STREAMBANK STABILIZATION WITH RIPRAP AND TREE REVETMENT IN DEEP CREEK, BROADWATER COUNTY, MONTANA

Part III of a Final Report
to
The Montana Department of Natural Resources and Conservation
on
Project No. RIT-87-8506:
Stream Restoration on Confederate Gulch and Deep Creek

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SUMMARY

We studied effects of streambank tree revetment and riprap (rock blanketing), on the channel and on wild brown and rainbow trout in a 1.4-km study area of Deep Creek from fall 1986 to fall 1989; the first part of an investigation that needs a follow-up phase. Our hypothesis was that (1) revetting badly eroded stream banks with trees or riprap would reduce erosion, (2) this would improve the channel's physical characteristics for trout by narrowing and deepening, and (3) tree revetment would, because it offers more hiding cover, benefit trout more than riprap would, and this would result in greater trout abundance in tree-revetted areas than in riprapped areas (and less trout abundance in untreated areas than in either type of treated area). Study was hampered by severe drought in 1987-88, which, combined with upstream diversion of water for irrigation, culminated in a 2.5-month dewatering of the study area in summer 1988, a few months after construction. This particularly limited evaluation of trout population responses to the bank revetments.

In spring 1988, we built juniper tree revetment along 6 high, eroding, current-bearing stream banks (over 100 trees anchored with over 200 steel rods on 211 m of bank), we riprapped 6 similar banks (320 m^3 of rock on 236 m of bank), and left 6 other such banks untreated as reference. Tree revetment immediately created large increases in overhead hiding cover for trout, but in riprapped and untreated bends, if any change in cover occurred, it was on average a slight decrease. Pool habitat may have increased in tree-revetted areas but remained unchanged in riprapped and untreated areas. Stream flows of pool-forming strength did not occur. There were no significant changes in channel width or depth.

Most streambank erosion was by ice-levered fracturing during spring thaw. Both tree-revetment and riprap prevented such erosion.

Trout decreased during the progressing drought. They disappeared, except for some of the smallest fish, in the summer 1988 dewatering, started recolonizing the when flow resumed, and began a reproduction-based recovery toward pre-drought abundance. In June 1988, about a month after construction (and before the dewatering), small (under-10-cm) trout were closely associated with submerged structural hiding cover and were most abundant in tree-revetted bends, second most abundant in untreated bends, and least abundant in riprapped bends, but for larger trout, there were no differences between treatments. In October 1988, soon after the dewatering, trout were more closely associated with pool habitat than with structural hiding cover, and total trout abundance was greater in untreated bends than in the tree-revetted and riprapped bends, between which there was no difference. But in terms of under-10-cm trout, both the tree-revetted and untreated bends had greater biomass density (weight per unit channel length) than did the riprapped bends. It seems that in general, it seems that tree-revetted and some untreated bends offered complex vegetational structure and were therefore more attractive to small trout than were riprapped bends.

At this point, the study's most useful findings may concern dewatering effects, the trout population's partial recovery from them, the ice-levered fracture of stream banks, and the effectiveness of tree revetment and riprap against such erosion. Evaluation of trout responses to the bank stabilization methods remains weak, pending follow-up study.

INTRODUCTION

Streambank erosion is of much concern in agriculture, in the planning and engineering of urban areas and roadways, and in the management of flowing waters as fisheries. The rate at which stream banks erode is influenced by human activities and natural events that change the interrelated variables controlling channel shape (Heede 1986; Henderson 1986; White 1973). Where stream banks erode excessively, people often react to protect property and resource values. Some common methods, such as concrete walls or other hard, flat-surfaced are often highly artificial and harm fish and wildlife values.

We undertook this study to evaluate physical and biological effects of two methods of reinforcing stream banks against erosion: revetment with rock, commonly called riprap, and with freshly cut trees, which we refer to as tree revetment. This report covers the pre-treatment (October 1986-March 1988), construction (April-May 1988), and immediate post-treatment (June 1988-November 1988) phases of the study, as well as some data from 1989. True evaluation of effects will require a future follow-up evaluatory study.

Riprap is a common method for stabilizing banks. Based on field observations, author White and others have long felt that , if properly constructed, riprap can, besides retarding erosion, create overhead hiding and resting niches for trout (White and Brynildson 1967; Binns 1986), provides habitat for benthic invertebrates (Henderson and Shields 1984), and causes deepening of pools (British Columbia Ministry of Environment 1980). Deeper pools benefit trout (Elser 1968). In Huff Creek, Wyoming, trout abundance increased from 36 to 436 trout per mile (1100%) after 3,760 feet of eroding stream banks were stabilized with riprap, check dams and other instream structures (Pistono 1986). In the Upper Mississippi River, Farbee (1986) found more warmwater fish in areas loosely revetted with stones than in areas revetted with tightly placed smaller stones. Thurow (1987), however, reported lower densities of rainbow trout in riprapped sections than in unaltered sections of the Big Wood River, Idaho.

Installing felled trees as trout cover and to stabilize eroding soil along current-bearing stream banks was recommended by White and Brynildson (1967), according to methods they had observed and envisaged, or that had been described by others. Various agencies, particularly the U.S.D.A. Forest Service (Pistono 1986), further developed this method.

Tree revetment is now widely used to stabilize stream banks, to provide cover for trout, and to cause silt deposition as sites for willow establishment along banks (Sheeter and Claire 1989). Binns (1986) recommends using green (freshly cut), thickly branched conifers because they provide maximal silt trapping, suitable cover for trout, and attachment surfaces for benthic macroinvertebrates. Pistono (1986) found increases in trout habitat quality and trout numbers due to such tree revetments in Wyoming streams. Sheeter and Claire (in Reeves and Roelofs 1982) reported that whole juniper trees halted bank erosion in Oregon.

We emphasize that a major aspect to be studied was the effect of revetment on structural habitat for trout, particularly those features that offer hiding/security. Various studies have demonstrated direct relationships between trout abundance and structural habitat in streams (Boussu 1954; Enk

1977; Gunderson 1966; Lewis 1969; Thurow 1990; Wesche et al. 1987; White 1986). Of published evaluations of stream management to create structural habitat, the majority have shown increased fish populations, but a substantial proportion have shown decline or lack of change (Hamilton 1989). Evaluations showing positive population responses undoubtedly are more likely to be reported and to be reported in more widely available form (Hamilton 1989; Reeves and Roelofs 1982).

A larger problem is the scarcity of project evaluations. Few adequate preliminary and follow-up studies are done because they lengthen the time horizon for planning and institutional commitment, can make scheduling and logistics more complex, and always add significantly to project cost. Also, some people who fund, design, or carry out the projects are so confident in the assumption of beneficial results that they think evaluation unnecessary, and others are so lacking of confidence that they resist having their work evaluated--or even truly evaluating it themselves. In short, evaluation of management is a lot of trouble and can be painful.

The study's objectives were to evaluate (1) physical changes of the stream that were associated with riprap and tree revetments, (2) the trout population's responses to these changes, and (3) costs of constructing riprap and tree-revetment. Our hypothesis was that (1) revetting badly eroded stream banks with trees or riprap would reduce erosion, (2) this would improve the channel's physical characteristics for trout by narrowing and deepening, and (3) tree revetment would, because it offers more hiding cover, benefit trout more than riprap would, and this would result in greater trout abundance in tree-revetted areas than in riprapped areas (and less trout abundance in untreated areas than in either type of treated area).

DESCRIPTION OF STUDY AREA

Deep Creek, which flows through Broadwater County in central Montana, originates on the north slope of Grassy Mountain in the Big Belt range. It flows westward about 36 km to the Missouri River, 4 km south of the town of Townsend. In this area, average annual precipitation during 1978 to 1988 was 34 cm, most of which occurred between February and June. However, precipitation was only 19 cm in 1987 and 25 cm in 1988.

The study area contains about 1,400 m of the creek in Section 2, Township 6 North, Range 2 East (Figure 1). It is on a ranch (Figure 2) that Mr. and Mr. Ray Goodwin of Helena, Montana, owned until winter 1988-89, the Leslie L. Schipman family bought it. When the study began in 1986, the ranch was run as a grain farm by the Kurt Spazierath Family (Goodwins' son-in-law and daughter), after having been converted from a cattle operation about three years before.

Natural low flow discharge in the study area may be about 200 to 350 L/s (7 to 12 cfs). Upstream irrigation diversions severely reduce summer discharge in the study area. Analysis of chemical constituents in the water during autumn low flow (Table 1 and Appendix A) indicates substantial nutrients for aquatic life, e.g., alkalinity of 196 mg/L and nitrate content of 0.05 mg/L. Indeed, in addition to the usual algal coating of the streambed stones, they are covered with a limey-appearing crust.

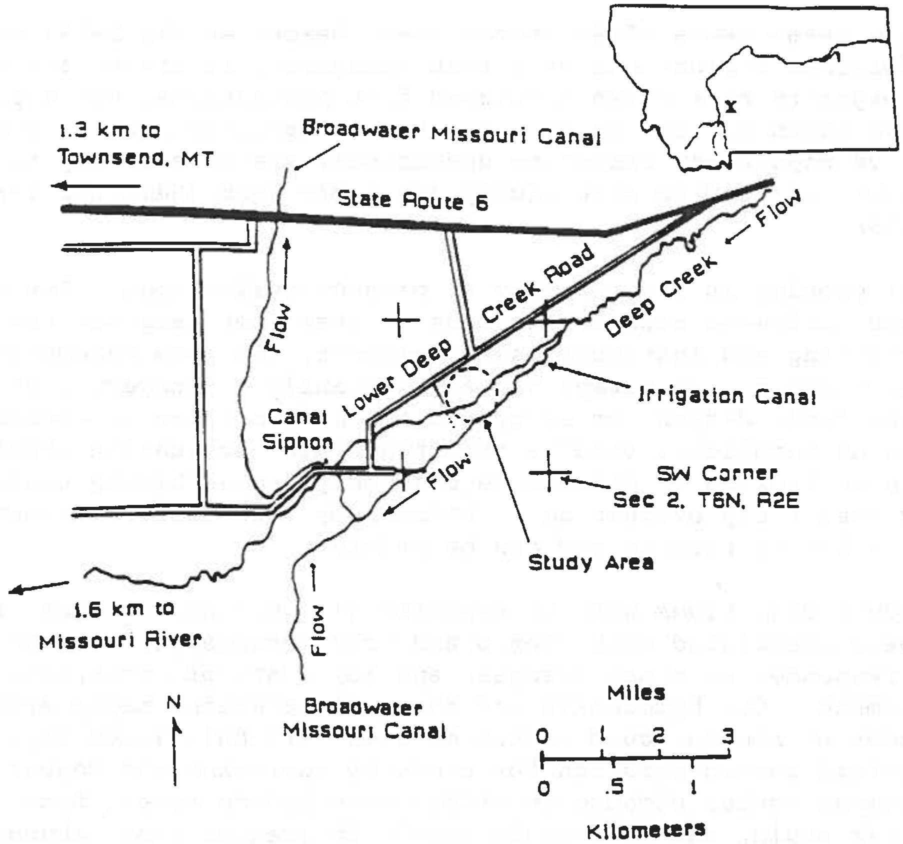

Figure 1. Location of Deep Creek study area relative to local features.

Figure 2. A view southward across Deep Creek valley and part of the study area, March or April 1988. Note riparian vegetation. On the opposite hill-side is an irrigation ditch from upstream diversion of Deep Creek. Also on that slope is the juniper grove from which trees were cut for streambank revetment.

Table 1. Chemical analysis of water just upstream from the study area, Deep Creek, Montana, 21 October 1991 (complete report in Appendix A).

Analysis	Value	Analysis	Value
pH (lab)	8.16	Manganese	<0.002 mg/L
Tot alkalinity as CaCO3	196 mg/L	Silica (SiO2)	16 mg/L
Tot hardness as CaCO3	201 mg/L	Bicarbonate	239 mg/L
Total dissolved solids (calculated)	262 mg/L	Chloride	3.9 mg/L
		Sulfate	40 mg/L
Lab conductivity	462 micromhos	Nitrate as N	0.05 mg/L
Calcium	44 mg/L	Fluoride	0.45 mg/L
Magnesium	22 mg/L	Orthophosphate as P	<0.05 mg/L
Sodium	14 mg/L	Total dissolved phosphate as P	<0.1 mg/L
Potassium	2.85 mg/L		
Iron	<0.005 mg/L		

The study area was chosen in 1984 because many of the current-bearing (outer or concave) banks of its meander bends were high, steep, and composed of raw soil. The site was also chosen because the riparian area was not grazed by livestock and, due to the ranch's purpose of grain production, appeared likely to remain free of grazing.

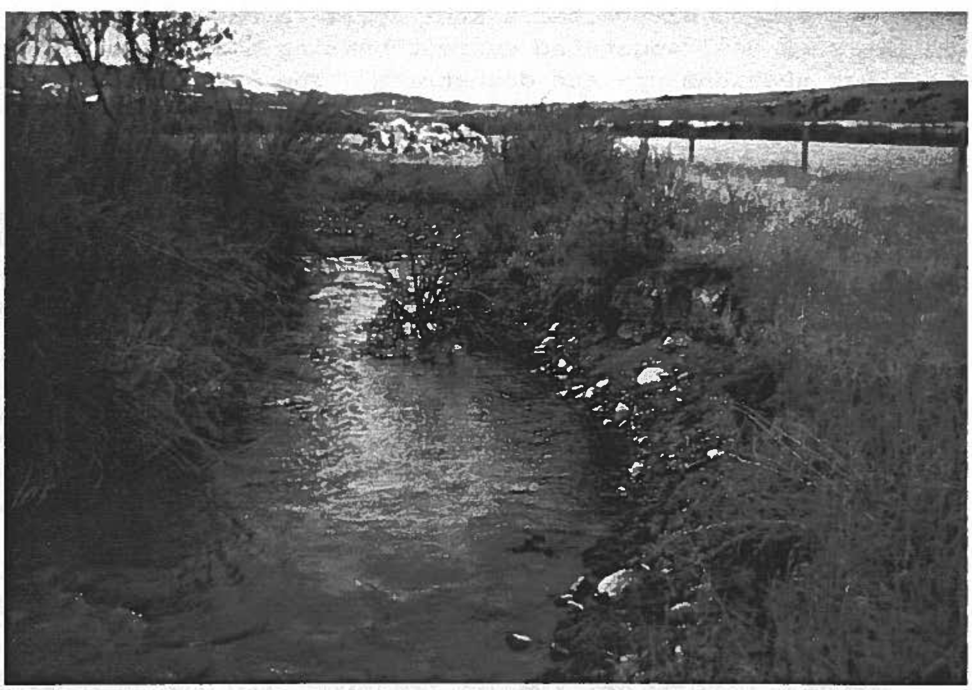

Figure 3. A high, eroding bank, Deep Creek study area, April 1988--bend 16, before its ripraping. Note ungrazed grass atop bank and dense woody vegetation on point-bar bank. In foreground (downstream part of bend) the point-bar bank bears flow and offers juxtaposition of current and dense hiding cover for trout. Most of the high bank has no vegetation at the water line where trout could hide in it, but a toppled juniper tree offers some excellent cover.

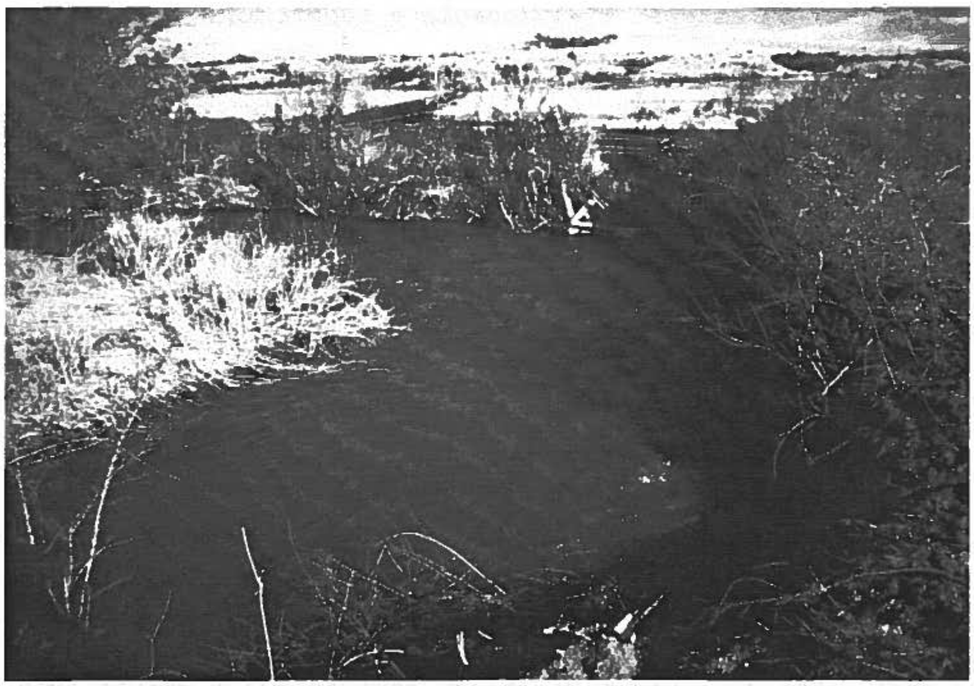

Figure 4. A well vegetated, outer, current-bearing bank, Deep Creek, April 1989--bend 1, near the study area's lower end. This was not an eroding bend, so was not a revetment (or control) site. In electrofishing of the whole study area, this bend always had a substantial trout population. The study area had few such well vegetated current-bearing banks, but many existed in adjacent creek sections up- and downstream. The land owner had excavated a patch of bank in the foreground shortly before the photo was taken.

Figure 5. A closer view of the dense woody vegetational cover in bend 1. The study team is measuring trout hiding cover and pool area.

The approximate mean trend of the creek was paralleled on both sides by fences that were about 90 m apart and in most places outside the riparian zone. At one bend, the channel had migrated to within two meters of the fence. Had the stream not become incised (probably due to beaver removal, past grazing, and other human influence), the riparian vegetational zone probably would have been much wider than the area bounded by the fences.

When we selected the study site, vegetation of the area between the fences appeared healthy relative to the region's usual heavily grazed streams The people involved the selection assumed it had not been grazed for many years. But in 1988, land owner Goodwin reported that it had been pastured until about 1983. Therefore, the riparian vegetation during the study probably represented an early stage in recovery from grazing. On parts of the stream above and below the study area, woody riparian vegetation is more lush.

The tops of most high, eroded banks were covered with orchard grass (*Dactylis glomerata*) and smooth brome (*Bromus inermus*). The inside (point-bar) banks usually were lower, had moister soils, and were thicketed with brush upslope from the point bar area of gravel or other sediment. Woody vegetation in the study area included willows (*Salix* sp.), dogwood (*Cornus stolonifera*), water birch (*Betula occidentallis*), common snowberry (*Symphoricarpos albus*) and black cottonwood (*Populus trichocarpa*).

The fishes included rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), mountain whitefish (*Prosopium williamsoni*), longnose dace (*Rhinichthys cataractae*) and sculpin (*Cottus* sp.).

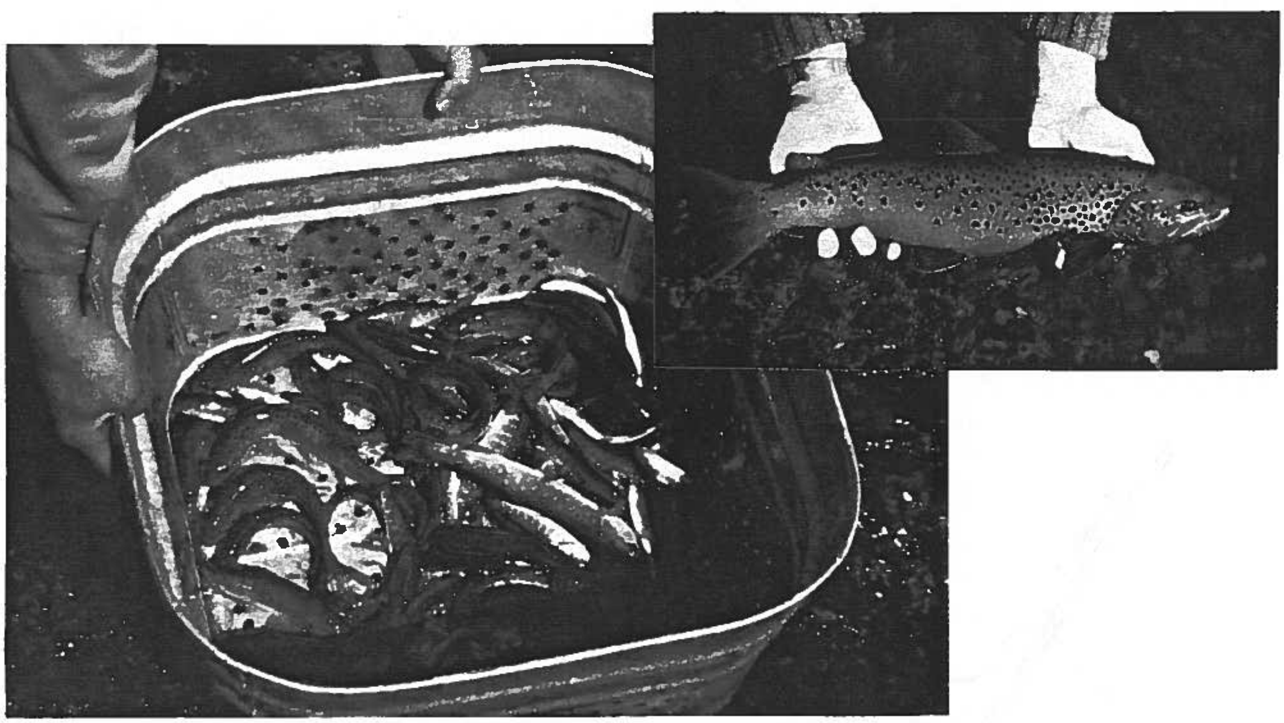

Figure 6. Trout captured by electrofishing, Deep Creek study area, October 1986--when the population was relatively high. All fish in the photos appear to be brown trout, but rainbow trout also occurred. The tub probably contains a catch from 300 meters.

METHODS

General Approach

We measured the centerline length of the channel and marked the study area off into 100-m reference stations, numbered from 0 at the lower end to 14 at the upper end. Each 100-m "station" segment was identified by the number of the marker at its upper end. We determined mean wetted width of each station by averaging waterline-to-waterline measurements made at 10-m intervals during "normal" streamflow discharge of about 285 L/s.

In August 1987, we identified and numbered the 25 definite channel bends of the study area. Of these, 18 had high, outer (current-bearing) banks, and we used these as test bends, selecting 6 of them to have their current-bearing banks revetted with juniper trees, 6 to be riprapped, and 6 to remain untreated as references or "controls" (Figure 7, Table 2). Selection was by use of a random-number table, except that we made the two upstream-most bends controls, so at least two would be unaffected by sediments that might flow from construction. We marked the up- and downstream limits of the erosional or current-bearing zone of each test bend with stakes, designated this as the "study bend," and measured its channel centerline length.

In April and May 1988, the riprap and juniper-tree revetment were installed on the banks of the designated bends. To monitor changes, we measured fish populations and physical characteristics of the 18 channel bends before and after treatment.

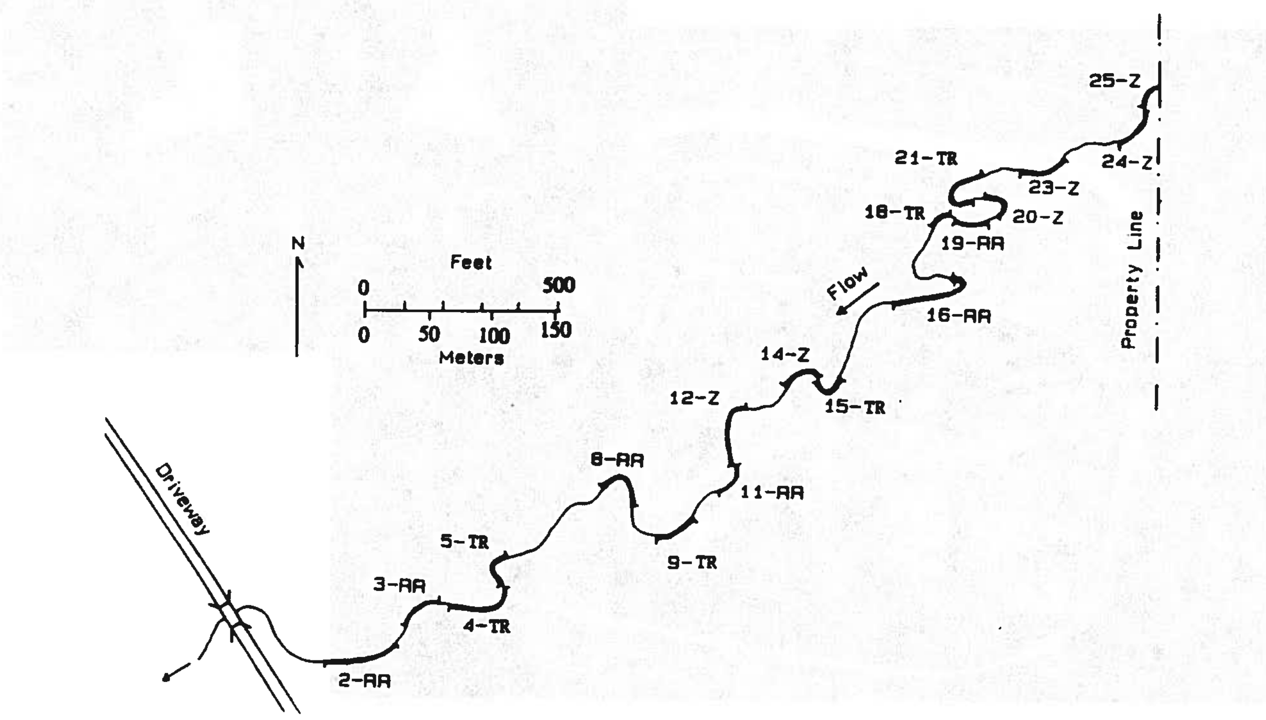

Figure 7. Deep Creek study area, numbers refer to stream bends studied RR = riprap, TR = tree revetment, Z = control.

Table 2. Treatments and lengths of study bends in the 1.4-km study area of Deep Creek, Montana, 1988. Refer to Figure 7 for locations.

Treatment	Bend no.	Length (m)	Treatment	Bend no.	Length (m)	Treatment	Bend no.	Length (m)
Tree revetment	4	60	Riprap	2	60	Control	12	68
	5	32		3	29		14	23
	9	28		8	50		20	20
	15	43		11	29		23	58
	18	14		16	46		24	29
	21	34		19	22		25	21
Totals		211			236			219

Construction of Revetments

Riprap

In April 1988, the current-bearing banks of bends 2, 3, 8, 11, 16, and 19 were riprapped with angular (blast-quarried) limestone from the Continental Lime Company quarry west of Townsend. The stone was selected in consultation with Dr. David W. Mogk, Montana State University Earth Sciences Department, an expert on suitability of rock for construction, including riprap. The limestone was of a hard, fine-grained structure, considered to have low water absorption, hence low risk of freeze-shattering.

The construction steps were: (1) uneven or overhanging parts of the bank were sloped back to about 1:1 to 1:1.5 grade; (2) rocks of about 1 m diameter were placed at the bank toe--as a foundation and to create cover for trout--; and (3) smaller rocks were laid along the bank above this foundation. The steps are illustrated in more detail in Appendix B. All work was done with a backhoe. We had intended not to back-slope the banks but to "tuck" the riprap up under overhangs, however, this proved impractical, not only because it was difficult, but because it would have resulted in too much channel constriction. Finished face slope was about 1:1 to 1:2, except the large rocks at the toe formed a much steeper (or overhanging) irregular face. Riprap was 1 m or more thick at the base, tapering to about 0.5 m thick near the bank top (Figures 8 and 9).

Although it is standard practice to key such riprap about one half meter into a "toe trench" that is dug into the stream bed, we got approval not to make such a trench from the Broadwater Conservation District, which administers stream alteration permits, and from its advisers in the USDA Soil Conservation Service. Instead, the large foundation rocks were laid directly on the stream bed, which was already well armored with large stones. The resulting, unkeyed structure was more likely to have overhanging rock elements that could provide cover for trout.

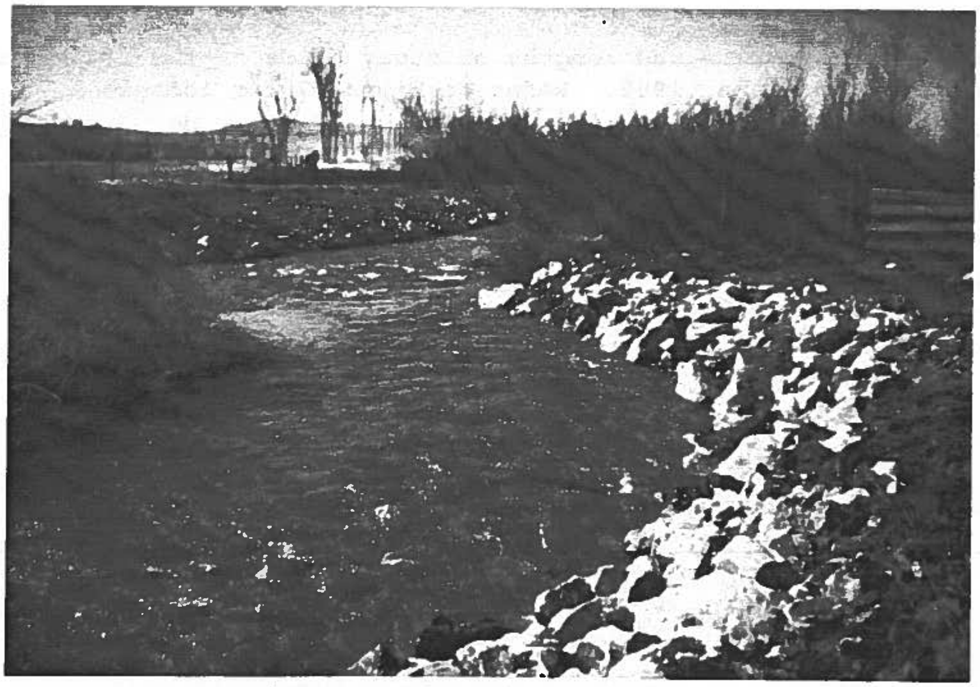

Figure 8. Two riprapped current-bearing banks--the view from study bend 3 downstream toward bend 2, just after construction, Deep Creek, April 1988.

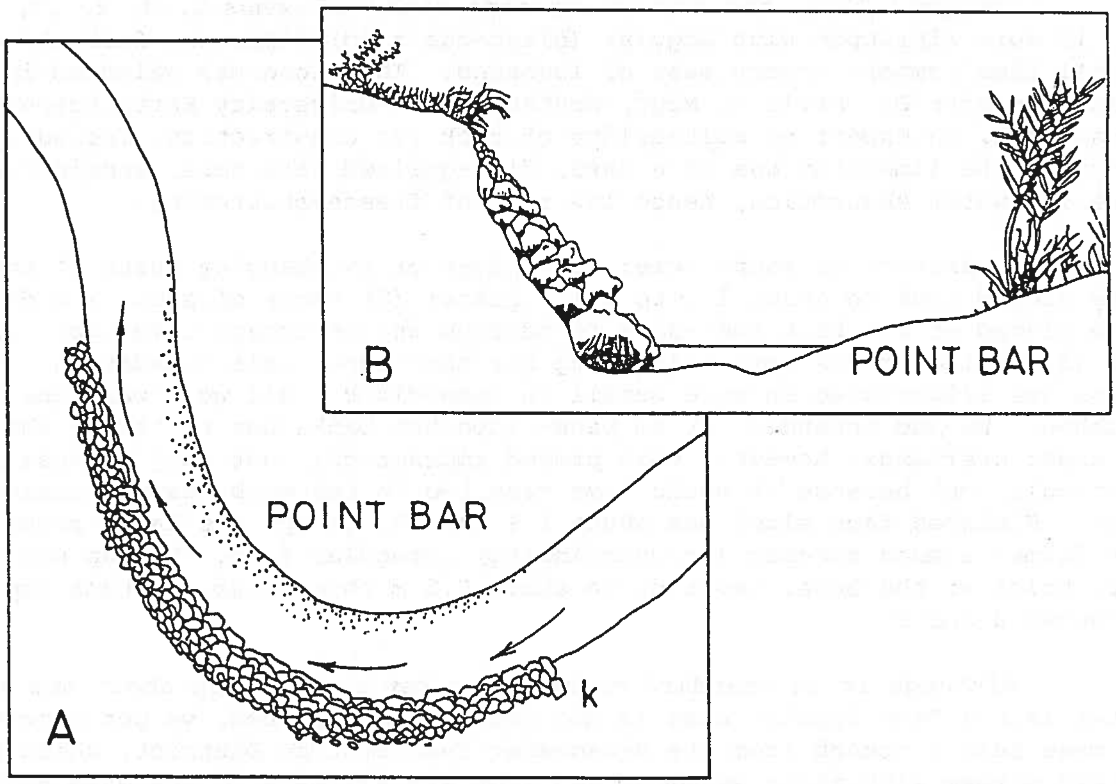

Figure 9. (A) Typical stream bend after installation of riprap. At upstream end of riprap (k), large rocks are key-trenched into the bank. (B) Cross section of riprap revetment with "foundation" rocks (typically greater than 1 m diameter) at base of the blanket. Typical talweg depth was 25-30 cm at "normal" low flow (285 L/s).

Tree Revetment

In April and May 1988, we used Rocky Mountain juniper trees (*Juniperus scopulorum*) to revet the current-bearing banks (Figure 10 of bends 4, 5, 9,

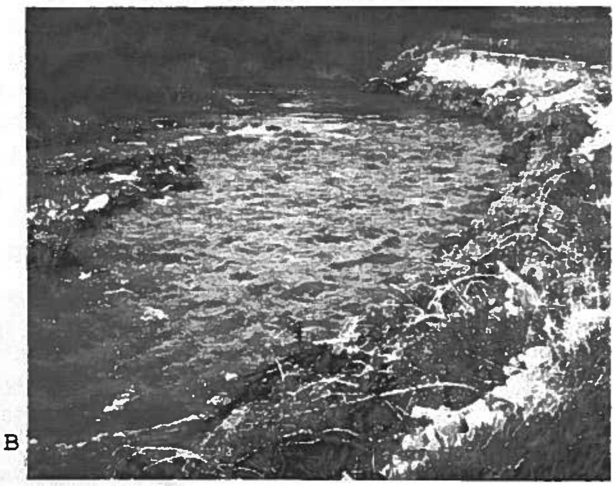

Figure 10. Study bend 4 (A) before and (B) after tree revetment.

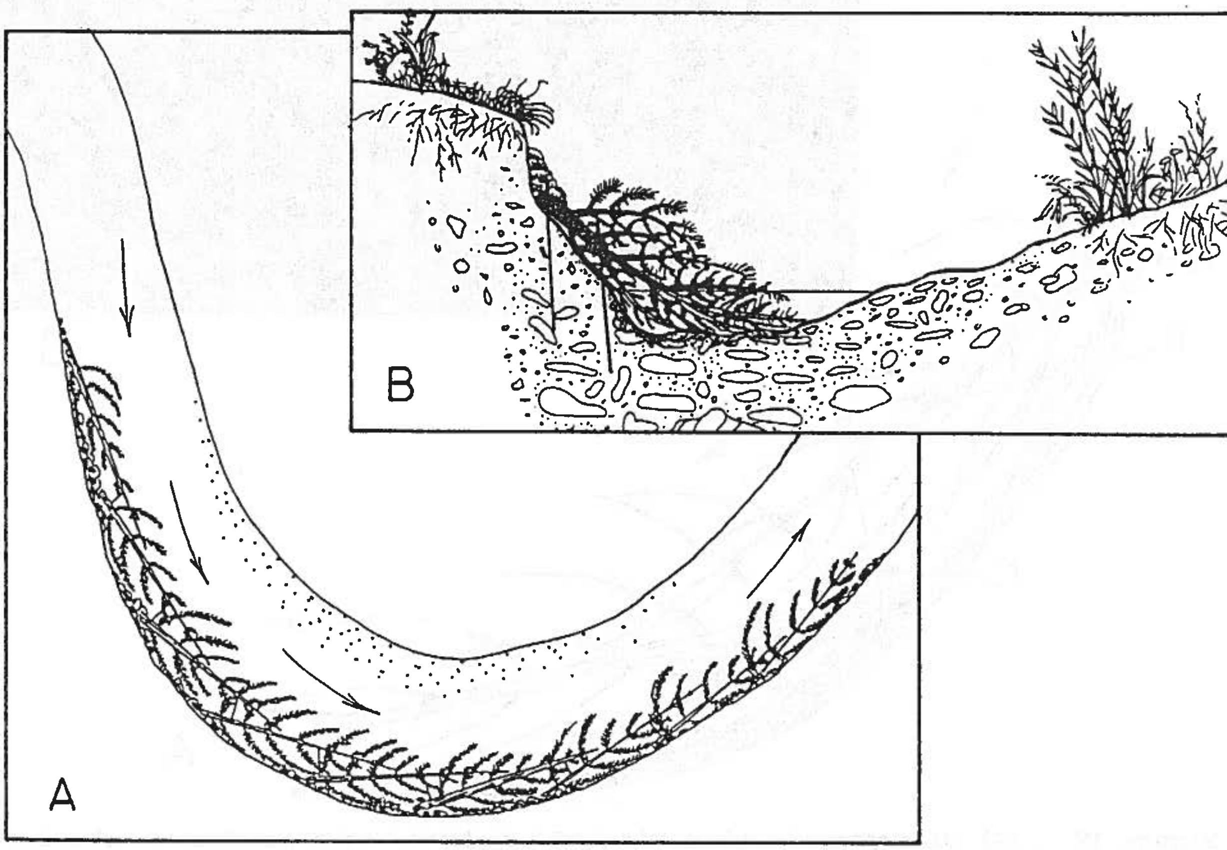

Figure 11. (A) Diagrammatic plan view of tree revetment. Branching and foliage of junipers used in Deep Creek were much denser than shown. (B) Cross section of tree revetment at very low flow. Note vertical steel rod anchors.

15, 18, and 21. The trees were 5 to 10 m long, and most were of 15 to 20 cm butt diameter. We laid the trees in a horizontally overlapped (1/3 to 1/2 of tree length), thatch-like manner, butt ends pointed upstream and somewhat upslope along the bank (Figures 11 and 12). We anchored the trees to the streambank and bed by drilling two 1.9 cm holes through each trunk, then driving steel reinforcement rods of 1.9 cm diameter (number-6 rebar) and about 1.5 m in length through the holes and into the bank with a pneumatic hammer until the amount of bar remaining above the trunk was about 20 cm, which was then bent over (clinched) at about a 90 degree angle (Figures 11B and 12). Some rock of about 10-20 cm was back-filled between the trees and bank as reinforcement. On bends 5 and 21, we installed two vertically overlapped tiers of trees, so as to protect a greater height of exposed bank and make a denser thatch for erosion control and trout cover. Construction steps are illustrated in more detail in Appendix C.

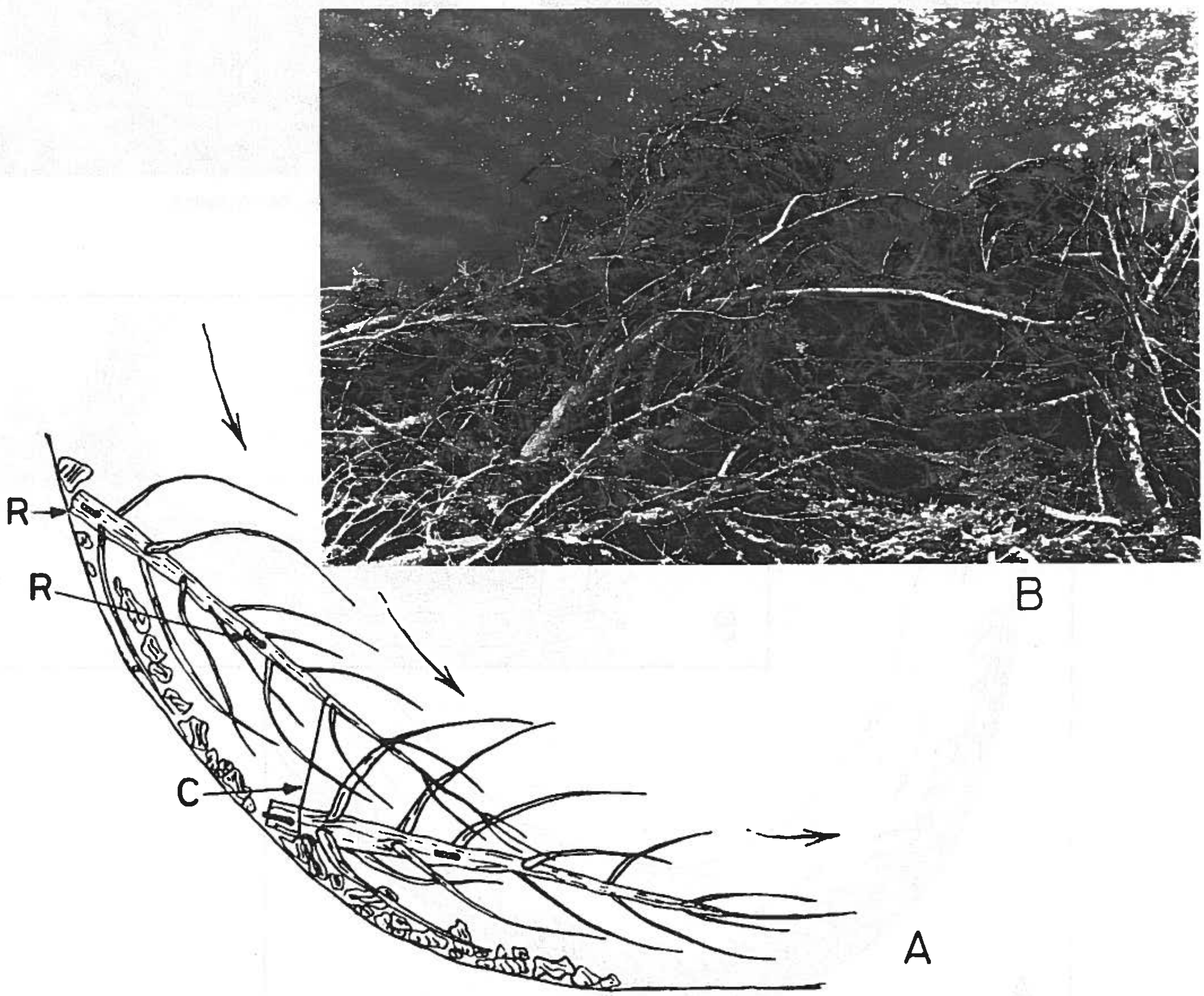

Figure 12. (A) Diagrammatic plan view of two trees in a revetment, showing overlap, rebar anchors (R), cabling (C), and rock backfill. (B) Close-up detail of juniper trees installed in revetment.

Measurement of Physical Characteristics

We measured physical characteristics along 11 or more cross sections (transverse transects) in each study bend during September 13 to November 8, 1987 and during July 2 to August 5, 1988. We chose cross section sites by dividing each bend's centerline length into 10 equal intervals and placing a transect at each division point.

To describe cross-sectional profiles of the channel bed and banks, we measured the horizontal locations and elevations of (1) the edges of permanent vegetation, which defined the "active channel width", (2) water lines (intersection of water surface with banks) which defined the "wetted width", (3) low point (talweg) of the bed, (4) toe of the current-bearing bank, (5) top of the high bank, (6) crest of the high bank, and (7) bank and channel-bed profile points at 0.5-m intervals from beyond both banks (Figure 8).

We surveyed elevations to the nearest 0.01 foot with a Lietz model C3E automatic-leveling level and stadia rod, then converted to meters. At each measurement point, the dominant streambed material was visually classified as soil, mud, sand, gravel, rubble, rock (boulder), or vegetation.

Thus, for most bends, there were 11 transects: one at each end and 9 interior transects. We marked the ends of transect lines with labeled stakes on each side of the channel. We stretched a measuring tape between the stakes to determine locations of measurement points. The network of transect end points was surveyed for elevation and horizontal position with an EDM transit under direction of D. A. Tyler, MSU Civil Engineering Department.

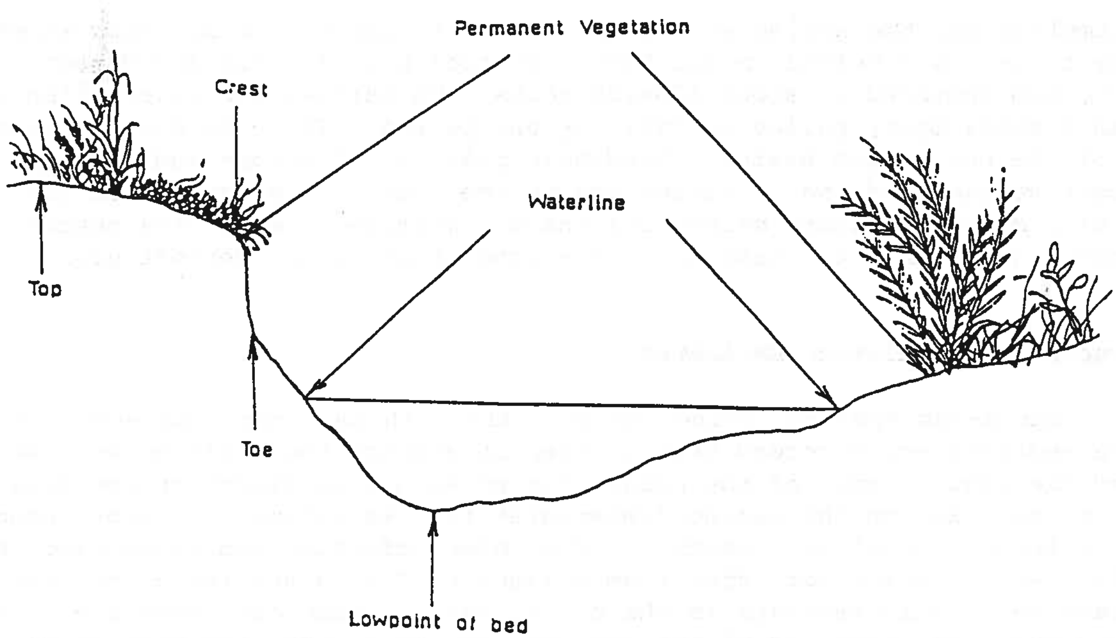

Figure 13. Transect features measured in study bends, Deep Creek, 1988.

We calculated the mean water depths and wetted channel widths that would have occurred 285 L/s discharge, using the Army Corps of Engineers HEC-II computer program. The HEC-II program predicts water surface elevations based on channel cross sectional profiles and discharge.

During streamflow discharge of about 285 L/s (10 cfs) on March 29, 1988, just before structure installation began, we measured hiding/security cover available for trout in each study bend. We made such measurements again about 6 months after treatment on November 12, when flow was about 300 L/s. We defined hiding/security cover as pools and as any object offering at least a 10-cm overhang, the overhang having water at least 15 cm deep beneath it and being either submerged or not higher than 50 cm above the water surface. We defined pools as parts of the stream where water was at least 40 cm deep and of slow velocity relative to areas immediately up-and downstream. We measured pool and other cover with a 2-m range pole, marked at 5-cm intervals.

We installed a porcelain staff gauge to record water level a station 0 and calibrated it by measuring discharge at different stages with a Montedoro-Whitney electromagnetic water velocity meter. We read the water stage on the days we visited the stream, and converted the readings to discharge.

Measurement of Trout Populations

We used two methods to inventory the trout populations. To inventory trout throughout the study area, we made mark-and-recapture (Petersen-type) population estimates in October 1986, June 1988, October 1988, April 1989, and October 1989. To inventory trout in each of the 18 study bends, we made multiple removal estimates (Zippin method) in March, June, and October 1988.

Sampling for the estimates was by electrofishing with a 220-volt alternator, rectified by a Coffelt model VVP-15 control unit to unpulsed direct current, and operated at about 175-200 volts. We carried the electrofishing gear in a small boat, pulled upstream by one person. Two crew members waded ahead of the boat, each having a hand-held positive electrode and a handnet. The negative electrode was attached behind the boat. We anesthetized captured trout with MS-222 (tricane methanesulfonate), measured them to the nearest millimeter (maximum total length), and weighed them to the nearest gram.

Mark-recapture Population Estimates

In double-run electrofishing, we kept the fish captured from each 100-m station separate and recorded data on them by station the field notes. We clipped the lower corner of the caudal fin of each fish caught on the first (marking) run, and on the second (recapture) run, we clipped the upper caudal corner clipped of each fish caught. After electrofishing and processing, the fish from each station (or often from a group of 2 or 3 stations--the fish from each being held separate in the boat), were carried back downstream and released near the lower end of the station from which they had been caught. This allowed them to use their sense of smell in finding their way upstream into home territories. To let the fish to recover from the fatigue of being electroshocked, captured, and handled, there was an interval of at least two days between the marking run and the recapture run.

To calculate estimates of trout populations, we stratified the data by species and length class, and within each class we applied the Chapman modification of the Petersen formula (Ricker 1975):

$$N = \frac{(M+1)\ (R+U+1)}{(R+1)} - 1$$

where N is the population estimate, M is the number of fish marked on the first run, R is the number of marked fish recaptured on the second run, and U is the number of unmarked fish captured on the second run.

We chose length classes so as to maintain similarity of recapture rates (R/M) within class. We reapportioned the estimate for each length class into one-centimeter groups, according to the distribution of M+U among centimeter groups. M+U is the total of initial captures of fish during the electrofishing. For the mark-recapture estimates, we calculated 95% confidence intervals according to Ricker (1975).

We calculated biomass by multiplying the estimated number of fish in each centimeter group by mean body weight of fish in that group, as determined graphically from the length-weight relationship of M and U fish. We summed the biomasses of the centimeter groups to obtain population biomass.

Multiple-removal Population Estimates

In Zippin-method population estimates, we made removals by 3- and 4-pass electrofishing, while the upper end of each stream bend was blocked with a net. Fish caught on each pass were measured as previously described, then held in separate nets until the last pass was completed. We made each pass immediately after the one preceding it. After measuring lengths and weighing the fish from all passes through a bend, we released them near the lower end of the bend.

We calculated Zippin population estimates as N = T/Q-hat, where N = population estimate; T = number of fish captured; and Q-hat = estimated proportion of population captured during all the removal runs. We calculated Q-hat, the population estimate, and confidence intervals using the FPSP-A1 computer program described in Platts et al. (1983).

Statistical Analyses

We made statistical analyses with programs from MSUSTAT (Lund 1987) under direction of M. A. Hamilton, MSU Department of Mathematical Sciences. We used paired-T tests to compare pre- and postconstruction water depths, channel widths, and trout abundance in the study bends. One-way ANOVA was used to (1) test for differences between treatments in amount of change in mean widths, mean depths, and cover after construction of revetments; (2) compare mean stock densities and standing crops of trout between the treated and control bends; and (3) compare differences between treatment changes in stock densities and standing crops before and after construction of revetments.

RESULTS AND DISCUSSION

Streamflow Discharge

Drought and severe summer low flows prevailed during the study. In 1987, precipitation in the Townsend, Montana, area was 74% of the long-term average, and in 1988, it was only 55% of average (NOAA 1988). In Deep Creek, irrigation diversion exacerbated low natural discharge. As a result, flow fell to near zero in summer 1987 and surface flow in the study area completely halted for 2 1/2 months in summer 1988 (Figure 14). The 1988 dewatering disrupted or partially invalidated various aspects of the study, particularly trout population assessments.

In summer 1988, the drought in Montana reached its extreme, and parts of many streams went dry, particularly reaches below irrigation diversions. This happened in Deep Creek. Flow stopped in the study area on August 3, 1988, and probably did not resume for over 74 days. We observed no flow, but only some shallow, isolated pools in the channel during various visits to the stream during that period. On October 16 there was no flow, but on October 19, apparently after irrigation withdrawal had ceased or been reduced, flow was 230 L/s. Conditions and consequences of the dewatering are further described in this report's section on trout populations.

After start of the study in 1986, the occupant of the property, Mr. Spazierath, reported that the stream had "almost dried up" a summer or two before that. From his report and our experience during the worsened drought that followed, it can be surmised that the trout population of the study area undergoes occasional, perhaps frequent, reduction due to extreme low flow. Perhaps the trout population existing there at most times represents some stage of rebuilding after a recent severe setback.

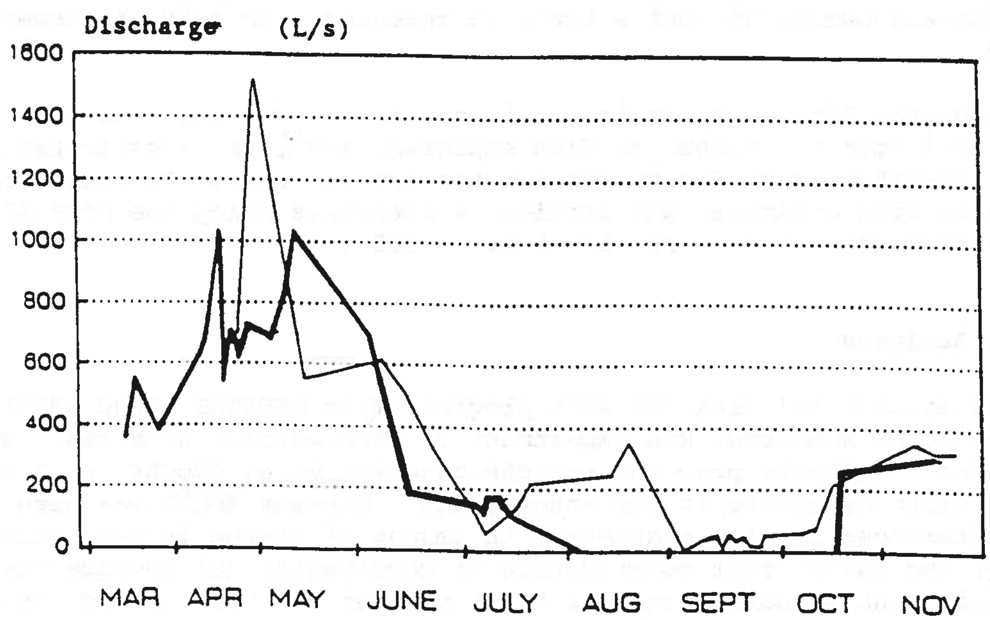

Figure 14. **Streamflow discharge of Deep Creek, Montana, measured at the downstream end of the study area during 1987 (——) and 1988 (━━).**

Physical Changes in Study Bends

Cover

Tree revetment immediately increased hiding cover for trout, but in riprapped and control bends, there was slight decrease (Figures 15A and 16). As measured in November 1988, about 6 months after installation, the mean overhead (non-pool) cover density (square meters of cover per meter of channel) of tree-revetted bends had increased 195% ($p = 0.02$) to 1.24 m2/m from a March pre-treatment mean of 0.42 m2/m (Figure 16, Appendix D Table 11); in the 6 bends, the changes were all positive and ranged from 62% to 2075%. As expected, the branches and foliage of the juniper trees in revetment simulated submerged streamside brush and created large amounts of overhead cover.

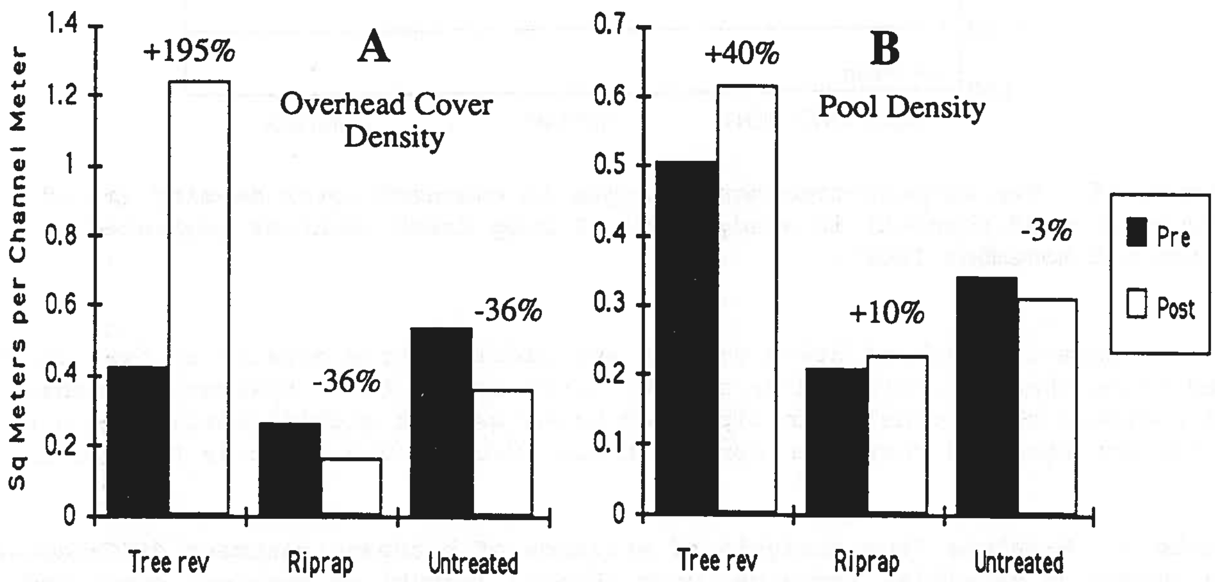

Figure 15. Means of overhead cover (A) and pool (B) density (m^2 per channel meter) in tree-revetted, riprapped and untreated stream bends during March (about one month pre-treatment) and November (about 6 months post-treatment), Deep Creek, Montana, 1988. Mean percent change shown above each pair of columns. The number of bends in each treatment was 6. For measurement ranges, see Figures 16 and 17 and Appendix D Tables 11 and 12.

In riprapped bends, on the other hand, despite efforts to position rock so as to create overhead cover, its density, on average, decreased 36% ($p = 0.08$) from the 0.25-m2/m pre-treatment mean to 0.17 m2/m (Figures 15A and 16, Appendix D Table 11). In individual riprapped bends, proportional changes in cover density ranged from 88% decrease to 72% increase (Appendix D Table 11).

In untreated bends, overhead cover density did not change significantly ($p = 0.41$). Means were 0.53 m2/m in March 1988 and 0.34 m2/m in November, an average decrease of 36%, but the variation of change among the 6 bends (Figure 11) prevents considering the mean change significant; the proportional changes ranged from 68% decrease to 100% increase (Appendix D Table 11).

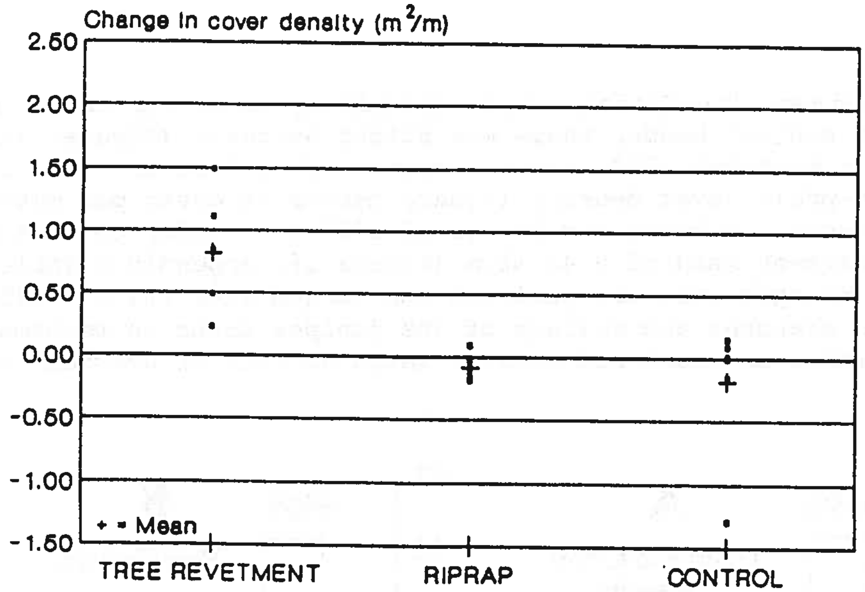

Figure 16. Pre-to-post-treatment changes in overhead cover density (m2 of cover per m of channel) in study bends of Deep Creek, Montana (measured in March and November 1988).

Change in overhead cover density was significantly greater in tree revetted bends than in riprapped or control bends ($p < 0.01$). However, the change of overhead cover density in riprapped bends was not significantly ($p = 0.63$) different than the change in control bends (Table 3 and Appendix D Table 11).

Table 3. P-values from analysis of variance of between-treatment differences in change of densities (area per unit channel length) of overhead cover and pools in study bends of Deep Creek, Montana, measured in March, 1988, which was just before construction of streambank revetments, and the next November, about 6 months after construction.

Comparison	Overhead cover density	Pool density	Combined density, overhead cover & pool
Tree revetment vs. riprap	<0.01	0.21	<0.01
Tree revetment vs. control	<0.01	0.71	0.58
Riprap vs. control	0.63	0.16	<0.01

Pools

In tree-revetted bends, mean density of pools (m^2 of pool per channel meter), measured in November 1988, had increased 40% ($p = 0.11$) to 0.60 m^2/m from the March pre-treatment mean of 0.43 m^2/m (Figures 15B and 17, Appendix D

Table 12). Among the 6 tree-revetted bends, the changes in pool density ranged from -16% to +1500% (Appendix D Table 12).

In riprapped bends, mean density of pools stayed essentially unchanged between the March 1988 pre-treatment measurement of 0.21 m^2/m and the November post-treatment measurement of 0.23 m^2/m. Mean change was only 10% and not statistically significant ($p = 0.66$). Proportional changes ranged from 100% decrease to 185% increase (Appendix D Table 12).

In control bends, pool density also stayed about the same: a nonsignificant ($p = 0.96$) mean decrease of 3% between March and November 1988, and proportional changes ranged from 50% decrease to 500% increase (Figures 15B and 17, Appendix D Table 12).

Change in pool density was not significantly different (95% C.L.) between treatments or between the treatments and the control (Table 3 and Appendix D Table 12).

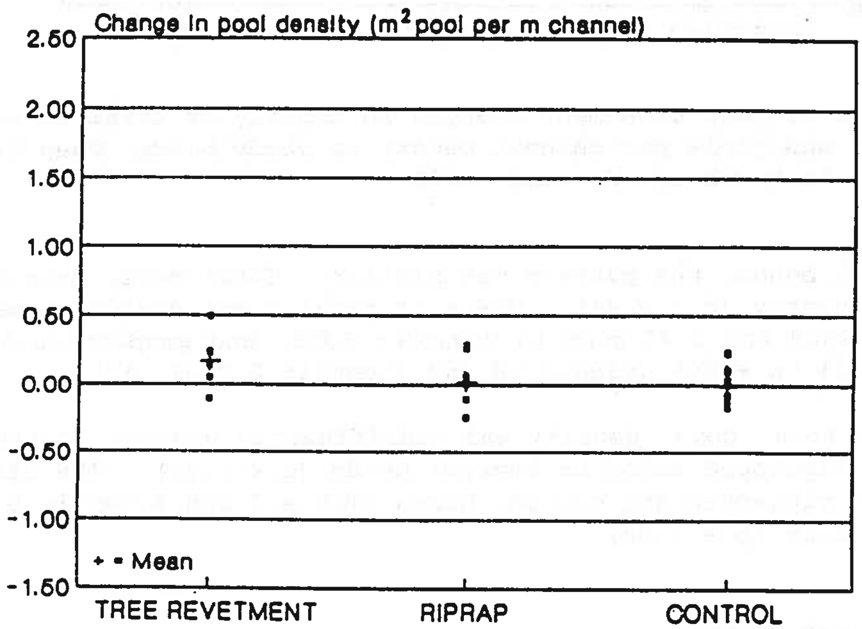

Figure 17. Pre-to-post-treatment changes in pool density (m^2 of pool per channel meter) in study bends of Deep Creek, Montana, measured in March and November 1988.

Total Cover (Overhead Cover and Pools, Combined)

When, in addition to overhead cover, we included pools as cover in tree-revetted bends, the results resembled the changes in overhead cover alone: a significant increase ($p = 0.01$) from the March estimate of 0.76 m^2/m to the November estimate of 1.71 m^2/m, and average increase of 0.95 m^2/m or 125% (Figure 18 and Appendix D Table 13). In riprapped bends, total cover density changed little ($p = 0.70$). Means decreased 16% from a pre-treatment value of 0.51 m^2/m to 0.39 m^2/m at 6 months post-treatment, and proportional change ranged from -85% to +61% (Figure 18 and Appendix D Table 13).

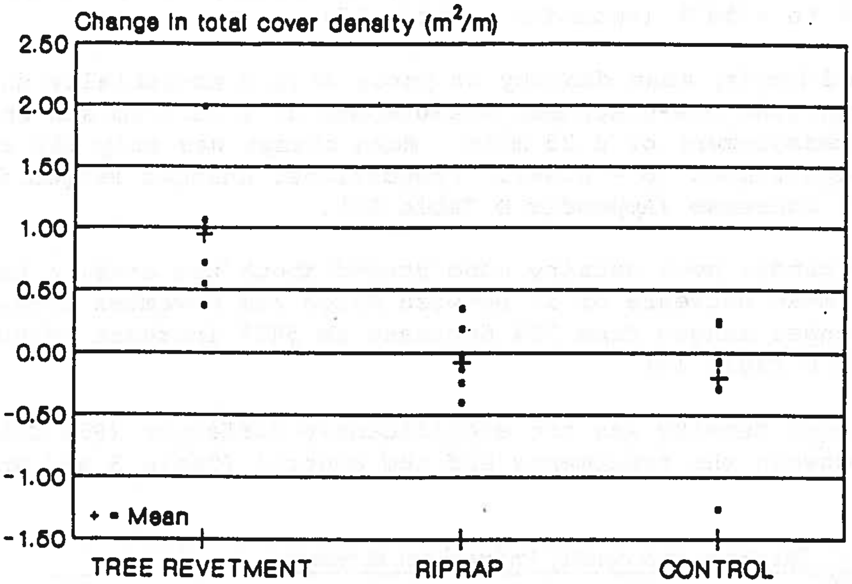

Figure 18. Pre-to-post-treatment changes in density of total cover (m^2 of overhead cover and pools per channel meter) in study bends, Deep Creek, Montana, measured in March and November 1988.

In control bends, the pattern was similar. Total cover density did not change significantly ($p = 0.41$). Means of total cover densities were 0.93 m^2/m in March 1988 and 0.73 m^2/m in November 1988, and proportional change ranged from -67% to +109% (Figure 18 and Appendix D Table 13).

Change in total cover density was significantly greater in tree revetted bends than in riprapped bends or control bends ($p < 0.01$). The difference of change between riprapped and control bends (Table 3 and Appendix D Table 13) was nonsignificant ($p = 0.58$).

Channel Width and Depth

The revetment caused little if any change in channel width. Calculated at streamflow discharge of 285 L/s (10 cfs), there was no significant pre-to-post construction mean change in wetted width for tree-revetted ($p = 0.59$) or control ($p = 0.40$) bends, and for riprapped bends, the apparent 10% decrease ($p = 0.14$) in width could only be considered significant at the 85% confidence level. Between-treatment differences in amounts of change could only be considered significant at about the 90% confidence level for tree revetment vs. riprap bends ($p = 0.09$) and for riprap vs. control bends ($p = 0.08$). For tree revetment vs. controls ($p = 0.96$), the difference in amount of change was insignificant (Figure 19 and Appendix D Table 14).

No significant difference in mean depth, calculated at 285 L/s, occurred between pre-and-post-construction in either the treated bends or the controls (tree revetment $p = 0.66$, riprap $p = 0.14$, control $p = 0.45$). Also, there were no significant differences in change between the treatments ($p = 0.77$

between tree and riprap, p = 0.21 between riprap and control, p = 0.57 between cable tree and control)--Figure 20 and Appendix D Table 14).

Rock revetments should deepen and narrow the channel by retarding lateral scour and promoting downcutting of the bed (British Columbia Ministry of Environment 1980). Tree revetments should do likewise. The spring runoff of 1988 was probably abnormally weak and did not provide the erosive power to scour the channel deeper, but this may occur over time.

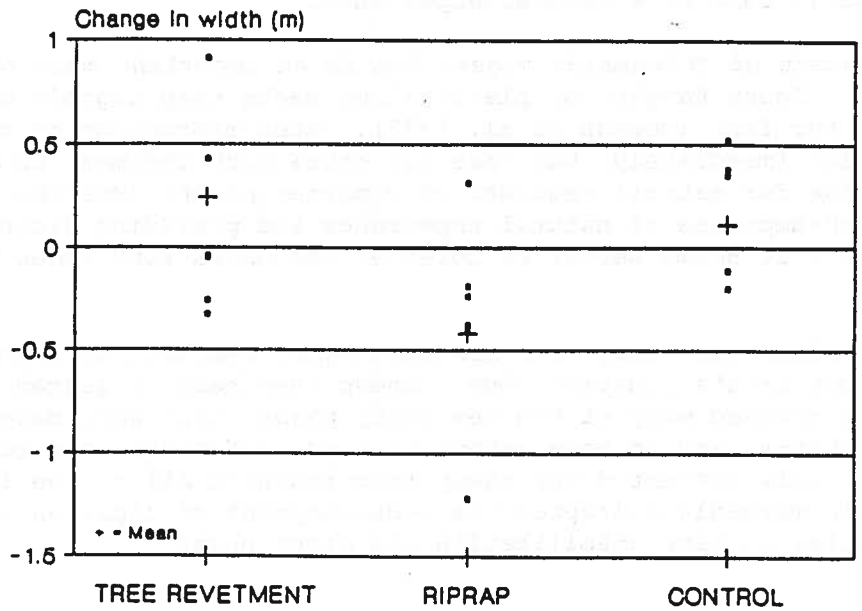

Figure 19. Pre-to-post-construction changes in mean wetted <u>channel widths</u> in study bends at a calculated discharge of 285 L/s, Deep Creek, Montana.

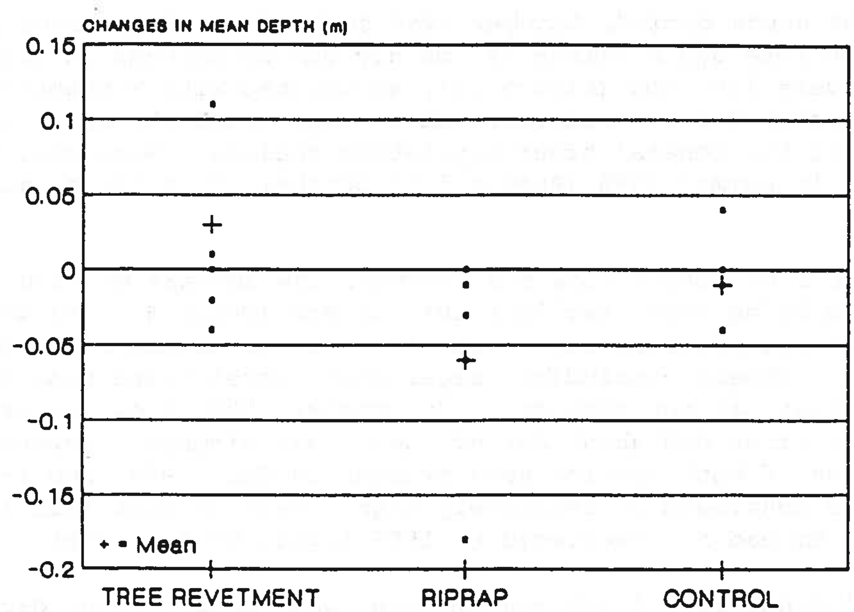

Figure 20. Pre-to-post-construction changes in mean <u>talweg water depths</u> in study bends at a calculated discharge of 285 L/s, Deep Creek, Montana.

Further Aspects of the Revetted Banks

During high flows or flows that are receding from highs, the space between a tree revetment and the bank it lines is protected from swift current, and stream-borne sediment can deposit there. It is also a trough that, at lower flow, catches soil sloughed from the bank. In less than a year, willows and other riparian vegetation sprouted in the resulting soil beds behind the study area's tree revetments. As vegetation colonizes the area behind the revetment, and as the juniper trees decompose, the banks revetted with trees should eventually take on a natural appearance.

Establishment of streamside vegetation is an important mode of bank stabilization. Dense tangles of plants along banks trap organic debris and provide cover for fish (Meehan et al. 1977). Rock riprapping of bends solve erosion problems immediately, but does not cause much sediment to accumulate so as to provide for natural regrowth of riparian plants (McBride and Strahan 1983). From standpoints of natural appearance and providing hiding/security cover for trout, it seems better to revet stream banks with trees than with rock.

In 1990, after the study, the new land owner resumed pasturing of the Deep Creek study area's riparian zone. Sheep then heavily grazed the streambank grass and browsed many of the new woody plants that were developing. On tree-revetted banks, and to some extent on riprapped banks, the revetment materials obviously prevented the sheep from reaching all of the live plants, but the animals markedly disrupted the redevelopment of riparian vegetation and its potential as bank stabilization and trout cover.

Trout Abundance

General Trends

During the study period, October 1986 to October 1989, trout abundance decreased, then rose again (Table 4), mainly due to changes in streamflow discharge. Severe low flow (Figure 14), associated with Montana's ongoing drought and exacerbated by irrigation diversions above the study area, undoubtedly caused the general trout population decline. Moreover, the over-74-day dewatering in summer 1988 (August 3 to October 17 or 18) eliminated almost all fish.

In October 1988, after flow had resumed, low numbers of trout existed, small-size ones being more prevalent than before (Table 4). As we observed during the dewatered period, some under-10-cm trout survived in shallow, isolated pools. Others, including larger fish, recolonized from other parts of the stream that had not gone dry. In October 1988, brown trout had about 18% and rainbow trout had about 25% of their 1986 biomass. However, many more under-10-cm fish of both species were present in fall 1988, and the numbers in this size class continued at relatively high levels through fall 1989. Trout larger than 20 cm had not recovered to 1986 levels by fall 1989.

Numerical densities of over-20-cm brown and rainbow trout decreased about 80% from October 1986 to April 1989 and were still about this low in October 1989, although biomass had increased markedly (Table 4). Similarly, in the

1970s, summer low flows, exacerbated by irrigation withdrawals, negatively affected age-II-and-older rainbow trout and age-III-and-older brown trout in the West Gallatin River, Montana (Vincent and Nelson 1978). And in the upper Beaverhead River, Montana, age-III-and-older rainbow trout declined in abundance when subjected to flow reductions, whereas age-II-and-younger brown and rainbow trout were less affected (Nelson 1978).

The relatively high fall 1986 population of over-20-cm brown trout may have been due in part to spawning immigration. Although gravel in the study area appeared to us as of only mediocre suitability for trout spawning, gravels may have been even worse in nearby parts of the creek. Author McClure saw many more redds and paired fish in fall 1986 than in fall 1988.

By the end of the study in fall 1989, small rainbow trout had become far more numerous than small brown trout. The one over-400-mm (actually 502 mm) rainbow trout caught during April 1989 electrofishing (Table 4) was a ripe female having the silver hue that is characteristic of lake-dwelling rainbow trout. This fish probably came from Canyon Ferry Reservoir, and the large numbers of young rainbow trout probably indicates that this part of Deep Creek is a rearing area for that reservoir's rainbow trout population.

Table 4. Numerical and biomass densities of trout in the 1.4-km study area of Deep Creek, Montana, October 1986 through October 1989.

		Lineal numerical density (fish/km)					Lineal biomass density (g/m)				
Trout species	Size class (mm)	Oct 1986	Jun 1988	Oct 1988	Apr 1989	Oct 1989	Oct 1986	Jun 1988	Oct 1988	Apr 1989	Oct 1989
Brown	< 100	1	38	186	139	57	0.004	0.07	0.60	0.65	0.39
	100-199	44	123	49	85	53	2.43	3.93	2.16	1.27	1.84
	200-299	58	8	7	16	16	7.23	1.93	0.90	1.23	3.18
	300-399	35	12	5	3	6	12.20	4.52	1.74	0.81	2.84
	≥ 400	8			1	3	7.63			0.47	2.93
	Total	146	181	247	244	135	29.49	9.85	5.40	4.45	11.13
Rainbow	< 100	13	3	108	269	413	0.03	0.006	0.33	1.52	1.99
	100-199	62	253	44	54	77	3.19	7.16	1.33	1.44	2.23
	200-299	41	8	5	8	6	5.14	1.48	0.64	0.61	0.67
	300-399	4	2	1	1		0.95	0.68	0.18	0.33	
	≥ 400	1			1		0.43			0.86	
	Total	121	266	158	333	496	9.74	9.32	2.48	4.76	4.89
Total trout		267	447	405	577	631	39.24	19.17	7.88	9.21	16.02

Observations and Analyses from the Summer 1988 Dewatering

In the late afternoon and evening of 3 August 1988, the day when flow stopped, apparently for the first time that summer, author White found the study area dewatered (Figure 21) from its lower end up to between station markers 11 and 12, where flow resumed, but only to an amount (in the rest of the study area) that was far less than he had seen in the creek before. He estimated flow at 0.1 to 0.5 cfs in various areas upstream from station 12. In the downstream, dewatered part of the stream on that occasion, residual pools, wet streambed, and moist algal mats indicated recent flow, and in the station 11-12 zone of transition to flow, he observed flow diminution in progress--the visible upstream retreat of the trickle. He saw trout of about 15-30 cm in thermal or oxygen distress in isolated residual pools. Some of these fish were gulping at the water surface. He also found a mink dragging an over-30-cm brown trout away from one such pool.

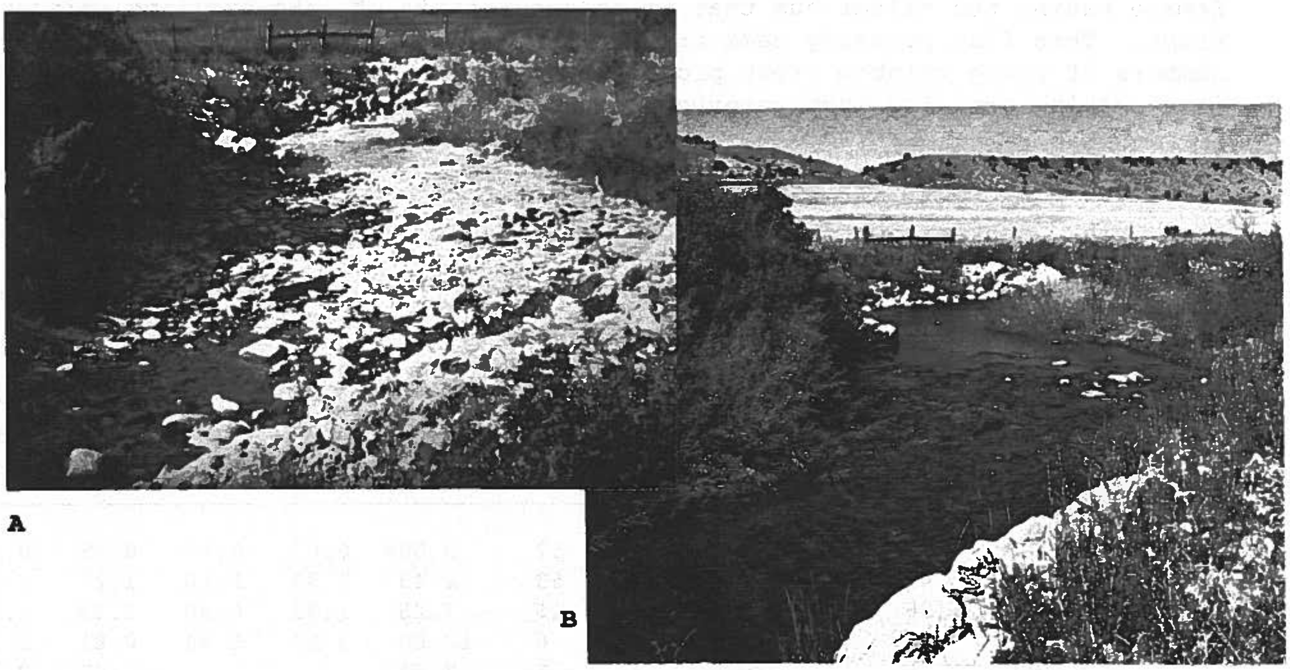

Figure 21. (A) The afternoon that flow stopped in the study area: study bends 2 (foreground) and 3, about 5 p.m. (Mountain Daylight-saving Time), August 3, 1988. Note residual pools in the fore- and middleground. The pool in the foreground apparently persisted (though at further reduced size) throughout the dewatered period, receiving an obvious trickle of groundwater at its upper end, and harboring a group of small (fingerling) trout. (B) For comparison, about the same view in September 1989.

During the dewatered period, we observed no trout larger than about 10 cm but saw some smaller trout in shallow, isolated pools, most of which were devoid of hiding cover other than streambed stones and crevices between them; the waterline had retreated from most other cover, such as streambank vegetation and the revetments we had installed. Author McClure saw belted kingfisher (*Ceryle torquata*) and great blue heron (*Ardea herodias*) fishing and inhabiting the study area. Apparently many small trout survived or quickly moved in from other parts of the stream.

After the 1988 dewatering, small trout of both species suddenly were much more abundant than they had been before (Table 4). The 10-cm-and-under trout in the fall 1988 population were age 0 (the 1988 year class--which would not have shown up in the June 1988 estimate because they were then too small to be caught by electrofishing). The relatively high population of age 0 in fall, just after the dewatering ended, may have been due to a faster recolonization rate than that of large trout, or due to the very scarcity of large trout, which may ordinarily compete with or prey on the small trout.

During the dewatered period, we still observed substantial flow in the channel above the irrigation diversion, which was somewhat more than a kilometer upstream from the study area. Some of the study area's trout may have escaped into that area or downstream into an area of flow resumption. Clothier (1953) found that trout in irrigation ditches of the West Gallatin River, Montana, moved upstream when flows were reduced in the ditches. In Blacktail Creek, Montana, 90% reduction in stream flow resulted in about a 75% decrease in numerical density of brook trout and caused the fish to move upstream, and when flows were reduced by 75%, brook trout densities in runs decreased by 20%, representing a shift to pools (Kraft 1968, 1972). Thurow (1988) observed declines of rainbow trout populations in the Big Wood River, Idaho, due to dewatering.

Trout Abundance in Treatment Areas

CAUTION: The results of this part of the study should be regarded as very preliminary. To respond fully to habitat manipulations, the trout population, which reproduces only once a year, needs several more years more than we have monitored it--and the possible trout response was at first disrupted by the dewatering. At this point, the results may tell us more about how dewatering and initial flow resumption affect trout than about how revetments affect them. Especially in the trout population aspects, the study should be regarded as a pre-response phase of what should be a much longer study.

We detected few statistically significant **within**-treatment time trends in trout abundance in the first 5 post-treatment months, but significant **between**-treatment differences developed. Five months after construction, riprapped bends, on average, had less trout than control bends--and harbored less small-sized trout than either control or tree-revetted bends (Tables 5, 6 and 7).

With regard to the few significant time trends, biomass of small trout declined significantly at first in all treatments, perhaps due to construction activity, then more or less recovered, and in riprapped bends, the total population declined numerically at first and was perhaps less depressed 5 months later (Tables 5 and 6). What might be viewed as a recovery from the initial postconstruction low abundance of June, really represents a rapid recolonization rebound from a far lower abundance during the dewatered period that had ended only a few days before the October population inventory.

In terms of total trout biomass, none of the treatments (tree revetment, riprap or control) differed significantly, on average, from the March 1988 preconstruction level in either June, about a month after construction, or October 1988, about 5 months after construction (Table 5). Some individual bends underwent marked pre-to-post-construction change in biomass, but large variation of results between the 6 bends within each treatment (Figures 26 and 27, and see standard deviations in Table 5 and Figure 22B) rendered the mean changes nonsignificant.

Table 5. Within-treatment means of numerical and biomass densities of <u>all trout</u> before (March) and after (June and October) construction of bank revetments in Deep Creek, Montana, 1988. Standard deviations are in parentheses; p-values are from paired T-tests, those of 0.20 or lower shown in bold.

		Numerical density				Biomass density			
		Fish per stream meter	Change from March 1988			Grams per stream meter	Change from March 1988		
1988 month	Treat- ment*		Fish/m	%	P		G/m	%	P
March	TR	0.24 (0.19)				4.35 (3.49)			
	RR	0.24 (0.10)				6.84 (6.15)			
	Z	0.26 (0.16)				6.93 (7.39)			
June	TR	0.16 (0.12)	-0.08	-33	0.45	4.61 (5.78)	+0.26	+6	0.91
	RR	0.15 (0.11)	-0.09	-38	**0.03**	5.41 (2.59)	-1.43	-21	0.61
	Z	0.15 (0.09)	-0.11	-42	0.25	2.62 (1.24)	-4.31	-62	0.25
October	TR	0.26 (0.20)	+0.02	+8	0.88	3.77 (3.44)	-0.58	-13	0.57
	RR	0.13 (0.13)	-0.11	-46	0.23	3.24 (1.99)	-3.60	-53	0.23
	Z	0.30 (0.17)	+0.04	+15	0.78	9.27 (10.12)	+2.34	+34	0.50

* TR = tree revetment, RR = riprap, Z = control.

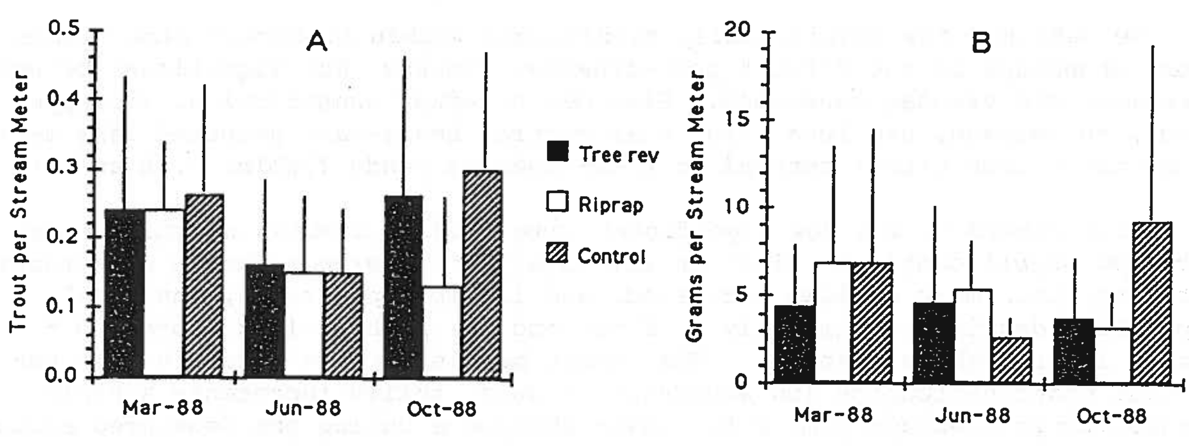

Figure 22. Mean numerical densities (A) and biomass densities (B) of trout (all species and sizes, combined) in study bends receiving different treatments before (March), about a month after (June), and about 5 months after (October) construction of tree revetment and riprap in study bends, Deep Creek, Montana, 1988. N for all treatments = 6; standard deviations indicated by vertical lines.

Biomass of small trout, e.g., those less than about 10 cm long, decreased significantly just after construction, and (despite intervening dewatering) recovered to preconstruction levels by October (Table 6, Figure 23B). This occurred in all treatment types.

Table 6. Within-treatment means of numerical and biomass densities of 10-cm-and smaller trout before (March) and after (June and October) construction of bank revetments in Deep Creek, Montana, 1988. Standard deviations are in parentheses; p-values are from paired T-tests, those of 0.20 or lower shown in bold.

		Numerical density				Biomass density			
1988 month	Treat-ment*	Fish per stream meter	Change from March 1988 Fish/m	%	P	Grams per stream meter	Change from March 1988 G/m	%	P
March	TR	0.16 (0.13)				0.83 (0.67)			
	RR	0.13 (0.07)				0.72 (0.47)			
	Z	0.17 (0.10)				0.87 (0.49)			
June	TR	0.08 (0.12)	-0.08	-50	0.42	0.14 (0.20)	-0.69	-83	0.07
	RR	0.01 (0.01)	-0.12	-92	0.01	0.02 (0.03)	-0.70	-97	0.02
	Z	0.05 (0.05)	-0.12	-71	0.69	0.10 (0.10)	-0.77	-88	0.02
October	TR	0.18 (0.16)	+0.02	+13	0.79	1.21 (1.01)	+0.38	+46	0.56
	RR	0.09 (0.12)	-0.04	-31	0.67	0.47 (0.49)	-0.25	-35	0.55
	Z	0.19 (0.14)	+0.02	+12	0.81	1.25 (0.93)	+0.38	+44	0.48

* TR = tree revetment, RR = riprap, Z = control.

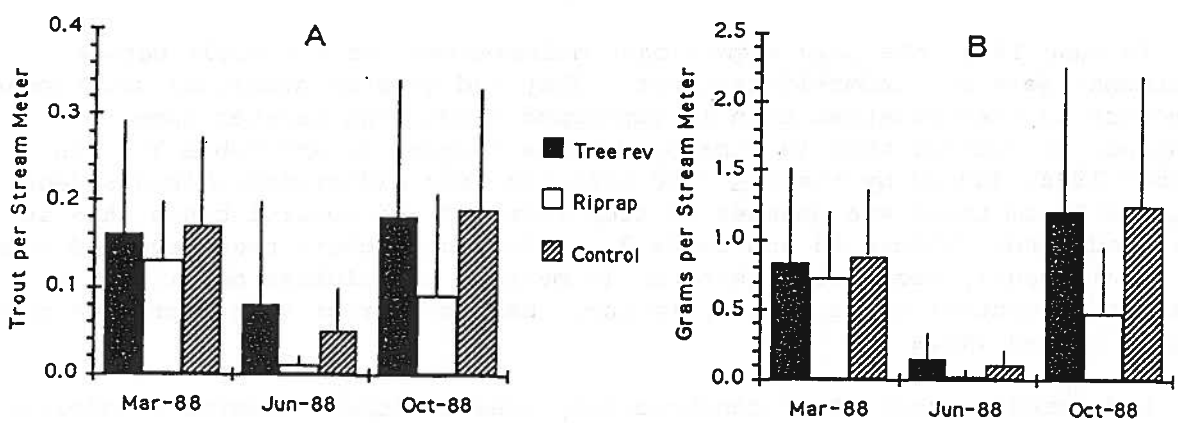

Figure 22. Mean numerical densities (A) and biomass densities (B) of 10-cm-and-under trout (all species) in study bends receiving different treatments before (March), about a month after (June), and about 5 months after (October) construction of tree revetment and riprap in study bends, Deep Creek, Montana, 1988. N for all treatments = 6; standard deviations indicated by vertical lines.

Total trout numbers (which, due to the population's wide size range may be less descriptive of abundance than biomass) underwent few definite changes. In riprapped bends, trout were significantly ($P = 0.03$) less numerous in June than they had been in March (Table 5, Figure 22A). This decrease in the riprapped bends may have been due to physical disturbance or loss of streamside during construction. Both could have caused fish to move out of the riprapped bends temporarily. Binns and Eiserman (1979) suggested that a varied stream channel morphology, stable in-stream debris, and variety of substrate sizes are needed for substantial fish production. Generally, riprapping probably creates far less cover diversity than occurs on natural stream banks--and may even reduce the amount of cover on previously rather unvegetated banks, as apparently in our study (Figure 15A).

It is important to keep in mind that between June and October, the trout population must have declined to near zero in each treatment type because the study area was dewatered for about 2 1/2 months, beginning in early August. The populations found in bends in October must represent a rapid recovery--but only to the abundance of March 1988, which was low compared to that of October 1986 (Table 4). After such a disruption as the summer 1988 dewatering, even such increase of trout abundance in test and control bends seems remarkable.

The June-to-October trout population increase in study **bends** differs from the trend for the entire study area, in which the October 1988 level was much lower than that of June (Table 4). We suspect recovery from the August dewatering was much stronger, on average, in the 12 test and 6 control sections than in the study area as a whole because these sections were meander bends. Meander bends generally contain a stream's best habitat for trout in the form of lateral scour pools--and in that deeper water, the veering of current close along meander cutbanks, which often contain roughness elements, such as rocks and vegetation. The nearness of swift current to roughness elements makes favorable sites for trout. There, trout have hiding cover, and they have pockets of slow water in which to lie in wait close to swift current that carry the most drifting food. The non-meander-bend parts of stream channels usually are shallower and have less juxtaposition of current and cover.

In June 1988, the only significant differences (at $P \leq 0.20$) between treatments were for under-10-cm trout. They had greater numerical and biomass abundance in tree-revetted than in riprapped bends, and greater numerical abundance in control than in riprapped bends (Figure 23 and Table 7). In October 1988, judged by the $P \leq 0.20$ criterion for difference, biomass density of under-10-cm trout was greater in tree-revetted and control bends than in riprapped bends (Figure 23 and Table 7). Also in October, tree-revetted bends had significantly more trout in total (numerical and biomass density of all sizes) than control bends, which, in turn, had more trout than riprapped bends (Figure 22 and Table 7).

Undoubtedly, soon after construction, tree revetment created a condition that, for small trout, was less harsh than in unaltered bends, and the unaltered bends were probably less harsh than the riprapped bends. Biomass density of under-10-cm trout decreased significantly in each type of treatment bend and in untreated bends from March to June (Table 6). The decrease was greatest (97%) in riprapped bends, least (83%) in tree-revetted bends, and intermediate (88%) in control bends. The pattern for total trout biomass appeared similar, but none of the March-to-June differences was significant.

Table 7. P-values from between-treatment ANOVAs of trout abundance (numerical and biomass densities) in study bends, Deep Creek, Montana, 1988. Values ≤0.20 shown bold.

		Trout ≤10 cm		All trout	
Month	Treatment comparison	Fish/m	G/m	Fish/m	G/m
March*	Tree-revetment vs riprap*	0.67	0.75	0.99	0.52
	Riprap vs control*	0.44	0.66	0.84	0.98
	Tree-revetment vs control*	0.86	0.90	0.82	0.51
June	Tree-revetment vs riprap	**0.20**	**0.16**	0.88	0.74
	Riprap vs control	**0.12**	0.35	0.92	0.25
	Tree-revetment vs control	0.57	0.61	0.81	0.40
October	Tree-revetment vs riprap	0.32	**0.18**	0.89	0.96
	Riprap vs control	0.26	**0.16**	**0.15**	**0.17**
	Tree-revetment vs control	0.96	0.96	**0.19**	**0.20**

*Pre-treatment.

The amount of change in trout biomass density from March to June (Figure 24) and March to October (Figure 25) in individual study bends varied greatly, and between-treatment differences in amount of change were nonsignificant for all comparisons (Table 8).

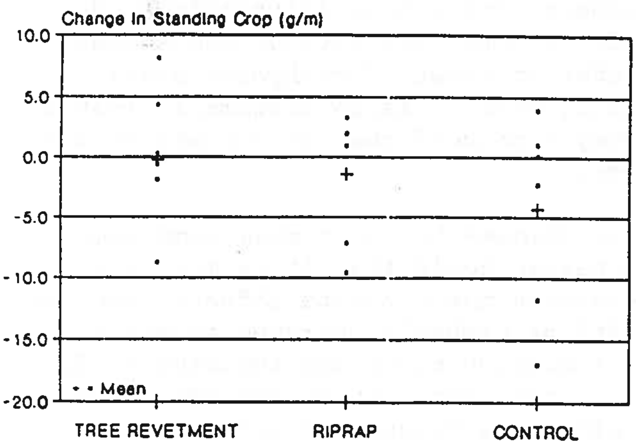

Figure 24. March-to-June changes in trout biomass density in study bends, Deep Creek, Montana, 1988. Each data point represents a study bend.

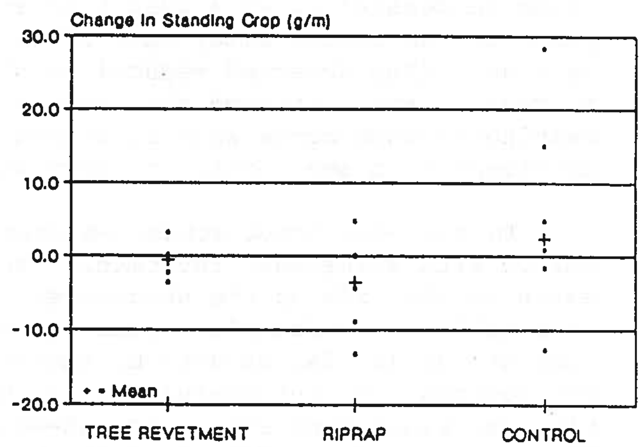

Figure 25. March-to-October changes in trout biomass density in study bends, Deep Creek, Montana, 1988. Each data point represents a study bend.

These results from the first few months after bank revetment (and despite disruption by dewatering) suggest that the complex structure offered by tree revetment and by the natural vegetation along untreated bends is more attractive to small trout than are the conditions created by riprap. This is consistent with previous studies of riprap. In the Big Wood River, Idaho, stock densities of rainbow trout were 8 to 10 times higher in natural sections than in riprapped areas (Thurow 1987). In the Ruby River, Montana, stock densities of brown trout in riprapped sections were half those in unaltered sections (Peterson 1974).

Table 8. P-values from ANOVAs of between-treatment differences in changes in trout abundance (numerical and biomass densities) before (March) and after construction in study bends, Deep Creek, Montana, 1988. Values ≤0.20 shown bold.

		Trout ≤10 cm		All trout	
Period	Treatment comparison	Fish/m	G/m	Fish/m	G/m
Mar-Jun	Tree-revetment vs riprap	0.60	0.98	0.91	0.21
	Riprap vs control	0.98	0.83	0.73	**0.17**
	Tree-revetment vs control	0.59	0.81	0.81	0.93
Mar-Oct	Tree-revetment vs riprap	0.63	0.26	0.66	0.63
	Riprap vs control	0.66	0.37	0.46	0.34
	Tree-revetment vs control	0.97	0.79	0.24	0.64

Knudsen and Dilley (1987) suggest the magnitude in the reduction of salmonid densities, as a result of streambank alterations (riprapping), depends on the stream size, size of salmonid, and the severity of the change in habitat. They observed reductions of cutthroat trout (*Oncorhyncus clarki*) biomass in small streams and increases in biomass in large streams in Western Washington when banks were riprapped. They concluded that riprap may be more detrimental in small than in large streams.

In the Deep Creek study, we found few changes in trout abundance associated with streambank revetment. We emphasize again that it is much too early in the life of the structures to evaluate the ultimate effects, and the abnormally low streamflow discharge of 1987-88 probably overrode or masked some of the initial effects by severely disrupting trout and reducing their populations. Proper evaluation can be done only after there has been more time for trout populations to redevelop after the dewatering and respond (or fail to respond) to the physical changes brought about by the revetments. Moreover, we expect the stream to alter physically for several years after the revetment, with trout populations continuing to adjust in response to that.

However, the data **suggest** that already in the first few months after construction and despite the dewatering, tree revetment may have had positive effects and riprap may have had negative effects (Figures 22 and 23). That the tree-revetted bends had significant pre-to-post-treatment increase in overhead cover, whereas riprapped bends did not (Table 3, Figure 10), and that there may be more positive change in trout abundance in tree revetted than in riprapped bends (Tables 5 and 6, Figures 22 and 23) might suggest that the fish were responding positively to cover.

Relationship of Hiding Cover and Trout Abundance

In regression analysis of trout and physical variables (pools and overhead cover) in the test bends, trout abundance generally was more closely associated with overhead cover than with pools in March 1988, just before construction (Table 9). But 5 months after construction (and less than a

Table 9. Coefficients of determination (R^2) for regressions of numerical and biomass densities of trout on densities of overhead cover and pool area in test bends just before and five months after construction of bank revetment in Deep Creek, Montana, 1988.

		Numerical density (fish/channel meter)				Biomass density (grams/channel meter)			
				Cover & pool				Cover & pool	
Date	Trout group	Cover	Pool	Simple[a]	Multi[b]	Cover	Pool	Simple[a]	Multi[b]
All bends									
Mar	All	.299*	.017	.116	.308*	.005	.001	.001	.006
	<10 cm	.379**	.034	.129	.399*	.337*	.012	.147	.342*
Oct-Nov	All	.019	.347*	.175	.348*	.030	.274*	.028	.390*
	<10 cm	.013	.302*	.144	.305	.024	.238	.140	.238
Without tree-revetted bend 4									
Mar	All	.280*	.069	.066	.319	.002	.006	.000	.008
	<10 cm	.373**	.137	.063	.459*	.325*	.076	.079	.367*
Oct-Nov	All	.077	.572**	.420**	.601**	.012	.419**	.091	.462*
	<10 cm	.048	.463**	.314*	.478*	.074	.383**	.317*	.418*
Riprapped and untreated (control) bends only									
Mar	All	.409*	.098	.163	.429	.013	.004	.005	.014
	<10 cm	.595**	.214	.186	.663**	.391*	.235	.077	.498*
Oct-Nov	All	.002	.540**	.525**	.567*	.051	.448*	.214	.462
	<10 cm	.000	.643**	.579**	.656**	.003	.524**	.481*	.538*

[a]From regression of the combined density of cover and pools.

[b]Unadjusted R^2 from multiple regression of cover and pool densities as separate variables.

*$p<0.05$

**$p<0.01$

month after dewatering), trout abundance was more closely correlated with pool habitat than with overhead cover. This may have occurred because in March, when we sampled the trout, stream flow was relatively high--400-500 L/s (Figure 9)--and the supply of pool habitat may have been less limiting for trout than during the October fish sampling, when flow was about 280 L/s. Moreover, during the dewatered period that had just ended, trout that had not left the study area could have survived only in shallow pools (where we then observed some under-10-cm trout), therefore, may have still been highly oriented to pools when we sampled the population.

In regressions of October 1988 trout abundance against overhead cover and pools (measured in early November), it seemed that the relationship for data from tree-revetted bends might be much different than for data from the other bends. In particular, tree-revetted bend 4, which had much cover and pool area but few trout, seemed to lie far outside the relationship, as in Figure 26, which we include as an example. The same was so in many other regressions. Indeed, regressions that omitted bend 4 as an outlier and that omitted all tree-revetted bends generally had much stronger correlation than those that included all data points (Table 9). This and the positions of the tree-revetment data points relative to the others might suggest that trout were negatively affected by some characteristic of the juniper trees, such as their pungent odor. However, omitting tree-revetted bends from the analysis similarly strengthened correlations for March, which was before we installed the junipers. Therefore, the effect of tree-revetted bends on the statistical analysis, if such effect is real and not sampling error, is probably due to some pre-existing characteristic of some of the bends we selected to be treated with tree revetment.

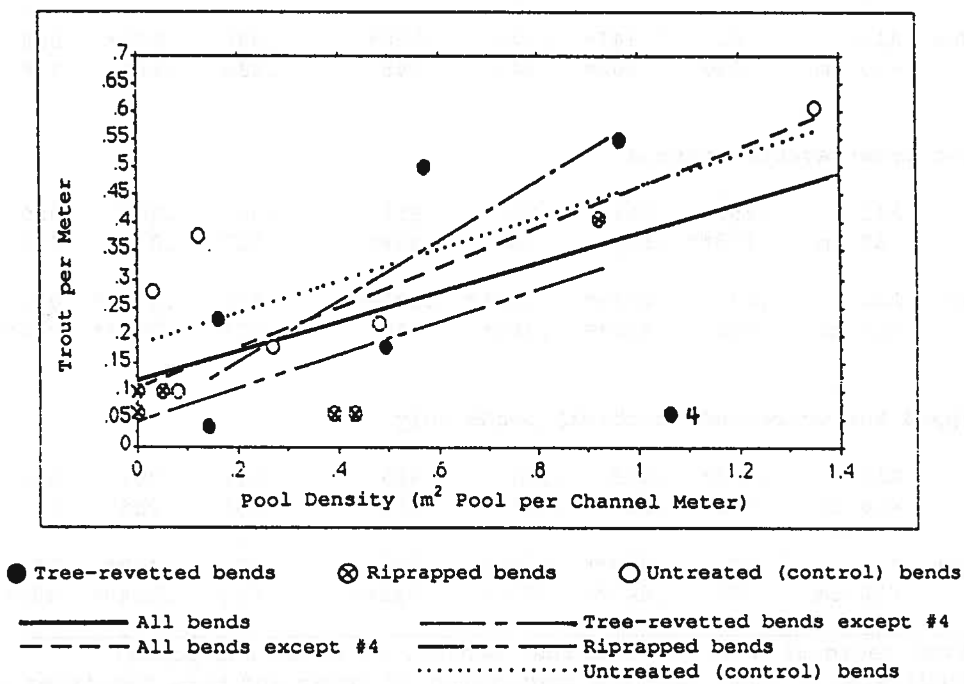

Figure 26. Regressions of total trout numerical density (all species and sizes) in late October 1988 against pool density in study bends in early November 1988, Deep Creek, Montana. Bend 4 omitted as an outlier in some of the regressions.

Also, correlations involving small trout (less than 10 cm) only are generally stronger than correlations that include trout of all sizes (Table 9). This could have been because small trout are more closely associated with the kinds of structure we measured but may have been because larger trout were relatively sparse and erratically distributed, especially after the dewatering.

Further study is needed to assess effects of the habitat treatments on this trout population. The natural variability of salmonid populations as described by Hall and Knight (1981) and Platts and Nelson (1988) must be taken into account when evaluating a biological response to an instream physical habitat alteration or land management activity. Everest et al. (1984) suggest a post-construction period of at least 3 years to effectively evaluate habitat utilization by fish, and Hunt (1976) found that a brook trout population approached maximum response 5 to 6 years after habitat alteration.

Effects of Revetment on Streambank Erosion by Ice

Most streambank erosion in the study area was by ice-levered fracturing during spring thaw (Figure 27). Each winter, ice covered the creek surface throughout the study area more than a meter thick in most places. It filled

Figure 27. Ice-levered erosion of a stream bank, Deep Creek, spring 1988.

the channel such that streambank crests that were about two meters higher than the water level during summer low flow were only about 30 cm above the ice surface in winter (Figure 28). As it thawed in springtime the ice layer typically melted through at midstream first, becoming long ledges of shelf-ice attached to the bank and suspended in air above the stream (Figure 29). The ice ledges were tapered in cross-section, the part attached to the bank being thick, the mid-channel edge thin. Eventually, many of these ice ledges tipped into the channel, often pulling slabs of partly thawed bank soil into the stream with them (Figure 30), where the soil soon washed away.

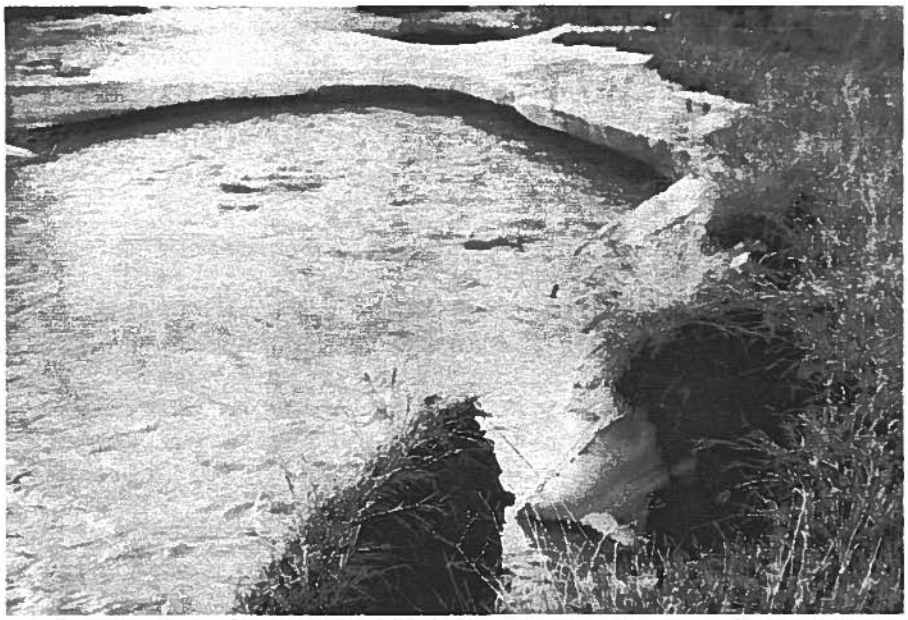

Figure 28. Ice bridge spanning Deep Creek during spring thaw, 1989. The runoff water level is high and melting the ice from beneath. Note the level of the ice surface, which is about the same as the tops of the banks, indicating that the ice filled the chanel to almost "bankfull" in winter. In foreground right are slabs of frozen soil that the ice has levered away from the bank.

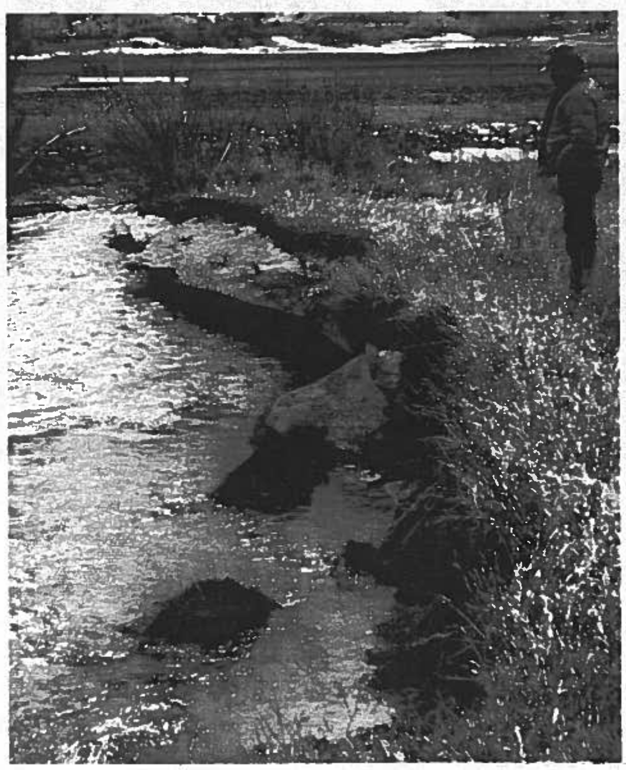

Figure 29. Ice shelf before collapse (background) and ice-levered blocks of stream bank being thawed and eroded in the stream (foreground), Deep Creek, spring 1989.

In March and April 1988, while supervising construction of bank revetments, author White first saw the massive lever-fracturing of current-bearing banks by the shelf-ice ledges in Deep Creek (Figure 27). Excavation with a backhoe further revealed that the suspended ice ledges were contiguous with a dense ice layer in the soil of the stream banks.

Such ice-caused mass wasting of stream banks was common on the current-bearing side of the channel bends and seldom if ever occurred on the inner (point-bar) side. This may have been because the point-bar banks were usually of gentler slope and had dense growth of bushes.

The study area's few current-bearing banks that were densely thicketed with bushes held the ice shelves without bank fracture (Figure 30) in all cases that we observed. Obviously, this is a function to be promoted by protecting and restoring healthy riparian vegetation.

Figure 30. Dense woody vegetation holding a streambank ice shelf in place without bank fracture, until the ice melts away.

In 1989, author McClure made closer observations of the process, which might be termed "frozen block wasting" of stream banks: The ice that covered the stream began to melt in early March, and little remained by April 1st. The stream's ice sheet began disappearing first along a strip near the center of the channel, and this open strip progressively widened toward the banks, typically leaving the ice on each side as a tapered shelf that was about 60 cm thick at the line of attachment to the bank and about 30 cm thick near the channelward edge. All or most of the shelf was suspended (as much as 1/2 meter) above the water surface (Figure 29), depending on water level, which varied over time according to discharge. In some of the more heavily shaded pools, the ice remained as complete bridges over the stream after the center strip had thawed in the rest of the channel.

Where collapsing ice shelves pulled slabs of attached stream bank off of (non-revetted) banks, the line of soil fracture was usually about 30 cm behind the bank edge. The upper surfaces of the high, current-bearing (outer or concave) banks where such frozen block wasting occurred were vegetated, mainly with grass; the high, vertical faces of these banks were bare soil, sometimes containing gravel. The large blocks of ice and attached soil fell to the toe of the bank slope and onto the stream bed. The stream current then washed away much of the fallen soil within several days.

Bohn (1989) found stream banks vegetated with grass were better insulated from freeze-thaw cycles and frost heaving than bare soil banks; she concluded that the internal structure of stream banks vegetated with grasses were stronger than those with exposed soil, therefore more resistant to erosion by the stream.

As the stream current eroded the fallen slabs of bank soil, stream turbidity increased, and some of the eroded sediment deposited immediately downstream from the site of bank failure. The increased sediment deposition from such bank erosion may have several negative effects for trout. Increased embeddedness of streambed gravel probably eliminates space for aquatic macroinvertebrates, thus reducing food supply (Binns 1986). Fine sediment also hampers spawning and embryonic survival of salmonids (Chapman and McLeod 1987). Undercut banks that slump into the stream can constitute loss of overhead cover, and pools become shallower as they fill with sediment (Binns 1986).

Such ice-levered fracturing of current-bearing banks did not occur along bends that had been revetted with riprap or trees. The tree revetments supported the ice shelf, allowing it to melt in place (Figure 31). The riprapped bends undoubtedly also increased the banks' structural integrity, enabling them to support the ice shelf until it melted or broke off (Figure 29). We did not observe that ice pulled any riprap into the stream.

As the ice shelves broke loose in 1989, they formed an ice dam at bend 2 and at the bridge at the lower end of the study area. This caused the stream to flood its banks and form temporary side channels in low spots. Such flooding can leave trout stranded away from the main channel (White and Brynildson 1967). Also, early in the spring runoff, when (and largely because) the channel's ice cover is still complete, high water sometimes flows over the ice, cuts across meanders, and otherwise floods over some of the banks.

The well-vegetated high banks in the study area that withstood the ice erosion may have been relatively undamaged by past grazing because their thicketing protected them from livestock--as appears to happen on neighboring property, which is grazed but in the riparian zone has dense woody vegetation. The thicketed banks undoubtedly resisted ice-levered erosion better than the grass-topped banks because they were better insulated and were held together by more extensive rootwork. Also, if some ice-levered fracturing of densely vegetated banks does occur, the plants may hide it from view.

From our observation of ice action in the study area, we conclude that ice-levered fracturing of the soils of steep, poorly vegetated stream banks during springtime thaw may be a major process of channel erosion in streams that develop significant ice cover or shelf ice. Dense growth of woody vege-

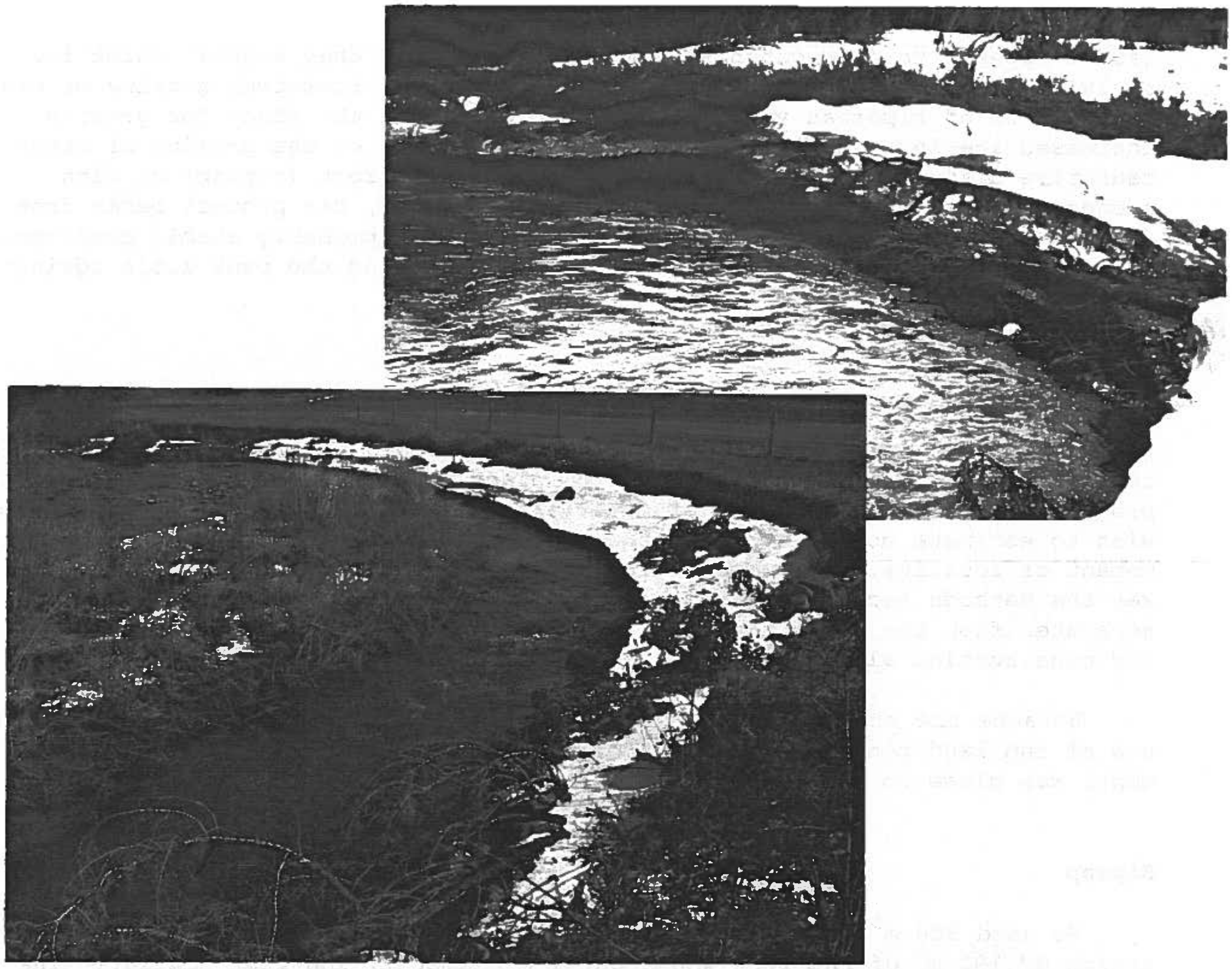

Figure 31. Streambank ice shelves supported by juniper-tree revetment in study bends 4 (lower) and 18, Deep Creek, Montana, spring 1989.

Figure 32. A streambank ice shelf supported by riprap, Deep Creek, Montana, spring 1989.

tation appears to strengthen stream banks such that they support thick ice shelves without bank fracture until the ice melts. Livestock grazing or other disturbance of riparian vegetation undoubtedly sets the stage for greatly increased ice-levered bank fracture. After removal of the grazing or other causative disturbance, revetment with large enough rock (riprap) or with anchored trees, which would usually be much cheaper, can protect banks from further ice-levered fracture. Tree-revetment will probably enable development of natural vegetation that will more permanently bind the bank soils against such erosion.

Construction Costs

Because monetary prices and physical conditions for construction, such as terrain, vary greatly over time or from place to place, it is best to describe project costs mainly in terms of materials, equipment and labor. People who wish to estimate dollar cost can then apply the appropriate unit costs of the moment or locality. For added information on materials and specifications, see the Methods section of this report. Research costs could not always be separated from the costs that would have derived from project design, planning and construction alone.

Because the study area topography was flat, vegetation sparse, and human use of the land non-conflicting (Figure 2), access for construction of revetments was close to ideal.

Riprap

We used 320 m^3 (420 yd^3) of rock to riprap 236 m of stream bank. An estimated 190 m^3 of the rock was about 1 m diameter, the rest smaller. The contractor bought the rock at a quarry about 26 km away (road distance) and trucked it to the site. Backhoe operation time to install the riprap was about 100 hours. The cost of the rock, its transport, the bank preparation and rock installation was $8,280 (1988 dollars). Also, author White spent 8 to 10 days supervising construction, on top of several weeks' time designing and planning this part of the project, drawing up the materials list, finding and negotiating the rock source, securing governmental permits, securing approvals from the funder, and administering the contracting process.

Tree-revetment

A crew of two (author McClure and a helper) spent 4 days cutting juniper trees from a hillside, hauling them to the site, and stockpiling them along the banks on which they were to be installed. They used a 3/4-ton pickup truck to drag the trees from the source groves for a travel distance of less than one kilometer to the recipient sites.

The same crew worked 12 days (three 8-hr days for 4 weeks) to install the trees. They used about 100 to 110 juniper trees. In each horizontal tier of tree revetment, they installed a tree about every 2.5 to 2.8 meters (36-40 trees per 100 layer-meters). Four of the 6 tree-revetted bends were low enough to require only one tier, and two banks (bends 5 and 21) needed double tiers. Therefore, the 211 m of current-bearing bank in bends selected for tree revetment received 277 tier-meters of that treatment, 66 m of this being double tiered.

Other materials included 200 to 220 steel anchor rods (2-m lengths of 1.9-cm diameter [3/4-inch] rebar), about 100 meters of 3/16-inch multi-strand steel cable, about 400 cable connectors, and about 20 cubic meters of field rock. The equipment included a chainsaw, an air compressor, a 95-pound air hammer (with pin-driver bit), a manual fencepost driver (weighted steel cylinder with handles), mauls, axes, tools for cutting cables and crimping cable connectors, and hearing and eye protection gear.

(If field personnel are not available, who are big enough, strong enough, and willing enough to lift a 95-pound air hammer several feet and operate it in such an awkward position repeatedly, a scaffold and pulley-lift can be used to raise the air-hammer into position--but this is more cumbersome and much slower. For rebar-driving in some U.S. Forest Service projects involving even air hammers that weigh less, an orchard ladder or aluminum construction scaffold is used for this.)

Rock for backfill was secured on site (piles of field rock provided by the land owner) and installed by 11 hours of work with a backhoe and dump truck (contracted equipment and operators).

Total time for tree cutting, hauling and installation (including equipment breakdown time and some time supervising rock fill) was 21 crew-hours per bend or 0.6 crew-hour per meter of bank length. This did not include travel time to and from the site, which was substantial. For tree revetment, author White's spent only about two days in supervising and helping with field work--and less than a week in planning, arranging for trees, and buying and hauling rebar and cable.

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APPENDIX A: WATER CHEMISTRY REPORT

DRAFT

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO.: 91Q1064

State:	MT	County:	BROADWATER
Latitude-Longitude:	46D18'30'N 111D25'30'W	Site Location:	06N 02E 01 BB 01
Topographic Map:	HOLKER 7 1/2'	MBMG Site:	M:124388
Geologic Source:		Project Id:	
Drainage Basin:	BA	Station Id:	461830111253001
Agency + Sampler:	*ATS	Sample Source:	STREAM
Bottle number:	SHIPMAN	Land Surface Altitude:	4040.0 FT.
Date Sampled:	21 OCT 1991	Water Flow Rate:	6.0 CFS
Time Sampled:	07:30	Flow Meas Method:	ESTIMATED
Lab + Analyst:	MBMG*SFM	Staff Gage:	
Date Complete:		Stream Stage:	
Sample Handling:	3120	Depth to Sample:	0.50 FT esti.
Method Sampled:	GRAB	Total Depth of Water:	2.50 FT esti.
Procedure Type:	DISSOLVED	Stream Width:	7 FT esti.
Water Use:	STOCK		

Sampling Site: DEEP CREEK
Drainage Basin: MISSOURI RIVER BTWN L. PRICKLY PR. CK. AND THREE FORKS

	mg/L	meq/L		mg/L	meq/L
Calcium (Ca)	44.38	2.21	Bicarbonate (HCO3)	239.1	3.92
Magnesium (Mg)	22.03	1.81	Carbonate (CO3)	0.0	0.00
Sodium (Na)	13.91	0.61	Chloride (Cl)	3.9	0.11
Potassium (K)	2.85	0.07	Sulfate (SO4)	40.0	0.83
Iron (Fe)	<0.005	0.00	Nitrate (as N)	0.05	0.00
Manganese (Mn)	<0.002	0.00	Fluoride (F)	0.45	0.02
Silica (SiO2)	16.41		OrthoPhosphate (as P)	<0.05	0.00
Total Cations:		4.72	Total Anions:		4.89

Standard Deviation of Anion-Cation Balance (Sigma): 0.99

Calculated Dissolved Solid:	261.77	Total Hardness as CaCO3:	201.49
Sum of Diss, Constituent:	383.09	Field Hardness as CaCO3:	
Field cnductvy, micromhos:		Total Alkalinity as CaCO3:	196.10
Lab cnductvy, micromhos:	461.9	Field Alkalinity as CaCO3:	
Field PH:		Ryznar Stability Index:	6.96
Laboratory PH:	8.16	Langlier Saturation Index:	0.60
		Sodium Adsorption Ratio:	0.43

Parameter	Value	Parameter	Value
Field Temp, Air		Field Temp, Water	3.9 C
ALUMINUM, DISS (UG/L-AL)	<100.	NICKEL,DISS (UG/L AS NI)	<20.
BARIUM,DISS (UG/L AS BA)	52.	PHOSPHATE,TO,DIS(MG/L-P)	<0.1
BORON,DISS (UG/L AS B)	<100.	SILVER, DISS(UG/L AS AG)	<5.
BROMIDE,DISS (UG/L AS BR)	<100.	STRONTIUM,DISS (UG/L-SR)	475.
CADMIUM,DISS(UG/L AS CD)	<5.	TITANIUM DIS(UG/L AS TI)	<6.
CHROMIUM, DISS (UG/L-CR)	<5.	VANADIUM,DISS(UG/L AS V)	<5.
COPPER,DISS (UG/L AS CU)	<5.	ZINC, DISS (UG/L AS ZN)	<5.
LITHIUM,DISS(UG/L AS LI)	15.	ZIRCONIUM DIS(UG/L - ZR)	<5.
MOLYBDENUM,DISS(UG/L-MO)	<40.		

Water condition:
1: CLEAR

Field remarks:
1: BOTTLE #: SHIPMAN'S PROP #2

Lab remarks:
1: AS DATA NEEDED

Explanation: mg/L = milligrams per liter, ug/L = micrograms per liter, meq/L milliequivelents per liter. FT = feet, Mt = meters, TR = total recoverable, TOT = total, BIO = biologically available. Sigma includes AL, CU, SR, ZN, and H+ if reported.

Printed: 15 JAN 92

Percent Meq/L (For Piper Plot)

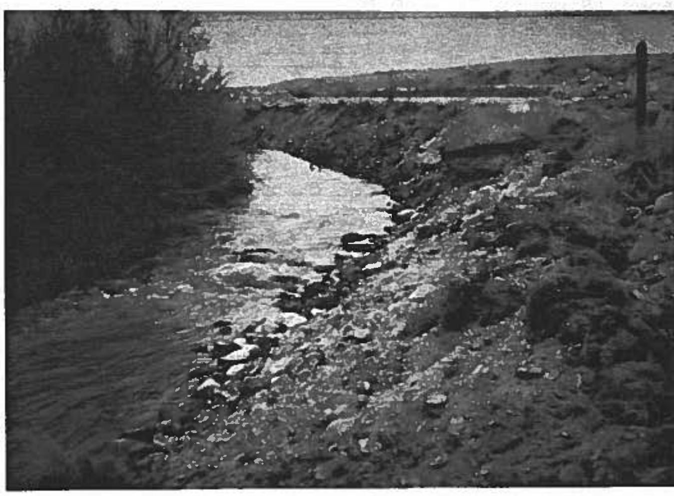
Ca	Mg	Na	K	Cl	SO4	HCO3	CO3
47.1	38.5	12.9	1.5	2.3	17.1	80.6	0.0

NOTE: In correspondence, please refer to Lab Number: 91Q1064

APPENDIX B: CONSTRUCTION STEPS FOR RIPRAP

1. High, eroding bank of bend 16, also described in Figure 3 caption. View is in the upstream direction in photos 1 through 5.

2. Shaping a bank for riprap (bend 3). A plan to "tuck" rocks under overhangs proved impractical, as banks were less even than they had appeared, and installing riprap without pre-sloping would have narrowed the channel.



3. Bend 16 after pre-shaping.

4. The foundation row of large rock at bank slope toe (bend 8). Each rock placed to make overhanging cover for trout and contain smaller rock, on slope above.

5. Finished riprap (bend 16).

6. A riprapped bend about 1 1/2 years after construction (bend 2, viewed in downstream direction, September 1989). Only the current-bearing (outside) bank is riprapped; stabilizing inner (point bar) banks of bends is unneeded, even where less well vegetated than this--and is unwise from standpoints of cost and fish/wildlife habitat. A common mistake in streambank stabilization, done in the name of fish habitat improvement, is to revet both stream banks, thus often overly constricting the channel, impeding natural processes to which fish are adapted, and destroying or hampering regrowth of bankside vegetation.

APPENDIX C: CONSTRUCTION STEPS FOR TREE REVETMENT

1. Juniper trees staged along the top of the stream bank just before installation (viewed is downstream direction).

2. Driving a rebar anchor rod with air hammer. After aligning tree on bank slope, crew puts rod in hole drilled in the tree trunk, rams it with manual post-pounder as far as it easily goes, then lifts air hammer (one man holding the handle, one guiding the bit) onto rod, and drives it down, leaving 20-cm end protruding from tree. Rod end is clinched with 2-meter iron pipe lever. They then cable the trees together (Figure 12).

3. Stream bend after trees have been anchored.

4. Backfilling with field rock.

5. The just-completed installation.

APPENDIX D: APPENDIX TABLES

The tables in this appendix are direct copies of the appendix tables from the Masters Thesis of author McClure (McClure 1991). They bear the same table numbers as in that thesis appendix, which begins with Table 11. The last table in the body of the present report was Table 9. Therefore, no Table 10 exists in this report.

In these tables, **"standing crop"** has the same meaning as **"biomass density,"** the term used in the rest of this report. Likewise, **"stock density"** is the same as **"numerical density."**

Table 11. Changes in overhead cover area and density per length of channel before and after construction, Deep Creek, Montana (measured in March and November 1988).

Treatment Bend # and Length (m)		Cover area (m^2)			Cover density (m^2/m)		Percent Change
	Pre	Post	Change	Pre	Post	Change	
Tree revetment							
4 (60)	40.00	89.81	+49.81	0.67	1.50	+0.83	+124
5 (32)	2.30	50.02	+47.72	0.07	1.56	+1.49	+2075
9 (28)	10.23	16.58	+6.35	0.37	0.59	+0.23	+62
15 (43)	11.94	48.22	+36.28	0.28	1.12	+0.84	+304
18 (14)	1.23	16.70	+15.47	0.09	1.19	+1.11	+1258
21 (34)	22.81	39.63	+16.82	0.67	1.17	+0.49	+74
Mean (35.2)	14.76	43.49	+28.76	0.42	1.24	+0.82	+195
Riprap							
2 (60)	3.59	1.35	-2.24	0.06	0.02	-0.04	-62
3 (29)	6.32	1.89	-4.43	0.22	0.07	-0.15	-68
8 (50)	16.87	7.47	-9.40	0.34	0.15	-0.19	-56
11 (29)	4.61	2.08	-2.53	0.16	0.07	-0.09	-55
16 (46)	27.93	21.66	-6.27	0.61	0.47	-0.14	-22
19 (22)	2.71	4.67	+1.96	0.12	0.21	+0.09	+72
Mean (39.3)	10.33	6.52	-3.82	0.25	0.17	-0.09	-36
Control							
12 (68)	37.45	26.38	-11.07	0.55	0.39	-0.16	-29
14 (23)	10.14	12.25	+2.11	0.44	0.53	+0.09	+21
20 (20)	2.38	2.25	-0.13	0.12	0.11	-0.01	-5
23 (58)	12.08	20.95	+8.87	0.21	0.36	+0.15	+71
24 (29)	54.75	17.36	-37.39	1.89	0.60	-1.29	-68
25 (21)	0.12	0.33	+0.21	0.01	0.02	+0.01	+100
Mean (36.5)	19.49	13.25	-6.24	0.53	0.34	-0.19	-36

Table 12. Changes in pool area and density per length of channel of stream before and after construction, Deep Creek, Montana (measured in March and November 1988).

Treatment Bend # and Length (m)		Pool area (m^2)			Pool density (m^2/m)			Percent Change
		Pre	Post	Change	Pre	Post	Change	
Tree revetment								
4	(60)	50.00	63.61	+13.61	0.83	1.06	+0.23	+28
5	(32)	0.00	15.75	+15.75	0.00	0.49	+0.49	*
9	(28)	0.00	4.16	+4.16	0.00	0.14	+0.14	*
15	(43)	0.48	6.97	+6.49	0.01	0.16	+0.15	+1500
18	(14)	9.60	4.09	-5.15	0.68	0.57	-0.11	-16
21	(34)	31.00	32.62	+1.62	0.91	0.96	+0.05	+5
Mean	(35.2)	15.18	21.20	+6.02	0.43	0.60	+0.17	+40
Riprap								
2	(60)	0.00	0.00	0.00	0.00	0.00	0.00	0
3	(29)	7.37	0.00	-7.37	0.25	0.00	-0.25	-100
8	(50)	0.00	2.71	+2.71	0.00	0.05	+0.05	*
11	(29)	4.40	12.52	+8.12	0.15	0.43	+0.28	+186
16	(46)	22.83	18.11	-4.72	0.50	0.39	-0.11	-22
19	(22)	14.40	20.16	+5.76	0.65	0.92	+0.26	+40
Mean	(39.3)	8.13	8.92	+0.75	0.21	0.23	+0.02	+10
Control								
12	(68)	27.50	18.90	-8.60	0.40	0.27	-0.13	-33
14	(23)	15.00	11.20	-3.80	0.65	0.48	-0.17	-26
20	(20)	3.20	1.62	-1.58	0.16	0.08	-0.08	-50
23	(58)	1.08	6.87	+5.79	0.02	0.12	+0.10	+500
24	(29)	0.00	0.90	+0.90	0.00	0.03	+0.03	*
25	(21)	23.58	28.27	+4.70	1.12	1.35	+0.23	+21
Mean	(36.5)	11.73	11.29	-0.44	0.32	0.31	-0.01	-3

* = % change inappropriate for increase from 0

Table 13. Changes in cover area and density (including pools) per length of channel before and after construction, Deep Creek, Montana (measured in March and November 1988).

Treatment Bend # and Length (m)		Cover area (m^2)			Cover density (m^2/m)			Percent Change
		Pre	Post	Change	Pre	Post	Change	
Tree revetment								
4	(60)	90.00	153.43	+63.43	1.50	2.56	+1.06	+71
5	(32)	2.30	65.78	+63.43	0.07	2.06	+1.99	+2842
9	(28)	10.23	20.74	+10.51	0.37	0.74	+0.38	+103
15	(43)	12.43	55.20	+42.77	0.29	1.28	+0.99	+341
18	(14)	10.83	20.80	+9.97	0.77	1.49	+0.72	+94
21	(34)	53.82	72.26	+18.44	1.58	2.13	+0.55	+35
Mean	(35.2)	29.94	64.70	+34.76	0.76	1.71	+0.95	+125
Riprap								
2	(60)	3.59	1.35	-2.24	0.06	0.02	-0.04	-66
3	(29)	13.69	1.89	-11.80	0.47	0.07	-0.40	-85
8	(50)	16.87	10.18	-6.69	0.34	0.20	-0.13	-38
11	(29)	9.01	14.60	+5.59	0.31	0.50	+0.19	+61
16	(46)	50.77	39.78	-10.99	1.10	0.86	-0.24	-22
19	(22)	17.11	24.83	+7.72	0.78	1.13	+0.35	+45
Mean	(39.3)	18.51	15.44	-3.07	0.51	0.39	-0.08	-16
Control								
12	(68)	64.95	45.29	-19.66	0.96	0.67	-0.29	-30
14	(23)	25.14	23.45	-1.69	1.09	1.02	-0.07	-6
20	(20)	5.57	3.88	-1.69	0.28	0.19	-0.08	-29
23	(58)	13.16	27.82	+14.66	0.23	0.48	+0.25	+109
24	(29)	54.74	18.26	-36.48	1.89	0.63	-1.26	-67
25	(21)	23.70	28.61	+4.92	1.13	1.36	+0.23	+20
Mean	(36.5)	31.21	24.55	-6.66	0.93	0.73	-0.20	-22

Table 14. Pre-to-post-construction changes in mean depths and widths calculated at a streamflow discharge of 285 L/s, Deep Creek, Montana 1988.

Treatment Bend # and Length (m)		Depth (m)				Width (m)			
		Pre	Post	Change	% Change	Pre	Post	Change	% Change
Tree revetment									
4	(60)	0.34	0.45	+0.11	+32	6.57	7.48	+0.91	+14
5	(32)	0.35	0.31	-0.04	-11	3.45	3.12	-0.33	-10
9	(28)	0.19	0.19	0.00	0	5.31	5.27	-0.04	-1
15	(43)	0.26	0.26	0.00	0	4.38	4.33	-0.05	-1
18	(14)	0.27	0.25	-0.02	-7	4.99	4.73	-0.26	-5
21	(34)	0.28	0.29	+0.01	+3	4.71	5.14	+0.43	+9
Mean	(35.2)	0.30*	0.32*	+0.03*	+8	5.08*	5.32*	+0.24*	+5
Riprap									
2	(60)	0.25	0.19	-0.06	-24	4.09	3.85	-0.24	-6
3	(29)	0.30	0.27	-0.03	-10	2.86	3.17	+0.31	+11
8	(50)	0.43	0.25	-0.18	-42	4.37	3.15	-1.22	-28
11	(29)	0.27	0.26	-0.01	-4	3.45	3.26	-0.19	-6
16	(46)	0.28	0.28	0.00	0	4.30	3.92	-0.38	-9
19	(22)	0.40	0.39	-0.01	-2	4.34	3.93	-0.41	-9
Mean	(39.3)	0.32*	0.26*	-0.06*	-19	3.98*	3.56*	-0.42*	-10
Control									
12	(68)	0.24	0.23	-0.01	-4	3.93	3.82	-0.11	-3
14	(23)	0.33	0.37	+0.04	+12	2.90	3.25	+0.35	+12
20	(20)	0.24	0.23	-0.01	-4	3.41	3.21	-0.20	-6
23	(58)	0.28	0.28	0.00	0	3.59	3.97	+0.38	+11
24	(29)	0.25	0.21	-0.04	-16	3.41	3.21	-0.20	-5
25	(21)	0.24	0.20	-0.04	-17	3.85	4.37	+0.52	+14
Mean	(36.5)	0.26*	0.26*	-0.01*	-2	3.61*	3.72*	+0.11*	+3

*Length-weighted

Table 15. Number and biomass of trout in the 1.4-km study area of Deep Creek, Montana October 1986 (95% C.I.).

Size class (cm)	Brown trout No. of fish	Brown trout Biomass (g)	Rainbow trout No. of fish	Rainbow trout Biomass (g)	Total trout No. of fish	Total trout Biomass (g)
< 10	1 (*)	5	18 (5-31)	46	19	51
10-19	62 (39-86)	3399	87 (64-110)	4468	149	7867
20-29	81 (45-117)	10128	58 (46-70)	7194	139	17322
30-39	49 (36-62)	17085	5 (3-7)	1335	54	18420
> 40	11 (5-17)	10677	1 (*)	600 (*)	12	11277
Total	204 (125-282)	41294	169 (118-218)	13643	373	54937

* = estimates too small for confidence interval

Table 16. Number and biomass of trout in the 1.4-km study area of Deep Creek, Montana June 1988 (95% C.I.).

Size class (cm)	Brown trout		Rainbow trout		Total trout	
	No. of fish	Biomass (g)	No. of fish	Biomass (g)	No. of fish	Biomass (g)
< 10	53 (53-126)	100	4 (*)	8 (*)	57	108
10-19	172 (115-229)	5504	354 (230-478)	10018	526	15522
20-29	11 (5-23)	1850	11 (5-23)	2070	22	3920
30-39	17 (12-28)	6334	3 (*)	947	20	7281
> 40	0	0	0	0	0	0
Total	253 (185-406)	13788	372 (235-501)	13043	625	26831

* = estimates too small for confidence interval

Table 17. Number and biomass of trout in the 1.4-km study area of Deep Creek, Montana October 1988 (95% C.I.).

Size class (cm)	Brown trout No. of fish	Brown trout Biomass (g)	Rainbow trout No. of fish	Rainbow trout Biomass (g)	Total trout No. of fish	Total trout Biomass (g)
< 10	260 (78-442)	845	151 (74-228)	462	411	1307
10-19	69 (55-89)	3026	62 (44-80)	1869	131	4895
20-29	10 (8-16)	1261	7 (6-11)	891	17	2152
30-39	7 (5-12)	2433	1 (*)	250	8	2683
> 40	0	0	0	0	0	0
Total	346 (146-559)	7565	221 (124-319)	3472	567	11037

* = estimates too small for confidence interval

Table 18. Number and biomass of trout in the 1.4-km study area of Deep Creek, Montana April 1989 (95% C.I.).

Size class (cm)	Brown trout No. of fish	Brown trout Biomass (g)	Rainbow trout No. of fish	Rainbow trout Biomass (g)	Total trout No. of fish	Total trout Biomass (g)
< 10	195 (67-323)	917	377 (228-526)	2130	572	3047
10-19	120 (58-182)	1780	75 (53-100)	2022	195	3802
20-29	22 (15-35)	1729	11 (9-16)	849	33	2578
30-39	4 (4-8)	1135	2 (*)	464	6	1599
> 40	1 (*)	665	1 (*)	1208	2 (*)	1873 (*)
Total	342 (144-548)	6226	466 (290-642)	6673	808	12899

* = estimates too small for confidence interval

Table 19. Stock density and standing crop of trout in the 1.4-km study area of Deep Creek, Montana October 1986 (95% C.I.).

Size class (cm)	Brown trout Fish/km	Brown trout Kg/km	Rainbow trout Fish/km	Rainbow trout Kg/km	Total trout Fish/km	Total trout Kg/km
< 10	1 (*)	0.004	13 (4-22)	0.033	14	0.034
10-19	44 (28-61)	2.430	62 (46-79)	3.190	106	5.620
20-29	58 (32-84)	7.230	41 (33-50)	5.140	99	12.370
30-39	35 (26-44)	12.200	4 (2-5)	0.950	39	13.150
> 40	8 (4-12)	7.630	1 (*)	0.430	9	8.06
Total	146 (90-201)	29.494	121 (85-156)	9.740	267	39.234

* = estimates too small for confidence interval

Table 20. Stock density and standing crop of trout in the 1.4-km study area of Deep Creek, Montana June 1988 (95% C.I.).

Size class (cm)	Brown trout Fish/km	Brown trout Kg/km	Rainbow trout Fish/km	Rainbow trout Kg/km	Total trout Fish/km	Total trout Kg/km
< 10	38 (38-90)	0.071	3 (*)	0.006	41	0.077
10-19	123 (82-164)	3.931	253 (164-341)	7.156	376	11.087
20-29	8 (4-16)	1.321	8 (8-16)	1.479	16	2.800
30-39	12 (9-20)	4.524	2 (*)	0.676	14	5.200
> 40	0	0	0	0	0	0
Total	181 (133-290)	9.847	266 (172-357)	9.31	447	19.164

* = estimates too small for confidence interval

Table 21. Stock density and standing crop of trout in the 1.4-km study area of Deep Creek, Montana October 1988 (95% C.I.).

Size class (cm)	Brown trout		Rainbow trout		Total trout	
	Fish/km	Kg/km	Fish/km	Kg/km	Fish/km	Kg/km
< 10	186 (56-316)	0.600	108 (53-163)	0.330	294	0.930
10-19	49 (39-64)	2.160	44 (31-57)	1.330	93	3.490
20-29	7 (6-11)	0.900	5 (4-8)	0.640	12	1.540
30-39	5 (4-9)	1.740	1 (*)	0.180	6	1.920
> 40	0	0	0	0	0	0
Total	247 (105-400)	5.400	158 (88-228)	2.480	405	7.880

* = estimates too small for confidence interval

Table 22. Stock density and standing crop of trout in the 1.4-km study area of Deep Creek, Montana April 1989 (95% C.I.).

Size class (cm)	Brown trout Fish/km	Brown trout Kg/km	Rainbow trout Fish/km	Rainbow trout Kg/km	Total trout Fish/km	Total trout Kg/km
< 10	139 (48-230)	0.655	269 (163-376)	1.521	408	2.176
10-19	85 (41-130)	1.271	54 (38-71)	1.444	139	2.715
20-29	16 (11-25)	1.235	8 (6-11)	0.606	24	1.841
30-39	3 (3-6)	0.811	1 (*)	0.331	4	1.142
> 40	1	0.475	1	0.863	2	1.338
Total	244 (103-391)	4.447	333 (207-458)	4.765	577	9.212

* = estimates too small for confidence interval

Table 23. Number and biomass of trout in study bends before revetment construction in Deep Creek, Montana March 1988.

Treatment Bend	Brown trout		Rainbow trout		Total trout	
	No. of fish	Biomass (g)	No. of fish	Biomass (g)	No. of fish	Biomass (g)
Tree revetment						
4	11	75	16	109	27	184
5	0	0	4	257	4	257
9	1	5	1	13	2	18
15	13	48	9	169	22	217
18	0	0	0	0	0	0
21	4	267	5	50	9	317
Riprap						
2	5	45	9	77	14	122
3	6	13	2	489	8	502
8	2	15	4	33	6	48
11	10	13	2	215	12	138
16	8	16	2	61	10	77
19	3	11	1	304	4	315
Control						
12	9	38	6	86	15	124
14	7	293	3	131	10	424
20	3	23	0	0	3	23
23	6	610	6	317	12	927
24	10	32	5	84	15	116
25	0	0	1	5	1	5

Table 24. 95% confidence intervals for Zippin population estimate of trout in Deep Creek, Montana March 1988.

Treatment Bend	Brown trout No. of fish	Rainbow trout No. of fish
Tree revetment		
4	(11-12)	(16-17)
5	*	(4-5)
9	*	*
15	(13-15)	(9-10)
18	*	*
21	(4-5)	(5-6)
Riprap		
2	(5-6)	(9-10)
3	(6-7)	(2-2)
8	(2-2)	(4-6)
11	(10-12)	*
16	(8-9)	(2-2)
19	*	*
Control		
12	(9-11)	(6-6)
14	(7-8)	(3-3)
20	*	*
23	(6-6)	(6-6)
24	(10-12)	(5-5)
25	*	*

* = estimates too small for confidence interval

Table 25. Number and biomass of trout in study bends after revetment construction in Deep Creek, Montana June 1988.

Treatment Bend	Brown trout No. of fish	Brown trout Biomass (g)	Rainbow trout No. of fish	Rainbow trout Biomass (g)	Total trout No. of fish	Total trout Biomass (g)
Tree revetment						
4	7	285	5	161	12	446
5	7	432	3	86	10	518
9	0	0	0	0	0	0
15	3	136	0	0	3	136
18	1	4	0	0	1	4
21	9	19	2	162	11	181
Riprap						
2	2	160	2	158	4	318
3	0	0	3	295	3	295
8	2	65	1	30	3	95
11	6	105	5	89	11	194
16	3	72	3	95	6	167
19	2	64	2	40	4	104
Control						
12	4	100	1	31	5	131
14	0	0	1	34	1	34
20	0	0	1	44	1	44
23	5	26	5	219	10	245
24	5	30	1	20	6	50
25	3	6	3	81	6	87

Table 26. 95% confidence intervals for Zippin population estimate of trout in Deep Creek, Montana June 1988.

Treatment Bend	Brown trout No. of fish	Rainbow trout No. of fish
Tree revetment		
4	(7-8)	(5-6)
5	(7-8)	*
9	*	*
15	(3-3)	*
18	*	*
21	(9-10)	(2-2)
Riprap		
2	(2-2)	*
3	*	(3-3)
8	(2-2)	*
11	(6-7)	(5-6)
16	(3-4)	(3-3)
19	*	*
Control		
12	*	*
14	*	*
20	*	*
23	(5-5)	(5-5)
24	*	*
25	*	*

* = estimates too small for confidence interval

Table 27. Number and biomass of trout in study bends after construction, Deep Creek, Montana October 1988.

Treatment Bend	Brown trout No. of fish	Brown trout Biomass (g)	Rainbow trout No. of fish	Rainbow trout Biomass (g)	Total trout No. of fish	Total trout Biomass (g)
Tree revetment						
4	2	12	2	35	4	47
5	3	148	3	116	6	264
9	1	9	0	0	1	9
15	3	19	7	42	10	61
18	5	36	2	9	7	45
21	9	277	4	18	13	295
Riprap						
2	2	11	2	108	4	119
3	2	40	1	78	3	118
8	3	81	2	207	5	288
11	1	8	1	3	2	11
16	1	8	2	76	3	84
19	5	72	4	48	9	120
Control						
12	10	197	2	31	12	228
14	3	43	2	12	5	55
20	2	40	0	0	2	40
23	5	49	9	148	14	197
24	2	14	6	55	8	69
25	7	469	6	132	13	601

Table 28. 95% confidence intervals for Zippin population estimate of trout in Deep Creek, Montana October 1988.

Treatment Bend	Brown trout No. of fish	Rainbow trout No. of fish
Tree revetment		
4	*	(2-3)
5	*	*
9	*	*
15	(3-4)	(7-9)
18	(5-5)	*
21	(9-11)	(4-6)
Riprap		
2	*	*
3	*	*
8	(3-4)	(2-3)
11	*	*
16	(1-2)	*
19	(5-7)	(4-5)
Control		
12	(10-11)	*
14	(3-4)	*
20	(2-3)	*
23	(5-6)	(9-9)
24	*	(6-7)
25	*	(6-7)

* = estimates too small for confidence interval

Table 29. Stock density and standing crop of trout in study bends. Means and standard deviations (S.D.) Deep Creek, Montana March 1988.

Treatment Bend # and Length (m)		Brown trout		Rainbow trout		Total trout	
		Fish/m	g/m	Fish/m	g/m	Fish/m	g/m
Tree revetment							
4	(60)	0.18	1.25	0.27	1.82	0.45	3.07
5	(32)	0.00	0.00	0.13	8.03	0.13	8.03
9	(28)	0.04	0.17	0.04	0.46	0.08	0.63
15	(43)	0.30	1.12	0.21	3.93	0.51	5.05
18	(14)	0.00	0.00	0.00	0.00	0.00	0.00
21	(34)	0.11	7.85	0.15	1.47	0.26	9.32
Mean	(35.2)	0.11	1.73	0.13	2.62	0.24	4.35
S.D.	(14.1)	0.11	2.78	0.09	2.72	0.19	3.49
Riprap							
2	(60)	0.08	0.75	0.15	1.28	0.23	2.03
3	(29)	0.21	0.44	0.07	16.86	0.28	17.31
8	(50)	0.04	0.30	0.08	0.66	0.12	0.96
11	(29)	0.34	0.45	0.07	4.31	0.41	4.76
16	(46)	0.17	0.35	0.04	1.33	0.21	1.68
19	(22)	0.14	0.48	0.05	13.82	0.19	14.32
Mean	(39.3)	0.16	0.46	0.08	6.38	0.24	6.84
S.D.	(13.5)	0.10	0.14	0.04	6.50	0.10	6.51
Control							
12	(68)	0.13	0.55	0.09	1.26	0.22	1.81
14	(23)	0.30	12.74	0.13	5.70	0.43	18.43
20	(20)	0.15	1.15	0.00	0.00	0.15	1.15
23	(58)	0.10	10.52	0.10	5.47	0.20	15.98
24	(29)	0.34	1.10	0.17	2.90	0.51	4.00
25	(21)	0.00	0.00	0.05	0.23	0.05	0.23
Mean	(36.5)	0.17	4.34	0.09	2.59	0.26	6.93
S.D.	(19.2)	0.12	5.21	0.05	2.31	0.16	7.39

Table 30. Stock density and standing crop of trout in study bends. Means and standard deviations (S.D.) Deep Creek, Montana June 1988.

Treatment Bend # and Length (m)		Brown trout		Rainbow trout		Total trout	
		Fish/m	g/m	Fish/m	g/m	Fish/m	g/m
Tree revetment							
4	(60)	0.12	4.75	0.08	2.68	0.20	7.43
5	(32)	0.22	13.50	0.09	2.69	0.31	16.19
9	(28)	0.00	0.00	0.00	0.00	0.00	0.00
15	(43)	0.07	3.16	0.00	0.00	0.07	3.16
18	(14)	0.07	0.29	0.00	0.00	0.07	0.29
21	(34)	0.26	0.56	0.06	4.76	0.32	0.56
Mean	(35.2)	0.12	3.71	0.04	1.69	0.16	4.61
S.D.	(14.1)	0.09	4.70	0.04	1.82	0.12	5.78
Riprap							
2	(60)	0.03	2.67	0.03	2.63	0.06	5.30
3	(29)	0.00	0.00	0.10	10.17	0.10	10.17
8	(50)	0.04	1.30	0.02	0.60	0.06	1.90
11	(29)	0.21	3.62	0.17	3.07	0.38	6.69
16	(46)	0.06	1.57	0.07	2.07	0.13	3.64
19	(22)	0.09	2.91	0.09	1.82	0.18	4.73
Mean	(39.3)	0.07	2.01	0.08	3.39	0.15	5.41
S.D.	(13.5)	0.07	1.20	0.05	3.13	0.11	2.59
Control							
12	(68)	0.06	1.47	0.06	0.46	0.12	1.93
14	(23)	0.00	0.00	0.04	1.48	0.04	1.48
20	(20)	0.00	0.00	0.05	2.20	0.05	2.20
23	(58)	0.09	0.45	0.09	3.78	0.18	4.23
24	(29)	0.17	1.03	0.03	0.69	0.20	1.72
25	(21)	0.14	0.29	0.14	3.86	0.28	4.15
Mean	(36.5)	0.08	0.54	0.07	2.08	0.15	2.62
S.D.	(19.2)	0.06	0.54	0.04	1.35	0.09	1.24

Table 31. Stock density and standing crop of trout in study bends. Means and standard deviations (S.D.) Deep Creek, Montana October 1988.

Treatment Bend # and Length (m)		Brown trout		Rainbow trout		Total trout	
		Fish/m	g/m	Fish/m	g/m	Fish/m	g/m
Tree revetment							
4	(60)	0.03	0.20	0.03	0.58	0.06	0.78
5	(32)	0.09	4.63	0.09	3.63	0.18	8.26
9	(28)	0.04	0.32	0.00	0.00	0.04	0.32
15	(43)	0.07	0.44	0.16	0.98	0.23	1.42
18	(14)	0.36	2.57	0.14	0.14	0.50	3.21
21	(34)	0.43	8.15	0.12	0.53	0.55	8.68
Mean	(35.2)	0.17	2.72	0.09	0.98	0.26	3.77
S.D.	(14.1)	0.16	3.18	0.06	1.23	0.20	3.44
Riprap							
2	(60)	0.03	0.18	0.03	1.80	0.06	1.98
3	(29)	0.07	1.38	0.03	2.69	0.10	4.07
8	(50)	0.06	1.62	0.04	4.14	0.10	5.76
11	(29)	0.03	0.27	0.03	0.10	0.06	0.37
16	(46)	0.02	0.17	0.04	1.65	0.06	1.82
19	(22)	0.23	3.27	0.18	2.18	0.41	5.45
Mean	(39.3)	0.07	1.15	0.06	2.09	0.13	3.24
S.D.	(13.5)	0.07	1.11	0.05	1.21	0.13	1.99
Control							
12	(68)	0.15	16.42	0.03	0.46	0.18	16.88
14	(23)	0.13	1.87	0.09	0.52	0.22	2.39
20	(20)	0.10	2.00	0.00	0.00	0.10	2.00
23	(58)	0.22	0.84	0.16	2.55	0.38	3.39
24	(29)	0.07	0.48	0.21	1.90	0.28	2.38
25	(21)	0.33	22.33	0.28	6.29	0.61	28.62
Mean	(36.5)	0.16	7.32	0.13	1.95	0.30	9.27
S.D.	(19.2)	0.09	8.70	0.10	2.13	0.17	10.12

Table 32. Number and biomass of trout ≤10 cm in length in study bends before and after construction of revetments, Deep Creek, Montana 1988.

Treatment Bend	March No. of fish	March Biomass (g)	June No. of fish	June Biomass (g)	October No. of fish	October Biomass (g)
Tree revetment						
4	20	105	2	4	3	17
5	3	15	0	0	2	19
9	1	5	0	0	1	9
15	14	62	0	0	10	61
18	0	0	2	4	7	45
21	5	41	11	19	8	49
Riprap						
2	10	49	0	0	2	11
3	4	28	0	0	1	9
8	5	15	0	0	1	8
11	6	43	1	2	2	11
16	7	33	1	2	2	11
19	0	0	0	0	8	34
Control						
12	11	51	1	2	7	41
14	5	23	0	0	2	12
20	2	9	0	0	1	6
23	8	58	4	8	11	88
24	10	52	2	4	7	44
25	1	5	3	6	10	64

Table 33. Stock density and standing crop of trout ≤10 cm in length in study bends. Means and standard deviations (S.D.) Deep Creek, Montana 1988.

Treatment Bend # and Length (m)	March Stock Density fish/m	March Standing Crop g/m	June Stock Density fish/m	June Standing Crop g/m	October Stock Density fish/m	October Standing Crop g/m
Tree revetment						
4 (60)	0.33	1.75	0.03	0.07	0.05	0.28
5 (32)	0.09	0.47	0.00	0.00	0.06	0.59
9 (28)	0.04	0.10	0.00	0.00	0.04	0.32
15 (43)	0.33	1.44	0.00	0.00	0.23	1.42
18 (14)	0.00	0.00	0.14	0.22	0.50	3.21
21 (34)	0.15	1.21	0.32	0.56	0.24	1.44
Mean (35.2)	0.16	0.83	0.08	0.14	0.18	1.21
S.D. (14.1)	0.13	0.67	0.12	0.20	0.16	1.01
Riprap						
2 (60)	0.17	0.82	0.00	0.00	0.03	0.18
3 (29)	0.14	0.97	0.00	0.00	0.03	0.31
8 (50)	0.10	0.30	0.00	0.00	0.02	0.16
11 (29)	0.21	1.48	0.03	0.07	0.07	0.38
16 (46)	0.15	0.72	0.02	0.04	0.04	0.24
19 (22)	0.00	0.00	0.00	0.00	0.36	1.55
Mean (39.3)	0.13	0.72	0.01	0.02	0.09	0.47
S.D. (13.5)	0.07	0.47	0.01	0.03	0.12	0.49
Control						
12 (68)	0.16	0.75	0.01	0.03	0.10	0.60
14 (23)	0.22	1.00	0.00	0.00	0.09	0.52
20 (20)	0.10	0.45	0.00	0.00	0.05	0.30
23 (58)	0.14	1.00	0.07	0.14	0.19	1.52
24 (29)	0.35	1.79	0.07	0.13	0.24	1.52
25 (21)	0.05	0.24	0.14	0.29	0.48	3.05
Mean (36.5)	0.17	0.87	0.05	0.10	0.19	1.25
S.D. (19.2)	0.10	0.49	0.05	0.10	0.14	0.93