Evaluation of trout spawning gravel restoration in a placer-mined Montana stream
by Christopher William Riley

A thesis submitted in partial fullfillment of the requirements for the degree of Master of Science in Biological Sciences
Montana State University
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Abstract:
Log sills installed in Confederate Gulch, Montana in the summer of 1986 trapped trout spawning gravel in 1989 and 1990. By 1990, surface gravel area in sections containing log sills increased 37 times over the pre-treatment level of 1987. In 1987, density of surface gravel area in sections treated with log sills was less than half that in untreated sections; by 1990, density of surface gravel area in treated sections was more than 3 times that in untreated sections. In 1987, gravel patch density in sections treated with log sills was 65% of that in untreated sections; by 1990, patch density in treated sections was 21% greater than in untreated sections. Mean gravel patch area in treated sections increased from 0.41 m2 in 1987 to 1.45 m2 in 1990, while decreasing in untreated section from 0.68 m2 to 0.45 m2 over the same period. The density of definite and probable brook trout redds increased 186% from 1988 to 1990, and in 1990, was 86% greater in sections treated with log sills than in untreated sections. Age-0 brook trout density more than tripled in the study area from 1986 to 1990, increasing 51% and 378% in treated and untreated sections, respectively. By 1990, plunge pools, sill undercuts, and turbulence associated with log sills accounted for 72% and 40% of all trout hiding cover (excluding beaver ponds) in treated sections and in the study area, respectively. Number of pools > 0.4 m in sections treated with log sills increased from 1 in 1986 to 23 in August 1990; mean residual depth of these pools increased from 0.43 m to 0.53 m over the same period. Beaver dam construction increased from 1 in 1986 to 18 in 1990, primarily in the middle of the study area. Densities of surface gravel area, trout hiding cover, and number and biomass of age-0, age-1, and age-2 brook trout were all considerably greater in sections affected by beaver. All 40 log sills were intact and functioning as of October 1996.

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Christopher William Riley

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

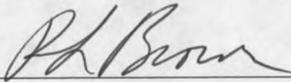_12/3/96_
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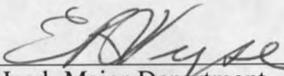
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ABSTRACT

Log sills installed in Confederate Gulch, Montana in the summer of 1986 trapped trout spawning gravel in 1989 and 1990. By 1990, surface gravel area in sections containing log sills increased 37 times over the pre-treatment level of 1987. In 1987, density of surface gravel area in sections treated with log sills was less than half that in untreated sections; by 1990, density of surface gravel area in treated sections was more than 3 times that in untreated sections. In 1987, gravel patch density in sections treated with log sills was 65% of that in untreated sections; by 1990, patch density in treated sections was 21% greater than in untreated sections. Mean gravel patch area in treated sections increased from 0.41 m^2 in 1987 to 1.45 m^2 in 1990, while decreasing in untreated section from 0.68 m^2 to 0.45 m^2 over the same period. The density of definite and probable brook trout redds increased 186% from 1988 to 1990, and in 1990, was 86% greater in sections treated with log sills than in untreated sections. Age-0 brook trout density more than tripled in the study area from 1986 to 1990, increasing 51% and 378% in treated and untreated sections, respectively. By 1990, plunge pools, sill undercuts, and turbulence associated with log sills accounted for 72% and 40% of all trout hiding cover (excluding beaver ponds) in treated sections and in the study area, respectively. Number of pools $\geq$ 0.4 m in sections treated with log sills increased from 1 in 1986 to 23 in August 1990; mean residual depth of these pools increased from 0.43 m to 0.53 m over the same period. Beaver dam construction increased from 1 in 1986 to 18 in 1990, primarily in the middle of the study area. Densities of surface gravel area, trout hiding cover, and number and biomass of age-0, age-1, and age-2 brook trout were all considerably greater in sections affected by beaver. All 40 log sills were intact and functioning as of October 1996.

INTRODUCTION

A major rain storm in May 1981 severely flooded the Confederate Gulch stream, destroying trout habitat, as has probably happened from time to time since the severe human disturbance of this valley. Particularly hard hit was a several-kilometer-long canyon area, in which placer mining for gold in the 1860's had lowered the valley floor by about 12 m. This and later mining in the 1930's and 1940's (Lyden 1948) left many parts of the channel in unnaturally straight courses and otherwise destabilized the stream and riparian system, leaving it abnormally susceptible to damage from high water. The May 1981 flood, which apparently involved a debris torrent, removed wood debris, beaver dams, and other fish habitat features from the channel. Most of the beaver and trout populations disappeared in that event. The channel was left nearly devoid of hiding cover for trout and gravel beds suitable for trout spawning. The post-flood streambed surface consisted almost entirely of armoring rock having diameters of about 10-30 cm. However, much gravel remained on the stream banks and beneath the armor layer. Whereas Confederate Gulch had been a trout fishery before the flood, as of 1985 — 4 years afterward — little recovery of the trout habitat or population was evident.

Montana Department of Fish, Wildlife, and Parks Fishery Biologist, Bruce J. Rehwinkel, considered the unfavorable fishery conditions of Confederate Gulch's canyon area to represent those in other placer-mined streams of his district. He suggested that the Montana State University Department of Biology (MSU) evaluate methods for restoring trout habitat there and in some other streams (McClure and White 1992; White et al 1992). Results from that work, if effective, could be applied in similar situations elsewhere. Under funding from the Montana Depatment of Natural Resources and Conservation, in consultation with university and agency geomorphologists and hydrologists, and with the help of several students, Dr. Ray J. White of MSU undertook an investigation of Confederate Gulch's canyon area, then designed, organized, and supervised construction there of low log sills to trap gravel for trout spawning

and, secondarily, to create hiding cover for trout. The log sills, oriented according to Anderson et al. (1984) and built following structural designs of Reeves and Roelofs (1982), were to simulate optimal effects of naturally-recruited large wood debris. Gravel transported during high water was to deposit just above and below the sills, as happens near naturally-fallen logs that span streambeds. Water pouring over the sills was to scour out plunge pools, such as occur below natural logs in streams. Trout would find shelter in the pools and beneath the log sills.

Reeves et al (1991) reviewed numerous evaluations of techniques employed to improve spawning habitat for salmonids. Rock gabion sills have trapped spawning gravels in coastal streams of Washington (Gerke 1974; Wilson 1976), California (Moreau 1984; West 1984), and Oregon (House 1984; Anderson et al 1984); in many cases spawning structures simultaneously enhance rearing habitat. Kaufmann (1987) found that during high flow events, undisturbed channels containing wood debris had a greater coefficient of friction and a higher proportion of low-velocity area than did debris-torrented channels treated with boulder berms. Kaufmann's work suggests that structural complexity afforded by wood debris provides more juvenile resting habitat than does rock structures, and that wood debris is more effective in dissipating stream energy, causing gravel to deposit for spawning habitat. The general consensus is that structures built from logs are more durable, effective, and less expensive than rock gabions (Bisson et al 1987; Reeves et al 1991; J. Anderson, personal communication).

Of the many functions provided by wood debris within stream channels, its importance in collecting and storing sediment is well recognized (Gilbert 1914; Megahan and Nowlin 1976; Swanson and Leinkaemper 1978; Sedell and Luchessa 1982; Triska 1984; Lisle 1986a; Sullivan et al 1987). The value of wood debris in providing natural, high quality spawning habitat to salmonids is well established (Sedell and Luchessa 1982; House 1984; Lisle 1986b; Bisson et al 1987; Meehan 1991). In the United States, wood structures have been built to mimic naturally occuring wood debris and improve fish habitat since the work of the Civilian Conservation Corps in the 1930's (Tarzwell 1937; 1938) and have been refined over time (Shetter et al 1946; Gard 1961; Tripp 1986; Hunt 1988). The few studies of habitat improvement that include log sills derive from objectives focused upon improving rearing habitat for

salmonids (Anderson et al 1984; Everest et al 1985; Fontaine 1988). Few published accounts of the effectiveness of log sills to trap spawning gravels exist.

Reeves et al (1991) describe two projects (Bender 1978; Anderson et al 1984) outlining design of log sills that trapped spawning gravels. These structures imitated two previously used gabion designs, the oblique sill and the downstream-pointing "V" sill. Anderson et al (1984) preferred the "V" sill, with the vertex pointing downstream, for containing introduced gravels in gravel-poor streams. The face of a sill oriented oblique to the direction of flow forces the flow alignment to be perpendicular to its face and toward the bank, or both banks in the case of this "V" design. Such redirection will scour the streambank under high flow conditions, creating pool habitat useful for rearing juvenile salmonids. Scoured gravels entering the channel's bedload may deposit and provide spawning habitat in the tailcrest of such a pool, or at other channel obstructions such as upstream of the next log sill, as observed by Anderson et al (1984) when structures were grouped and appropriately spaced.

To assess the effectiveness of sills in introducing and trapping spawning-sized gravels, physical and biological data were collected describing pre- and post-treatment conditions within the study area. The following objectives were chosen for evaluation:

1) Comparison of pre- and post-treatment longitudinal streambed profile in treated reaches of the study area.

2) Comparison of changes in streambed gravel patch number and area in treated and control reaches of the study area.

3) Comparison of changes in number of trout redds in treated and control reaches of the study area.

4) Comparison of changes in hiding cover in treated and control reaches of the study area.

5) Comparison of changes in trout populations in treated and control reaches of the study area.

STUDY AREA

Historical Perspective

The written history of Confederate Gulch dates back to the Civil War, when rebel prisoners taken during the Union's Missouri campaign of 1864 were repatriated by the government to the territories of Idaho and Montana (Montana State Historical Archives). Relocation reduced the chance of re-enlistment in the Confederate Army, and accelerated the settlement of a wild, sparsely populated region of great natural resource potential. In the spring of 1866, three such exiles, exploring the side canyons of the Missouri River southeast of what is now the city of Helena, Montana, panned gold from what are considered to be the richest placer deposits ever discovered in the state (Lyden, 1948). Word of a gold strike at "Confederate Gulch" spread quickly and within a matter of weeks 10,000 people had congregated in the upper reaches of the watershed and formed a mining camp known as Diamond City.

Placer mining techniques employed during this period were relatively crude yet intensive (Lyden, 1948). Headwaters were diverted into a canal system and transported across slopes at minimal grade. At desired locations downstream, flow was directed downhill into hydraulic giants — water cannon the nozzle of which focus water into a powerful jet — that eroded valley side soils containing gold placers. Such mining reduced Confederate Gulch's valley floor elevations by as much as 12 m in some areas (Figure 1), and have yet to be reclaimed (Figure 2). Gold particles were then separated from the eroded streambed materials and collected in rockers or sluice boxes, the spoils being washed back into the stream or onto the streambank.

The majority of rich placer deposits within Confederate Gulch were extracted within 5 years of discovery. Mining decreased drastically afterwards, and Diamond City was a ghost town by 1880. The effects of hydraulic mining upon channel morphology and habitat diversity within Confederate Gulch

Figure 1. Diamond City, Confederate Gulch, MT, 1871. Note downcut channel, hillslope canal system, and vegetative composition. Montana Bar is left of center. Montana State Historical Archives.

Figure 2. Same photo point, 1991. Vegetation has changed from open rangeland to closed canopy forest. The foreground where buildings stood in 1871 is now washed away; the canal system is still discernible across the slope at upper center where trees have grown in its wetter depressions. Photo by C. Riley.

during this period likely paralleled those occurring two decades before in the central Sierra Nevada Gilbert, 1917). Similarly, mining-induced impacts upon the native trout population in Confederate Gulch must have been great (McEvoy, 1986).

Advances in mining technology, combined with the high value of gold on the speculative market, prompted further activity within Confederate Gulch from the mid-1930's through 1942 (Lyden, 1948). This second phase of mining employed large floating dredges that washed streambed materials more efficiently, depositing spoils on streambanks in tailings piles sometimes as tall as 6 m and easily observed today. Smaller scale commercial and recreational mining continue in the watershed to date.

A large magnitude rainstorm struck west-central Montana on May 21-22, 1981, following two storms over the previous 2 weeks that had saturated a melting snowpack. Floods occurring regionally were in the range of a 100-year flood, causing damages exceeding $30 million (Parrett, et. al., 1982). Plots of annual maximum discharge ranked by order of magnitude for Confederate Gulch and Ten Mile Creek, a geomorphologically similar watershed southwest of Helena, indicate that the flood in Confederate Gulch was on the order of a 90 to 100-year event and is the highest flow ever recorded in either watershed.

Apparently a debris torrent occurred during the flood that washed large wood debris downstream and out of the channel. The debris torrent also destroyed culverts and sections of road near the stream, and left behind a streambed armored by material of cobble to boulder size. Few fish survived this catastrophic disturbance (White et al 1992), and, combined with the loss of spawning gravels, the ability of the population to rebuild itself was greatly reduced.

Physical Characteristics

Confederate Gulch originates in the Big Belt mountains of central Montana, flowing southwestward into the Missouri River at Canyon Ferry Reservoir, approximately 27 km northeast of Townsend in Broadwater County (Figure 3). The watershed's geologic constituents are primarily shales and limestones interspersed with quartz diorite dikes (Pardee and Schrader 1933). These dikes are the source
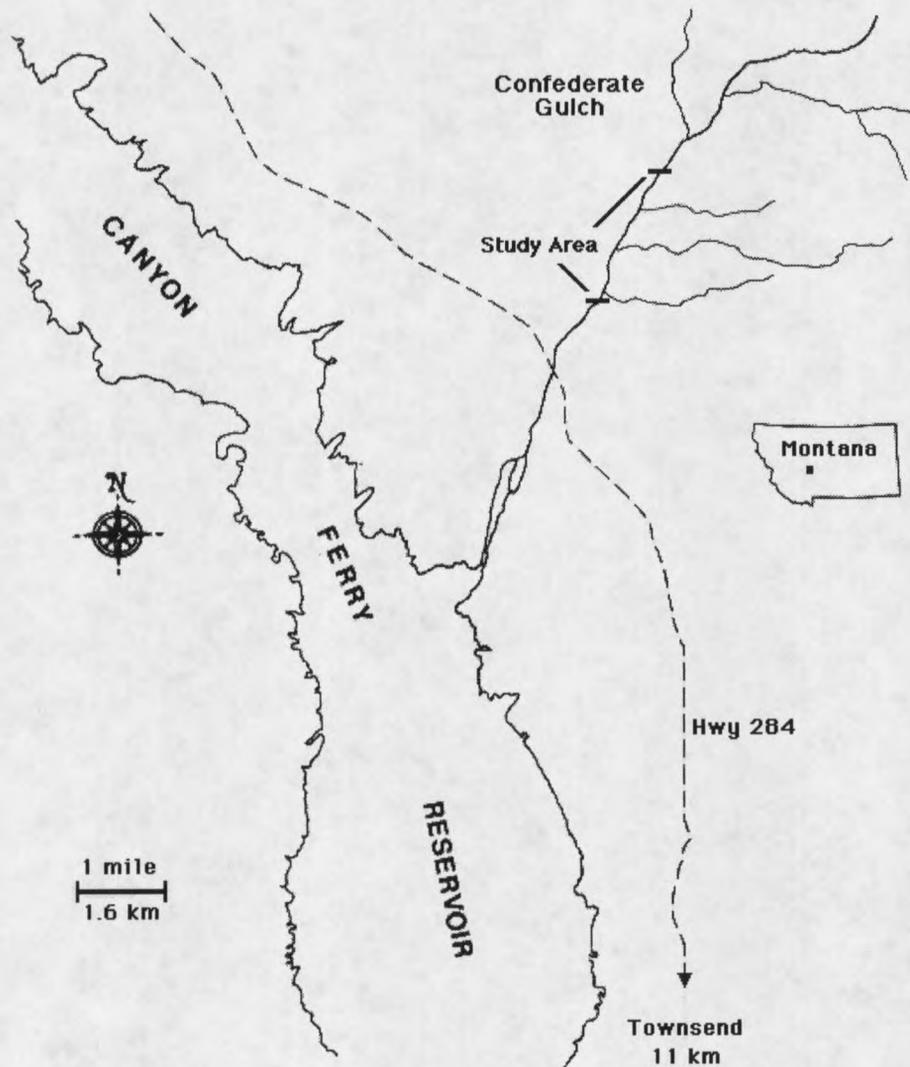
Figure 3. Relative location of Confederate Gulch and the study area within the state of Montana.

of gold placer deposits evolved from the early Pleistocene, the richest having been found in the vicinity of

the confluences of Montana Gulch, Boulder Creek, and Cement Gulch with Confederate Gulch.

Confederate Gulch drains 39.2 km^2 of what is chiefly mixed conifer forest (Figure 2) that before fire

control was a sagebrush/grassland dominated landscape (Figure 1; Gruell 1983). Such changes in

vegetative composition and structure may have affected seasonal streamflow and flood characteristics

within the watershed as inferred from studies of vegetation manipulation (Wilm and Dunford 1948; Bosch and Hewlett 1982; Troendle and King 1985). Climatic data recorded at Canyon Ferry Dam (20 km northwest of the study area) from 1958 through 1991 indicate a wet-dry sequence in which the years 1986-1991 had a drying trend during a period of above average annual precipitation (White et al 1992). Most floods that occur within the watershed are likely generated by long and/or intense rainfall rather than snowmelt, as most of the drainage is not high enough for much snow accumulation.

The study area includes 3.9 km of perennially flowing stream, beginning a few meters downstream of its confluence with Hunter Creek and continuing upstream. Land ownership includes private range within the lower two-thirds of the study area downstream to the mouth of the canyon including the south slope, lands administered by the Bureau of Land Management (BLM) primarily in the upper half of the study area including the north slope of the canyon, and patented mining claims in the upper third of the study area and various headwaters. The Helena National Forest administers most of the lands upstream of the study area. A few livestock grazed freely in the study area during summer. A diversion dam about one-quarter mile downstream of the study area supplies water to irrigators. Stream diversions generally reduce streamflow such that the channel runs dry for at least a mile below the dam during winter and some periods during late summer, when streamflows are naturally low. Sub-surface flow is likely related to changes in valley floor materials due to mining. About three-fourths the way up the study area is a reach of stream about 300 m long that also flows sub-surface during winter low-flow. At the mid-point of this reach, between its channel and the road, emanates a spring. Discharge from this spring is relatively stable (0.05 cms) year-round. The stream flowing from the spring supports a dense growth of aquatic vegetation in its channel. Juvenile brook trout are very numerous in that channel, and many brook trout spawn there in the fall. Due to its protected location and stable flow, the spring channel probably serves as a refuge to trout during disturbances such as high flows, debris torrents, freeze-out, and ice scour (Sedell et al 1990).

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METHODS

Reference Stationing and Sections

In 1986, the study area was divided into 39 consecutive 100-m stations for spatial reference in data collection. Measurements were made using a fiberglass tape floating in the thalweg; stations were flagged and numbered individually at each upstream boundary. Station 26 (131 m) and station 39 (40 m) were the only deviations from the 100-m standard length in 1986 (Appendix A); all station lengths were measured again in 1989. Station 99 is the small spring channel previously mentioned; it emanates from the base of an old spoils pile and flows 160 m between the road and main channel to confluence near station 31 (Figure 4).

Stations were grouped into sections labelled as treated or control according to whether or not sill installation occurred within the bounds of a station. Sill # 24, a downstream-pointing "V" design, was installed straddling the boundary of stations 24 and 25. Station 24 contained no other sills, and to maintain its status as a control section (C6), I chose to include sill # 24 in section T5, as it was mapped by White, et. al. (1992). Treated sections were abbreviated as T1, T2, T3, T4, T5, and T6, ascending in order of upstream location; control sections were similarly abbreviated substituting "C" for "T" (Appendix A).

Sections T3 and C4 (stations 9-14) were altered by beaver during the course of the study, and I considered the distribution of surface gravel, trout redds, hiding cover, and trout populations in these sections to differ from that in areas less affected by beaver. To reduce the confounding effect of beaver upon my assessment of log sills, I chose to omit data collected in stations 9-14 in all years from data in all other stations during my evaluation. I did not regard beaver activity in stations 8, 15, and 34 to be

considerable enough to affect trout habitat or populations, and their occurrence was limited primarily to
the summer of 1990, before most potential changes in habitat or population could be detected during fall
data collection of that year.
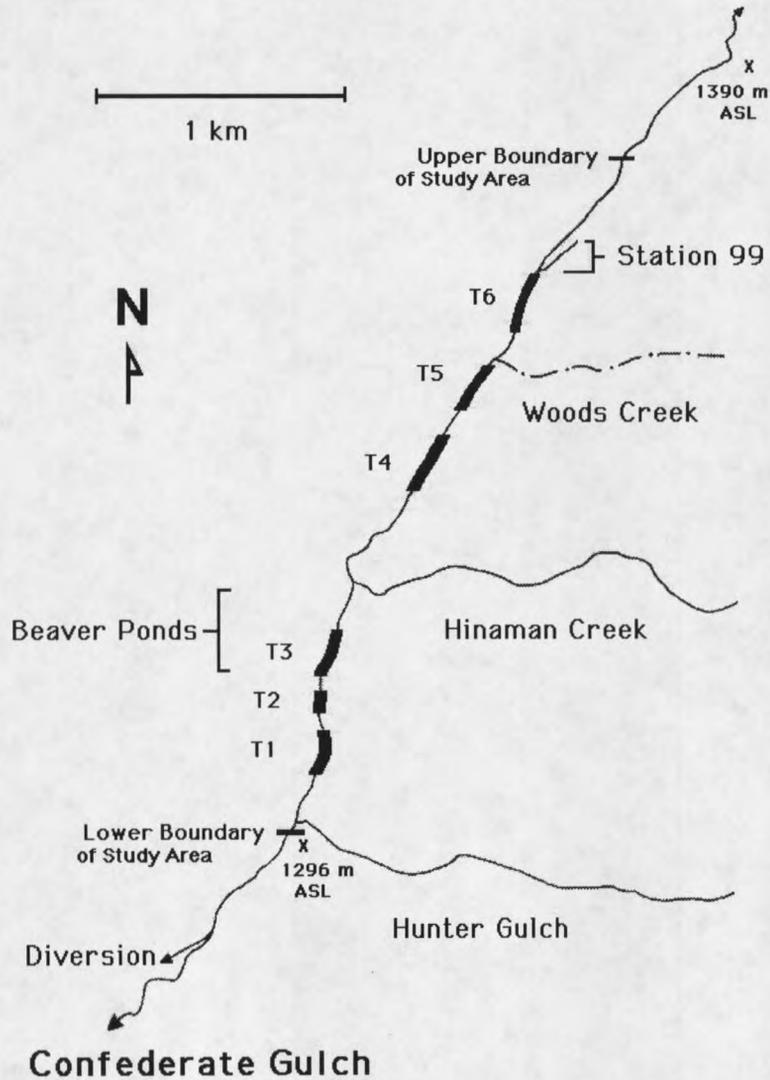
Figure 4. Study area, Confederate Gulch, MT. Note relative location of sections treated with log sills
and station 99. Treated sites are labelled T1, T2, T3, T4, T5, and T6, increasing
numerically in an upstream direction.

Design and Construction of Log Sills

During the summer of 1988, 40 sills were installed at Confederate Gulch in six treatment sites to trap gravels and create spawning habitat. Of the 40 sills, 27 were installed across the channel in an oblique (White et al 1992) orientation; the remaining 13 sills were of the downstream-pointing "V" design (Table 1). All sills were constructed with two logs, about 30 cm diameter, arranged one on top of the other such that the top log was aligned slightly downstream of the bottom log. Logs used in both oblique and "V" structures were cut to length such that each end of a structure was keyed about 2 m into its bank, buried with streambed materials dug from the scour pool below the sill, and then covered with small boulders to protect from erosion (White et al 1992). Steel rebar 1.5 m long was driven thru holes drilled through both logs and into the streambed to provide greater structural integrity. Wood slats of "2-by-4" about 2 m long were aligned perpendicular to the upstream sill face and nailed in place. Wire-mesh was then stapled upon these slats and backfilled with streambed material dug from the scour pool area.

Table 1. Description of physical characteristics and sill types within treatment sites, Confederate Gulch study area, 1987. Gradient measured in July, 1988; thalweg length measured in August, 1988.

Treatment section	Channel length (m) actually treated	in treated site	Gradient (%)	Number of sills Oblique	"V"	Total	Sill spacing (m)
T1	91	200	0.98	7	0	7	13.0
T2	24	100	1.86	2	0	2	12.0
T3	201	300	1.56	9	0	9	22.3
T4	104	300	1.48	1	4	5	20.8
T5	183	231	1.47	0	9	9	20.3
T6	166	300	2.06	8	0	8	20.8
Total	769	1,431	–	27	13	40	–

Streamflow

Water stage was recorded continuously, except when the stream was frozen, at station 8. The stage recorder was a Leupold-Stevens 16-day drum-chart gauge. The instrument was calibrated to stream stage as read from a staff gage set nearby. As charts were replaced, initial and final stage height were recorded along with respective date and time for each chart. Rating curves describing the relationship of instantaneous discharge to staff gage height were developed annually (Appendix B). I established a midnight bench mark for each chart, and after determining the pen's chart rate, I located and marked subsequent daily midnight points. I then measured daily high and low stage heights, transferred these data to a Lotus 123 spreadsheet, and computed mean daily stage height. Using the respective rating curve, I converted stage height to discharge (cubic meters per second; cms) and recorded this in the spreadsheet. I then plotted mean discharge by day for each year and overlaid line graphs displaying mean daily discharge for 1987, 1988, 1989, and 1990.

Flood Frequency and Magnitude

To estimate the frequency of various flood stages, particularly the May 1981 event, short-term flood recurrence intervals were estimated by plotting maximum annual discharge for Confederate Gulch and Ten Mile Creek, a geomorphologically similar watershed west of Helena (Dr. Stephen Custer, Department of Earth Sciences, personal communication). Dr. Daniel J. Gustafson, Department of Biology staff, plotted annual maxima ranked by order of magnitude for the continuous 82-year record of peak annual flows of Ten Mile Creek (1914-1991; 0.8-93.0 cms).

Dr. Gustafson approximated a straight-line fit of the data points by developing a logrithmic distribution along the x- (flood recurrence interval) and y-(annual maximum discharge) axes to model the probability of exceeding a particular discharge. Dr. Gustafson then plotted available annual maximum flow data for Confederate Gulch (1981, 1983-84, 1987-91) on the graph with data from respective years for Ten Mile Creek to examine for similarity of flood frequency between the two watersheds. If annual

maxima of respective years are of equal rank when ordered by magnitude, and the shape and slope of the resulting frequency curves are similar, then Confederate Gulch and Ten Mile Creek can be assumed to have similar hydrologic responses to particular precipitation events and the long-term data record available from Ten Mile Creek can be used as a surrogate to estimate flood recurrence intervals for Confederate Gulch.

Longitudinal Streambed Profiles

Longitudinal profiles of streambed elevation were developed for all treated sections in July 1988, February-March 1990, and August-September 1990. Each section was referenced as a numbered site, beginning with one (1) for the treated section farthest downstream and ascending in an upstream direction to Site 6. Selected high and low points of the streambed within the thalweg, including the deepest point and tailcrest of each pool, were measured with a Leitz model C3E automatic level and surveyor's rod to the nearest 0.01 foot. Measures of elevation were relative to a benchmark, generally a nail at the base of a tree, at each site. Data collected were then input into a spreadsheet, and Dr. Ray J. White and I created an equation based on the Law of Cosines to compute distance between succeeding survey points.. I transformed horizontal distance and elevation data relative to the each respective benchmark, referenced as zero. I then input transformed data for each profile into CricketGraph, a statistical-graphics software program, and plotted elevation as a function of horizontal distance to produce longitudinal profiles. I overlaid plotted profiles of all surveys made at each site for graphic comparison of changes in streambed gradient and channel morphology.

I computed residual pool depths (Lisle 1987) for all pools by subtracting the tailcrest depth of each pool from its maximum depth. I adopted a residual pool depth of greater than or equal to 0.4 m as a minimum criteria for defining pools valuable as habitat to trout. I calculated mean residual pool depths for all treatment sites and the entire study area for each survey.

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Surface Gravel

Surveys of area of surface gravel available to spawning brook trout were made within each station during fall-winter low flow conditions throughout the study area, working upstream from the lower boundary. A pre-treatment survey was conducted in January-February of 1987 followed by surveys in October-November of 1989 and December 1990 after sill installation. Measurements of "squared-off" (Binns, 1982) length and width were made to the nearest centimeter employing a 2 m length of 1-inch PVC tubing calibrated to 5 cm intervals. Lengths and widths were recorded for all patches of surface gravel having particle diameter 0.5-8.0 cm. Patches were further defined to be at least 10 cm squared-off length or width, covered by a minimum of 1 cm of water, and not covered by silt. For each patch, the depositional feature was noted, including: streambed contour, woody debris, pools, and beaver ponds, and data were entered into a spreadsheet where individual patch area was computed. I summed total gravel patch area by depositional feature, station, control and treated sections, and for the study area as a whole for each survey.

Trout Redd Counts

Weekly or biweekly surveys of brook trout redds were made in the fall of 1988, 1989, and 1990. Spring surveys for cutthroat and rainbow trout spawning were made from late April thru early June of 1990 and 1991. Counts were made walking upstream from the lower boundary of the study area, and were recorded by station. Level of development, or maturity, of redds was classified, in order of increasing pit and tailspill development, as trial, possible, probable, and definite. In the fall of 1989 and 1990, redds cut in gravels deposited upstream of log sills or in the tailspill of the downstream scour pool were noted, along with sill type. Also, in 1990, physical characteristics of individual redds (uniquely numbered with fluorescent painted rocks) were inventoried by redd type describing distance to nearest

cover, pit and tailspill depths, and water velocity within the water column, for selected redds. I input all data describing counts and physical characteristics of trout redds into a spreadsheet and computed totals and means where pertinent.

Trout Hiding Cover

Trout hiding cover was measured throughout the study area in the fall of 1986, 1989, and 1990. Types of cover measured in all 3 years included natural pool, beaver pond, undercut bank, brush debris, complex debris, log, overhead brush, overhead vegetation, and substrate. In 1989 and 1990, sill pool, undercut sill, rootwad (inventoried in 1986 as brush debris), and aquatic vegetation were inventoried; turbulence was added in 1990. For ease of comparison and consistency during analysis, brush debris, log, rootwad, and complex debris were combined into one designation of "wood debris". Measurements of "squared-off" length and width were made of all hiding cover to the nearest centimeter employing a 2 m length of 1-inch PVC tubing calibrated to 5-cm intervals. Lengths and widths were recorded for all patches of hiding cover having length and width greater than 10 cm and if in water depth of at least 10 cm. Non-submerged objects were included as cover if they were within 50 cm of the water surface.

Pools were identified as low-velocity areas of stream with maximum depth at least 40 cm. Quality of pool habitat was rated using a point system developed by the U.S. Forest Service (Rainville, personal communication). I rated the area of a pool as a "1" if its length or width was less than mean stream width, a "2" if its length or width was the same as mean stream width, or a "3" if its length or width exceeded mean stream width. I rated the depth of a pool as a "1" if its maximum depth was < 60 cm, a "2" if 60 to 90 cm deep, or a "3" if > 90 cm deep. I rated the cover of a pool according to the percent surface area of the pool containing trout hiding cover; a pool's cover was rated a "1" if less than 35% of its surface area contained cover, "2" if 35-65% of its surface area contained cover, or "3" if more than 65% of its surface area contained cover.

All data describing trout hiding cover and pool quality ratings were entered into a spreadsheet where I computed total hiding cover for the entire study area and total hiding cover stratified by station, section,

and cover type. I also computed total pool quality for each pool, and then computed means of total pool quality, pool area, pool depth, and pool cover for the entire study area and for each pool type. Pool types included natural pools, sill plunge pools, and beaver ponds.

Trout Populations

Trout populations were estimated using a modified Petersen mark-recapture method. Trout were electrofished with a boat-mounted 240-volt AC generator and Coffelt control unit set to about 175 volts DC (non-pulsed) output. The boat was pulled upstream by one crew member who also tended captured fish held in a live well. Fish captured within a particular station were held separate from those of other stations. Two other crew members each carried an anode pole and a short-handled net with which they captured fish. Where flow or wetted stream width were small enough to make boat use impractical, generator and control unit were operated from the bank and the electricity was conducted to the anodes by a long wire. To allow for safe and efficient electrofishing of beaver ponds in 1986, 1988, and 1989, each dam was breached to sufficiently drain the pond. Outflow was fished to ensure that trout did not escape downstream.

Trout were anesthetized with MS-222, and for each, data were recorded describing station caught, species, total length in millimeters, weight to the nearest 0.1 gram, and fin clip marks. Fish marked on the first pass recieved a clip of the corner of the lower caudal lobe; recaptured fish recieved a clip of the upper caudal lobe to prevent double-counting. After reviving, fish were transported to the downstream boundary of the respective station from which they had been captured and were released. The few fish which died during handling were noted as dead.

Fish population data were entered in a spreadsheet describing station caught, species, total length, weight, and whether unique, marked, recaptured, or dead. Due to the low number of recaptured fish in certain stations, I combined data from groups of neighboring stations to ensure greater accuracy when computing population estimates. Neighboring stations affected by beaver activities during the course the study were grouped together to allow separation of their data from data in stations unaffected by beaver within the study area .

To reduce the length bias of electrofishing upon capture efficiency, I developed length-frequency curves by 10-mm length class for all years electrofished (Appendix G). I visually inspected these curves for low-frequency size classes that relate separation between age classes, and interpreted size classes to further stratify data. After subtracting dead fish, I computed a population estimate by age class for each of the groups of data combined by stations. The formula used to compute the population estimate is:

$$N_g = m_g \, (r_g + u_g) \, / \, r_g$$

where "N_g" is the population estimate of the age class within station group g, "m_g" is the number of fish within the age class marked on the first pass of group g, "r_g" is the number of marked fish of the age class recaptured on the second pass of group g, and "u_g" is the number of unmarked fish of the age class caught on the second pass of group g. I computed population estimates for each 10-mm size class within a group of stations by multiplying the group population estimate by the proportion of uniquely caught fish ($m_i + u_i$) within each 10-mm size class relative to that within its respective age class, using the formula:

$$N_i = N_g \, (m_i + u_i) \, / \, (m_g + u_g)$$

where "N_i" is the population estimate of 10-mm size class i, "$(m_i + u_i)$" is the sum of marked and unmarked fish within 10-mm size class i, and "$(m_g + u_g)$" is the sum of marked and unmarked fish within the respective age class of group g. Finally, I computed population estimates for each station, by 10-mm size class, by multiplying the population estimate of a 10-mm size class for a group of stations (N_i) by the proportion of uniquely caught fish within station s relative to those of its respective group of stations, using the formula:

$$N_{is} = N_i \, (m_s + u_s) \, / \, (m_i + u_i)$$

where "N_{is}" is the population estimate for station s and 10-mm size class i, and "$(m_s + u_s)$" is the sum of marked and unmarked fish within station s.

To compute population estimates by age class for treated and control sections, I summed N_{is} respective of 10-mm size classes i within the respective age class and all stations s within the desired section. Similarly, I computed a population estimate of the study area, by age class and year, by summing all N_{is} for all stations s and all 10-mm size classes i, respective of age class.

Trout Biomass

Using CricketGraph graphics software, I plotted weight as a function of total length of individual fish, by species, for each group of stations by year. I then visually interpreted the best-fit line to the scatter-plot using polynomial and exponential equations drawn by CricketGraph. Choosing the 5-mm mid-point of each 10-millimeter interval of total length, I used a ruler to determine the weight in grams from the best-fit line. I then multiplied this weight by its respective population estimate (N_{is}) to compute a biomass within a particular station respective of its 10-mm size class in a particular year. I then calculated biomass of a particular age class by summing biomass of respective 10-mm size classes; similarly, I summed biomass by age class of respective stations to calculate biomass within a treated or control section.

RESULTS

Beaver Dams and Ponds

In 1986, a large beaver pond existed in station 13. By February of 1990, 14 dams had been constructed in stations 8 through 14 and three more were subsequently built in station 15 and one in station 34 by August of 1990. By March 1992, 18 dams had been constructed, of which six were directly upon sills that were installed as part of the gravel trapping project. One of these six dams was swept away by flooding and/or ice during the winter of 1989-90; two more were gone by the next spring. The sills probably afforded poor anchoring characteristics for beaver dams during high flow.

To reduce confounding effects of beaver activities upon the evaluation of sills to trap gravel and benefit trout habitat and populations, I omitted data describing surface gravel area, trout redd counts, trout hiding cover, and trout populations in stations 9-14, sections T3 and C4, where beaver activity was greatest during the course of the study. I judged the effects of beaver activity upon trout and their habitat in station 8, which existed in 1989, and stations 15 and 34, which occurred during the second half of the summer of 1990, to be considerably less than that observed in stations 9-14 and chose not to omit these two stations from the body of data used to evaluate sill effectiveness.

Streamflow

Drought prevailed in 1987 and 1988, and no significant high water occurred in either of those years, but 1989 and 1990 had major high water (Figure 5). Spring runoff in 1990 was particularly notable for the extended duration of its high flow. Maximum annual discharge of 5.45 m^3 and 4.40 m^3 in 1989 and 1990, respectively, represent a roughly four-fold increase in maxima over the previous 2 years. In 1990, mean daily discharge exceeded the maximum of 1.25 m^3 in 1988 for 39 consecutive days; and for 19 consecutive days in 1989, preceded by a short period of 4 days.
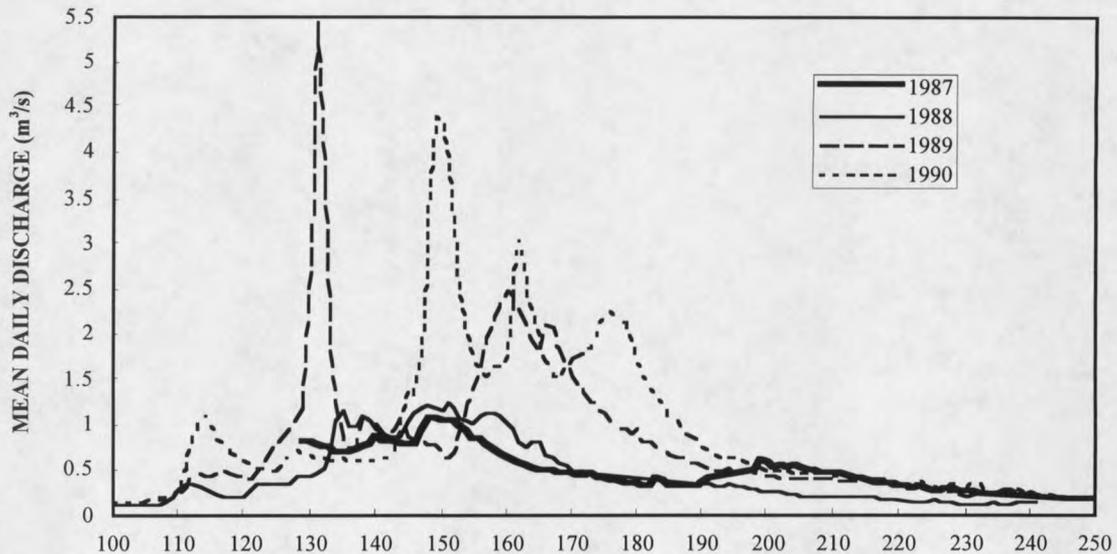
Figure 5. Mean daily discharge in Confederate Gulch, MT, as recorded at station 8, 1987-1990.

Flood Frequency and Magnitude

Flood frequency curves from short-term records for Confederate Gulch and Ten Mile Creek were developed (Figure 6). I inspected annual maxima and determined that respective years were of the same rank for each watershed. I then determined that the shape and slope of the two short-term flood frequency curves were similar enough, within the range of annual maxima of interest, such that the flood frequency curve developed from the long-term record of Ten Mile Creek would be appropriate for relating accurate flood recurrence intervals for Confederate Gulch. Upon relating the discharge measured during the May 1981 flood in Confederate Gulch to the long-term flood frequency curve for Ten Mile Creek, I determined that the flood was on the order of a 90- to 100-year event.

The relation of annual maximum discharge for Confederate Gulch recorded in 1989 and 1990 to the long-term flood frequency curve of Ten Mile Creek, indicates that flows of this magnitude or greater occur approximately once every 3 and 2 years, respectively, in Confederate Gulch.

EXCEEDENCE PROBABILITY
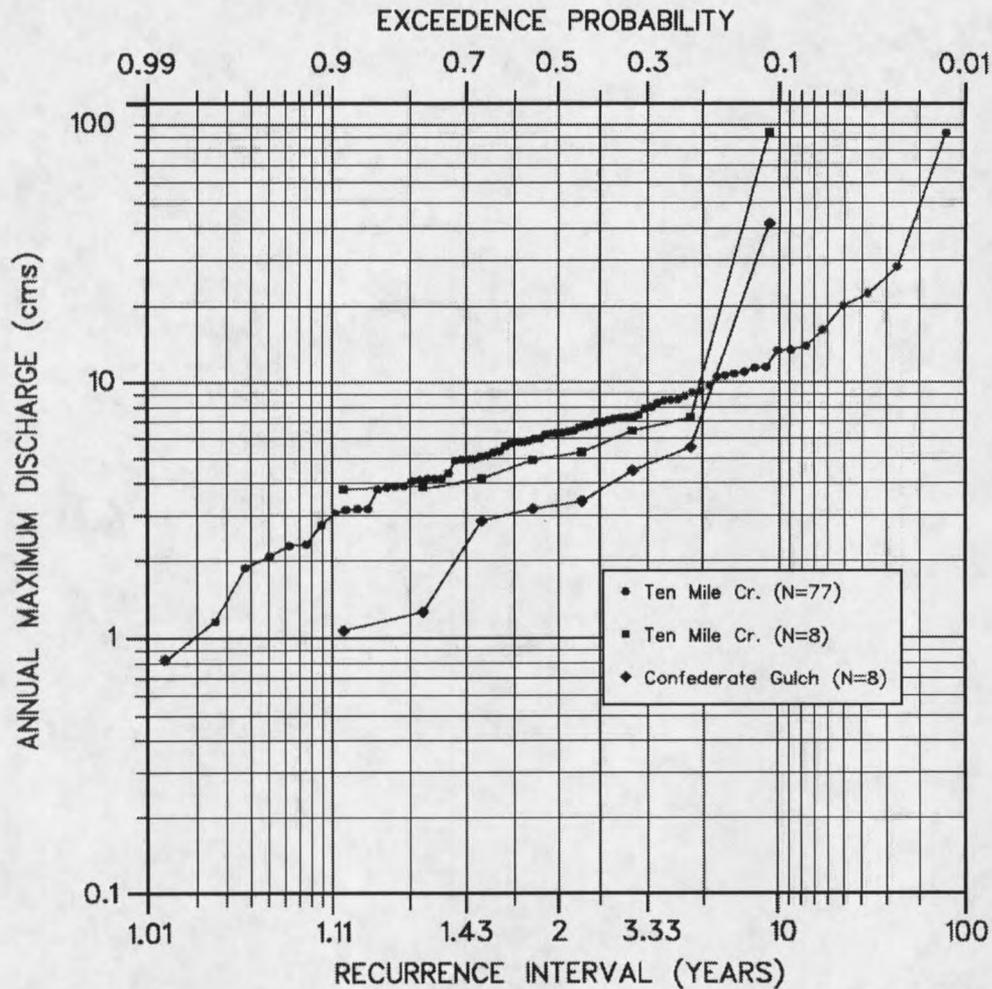
Figure 6. Flood frequency curves comparing relationships between short-term records of ranked annual maximum discharge (1981, 1983-84, and 1987-91) for Confederate Gulch, MT and Ten Mile Creek, MT, and to the long-term record (1914-1991) for Ten Mile Creek. Flows measured during the flood in May 1981 are the highest ever recorded in either watershed. Graph courtesy of Dr. Daniel Gustafson, MSU Department of Biology.

Longitudinal Streambed Profiles

Installation of log sills increased the complexity of the streambed profile (Figures 7-12). Sills raised

the base level of the stream in their immediate locality. Acting as a dam, each sill trapped transported

bedload, raising streambed elevation on the upstream side, while water dropping over each sill scoured

the streambed on the downstream side. It should be noted that sill construction included backfilling upstream of each structure using material dug from the expected scour zone (White et al 1992). This practice was necessary in sealing each structure to ensure surface flows and reduce risk of wash-out. Heavy machinery used to dig downstream material for upstream deposit penetrated the armored surface layer of substrate, exposing underlying gravel and enhancing the desired effects of deposit and scour.

In July of 1988, one pool with residual pool depth greater than 40 cm existed within treatment sites 1, 2, 4, 5, and 6 (Table 2). Many of the pools in treatment site 3 were beaver ponds, and their residual depths were excluded from my analysis relative to log sills. By March and September of 1990, 24 and 23 pools, respectively, exceeded residual pool depth criteria. Mean residual pool depth in these five treated sites increased with each successive survey.

Sill installation tended to increase both streambed gradient and elevation (Table 2). After sills were installed, slope increased at sites 1, 2, 3, 5, and 6, and mean streambed elevation increased at sites 1, 3, 5, and 6. In general, increases in slope were greatest at sites where pre-treatment slope was least. A relationship between pre-treatment slope and mean elevation was not readily apparent.

Standard deviation of all streambed elevation points in a survey indicated relative complexity in vertical streambed morphology. In comparison of pre- and post-treatment surveys by site, standard deviation of mean streambed elevation increased in 11 of 12 possible comparisons (Table 2).
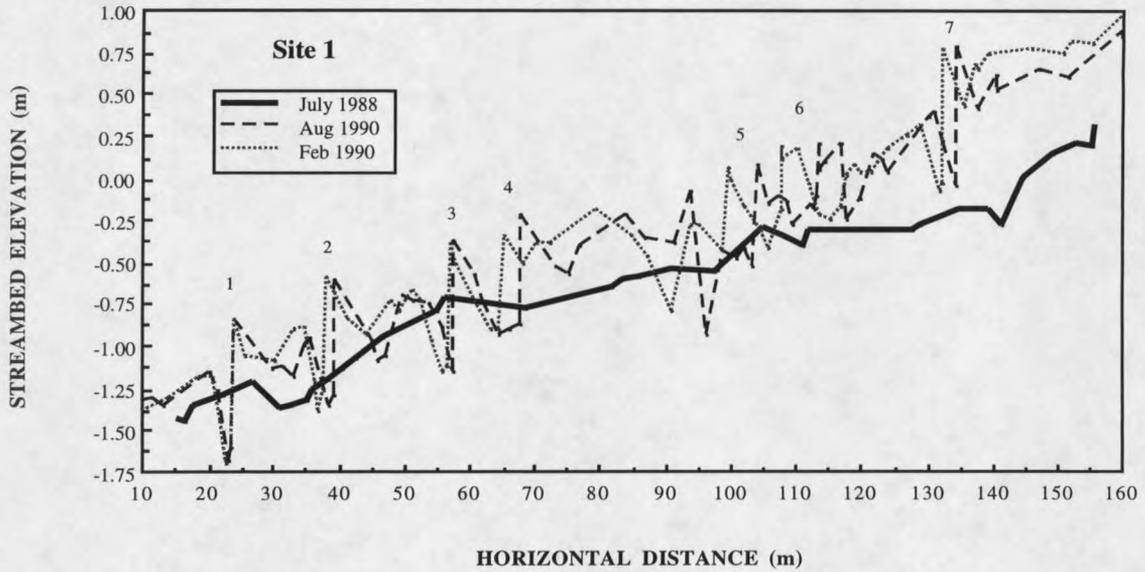
Figure 7. Longitudinal profile of streambed elevation, log sill treatment site 1, Confederate Gulch study area, previous to (July, 1988) and after (February, 1990 and August, 1990) sill construction. Sill position identified by number.
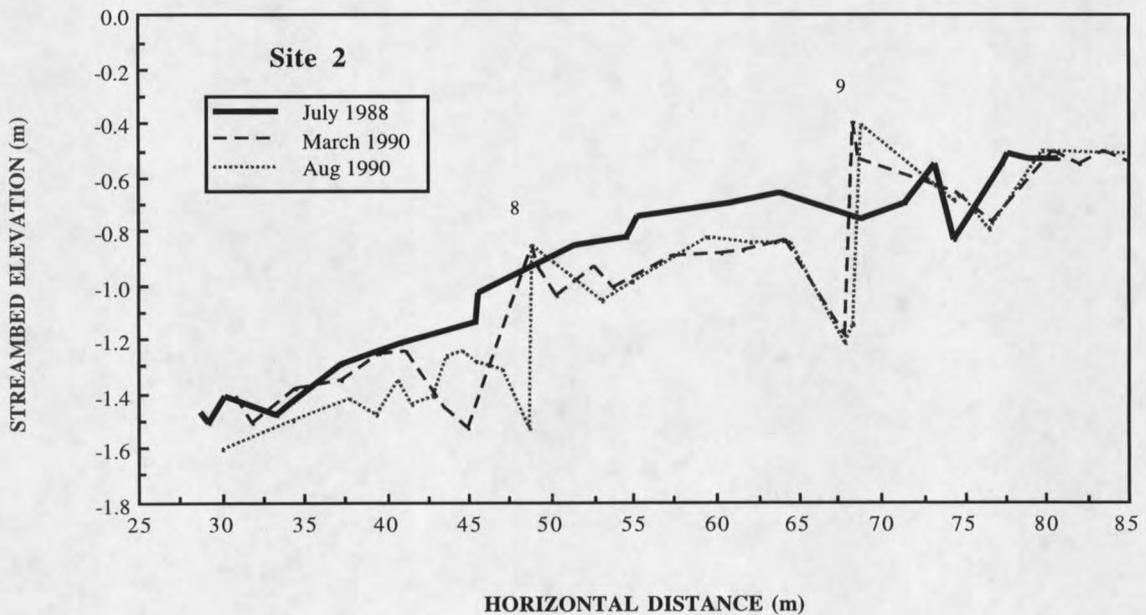
Figure 8. Longitudinal profile of streambed elevation, log sill treatment site 2, Confederate Gulch study area, previous to (July, 1988) and after (March, 1990 and August, 1990) sill construction. Sill position identified by number.

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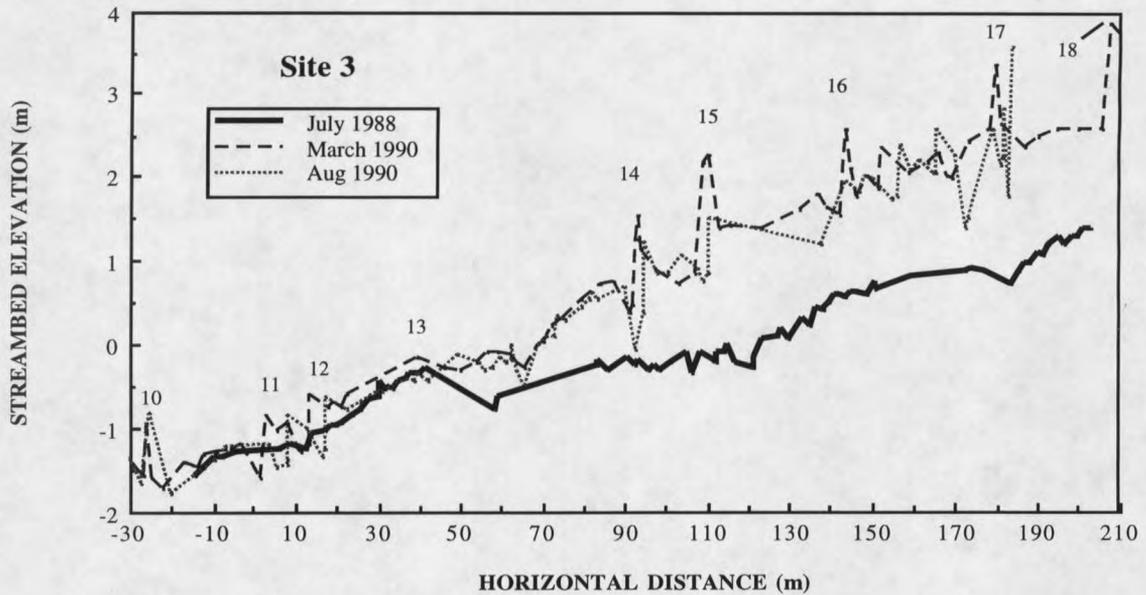
Figure 9. Longitudinal profile of streambed elevation, log sill treatment site 3, Confederate Gulch study area, previous to (July, 1988) and after (March, 1990 and August, 1990) sill construction. Sill position identified by number.
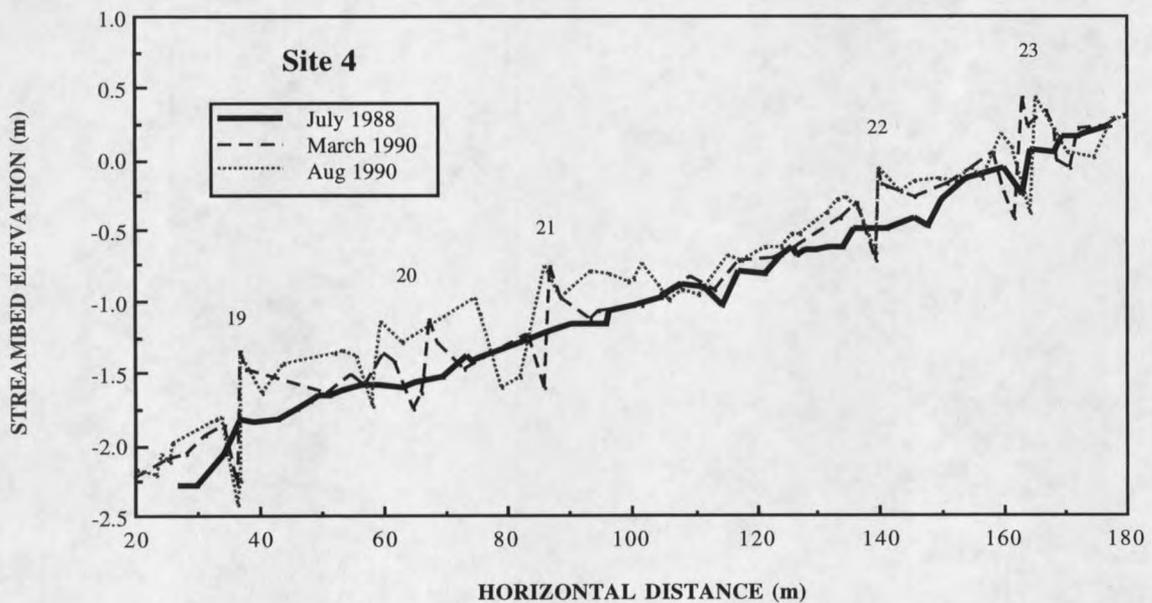
Figure 10. Longitudinal profile of streambed elevation, log sill treatment site 4, Confederate Gulch study area, previous to (July, 1988) and after (March, 1990 and August, 1990) sill construction. Sill position identified by number.
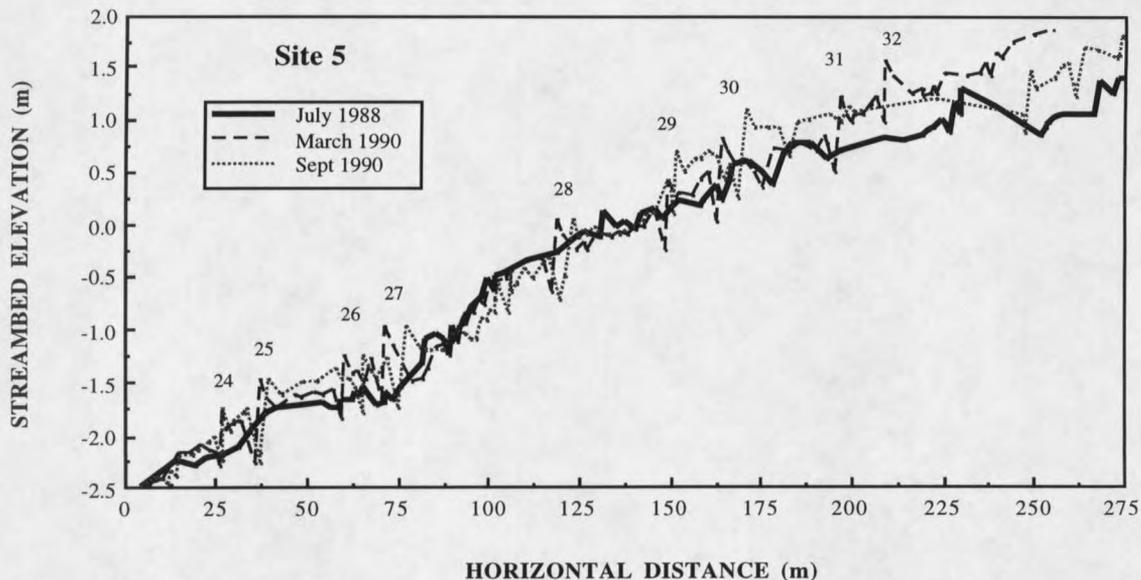
Figure 11. Longitudinal profile of streambed elevation, log sill treatment site 5, Confederate Gulch study area, previous to (July, 1988) and after (March, 1990 and September, 1990) sill construction. Sill position identified by number.
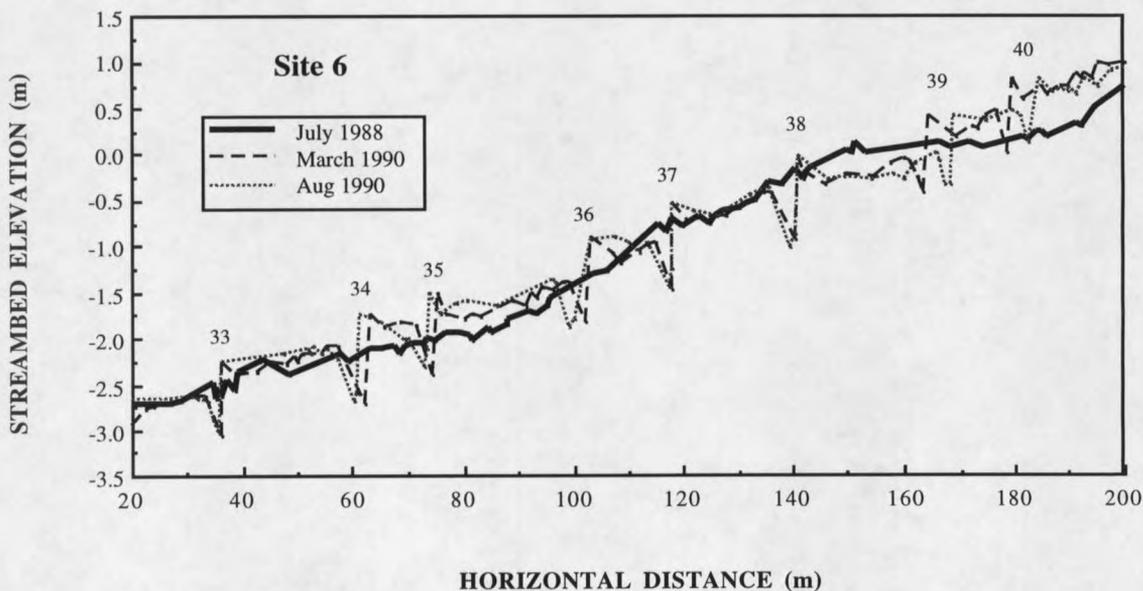
Figure 12. Longitudinal profile of streambed elevation, log sill treatment site 6, Confederate Gulch study area, previous to (July, 1988) and after (March, 1990 and August, 1990) sill construction. Sill position identified by number.

Table 2. Changes in thalweg length, streambed elevation, and pools ≥ 0.4 m residual pool depth at treatment sites surveyed before (July 1988) and after sill construction. Thalweg measurements relative to a benchmark at each site. Slope is by linear regression. σ = standard deviation. RPD = residual pool depth. NA = not applicable.

Site	Survey date	Number of points	Survey length (m)	Slope (%)	Mean elevation (m)	σ elevation (m)	Number of pools	Mean RPD (m)
1	July 1988	35	141	0.98	- 0.66	0.46	0	NA
	February 1990	71	142	1.52	- 0.39	0.53	7	0.52
	August 1990	70	147	1.45	- 0.40	0.52	7	0.56
	7/88 to 2/90	+36	+1	+0.54	+0.27	+0.07	+7	+0.52
	7/88 to 8/90	+35	+6	+0.47	+0.26	+0.06	+7	+0.56
2	July 1988	22	52	1.86	- 0.95	0.32	0	NA
	March 1990	28	54	1.84	- 0.94	0.35	0	NA
	August 1990	27	58	1.92	- 1.11	0.30	0	NA
	7/88 to 3/90	+6	+2	−0.02	+0	+0.04	+0	NA
	7/88 to 8/90	+5	+6	+0.06	- 0.16	- 0.02	+0	NA
3	July 1988	85	217	1.56	- 0.01	0.64	1	0.50
	March 1990	69	217	1.97	+0.70	1.22	7	0.69
	August 1990	72	193	1.96	+0.52	1.08	5	0.63
	7/88 to 3/90	- 16	+0	+0.41	+0.70	+0.58	+6	+0.19
	7/88 to 8/90	- 13	- 24	+0.40	+0.53	+0.44	+4	+0.13
4	July 1988	54	151	1.48	- 0.98	0.56	0	NA
	March 1990	60	178	1.59	- 1.00	0.75	5	0.44
	August 1990	61	160	1.46	- 0.89	0.59	5	0.52
	7/88 to 3/90	+6	+17	+0.11	- 0.02	+0.19	+5	+0.44
	7/88 to 8/90	+7	+9	−0.03	+0.08	+0.03	+5	+0.52
5	July 1988	95	283	1.47	- 0.27	1.03	1	0.43
	March 1990	115	272	1.74	- 0.41	1.20	4	0.48
	September 1990	115	282	1.61	- 0.44	1.09	6	0.46
	7/88 to 3/90	+20	- 11	+0.27	- 0.14	+0.17	+3	+0.05
	7/88 to 9/90	+20	- 1	+0.14	- 0.16	+0.06	+5	+0.03
6	July 1988	78	194	2.06	- 1.04	1.06	0	NA
	March 1990	85	185	2.14	- 0.95	1.07	8	0.50
	August 1990	76	215	2.11	- 0.95	1.08	5	0.57
	7/88 to 3/90	+7	- 9	+0.08	- 0.09	+0.01	+8	+0.50
	7/88 to 9/90	-2	+21	+0.05	- 0.09	+0.02	+5	+0.57
Totals	July 1988	369	1038	NA	NA	NA	2	0.46
	Feb-Mar 1990	428	1048	NA	NA	NA	31	0.54
	Aug-Sept 1990	421	1055	NA	NA	NA	28	0.55
	July 1988[a]	284	821	NA	NA	NA	1	0.43
	Feb-Mar 1990[a]	359	831	NA	NA	NA	24	0.49
	Aug-Sept 1990[a]	349	862	NA	NA	NA	23	0.53

[a] - Totals for all treatment sites excluding site 3, which contained beaver ponds.

Surface Gravel

Density of surface gravel (m^2 per 100 meters thalweg distance) increased over successive years for 1987, 1989, and 1990 (Figure 13). In 1987, before sill construction, surface gravel density in control sections C1-C3 and C5-C8 was more than double that of future treatment sections T1-T2 and T4-T6. This relationship changed by 1989 when gravel density in treated sections was 31% greater than in control sections. By 1990, density in treated sections had increased more than 37 times the 1987 density and exceeded control density by about 319%. By 1990, density in control sections increased by only one and three-quarters of their 1987 level.
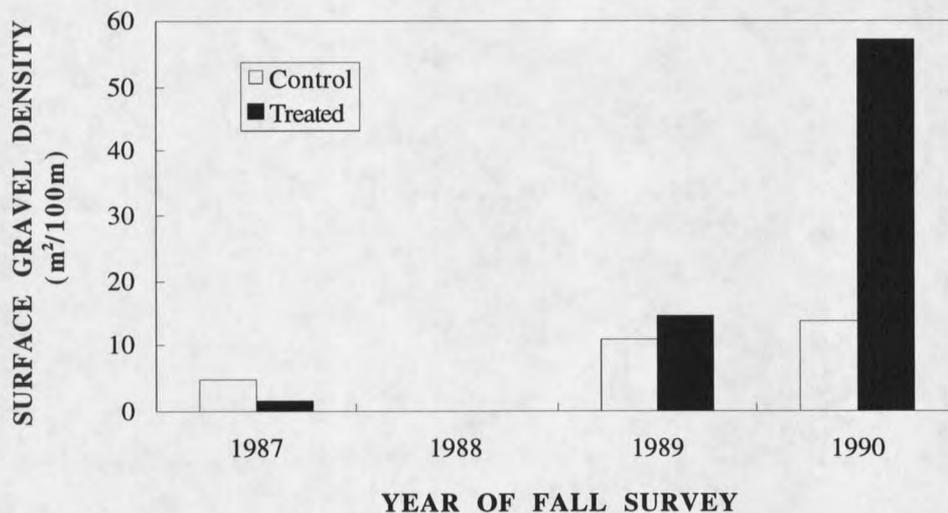
Figure 13. Lineal density of surface gravel area, stations 1-8 and 15-39, stratified by treated or control, Confederate Gulch, MT, fall of 1987, 1989, and 1990. No survey was conducted in 1988. Stations 9-14 were excluded to reduce confounding effects of beaver activities.

In 1987, the relative distribution of surface gravel density in upstream sections (T4-C8) resembled that in downstream sections (C1-C5), but by 1989, and particularly by 1990, surface gravel density in sections T4-C8 was greater than sections C1-C5, although section T1 had a large increase in 1990 (Figure 14). Sections T3 and C4, containing the greatest quantity of beaver habitat within the study area, had a relatively large increase in gravel density, in particular section C4 which lies upstream of T3.

After sill installation during the summer of 1988, surface gravel densities measured within all treated sections in 1989 and 1990 exceeded densities in neighboring control sections, with two exceptions (C5 in 1989 and C4 in 1990).
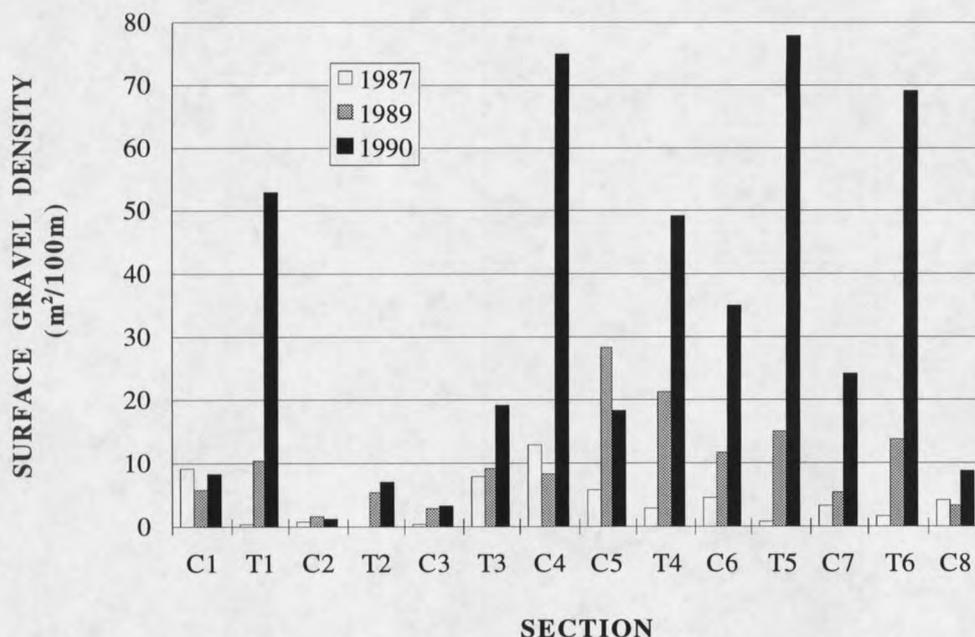
Figure 14. Lineal density of surface gravel area by section, Confederate Gulch, MT, fall of 1987, 1989, and 1990.

Surface gravel densities above and below sills, as measured in treated sections for 1989 and 1990 (Figure 15) were greater within the upper half of the study area than densities within the lower half of the study area, following the pattern observed throughout the study area. Mean surface gravel density below sills was 154% greater than mean density upstream of sills in 1989; in 1990 mean density below sills was 62% greater than mean density above sills. In 1989 and 1990, surface gravel density was greater below sills versus upstream of sills in all treated sections except section T4, which was composed primarily of downstream-pointing ɘV structures (as was section T5).
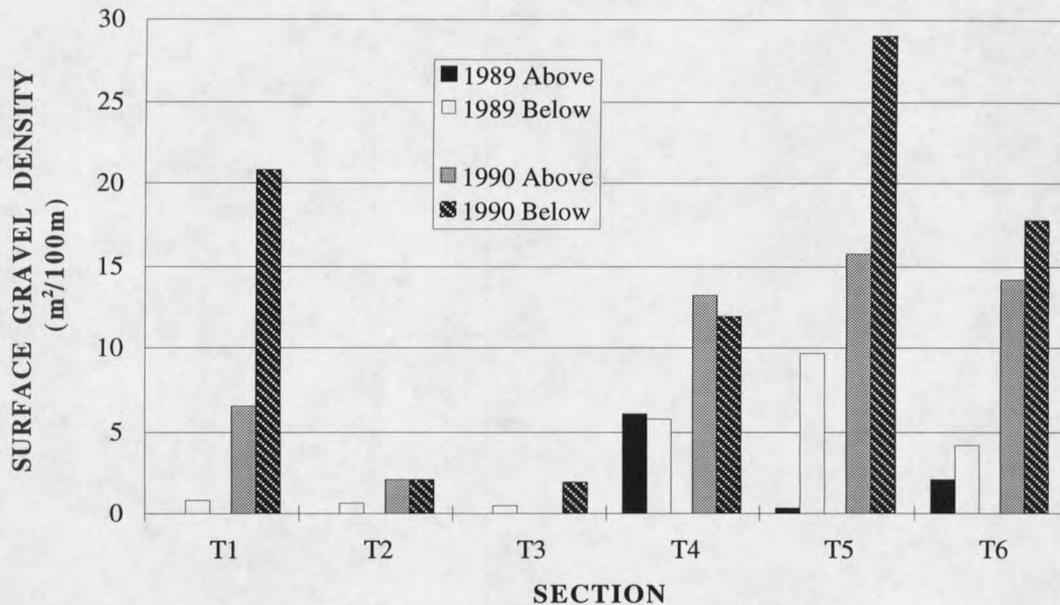
Figure 15. Lineal density of surface gravel area, stratified above and below sills by treated section, Confederate Gulch, MT, fall of 1989 and 1990.

The density of surface gravel patches increased 313% in control stations and 959% in treated stations from 1987 to 1990, excluding stations 9-14 affected by beaver activity (Figure 16). Patch density in control stations (7.3/100 m and 20.4/100 m) was slightly greater than densities observed in treated stations (3.7/100 m and 15.6/100 m) in 1987 and 1989; in both years density in control stations exceeded that in treated stations by at least 30%. In 1990, a dramatic increase within treated stations (39.3/100 m) resulted in a 30% greater patch density than that in control stations (30.2/100 m).

Mean gravel patch area increased in treated stations unaffected by beaver from 0.41 m^2 in 1987 to 0.93 m^2 1989 and 1.45 m^2 in 1990 (Figure 17), a cumulative increase of 253% from 1987 to 1990. Mean gravel patch area in control stations, excluding stations 12-14, decreased from 0.68 m^2 1987 to 0.54 m^2 in 1989 and 0.45 m^2 in 1990, resulting in a 33% cumulative decrease in over the entire 4 year period.

Figure 16. Gravel patch density, stations 1-8 and 15-39, stratified by treated or control, Confederate Gulch, MT, fall of 1987, 1989, and 1990. No survey was conducted in 1988. Stations 9-14 were excluded to reduce confounding effects of beaver activities.

Figure 17. Mean gravel patch area, stations 1-8 and 15-39, stratified by treated or control, Confederate Gulch, MT, fall of 1987, 1989, and 1990. No survey was conducted in 1988. Stations 9-14 were excluded to reduce confounding effects of beaver activities.

Before sill construction in 1987, mean gravel patch area in treated sections was generally less than that of control sections at their immediate boundary (Figure 18). This relationship began to change in 1989 and reversed itself such that by 1990, excluding section C4 which was greatly altered by beaver dams, mean gravel patch area within treated sections exceeded that in neighboring control sections.
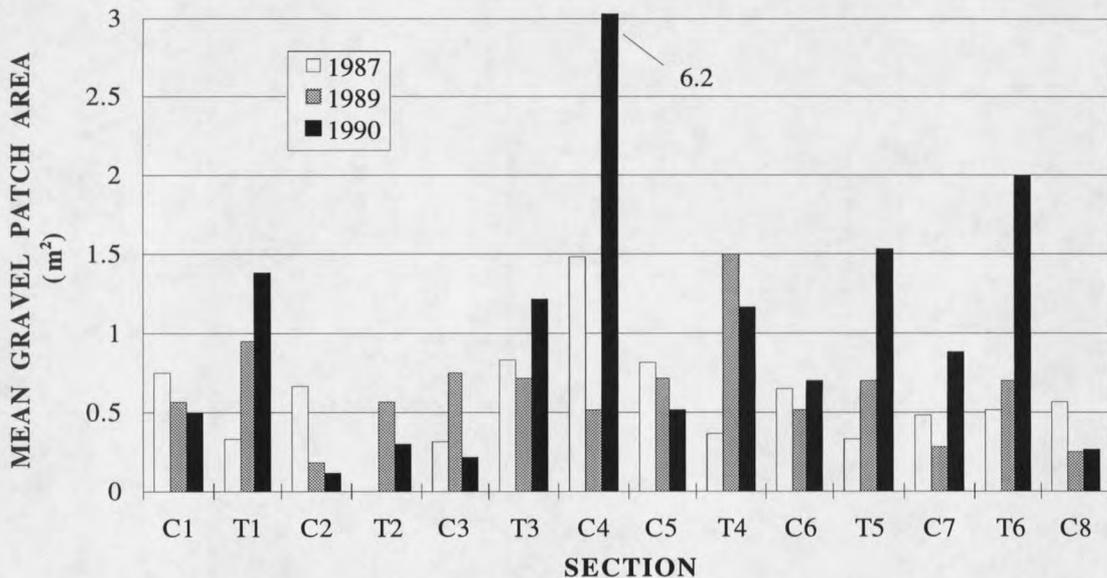
Figure 18. Mean gravel patch area by section, Confederate Gulch, MT, fall of 1987, 1989, and 1990.

As a depositional feature, streambed contour accounted for the greatest proportion of surface gravel area (67%) in the study area, excluding stations 9-14, in 1987 (Figure 19). The next greatest proportion of surface gravel area was associated with wood debris (22%), followed by pools (8%) and beaver dams (0%). By 1989, sills (built the summer before) accounted for 19% of all surface gravel area; streambed contour (54%) and wood debris (21%) exhibited greater proportions of surface gravel area while pool (6%) and beaver ponds (0%) described lesser amounts. In 1990, these ratios changed once again as surface gravel area associated with streambed contour dropped to 47% of the total. Sills (36%) increased considerably, while wood debris (10%) and pools (3%) declined and beaver dams were barely noticeable (1%).

GRAVEL DEPOSITION FEATURE
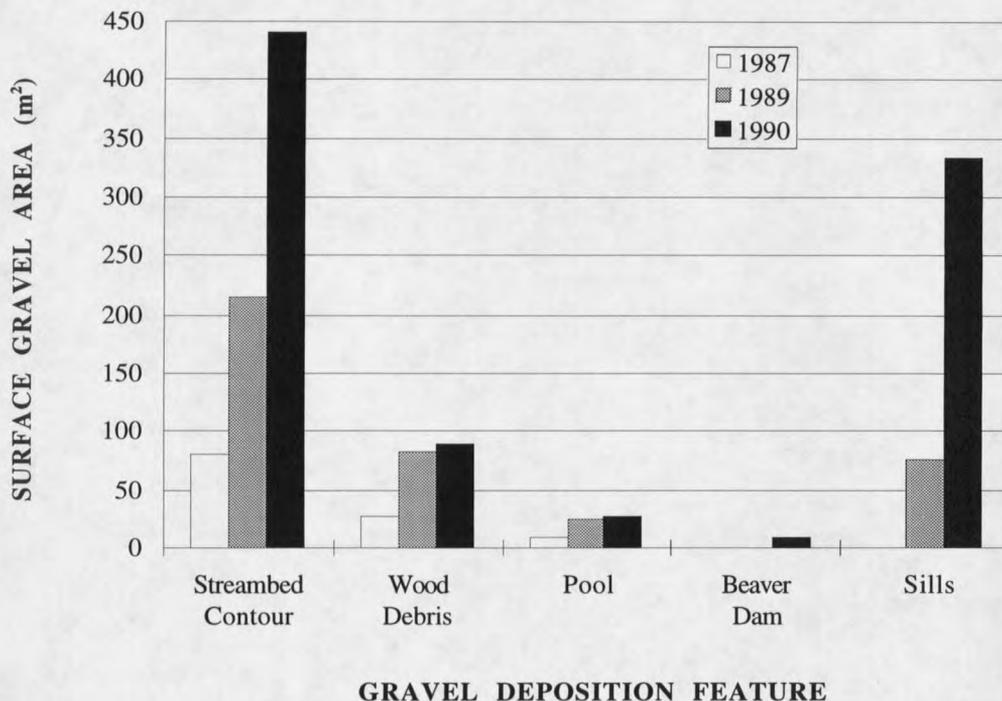
Figure 19. Surface gravel area stratified by depostional feature, stations 1-8 and 15-19, Confederate
Gulch, MT, fall 1987, 1989, and 1990. Stations 9-14 excluded to reduce confounding effects
of beaver activities.

In 1987, before sills were constructed, lineal density of surface gravel area was greater for all
depositional features in control stations than in treated stations (Figure 20). In 1989, lineal density of
surface gravel by depositional feature was still greater for all comparable control stations, however the
margins of difference had shrunk, and surface gravel density associated with sills was the largest measured.
By 1990, treated stations had relatively large increases in surface gravel density over 1989 levels for all
depositional features except beaver dams, which was zero for all years; control stations had decreases
associated with pools and wood debris, and surface gravel density associated with beaver dams increased
slightly from zero.
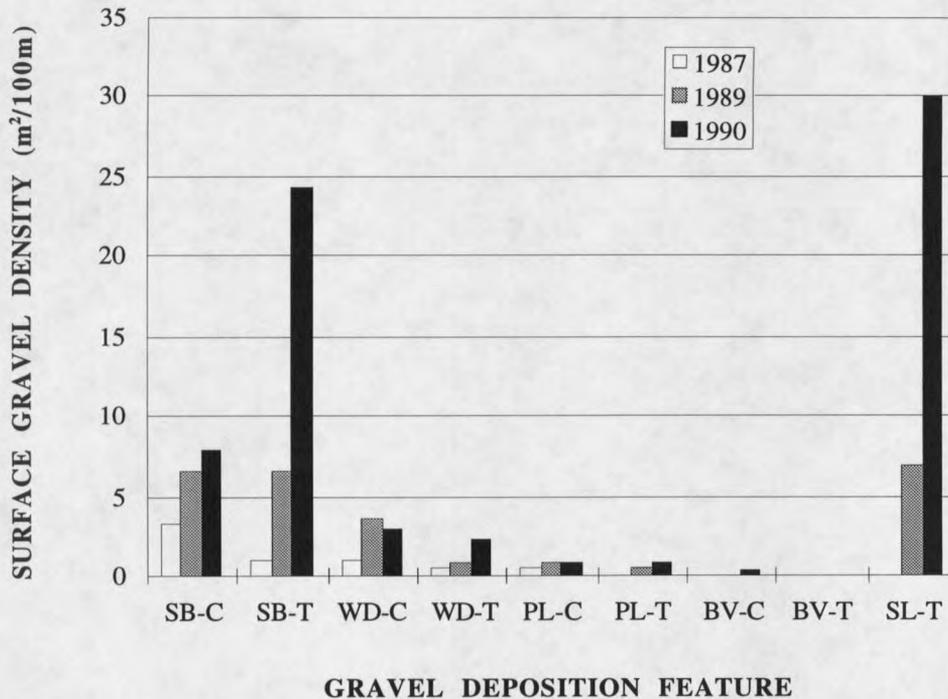
Figure 20. Lineal density of surface gravel, stratified by depositional feature, stations 1-8 and 15-39, Confederate Gulch, MT, fall of 1987, 1989, and 1989. Depositional features abbreviated as: SB = streambed contour, WD = woody debris, PL = pools, BV = beaver dams, and SL= sills. Control and treated abbreviated using "-C" and "-T" suffixes. Stations 9-14 were excluded to reduce confounding effects of beaver activities.

In 1987, the distribution of surface gravel density as a function of streambed contour (Figure 21) was relatively even between sections across the study area; after sill installation in 1989 and 1990, these densities increased more in the upper half of the study area (T4-C8) than within the lower half (C1-C5). A similar change between 1987 and 1990 in distribution of surface gravel density deposited by wood debris (Figure 22) and pools (Figure 23) occurred; pool-associated surface gravel surveyed in sections C1 and T1 in 1989 were present in 1990, but were excluded from that inventory due to a shallow covering of silt. It is worth noting that the upstream boundary of beaver activity was just downstream of the center of the study area. The density of surface gravel deposited at beaver ponds and dams (Figure 24) within the study area increased in 1990 17-fold over 1987 gravel densities. During the period of study, beaver ponds and dams were limited primarily to sections near the middle of the study area, although in 1990 beaver
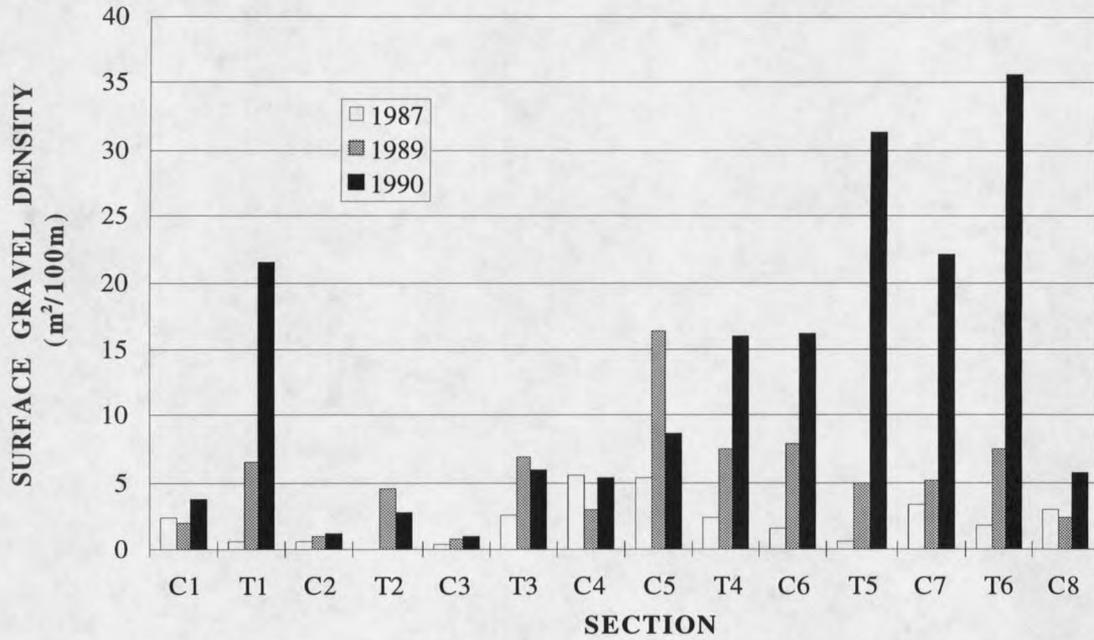
Figure 21. Lineal density of surface gravel associated with streambed contour, by section, Confederate Gulch, MT, fall of 1987, 1989, and 1990.
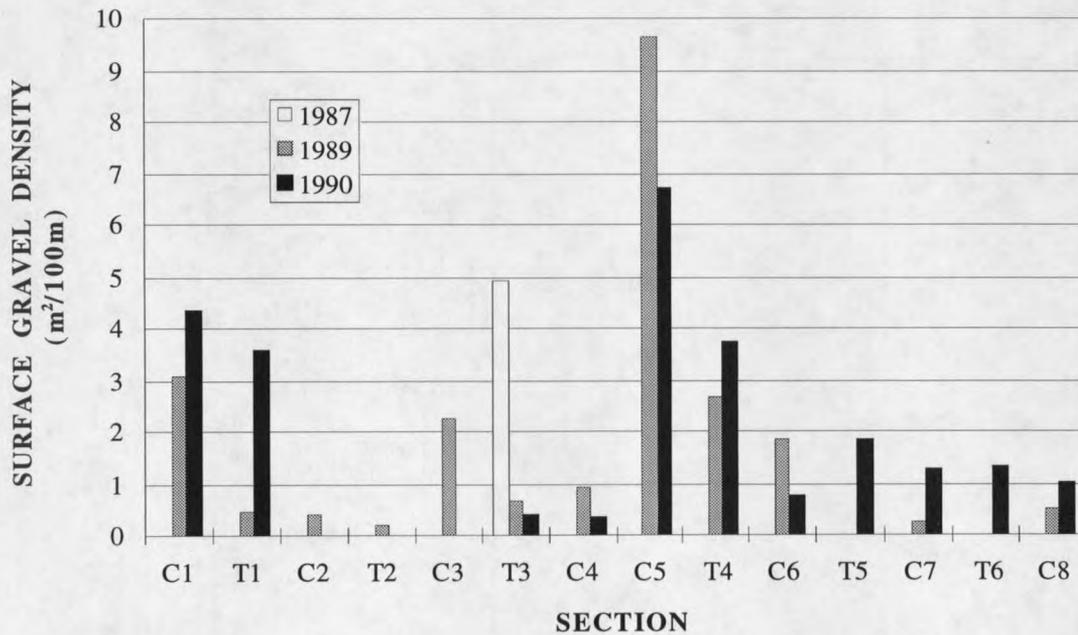
Figure 22. Lineal density of surface gravel associated with wood debris, by section, Confederate Gulch, MT, fall of 1987, 1989, and 1990.
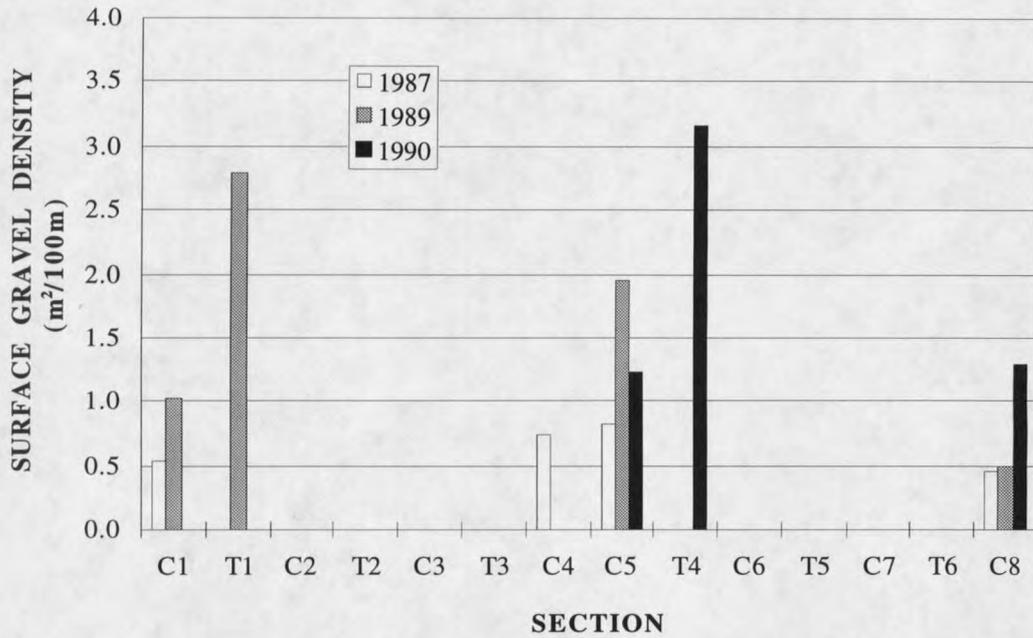
Figure 23. Lineal density of surface gravel associated with pools, by section, Confederate Gulch, MT, fall of 1987, 1989, and 1990.
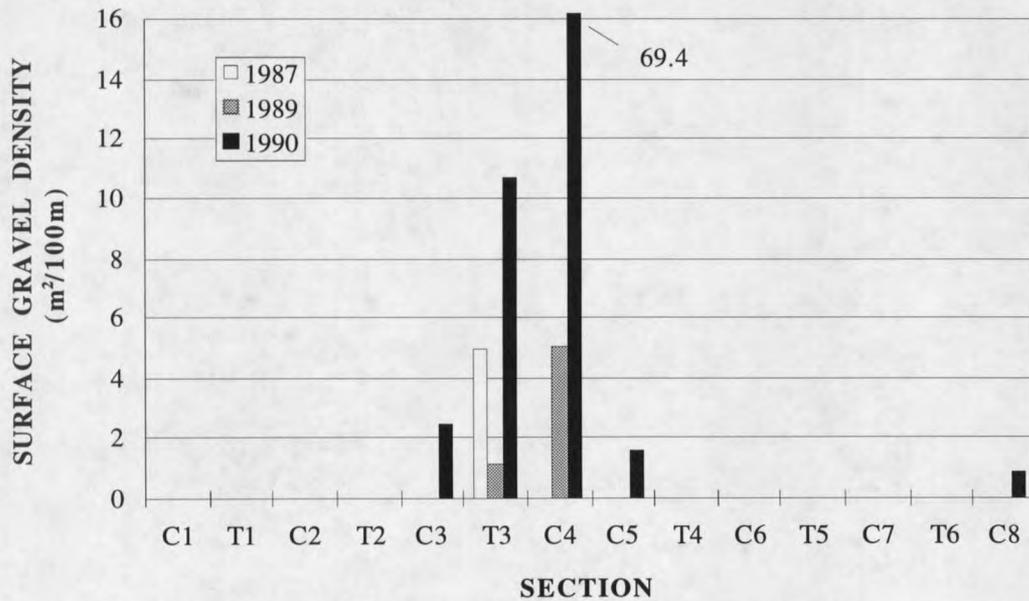
Figure 24. Lineal density of surface gravel associated with beaver ponds and dams, by section, Confederate Gulch, MT, fall of 1987, 1989, and 1990.

had dispersed downstream to station 8, upstream into station 15, and 1.9 km further upstream to station 34. In 1989, sections T3 and C4 contained all surface gravel deposited because of beaver activity; in 1990 this figure was 94%.

Trout Redd Counts

High, turbid flow prevented cutthroat trout redds from being seen during attempts to make springtime redd surveys from 1987 through 1990. Fall surveys of brook trout spawning indicated that lineal density of redds increased from 1988 to 1989, followed by a slight decrease in 1990 (Figure 25). In 1988, treated sections accounted for 45% of all brook trout redds and redd density was 40% greater than density in control sections. By fall of 1989, redd density within the study area increased 234% above the 1988 level and 44% of all redds occurred in treated sections; redd density in treated sections was 35% greater than density in control sections, a decrease of 5%. In 1990, redd density within the study area decreased by 14% of fall 1989 levels, but was 186% over fall 1988 density. Treated sections contributed 52% of all redds in 1990 and exhibited 86% greater redd density than control sections within the study area.
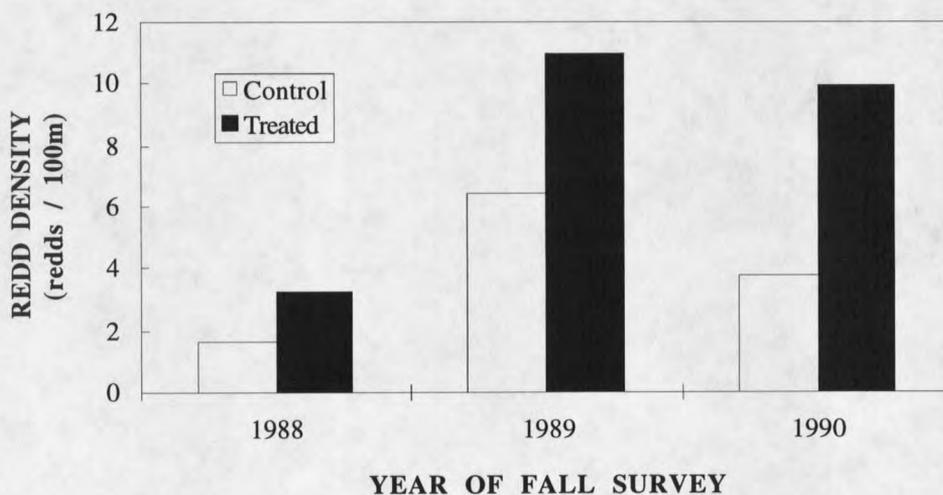
Figure 25. Lineal density of definite and probable brook trout redds combined, stations 1-8 and 15-39, stratified by treated or control, Confederate Gulch, MT, fall of 1988, 1989, and 1990.

In all 3 years, 1988-1990, redd density was greater in the upstream half (T4-C8) of the study area than in the downstream half (C1-C5) of the study area (Figure 26). In 1988, section T6 had the greatest lineal density of redds (8/100m). In 1989, lineal redd density was greatest in section T5 (18.9/100m), followed by section T6 (16.7/100m); redd density in 1990 was again greatest in section T6 (15.7/100m), and section C4 (12.0/100m). The sections exhibiting greatest redd density over the course of the study were T6, T5, C4, C8, and T4, in decreasing order.
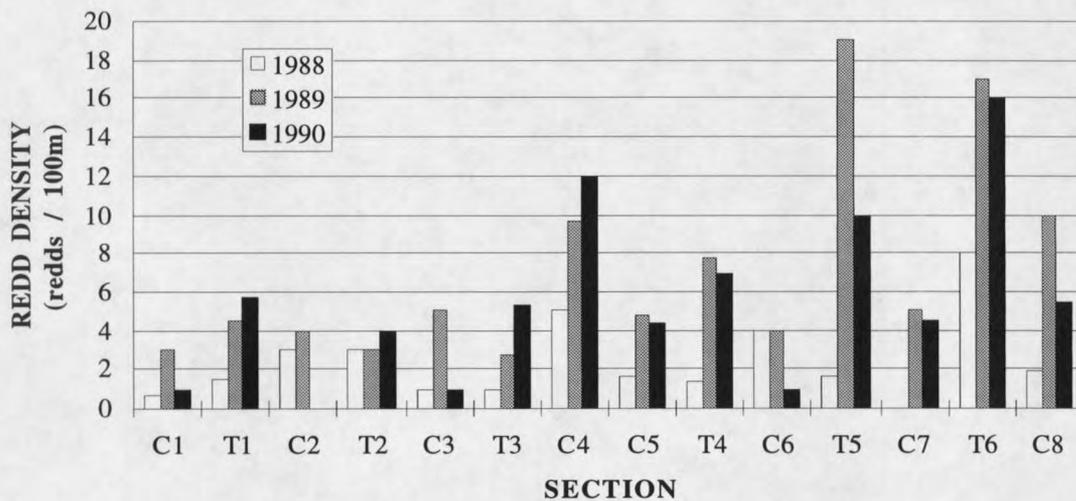
Figure 26. Lineal density of definite and probable brook trout redds combined, by section, Confederate Gulch, MT, fall of 1988, 1989, and 1990.

Oblique sills had 30% greater total redd density than "V" sills; conversely, density of definite plus probable redds, an index of redd quality (and implicitly spawning habitat quality) was 16% greater in sites having "V" sills than in those having oblique sills (Table 3).

Table 3. Mean number of redds per sill stratified by redd maturity and sill type, Confederate Gulch, fall of 1990.

Sill type	Number of sills	Redd density / sill type					
		Trial	Possible	Probable	Definite	Def+Prob	Total
Oblique	27	0.61	0.54	1.00	0.46	1.46	2.61
"V"	13	0.07	0.22	0.85	0.85	1.70	2.00
Total	40	0.25	0.32	0.90	0.72	1.62	2.20

Patterns relating redd maturity to redd-to-cover distance are not readily apparent (Table 4). Mean redd-to-cover distance for definite redds is considerably less than for probable or possible redds, while for trial redds this distance is slightly less. Mean redd-to-cover distance for definite redds not associated with sills is considerably less than for sill-associated definite redds; this pattern is reversed for trial redds while data for probable and possible redds indicate little difference.

Table 4. Mean physical characteristics of brook trout redds stratified by redd maturity and sill presence, October-November, 1990. Numbers in parentheses indicate sample size.

Physical characteristic	Sill presence	Maturity of redd			
		Trial	Possible	Probable	Definite
Distance to cover (m)	sill	0.86 (10)	1.99 (12)	2.38 (28)	1.90 (22)
	non-sill	1.75 (11)	1.86 (16)	2.47 (14)	1.11 (24)
	total	1.32 (21)	1.92 (28)	2.41 (42)	1.49 (46)
Pit Depth (m)	sill	0.26 (10)	0.21 (12)	0.19 (28)	0.21 (22)
	non-sill	0.25 (11)	0.22 (19)	0.17 (21)	0.25 (27)
	total	0.26 (21)	0.22 (31)	0.18 (49)	0.23 (49)
Tailspill depth (m)	sill	0.26 (9)	0.15 (12)	0.13 (28)	0.13 (22)
	non-sill	0.14 (10)	0.17 (19)	0.11 (21)	0.18 (27)
	total	0.19 (19)	0.16 (31)	0.13 (49)	0.16 (49)
Residual pit depth (m)	sill	0.04 (9)	0.06 (12)	0.06 (28)	0.08 (22)
	non-sill	0.04 (10)	0.05 (19)	0.05 (21)	0.07 (27)
	total	0.04 (19)	0.06 (31)	0.06 (49)	0.08 (49)
Water velocity .6 pit depth (cfs)	sill	[a]	0.28 (2)	0.70 (12)	0.81 (10)
	non-sill	[a]	0.51 (5)	0.40 (11)	0.53 (25)
	total	[a]	0.44 (7)	0.56 (23)	0.61 (35)
Water velocity pit bed (cfs)	sill	[a]	0.04 (2)	0.32 (12)	0.48 (10)
	non-sill	[a]	0.35 (5)	0.21 (11)	0.36 (23)
	total	[a]	0.26 (7)	0.27 (23)	0.40 (33)
Water velocity .6 tailspill (cfs)	sill	[a]	0.30 (2)	0.94 (12)	1.02 (10)
	non-sill	[a]	0.66 (5)	0.69 (11)	0.62 (25)
	total	[a]	0.56 (7)	0.82 (23)	0.73 (35)
Water velocity tailspill bed (cfs)	sill	[a]	0.16 (2)	0.60 (12)	0.76 (10)
	non-sill	[a]	0.41 (5)	0.58 (11)	0.55 (23)
	total	[a]	0.34 (7)	0.59 (23)	0.62 (33)

[a] Water velocity not measured for trial redds due to lack of depth.

Relationships of pit depth or tailspill depth to redd maturity and/or sill presence are not apparent

from the data. Mean residual pit depth tended to increase with redd maturity (Table 4). Redds associated

with sills had greater residual pit depth than redds not associated with sills for all redd types except trial

redds, whose differences were not discernible and may be due to small sample sizes.

Mean water velocity, which I computed for measures at the bed and at 0.6 of the water column of

both the pit and the tailspill of redds, increased with redd maturity at all positions for redds associated

with sills (Table 4). No patterns relating mean water velocity to redd maturity were readily apparent at

any position of the water column or pit.

Trout Hiding Cover

Density of trout hiding cover (m^2 / 100 m) decreased from 1986 to 1990 in treated stations, and

increased in control stations, excluding stations 9-14 affected by beaver (Figure 27). Aquatic vegetation

and turbulence were not included as trout hiding cover as neither cover types were sampled in 1986.

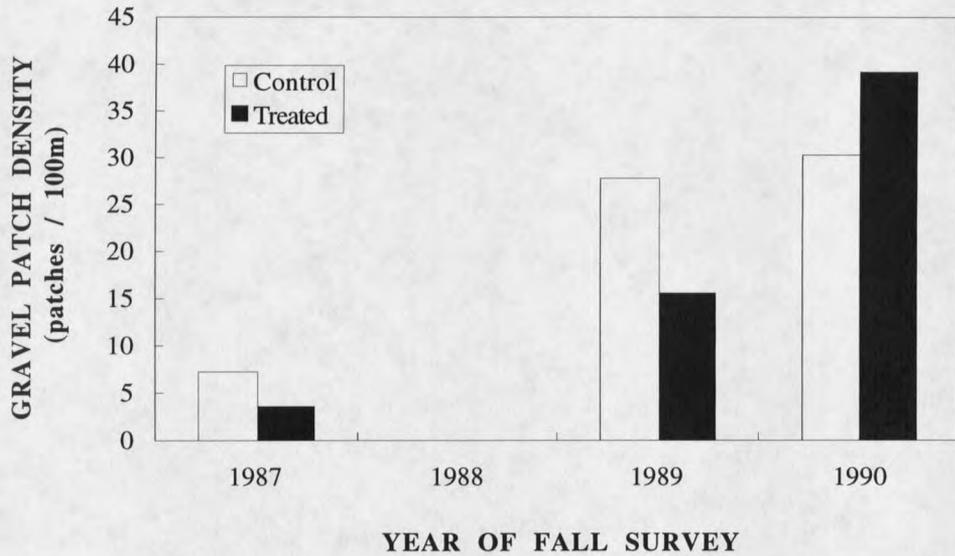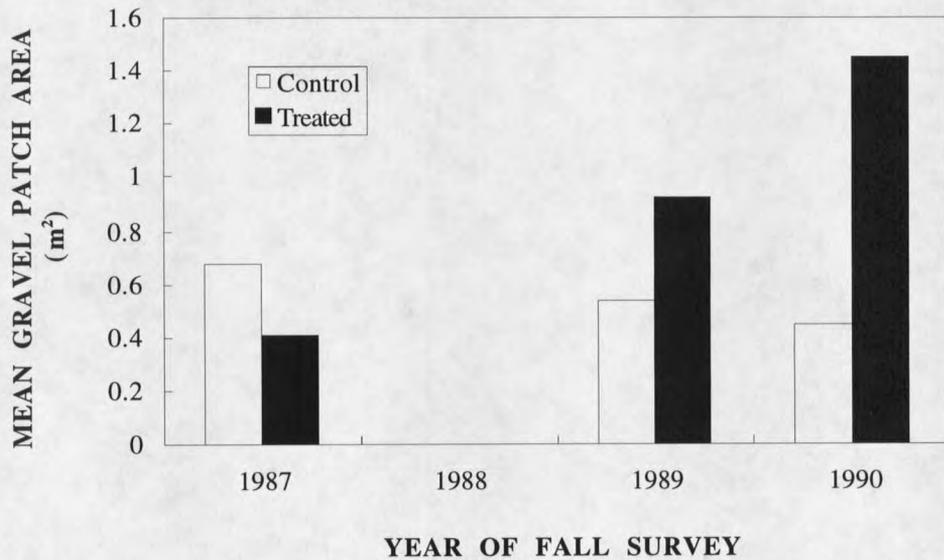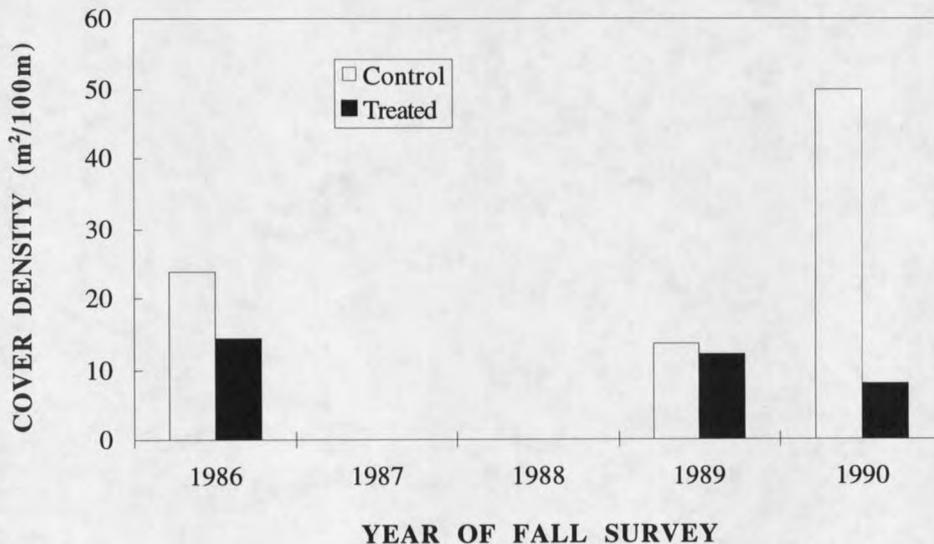Figure 27. Lineal density of trout hiding cover, stations 1-8 and 15-39, stratified by treated or control,
Confederate Gulch, MT, fall of 1986, 1989, and 1990. Stations 9-14 excluded to reduce
confounding effects of beaver activity.

In 1986, excluding stations 9-14 that were affected by beaver, cover density in control stations was two-thirds greater than that in treated stations. By fall of 1989, cover density decreased 15% in treated stations and 57% in control stations; cover density in control stations was 11% greater than in treated stations. In 1990, cover density in control stations increased 269% from its 1989 level, and decreased 36% in treated stations; cover density in control stations was 542% greater than in treated stations. Cover density in control stations increased 110% from 1986 to 1990, as a decrease of 46% occurred in treated stations over the same period.

Most hiding cover existed within the middle sections (T3 and C4) of the study area where beaver activity occurred (Figure 28). Large increases in cover density in sections C3 and C5 in 1990 were primarily a result of beaver expanding their habitat in both downstream and upstream directions.
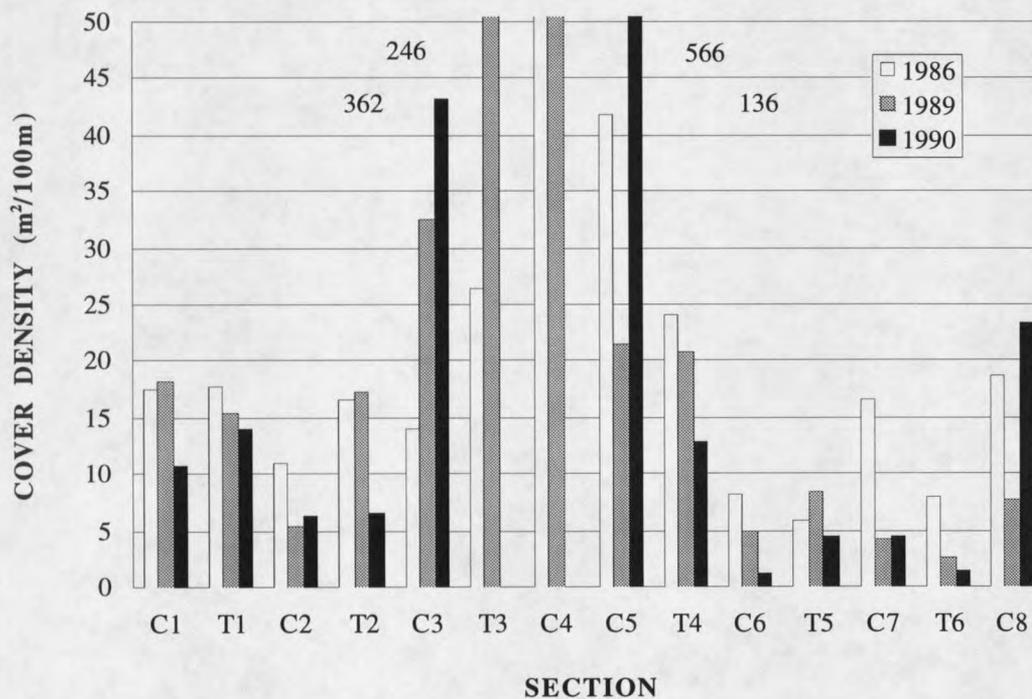
Figure 28. Lineal density of trout hiding cover by section, Confederate Gulch, MT, fall of 1986, 1989, and 1990. Sections T3 and C4 were not sampled in 1990.

In 1986, the majority of trout hiding cover in stations 1-8 and 15-39 (Figure 29) was composed of overhead brush (300 m^2), followed by wood debris (a combination of logs, brush debris, rootwads, and complex debris; 244 m^2), natural pools (99 m^2), undercut bank (29 m^2), and beaver ponds (0 m^2). In 1989, after sills had been installed, wood debris provided the majority of cover (301 m^2), followed by sill pools (158 m^2), natural pools, (97 m^2), overhead brush (64 m^2), sill undercuts (59 m^2), beaver ponds (32 m^2), and undercut banks (28 m^2). By 1990, wood debris continued to supply the greatest amount of cover (169 m^2) despite considerable reduction, and was followed closely by beaver ponds (151 m^2), sill pools (142 m^2), natural pools (81 m^2), sill undercuts (55 m^2), overhead brush (51 m^2), and undercut banks (30 m^2).
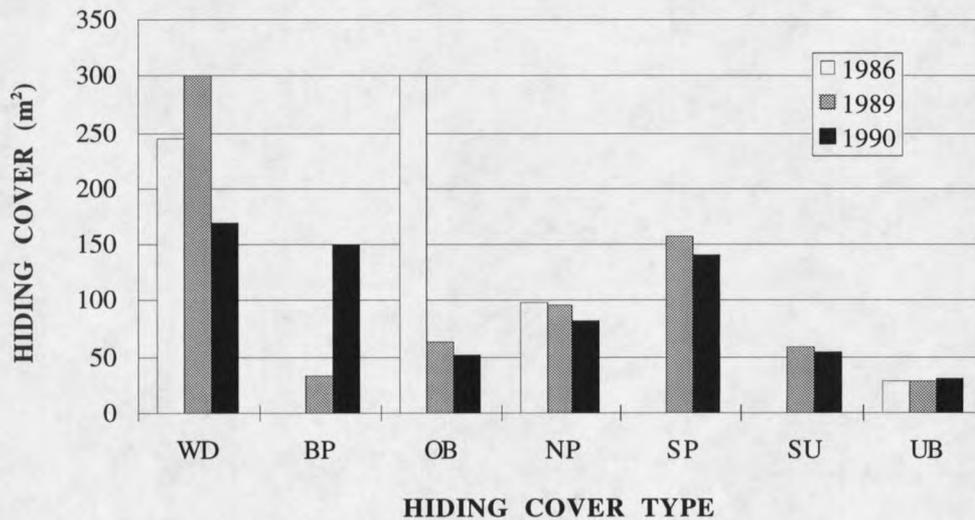
Figure 29. Trout hiding cover by cover type, Confederate Gulch, MT, fall of 1986, 1989, and 1990. Stations 9-14 were excluded to reduce confounding effects of beaver activity. WD = wood debris, BP = beaver pond, OB = overhead brush, NP = natural pool, SP = sill pool, SU = sill undercut, and UB = undercut bank.

Number of natural pools in stations 1-8 and 15-39 decreased from 1986 to 1990, as number of beaver ponds increased (Table 5). After installation of sills in 1988, number of sill plunge pools were stable in 1989 and 1990. In 1989 and 1990, mean overall pool quality was greatest for beaver ponds, followed by natural pools and then sill pools. From 1986 to 1990, mean overall pool quality of natural and sill plunge pools increased, while that of beaver ponds decreased. Mean rating of quality of pool area and

pool depth were greatest for beaver ponds in all years, followed by sill pools and then natural pools. No pattern relating pool type to mean rating of quality of pool cover was readily apparent, although quality of cover for natural pools was greater than that of sill plunge pools in 1989 and 1990.

Mean area of natural pools and beaver ponds increased from 1986 to 1990, while that of sill plunge pools decreased (Table 5). In all comparable years, sill plunge pools had greater mean width and mean area than natural pools, while mean length was less. Mean length, width, and area of beaver ponds were greater than respective dimensions of natural and sill pools in comparable years.

Table 5. Mean dimensions and quality ratings of pools stratified by pool type, stations 1-8 and 15-39, Confederate Gulch, MT, fall of 1986, 1989, and 1990. Number of pools are indicated by "n= ".

Pool type	Year	Length (m)	Width (m)	Area (m)	Pool quality rating [a]			
					Area	Depth	Cover	Overall
Natural pool	1986 n=26	2.55	1.25	3.74	1.2	1.3	2.3	4.8
	1989 n=27	2.63	1.22	3.53	1.9	1.3	1.7	4.9
	1990 n=21	2.73	1.27	4.26	1.7	1.8	2.0	5.5
Sill plunge	1986 n=0	b	b	b	b	b	b	b
	1989 n=33	1.38	3.60	5.20	2.1	1.4	1.0	4.5
	1990 n=32	1.15	3.44	4.43	2.2	2.0	1.2	5.4
Beaver pond	1986 n=0	b	b	b	b	b	b	b
	1989 n=1	3.90	4.50	17.55	3.0	2.0	3.0	8.0
	1990 n=6	22.45	5.28	135.17	2.7	2.3	1.3	6.3

[a] - Rainville method, U.S. Forest Service (see Methods section)
[b] - pool type not present at time of survey

Brook Trout Populations and Biomass

Age-0. After inspecting length-frequency plots of electrofished brook trout, I designated brook trout <110 mm as age-0, 110 mm to 199 mm as age-1, and 200 mm and larger as age-2 and older, to reduce the effect of length bias of electrofishing when computing population estimates (Appendix G). I postulated that sills create trout spawning habitat, and hiding cover in the form of sill plunge pools, undercuts, and turbulence, which improve recruitment of age-0 brook trout. I used autumn numerical density of age-0 brook trout as a biological index of the effectiveness of sills in recruiting brook trout into the population. Excluding stations 9-14 affected by beaver, autumn density of age-0 brook trout in treated and control stations increased 51% and 378%, respectively, from 1986 to 1990 (Figure 30).
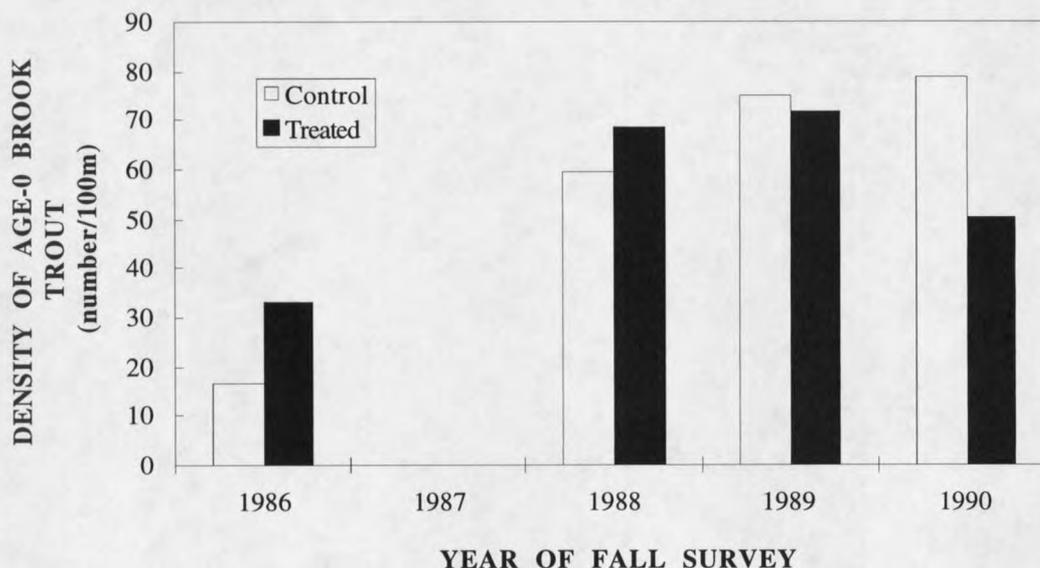
Figure 30. Autumn density of age-0 brook trout, stations 1-8 and 15-39, stratified by treated or control Confederate Gulch, MT, 1986, 1988, 1989, and 1990. Stations 9-14 were excluded to reduce the confounding effects of beaver activities.

In 1986, autumn density of age-0 brook trout in treated sections was 102% greater than in control stations, and in 1988, fall density in treated stations was 16% greater than in control stations, about two months after sills were completed. By 1989, density of age-0 brook trout in control stations exceeded

that in treated sections by 9%, and in 1990 this difference increased to 57% as age-0 density decreased considerably in treated stations.

Increase in density of age-0 brook trout in section C4 from 1986 to 1988 and 1989 was considerably greater than occurred elsewhere in the study area during the same period (Figure 31). Density of age-0 brook trout in section C2 remained low during all 4 years of survey and C2 was the only section not to experience an increase in age-0 density during the study. I detected no other consistent patterns in spatial distribution of autumn density of age-0 brook trout by section within the study area from 1986 to 1990.
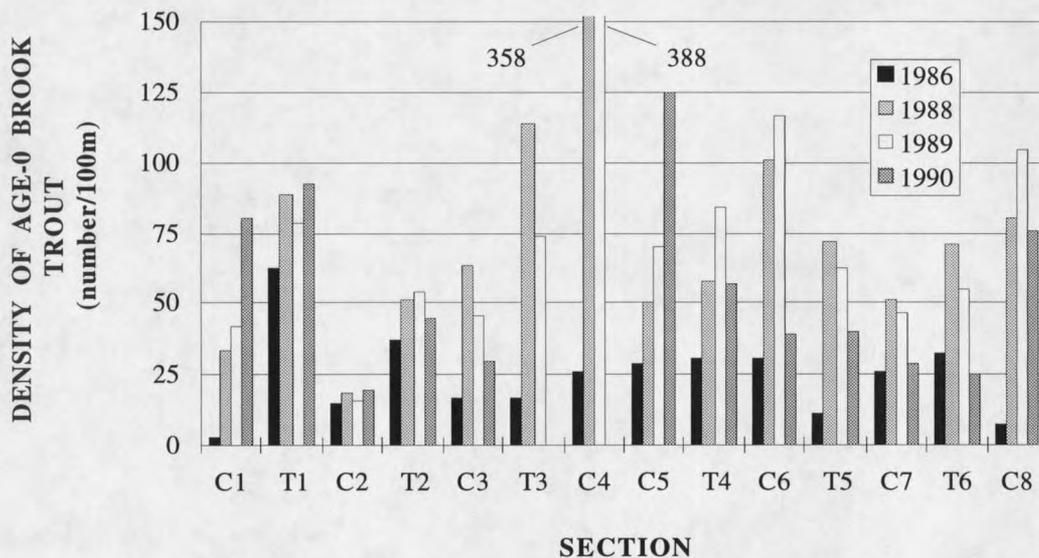
Figure 31. Autumn density of age-0 brook trout by section, Confederate Gulch, MT, 1986, 1988, 1989, and 1990. Sections T3 and C4 were not sampled in 1990.

Autumn density of age-0 brook trout biomass in stations 1-8 and 15-39 increased in both treated and control stations in the study area from 1986 to 1990 (Figure 32). In 1986, density of age-0 brook trout biomass in treated sections was 106% greater than in control stations, and in 1988, density of biomass in treated stations was 19% greater than in control stations. By 1989, density of age-0 brook trout biomass in treated stations exceeded that in control stations by 3%. In 1990, density of biomass in control stations exceeded that in treated stations by 26%. The shift in density of age-0 brook trout biomass from

treated to control stations was due to the considerable decrease in the density of treated stations in 1990. The increase in density of age-0 biomass in both treated and control stations was similar to that of age-0 numerical density (Figure 30) for all years.
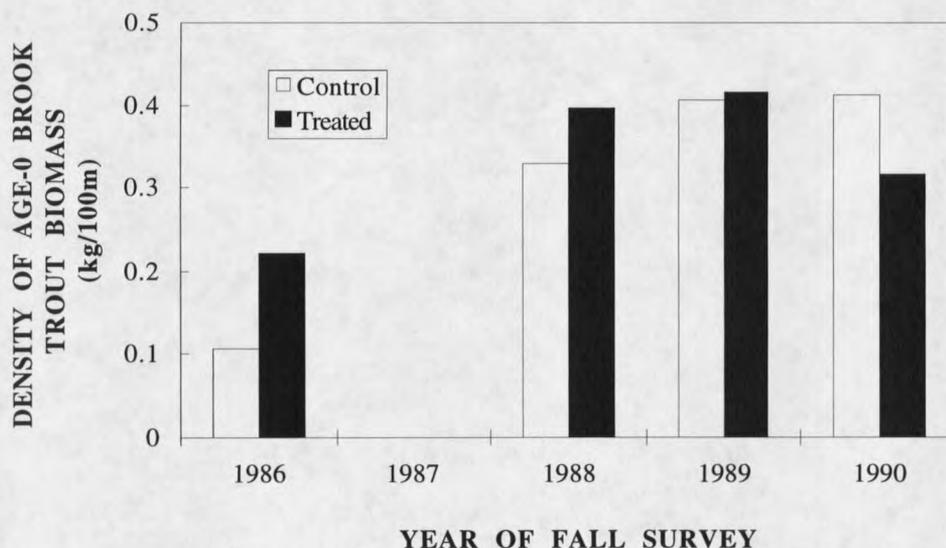
Figure 32. Autumn density of age-0 brook trout biomass, stations 1-8 and 15-39, stratified by treated and control, Confederate Gulch, MT, 1986, 1988, 1989, and 1990. Stations 9-14 were excluded to reduce confounding effects of beaver activity.

Density of autumn biomass of age-0 brook trout tended to increase in treated and control sections of the study area from 1986 to 1990 (Figure 33). In 1986, only one section, T1, exceeded an arbitrary biomass density I had chosen of 0.30 kg/100 m; by 1988, 8 of 14 sections exceeded this threshold value. In 1989 and 1990, nine and five sections, respectively, exceeded 0.30 kg/100 m; the large decrease in 1990 is likely an artifact of not having sampled sections T3 and C4. Section C1 experienced a 24-fold increase in biomass density after sill installation, the greatest increase during the study and due primarily to its relatively low pre-installation density (0.02 kg/100m). Biomass density within section C4 in 1988 (1.70 kg/100m) and 1989 (1.82 kg/100m) were the largest measured for age-0 brook trout during the study, increasing more than nine-fold over the 1986 density. I detected no other consistent patterns in the spatial distribution of autumn density of age-0 brook trout biomass by section within the study area in 1986, 1988, 1989, and 1990.
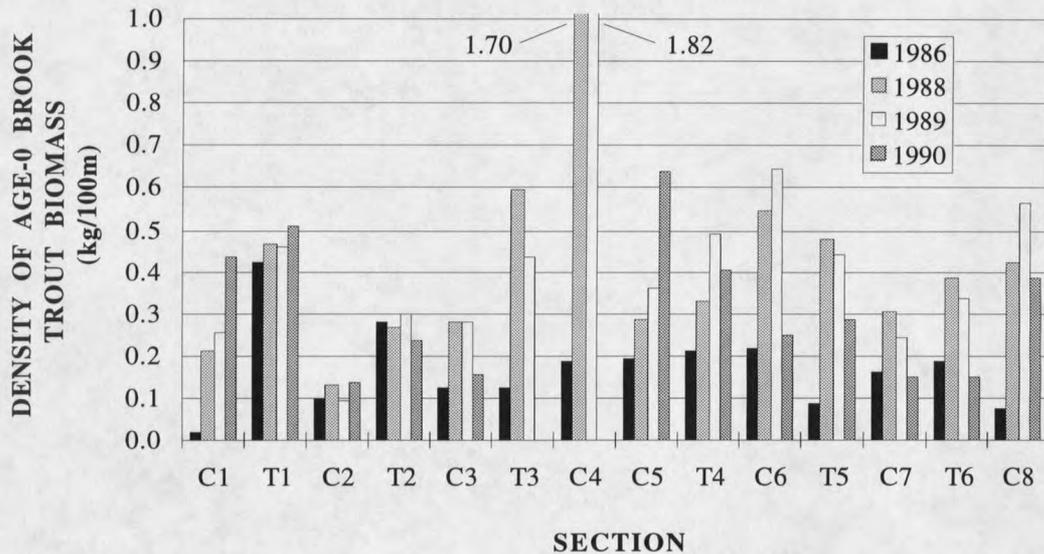
Figure 33. Autumn density of age-0 brook trout biomass by section, Confederate Gulch, MT, 1986, 1988, 1989, and 1990. Sections T3 and C4 containing large beaver ponds were not sampled in 1990.

Age-1. Autumn density of age-1 brook trout, excluding stations 9-14 affected by beaver, decreased in treated and control stations from 1986 to 1990 (Figure 34). The greatest decrease occurred in 1988, and while age-0 brook trout density increased in both treated and control stations in 1989 and 1990, it did not return to pre-treatment levels of 1986. Throughout the study, density in treated sections exceeded that within control sections, by as much as 10% in 1988 to 75% in 1990.

Autumn density of age-1 brook trout generally decreased from 1986 levels in both treated and control sections of the study area (Figure 35). Four sections had increases in post-1986 density of age-1 brook trout; section C1 in 1988, 1989, and 1990; section T6 in 1989 and 1990; section C4 in 1988 and 1989 (not sampled in 1990); and section T3 in 1989 (also not sampled in 1990). The greatest density of age-1 brook trout occurred in section C4 in 1988 and 1989, and section C5 in 1990. I detected no other consistent spatial patterns in autumn density of age-1 brook trout within the study area from 1986 to 1990.
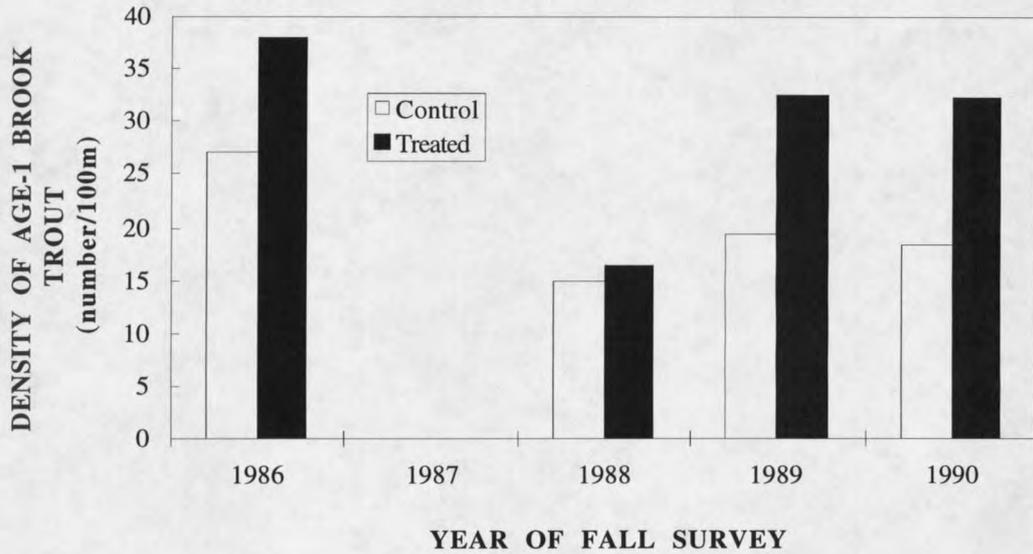
Figure 34. Autumn density of age-1 brook trout, stations 1-8 and 15-39, stratified by treated or control, Confederate Gulch, MT, 1986, 1988, 1989, and 1990. Stations 9-14 were excluded to reduce the confounding effect of beaver activities.
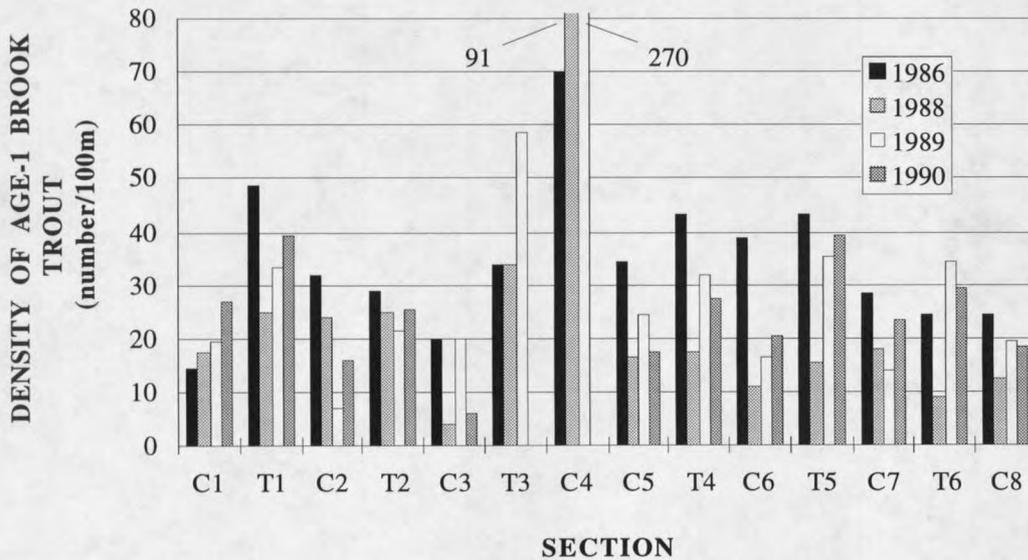
Figure 35. Autumn density of age-1 brook trout by section, Confederate Gulch, MT, 1986, 1988, 1989, and 1990. Sections T3 and C4 were not sampled in 1990.

Density of age-1 brook trout biomass, excluding stations 9-14 affected by beaver, decreased in treated and control stations from 1986 to 1990 (Figure 36). The greatest decrease occurred in 1988, followed by an upsurge in 1989 and 1990, similar to the pattern of numerical density of age-1 brook trout described in Figure 34. Throughout the study, density of age-1 brook trout biomass in treated sections exceeded that within control sections, by as much as 10% in 1988 to 75% in 1990. In 1990, density of age-1 brook trout biomass in treated stations was 97% of its value in 1986; in control stations, this figure was only 71%.
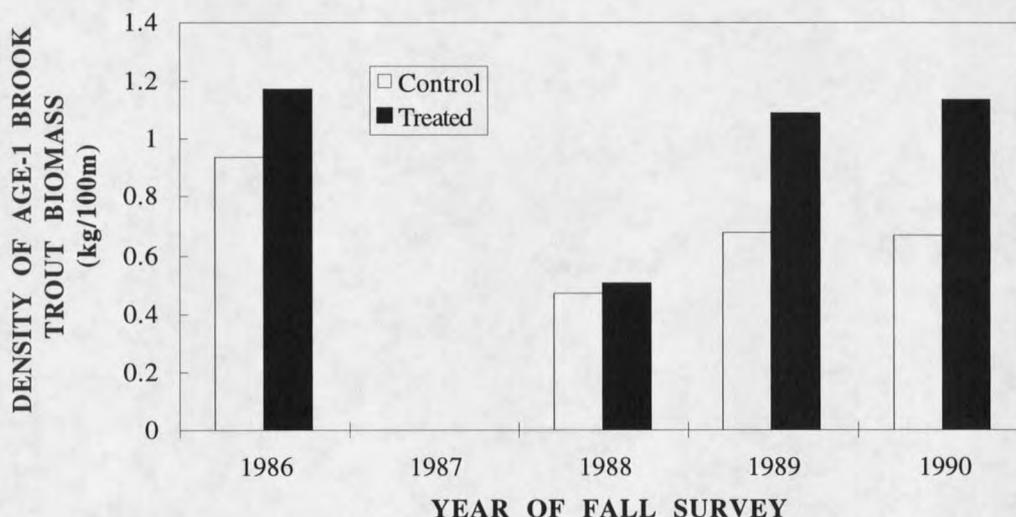
Figure 36. Autumn density of age-1 brook trout biomass, stations 1-8 and 14-39, stratified by treated or control, Confederate Gulch, MT, 1986, 1988, 1989, and 1990. Stations 9-14 were excluded to reduce confounding effects of beaver activities.

In 1986, density of age-1 brook trout biomass in 10 of 14 sections exceeded an arbitrary threshold that I chose of 1 kg/100-m, split evenly between treated and control sections (Figure 37). In 1988, this figure decreased to one section (C4), and by 1989, increased up to six sections, of which four were treated. In 1990, four sections, all treated, exceeded the threshold of biomass density, in spite of the failure to sample sections T3 and C4. Biomass of age-1 brook trout was greatest in section C4 in 1986, 1988, and 1989; in 1990, when sections T3 and C4 were not sampled, density of age-1 brook trout in sampled

sections was greatest in section T5. I detected no other patterns in the spatial distribution of biomass of age-1 brook trout per 100-m within the study area during from 1986 to 1990.
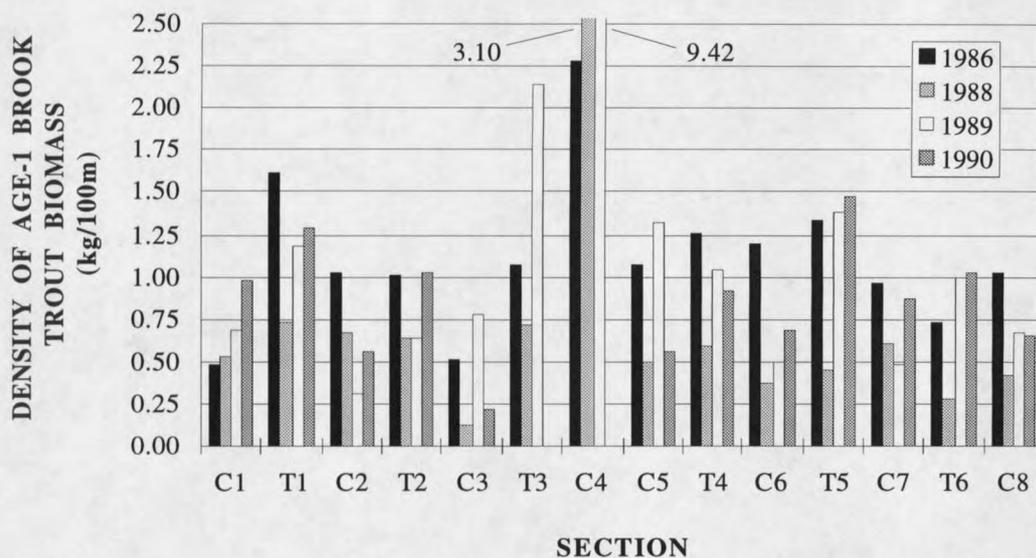
Figure 37. Autumn density of age-1 brook trout biomass by section, Confederate Gulch, MT, 1986, 1988, 1989, and 1990. Sections T3 and C4 were not sampled in 1990.

Age-2 and older. From 1986 to 1990, autumn density of age-2 and older brook trout, excluding stations 9-14 affected by beaver, decreased 3% in treated stations and increased 14% in control stations (Figure 38). Numerical density in treated stations was relatively stable throughout the period of study, and did not suffer the severe decrease in 1988 as did age-1 brook trout. Numerical density in control stations exceeded the pre-sill installation level of 1986 in all subsequent years, increasing in 1988 and 1989, followed by a decrease in 1990.

Numerical density of age-2 and older brook trout in treated stations (6.9/100-m) exceeded that in control stations (4.2/100-m) by 64% in 1986 (Figure 39). In 1988, control stations (6.5/100-m) had 10% greater density than treated stations (5.9/100-m). By 1989, density in treated stations (7.1/100-m) increased and again exceeded that in control stations (6.5/100-m) by 9%. By 1990, treated density (6.7/100-m) exceeded control density (4.8/100-m) by 40%; numerical density in four control sections

increased, three other sections decreased, and one section remained the same. Over the same period, numerical density of age-2 and older brook trout decreased in four treated sections and increased in two others.
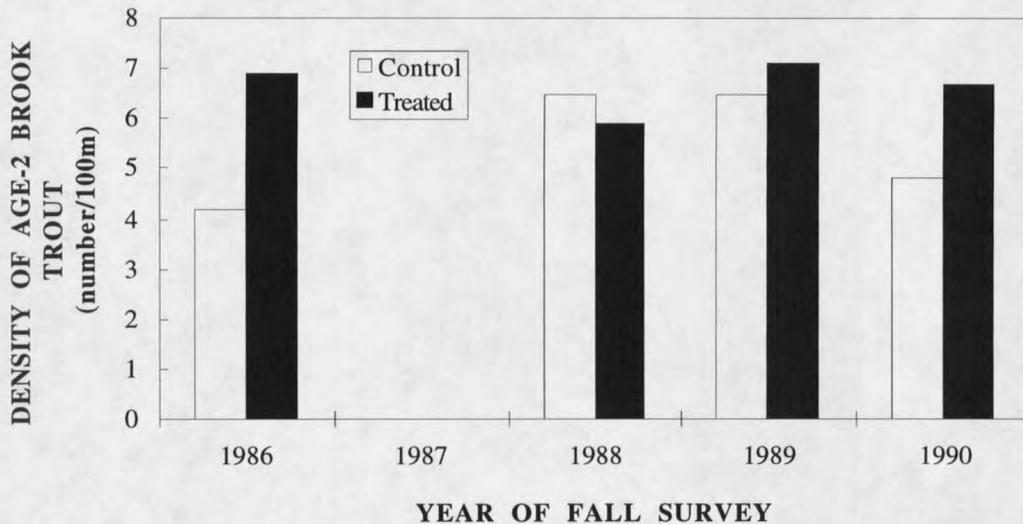
Figure 38. Autumn density of age-2 and older brook trout, stations 1-8 and 15-39, stratified by treated or control, Confederate Gulch, MT, 1986, 1988, 1989, and 1990. Stations 9-14 were excluded to reduce the confounding effect of beaver activities.

Section C4 had the greatest density of age-2 and older brook trout in 1986, 1988, and 1989; in 1990, when sections T3 and C4 were not sampled, section T5 had the greatest density. I detected no other consistent patterns in spatial distribution of autumn density of age-2 and older brook trout during the course of the study.

From 1986 to 1990, density of age-2 and older brook trout biomass, excluding stations 9-14 affected by beaver, was relatively stable in treated stations (-3%) and increased 6% in control sections (Figure 40). Year-to-year changes in biomass per 100-m of age-2 and older brook trout in treated and control stations was similar to those previously discussed for numerical density. In 1986 and 1990, density of biomass in treated sections exceeded that of control sections considerably; in 1989 this difference was slight. In 1988, density of biomass of control sections was considerably greater than that of treated sections.
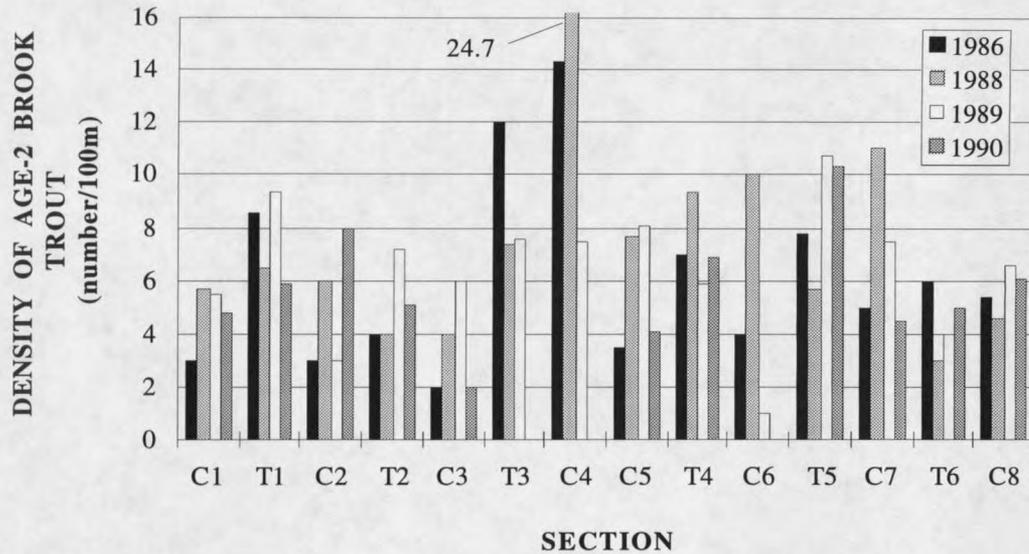
Figure 39. Autumn density of age-2 and older brook trout by section, Confederate Gulch, MT, 1986, 1988, 1989,and 1990. Sections T3 and C4 were not sampled in 1990.
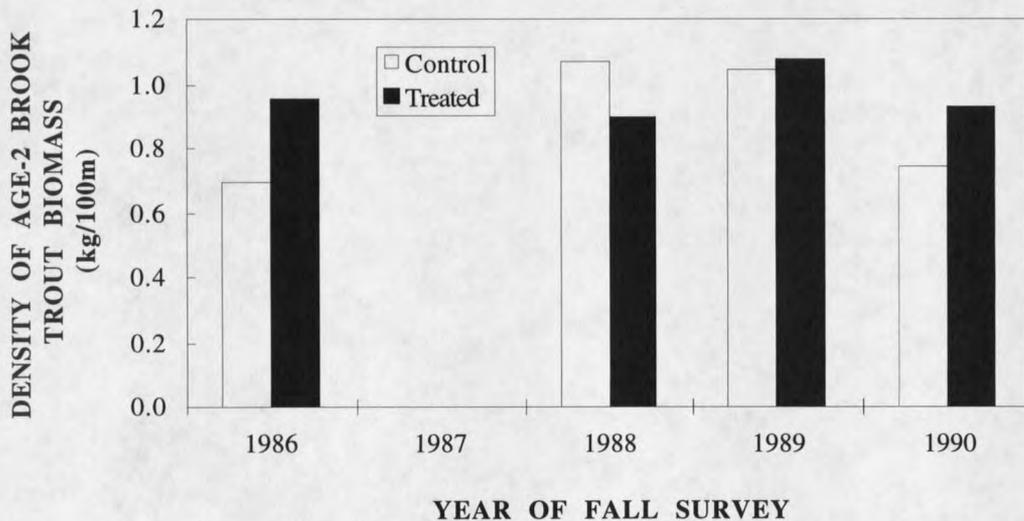
Figure 40. Autumn density of age-2 and older brook trout biomass, stations 1-8 and 14-39, stratified by treated or control, Confederate Gulch, MT, 1986, 1988, 1989, and 1990. Stations 9-14 were excluded to reduce confounding effects of beaver activities.

As an arbitrary threshold of density of age-2 and older brook trout biomass, I chose the value 1

kg/100-m. In 1986, biomass density in four of 14 sections, split evenly between treated and control

sections, exceeded this value (Figure 41). In 1988, this figure increased to six sections, of which two

were treated. By 1989, biomass density of age-2 and older brook trout in 10 sections surpassed 1

kg/100-m, and was split evenly between treated and control. In 1990, when sections T3 and C4 were not
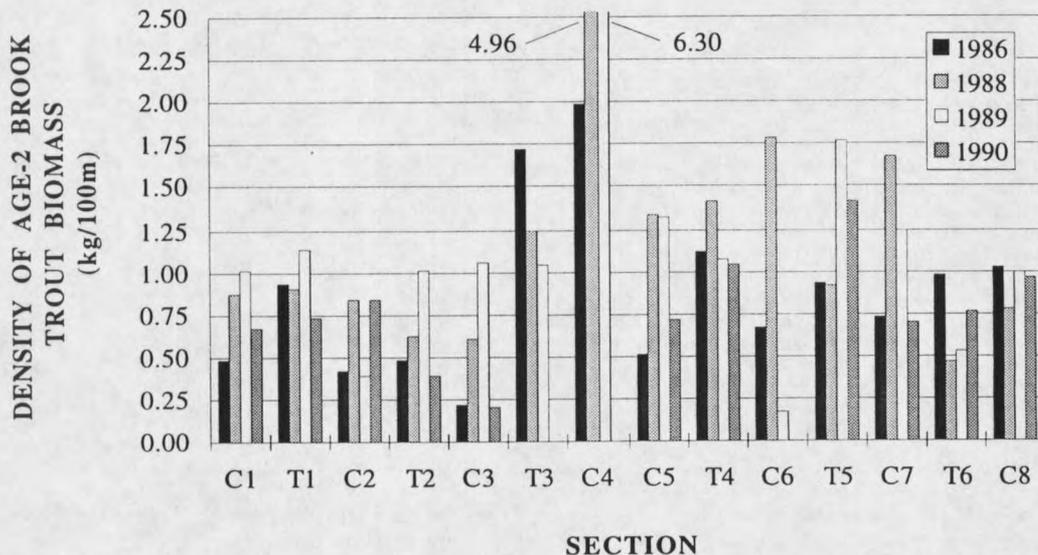
Figure 41. Autumn density of age-2 and older brook trout biomass by section, Confederate Gulch, MT, 1986, 1988, 1989, and 1990. Sections T3 and C4 were not sampled in 1990.

sampled, only one section, C4, exceeded the arbitrary threshold. Biomass of age-2 and older brook trout

was greatest in section C4 in 1986, 1988, and 1989. In 1990, when sections T3 and C4 were not

sampled, section T5 had the greatest biomass density (1.42 kg/100-m). I detected no other patterns in

the spatial distribution of autumn biomass density of age-2 and older brook trout.

Cutthroat Trout Populations and Biomass

Few cutthroat trout existed in the study area from 1986 to 1990. After inspecting length frequency

plots of electrofished cutthroat trout, I designated those < 100 mm as age-0, and those >100 mm as age-1

and older. These age-length classes agree with the findings of Pratt (1984) for westslope cutthroat trout in the upper Flathead River. Numbers of cutthroat trout per 100-m were less than densities of brook trout by more than an order of magnitude in all respective age classes and years (Tables 6 and 7).

Table 6. Autumn numerical and biomass density of age-0 cutthroat trout by section, Confederate Gulch, MT, 1986, 1988, 1989, and 1990

Section	Age-0 cutthroat density (fish/100m)				Biomass density (kg/100m)			
	1986	1988	1989	1990	1986	1988	1989	1990
C1	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
T1	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
C2	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
T2	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
C3	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
T3	0.0	0.0	0.0	[a]	0.00	0.00	0.00	[a]
C4	0.0	0.7	0.3	[a]	0.00	0.01	0.01	[a]
C5	0.0	1.0	0.7	0.2	0.00	0.01	0.00	0.00
T4	0.0	0.0	0.0	0.0	0.00	0.00	0.01	0.00
C6	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
T5	0.0	0.0	2.0	0.0	0.00	0.00	0.02	0.00
C7	0.0	1.0	7.0	0.5	0.00	0.01	0.03	0.01
T6	0.0	10.7	25.3	0.0	0.00	0.03	0.07	0.00
C8	0.1	5.0	7.7	0.1	0.01	0.01	0.06	0.00
Treated	0.0	2.2	6.0	0.0	0.00	0.01	0.02	0.00
Control	0.0	2.0	3.0	0.1	0.00	0.01	0.01	0.00
Total	0.0	2.1	4.1	0.1	0.00	0.01	0.01	0.00
99	[b]	[b]	0.0	0.0	[b]	[b]	0.00	0.00

[a] - Sections T3 and C4 containing large beaver ponds were not sampled in 1990.
[b] - Station 99 not sampled in 1986 or 1988.

Numerical density of age-0 cutthroat trout in the study area increased from zero in treated and control sections in 1986, to about two cutthroat per 100-m in 1988 (Table 6). By 1989, density of age-0 cutthroat trout almost tripled in treated sections, and increased by half in control sections, over 1988 levels. In 1988 and 1989, age-0 cutthroat density existed primarily in sections C7, T6, and C8, and to a lesser extent in sections C4 and C5; age-0 cutthroat were non-existent in the lower half of the study area over the course of the study. By 1990, density of age-0 cutthroat trout decreased to trace levels in treated and control sections. Density of age-0 cutthroat trout biomass, reported as kilograms per 100-m, was barely detectable in all sections of all years.

Autumn numerical density of age-1 and older cutthroat trout within the study area increased gradually

from 1986 through 1989, followed by a large decrease in 1990 (Table 7). Age-1 and older cutthroat trout

were distributed in all sections of the upstream-half of the study area except section C6 from 1986 to

1990; few cutthroat existed downstream of section T3 during the course of the study. Density of age-1

Table 7. Autumn numerical and biomass density of age-1 and older cutthroat trout by section, Confederate Gulch, MT, 1986, 1988, 1989, and 1990.

Section	Age-1 cutthroat density (fish/100-m)				Biomass density (kg/100-m)			
	1986	1988	1989	1990	1986	1988	1989	1990
C1	1.0	0.0	0.0	0.0	0.15	0.00	0.00	0.00
T1	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
C2	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
T2	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
C3	0.0	0.0	0.0	1.0	0.00	0.00	0.00	0.03
T3	1.0	0.0	1.3	[a]	0.21	0.00	0.55	[a]
C4	0.0	7.0	6.0	[a]	0.00	0.46	0.22	[a]
C5	1.2	1.2	1.2	0.5	0.30	0.91	0.04	0.05
T4	2.3	1.0	1.3	1.0	0.41	0.10	0.01	0.02
C6	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.10
T5	1.0	0.5	4.5	0.4	0.22	0.12	0.16	0.01
C7	0.5	2.0	0.5	3.0	0.70	0.05	0.01	0.07
T6	1.0	2.0	2.6	1.7	0.21	0.16	0.10	0.09
C8	2.7	0.9	0.8	0.4	0.30	0.10	0.05	0.02
Treated	1.2	0.6	1.4	0.8	0.39	0.07	0.04	0.03
Control	1.2	1.6	1.4	0.6	0.19	0.11	0.12	0.03
Total	1.2	1.3	1.4	0.7	0.21	0.10	0.10	0.03
99	[b]	[b]	0.0	0.0	[b]	[b]	0.00	0.00

[a] - Sections T3 and C4 containing large beaver ponds were not sampled in 1990.
[b] - Station 99 not sampled in 1986 or 1988.

and older cutthroat trout biomass decreased in treated and control sections from 1986 to 1990 (Table 7).

In 1986, biomass density of treated sections was more than twice that of control sections. In 1988 and

1989, biomass density was greater in control sections, and by 1990, was similar between treated and

control.

DISCUSSION

Streamflow

High water that occurred during spring runoff of 1989 and 1990 provided the force necessary to generate and transport considerable quantities of bedload in the study area (Figure 5). The annual maxima of 1989, the greatest flow measured from 1987 to 1990, in combination with gravel-trapping log sills, yielded increased density of surface gravel area in both treated and control stations that fall (Figure 13). Spring runoff of 1990 had the second-highest discharge recorded during the study, and was of considerably greater duration than the 1989 event. The extended duration of spring runoff, combined with its above-average magnitude, is probably the factor most responsible for the large increase of surface gravel density in treated and control sections in 1990.

Longitudinal Streambed Profiles

Vertical complexity in profiles of streambed elevation at all treatment sites increased from July 1989 to February-March and August-September 1990 (Figures 7-12). Resultant areas of deposition and scour stand out as peaks and valleys when compared to their relatively flat pre-treatment profile. To evaluate changes in streambed elevation relative to fish habitat, I compared number and mean residual depth of pools ≥ 0.4 m. In treatment sites 1, 2, 4, 5, and 6, number of pools of residual depth ≥ 0.4 m increased from one in 1988 to 24 in March 1990, followed by a decrease by one pool to 23 in September of 1990 (Table 2). The increase in number of pools is a result of the construction of log sills, during which sill plunge pools were excavated by heavy machinery.

Residual pool depth of the one pool in 1988 was 0.43 m. By March of 1990, mean residual pool depth was 0.49 m, and increased by that fall to 0.53 m, probably due to the scouring force of high flow acting upon the sills and their plunge pools during spring runoff.

Increases or decreases in mean streambed elevation (Table 2) immediately after sill installation are, in large, a result of the elevation of each sill relative to its original streambed elevation, the cumulative effect of sills, including spacing between sills and sill type, upon mean elevation within respective surveys, and the enhancement of pools and bars by heavy machinery during instream construction. Post-treatment changes in streambed elevation, such as those observed between spring and summer surveys made in 1990, are due primarily to high flow events and the availability of bedload. The decrease in slope and increase in mean elevation at treatment site 4 between February and August of 1990 (Table 2) is the result of increased deposition in the downstream-half of the site, as readily confirmed in Figure 10.

Surface Gravel Area

Considerable increase in surface gravel density took place in treated and control sections unaffected by beaver after log sills were installed to trap gravel (Figure 13). The relative increase in density of surface gravel area from 1986 to 1990 was more than 21 times greater in treated sections than in control sections, suggesting that sills were effective in trapping spawning-sized gravel. By 1990, distribution of surface gravel density was considerably higher in the upstream half of the study area, while in the lower half, increases in gravel density were conspicuously missing (Figure 14). Beaver dams and ponds in sections C3, T3, and C4 intercepted gravel drifted from upstream, preventing transport to and deposition in the lower areas (Figure 14). The large increase of gravel density in section T1 of 1990 was probably due to gravel generated from the streambed and banks downstream of beaver activity, in addition to the presence of log sills and the relatively low streambed gradient (Tables 1 and 2) within this site.

The 40 log sills were relatively efficient in trapping spawning gravel (Figure 19). Although they occupied little streambed area, log sills had the highest density of surface gravel associated with any depositional feature inventoried after their installation (Figure 20). In 1990, surface gravel density associated with streambed contour, the second most efficient depositional feature, was more than two-fold greater in treated sections than in control sections, and suggests that greater energy dissipation was afforded by log structures in treated sections, influencing gravel deposition by features other than sills.

I use caution in making this statement as less efficient depositional features, such as wood debris and pools, did not exhibit this same relationship.

In 1989 and 1990, surface gravel deposited in the immediate vicinity of log sills of all treatment sections, except T4, were in greater quantities downstream of sills than upstream of them (Figure 15). Four of five sills in section T4 are downstream-pointing "V" structures, which may explain in part why such a large proportion of gravel deposited upstream of sills in this section. However, section T5 is composed entirely of "V" sills and gravel in this site, as much as in any other, tended to deposit primarily below sills. Some other factor, such as streambed gradient (Tables 1 and 2), bankfull width, sinuosity, etc., may have influenced section T4's difference in gravel deposition. Section T4 had the only cumulative decrease in streambed gradient during the study, which occurred between February and August of 1990 (Table 2). Section T5 experienced a net increase in gradient over the duration of the study, however the change in gradient (-0.13%) between February and August of 1990 was about the same as that which occurred in section T4. Forces acting at a scale smaller than the length of section or treated site may have been responsible for this inconsistency.

For treated reaches exhibiting slopes similar to that within the study area (1.5%), energy dissipation below sills likely allowed for greater deposition than higher velocity areas upstream of sills, regardless of sill configuration. Gravel deposition upstream of sills probably occurred only in reaches or micro-habitats where gradient was < 0.5% or where increased quantities of natural or enhanced bedload transported through the system deposited under normal circumstances, as observed at the head of beaver ponds where water velocity and base level are controlled by dam construction.

Number of surface gravel patches per 100-m increased in both treated and control sections unaffected by beaver from 1987 to 1989, and again in 1990 (Figure 16). Patch density in control sections exceeded that in treated sections by 97% in 1987 and 31% in 1989. By 1990, this relationship reversed itself dramatically as patch density in treated sections was 30% greater than in control sections.

Mean gravel patch area increased 253% in treated stations, unaffected by beaver, from 1987 to 1990 (Figure 17). Over the same period of time, mean patch area in control stations decreased by 35%. In 1987, mean patch area in control sections exceeded that in treated sections by 66%. After sill installation

in 1988, mean patch area in treated sections exceeded that in control sections by 72% in 1989 and

222% in 1990 (Figure 18). The large mean patch area in section C4 in 1990 was a result of the

deposition of large patches of gravel at the head of its upper-most beaver pond. In spite of C4's extreme

mean patch size in 1990, which in fact exceeds the next largest (T6) by two-fold, the overall mean patch

area within treated sections exceeded that of control sections. The transposition of dominant gravel patch

density and mean patch area from control sections in 1987 to treated sections after sills were installed is

evidence that within a trend of increasing surface gravel deposition, sills trapped spawning-sized gravel

more efficiently than untreated sections of channel did.

Trout Redds

From 1988 to 1990, the number of definite and probable brook trout redds per 100-m in stations

unaffected by beaver increased 186% (Figure 25). In 1988, two months after sill construction was

completed, density of definite and probable redds in treated stations exceeded that of control stations by

40%. By 1990, this figure increased to 86%, suggesting that stations with log sills supported relatively

more brook trout redds. The spatial distribution of redd density within the study area was relatively even

in 1986; by 1989 and 1990, redd density within the upper half of the study area was two- to four-fold

greater than that in the lower half of the study area (Figure 26). The pattern in spatial redistribution of

redd density tracked the spatial redistribution of mean lineal density of gravel over the same period of

time and suggests that brook trout spawning was, and may still be, limited by spawning gravel

availability.

To compare the density of brook trout redds in treated and control stations under what I described as

optimal spawning conditions, I plotted the number of definite and probable brook trout redds in a station,

stratified by treated or control, as a function of number of gravel patches > 3 m^2 within that station, for

1989 and 1990 (Figure 42). In 1990 and particularly 1989, for a given number of gravel patches > 3 m^2,

treated stations produced greater redd density than did control stations. Correlation coefficients (r) for

regressions of control stations in 1989 and 1990, and treated stations in 1990 all exceeded 0.87, implying

a strong linear relationship of brook trout redd density to number of gravel patches > 3 m^2. The

correlation coefficient for treated stations in 1989 was 0.40, implying a linear relationship of less strength.

The results obtained from the analysis of 1990 data led me to conclude that brook trout preferred to spawn

in stations treated with log sills, as opposed to those containing only natural deposition features.

Lacking regression data that describes redd density as a function of number of patches > 3 m^2 in treated

and control sections previous to sill installation, this conclusion could be confounded by factors not

included in the analysis, such as a preponderance of upwelling flows in treated sections (if they do in fact

exist) that could explain a spawning preference.

Figure 42. Simple linear regression of number of definite and probable brook trout redds as a function of
number of gravel patches within a section > 3 m^2, by treated and control, Confederate Gulch,
MT, 1989 and 1990.
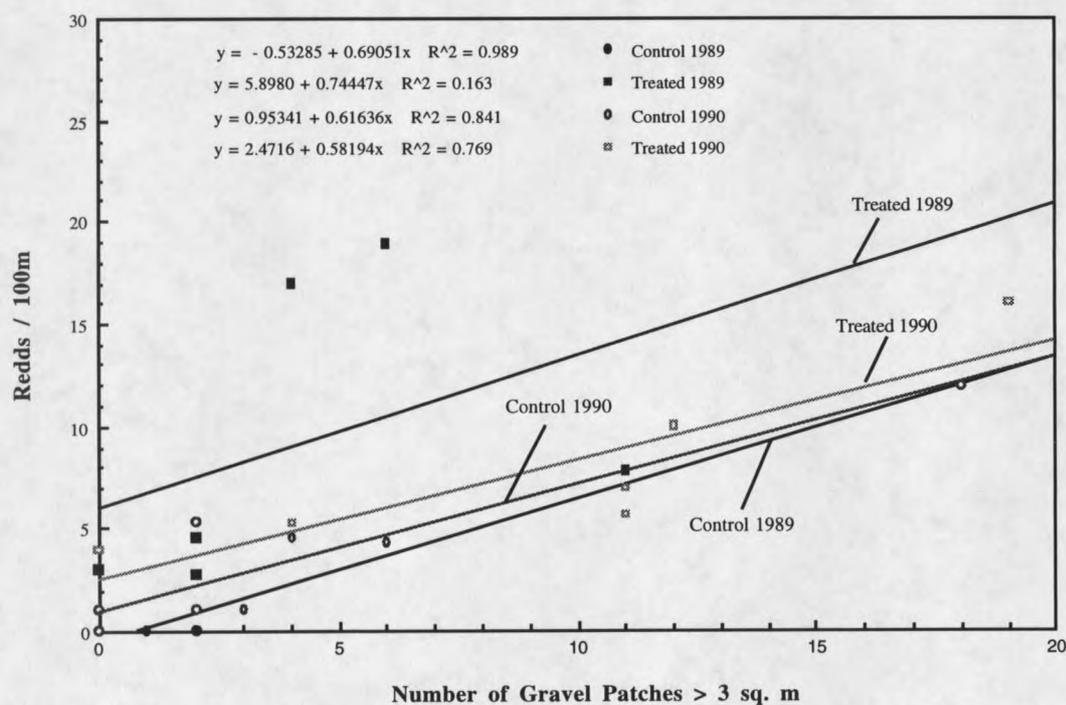
Empirical data collected from 1988 through 1990 further supports my conclusion that brook trout

prefer to spawn in treated rather than control sections of the study area. Numbers and density of definite

and probable brook trout redds increased in 1989 and 1990 after sill installation, and, when number and

density declined in 1990 from 1989 levels, the greater proportion (72%) of decrease occurred in control sections (Figure 25). This difference was most obvious in the gravel-limited lower half of the study area, where redd densities actually increased in all treated sections, while decreasing in all control sections except section C4, was further evidence that brook trout preferred to spawn in habitat improved with log sills. Increased gravel deposition at treated sites probably provide brook trout with adequate quantities of material, in a gravel-limited environment, needed to develop optimal redd characteristics which enhance egg survival.

Sill type appears to have influenced the number and maturity of redds, but not in a consistent manner. Density of redds per sill, particularly trial, possible, and probable redd types, was higher when associated with laterally aligned log sills, than with downstream-pointing "V" sills (Table 3). Conversely, the per-sill density of definite redds, and definite plus probable redds, associated with "V" sills, was 85% and 16% greater, respectively, than that associated with sills in oblique alignment, indicating that the V-sill design provided for greater redd development than the oblique sill design.

Physical characteristics of brook trout redds inventoried in 1990 described quality of spawning habitat of individual redds stratified by maturity and sill association (Table 4). Redds judged to be of greater maturity tended to occur closer to cover, exhibit greater residual pit depth, and greater water velocity throughout the water column and length of the redd than those of lesser maturity. These findings suggest, as one would expect, that brook trout prefer spawning in sites close to cover, with gravel sufficient to allow for morphologic development of the redd, and with enough water flow to provide for the down-welling currents required to supply oxygen to fertilized eggs and remove wastes.

Regardless of their level of development, redds associated with sills tended to have greater residual pit depth than redds not associated with sills. Definite and probable redds consistently experienced higher velocities at all depths within the pit and tailspill when associated with sills than when not; this relationship was distinctly opposite for probable redds, possibly due to the lack of pit and tailspill development of the redd, the absence of which tends to increase velocity due to decreased frictional resistance. No consistent pattern in the relationship of distance to cover and redd association with sills was apparent. Results indicate that greater redd development, residual pit depth, and water velocity are

found in redds associated with sills than in redds which are not, suggesting that log sills produce spawning habitat that support optimal redd development, and as a result, greater egg-to-fry recruitment.

Hiding Cover

Hiding cover for salmonids within treated and control stations unaffected by beaver decreased considerably from 1986 to 1989 (Figure 27). In 1986, and particularly 1989 and 1990, density of hiding cover in control stations exceeded that in treated stations by a considerable margin. From 1986 to 1989, decrease of hiding cover in control stations was distributed throughout the study area, although an increase occurred in section C3 (Figure 28) which could be credited to beaver ponds and wood debris (Figure 29). Decrease in hiding cover in treated stations from 1986 to 1989 was distributed evenly throughout the study area, the majority of which could be attributed to overhead brush, in spite of increases in sill pool and sill undercut.

From 1989 to 1990, continued decrease of trout hiding cover in treated stations was distributed evenly throughout the study area, and the majority of decrease was accountable to wood debris. In control sections, hiding cover increased dramatically from 1989 to 1990, and was attributed to beaver dams and ponds built in sections C3, C5, and C8 (Figure 29). In 1990, hiding cover in control sections again exceeded that in treated sections, a result of the capacity of beaver ponds to foster a variety of trout cover in large quantities.

The installation of log sills in the study area produced large amounts of hiding cover for trout. Sill plunge pools and undercuts accounted for more hiding cover in stations unaffected by beaver in 1990, than all other cover types except wood debris, and were exceeded only by wood debris in 1989 (Figure 29).

All cover types except beaver ponds and undercut bank decreased in cover density between 1989 and 1990 (Figure 29), which could be explained by decreased water stage, observer bias, or possibly the erosional effects of above average magnitude and duration of spring runoff sustained in 1990. The relatively large decreases in mean cover density of overhead brush from 1986 to 1989 could be explained by observer bias, however beaver affected this cover type also as they expanded their habitat in section

C3. If beaver do affect overhead brush cover, the relatively small decrease in this cover type between 1989 and 1990 would not seem proportionate to the large increase of beaver habitat in sections C5 and C8 that occurred by the fall of 1990.

Number of pools within the study area, excluding beaver-affected stations, increased from 26 in 1986 to 61 in 1989 (Table 5), due primarily to the installation of log sills and the expansion of beaver habitat (one pond in 1989 compared to zero in 1986). By 1990, number of pools decreased to 59, as natural pools decreased by six, sill pools by one and beaver ponds increased by five. Lacking data as proof, I would propose that gravel introduced, transported, and deposited in the channel during spring runoff of 1990, also filled in the sill pool and natural pools that had existed in 1989.

Overall pool quality increased for all pool types over the course of the study (Table 5). Beaver ponds afforded highest overall pool quality due to greater area and depth, while natural pools afforded higher overall pool quality than sill pools due to greater quality of cover, which also exceeded that of beaver ponds. Given the expected dimensional differences between beaver ponds and natural and sill pools, sill pools tended to be considerably wider, shorter, and of greater surface area than naturally occurring pools, probably a result of the cross-channel orientation of sills as points of scour.

Brook Trout Populations and Biomass

Age-0. Autumn numerical density of age-0 brook trout in the study area, excluding stations affected by beaver, increased from 1986 to 1988 to 1989, followed by a decrease in 1990 (Figure 30). Density of age-0 brook trout increased in treated and control stations of all subsequent years except 1990, when density in treated stations decreased from its level in 1989. Numerical density of age-0 brook trout, spawned in brood years previous to sill installation, were greater in treated stations than in control stations in 1986 and 1988, and suggests that age-0 brook trout preferred untreated stations previous to sill installation. By 1989 and 1990, numerical density of age-0 brook trout, spawned in brood years after sills were installed, was less in treated stations than in control stations, and indicates that after log sills were constructed, stations treated with log sills contained fewer age-0 brook trout.

Numerical density of age-0 brook trout increased from depressed levels of 1986 before sills were installed in the summer of 1988, suggesting that the age-0 brook trout populations had rebounded before log sills could trap gravel and affect an increase in the population. The reversal in preference from treated to control stations after sills were installed, may indicate that log sills are not preferred by age-0 brook trout as rearing habitat. Patterns of change in density of age-0 brook trout biomass from 1986 to 1990 track that of numerical density, supporting my conclusion (Figure 32).

Although the data collected during the study indicate that brook trout preferred to spawn in stations treated with log sills, age-0 brook trout were found in lower densities within treated sections, as compared to control sections. I propose that age-0 brook trout may be migrating from treated stations to control stations. Hunt (1965) found that age-0 brook trout in Lawrence Creek, Wisconsin, tended to disperse downstream during their first year of life. If this behavior occurred in Confederate Gulch during the study, it could partially explain the preference of age-0 brook trout for control stations.

The density of age-0 brook trout numbers and biomass were conspicuously low in sections C2, T2, and C3 in all years inventoried, while these densities were an order of magnitude greater immediately upstream in sections T3 and C4, where beaver had built dams and ponds (Figure 30). Age-0 brook trout density in sections upstream of T3 and C4 were also relatively less, but tended to increase after log sills were installed. The concentration of age-0 brook trout in sections T3 and C4 suggest that beaver ponds provide high quality habitat for age-0 brook trout, and those that migrate into the ponds from upstream sections tend to remain. The high density of age-0 brook trout in beaver ponds of sections T3 and C4 were probably a result of greater year-round water volume, as compared to non-beaver affected sections, and greater quantities of hiding cover, particularly in the form of water depth, bank cover, and wood debris.

The preponderance of hiding cover existing in control stations in 1990 could explain the high density of age-0 brook trout in these stations for that year. Hiding cover does not explain the spatial distribution of age-0 brook trout in 1990, as their numbers were greatest in treated stations, but cover density was lower. I believe some other factor was acting upon the age-0 population to influence its spatial distribution in habitat not affected by beaver.

Age-1. Autumn density of age-1 brook trout numbers and biomass decreased considerably from 1986 to 1988, possibly as a result of drought conditions during the summer of 1988, or to activities related to sill construction (Figures 34 and 36). The decrease in 1988 was followed by an increase of age-1 biomass and numbers in 1989, which was repeated in 1990; in neither year did numbers or biomass of age-1 brook trout returned to the levels of 1986, in treated or control stations.

The numerical density of age-1 brook trout numbers in treated stations exceeded that in control stations by 41% in 1986. After log sills were installed in 1988, numerical density of age-1 brook trout in treated stations exceeded that in control stations by 67% in 1989, and 75% in 1990, and density of age-1 brook trout biomass in treated stations exceeded that in control stations by similar amounts in respective years. The pattern of higher age-1 brook trout numbers and biomass in stations treated with log sills was supported by the fact that in 1986 and 1988, density of numbers and biomass in three control sections exceeded that in a neighboring treated section, but in 1989 and 1990, numerical or biomass density in none of the control sections exceeded that of a neighboring treated section (Figures 35 and 37).

As density of trout hiding cover in control stations exceeded that in treated stations in years before and after log sills were installed, I would suggest that total hiding cover was not an important factor influencing the greater number and biomass of age-1 brook trout occurring in treated sections. However, sill plunge pools and undercuts made up about two-thirds of all hiding cover in treated sections in 1989 and 1990 (Appendix F), and given that total hiding cover in treated stations decreased from 1986 to 1990, the importance of cover provided by log sills to age-1 brook trout in treated sections was probably great.

Number and biomass of age-1 brook trout in sections T3 and C4, altered by beaver during the study, were each 2 to 10 times greater than respective values of any station in each year. Combined with the fact that numbers and biomass of age-1 brook trout in neighboring control stations C3 and C5 were relatively depressed during the course of the study, I postulate that age-1 brook trout tended not to migrate out of beaver ponds, and those that immigrated into ponds tended to stay there.

Age-2. From 1986 to 1990, autumn numerical density of age-2 brook trout was relatively stable in treated sections not affected by beaver (Figure 38). Over the same period, numerical density of age-2 brook trout in control sections increased slightly in 1988 and 1989, but returned to its 1986-level by

1990. Annual changes in biomass density of age-2 brook trout was similar to changes in numerical density in both treated and control stations (Figures 39 and 41). Numbers and biomass of age-2 brook trout in treated stations exceeded those in control sections by a considerable margin in 1986 and 1990, and in 1989, this margin was slight. In 1988, density of age-2 brook trout numbers and biomass in control stations exceeded those in treated stations. I found these results did not present any clear evidence relating benefit(s) or impact(s) of log sills upon the age-2 brook trout population. The fact that the age-0 brook trout population increased after sill installation, while age-1 and older brook trout did not, suggests that within the study area, trout habitat is limited more by rearing habitat than it is by spawning habitat.

Numerical and biomass density of age-2 brook trout in sections T3 and C4, while greater than that of any other section in 1986 or 1988, were for the most part unexpectedly low. By 1989, numerical and biomass density of age-2 brook trout in sections T5, T1, and C5 exceeded that in either section T3 or C4. From 1989 through 1991, I saw increasing amounts of fishing tackle, bait, and fish remains lost or left behind in the study area, particularly in the vicinity of sections T3 and C4. Increased fishing pressure is my best explanation as to the decrease in density of age-2 brook trout numbers and biomass in sections T3 and T4.

Cutthroat Trout Populations and Biomass

Numbers and biomass of age-0 and age-1 and older cutthroat trout were so low in the study area in all years that conclusions as to the effect of log sills upon their populations are not possible (Tables 7 and 8). It is of interest that in 1988 and 1989, large densities of number and biomass of age-0 cutthroat were concentrated in section T6, with lesser densities in surrounding sections C7 and C8. These three sections may be preferred as spawning habitat by cutthroat trout, possibly due to the proximity of station 99 which is so productive for brook trout. Age-1 and older cutthroat were somewhat more dispersed within the study area, with the greatest density occurring in beaver-affected section C4 in 1988 and 1989. Sections T4, T5, T6, C5, C7, and C8 also had relatively large densities of age-1 and older cutthroat trout from 1986 to 1990.

Durability of Log Sills

Practically no maintenance of the 40 log sills was required to preserve their physical integrity during the years of study. After spring runoff of 1990, two oblique sills in treatment site T6, # 33 and # 35, each developed a cavity in its upstream face, where rubble and gravel had been backfilled during construction and bedload had deposited afterwards. Each of the cavities appeared to be a result of underscouring of the sill during the extended high flows in the spring. Underscour occurs as water flowing over the sill drops down into the scour pool, some of which "eddies" back against the bottom of the sill. Under most conditions, this eddy effect is cause for little erosion of the sill beneath its downstream side, and the fact that the other 38 sills received no damage after spring runoff in 1990 is a testament to the durability of their design.

As high flows were considered the causative agent of the cavities, I made field observations of each cavity and sill which may be useful regarding future installations. Each cavity had one or more large pieces of rubble, almost the size of a small boulder (40-50 cm diameter) whose surface was smooth from stream wear. These small boulders were probably deposited during backfilling of the sill. As these small boulders became exposed by the effects of underscouring, their relatively large size probably acted as a scour point that prevented bedload transported during high flow from re-sealing the sill face. The smooth nature of the surface of these small boulders probably did not improve conditions for deposition. I would recommend that large, smooth-faced substrates be avoided when backfilling sills during their construction.

Compared to most other oblique sills in the study area, the angle of departure formed by the axis of sill # 33 and sill # 35, with the direction of flow, was relatively acute. It may be that such relatively extreme orientation of a sill enhances the effects of underscour and shortens its lifespan. I have noticed that sill # 6 in treatment site T1 and sills # 8 and 9 in site T2 each have relatively acute angles of departure, but have not been damaged by underscour. It would be of interest to monitor the condition of sills in the study area, particularly their angle of departure and ant maintenance required, for the next decade or two.

In the fall of 1990, I replaced a few large rock protecting the streambank where log sills were keyed to the bank at sill # 36, # 37, and # 38 of site T6 and sill # 7 of site T1. The smaller substrate surrounding these rocks had been washed away by high spring flows, and the larger rocks had fallen into the plunge pools of their respective sills. Given the alluvial nature of most of the study area, such rip-rapping of the streambank is extremely important to maintaining the integrity of sills over their expected lifespan.

I surveyed the study area in late October of 1996 to count the number of remaining log sills and assess their condition (Table 8). All 40 sills were intact and functioning. Seventeen of the 40 sills appeared in need of minimal maintenance, generally simple work such as replacing rip-rap boulders on the streambank. In treatment sites T4 and T5, none of the "V" sills required maintenance. In treatment site T6, six of eight sills were in need of rip-rap maintenance, and sill # 34 had developed a cavity. Given that the gradient of T6 (2%) is the highest of all treatment sites in the study area, it may be that log sills in alluvial systems require greater maintenance when constructed in channels whose gradient exceeds 2%.

Table 8. Number of intact log sills and log sills in need of maintenance, Confederate Gulch, MT, October 1996.

Site	Oblique sills		"V" sills	
	Number	Maintenance needed	Number	Maintenance needed
T1	7	3	0	0
T2	2	2	0	0
T3	9	5	0	0
T4	1	1	4	0
T5	0	0	9	0
T6	8	6	0	0
Total	27	17	13	0

Effects of Beaver

Beaver built dams in the middle of the study area and increased their habitat during the course of the study. Log sills were covered by beaver dams and inundated by ponds in treatment site T3 intermittently from 1989 through 1990. Dams, and the water ponded behind them, interrupted the downstream transport of bedload, specifically spawning-sized gravel, reducing the effectiveness of log

sills in sites T1, and in particular, T2. Surface gravel area, redd counts, hiding cover, and number and biomass of brook trout all increased dramatically in stations where beaver built dams and modified the habitat. Because these changes were so obviously different from those occurring in stations unaffected by beaver, the analysis of data had to be stratified to avoid inappropriate comparisons when assessing the effectiveness of log sills to trap spawning gravel and provide hiding cover to trout.

Beaver dams and their ponds probably benefited the trout population of Confederate Gulch by providing relatively more spawning and rearing habitat, per 100-m of stream, than log sills or any other feature in the study area, outside of the spring we labeled station 99. The relatively high densities of all age classes of brook trout in beaver-affected sections of Confederate Gulch agree with the findings of studies reviewed by Olson et al (1994), which indicate that in the western United States, trout populations generally benefit where beaver create dams and ponds. Rabe (1970) found in the central Colorado Rockies that brook trout populations tended to stunt in beaver ponds where spawning habitat was not limiting, and similar results were reported by Johnson et al (1992) and Winkle et al (1990) in Wyoming. Considering the success of log sills in restoring spawning habitat, and the large quantities of surface gravel trapped in beaver ponds in 1990, it would be of interest to monitor the brook trout population for stunting. As only one pond was observed intact in October 1996, and at least 17 had failed within the study area since March of 1992, such monitoring may not be warranted until beaver and their ponds stabilize, if this is possible.

Ives (1942) reported large beaver dams excavated from quaternary deposits in Colorado, and concluded that over long periods of time, beaver were largely responsible for vast quantities of deposited sediments and the evolution of meadows. Rudemann and Schoonmaker (1938) made similar conclusions from observations in the New York Catskills, and cited reports of beaver as agents in storing stream sediments and forming meadows, primarily in the western United States. Beaver dams have probably been more effective in storing bedload in Confederate Gulch than any other process that has occurred since streambed elevation was altered by placer and dredge mining. Although on the order of geologic time, beaver provide a cost-efficient means of reclaiming streambed elevation and channel morphology lost in the rush for gold.

Ponding of water by beaver dams raised sub-surface water levels in sections T3 and C4 such that during spring runoff and other wet times of the year water inundated low-lying sections of the road 30 m away. This effect was not considered positive by county road maintenance crews, however increased sub-surface water levels probably benefited vegetation at the outer margins of the riparian zone (Stabler 1985). Beaver activity did considerably impact riparian vegetation as large cottonwoods and much of the streamside growth of red-osier dogwood were cut down by beaver for use in building dams and as forage.

Station 99

Station 99 contained the highest numerical and biomass densities of all age classes of brook trout measured in 1989 and 1990. Spawning habitat in station 99 was considerable, and hiding cover in the form of aquatic vegetation was dense. The stable nature of water flow and temperature year-round (I never observed it to freeze, although I was rarely present during extreme cold), combined with the protected location from high water disturbance, are probably most responsible for the relatively large population of brook trout and growth of aquatic vegetation in station 99.

MANAGEMENT IMPLICATIONS

Log sills are an effective means for restoring spawning habitat for trout. Both oblique and downstream-pointing "V" structures were effective structures, and "V" structures trapped higher densities of gravel and had greater number of definite and probable brook trout redds per sill. Sills maintained plunge pools dug by heavy machinery, and increased pool frequency in the study area, although the quality of sill plunge pools was rated less than that of natural pools or beaver ponds. Sill plunge pools, sill undercuts, and turbulence associated with sills considerably increased hiding cover for trout in treated stations, where hiding cover was relatively low previous to sill installation.

Numerical and biomass density of age-0 brook trout increased within the study area after log sills were installed, and these densities were greater in control sections than in sections treated with log sills, possibly due to downstream migration. Density of number and biomass of age-1 and age-2 and older brook trout did not increase after log sills were installed, indicating that sills and plunge pools were not effective means of enhancing hiding cover, and that within the study area, the brook trout population was probably limited more by rearing habitat than by spawning habitat. In the future, it would be of interest to investigate the effectiveness of upstream-pointing "V" structures (constructed of logs), and structures such as logjams which imitate naturally deposited instream wood, to provide pool habitat and hiding cover for trout, and how trout populations respond to these structures.

In the first 8 years after their construction, all 40 log sills remained intact and required little maintenance. I believe that the techniques and photographs provided in White et al (1992) are valuable to anyone planning a project with similar objectives and equipment. The only recommendations I would add is that where logs are keyed into banks, soil, if exposed, should be seeded immediately to further protect the integrity of the structure, and that care should be taken in backfilling the sill such that large diameter, smooth-surfaced materials be excluded from the fill to reduce the effects of underscouring.

As noted by Hunt (1976), collection of post-treatment data should be delayed at least 3 years after treatment to provide for a more valid evaluation, and I propose that subsequent data collection would be useful in further evaluation of log sills, particularly their effect upon the trout population. Surveys of surface gravel area, pools and pool quality, trout hiding cover, redd counts, and trout populations would all be useful. Surveys conducted in the fall, just previous to spawning (excepting redd counts; spring spawning surveys would also be desirable) would be appropriate, on the order of once every 3 to 5 years. A quick survey once a year to count intact sills and the number of sills requiring maintenance would also be of interest.

Beaver altered habitat in the middle of the study area that resulted in considerable increases in surface gravel, brook trout redds, trout hiding cover, and numbers and biomass of all age classes of brook trout. Beaver dams ponded water, raising the water table, and stored sediment, increasing streambed elevation. Beaver had a positive effect upon channel morphology and aquatic biota, slowly restoring the system to its pre-mining condition. With proper planning, beaver can provide a cost-effective role in improving long-term watershed function in Confederate Gulch.

Cutthroat trout within the study area were few in all years, and increases in number and biomass in 1988 and 1989 dropped back to pre-treatment levels in 1990. If this population were analyzed and found to be genetically pure, it may be worth restoring, particularly as it exists at the eastern extent of the original range for the westslope race (Brown 1971). The diversion dam at the mouth of the canyon is an excellent barrier to upstream migration for non-native species, and in the event of another natural disturbance on the scale of the flood of 1981, it would be preferable to manage the fishery upstream of the diversion for native cutthroat trout. If cutthroat trout currently inhabiting the drainage were not of the westslope race, or had hybridized with rainbow or another race of cutthroat, the state may consider identifying a stock best suited for re-introduction. Other factors that need to be considered include methods to completely remove brook trout from the watershed, and how landownership patterns and mining claims could affect the population. Such planning could be relatively simple and inexpensive, and could be done at a regional scale (if it has not already been done) to rank watersheds by priority.

SUMMARY

1. Three years after log sills were installed, stations containing sills trapped 37 times the density of surface gravel than existed before sills were constructed, while densities in untreated stations increased only 3 times their pre-treatment level.

2. In 1987, before log sills were constructed, surface gravel density in control stations (4.92 m^2/100-m) exceeded that in treated stations (1.51 m^2/100-m) by more than a factor of 3. By 1990, this relationship was reversed, as gravel density in treated stations (57.12 m^2/100-m) was more than 4 times that in control stations (13.62 m^2/100-m).

3. Density of patches of surface gravel in 1987 in control stations (7.46/100-m) was more than 50% greater than that in treated stations (4.89/100-m). By 1990, patch density in treated stations had increased almost six times (34.02/100-m) and was 21% greater than in control stations (28.01/100-m).

4. Mean gravel patch area in control stations of 1987 (0.68 m^2) was 66% larger than in treated stations (0.41 m^2). By 1990, mean patch area in treated stations increased 254% (1.45 m^2), and was more than 3 times mean patch area in control stations (0.45 m^2), which had decreased by one-third.

5. Previous to sill installation, trout redds in the study area were rarely observed (white et al 1992). Density of definite and probable brook trout redds in the study area increased 186% from 1988 (immediately after sills were constructed) to 1990. In 1990, density of definite and probable brook trout redds was 86% greater in stations treated with log sills than in control stations.

6. Number of pools ≥ 0.4 m residual pool depth in stations treated with log sills increased from 1 in 1986 to 23 in August of 1990. Residual pool depth in 1986 was 0.43 m, and by 1990, mean residual pool depth was 0.53 m, an increase of about 23%.

7. In 1990, trout hiding cover associated with log sills (plunge pools, sill undercut, and turbulence) accounted for 72% of all non-beaver associated hiding cover in treated stations, and 40% of all non-beaver associated cover in the study area.

8. Numerical density of age-0 brook trout in the study area more than tripled three years after log sills were installed. In treated stations, age-0 brook trout density increased 51%, and in control stations, this increase was 378%.

9. Numerical density of age-1 brook trout decreased slightly from 1986 to 1990, likely due to the effects of drought in 1988. Density of age-1 brook trout were greater in treated stations than in control stations by about the same proportion (40-60%) in years before and after log sills were constructed.

10. Numerical density of age-2 brook trout was relatively stable in the study area from 1986 to 1990. In 1986, density of age-2 brook trout in treated stations was 64% greater than in control stations, and by 1990, this figure had shrunk to 39%.

11. Eight years after they were installed, all 40 log sills were intact and functioning, and little maintenance had been required during this period.

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APPENDICES

Appendix A : Stream Dimensions

Station Number	Length (m) 1986	Length (m) 1990	Mean Width (m) 1986	Mean Width (m) 1990	Area (m²) 1986	Area (m²) 1990	Section Number	Length (m) 1986	Length (m) 1990	Mean Width (m) 1986	Mean Width (m) 1990	Area (m²) 1986	Area (m²) 1990
1	100	100	4.80	4.80	480	480	C1	300	294	4.14	4.14	1241	1220
2	100	94	3.45	3.45	345	324							
3	100	100	4.16	4.16	416	416							
4	100	104	5.65	5.65	565	588	T1	200	204	5.20	5.20	1040	1063
5	100	100	4.75	4.75	475	475							
6	100	101	4.25	4.25	425	429	C2	100	101	4.25	4.25	425	429
7	100	98	4.67	4.67	467	458	T2	100	98	4.67	4.67	467	458
8	100	100	3.95	3.95	395	395	C3	100	100	3.95	3.95	395	395
9	100	103	4.17	5.05	417	520	T3	300	304	4.68	6.30	1404	1915
10	100	104	5.56	5.56	556	578							
11	100	97	4.31	8.29	431	804							
12	100	98	6.43	10.98	643	1076	C4	300	308	5.87	9.79	1761	3015
13	100	103	6.76	8.55	676	881							
14	100	107	4.43	9.84	443	1053							
15	100	123	4.62	4.62	462	568	C5	600	583	4.82	4.82	2892	2810
16	100	102	4.86	4.86	486	496							
17	100	100	4.69	4.69	469	469							
18	100	103	4.77	4.77	477	491							
19	100	91	5.27	5.27	527	480							
20	100	64	4.73	4.73	473	303							
21	100	100	4.72	4.72	472	472	T4	300	291	4.29	4.29	1287	1248
22	100	104	4.29	4.29	429	446							
23	100	87	3.85	3.85	385	335							
24	100	98	4.40	4.40	440	431	C6	100	98	4.40	4.40	440	431
25	100	101	4.02	4.02	402	406	T5	231	233	4.20	4.20	970	979
26	131	132	4.33	4.33	567	572							
27	100	103	4.62	4.62	462	476	C7	200	201	4.47	4.47	894	898
28	100	98	4.32	4.32	432	423							
29	100	102	4.60	4.60	460	469	T6	300	300	4.33	4.33	1299	1299
30	100	101	4.49	4.49	449	454							
31	100	97	3.91	3.91	391	379							
32	100	102	3.41	3.41	341	348	C8	740	746	3.82	3.82	2827	2850
33	100	97	3.35	3.35	335	325							
34	100	105	3.68	3.68	368	386							
35	100	100	5.17	5.17	517	517							
36	100	100	3.45	3.45	345	345							
37	100	100	3.61	3.61	361	361							
38	100	101	4.08	4.08	408	412							
39	40	41	3.81	3.81	152	156							
Treated	1431	1430	4.52	4.91	6466	6962							
Control	2440	2431	4.44	4.87	10878	12048							
Total	3871	3861	4.47	4.90	17344	19010							
99	a	160	a	1.10	a	176							

a - indicates station not sampled that year

Appendix B : Rating Curves
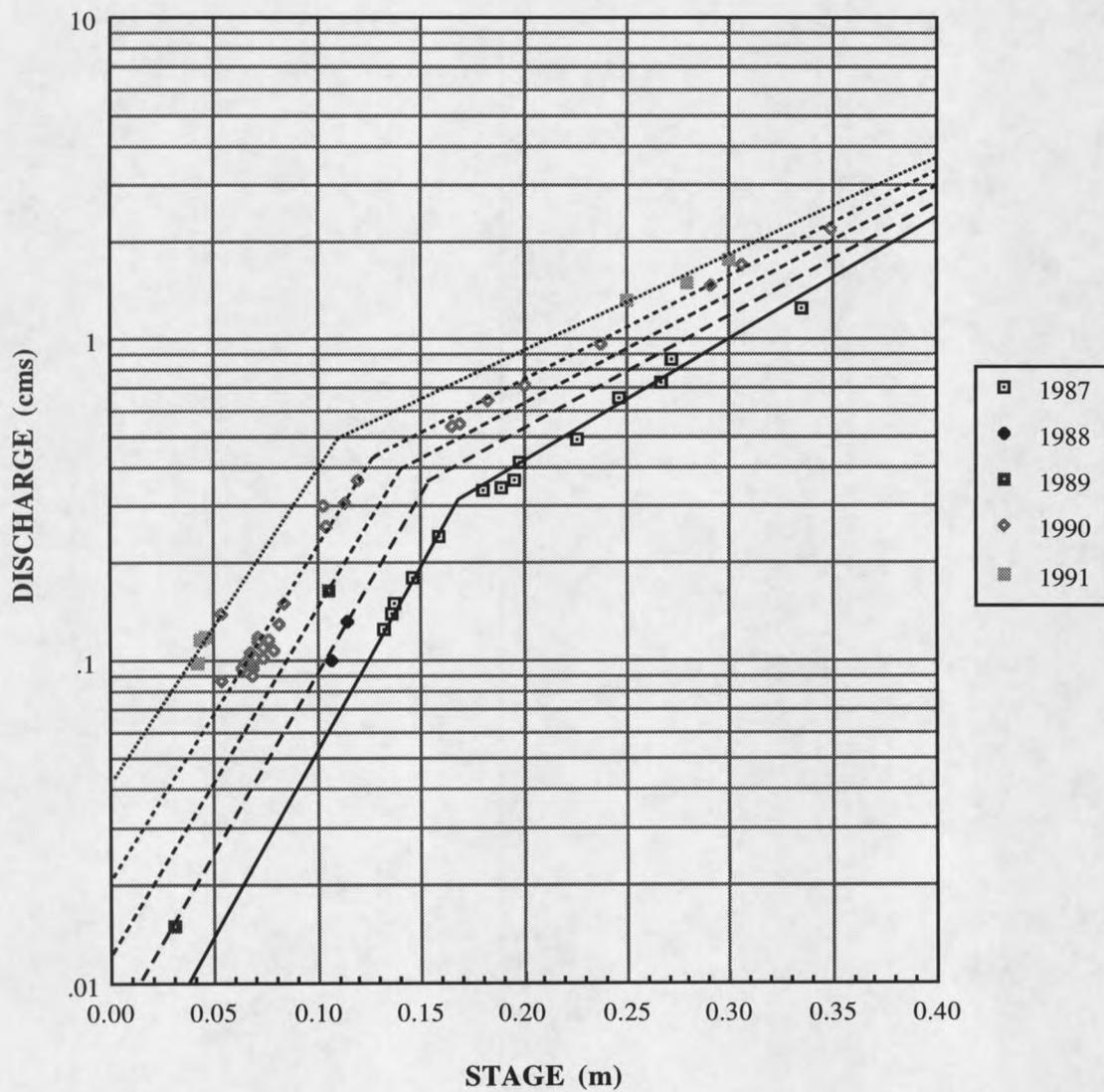
Appendix C : Surface Gravel Area (m^2)

Station Number	Wood Debris			Pools			Beaver		
	1987	1989	1990	1987	1989	1990	1987	1989	1990
1	0.00	3.00	0.84	1.60	0.24	0.00	0.00	0.00	0.00
2	0.00	4.96	11.98	0.00	2.80	0.00	0.00	0.00	0.00
3	0.00	1.22	0.30	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	1.14	0.00	0.28	0.00	0.00	0.00	0.00
5	0.00	0.90	6.04	0.00	5.28	0.00	0.00	0.00	0.00
6	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	2.25	0.00	0.00	0.00	0.00	0.00	0.00	2.49
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.78	1.99	1.18	0.00	0.00	0.00	14.78	0.00	12.60
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.41	19.37
12	19.44	1.98	1.12	2.20	0.00	0.00	0.00	3.07	3.76
13	0.00	0.90	0.00	0.00	0.00	0.00	0.00	2.56	0.00
14	4.00	0.00	0.00	0.00	0.00	0.00	0.00	9.52	204.56
15	1.22	13.82	0.00	0.00	6.39	0.00	0.00	0.00	9.03
16	1.52	1.35	3.28	0.00	0.00	0.00	0.00	0.00	0.44
17	0.00	1.77	0.74	0.00	0.00	0.00	0.00	0.00	0.00
18	1.44	8.90	21.17	0.00	0.00	0.00	0.00	0.00	0.00
19	4.00	4.26	4.58	0.00	5.30	0.00	0.00	0.00	0.00
20	4.92	26.23	9.54	4.92	0.00	7.36	0.00	0.00	0.00
21	0.44	4.85	5.65	0.00	0.00	0.00	0.00	0.00	0.00
22	0.64	0.00	1.36	0.00	0.00	0.00	0.00	0.00	0.00
23	3.48	2.92	3.94	0.00	0.00	9.47	0.00	0.00	0.00
24	2.94	1.80	0.76	0.00	0.00	0.00	0.00	0.00	0.00
25	0.45	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00
26	1.16	0.00	3.94	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	0.57	2.56	0.00	0.00	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	3.40	0.00	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.52	0.00	0.00	0.00	0.00	0.00	0.00
31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	2.25	0.00	1.90	2.30	0.65	7.04	0.00	0.00	0.00
33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	0.00	0.37	0.49	0.00	0.15	0.00	0.00	0.00	6.26
35	1.77	0.00	2.92	0.00	2.85	0.00	0.00	0.00	0.00
36	1.19	1.08	1.70	1.04	0.00	0.00	0.00	0.00	0.00
37	0.00	0.56	0.72	0.00	0.00	0.00	0.00	0.00	0.00
38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	0.00	1.86	0.00	0.00	0.00	2.52	0.00	0.00	0.00
Treated	6.95	10.84	27.54	0.00	5.56	9.47	14.78	3.41	31.97
Control	44.68	77.30	64.59	12.06	18.38	16.92	0.00	15.15	226.54
Total	51.64	88.14	92.13	12.06	23.94	26.39	14.78	18.56	258.51
99	a	0.00	a	a	0.00	a	a	0.00	a

a - indicates station not sampled that year

Appendix C : Surface Gravel Area (m^2)

Station	Above Sills			Below Sills		
Number	1987	1989	1990	1987	1989	1990
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	10.43	0.00	0.00	20.35
5	0.00	0.00	2.87	0.00	1.60	22.06
6	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	2.01	0.00	0.66	2.10
8	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	1.10	0.91
10	0.00	0.00	0.00	0.00	0.31	1.26
11	0.00	0.00	0.14	0.00	0.00	3.57
12	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	15.64	35.80	0.00	9.38	27.18
23	0.00	2.02	2.59	0.00	4.14	7.60
24	0.00	0.00	0.00	0.00	2.04	0.00
25	0.00	0.60	21.78	0.00	11.58	35.41
26	0.00	0.00	14.70	0.00	10.94	32.41
27	0.00	0.00	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00	0.68	0.58	0.00	2.60	6.60
30	0.00	0.45	39.87	0.00	8.23	44.26
31	0.00	5.13	1.92	0.00	1.40	2.70
32	0.00	0.00	0.00	0.00	0.00	0.00
33	0.00	0.00	0.00	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00	0.00	0.00
35	0.00	0.00	0.00	0.00	0.00	0.00
36	0.00	0.00	0.00	0.00	0.00	0.00
37	0.00	0.00	0.00	0.00	0.00	0.00
38	0.00	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00	0.00	0.00
Treated	0.00	24.52	132.70	0.00	51.92	206.41
Control	0.00	0.00	0.00	0.00	2.04	0.00
Total	0.00	24.52	132.70	0.00	53.96	206.41
99	a	0.00	a	a	0.00	a

a - indicates station not sampled that year

Appendix C : Surface Gravel Area (m^2)

Station	Streambed			Total		
Number	1987	1989	1990	1987	1989	1990
1	0.43	3.95	3.27	20.26	6.83	4.10
2	5.04	0.66	7.10	5.04	8.42	19.08
3	1.93	1.32	1.13	1.93	2.54	1.43
4	0.24	0.84	18.08	0.24	1.12	50.00
5	0.77	12.33	24.70	0.77	20.11	55.67
6	0.66	1.04	1.28	0.66	1.46	1.28
7	0.00	4.63	2.84	0.00	5.47	6.94
8	0.32	0.74	0.96	0.32	3.00	3.46
9	0.62	1.01	1.62	0.62	2.11	2.53
10	0.52	19.67	15.49	16.08	21.97	30.44
11	6.48	0.00	0.66	6.44	3.41	23.94
12	9.54	2.86	4.81	31.18	5.35	9.70
13	3.12	0.00	11.16	3.12	3.46	11.16
14	4.05	6.19	0.00	4.45	15.71	204.56
15	0.56	21.42	0.00	1.78	41.63	9.03
16	0.45	9.61	8.82	1.97	10.96	12.53
17	0.48	1.96	8.44	0.48	3.73	9.18
18	3.85	19.60	8.86	5.29	28.50	30.03
19	11.00	9.99	16.51	5.10	19.55	21.08
20	15.75	35.40	9.11	20.67	61.63	26.02
21	1.20	3.18	19.25	1.64	8.03	24.90
22	0.46	2.18	17.11	1.10	27.20	81.75
23	1.99	16.88	11.36	5.47	25.98	34.95
24	1.66	7.93	16.18	4.60	11.77	39.48
25	0.58	6.66	44.71	1.03	18.83	102.30
26	0.45	4.88	27.59	1.61	15.82	78.65
27	4.34	6.18	24.30	4.34	6.75	26.86
28	2.43	3.88	19.62	2.43	3.88	19.62
29	0.84	5.70	52.62	0.84	8.98	63.20
30	2.97	11.32	23.07	2.97	20.00	107.72
31	1.34	5.36	31.38	1.34	11.89	36.00
32	2.19	1.49	5.30	6.74	2.14	14.23
33	0.80	2.62	4.72	0.80	2.62	4.72
34	1.48	3.40	4.93	1.48	3.92	11.68
35	7.67	0.90	7.40	9.44	3.76	10.31
36	2.08	0.61	2.72	4.31	1.69	4.41
37	0.36	2.34	4.35	0.36	2.90	5.07
38	6.28	1.75	6.35	6.28	1.75	6.35
39	1.05	3.70	6.65	1.05	5.57	9.17
Treated	18.48	94.66	290.48	40.22	190.92	698.96
Control	87.52	149.54	183.97	144.09	259.50	514.56
Total	106.00	244.20	474.44	184.31	450.42	1,213.52
99	a	41.99	39.88	a	41.99	39.88

a - indicates station not sampled that year

Appendix D : Redd Counts

Station Number	Trial Redds 1988	1989	1990	Possible Redds 1988	1989	1990	Probable Redds 1988	1989	1990	Definite Redds 1988	1989	1990	Definite + Probable 1988	1989	1990
1	0	0	0	2	1	0	0	0	1	0	0	0	0	0	1
2	0	1	0	0	2	1	2	0	2	0	5	0	2	5	2
3	0	0	0	0	0	0	0	0	0	0	4	0	0	4	0
4	0	0	0	0	2	6	1	0	8	0	4	6	1	4	14
5	0	3	1	2	0	0	2	3	2	0	2	1	2	5	3
6	0	0	0	0	0	0	3	3	0	0	1	0	3	4	0
7	0	5	2	3	0	1	3	3	1	0	0	3	3	3	4
8	0	0	0	1	0	0	1	2	0	0	3	1	1	5	1
9	0	0	0	0	0	0	0	0	1	0	0	6	0	0	7
10	0	0	0	0	1	0	2	4	5	1	4	0	3	8	5
11	0	1	0	1	3	1	0	0	2	0	0	2	0	0	4
12	0	1	3	0	3	3	4	1	7	0	7	4	4	8	11
13	0	2	0	0	4	1	0	1	1	11	12	3	11	13	4
14	0	0	0	0	0	0	0	1	8	0	7	14	0	8	22
15	0	1	4	0	7	8	1	1	10	1	5	7	2	6	17
16	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0
17	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
18	0	1	0	0	2	0	2	6	0	1	6	3	3	12	3
19	0	0	0	0	0	0	0	3	1	2	3	1	2	6	2
20	0	2	0	0	1	0	2	1	1	1	3	3	3	4	4
21	0	3	0	0	1	1	2	2	0	2	9	3	4	11	3
22	0	0	2	1	0	0	0	0	3	0	3	5	0	3	8
23	0	0	2	0	0	0	0	1	2	0	3	8	0	4	10
24	0	2	0	1	0	0	2	2	1	2	2	0	4	4	1
25	0	1	4	0	7	3	0	10	9	0	14	3	0	24	12
26	0	2	2	3	3	4	0	3	4	3	17	7	3	20	11
27	0	3	1	0	1	2	0	2	3	0	2	2	0	4	5
28	0	2	0	2	4	4	0	4	4	0	2	0	0	6	4
29	0	0	0	1	1	1	3	3	1	2	10	11	5	13	12
30	0	3	1	0	4	2	8	5	8	3	28	13	11	33	21
31	0	1	1	1	1	0	3	1	6	5	3	8	8	4	14
32	0	2	0	0	1	5	0	9	1	0	9	4	0	18	5
33	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	1	2	0	1	1	0	1	4	0	3	5	0	4	9
35	0	4	2	0	2	2	2	5	0	3	2	0	5	7	0
36	0	3	0	0	0	2	2	0	0	0	1	0	2	1	0
37	0	9	0	2	6	3	2	6	2	0	8	8	2	14	10
38	0	5	4	3	4	4	3	7	6	2	6	1	5	13	7
39	0	1	0	0	6	0	0	12	3	0	8	6	0	20	9
Treated	0	19	15	12	23	19	24	35	52	16	97	76	40	132	128
Control	0	42	16	14	45	36	26	77	55	23	99	62	49	166	117
Total	0	61	31	26	68	55	50	112	107	39	196	138	89	298	245
99	0	10	4	1	18	3	8	8	4	23	16	21	31	24	25

Appendix E : Redd Counts by Sill Type, Fall 1990

Sill #	Type	Station	Trial	Possible	Probable	Definite	Def+Prob	Total
1	L	4	1	4	5	6	11	16
2	L	4	0	0	0	0	0	0
3	L	5	0	0	2	2	4	4
4	L	5	0	0	0	0	0	0
5	L	5	0	0	0	0	0	0
6	L	5	0	0	0	0	0	0
7	L	5	0	0	0	0	0	0
8	L	7	0	0	0	0	0	0
9	L	7	0	0	1	0	1	1
10	L	9	0	0	2	6	8	8
11	L	9	0	0	0	0	0	0
12	L	10	0	0	0	0	0	0
13	L	10	0	0	4	0	4	4
14	L	10	0	0	0	0	0	0
15	L	11	0	0	0	0	0	0
16	L	11	0	1	0	0	0	1
17	L	11	0	0	0	1	1	1
18	L	11	0	0	1	1	2	2
19	L	22	0	0	0	0	0	0
20	V	22	0	0	0	0	0	0
21	V	22	0	0	0	0	0	0
22	V	23	1	0	0	0	0	1
23	V	23	2	0	1	2	3	4
24	V	24	0	0	0	0	0	0
25	V	25	0	0	1	0	1	1
26	V	25	1	0	1	0	1	2
27	V	25	1	4	1	3	4	9
28	V	25	2	1	7	0	7	10
29	V	26	1	0	0	0	0	1
30	V	26	0	0	0	0	0	0
31	V	26	0	1	0	0	0	1
32	V	26	0	1	2	1	3	4
33	L	29	0	0	0	0	0	0
34	L	30	0	0	0	0	0	0
35	L	30	1	0	2	0	2	3
36	L	30	0	1	0	1	1	2
37	L	30	0	0	2	3	5	5
38	L	30	0	0	0	0	0	0
39	L	31	0	0	2	1	3	3
40	L	31	0	0	2	2	4	4
"L" type	27	10	2	6	23	23	46	54
"V" type	13	5	8	7	13	6	19	34
Total	40	14	10	13	36	29	65	88

Appendix F : Hiding Cover (m^2)

Station Number	Natural Pool 1986	1989	1990	Sill Pool 1986	1989	1990	Beaver Ponds 1986	1989	1990
1	5.94	3.48	3.42	0.00	0.00	0.00	0.00	0.00	0.00
2	0.23	4.14	1.16	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	1.50	0.00	0.00	22.75	11.08	0.00	0.00	0.00
5	14.62	16.42	19.79	0.00	23.58	18.76	0.00	0.00	0.00
6	1.76	1.28	3.20	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	2.42	1.28	0.00	9.68	6.74	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.55	34.30
9	0.00	18.92	a	0.00	5.22	a	0.00	389.50	a
10	2.94	1.52	a	0.00	41.07	a	0.00	45.60	a
11	0.00	0.00	a	0.00	4.35	a	0.00	454.09	a
12	69.99	0.00	a	0.00	0.00	a	0.00	534.55	a
13	0.00	0.00	a	0.00	0.00	a	438.15	791.94	a
14	0.96	0.00	a	0.00	0.00	a	0.00	464.00	a
15	4.05	1.68	0.00	0.00	0.00	0.00	0.00	0.00	643.92
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.28
17	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	5.51	0.00	4.40	0.00	0.00	0.00	0.00	0.00	0.00
19	4.80	3.00	16.20	0.00	0.00	0.00	0.00	0.00	0.00
20	12.32	5.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	7.12	6.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.50	0.00	13.22	23.24	0.00	0.00	0.00
23	3.20	13.91	11.10	0.00	8.87	4.68	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	7.20	0.00	0.00	16.63	10.97	0.00	0.00	0.00
26	2.21	5.26	3.22	0.00	6.94	12.90	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	4.44	1.89	1.12	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	0.00	0.00	6.63	5.19	0.00	0.00	0.00
30	0.00	0.52	0.00	0.00	42.48	43.03	0.00	0.00	0.00
31	1.83	0.24	0.00	0.00	7.68	5.06	0.00	0.00	0.00
32	20.20	12.32	13.20	0.00	0.00	0.00	0.00	0.00	0.00
33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	4.67	0.00	0.34	0.00	0.00	0.00	0.00	0.00	116.53
35	4.20	9.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36	1.26	0.00	2.20	0.00	0.00	0.00	0.00	0.00	0.00
37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Treated	31.92	74.23	35.89	0.00	209.10	141.65	0.00	889.19	0.00
Control	141.11	43.29	45.24	0.00	0.00	0.00	438.15	1808.04	811.03
Total	173.03	117.52	81.13	0.00	209.10	141.65	0.00	2697.23	811.03
99	a	37.90	a	0.00	0.00	0.00	a	a	a

a - indicates station not sampled that year

Appendix F : Hiding Cover (m^2)

Station	Undercut Bank			Undercut Sill			Turbulence		
Number	1986	1989	1990	1986	1989	1990	1986	1989	1990
1	0.84	0.18	0.00	0.00	0.00	0.00	a	a	0.00
2	2.72	7.42	8.96	0.00	0.00	0.00	a	a	0.00
3	1.79	2.28	0.08	0.00	0.00	0.00	a	a	0.00
4	0.00	0.14	0.00	0.00	4.24	5.24	a	a	2.88
5	2.16	2.13	1.36	0.00	10.94	10.31	a	a	7.84
6	0.65	0.00	0.00	0.00	0.00	0.00	a	a	0.00
7	0.00	1.68	0.00	0.00	5.86	5.25	a	a	4.00
8	0.00	0.00	0.10	0.00	0.00	0.00	a	a	0.00
9	3.10	7.36	a	0.00	3.88	a	a	a	a
10	3.51	5.10	a	0.00	7.22	a	a	a	a
11	0.00	1.22	a	0.00	2.41	a	a	a	a
12	1.57	6.48	a	0.00	0.00	a	a	a	a
13	4.34	3.39	a	0.00	0.00	a	a	a	a
14	1.34	5.01	a	0.00	0.00	a	a	a	a
15	1.17	1.49	2.85	0.00	0.00	0.00	a	a	0.00
16	1.63	0.03	0.18	0.00	0.00	0.00	a	a	0.00
17	0.00	1.56	1.08	0.00	0.00	0.00	a	a	0.00
18	0.88	0.00	0.56	0.00	0.00	0.00	a	a	0.00
19	0.14	0.00	0.20	0.00	0.00	0.00	a	a	0.00
20	1.34	0.18	0.68	0.00	0.00	0.00	a	a	1.60
21	2.85	0.92	0.71	0.00	0.00	0.00	a	a	0.00
22	4.86	2.88	2.08	0.00	6.04	4.07	a	a	5.06
23	2.48	1.54	1.42	0.00	4.41	2.51	a	a	4.47
24	0.00	0.00	0.00	0.00	0.90	1.26	a	a	1.25
25	1.03	0.00	0.26	0.00	7.34	4.98	a	a	5.93
26	0.63	0.68	0.09	0.00	4.43	5.43	a	a	7.41
27	0.73	0.00	0.38	0.00	0.00	0.00	a	a	0.00
28	0.30	0.00	0.15	0.00	0.00	0.00	a	a	0.00
29	0.64	0.00	0.00	0.00	2.35	1.89	a	a	1.44
30	0.18	1.17	2.26	0.00	15.08	15.96	a	a	7.16
31	0.00	0.00	0.00	0.00	5.20	4.42	a	a	1.74
32	0.00	0.00	0.00	0.00	0.00	0.00	a	a	0.00
33	0.12	0.00	0.00	0.00	0.00	0.00	a	a	0.00
34	0.00	0.00	4.81	0.00	0.00	0.00	a	a	0.00
35	0.67	1.16	1.23	0.00	0.00	0.00	a	a	0.00
36	1.30	0.00	0.12	0.00	0.00	0.00	a	a	0.00
37	0.14	0.00	0.00	0.00	0.00	0.00	a	a	0.00
38	0.00	0.00	0.00	0.00	0.00	0.00	a	a	0.00
39	0.00	2.40	0.00	0.00	0.00	0.00	a	a	0.00
Treated	21.44	24.82	8.18*	0.00	72.16	55.08*	a	a	42.00*
Control	21.67	31.58	21.38*	0.00	0.90	1.26*	a	a	2.85*
Total	43.11	56.40	29.56*	0.00	72.16	55.08*	a	a	44.85*
99	a	0.71	a	a	0.00	a	a	a	a

a : indicates station not sampled that year

Appendix F : Hiding Cover (m^2)

Station	Brush Debris			Complex Debris			Log		
Number	1986	1989	1990	1986	1989	1990	1986	1989	1990
1	0.00	2.62	2.60	0.00	2.02	0.34	0.32	0.00	0.00
2	0.40	10.49	3.54	0.00	1.89	4.12	0.23	3.50	2.05
3	1.14	1.14	0.94	0.00	0.00	0.36	0.00	0.00	0.18
4	0.00	2.06	0.92	0.00	0.00	0.00	0.51	0.67	0.40
5	5.41	5.12	4.36	0.00	0.00	0.00	0.78	0.93	0.55
6	7.24	2.69	2.56	0.00	0.00	0.00	0.16	0.00	0.00
7	2.66	1.92	1.80	2.14	7.07	0.94	0.58	0.00	0.00
8	3.31	3.76	0.98	0.00	8.60	6.65	0.00	0.00	0.00
9	5.65	16.04	a	0.23	5.28	a	0.00	1.77	a
10	0.98	11.98	a	0.60	15.64	a	0.65	3.54	a
11	1.08	43.37	a	0.00	15.11	a	0.00	32.91	a
12	8.74	19.61	a	23.65	31.12	a	6.89	33.71	a
13	0.49	55.01	a	21.80	150.48	a	6.19	67.15	a
14	8.43	17.83	a	0.00	21.56	a	2.97	21.95	a
15	2.69	14.42	7.62	0.48	6.12	29.44	1.05	0.59	1.18
16	16.22	0.25	2.07	0.00	9.84	0.00	0.89	0.36	0.00
17	12.02	0.24	3.24	0.00	2.25	0.00	0.73	0.00	0.00
18	8.82	0.15	6.47	0.00	4.76	0.00	4.88	2.42	1.74
19	10.87	5.29	5.20	0.00	2.10	1.98	3.51	4.26	3.20
20	32.34	1.64	14.12	0.00	25.34	0.00	9.01	4.72	1.39
21	1.25	1.26	1.08	0.00	1.65	0.20	0.65	0.18	0.00
22	2.58	2.96	2.39	0.00	4.98	0.00	0.28	0.08	0.00
23	13.85	6.22	5.92	0.16	9.32	0.00	3.23	2.25	1.70
24	6.73	0.00	0.35	0.00	3.61	0.78	1.19	0.48	0.00
25	2.76	0.48	0.00	0.00	0.00	0.00	0.70	0.19	0.00
26	4.35	0.17	5.36	0.00	3.44	0.00	2.00	1.46	0.76
27	0.69	0.00	0.11	0.00	0.70	0.00	0.52	0.18	0.00
28	2.20	1.18	0.00	0.00	0.18	0.00	0.17	0.00	0.00
29	5.12	1.94	0.32	0.00	0.00	0.00	0.00	0.00	0.00
30	3.04	1.18	0.00	0.00	2.05	0.00	0.00	0.00	0.00
31	1.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70
32	15.62	2.52	0.56	0.00	0.00	5.50	5.25	0.52	1.08
33	0.00	0.18	0.00	0.00	0.00	0.00	0.10	0.11	0.00
34	5.31	0.80	0.00	0.00	5.00	10.23	1.02	0.00	0.00
35	11.74	3.15	3.28	0.24	4.43	0.00	0.93	0.00	2.53
36	12.14	2.13	0.60	0.00	1.46	2.96	1.51	0.00	0.00
37	3.17	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	0.22	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	3.74	0.06	0.28	0.00	5.00	6.20	0.33	0.00	0.00
Treated	50.52	94.70	22.15	3.13	135.93	1.14	9.37	43.98	4.11
Control	174.28	146.51	48.51	46.17	286.45	68.57	47.85	139.95	13.35
Total	224.80	241.21	70.66	49.30	422.38	69.71	57.22	183.93	17.46
99	a	4.22	a	a	5.38	a	a	1.86	a

* - indicates station not sampled that year

Appendix F : Hiding Cover (m^2)

Station	Overhead Brush			Overhead Vegetation			Aquatic Vegetation		
Number	1986	1989	1990	1986	1989	1990	1986	1989	1990
1	5.14	4.66	0.18	0.00	0.00	0.00	a	0.00	0.00
2	21.28	6.26	2.86	0.00	0.00	0.00	a	0.00	0.00
3	12.01	3.29	0.18	0.00	0.00	0.00	a	0.00	0.00
4	2.40	0.00	0.00	0.00	0.00	0.00	a	0.00	0.20
5	8.98	2.22	0.63	0.00	0.00	0.00	a	0.00	0.27
6	0.63	0.60	0.00	0.00	0.00	0.00	a	0.00	0.15
7	11.22	3.54	0.00	0.00	0.00	2.08	a	0.00	0.00
8	10.73	2.47	1.12	0.00	0.00	0.00	a	0.00	0.00
9	23.08	15.98	a	0.00	0.00	a	a	0.00	a
10	30.02	1.49	a	0.00	0.24	a	a	0.62	a
11	6.30	11.91	a	0.00	0.00	a	a	11.80	a
12	31.76	28.63	a	0.33	5.92	a	a	6.26	a
13	74.66	16.45	a	4.10	0.33	a	a	2.61	a
14	27.85	23.51	a	0.20	0.00	a	a	0.80	a
15	66.42	19.40	17.57	0.00	0.00	1.65	a	0.00	4.12
16	28.54	1.38	2.85	0.26	0.00	1.04	a	0.00	0.00
17	1.93	0.72	0.00	0.35	0.00	0.00	a	0.00	0.00
18	0.30	1.60	0.00	0.39	0.00	0.76	a	0.00	0.00
19	5.87	1.93	1.82	0.43	0.00	0.08	a	0.00	0.00
20	10.44	0.59	1.72	0.00	0.00	0.00	a	0.00	0.00
21	6.89	1.46	2.68	0.00	0.09	1.08	a	0.00	0.35
22	15.05	0.00	0.64	0.00	0.00	2.30	a	0.00	0.25
23	11.13	3.74	0.51	0.29	0.00	2.43	a	0.00	0.27
24	0.19	0.00	0.00	0.00	0.00	0.00	a	0.00	1.91
25	0.72	0.00	0.00	0.85	0.07	0.00	a	0.00	0.32
26	1.59	0.08	0.08	0.00	0.00	0.00	a	0.00	0.00
27	5.23	0.08	0.00	0.00	0.00	5.55	a	0.00	0.00
28	19.30	3.66	0.72	0.00	0.00	0.00	a	0.00	0.00
29	5.56	0.00	0.75	0.00	0.00	0.00	a	0.00	0.00
30	3.08	0.18	0.00	0.00	0.00	0.00	a	0.00	0.00
31	2.21	0.00	0.00	0.00	0.00	0.00	a	0.00	0.00
32	0.87	0.00	0.00	0.00	0.00	0.00	a	0.00	0.00
33	4.22	0.00	0.19	0.00	0.00	0.00	a	0.00	0.00
34	9.85	3.78	1.30	0.00	0.00	0.00	a	0.00	0.00
35	15.56	0.50	0.66	0.00	0.00	0.00	a	0.00	0.00
36	5.60	0.00	0.00	0.00	0.00	0.00	a	0.00	0.00
37	0.81	0.00	0.00	0.00	0.00	0.00	a	0.00	0.00
38	5.86	0.00	0.00	0.00	0.00	0.00	a	0.00	0.00
39	0.62	0.00	0.00	0.00	0.00	0.00	a	0.00	0.00
Treated	128.23	40.60	5.20	1.15	0.40	7.88	a	12.42	1.66
Control	365.69	120.26	45.37	6.05	6.25	9.08	a	9.67	6.18
Total	493.92	160.86	50.57	7.20	6.65	16.96	a	22.09	7.84
99	a	8.33	a	a	7.74	a	a	3.06	a

* - indicates station not sampled that year

Appendix F : Hiding Cover (m^2)

Station Number	Substrate 1986	Substrate 1989	Substrate 1990	Rootwad 1986	Rootwad 1989	Rootwad 1990	Total 1986	Total 1989	Total 1990
1	0.32	0.05	0.04	a	0.05	0.00	12.57	13.07	6.57
2	0.00	0.00	0.22	a	2.62	0.00	24.87	36.33	22.91
3	0.37	0.00	0.43	a	1.46	0.00	15.31	8.17	2.16
4	0.46	0.36	0.44	a	0.00	0.00	3.37	31.72	10.08
5	0.09	0.00	0.26	a	3.10	1.31	32.04	64.45	65.44
6	0.42	0.78	0.64	a	0.00	0.00	10.86	5.36	6.55
7	0.13	0.22	0.30	a	0.00	0.00	16.73	32.39	22.38
8	0.00	0.00	0.05	a	0.00	0.00	14.04	32.38	42.04
9	0.36	0.31	a	a	7.59	a	32.43	471.85	a
10	0.15	0.32	a	a	0.04	a	38.86	134.02	a
11	0.29	1.09	a	a	0.05	a	7.67	578.31	a
12	0.00	0.00	a	a	3.84	a	146.77	740.11	a
13	0.00	0.00	a	a	13.15	a	549.74	1100.51	a
14	0.27	0.20	a	a	3.59	a	42.03	558.46	a
15	0.04	0.51	0.36	a	0.40	0.24	75.91	44.62	708.95
16	0.00	0.32	0.31	a	0.00	0.30	47.54	12.18	23.03
17	0.00	0.00	0.05	a	0.00	0.00	15.80	4.77	4.38
18	0.00	0.00	0.21	a	1.24	0.00	20.77	10.18	14.13
19	0.09	0.00	0.05	a	1.26	0.20	25.70	17.84	28.92
20	0.00	0.09	0.00	a	0.09	0.22	65.46	38.54	19.73
21	0.66	0.68	0.44	a	0.28	0.05	19.41	12.85	6.24
22	0.00	0.04	0.07	a	0.96	0.33	17.90	31.16	40.92
23	0.23	0.16	0.22	a	1.03	0.30	34.58	50.42	35.52
24	0.00	0.00	0.03	a	0.02	0.00	8.11	5.01	5.58
25	0.37	0.06	0.26	a	1.42	1.03	6.44	33.39	23.75
26	0.49	0.56	0.20	a	0.03	1.52	6.92	23.04	36.97
27	0.43	0.62	0.68	a	0.00	0.21	7.60	1.58	6.93
28	0.00	0.10	0.04	a	0.32	0.32	26.42	7.32	2.35
29	0.00	0.07	0.06	a	0.40	0.00	11.31	11.39	9.65
30	0.16	0.36	0.31	a	0.14	0.00	6.47	63.15	68.72
31	0.08	0.10	0.18	a	0.60	1.05	5.88	13.82	13.16
32	0.08	0.00	0.10	a	0.47	2.20	42.01	15.83	22.64
33	0.04	0.00	0.03	a	0.00	0.00	4.48	0.29	0.22
34	0.32	0.00	0.16	a	0.15	0.26	21.17	9.73	133.21
35	0.00	0.00	0.14	a	0.00	0.20	33.34	18.83	7.84
36	0.00	0.50	0.16	a	1.36	1.20	21.81	5.45	7.23
37	0.00	0.00	0.16	a	0.23	0.13	4.12	1.53	0.29
38	0.00	0.00	0.00	a	0.00	0.00	6.08	0.04	0.00
39	0.00	0.00	0.00	a	0.00	0.00	4.69	7.46	6.48
Treated	3.49	4.25	2.75	a	15.63	5.60	240.02	1551.95	332.84
Control	2.38	3.16	3.86	a	30.26	5.47	1247.20	2695.58	1072.15
Total	5.87	7.41	6.61	a	45.89	11.07	1487.22	4247.53	1404.99
99	a	0.38	a	a	0.12	a	a	69.21	a

* - indicates station not sampled that year

Appendix F : Hiding Cover (m^2)

Station Number	Total [b] 1986	Total [b] 1989	Total [b] 1990	Total [c] 1986	Total [c] 1989	Total [c] 1990
1	12.57	13.02	6.50	12.57	13.02	6.57
2	24.87	33.70	22.91	24.87	33.70	22.91
3	15.31	6.71	2.16	15.31	6.71	2.16
4	3.37	4.73	1.76	3.37	4.73	1.76
5	32.04	26.82	26.95	32.04	26.82	26.95
6	10.86	5.36	6.40	10.86	5.36	6.40
7	16.73	16.86	6.38	16.73	16.86	6.38
8	14.04	32.38	43.21	14.04	14.83	8.91
9	32.43	455.16	a	32.43	65.66	a
10	38.86	85.42	a	38.86	39.82	a
11	7.67	559.70	a	7.67	105.61	a
12	146.77	660.02	a	146.77	125.47	a
13	549.74	1084.75	a	111.59	292.81	a
14	42.03	554.06	a	42.03	90.06	a
15	75.91	44.22	704.59	75.91	44.22	60.67
16	47.54	12.18	22.73	47.54	12.18	6.45
17	15.80	4.77	4.38	15.80	4.77	4.38
18	20.77	8.94	14.13	20.77	8.94	14.13
19	25.70	16.58	28.72	25.70	16.58	28.72
20	65.46	38.45	17.90	65.46	38.45	17.90
21	19.41	12.56	6.19	19.41	12.56	6.19
22	17.90	10.94	7.97	17.90	10.94	7.97
23	34.58	37.14	23.29	34.58	37.14	23.29
24	8.11	4.81	1.16	8.11	4.81	1.16
25	6.44	8.00	0.52	6.44	8.00	0.52
26	6.92	11.64	9.71	6.92	11.64	9.71
27	7.61	1.58	6.72	7.61	1.58	6.72
28	26.42	7.00	2.03	26.42	7.01	2.03
29	11.31	2.02	1.13	11.31	2.02	1.13
30	6.47	5.45	2.57	6.47	5.45	2.57
31	5.88	0.34	0.88	5.88	0.34	0.88
32	42.01	15.36	20.45	42.01	15.36	20.48
33	4.48	0.29	0.22	4.48	0.29	0.22
34	21.17	9.58	133.37	21.17	9.58	16.84
35	33.34	18.83	7.84	33.34	18.83	7.84
36	21.81	4.09	6.03	21.81	4.09	6.03
37	4.12	1.30	0.16	4.12	1.30	0.16
38	6.08	0.04	0.00	6.08	0.04	0.00
39	4.69	7.46	6.48	4.69	7.46	6.48
Treated	240.02	1236.79	87.36	240.02	347.60	87.36
Control	1247.20	2585.48	1058.11	1247.20	777.44	247.18
Total	1487.22	3822.27	1145.47	1487.22	1125.04	334.54
99	a	66.53	a	a	66.53	a

a - indicates station not sampled that year
b - Total including natural pools, beaver ponds, undercut bank, brush debris, complex debris, log, overhead brush, overhead vegetation, and substrate.
c - Total including natural pools, undercut bank, brush debris, complex debris, log, overhead rush, overhead vegetation, and substrate.

Appendix G : Length - Frequency Histograms for Brook Trout
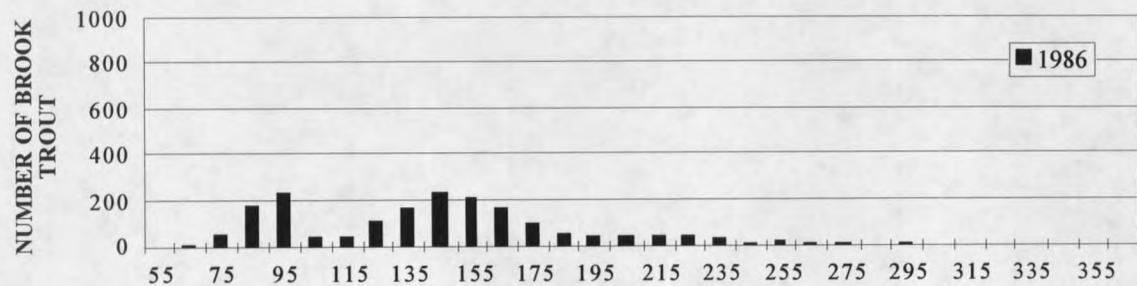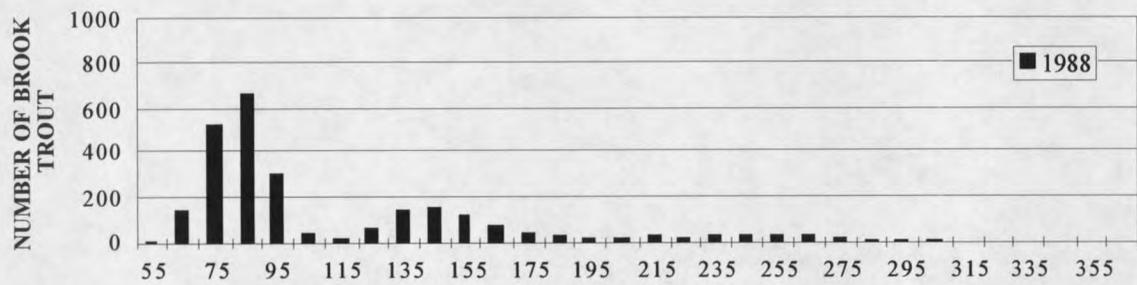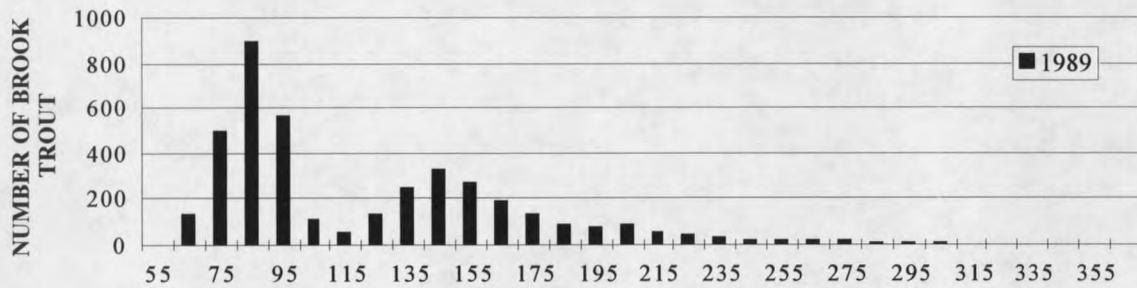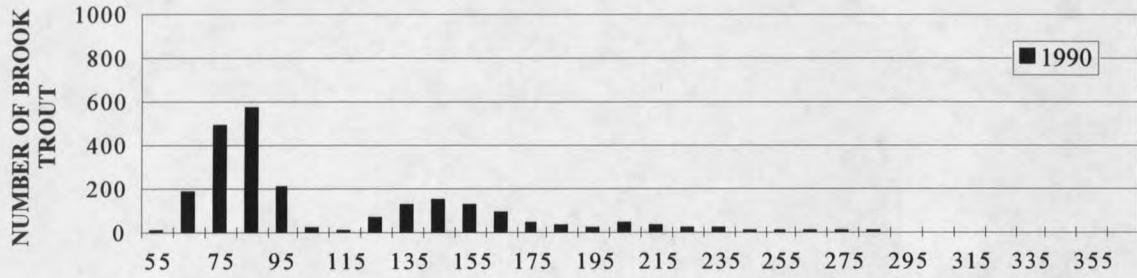
MID-POINT OF 10-mm LENGTH CLASS (mm)

Appendix H : Brook Trout Population Estimates

Station	TL(mm) < 110 mm				110mm ≤ TL(mm) < 200mm				200 mm ≤ TL(mm)			
Number	1986	1988	1989	1990	1986	1988	1989	1990	1986	1988	1989	1990
1	0	59	66	41	15	13	22	14	2	0	2	7
2	3	20	27	27	16	20	22	43	6	8	9	5
3	5	20	32	168	12	19	13	22	1	9	5	2
4	124	104	119	159	99	20	27	31	17	3	2	4
5	a	76	38	30	a	29	41	49	a	10	17	8
6	15	19	16	20	32	24	7	16	3	6	7	8
7	37	50	54	44	29	25	21	25	4	4	7	5
8	17	63	46	30	20	4	20	6	2	4	6	2
9	13	235	79	b	40	67	59	b	7	15	8	b
10	26	65	26	b	24	14	27	b	5	1	4	b
11	11	45	116	b	37	20	94	b	24	6	11	b
12	53	254	292	b	124	61	249	b	31	26	41	b
13	19	471	493	b	46	143	384	b	7	28	60	b
14	5	379	379	b	31	70	199	b	5	20	38	b
15	24	55	99	145	45	25	40	16	3	7	9	7
16	23	57	41	160	37	6	20	14	6	3	4	1
17	14	38	39	94	23	9	17	7	4	5	6	1
18	59	57	104	123	34	20	18	18	3	12	7	1
19	54	59	40	125	67	12	15	16	5	7	11	2
20	a	27	84	80	a	26	32	30	a	12	10	10
21	28	96	76	92	76	18	25	20	12	5	4	4
22	a	51	78	74	a	20	36	59	a	10	8	16
23	64	20	91	a	53	14	32	a	9	13	2	a
24	31	99	114	38	39	11	16	20	4	10	1	0
25	13	110	90	55	31	10	27	26	2	4	8	9
26	13	58	55	39	69	25	55	65	16	9	17	15
27	21	51	37	15	23	19	16	34	6	11	8	9
28	32	52	57	43	34	19	12	13	4	11	7	2
29	21	72	36	9	17	8	12	12	8	5	3	4
30	15	34	4	19	25	11	48	46	3	3	5	7
31	63	106	64	47	31	7	43	30	7	1	4	4
32	23	DRY	84	102	44	DRY	41	17	11	DRY	16	19
33	14	DRY	132	53	23	DRY	5	8	4	DRY	0	1
34	13	111	174	92	39	14	28	29	8	7	1	3
35	19	48	156	97	48	42	27	18	8	9	11	11
36	4	74	76	59	28	21	15	25	12	12	5	4
37	2	130	54	45	31	14	13	19	4	5	8	3
38	0	122	42	36	6	2	4	3	3	1	2	0
39	4	7	57	34	6	0	12	2	1	0	6	4
Treated	428	777	986	568	531	189	547	363	114	76	100	78
Control	431	1268	2742	1674	779	320	1247	390	143	213	280	102
Total	859	2045	3728	2242	1310	509	1794	753	257	289	380	180
99	b	b	594	951	b	b	116	72	b	b	25	17

a - Station not electrofished

b - Population estimate combined with previous station

DRY - Surface water non-existent at time of electrofishing

Appendix I : Cutthroat Trout Population Estimates

Station Number	$TL_{(mm)} < 100$ mm				$100mm \leq TL_{(mm)} < 200mm$				$200 mm \leq TL_{(mm)}$			
	1986	1988	1989	1990	1986	1988	1989	1990	1986	1988	1989	1990
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	1	0	0	0
3	0	0	0	0	0	0	0	0	2	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	b	0	0	0	b	0	0	0	b	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	0	0	0	0
9	0	0	0	a	0	0	0	a	2	0	0	a
10	0	0	0	a	0	0	0	a	0	0	0	a
11	0	0	0	a	0	0	2	a	1	0	0	a
12	0	0	0	a	0	6	0	a	0	0	0	a
13	0	0	0	a	0	2	2	a	0	4	3	a
14	0	2	0	a	0	8	7	a	0	2	6	a
15	0	0	0	1	0	0	1	0	2	2	1	2
16	0	2	0	0	1	0	0	0	0	0	2	0
17	0	0	0	0	0	2	0	1	1	0	0	0
18	0	2	4	0	0	0	3	0	2	0	0	0
19	0	4	0	0	0	0	0	0	2	1	0	0
20	b	0	0	0	b	2	0	0	b	0	0	0
21	0	0	0	0	1	0	0	0	2	2	0	0
22	b	0	0	0	b	0	0	3	b	0	0	0
23	0	0	0	b	0	0	1	b	5	1	0	b
24	0	0	0	0	0	0	0	0	0	0	0	1
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	10	0	0	0	8	1	3	1	0	0
27	0	2	1	1	0	2	1	5	0	0	0	0
28	0	0	12	0	0	2	0	1	1	0	0	0
29	0	2	12	0	1	0	0	3	2	1	0	0
30	0	26	55	0	0	0	6	1	0	0	0	0
31	0	4	9	0	0	4	2	3	1	0	0	0
32	0	DRY	14	0	1	DRY	2	1	3	DRY	0	0
33	0	DRY	34	0	0	DRY	0	1	0	DRY	0	0
34	0	4	4	1	0	0	0	0	4	0	1	0
35	0	6	1	0	2	0	0	0	1	0	0	0
36	1	6	0	0	2	2	1	0	5	4	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0
38	0	18	0	0	0	0	0	0	0	0	0	0
39	0	2	4	0	0	0	0	1	0	0	2	0
Treated	0	32	86	0	2	4	20	11	16	5	0	0
Control	1	48	74	3	6	26	19	11	24	13	15	3
Total	1	80	160	3	8	30	39	22	40	18	15	3
99	a	a	0	0	a	a	0	0	a	a	0	0

a   -   Station not electrofished

b   -   Population estimate combined with previous station

DRY -   Surface water non-existent at time of electrofishing

Appendix J : Brook Trout Biomass (kg)

Station	TL(mm) < 110 mm				110mm ≤ TL(mm) < 200mm				200 mm ≤ TL(mm)			
Number	1986	1988	1989	1990	1986	1988	1989	1990	1986	1988	1989	1990
1	0.00	0.42	0.38	0.25	0.43	0.47	0.79	0.44	0.35	0.00	0.29	1.14
2	0.03	0.11	0.17	0.17	0.58	0.60	0.80	1.50	0.98	1.29	1.80	0.62
3	0.03	0.11	0.20	0.86	0.48	0.55	0.44	0.92	0.13	1.30	0.90	0.19
4	0.85	0.51	0.64	0.83	3.24	0.64	0.88	0.98	1.88	0.37	0.25	0.39
5	b	0.42	0.30	0.23	b	0.82	1.54	1.64	b	1.42	2.06	1.12
6	0.10	0.13	0.10	0.14	1.02	0.67	0.32	0.56	0.42	0.84	0.39	0.85
7	0.28	0.27	0.29	0.24	1.01	0.64	0.62	1.01	0.49	0.62	0.99	0.38
8	0.12	0.28	0.28	0.16	0.51	0.12	0.77	0.22	0.21	0.61	1.06	0.21
9	0.10	1.16	0.44	a	1.28	1.20	1.90	a	0.96	2.28	1.10	a
10	0.18	0.38	0.17	a	0.70	0.39	0.94	a	0.68	0.15	0.62	a
11	0.09	0.24	0.72	a	1.20	0.56	3.68	a	3.52	1.30	1.45	a
12	0.36	1.31	1.34	a	4.29	2.62	8.86	a	4.18	5.01	6.50	a
13	0.16	2.24	2.68	a	1.52	4.34	12.75	a	0.98	6.32	7.88	a
14	0.04	1.53	1.58	a	0.95	2.33	7.41	a	0.80	3.54	4.48	a
15	0.16	0.32	0.50	0.74	1.18	0.77	1.35	0.57	0.39	1.22	1.46	1.20
16	0.15	0.33	0.23	0.86	1.25	0.29	0.87	0.36	0.96	0.42	0.40	0.20
17	0.11	0.24	0.19	0.46	0.76	0.32	0.56	0.23	0.44	1.03	0.98	0.13
18	0.36	0.35	0.52	0.63	1.07	0.63	0.68	1.18	0.43	1.81	1.11	0.38
19	0.38	0.33	0.21	0.69	2.06	0.47	0.40	0.54	0.95	1.41	2.12	0.55
20	b	0.16	0.44	0.43	b	0.51	1.07	0.97	b	2.10	1.58	1.86
21	0.20	0.55	0.40	0.59	2.13	0.72	0.74	0.68	1.86	0.56	0.56	0.49
22	b	0.33	0.51	0.50	b	0.58	1.21	1.97	b	1.64	1.53	2.52
23	0.44	0.10	0.52	b	1.60	0.45	1.09	b	1.48	2.05	1.05	b
24	0.22	0.55	0.63	0.24	1.17	0.38	0.48	0.67	0.67	1.68	0.16	0.00
25	0.10	0.70	0.57	0.42	0.91	0.29	1.04	1.12	0.24	0.70	1.41	1.28
26	0.10	0.41	0.45	0.22	2.12	0.76	2.18	2.26	1.93	1.43	2.71	2.03
27	0.15	0.33	0.20	0.08	0.90	0.71	0.54	1.23	0.88	1.76	1.31	1.17
28	0.17	0.28	0.28	0.21	1.02	0.51	0.44	0.51	0.59	2.09	1.20	0.24
29	0.13	0.38	0.22	0.07	0.47	0.25	0.38	0.41	1.57	0.80	0.44	0.81
30	0.11	0.22	0.41	0.14	0.71	0.38	1.42	1.73	0.45	0.50	0.58	0.90
31	0.32	0.57	0.37	0.33	0.92	0.22	1.20	0.86	0.94	0.11	0.55	0.57
32	0.14	DRY	0.48	0.55	1.44	DRY	1.49	0.74	1.90	DRY	2.29	3.33
33	0.10	DRY	0.76	0.30	0.62	DRY	0.15	0.36	0.45	DRY	0.00	0.13
34	0.10	0.54	0.94	0.56	1.13	0.48	0.69	1.06	1.27	1.12	0.00	0.46
35	0.13	0.74	0.79	0.56	1.53	1.26	0.86	0.75	1.32	1.24	1.75	1.51
36	0.04	0.38	0.41	0.35	0.96	0.88	0.57	1.02	1.29	2.20	0.88	0.59
37	0.02	0.73	0.31	0.28	1.25	0.45	0.56	0.67	0.55	0.98	1.32	0.56
38	0.00	0.71	0.23	0.18	0.24	0.08	0.11	0.12	0.70	0.18	0.20	0.00
39	0.04	0.04	0.30	0.17	0.17	0.00	0.49	0.05	0.12	0.00	0.83	0.58
Treated	2.89	6.25	6.00	3.56	16.52	7.90	18.81	12.66	15.98	13.93	15.30	10.49
Control	3.07	12.15	14.18	8.86	27.00	19.42	43.46	14.67	20.96	38.14	40.90	15.90
Total	5.96	18.40	20.18	12.42	43.52	27.32	62.27	27.33	36.94	52.07	56.19	26.39
99	a	a	2.61	4.20	a	a	2.79	2.45	a	a	4.18	2.80

a   -   Station not electrofished

b   -   Biomass combined with previous station

DRY -   Surface water non-existent at time of electrofishing

Appendix K : Cutthroat Trout Biomass (kg)

Station	TL(mm) < 100 mm				100mm ≤ TL(mm) < 200mm				200 mm ≤ TL(mm)			
Number	1986	1988	1989	1990	1986	1988	1989	1990	1986	1988	1989	1990
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	a	0.00	0.00	0.00	a	0.00	0.00	0.00	a	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	a	0.00	0.00	0.00	a	0.45	0.00	0.00	a
10	0.00	0.00	0.00	a	0.00	0.00	0.00	a	0.00	0.00	0.00	a
11	0.00	0.00	0.00	a	0.00	0.00	0.04	a	0.17	0.00	0.00	a
12	0.00	0.00	0.00	a	0.00	0.14	0.00	a	0.00	0.00	0.00	a
13	0.00	0.00	0.00	a	0.00	0.04	0.11	a	0.00	0.39	0.42	a
14	0.00	0.02	0.00	a	0.00	0.22	0.35	a	0.00	0.60	1.07	a
15	0.00	0.00	0.00	0.02	0.00	0.00	0.09	0.00	0.44	0.28	0.10	0.25
16	0.00	0.01	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.34	0.00
17	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.03	0.21	0.00	0.00	0.00
18	0.00	0.03	0.01	0.00	0.00	0.00	0.18	0.00	0.30	0.00	0.00	0.00
19	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.81	0.26	0.00	0.00
20	b	0.00	0.00	0.00	b	0.04	0.00	0.00	b	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.49	0.13	0.00	0.00
22	b	0.00	0.00	0.00	b	0.00	0.00	0.06	b	0.00	0.00	0.00
23	0.00	0.00	0.00	b	0.00	0.00	0.02	b	0.69	0.17	0.00	b
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	0.00	0.00	0.04	0.00	0.00	0.00	0.31	0.03	0.51	0.28	0.00	0.00
27	0.00	0.03	0.01	0.02	0.00	0.06	0.02	0.10	0.00	0.00	0.00	0.00
28	0.00	0.00	0.03	0.00	0.00	0.04	0.00	0.03	0.15	0.00	0.00	0.00
29	0.00	0.01	0.03	0.00	0.02	0.00	0.00	0.05	0.41	0.28	0.00	0.00
30	0.00	0.06	0.14	0.00	0.00	0.00	0.18	0.05	0.00	0.00	0.00	0.00
31	0.00	0.01	0.05	0.00	0.00	0.09	0.030	0.19	0.19	0.00	0.00	0.00
32	0.00	DRY	0.06	0.00	0.02	DRY	0.03	0.03	0.56	DRY	0.00	0.00
33	0.00	DRY	0.10	0.00	0.00	DRY	0.00	0.03	0.00	DRY	0.00	0.00
34	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.76	0.00	0.10	0.00
35	0.00	0.01	0.02	0.00	0.08	0.00	0.00	0.00	0.27	0.00	0.00	0.00
36	0.01	0.01	0.20	0.00	0.07	0.04	0.08	0.00	1.07	0.67	0.00	0.00
37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.22	0.00
Treated	0.00	0.08	0.26	0.04	0.07	0.09	0.58	0.38	2.91	0.86	0.00	0.00
Control	0.01	0.17	0.26	0.05	0.21	0.60	0.85	0.30	4.45	2.21	2.24	0.34
Total	0.01	0.25	0.52	0.05	0.28	0.69	1.43	0.68	7.36	3.07	2.24	0.34
99	a	a	0.00	0.00	a	a	0.00	0.00	a	a	0.00	0.00

a   -   Station not electrofished

b   -   Biomass combined with previous station

DRY- Surface water non-existent at time of electrofishing