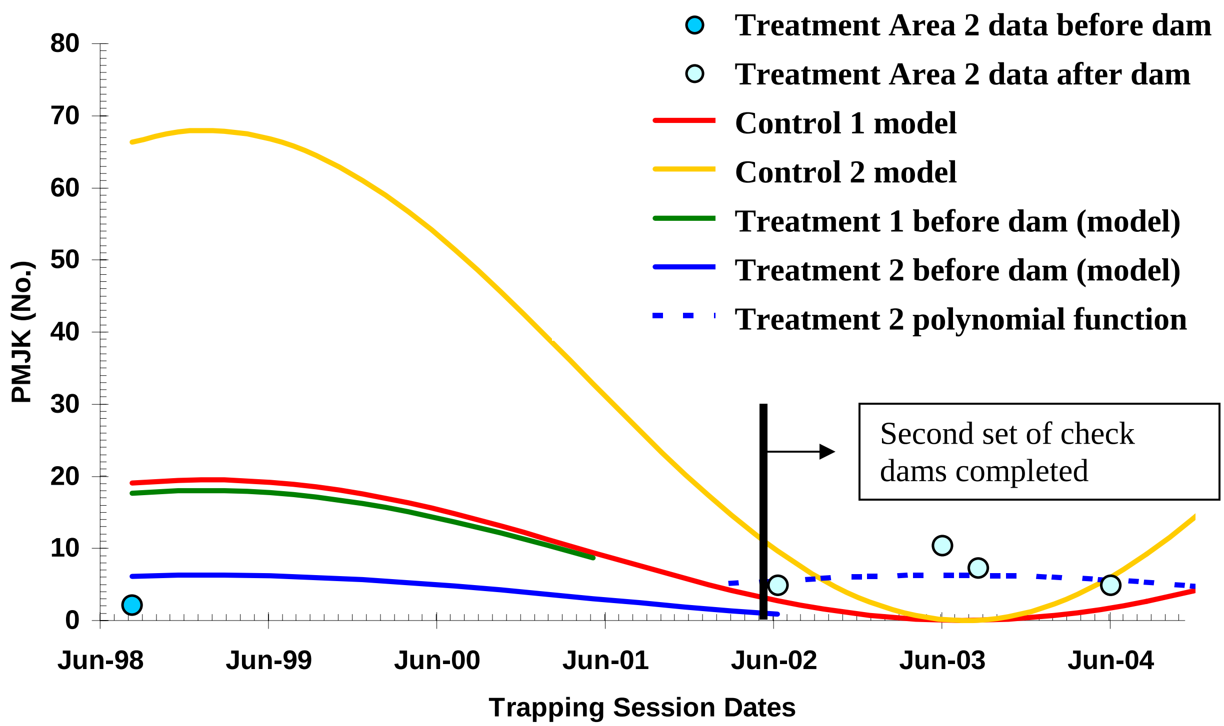


Figure 5. Control Observations of Preble's Meadow Jumping Mouse Abundance and Treatment Area 2 Effects from 1998-2004.

Data are shown for Treatment Area 2 (check dam construction in 2002); all other curves are fitted from models. Fitted models (solid lines) are sine functions with different amplitudes by area fitted to control areas and treatment areas before treatments were applied (September 1999 session was excluded from model fitting because population size at this time of year is not comparable). Dotted line represents polynomial function fitted independently to Treatment 2 series for comparison to the fitted sine-function models.

PMJM Survival

The data provide strong evidence of differences in survival rate between the sexes and between the active and hibernation seasons (Table C). Active season survival is much lower in both sexes, but more so in males. Hibernation season survival is similarly high in both sexes. Active season survival was only estimated for two years in which trapping sessions were conducted both in June and August/September (1999 and 2003). Furthermore, the low survival rates lead to few mice recaptured during the later sessions in each year. The result is very small sample sizes, which explains the low precision of these estimates. Full year survival rates were estimated directly for those years when trapping was spaced a full year apart. Another estimate is obtained by assuming that the active season rate applies for two months and the hibernation season rate for 10 months.

The possibility that PMJM survival was affected by the dam treatments was examined. There was essentially no evidence that winter or full-year survival rates differed at sites following treatment. There was some evidence that summer survival rate increased after treatment. However, only one summer period was measured before and one after treatment, so these results could easily be confounded with other differences between those periods. Furthermore, the evidence for no increase in summer survival following treatment was 2.3 times higher than the evidence for an effect. We conclude that any effect on survival changes resulting from the treatment cannot be distinguished from the normal large variation in annual survival rates. If a dam treatment effect exists on survival, a substantially larger sample size would be required to statistically see this effect.

Table C. Preble's Meadow Jumping Mouse Survival 1998-2004 (±1 Standard Error)

	Active Season (per month)	**Hibernation Season (per month)**	**Combined Seasons (per month)**	**Full Year (per month)**	**Full Year (per year)**
Male	21.0 ± 67.5%	91.5% ± 8.2%	1.8% ± 11.8%	85.8% ± 7.6%	15.9% ± 16.9%
Female	49.7% ± 31.5%	92.1% ± 8.3%	10.9% ± 16.9%	87.4% ± 7.2%	19.9% ± 19.6%

PMJM Movement

Grouping transects into control and treatment areas converted 10 of the 12 observed mouse movements from transect-to-transect into intra-area movements, which were no longer movements in a statistical sense. Only two mouse-movements occurred between these areas. In both cases, a male mouse moved from a control to a treatment area during a single trapping session. In both cases, the movement occurred into a treatment area after check dams had been installed.

Temporary immigration and emigration were not supported by this data set; both were estimated at zero. This is not surprising, because we combined data from multiple trapping grids in close proximity; thus each area was more likely to represent a closed population. The fact that only two movements between areas were observed supports this conclusion.

PMJM Capture and Recapture Probability

Initial capture probability was nearly twice as high for males (15.5% ± 9.5% SE) as for females (8.1% ± 6.9%). This could be the result of greater male movement activity, increasing their chance of encountering a trap. Males and females did not differ in recapture probability (19.2% ± 3.7%), which was higher than initial capture probability for either sex. Both sexes appear to become "trap happy" and return to traps once discovering them, presumably because of the attraction of the bait. Note that these capture probabilities are per night, therefore, the probability of capturing an individual over the course of a 6-7 night trapping session is much higher.

C. Vegetation Results

Vegetation Mapping

Mapping was conducted in 2001 and 2002 to determine baseline conditions prior to check dam construction. Eighteen map units were defined, 13 of which had various vegetation community types. The remaining five map units were unvegetated areas that were either anthropogenic structures or disturbance areas with bare ground (including naturally occurring disturbance areas within the creek channel).

The two check dam treatment areas comprised 19.93 acres (Table D). Eighty percent (80%) of the total area was vegetated, and the willow/cottonwood community was the most prevalent type, covering 33% of the treatment area. Herbaceous dry meadow, revegetated areas, and sandbar willow (*Salix exigua*) with understory vegetation were important community types. The willow and cottonwood type also had the greatest areal coverage at Control Areas 1 and 2. Herbaceous dry meadow was an important secondary community type at Control Area 1, and the mixed trees and shrubs community covered almost 34% of Control Area 2 (Tables E and F). See Figure 5 for a community map of the study area.

These cover values illustrate a wide range of plant community diversity within the study area ranging from wetland to upland communities, with many areas having one or more anthropogenic disturbance agents. Despite the diversity of the community types, willow/cottonwood was the most common type at all of the control and treatment sites.

Foliar Cover Analysis

Foliar cover data from treated and control areas were contrasted by comparing proportions of graminoid, shrub/tree, forb, bare ground, and litter cover. Analysis of the point intercept data provides strong evidence (99% AICc model weight) for a 20% increase over the three-year period in the proportion of graminoid cover in treated areas relative to the control areas (Figure

6, Table G). There was also evidence (92%) for a modest decline (5%) in litter cover on treated areas. There was minimal evidence for any changes on control areas of any cover type. There was weak (inconclusive) evidence of small declines in forbs and shrubs on treated sites. Overall, the check dam treatment appears to have increased grass cover by replacing litter and possibly displacing small amounts of other cover types. The estimated net change in total foliage cover was positive, but by a small amount (4%) and only weakly supported (64%).

Weed Mapping

Two hundred twelve occurrences of eighteen weed species were found in the 2003 survey. Diffuse knapweed (*Acosta diffusa*) was the most common weed with 32% of the occurrences, followed by Canada thistle (*Cirsium arvense*) with 24%. Other common weeds included toadflax (*Linaria vulgaris*), Russian olive (*Eleagnus angustifolia*), and common mullein (*Verbascum thapsis*). Weed occurrences are given in Table H.

Table D. Summary of Vegetation Communities at Treatment Areas, East Plum Creek, Douglas County, CO.

Community	Description Summary	Acres	Percent of Total Check Dam Area
Bare ground	Undisturbed, unvegetated bare soil.	0.1	0.5
Bare channel	Creek channel with no vegetation.	1.8	9.1
Emergent channel	Creek channel with herbaceous emergent vegetation.	0.1	0.5
Cattail and rush wetland	Herbaceous wetland community dominated by cattails and rushes.	0.03	0.2
Disturbed	Surface disturbance with debris and weedy herbaceous cover.	1.5	7.5
Disturbed woodlands	Areas with past surface disturbance, dominated by Chinese elm and Russian olive.	0.2	1.1
Herbaceous dry meadow	Drier areas dominated by upland forbs and graminoids. Often a large weed component. Few, if any, shrubs.	2.0	10.0
Herbaceous wet meadow	Moist areas dominated by hydrophytic forbs and graminoids. Few, if any, shrubs.	0.9	4.5
Mixed shrubs	Canopy layer of mixed shrub species with sparse forb and graminoid understory.	0.1	0.5
Mixed trees and shrubs	Multi-layered canopy of mixed tree and shrub species with a forb and graminoid understory.	0.1	0.5
Revegetated	Seeded or planted following surficial disturbance	1.9	9.5
Sandbar	Mostly unvegetated sand bar.	1.1	5.5
Sandbar forb community	Sandbars along the creek, vegetated with mostly forbs	0.1	0.5
Sandbar willow terrace	Sand bar terraces above the creek channel. Colonized with numerous sandbar willows and cottonwood saplings.	0.7	3.5
Sandbar willow with understory	Dense sandbar willow with occasional mixed shrubs and sparse graminoid and forb understory.	1.8	9.1
Willow and cottonwood	Willow and cottonwood canopy with understory of mixed shrubs, forbs and graminoids.	6.6	33.0
Bike path	Not a plant community, but occupies area within study site.	.8	4.0
Dam reinforcement structure	Not a plant community, but occupies area within study site.	0.1	0.5
	Total	**19.93**	**100**

Table E. Summary of Vegetation Communities at Control Area 1 (Seller's Gulch), East Plum Creek, Douglas County, CO.

Community	Description Summary	Acres	Percent of Site
Bare ground	Undisturbed, unvegetated bare soil	0.01	0.8
Bare channel	Creek channel with no vegetation.	0.1	7.6
Herbaceous dry meadow	Drier areas dominated by upland forbs and graminoids. Often a large weed component. Few, if any, shrubs.	0.4	30.5
Willow and cottonwood	Willow and cottonwood canopy with understory of mixed shrubs, forbs and graminoids.	0.7	53.5
Sandbar forb community	Sandbars along the creek, vegetated with mostly forbs	0.1	7.6
	Total	**1.31**	**100**

Aerial extent of each community (acres) was calculated from the ArcView shapefiles generated from GPS data.

Table F. Summary of Vegetation Communities at Control Area 2 (Sewage Treatment Plant), East Plum Creek, Douglas County, CO.

Community	Description Summary	Acres	Percent of Site
Bare channel	Creek channel with no vegetation.	0.20	12.1
Herbaceous dry meadow	Drier areas dominated by upland forbs and graminoids. Often a large weed component. Few, if any, shrubs.	0.24	14.5
Mixed trees and shrubs	Multi-layered canopy of mixed tree and shrub species with a forb and graminoid understory.	0.56	33.5
Sandbar	Mostly unvegetated sand bar.	.02	1.2
Willow and cottonwood	Willow and cottonwood canopy with understory of mixed shrubs, forbs and graminoids.	0.65	38.9
	Total	**1.67**	**100**

Aerial extent of each community (acres) was calculated from the ArcView shapefiles generated from GPS data.

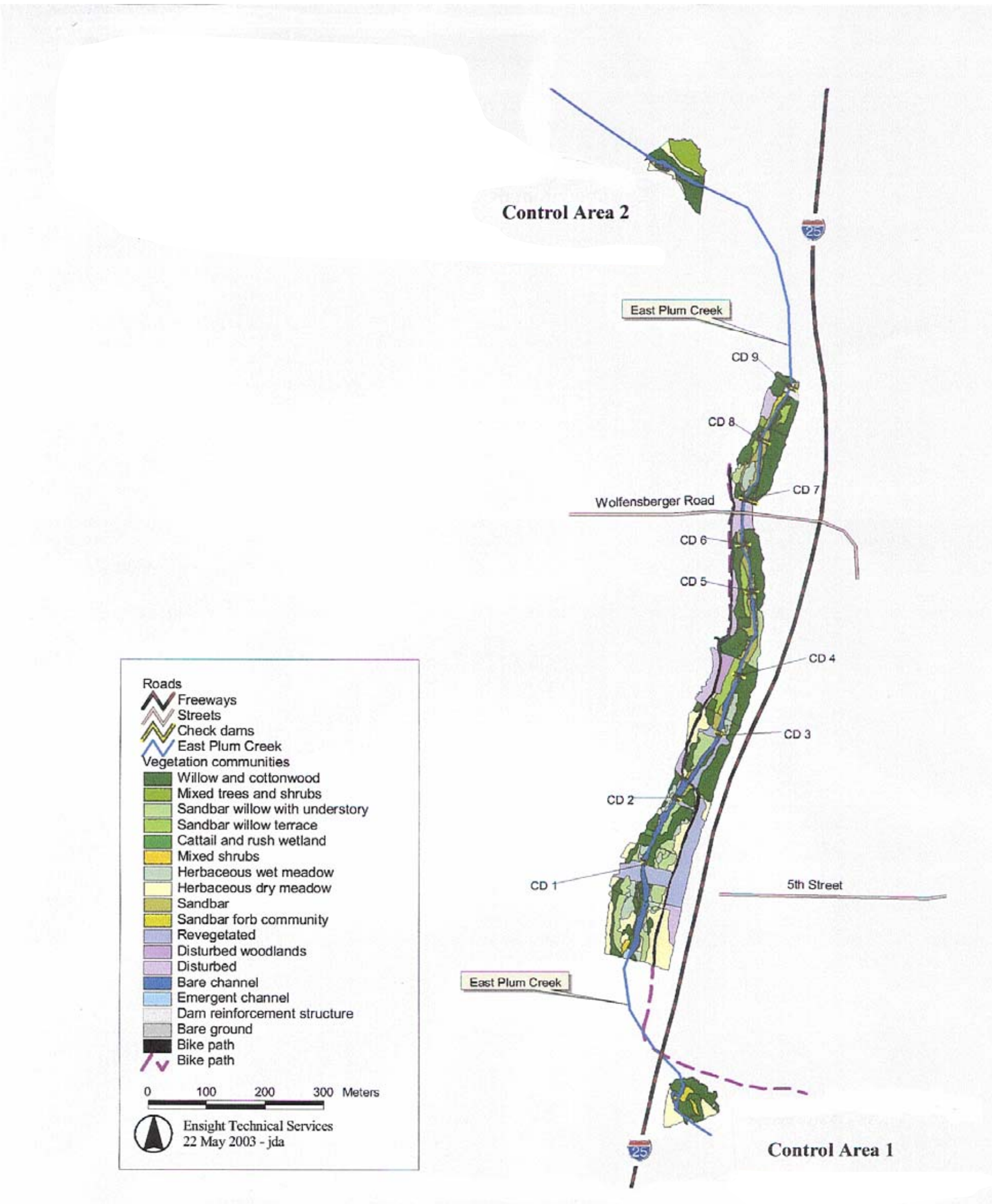


Figure 6. Study Area Vegetation Map on East Plum Creek Before Check Dams, Douglas County, CO.

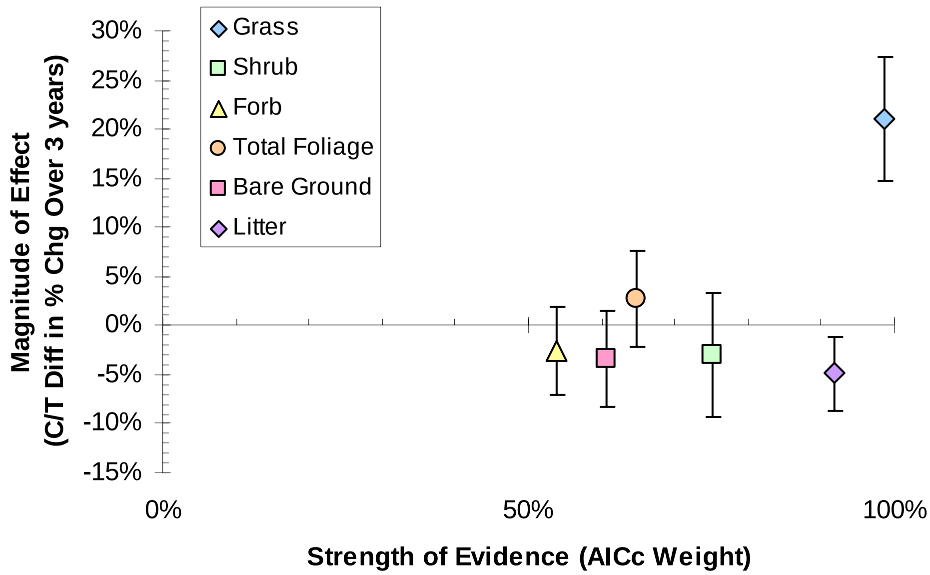


Figure 7. Ratio of Vegetation Classes from Control and Treatment Areas, East Plum Creek, CO.

The difference between the changes (2001-2004) on treatment sites versus control sites is shown (vertical axis) of each cover type, versus the strength of evidence (horizontal axis) provided by Akaike's Information Criterion (AICc) corrected for small sample bias for the presence of a treatment effect. The largest and most strongly supported effect is an increase in grass cover on treatment areas.

Table G. Summarized Data Used in Analysis of Variance (ANOVA) for Vegetation Foliar Cover, Castle Rock, Douglas County, CO.

			Proportion of Cover Type				
Group	**Year**	**Transect**	**Grass**	**Forb**	**Shrub**	**Litter**	**Bare ground**
Treatment	2001	1	0.2709	0.0669	0.4047	0.1739	0.0836
Treatment	2001	2	0.3438	0.1302	0.1927	0.2031	0.1302
Treatment	2001	3	0.2685	0.1479	0.2140	0.2179	0.1518
Control	2002	A	0.3500	0.1667	0.4000	0.0167	0.0667
Control	2002	B	0.3833	0.2167	0.0833	0.2833	0.0333
Treatment	2002	1	0.4167	0.2167	0.2333	0.0667	0.0667
Treatment	2002	2	0.3667	0.0667	0.4500	0.1000	0.0167
Treatment	2002	3	0.4333	0.0833	0.3667	0.0667	0.0500
Treatment	2002	4	0.1667	0.1000	0.5500	0.0833	0.1000
Treatment	2002	5	0.3000	0.0333	0.4833	0.1167	0.0667
Treatment	2002	6	0.3667	0.0667	0.4667	0.0667	0.0333
Treatment	2002	7	0.3333	0.2333	0.1333	0.1833	0.1167
Treatment	2002	8	0.2167	0.2167	0.2833	0.2500	0.0333
Treatment	2002	9	0.1667	0.1167	0.4833	0.1833	0.0500
Control	2003	1	0.3790	0.0645	0.3468	0.0887	0.1210
Control	2003	2	0.4080	0.1680	0.1760	0.2000	0.0480
Treatment	2003	1	0.4194	0.0968	0.1935	0.2581	0.0323
Treatment	2003	2	0.2742	0.3387	0.0968	0.0806	0.2097
Treatment	2003	3	0.4194	0.0484	0.4839	0.0000	0.0484
Treatment	2003	4	0.1774	0.0806	0.5323	0.0161	0.1935
Treatment	2003	5	0.4677	0.0806	0.2742	0.0000	0.1774
Treatment	2003	6	0.5323	0.0968	0.3710	0.0000	0.0000
Treatment	2003	7	0.5323	0.1290	0.2258	0.0806	0.0323
Treatment	2003	8	0.5484	0.0323	0.4194	0.0000	0.0000
Treatment	2003	9	0.6935	0.0323	0.2258	0.0000	0.0484

Table G

Cont'd

Group	Year	Transect	Grass	Forb	Shrub	Litter	Bare ground
Control	2004	A	0.2903	0.0806	0.4355	0.0968	0.0968
Control	2004	B	0.2419	0.1371	0.3145	0.2339	0.0726
Treatment	2004	1	0.4194	0.2097	0.1452	0.1613	0.0161
Treatment	2004	2	0.3710	0.1129	0.3065	0.2097	0.0000
Treatment	2004	3	0.6129	0.0161	0.3226	0.0323	0.0161
Treatment	2004	4	0.5968	0.0000	0.3226	0.0645	0.0161
Treatment	2004	5	0.4839	0.0968	0.3387	0.0323	0.0484
Treatment	2004	6	0.5323	0.0323	0.4032	0.0323	0.0000
Treatment	2004	7	0.6129	0.0484	0.0968	0.0968	0.1452
Treatment	2004	8	0.3548	0.0323	0.2097	0.2419	0.0000
Treatment	2004	9	0.2742	0.2258	0.0968	0.2903	0.0806

Table H. Weed Species Occurrences in the East Plum Creek Bank, 2003, Douglas County CO.

Record #	Longitude	Latitude	Species	Other Species Present	Radius (ft)	Cover (%)
1	-104.8646667	39.36400000	*Acosta diffusa*		15	0.01
2	-104.8647833	39.36391667	*Cirsium arvense*		6	0.10
3	-104.8649667	39.36396667	*Cirsium arvense*	*Centaurea diffusa & Cirsium vulgare*	30	0.03
4	-104.8650500	39.36421667	*Acosta diffusa*		30	0.01
5	-104.8653000	39.36428333	*Verbascum thapsus*		20	0.01
6	-104.8652833	39.36443333	*Linaria vulgaris*	*Centaurea diffusa & Verbascum thapsus*	5	0.60
7	-104.8654833	39.36466667	*Cirsium arvense*	*Centaurea diffusa & Cirsium vulgare*	4	0.25
8	-104.8652167	39.36536667	*Acosta diffusa*	*Verbascum thapsus*	70	0.03
9	-104.8650833	39.36575000	*Tamarix parviflora*	*Centaurea diffusa*	3	0.50
10	-104.8649500	39.36613333	*Linaria vulgaris*	*C. diffusa, V. thapsus & C. arvense*	50	0.05
11	-104.8648000	39.36648333	*Saponaria officianalis*		6	0.25
12	-104.8647000	39.36643333	*Linaria vulgaris*		2	0.30
13	-104.8647000	39.36633333	*Verbascum thapsus*	*Centaurea diffusa*	5	0.02
14	-104.8645000	39.36655000	*Linaria vulgaris*	*Centaurea diffusa & Cirsium arvense*	8	0.20
15	-104.8644833	39.36661667	*Linaria vulgaris*	*Cirsium arvense*	5	0.25
16	-104.8644167	39.36670000	*Cirsium arvense*	*Verbascum thapsus*	40	0.15
17	-104.8640667	39.36726667	*Acosta diffusa*	*Verbascum thapsus*	30	0.01
18	-104.8638333	39.36758333	*Acosta diffusa*	*Verbascum thapsus*	100	0.02
19	-104.8626833	39.36861667	*Eleagnus angustifolia*		5	0.90
20	-104.8625000	39.36888333	*Acosta diffusa*	*Verbascum thapsus & mat per*	15	5.00
21	-104.8623000	39.36905000	*Acosta diffusa*	*mat per & Verbascum thapsus*	10	0.04
22	-104.8620667	39.36965000	*Eleagnus angustifolia*	*mat per*	7	0.90
23	-104.8625333	39.37000000	*Acosta diffusa*	*Verbascum thapsus*	35	0.02
24	-104.8625167	39.37025000	*Linaria vulgaris*		0	0.10
25	-104.8624500	39.37025000	*Verbascum thapsus*	*Centaurea diffusa*	40	0.01

Table H. Cont'd.

Record #	Longitude	Latitude	Species	Other Species Present	Radius (ft)	Cover (%)
26	-104.8625333	39.37053333	*Acosta diffusa*		30	0.02
27	-104.8630167	39.37065000	*Acosta diffusa*	*Verbascum thapsus*	70	0.01
28	-104.8634167	39.37101667	*Acosta diffusa*	*Verbascum thapsus*	25	0.04
29	-104.8636000	39.37148333	*Cirsium arvense*		10	0.25
30	-104.8633167	39.37155000	*Saponaria officianalis*		2	0.50
31	-104.8638500	39.37423333	*Acosta diffusa*		25	0.30
32	-104.8637333	39.37435000	*Acosta diffusa*	*Verbascum thapsus*	25	0.02
33	-104.8636667	39.37460000	*Acosta diffusa*		6	0.10
34	-104.8640333	39.37428333	*Acosta diffusa*		10	0.02
35	-104.8644167	39.37443333	*Cirsium arvense*		8	0.10
36	-104.8638667	39.37480000	*Saponaria officianalis*		3	2.90
37	-104.8639333	39.37486667	*Verbascum thapsus*	*Centaurea diffusa*	3	0.50
38	-104.8638167	39.37483333	*Acosta diffusa*		25	0.02
39	-104.8639000	39.37501667	*Linaria vulgaris*	*Centaurea diffusa*	30	0.20
40	-104.8634333	39.37536667	*Acosta diffusa*	*Verbascum thapsus*	80	0.04
41	-104.8634167	39.37580000	*Cirsium arvense*	*Verbascum thapsus*	2	0.10
42	-104.8631833	39.37583333	*Cirsium arvense*		2	0.10
43	-104.8632000	39.37600000	*Saponaria officianalis*	*Verbascum thapsus*	2	0.70
44	-104.8631833	39.37603333	*Saponaria officianalis*	*Centaurea diffusa*	3	0.20
45	-104.8630500	39.37615000	*Acosta diffusa*	*C. arvense & V. thapsus*	40	0.03
46	-104.8628500	39.37625000	*Acosta diffusa*		5	0.10
47	-104.8627667	39.37605000	*Cirsium arvense*		5	0.20
48	-104.8628000	39.37650000	*Acosta diffusa*	*Verbascum thapsus*	15	0.04
49	-104.8625500	39.37668333	*Carduus nutans*		3	0.10
50	-104.8623667	39.37698333	*Cirsium arvense*		10	0.10
51	-104.8622667	39.37713333	*Cirsium arvense*		49	0.60
52	-104.8623667	39.37728333	*Cirsium arvense*		3	0.50
53	-104.8623833	39.37730000	*Verbascum thapsus*	*Centaurea diffusa*	6	0.20
54	-104.8621833	39.37731667	*Cirsium arvense*	*Centaurea diffusa& Cirsium vulgare*	40	0.20

Table H. Cont'd.

Record #	Longitude	Latitude	Species	Other Species Present	Radius (ft)	Cover (%)
55	-104.8623333	39.37753333	*Verbascum thapsus*	*Carduus nutans & Centaurea diffusa*	6	0.15
56	-104.8621333	39.37760000	*Cirsium arvense*	*Cirsium vulgare*	30	0.05
57	-104.8620000	39.37770000	*Cirsium arvense*		40	5.00
58	-104.8620333	39.37780000	*Acosta diffusa*		15	0.10
59	-104.8619500	39.37788333	*Eleagnus angustifolia*		25	0.50
60	-104.8618833	39.37793333	*Acosta diffusa*		3	0.90
61	-104.8618833	39.37808333	*Cirsium arvense*		3	0.20
62	-104.8619167	39.37816667	*Cirsium vulgare*	*Cirsium arvense*	20	0.95
63	-104.8618000	39.37823333	*Cirsium vulgare*	*Cirsium arvense & Centaurea diffusa*	15	0.05
64	-104.8617667	39.37846667	*Acosta diffusa*	*Verbascum thapsus*	30	0.10
65	-104.8617500	39.37883333	*Acosta diffusa*		30	0.15
66	-104.8618500	39.37903333	*Cirsium arvense*		6	0.20
67	-104.8618667	39.37913333	*Cirsium arvense*		7	0.20
68	-104.8619000	39.37905000	*Acosta diffusa*		8	0.15
69	-104.8618833	39.37933333	*Conium maculatum*	*Cirsium arvense & Centaurea diffusa*	30	0.20
70	-104.8619500	39.37941667	*Eleagnus angustifolia*		20	0.40
71	-104.8617000	39.37946667	*Acosta diffusa*		40	0.70
72	-104.8618833	39.37961667	*Eleagnus angustifolia*	*Cynoglossum officinale & Carduus nutans*	25	0.30
73	-104.8619667	39.37976667	*Carduus nutans*		2	0.15
74	-104.8620000	39.37980000	*Eleagnus angustifolia*	*Cirsium arvense*	10	0.90
75	-104.8621000	39.38001667	*Lepidium latifolium*	*Cirsium arvense & mat per*	15	0.30
76	-104.8619833	39.38011667	*Cirsium arvense*		15	0.10
77	-104.8616833	39.38058333	*Acosta diffusa*	*Cirsium arvense*	100	0.40
78	-104.8615000	39.38101667	*Cirsium arvense*		20	0.10
79	-104.8616167	39.38120000	*Cirsium arvense*		60	0.15
80	-104.8615833	39.38138333	*Cirsium arvense*		40	0.20

Table H. Cont'd.

Record #	Longitude	Latitude	Species	Other Species Present	Radius (ft)	Cover (%)
81	-104.8614000	39.38161667	*Cirsium arvense*	*Conium maculatum*	40	0.20
82	-104.8613000	39.38178333	*Verbascum thapsus*	*Centaurea diffusa*	45	0.15
83	-104.8649500	39.36445000	*Cirsium arvense*	*Conium maculatum*	25	0.10
84	-104.8652000	39.36461667	*Acosta diffusa*	*Verbascum thapsus*	20	0.10
85	-104.8651000	39.36491667	*Acosta diffusa*		15	0.05
86	-104.8650833	39.36498333	*Carduus nutans*		5	0.05
87	-104.8650833	39.36518333	*Linaria vulgaris*	*Verbascum thapsus*	5	0.10
88	-104.8650667	39.36531667	*Acosta diffusa*		6	0.05
89	-104.8650000	39.36536667	*Linaria vulgaris*		10	0.10
90	-104.8648500	39.36548333	*Eleagnus angustifolia*		8	0.75
91	-104.8649000	39.36581667	*Cirsium vulgare*		3	0.60
92	-104.8647833	39.36593333	*Acosta diffusa*		15	0.10
93	-104.8647333	39.36606667	*Linaria vulgaris*		10	0.20
94	-104.8645333	39.36623333	*Acosta diffusa*	*Verbascum thapsus*	80	0.05
95	-104.8641333	39.36671667	*Acosta diffusa*	*Verbascum thapsus*	8	0.05
96	-104.8638833	39.36691667	*Acosta diffusa*	*Verbascum thapsus*	65	0.01
97	-104.8635500	39.36723333	*leafy spurge*	*Cirsium arvense*	6	0.50
98	-104.8632500	39.36735000	*Acosta diffusa*	*Verbascum thapsus*	80	0.20
99	-104.8626500	39.36786667	*Eleagnus angustifolia*	*Verbascum thapsus*	15	0.30
100	-104.8628667	39.36825000	*Eleagnus angustifolia*	*Verbascum thapsus*	7	0.25
101	-104.8630500	39.36831667	*Acosta diffusa*	*Verbascum thapsus*	6	0.05
102	-104.8630333	39.36840000	*Linaria vulgaris*	*Verbascum thapsus*	5	0.30
103	-104.8623667	39.36868333	*Cirsium arvense*		6	0.40
104	-104.8622500	39.36861667	*Linaria vulgaris*		20	0.25
105	-104.8617667	39.36911667	*Cirsium arvense*		25	0.30
106	-104.8617667	39.36933333	*Chrysanthemum luecanthemum*		20	0.05
107	-104.8616667	39.36951667	*Linaria vulgaris*		10	0.10
108	-104.8615000	39.36980000	*Linaria vulgaris*		35	0.05
109	-104.8618500	39.36983333	*Cirsium arvense*	*Carduus nutans & Linaria vulgaris*	8	0.05

Table H. Cont'd.

Record #	Longitude	Latitude	Species	Other Species Present	Radius (ft)	Cover (%)
110	-104.8619333	39.36988333	*Cirsium arvense*		20	0.20
111	-104.8621500	39.37016667	*Acosta diffusa*	*Verbascum thapsus*	20	0.10
112	-104.8627333	39.37078333	*Acosta diffusa*	*Verbascum thapsus*	5	0.20
113	-104.8630833	39.37091667	*Acosta diffusa*	*Verbascum thapsus*	30	0.05
114	-104.8630833	39.37100000	*Carduus nutans*	*Verbascum thapsus*	5	0.10
115	-104.8630667	39.37115000	*Saponaria officianalis*	*Cirsium arvense*	2	0.50
116	-104.8631500	39.37138333	*Acosta diffusa*	*Verbascum thapsus*	25	0.20
117	-104.8631000	39.37145000	*Saponaria officianalis*	*Acosta diffusa*	10	0.30
118	-104.8632833	39.37166667	*Acosta diffusa*	*Cirsium arvense*	15	0.30
119	-104.8636333	39.37171667	*Eleagnus angustifolia*		10	0.50
120	-104.8636667	39.37178333	*Acosta diffusa*		15	0.05
121	-104.8636500	39.37176667	*Kochia scoparia*		60	0.30
122	-104.8640167	39.37173333	*Cirsium arvense*	*Saponaria officinalis*	8	0.30
123	-104.8643167	39.37195000	*Cirsium arvense*	*Carduus nutans*	7	0.20
124	-104.8642667	39.37213333	*Carduus nutans*		2	0.50
125	-104.8641833	39.37223333	*Acosta diffusa*		10	0.30
126	-104.8642667	39.37236667	*Saponaria officianalis*	*Verbascum thapsus*	4	0.30
127	-104.8643167	39.37251667	*Cirsium arvense*	*Acosta diffusa*	4	0.20
128	-104.8643333	39.37276667	*Cirsium arvense*	*Acosta diffusa*	7	0.30
129	-104.8640833	39.37295000	*Acosta diffusa*		50	0.20
130	-104.8643833	39.37303333	*Verbascum thapsus*	*Acosta diffusa*	6	0.20
131	-104.8641667	39.37330000	*Acosta diffusa*		25	0.20
132	-104.8641167	39.37355000	*Eleagnus angustifolia*	*Acosta diffusa*	10	0.50
133	-104.8643000	39.37410000	*Verbascum thapsus*	*Acosta diffusa*	5	0.20
134	-104.8644333	39.37428333	*Acosta diffusa*	*Verbascum thapsus*	8	0.30
135	-104.8643000	39.37438333	*Linaria vulgaris*		6	0.40
136	-104.8641333	39.37468333	*Acosta diffusa*		4	0.30
137	-104.8642500	39.37493333	*Acosta diffusa*		6	0.25
138	-104.8641667	39.37508333	*Acosta diffusa*		8	0.20
139	-104.8640167	39.37525000	*Saponaria officianalis*	*Acosta diffusa*	4	0.30
140	-104.8640167	39.37528333	*Eleagnus angustifolia*	*Acosta diffusa*	10	0.50

Record #	Longitude	Latitude	Species	Other Species Present	Radius (ft)	Cover (%)
141	-104.8636667	39.37573333	*Eleagnus angustifolia*	*Cirsium vulgare*	15	0.50
142	-104.8634667	39.37605000	*Acosta diffusa*		5	0.30
143	-104.8633833	39.37621667	*Acosta diffusa*	*Cirsium arvense*	8	0.30
144	-104.8632500	39.37618333	*Eleagnus angustifolia*	*Cirsium arvense*	8	0.40
145	-104.8631500	39.37643333	*Acosta diffusa*	*Verbascum thapsus*	40	0.30
146	-104.8629833	39.37653333	*Cirsium arvense*	*Acosta diffusa*	25	0.30
147	-104.8629500	39.37671667	*Acosta diffusa*	*Cirsium arvense*	10	0.20
148	-104.8629833	39.37666667	*Carduus nutans*	*Cirsium arvense*	4	0.30
149	-104.8629333	39.37680000	*Acosta diffusa*	*Verbascum thapsus*	15	0.20
150	-104.8627667	39.37700000	*Acosta diffusa*	*Verbascum thapsus*	25	0.20
151	-104.8627833	39.37715000	*Eleagnus angustifolia*	*Acosta diffusa*	50	0.25
152	-104.8626500	39.37736667	*Eleagnus angustifolia*	*Verbascum thapsus*	45	0.30
153	-104.8625000	39.37788333	*Acosta diffusa*		25	0.20
154	-104.8622333	39.37796667	*Eleagnus angustifolia*	*Acosta diffusa & Chrysanthemum luecanthemum*	15	0.30
155	-104.8623000	39.37800000	*Acosta diffusa*		20	0.20
156	-104.8621667	39.37806667	*Eleagnus angustifolia*	*Acosta diffusa*	15	0.30
157	-104.8621000	39.37816667	*Cirsium arvense*	*Eleagnus angustifolia*	10	0.40
158	-104.8620167	39.37838333	*Eleagnus angustifolia*	*Acosta diffusa*	40	0.30
159	-104.8620833	39.37853333	*Cirsium arvense*	*Eleagnus angustifolia*	20	0.20
160	-104.8620500	39.37860000	*Verbascum thapsus*	*Eleagnus angustifolia*	15	0.20
161	-104.8620833	39.37890000	*Acosta diffusa*	*Eleagnus angustifolia*	15	0.20
162	-104.8620833	39.37905000	*Eleagnus angustifolia*	*Acosta diffusa*	50	0.30
163	-104.8622167	39.37910000	*Acosta diffusa*		20	0.30
164	-104.8623000	39.37906667	*Saponaria officianalis*	*Acosta diffusa*	5	0.40
165	-104.8621167	39.37928333	*Eleagnus angustifolia*	*Verbascum thapsus*	45	0.40
166	-104.8622667	39.37933333	*Saponaria officianalis*	*Acosta diffusa*	15	0.30
167	-104.8621500	39.37941667	*Verbascum thapsus*	*Eleagnus angustifolia & Saponaria officianalis*	20	0.20
168	-104.8621167	39.37951667	*Acosta diffusa*	*Verbascum thapsus*	8	0.20

Table H. Cont'd.

Record #	Longitude	Latitude	Species	Other Species Present	Radius (ft)	Cover (%)
169	-104.8621667	39.37960000	*Cirsium arvense*	*Eleagnus angustifolia*	15	0.30
170	-104.8622167	39.37980000	*Cirsium arvense*	*Verbascum thapsus & Acosta diffusa*	7	0.30
171	-104.8622500	39.37985000	*Acosta diffusa*	*Cirsium arvense*	5	0.25
172	-104.8620333	39.37985000	*Acosta diffusa*	*Cirsium arvense*	10	0.25
173	-104.8621833	39.37993333	*Eleagnus angustifolia*	*Acosta diffusa*	4	0.50
174	-104.8623167	39.38008333	*Acosta diffusa*		7	0.20
175	-104.8622667	39.38043333	*Eleagnus angustifolia*	*Cirsium arvense*	4	0.50
176	-104.8622333	39.38048333	*Cirsium arvense*	*Acosta diffusa*	8	0.20
177	-104.8621333	39.38070000	*Acosta diffusa*		5	0.10
178	-104.8622000	39.38078333	*Carduus nutans*	*Acosta diffusa*	3	0.40
179	-104.8620333	39.38078333	*Cirsium arvense*	*Verbascum thapsus*	9	0.20
180	-104.8619833	39.38090000	*Acosta diffusa*	*Verbascum thapsus & Saponaria officianalis*	15	0.30
181	-104.8622333	39.38088333	*Cirsium arvense*		6	0.20
182	-104.8622167	39.38100000	*Acosta diffusa*	*Cirsium arvense*	10	0.30
183	-104.8621833	39.38105000	*Carduus nutans*	*Cirsium arvense*	3	0.50
184	-104.8621833	39.38103333	*Cirsium arvense*	*Acosta diffusa*	10	0.30
185	-104.8620333	39.38125000	*Eleagnus angustifolia*	*Acosta diffusa*	20	0.30
186	-104.8619333	39.38143333	*Cirsium arvense*	*Acosta diffusa*	4	0.30
187	-104.8616833	39.38183333	*Carduus nutans*	*Cirsium arvense*	5	0.10
188	-104.8616667	39.38180000	*Cirsium arvense*	*Acosta diffusa*	12	0.30
189	-104.8616333	39.38190000	*Acosta diffusa*	*Carduus nutans*	25	0.40
190	-104.8615833	39.38195000	*Carduus nutans*	*Acosta diffusa*	7	0.20
191	-104.8615500	39.38203333	*Cirsium arvense*	*Acosta diffusa*	3	0.50
192	-104.8615500	39.38218333	*Carduus nutans*	*Acosta diffusa*	3	0.30
193	-104.8614500	39.38223333	*Cirsium arvense*		15	0.30
194	-104.8613833	39.38233333	*Conium maculatum*		15	0.30
195	-104.8613333	39.38225000	*Eleagnus angustifolia*	*Cirsium arvense*	4	0.70
196	-104.8611833	39.38240000	*Acosta diffusa*	*Verbascum thapsus*	30	0.20

Table H. Cont'd.

Record #	Longitude	Latitude	Species	Other Species Present	Radius (ft)	Cover (%)
197	-104.8613500	39.38241667	*Cirsium arvense*		10	0.40
198	-104.8610833	39.38260000	*Verbascum thapsus*	*Acosta diffusa*	8	0.40
199	-104.8611167	39.38271667	*Eleagnus angustifolia*	*Acosta diffusa*	10	0.60
200	-104.8610667	39.38323333	*Eleagnus angustifolia*		4	0.50
201	-104.8610500	39.38343333	*Eleagnus angustifolia*	*Cirsium arvense*	6	0.70
202	-104.8610667	39.38358333	*Cirsium arvense*	*Acosta diffusa*	5	0.15
203	-104.8610667	39.38370000	*Linaria vulgaris*	*Cirsium arvense*	10	0.40
204	-104.8611167	39.38378333	*Cirsium arvense*	*Conium maculatum*	6	0.40
205	-104.8611167	39.38386667	*Linaria vulgaris*		8	0.40
206	-104.8612000	39.38386667	*Cirsium arvense*		15	0.30
207	-104.8613667	39.38420000	*Cirsium arvense*	*Acosta diffusa*	10	0.30
208	-104.8614000	39.38460000	*Cirsium arvense*	*Cynoglossum officinale*	35	0.40
209	-104.8612833	39.38433333	*Acosta diffusa*	*Cirsium arvense*	4	0.20
210	-104.8611667	39.38418333	*Linaria vulgaris*	*Linaria genistifolia*	5	0.40
211	-104.8611667	39.38400000	*Verbascum thapsus*	*Cirsium arvense*	6	0.10
212	-104.8611833	39.38373333	*Chrysanthemum luecanthemum*		2	0.50

D. Groundwater Results

Wells that were closer to the stream edge or check dam generally had shallower (closer to the surface) groundwater elevations. The original data collected in 1999 demonstrated that wetland hydrology requirements were not met for most of the MW wells. The wetland hydrology requirement was satisfied if the depth to the water table was continuously within 12 inches of the soil surface for at least 5% of the growing season, or seven consecutive days. Only 4 of the 37 MW wells met this condition in 1999. Groundwater levels fluctuated between 10 inches of the surface to 30 inches or deeper (these wells only reached a 30 inch depth). When flow volumes in the creek subsided, a corresponding immediate drop was observed in alluvial groundwater elevations. This strongly suggested a direct connection between surface and subsurface water in the floodplain of East Plum Creek.

Once deeper wells were installed in 2001, it became apparent that pre-check dam groundwater levels were actually much deeper in many locations than previously suspected, with no water detected on multiple occasions from several wells (implying that groundwater levels were deeper than 60 inches). The maximum groundwater depth of the CD and W wells exceeded 40 inches in 76% of the 80 wells available for analysis at some time during the sampling periods. There were several wells adjacent to the stream that had groundwater elevations between 50 and 60 inches. This demonstrated that many wells in the riparian zone had groundwater levels below optimal plant rooting depths for at least a portion of growing season. Twenty-one percent of the CD and W wells never had groundwater levels that were closer to the surface than 20 inches (over all sampling periods).

Annual cycles were apparent in groundwater levels, with lowest levels reached during fall and winter sampling. Groundwater levels would rise and peak during stream runoff in May and June, and then fall during the summer as average stream discharge would decrease and plant transpiration was at a maximum.

Installation of the first three dams was completed on April 30, 2001. Groundwater levels in the floodplain rose almost immediately. Sediment accumulation behind check dams occurred sequentially, with check dam 1 (CD1) filling with sediment first, followed by CDs 2 and 3. This process was quite rapid, and the segments between these dams had filled in by the end of May 2001.

All five of the wells upstream of CD 1 that had April and May 2001 data showed a gain in groundwater elevation during this period; the average May depth increased an average of 5.1 inches over the average April depth. Although this suggests that the rise in groundwater may have been related to the installation of the check dam, it also coincided with the normal seasonal gain in groundwater related to an increase in stream discharge. However, this same trend was also observed in the areas between CD 1-CD 2 and CD 2-CD 3, with both regions exhibiting an average gain in groundwater elevation of around 9 inches after installation of CDs 1-3.

Unfortunately, the April-May 2001 trend could not be evaluated in non-dam areas because deeper wells in these locations had not yet been installed. However, once the spring storms had subsided, groundwater levels were observed to have stabilized at higher levels than prior to check dam installation (See Figure 8).

The second set of six dams (CDs 4-9) was completed on April 30, 2002. These dams filled in with sediment at a much slower rate than the first three, because of the greater distance between CDs 4-9, and the greater channel volume that was available for filling (channel incision was greater in this area). Also, 2002 was a drought year and there were no significant storms to push sediment into the areas between the dams.

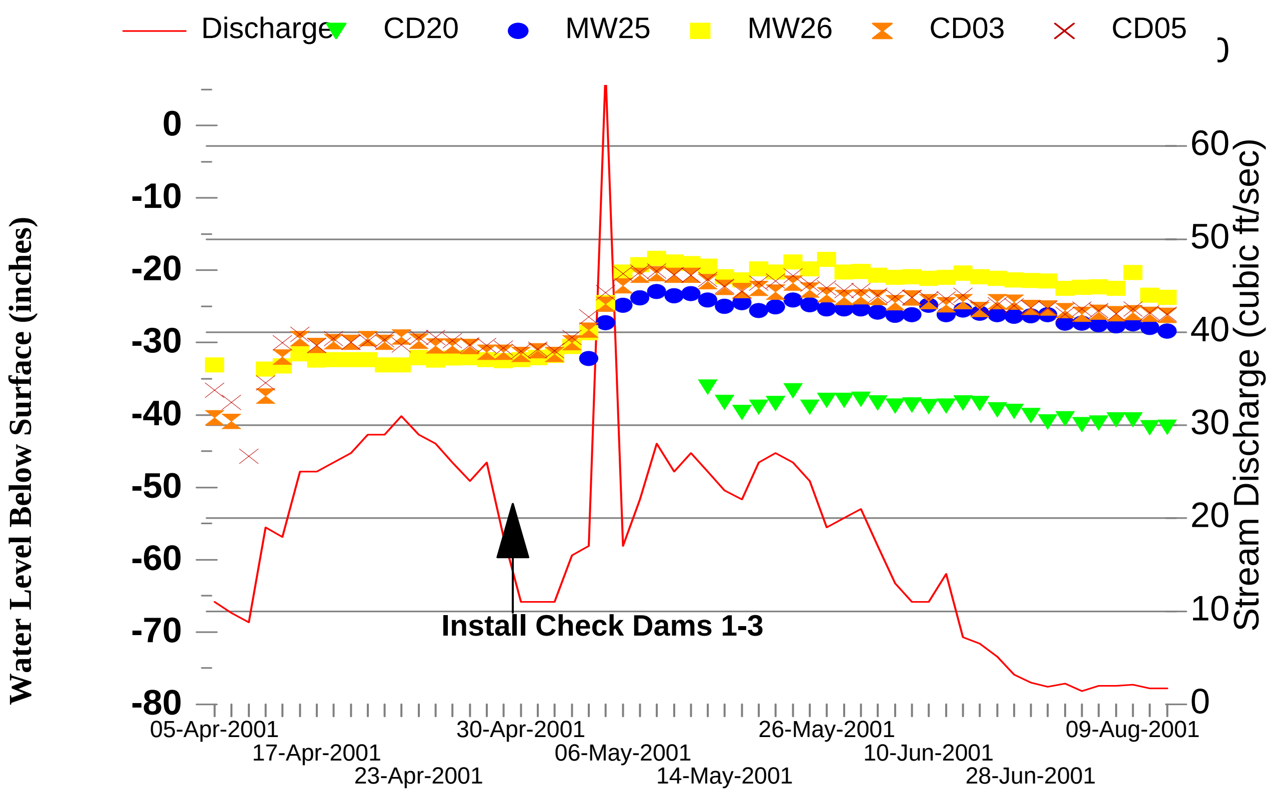


Figure 8. Groundwater Elevations Between Check Dams 2 and 3 with Stream Discharge, 2001 Growing Season, East Plum Creek, Douglas County, CO

Note: Groundwater levels rise after installation of CDs1-3 at nearly the same time of a peak in stream discharge in early May. But groundwater elevations remain elevated above 30 inches during the growing season even after stream discharge falls.

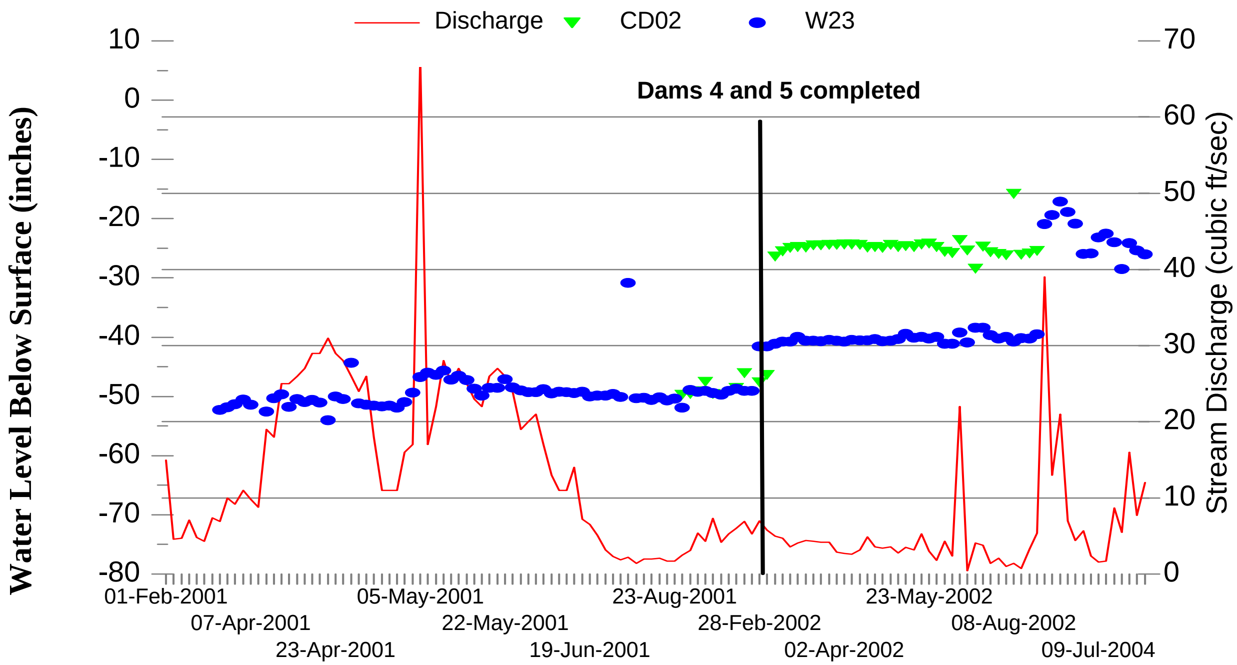


Figure 9. Groundwater Elevations in Two Monitoring Wells Between Check Dams 3 and 6 with Stream Discharge, 2001-2004, East Plum Creek, Douglas County, CO

Note: These were the only two wells in this region with pre and post dam groundwater data.

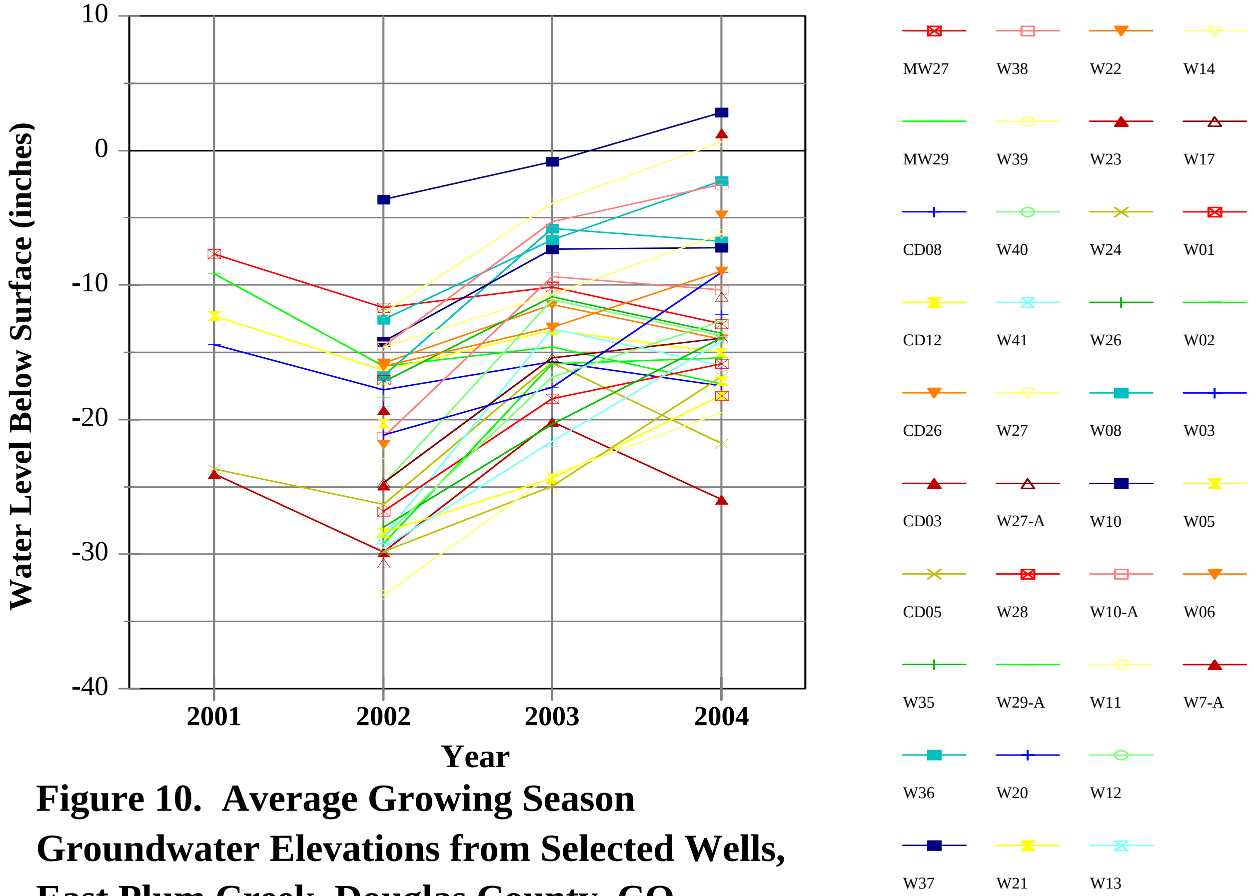


Figure 10. Average Growing Season Groundwater Elevations from Selected Wells, East Plum Creek, Douglas County, CO

There were also very few pre-dam data for this area, but a few wells had pre and post-dam measurements. In well W23 (between CDs 5 and 6) and well CD02 (between CDs 3 and 4), groundwater elevations ranged between -45 and -50 inches in February 2002. In March, elevations at both wells jumped 10 to 17 inches, corresponding to completion of the first dams in this section (Figure 9). Ponded water behind these dams caused an immediate rise in groundwater elevation. Other wells in this area also had very stable groundwater elevations during the 2002 growing season after dam installation, generally shallower than 30 inches and within the same range as the two wells with pre-dam data. These wells were also generally unaffected by stream discharge, suggesting that groundwater elevations here were also controlled by ponding. Although there are few pre-dam data to verify this comprehensive trend, it does appear that the stable, relatively higher groundwater elevations within Treatment Area 2 were immediately caused by ponding behind the dams. Ponding was common in this area during 2002 and the effect on groundwater levels was probably widespread.

General trends were also evident. Almost all wells in all locations had deeper growing season groundwater elevations during the drought of 2002. Most wells recovered during 2003 and many continued to rise during 2004. A subset of 39 wells were chosen for further examination; these wells all fell within the success criterion condition of having a ground surface elevation within 30 inches of the crest elevation of the nearest downstream check dam (success criteria are more fully explained in the Discussion section). These wells were especially important because they were within the expected “sphere of influence” of the check dams, and groundwater levels were expected to rise at these locations.

The average growing season groundwater elevation for each of these wells was examined from 2001-04. Only six of these wells had 2001 data, and all showed the expected decline in groundwater elevation from 2001 to 2002 associated with the 2002 drought. Almost all wells have recorded a trend in shallower, stable groundwater elevations since 2002, and average groundwater elevations are above 30 inches in almost all wells (Figure 10). This time period coincides with the sedimentation of CDs 4-9, and is indicative of a second rise in groundwater elevations after the ponding effect. It also appears that groundwater elevations after check dam installation were not as affected by stream discharge, providing a relatively stable water regime for riparian and wetland plants. More importantly, almost all average groundwater elevations have been above 30 inches depth, indicating that groundwater is now consistently within the rooting zone of many riparian plants in the study area. It is also interesting to note that in the area downstream of CD 9 (outside the area of check dam influence), that groundwater levels have never been above 36 inches from 2002-2004.

This positive trend was also confirmed when the maximum groundwater depth during the growing season was examined for the same set of 39 wells. Ten wells equaled or exceeded 30 inches in depth during at least one growing season sampling event during 2002, but no well had a depth exceeding 30 inches in the 2003 or 2004 growing seasons.

Groundwater data collection was completed in 2004. SAIC (2004) concluded that all potential Bank credit for groundwater had been earned because the depth to water below the soil surface during the growing season had been within 30 inches of the soil surface for a minimum of 18 consecutive days for a minimum of two years for applicable wells.

V. Discussion

The effects of stream restoration on vertebrate species has been studied from various perspectives. Perhaps the most commonly studied issue is the response of vegetation after elimination of livestock grazing in riparian areas (Clary and Kruse, 2004). Effects on avian communities have also been investigated, but there are few studies on small mammals. Anderson (1994) looked at small mammal communities on the Colorado River in Arizona in an area where invasive saltcedar (*Tamarix ramosissima*) had been removed and partially replaced by native vegetation. He found 9 of an expected 14 native small mammals in this partially restored area and concluded that most of these species could successfully reproduce in these habitats. Wike et al. (2000) looked at small mammals in a partially replanted river corridor in southeastern Georgia, and found no differences in habitat use among four small mammals between planted and control areas, but partially attributed this to potential movement of animals between treated and control areas.

This study investigated the effects of stream channel restoration on populations and habitat factors of a riparian obligate small mammal. The channel bed of East Plum Creek was largely restored with fresh sediment deposited over a four-year period following the installation of a series of nine dams. Current channel bed elevations closely resemble pre-erosion elevations behind all of the dams. Channel cross-sections taken at the second check dam before and after dam construction showed that the streambed elevation rose approximately two feet (CDOT 2004).

Groundwater monitoring was conducted within the study area for a variety of purposes from 1999 to 2004 at variable geographic and temporal intensities. Groundwater level at any individual well was influenced by a variety of factors such as stream discharge, time of sampling, proximity to stream and check dam, and rate of sediment filling behind dams. These factors could not be controlled in a strict sense, but two major patterns emerged. Groundwater elevations rose immediately behind dams where ponds formed, and stabilized at a new, higher elevation controlled by the crest elevation of the nearest dam. A second, more gradual but consistent rise in groundwater elevation became apparent as the eroded streambed filled with sediment. In the case of the first three dams, sedimentation was rapid and ponding was very short-term. Post-dam groundwater elevations were generally above 30 inches in depth at most study area wells during the growing season, and levels were buffered by the dams (less variable) to changes in stream discharge.

Restoring groundwater levels through sediment accretion was successful here, and set the stage for additional positive biological responses. We modeled PMJM population abundance in two control and two treated areas and tested how the four areas differed in abundance trends. Check dam installation did not affect the length (period) of the projected PMJM population cycle, but there were significant, separate treatment effects related to the timing and magnitude of PMJM abundance. In 2001, PMJM abundance was projected to decrease at all sites. Dam installation only occurred at Treatment Area 1 in 2001, and this was the only location where PMJM abundance increased, a clear treatment effect. This increase came at a time when all other sites were decreasing.

Treatment Area 2 was completed in 2002, and again, there was an almost immediate significant effect with an increase in Preble's abundance. When PMJM populations in control areas crashed to zero, Treatment Area 2 area showed a new, significant peak. It was remarkable that this peak came during a severe drought, and that PMJM were only found in both treatment areas in the 2002 drought year. Small mammal diversity in Treatment Area 2 also peaked in 2003 and exceeded the other sites in 2002-04. Dam installation may have led to improved habitat conditions for several small mammal species at Treatment Area 2. It is also interesting that Treatment Area 2 probably has the most degraded habitat in the entire study area, with the narrowest floodplain and most extensive anthropogenic disturbances.

What were the mechanisms behind the increases in PMJM abundance following check dam installation? And why did treatment areas vary in their responses?

The timing of ecosystem responses to the dams may partially answer these questions. Both sediment and groundwater responses to the dams were not uniform in the treatment areas, suggesting that Preble's population responses might not be either. Sediment infilling behind the first three dams was relatively rapid, with the first two dams backfilling within a few months of dam installation, and the entire stretch filling within one year. Ponding between dams was not a significant factor. Groundwater recovery within this area was subsequently rapid and occurred within a single growing season. Sediment accretion between dams was controlled by the severity of spring and summer storms, stream gradient, the volume of eroded channel, and the length of stream to fill.

In contrast, Treatment Area 2 had a much longer stream stretch, greater channel volume to fill, and fewer and less intense storms following dam installation. Sediment accretion occurred at a much lower rate, with little in-filling during the 2002 drought year. There were extensive ponds between most of the dams for two or more years before this stretch finally filled in during early 2005. During this period the ponds were colonized by both beavers (*Castor canadensis*) and bullfrogs (*Rana catesbeiana*). Groundwater levels initially rose in response to ponding, and rose again further after sedimentation between dams was complete.

Both areas also had similar construction disturbances during the dam treatment periods. In Treatment Area 1, 0.89 acres of habitat was affected by building a new bridge and installing three dams (0.76 acres of this total was successfully revegetated and 0.13 acres had permanent impacts, Ensight 2004). In Treatment Area 2, similar construction disturbances to habitat affected 1.25 acres, the majority of which has been successfully restored.

These physical ecosystem factors (sediment accumulation, groundwater level, channel profile, and disturbance) have ultimately affected the study treatment areas in similar ways but at different rates. Preble's abundance increased significantly in Treatment Area 1 immediately after the first three dams were installed and remained high for two years (2001 and 2002). Treatment Area 2 showed a similar increase in abundance following dam completion, despite having a very different suite of post-dam habitat conditions during the period of increase.

Preble's demographic processes were affected in both treatment areas; abundance can be affected by emigration/immigration, birth rate, and survival (with related factors such as predation). We did not find significant movement or survival effects during this study, because limited sampling in the latter part of the growing season resulted in low power to detect such effects. Preble's are thought to have two litters of young per growing season, and data on the second cohort were limited. Young PMJM could be born in July or August, emigrate to a new area, and be captured the following June for the first time. This capture record would only yield data on site abundance, and start the clock for a survival value. An estimate on emigration/immigration and survival from the previous period could not be determined.

In Treatment Area 1, male PMJM dominated the capture records prior to dam installation. The population after dam installation was dominated by females. The treatment may have made the area more attractive to females at the beginning of the active period in early June. Females are generally pregnant at this time and additional feeding and nesting opportunities may have been created.

Treatment Area 2 is the most non-typical Preble's habitat in the study area. It has some of the same urban influences as Treatment Area 1 (bikepath, bridge). It has the additional urban factors of residential homes and near-by fast-food restaurants, but the most telling factor is that Preble's habitat here is in close proximity to these influences because of the narrow floodplain. Small mammal diversity here is higher than any other study area location in part because house mice, feral Norway rats, and Mexican wood rats have been found here and are rare or absent at the other sites. The major change to habitat here was the formation of temporary ponds behind most of the dams; Preble's abundance increased significantly and beavers and bullfrogs colonized much of the area. Preble's are often found on streams with beaver ponds, and the temporary check dam ponds may simulate this condition. Two male PMJM also moved to Treatment Area 2 from Control Area 2 after dam installation, although the movements were not statistically significant.

Elevated PMJM abundance may also be partially explained by a 20% increase in graminoid foliar cover in treatment areas following check dam installation. Graminoids provide cover and food (seeds) for PMJM, and are used for nesting material. Sedges (*Carex* sp.) and rushes (*Juncus* sp.) were the most common graminoid species in the treatment areas, with 56% of the graminoid cover. The introduced grasses reed canary grass (*Phalaris arundinacea*) and smooth brome (*Bromus inermis*) also were well represented, accounting for 15 and 9% of the graminoid hits respectively. In a previous study of PMJM diet composition in the study area based on analysis of fecal pellets, graminoid seeds averaged 75% of the June diet of PMJM (n=38 animals, from Ensight, unpublished data). Although fecal analysis underestimates the more readily digestible foods, this does demonstrate the importance of grass seed in the PMJM diet.

The maximum of seven years of Preble's abundance data collected here suggest that PMJM populations may vary on a nine-year cycle, but there are too few data to make predictive statements about future abundance levels. Abundance data from nearby sites in El Paso County (Dirty Woman Creek n=7 years; Kettle Creek n=4; Ensight 2004b, c) suggest that these populations have followed similar trajectories as the Castle Rock population. Variance in abundance from El Paso County sites appears to be in-phase with Castle Rock, showing high population levels in the late 1990s, followed by a low trough in 2002-2003, and a modest recovery thereafter (Ensight 2004b, c). The region-wide drought in 2002 severely affected Preble's as well as all riparian small mammals. Many of these Preble's populations were at declining levels before the drought and were reduced to a handful of individuals per stream mile. The 2002 drought reduced PMJM Castle Rock abundance to the lowest levels measured, about 19 animals in the control and treatment sites. Synchronous environmental factors may have especially severe consequences on small populations, and increase the probability of local extinction in several locations (Ims and Andreassen, 1999).

Both the flora and fauna of riparian areas are adapted to disturbance regimes caused by flooding. PMJM are generally found in early to mid successional stage habitats that have heavy vegetation cover but are not dominated by mature cottonwood (*Populus sp.*) forest. PMJM responded positively to changes in this riparian system during a period when the system was still in a state of flux. We are still seeing changes in the physical system and can expect to see additional changes in riparian vegetation. During early 2005, sediment infilling between dams in Treatment Area 2 was completed. Due to the narrow nature of the floodplain in the northern section of this treatment area, sediment not only accumulated into the eroded channel, but also was deposited on the surrounding floodplain. Much of this new sediment deposition remained saturated during the growing season, and there was significant die-back of riparian shrubs. It was not surprising that we did not find any PMJM in this area during 2005 because of the reduced vegetation cover. We have also observed that the immediate positive response to dam ponds in Treatment Area 2 by beavers and bullfrogs was short-lived; both had disappeared from this area in 2005.

Additional vegetation responses are expected here as the stream channel matures. The substantial areas of moist sediment deposition behind the dams make an ideal substrate for riparian plant germination. However, plant germination on new sediments has been limited to date, probably because of powerful storm events in 2004 and 2005. We have observed that most of the woody colonizers have been from remnant pieces of crack willow (*Salix fragilis*) that have dislodged during storms and have rooted in the new sediment at downstream sites. Survival and growth of plant sediment colonizers is heavily dependent on the intensity of flood events prior to and following seedling germination (Johnson 1994). It does appear that willow shrubs that survived the period of groundwater depression are responding to elevated groundwater by growing new shoots from base clumps and possibly by reproducing vegetatively. The East Plum Creek channel is expected to narrow over time, as riparian vegetation colonizes and grows on the freshly deposited sediment. This pattern is readily apparent on East Slope Colorado plains streams, especially during periods between major floods (Friedman and Lee 2002, Friedman et al. 1996).

In 2000 CDOT Region 1 and FHWA began working with the U.S. Fish and Wildlife Service (USFWS) to create a conservation bank for Preble's in much of the study area. Initial discussion focused on what value the area provided to Preble's. It was decided early on that riparian habitat restoration was the principal concept of the proposed bank. Most conservation banks are established via habitat protection; habitat restoration is more difficult to conduct and prove successful. As the talks progressed, it became apparent that quantitative success criteria for restoration would be needed for CDOT to "prove" the value of the bank and earn subsequent credit. Groundwater success criteria were mentioned previously; groundwater had to be within 30 inches of the surface for 18 consecutive days during the growing season for two years. Additional success criteria were eventually established as with the following credit allocations: 1) 25% of total credit was given for the actual construction of the dams, 2) 50% for successful restoration of groundwater levels, 3) 15% for meeting habitat vegetation standards, and 4) 10% for target Preble's populations and distribution within the bank. Some of the data collected under this study for habitat vegetation and Preble's population/distribution were directly used to determine bank success criteria. See Appendix B for full details on bank success criteria. As of 2004, CDOT had earned 90% of the total credits available, with additional potential credits available in the areas of vegetation and Preble's populations (Ensight 2005).

The CDOT check dam project is unusual for several reasons. There are very few studies that have examined the consequences of experimental stream restoration on small mammals, and perhaps no particular studies on a riparian obligate small mammal. The study area is also unusual in that it is in a highly urbanized stream corridor; PMJM are typically not found in these habitats. The USFWS has conceded that Preble's have likely been extirpated from urban stream corridors in Denver and Colorado Springs (USFWS 2000, 2002). Finally, the major restoration of an urbanized corridor for an animal typically found in more natural environments is somewhat controversial.

Our study found positive responses in PMJM abundance following installation of a series of check dams on a degraded stream. Increases in PMJM abundance have occurred during a period when the riparian ecosystem is still changing extensively, and it is premature to speculate on final effects. We have also seen very positive changes in the physical system that will lead to more stable conditions for riparian vegetation. This stream system is still in a post-dam adjustment phase, and new patterns of sediment deposition, groundwater elevational changes, and riparian vegetation colonization may occur. It is likely that PMJM abundance will continue to change in these areas as well. However, it has been encouraging that positive responses could be demonstrated within a short period and within a meager portion of the PMJM habitat spectrum: an urbanized, degraded stream.

VI. Conclusions and Recommendations

East Plum Creek in Castle Rock contains one of the only known PMJM populations within an urban area. Population data were collected from 1998 to 2004 within stream stretches that were affected by a stream restoration project (check dams) and control reaches. The following information was determined about this population:

- Groundwater elevations are at higher levels (shallower depth) in the study area after construction of check dams. Although sedimentation between all dams eventually was completed within four years, there were immediate gains in groundwater elevation at some sites and more gradual gains at other sites. Groundwater elevations are now within the rooting zone of riparian plants and appear to be more stable during the growing season.
- The PMJM population in the study area may vary on a 9-year cycle, with the population peak occurring in 1998-1999 and the population trough occurring in 2002-2003. We have not sampled the population during the entire projected cycle and these results are preliminary. Data from other sites have similar peaks and troughs, and PMJM populations in Colorado may be affected by synchronous factors.
- PMJM populations vary considerably on a small geographic scale (on the order of a few hundred meters between sites) and on an annual basis.
- PMJM survival is lower during the active period than the hibernation period, and active season female survival is significantly greater than male survival (female 50%, male 21%). When survival is averaged over the entire year, both sexes are similar (female 20%, male 16%).
- PMJM do not readily move long distances (greater than 500 m) within the study area, as detected by mark/recapture methods. Males tend to move greater distances than females.
- The two check dam treatment areas both had higher PMJM populations following dam installation than would be expected from prior population trajectories at both control and treatment sites. The effects were not the same at both treatment sites, and both have been

short-term to date. PMJM abundance was higher at both treatment areas during a severe drought in 2002 while PMJM populations at both control areas had crashed to zero.

- Graminoid cover increased in treatment areas by 20%, and may be partially responsible for the increase in PMJM abundance. Graminoids are important to PMJM for cover and as a food source.
- There may be additional explanations for increases in abundance at treatment areas, but the power to detect detailed factors was low.
- Data collected during this study were directly integrated into a series of natural resource measures that were used to quantify the amount of restoration success that CDOT could earn for credits in a conservation bank.

This information is useful on several levels. This study provides baseline data on PMJM demographics. There are few published studies with detailed population data, and this information can be used to aid in conservation planning for PMJM. Second, there are few studies that examine the effects of stream restoration on small mammal populations. Most of the existing work in this area is on avian communities, and there limited studies on small mammals.

It is also rare to find this combination of unlikely factors: stream restoration, a vertebrate generally found in undisturbed riparian habitat, and an urban riparian corridor. Channel incision in urban areas is an increasing problem in the Colorado Front Range. The successful restoration of the stream channel on East Plum Creek is a stand-alone story that has already received considerable attention. There has been a positive response from local citizens that use the area, and other municipalities are using this technology for their own restoration projects.

This may also extend hope to restore PMJM habitat that was formerly considered too disturbed for further consideration. There is extensive habitat within the Colorado range of PMJM that has restoration potential. The following recommendations will help enable the transfer of the knowledge gained from this project:

- Continue to monitor PMJM populations in the study area. As the system continues to change, Preble's abundance may as well. Abundance data collected in 2005 (not analyzed yet) found Preble's only in Control Area 1.
- Play an active management role in the study area. Most of the study area has been designated a Conservation Bank, and general monitoring of Bank conditions is required. Weed control was conducted for the first time in 2005. A new series of dams was installed in early 2005 at the north end of the bank area, and sedimentation behind dams should be monitored.
- Continue to promote public awareness of this project - it is important for PMJM and Colorado riparian areas. This is the most public-accessible PMJM habitat in Colorado and it can serve as an outdoor laboratory. CDOT has been approached by municipalities that are also interested in stream restoration, and have responded to this demand by publishing an information booklet on the history of the project (CDOT 2004). The Town of Castle Rock has added a new 3-acre conservation area adjacent to the Bank in an effort to enlarge the riparian corridor for PMJM. Boulder County has started a similar restoration project on Coal Creek after reviewing the effects of this project. All of these actions illustrate the need and desire to protect natural riparian areas, even if they are within an urban setting.

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Appendix A.

Fitted models are all of the following form:

$$N(t) = A * \sin\left(2\pi \frac{t}{P} + \phi\right) + A$$

Where:_

N(t) = number of Preble's mice at time t
t = Time (number of years before 4 June 2004)
A = Amplitude (No. Preble's mice)
P = Period (time between peak and trough, approx. 9 years)
ϕ = Phase (radians)

The best model had the following parameter estimates:

<table>
<tr><th></th><th></th><th colspan="3">Fitted Model Parameters</th></tr>
<tr><th>Site</th><th>C/T</th><th>Amp</th><th>Phase</th><th>Period</th></tr>
<tr><td>Control 1</td><td>C</td><td>9.8</td><td rowspan="5">4.1</td><td rowspan="6">9.0</td></tr>
<tr><td>Control 2</td><td>C</td><td>34.0</td></tr>
<tr><td rowspan="2">Treatment 1</td><td>C</td><td>9.0</td></tr>
<tr><td>T</td><td>28.0</td></tr>
<tr><td rowspan="2">Treatment 2</td><td>C</td><td rowspan="2">3.1</td></tr>
<tr><td>T</td><td>0.9</td></tr>
</table>

Appendix B. Success Criteria for East Plum Creek Conservation Bank, Douglas County, CO

Total credits 25.2, 1 credit = 1 acre

Credit Category	Sub-Category	Credit/% total credit	Success Criterion
Signing		6.32/25	Check dams in-place, funds committed
Groundwater		12.65/50	
	Check dams 1-3 at signing	4.21/16.7	At each check dam the depth to water below the soil surface is proven to be within 30 inches of the soil surface for a minimum of 18 consecutive days (equal to 12.5%) during the growing season (May 9 through Oct. 2, 147 days) for a minimum of two years (not necessarily consecutive). This criterion is applicable to all floodplain areas where the ground surface elevation is within 30 inches of the crest elevation of the nearest downstream check dam
	Check dams 4-9	8.44/33.4	Depth to water below the soil surface is proven to be within 30 inches of the soil surface for a minimum of 18 consecutive days (equal to 12.5%) during the growing season (May 9 through Oct. 2, 147 days) for a minimum of two years (not necessarily consecutive). This criterion is applicable to all floodplain areas where the ground surface elevation is within 30 inches of the crest elevation of the nearest downstream check dam.

Credit Category	Sub-Category	Credit/% total credit	Success Criterion
Habitat Vegetation		3.80/15	
	Foliar cover in restored areas	1.26/5	Measure total foliar cover at two 15-meter long randomly placed transects (perpendicular from the edge of the active channel) at 0.5-meter intervals at each check dam (9 dams total), for a total of 18 transects (60 "hits" per dam). A hit will be coded by vegetation species, litter, or bare ground. If the area of the dam is too narrow for a 15-m transect, it will be assigned an alternative location. Eighty percent of the transects (0.8 * 18= 14) will have to equal or exceed 70% total foliar cover for two years (not necessarily consecutive) until success is achieved.
	Significant increase in shrub and native species foliar cover from check dam areas over reference areas	1.27/5	Assign two 15-meter long randomly placed transects at each dam and reference area (9 dams, 2 reference areas) perpendicular from the edge of the active channel. Measure foliar vegetation hits at 0.5 m intervals and species composition of all vegetation hits. The following hypotheses will be tested: There will be no significant difference in average shrub foliar cover between check dam and reference areas for two years ($\alpha = 0.1$), and There will be no significant difference in native species foliar cover between check dam and reference areas for two years ($\alpha = 0.1$). *Note: Average shrub foliar cover was significantly greater at treatment sites than reference sites in 2002 and 2003, and native foliar cover was not significantly different at treatment and reference sites in 2002 and 2003. Success conditions were therefore met for both of these criteria and credit was subsequently awarded.*

Credit Category	Sub-Category	Credit/% total credit	Success Criterion
	Weed Control	1.27/5	CDOT will commit to control noxious weed patches that are equal to or greater than 100 ft^2 in size by appropriate and acceptable means. Weeds that will be controlled will include those species on the state weed list. Control measures will be taken over the lifetime of the bank. Full credit will be awarded for this effort at year three (January 2006).

Credit Category	Sub-Category	Credit/% total credit	Success Criterion
Preble's Population and Distribution		2.53/10	
	Distribution	1.27/5	Preble's will be found in the following locations for at least two years at each of the following locations from the period 2002-2006: At check dams 4, 5 or 6 south of the Wolfensberger Bridge, starting 30 meters south of check dam 4 and extending 70 meters north of check dam 6, and At check dams 7 (starting at the northern boundary of check dam 6 from above), 8 and 9 (to the northern bank boundary) north of the Wolfensberger Bridge
	Populations	1.26/5	The three-year (1999-2001) pre-check dam average Preble's population density was 9.79 animals km^{-1} stream, with a standard error of 2.18. Credit will be awarded if the three-year post-dam population density exceeds 14 animals km^{-1} stream (this is the mean plus two standard errors). The three-year average can be taken from any three years within the five-year period from 2002-2006.