Evaluation of Trout Habitat Improvement Structures in Three High-Gradient Streams in Wisconsin

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ABSTRACT

Eight types of in-channel trout habitat improvement structures were installed in 3 treatment zones (TZs) on portions of 3 Wisconsin trout streams having TZ gradients of approximately 1% (53-72 ft/mile). The 3 streams are at the upper end of the gradient range for Wisconsin trout streams. A reference zone (RZ) was also established adjacent to each TZ to monitor changes in standing stocks of trout throughout the study; the RZs were not modified or changed in any way.

Structures were installed in the TZs at densities of 142/mile in Camp Creek, 100/mile in Devils Creek, and 208/mile in Twenty Mile Creek. Most of the wood and rock used to build the structures were gathered on site. Installation crews used only hand tools at 2 sites; mechanized equipment was used at the third site where access was favorable.

The objectives of the follow-up evaluation were to determine the physical durability of the structures and their effectiveness in increasing trout carrying capacity, especially for adult (primarily legal-sized) trout. Structures appeared to be more valuable in maintaining trout carrying capacity during low-flow years. Adult trout benefitted more from the structures than did subadults.

Approximately 63% of the 72 test structures provided good or excellent trout habitat 4 years after installation. Two structure types, the channel constrictor and the cross-channel log/bank revetment, provided consistently good habitat for adult trout. Durability and functional performance of structures were much better in the 2 smaller TZs, on Camp Creek and Twenty Mile Creek (summer baseflow discharge of 2-4 cfs), than in the largest TZ on Devils Creek (summer baseflow discharge of 12 cfs). Only the channel constrictor and some bank cover logs functioned effectively in the Devils Creek TZ.

Average cost per structure was $230 for the 2 smaller TZs on Camp and Twenty Mile creeks. Project cost per mile was approximately $38,000 (165 structures/mile). Wages for the professional crew accounted for 65% of the total cost.

Abundance and biomass of wild brown trout (*Salmo trutta*) in April increased significantly in the Camp Creek TZ (1984 vs. 1985-89 average), despite unfavorable below-normal stream flow regimes during the last 2-3 years of the postinstallation period. Average abundance of legal-sized trout ($\geq$9 inches) and average biomass in September also increased significantly in this TZ. Density of legal-sized trout peaked at 457 trout/mile; biomass peaked at 344 lb/mile (410 lb/acre). Spring and fall densities of legal-sized brown trout and total biomass in the spring and fall declined in the RZ during the postinstallation period.

At Devils Creek, densities of wild brook trout (*Salvelinus fontinalis*) and domestic brown trout in September were sparse in both the TZ and the RZ throughout the evaluation, due to lack of natural recruitment. Brook trout increased in abundance and biomass in both the TZ and the RZ, but proportionately more in the RZ than in the TZ (1983-85 vs. 1986-89). Brown trout decreased in abundance and biomass in the RZ, but increased in the TZ after installation of devices in this zone. This TZ was more useful to test durability of the structures than to monitor changes in the sparse standing stocks of trout.

At Twenty Mile Creek, legal-sized wild brook trout ($\geq$6 inches) increased an average of 118% (to 185 trout/mile) in the TZ (1983-85 vs. 1986-89) and peaked at 392 trout/mile in September 1986. In the adjacent RZ, no change occurred in average density (189 trout/mile) of legal-sized brook trout. Legal-sized wild brown trout increased an average of 48% (to 77 trout/mile) in the TZ after devices were installed and declined an average of 34% (to 19 trout/mile) in the RZ. Average biomass in September of both brook and brown trout increased in the TZ (13% and 27%, respectively) and decreased in the RZ (-27% and -33%, respectively). None of the changes in standing stocks in either zone were statistically significant, but positive changes in the TZ coupled with negative changes in the RZ were viewed as biologically meaningful.

Fisheries management recommendations include use of 7 of the 8 test structures to improve trout habitat in other small high-gradient streams in Wisconsin and greater use of volunteer labor to reduce project costs.

Key Words: Trout, trout habitat improvement, trout stream management, trout stream research.

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INTRODUCTION

The Wisconsin Department of Natural Resources (DNR) has been a national leader among resource management agencies for several decades in the development and application of technology to restore and enhance trout streams (O'Donnell and Threinen 1960, White and Brynildson 1967), especially for streams having low or moderate gradients (<1%). A strong emphasis on field evaluation has also characterized this facet of trout resource management in Wisconsin (Hunt 1988).

This report continues that tradition, but with the objective of evaluating trout habitat technology in some of the state's less common trout streams having gradients that exceed 1%. In these higher gradient streams, both physical integrity and functional performance of in-channel structures tend to decline more quickly over time than in lower gradient streams. However, the fisheries literature contains examples of trout habitat improvement projects that have been successful in streams having gradients exceeding 1% (Tarzwell 1938, Wilkins 1960, Gard 1961, Hale 1969, Barton et al. 1973, Duff 1979, Binns 1980, Seehorn 1980, Taylor 1980, Knox 1982). On Split Rock Creek in Minnesota, Hale (1969) documented a 223% increase in density of age I+ brook trout (*Salvelinus fontinalis*), a 356% increase in biomass of brook trout, and a 362% increase in harvest for the improved study zone. In the improved reach of Big Creek in Utah, Duff (1979) noted a 570% increase in trout density. Taylor's study (1980) in the Keogh River in British Columbia revealed a 300% increase in juvenile steelhead trout (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*). The recovery of cutthroat trout (*O. clarki*) in a devastated channelized reach of the Weber River in Utah was noted by Barton and Winger (1973). Binns' work (1980) in Beaver Creek in Wyoming showed a steady buildup of brook trout biomass from < 10 lb/acre before habitat improvement to 272 lb/acre 5 years later, despite one year of moderate drought and 2 years of severe drought.

In this study, I tested 8 types of in-channel structures: whole log cover, K dam, wedge dam, tip deflector (paired), wing (current) deflector and bank cover logs (often in combination), channel constrictor, and cross-channel log/bank revetment (see Glossary for illustrations and descriptions of design and installation procedures). My evaluation of these structures had 2 primary objectives: (1) to assess physical durability during a 4-year postinstallation period and (2) to determine how much the trout carrying capacity of each TZ was enhanced by the addition of structures designed to increase pool area and overhead cover for trout, especially legal-sized trout.

Several of the structures I tested are among the earliest types of trout habitat improvement techniques used in North America, but they have not been commonly used or evaluated in Wisconsin. The 8 types of structures had 2 common attributes: (1) they could be made largely from on-site green-cut logs and rocks (where such materials were present and legally useable), and (2) the structures could be installed without mechanized equipment.

Detailed descriptions of the designs of these structures and the equipment and materials needed to construct and install them were described by Davis (1935) and by Silcox (1936). Updated, slightly modified designs and procedures were subsequently explained in a handbook issued by the U.S. Department of Agriculture Forest Service (1952) and a report issued by the Tennessee Game and Fish Commission (Wilkins 1960). My primary source for structural design and selection of applicable in-channel sites was a U.S. Forest Service handbook (Seehorn 1985). This handbook also contains information about the channel constrictor structure designed and tested by Seehorn.

STUDY ZONES

Paired Treatment Zones (TZs) and Reference Zones (RZs) were established on 3 high-gradient streams in the state: Camp Creek, in the southwestern "coulee region", Devils Creek in the "blue hills" west-central region, and Twenty Mile Creek in the far northwestern Lake Superior region (Fig. 1). Stream gradient of the TZs on Camp Creek and Twenty Mile Creek was similar (1.4%) and baseflow in the study zones of the 2 streams was also similar (about 2.5 cfs in September 1983-84). Stream gradient of the TZ on Devils Creek was 1.0%. Devils Creek had a wider preinstallation stream channel than Camp or Twenty Mile creeks and a greater baseflow (approximately 12.1 cfs in September 1983).

Camp Creek

Camp Creek is a 5.5-mile-long trout stream in Richland County that enters the Kickapoo River near Viola. In April 1984, 2 TZs (one upper and one lower) and one RZ were established contiguously on the first-order upper mile reach of Camp Creek (Sections 23 and 26-R2W-T12N). This reach is accessible to anglers by a lease arrangement with the owner.

The upper TZ started at the confluence of the creek's 2 major groundwater sources—about 600 ft downstream along the main stem where a 200-ft-long tributary enters from a major groundwater spring. The upper TZ had a midchannel length of 968 ft (0.18 mile). The entire riparian zone of the upper TZ consisted of pasture land

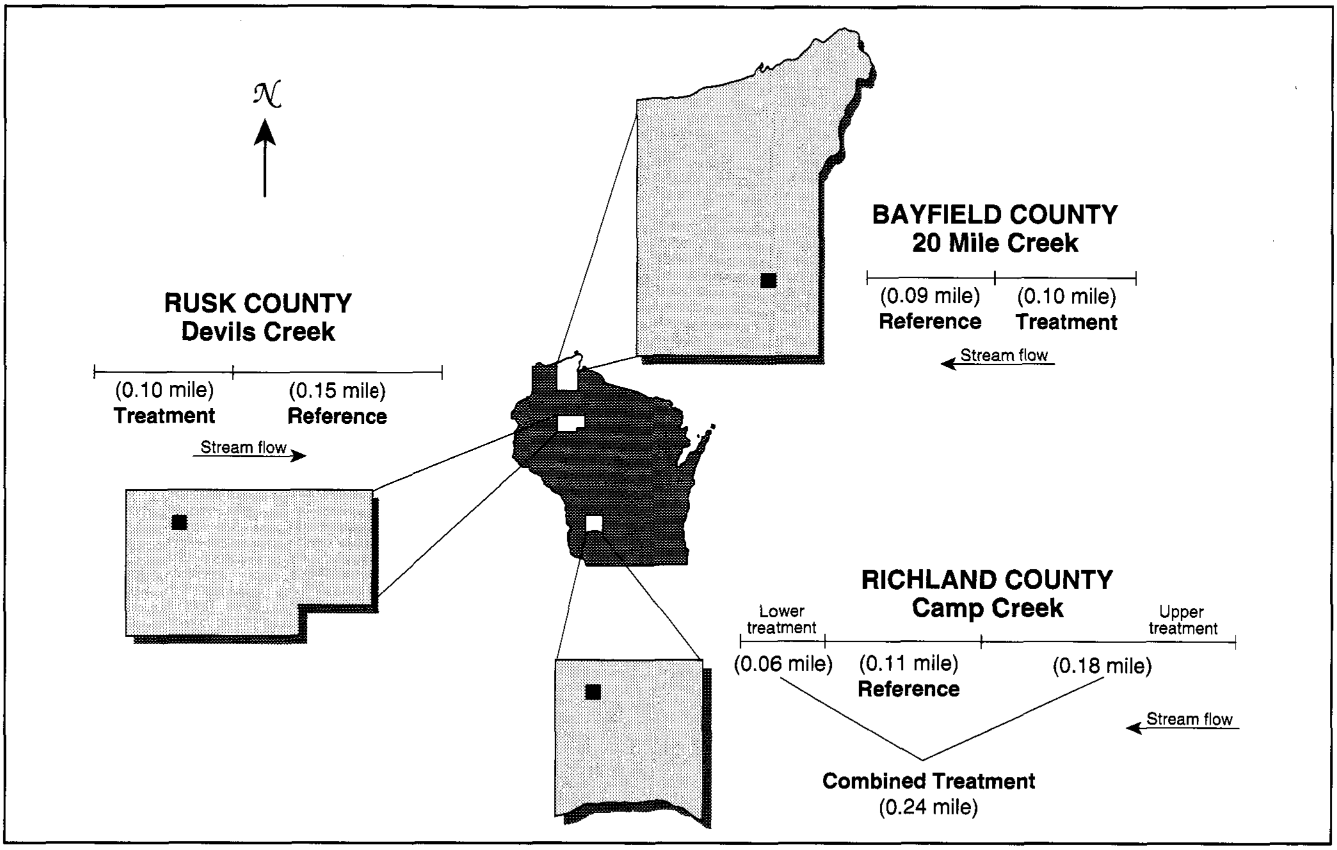


Figure 1. *Locations of study streams and zones, linear dimensions of study zones, and direction of stream flow.*

utilized each summer by dairy cows and beef cattle. A few box elder and walnut trees provided sparse shading of the stream channel.

A fence line marked the lower boundary of this upper TZ and the beginning of the 562-ft-long (0.11 mile) RZ that flowed parallel and adjacent to State Highway 56. Stream bank vegetation along the RZ was dominated by unpastured reed canary grass. Below the RZ another 325-ft-long (0.06 mile) TZ was established. This lower TZ was considerably shorter, wider, and shallower than the other TZ or RZ zones (Append. Table A.1). Both stream banks of the lower TZ were lined by box elder trees plus an understory of ungrazed reed canary grass.

Fist-sized or larger cobble and rock dominated the substrate in all 3 zones. Rooted aquatic vegetation was rare in the lower TZ. Sparse clumps of a filiform *Potamogeton* spp., water cress (*Nasturtium officinale*), and water moss (*Fontinalis* spp.) were present in the RZ and upper TZ. Extensive mats of filamentous algae developed in the upper TZ and RZ during the summer, with smaller mats forming in the more heavily shaded lower TZ.

Wild brown trout (*Salmo trutta*) were the only salmonid present in the Camp Creek study zones. A few wild brook trout (*Salvelinus fontinalis*) were also present in a small spring pond at the head of the tributary spring entering the upper TZ. Mottled sculpin (*Cottus bairdi*) provided a potentially rich forage food base. Other fish species sparsely present were brook sticklebacks (*Culaea inconstans* sp.), central mudminnows (*Umbra limi*), and several species of darters (*Etheostoma* spp.).

After initiation of the study I decided to combine the physical and biological data collected in the 2 TZs on Camp Creek and treated them as a single TZ (with the exception of information contained in Append. Table A.1). Two factors contributed to this decision: (1) when combined, the preinstallation habitat in both TZs was more similar physically to the variety of trout habitats existing in the RZ (some pools holding adult trout, plus shallow flat water habitat more suitable for juvenile trout), and (2) in retrospect, the short length of the lower TZ did not seem to be an appropriate base for expansion of trout abundance and biomass data to standard "per mile" values for each zone.

Devils Creek

Devils Creek, a second- and third-order stream in the northwestern corner of Rusk County, is approximately 18 miles long. The upper 4.5 miles are managed by the DNR as Class I trout water (no stocking of domestic trout). The next 7.5 miles are designated Class II (annual stocking of domestic trout to augment a sparse wild stock). The remainder of the stream is designated as Class III (trout fishing totally dependent on stocked fish).

A portion of Devils Creek was selected for this study because of its high gradient and because its discharge regime was prone to flash floods. In an internal DNR waters inventory memorandum (P. Gottwald, Wis. Dep. Nat. Resour., to D. A. Jacobson, in memo 1 Dec 1979), the area fisheries manager Frank Pratt describes Devils Creek as being "prone to severe flooding" and a creek where in-stream improvement techniques "applicable to flood-prone, high gradient streams, [such as] gabions, digger-logs, Hewitt dams, etc." should be tested to improve trout fishing.

In September 1983, a 550-ft-long TZ and contiguous 770-ft-long RZ were established in the upper half of the Class II reach (Section 16-R8W-T35N). The County Trunk O bridge marked the lower boundary of the RZ and the study area. Land along both study zones was publicly owned as part of the Rusk County Forest.

Stream banks of both zones were lined with natural vegetation, primarily speckled alder and spruce conifers, plus a few live and dead elm trees that collectively shaded most of the water surface during leaf-out periods. Substrate in both study zones was primarily cobble and rock. Rooted aquatic vegetation was rare, but the algae-coated stones were "cannon-ball slick" most of the year.

The sport fishery of Devils Creek was sustained by a sparse population of wild brook trout supplemented by annual stocking of domestic yearling brook and brown trout. Several species of minnows and darters provided a potentially rich forage food base. An unusual and abundant population of burbot (*Lota lota*) was also present.

Twenty Mile Creek

In September 1983, 2 study zones were also set up on Twenty Mile Creek in the southeast corner of Bayfield County. The entire 9.2 miles of this first- and second-order stream is managed as trout water, the upper 6.0 miles as Class I and the lower 3.2 miles as Class II. Study zones were located about 2.5 miles from the creek's origin in a first-order reach (Section 6-R5W-T44N). The upstream TZ, having a midchannel length of 700 ft (0.13 mile), lay within the Chequamegon National Forest. The 500-ft-long (0.09 mile) RZ was bordered by privately owned land. Forest Service Road 337 crossed the stream at the boundary of the RZ and TZ.

Stream banks of the study zones were well vegetated with mixed hardwoods (maple, ash, and birch) and scattered conifers (spruce and hemlock). The stream channel in each zone was well shaded most of the year by stream bank trees and adjacent wooded hills. No rooted aquatic vegetation was observed in either zone during preinstallation surveys.

Both study zones sustained wild stocks of small brook and brown trout. Mottled sculpin was the only other fish species collected during electrofishing operations.

PROCEDURES

Trout habitat improvement structures were installed in Camp Creek in July 1984, in Devils Creek in September-October 1985, and in Twenty Mile Creek in July-August 1985. Preinstallation measurements were taken in Camp Creek in April 1984, in Devils Creek in September 1983, and in Twenty Mile Creek in September 1983. Postinstallation measurements were taken in Camp Creek in September 1988, in Devils Creek in August 1989, and in Twenty Mile Creek in August 1989.

Preinstallation Assessment of Stream Channel Features

Lengths of the study zones were determined along a continuous tape-measured midchannel course. Metal stakes were temporarily inserted into the substrate around bends to provide a midchannel guide. Channel widths—wetted edge to wetted edge—were tape-measured to the nearest 0.1 ft at 50-ft intervals. At these cross-channel transect points, water depths were measured to the nearest 0.1 ft at 1-ft intervals. Substrate composition was also noted where the inch-square pad on the bottom of the probe used to measure water depth rested on the stream bottom. The proportion of each substrate type within a study zone was calculated as a simple percentage of each type represented in the sum of all point-specific measurements made in that zone.

I also established transect points at specific sites where some of the structures would be installed. At these locations—10 in the TZ on Camp Creek, 7 in the TZ on Twenty Mile Creek, and 4 in the TZ on Devils Creek—stream channel width, average depth, and average water velocity data were recorded. Transect sites were mapped so that postinstallation measurements could be taken at the same locations.

A continuous check was made of both stream banks to quantify underbank hiding cover—defined as the face length of stream bank providing at least 0.5 ft of overhang with at least 0.5 ft of water beneath it.

Gradient in each zone was determined with a surveyor's transit and stadia rod. Stream flow was quantified occasionally during the study at zone boundaries with a Gurley pygmy meter positioned at a depth equal to 0.4 of the total water depth at 1 ft intervals across the stream channel.

Design and Installation of In-channel Structures

The physical condition of the TZ channels dictated the selection and location of the test structures. To assist the installation crews, I prepared maps of the TZ channels showing the types, locations, and approximate dimensions of the structures to be installed (See Append. Figs. 1, 2 for examples of maps). Numbered wooden stakes were also placed temporarily along each TZ to match numbers of the structures indicated on the sketch maps.

DNR crews installed 34 structures (142/mile) in the TZ on Camp Creek, 11 structures (110/mile) in the TZ on Devils Creek, and 27 structures (208/mile) in the TZ on Twenty Mile Creek (Table 1). At least 2 each of 8 types of structures were installed in Camp Creek, 4 different types were installed in Devils Creek, and 7 different types were installed in Twenty Mile Creek. Installation of 6 additional structures in the TZ at Devils Creek was cancelled after major flood damage occurred to the first 11 structures soon after their completion. These structures were repaired after the flood, and I decided not to spend any more money to complete the original plan.

Two modifications were made to the structure designs described by Seehorn (1985). A polypropylene filter fabric material (Typar brand*, manufactured by DuPont Co.) was substituted for hog wire or hardware cloth as a base over which sand, gravel, and cobble were placed to seal the upstream sides of K dams, wedge dams, and cross-channel logs. Commercial polyethylene grids of Geoweb* (Presto Products, Inc.) were also incorporated into several channel constrictors, tip deflectors, and wing deflectors to determine the capacity of such grids to hold fill material, compared with other structures with no interstitial support to hold fill material. Seehorn's modification of bank cover logs and the cover log components of K dams and wedge dams—removal of portions of the underside of these logs to provide more space for trout—was also used to enhance performance.

Although the structures selected for testing could be constructed and installed with hand tools, mechanized equipment was used by the DNR crew at Camp Creek because of excellent access along the pastured stream banks and the crew's familiarity with the machinery. A hydraulic excavator (Komatsu Model PC-200-LC0 with a 1-yd bucket) and a bulldozer (Komatsu Model D-41) were used extensively to reduce the slope of stream banks at several sites and to transport and position logs and quarry stone trucked to the stream to augment cobble and rock fill obtained from the stream channel. The excavator was also used to construct 3 meanders in the TZ that increased midchannel length by 2% (Append. Table A.2).

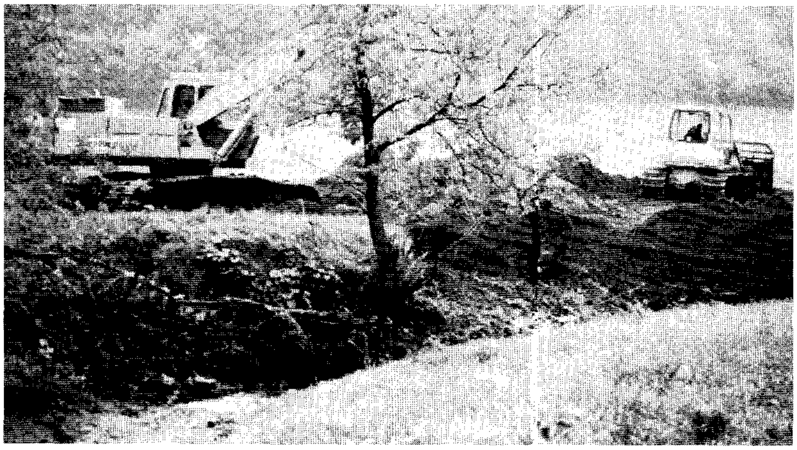
Only hand tools were used to build structures in the TZs at Devils Creek and Twenty Mile Creek. All logs and rock were obtained on site at Twenty Mile Creek. The same was true at Devils Creek, except for some large stones trucked to the TZ for completing the last 4 structures, including a channel constrictor that required more fill than any other structure installed.

Table 1. *Number and type of trout habitat improvement structures placed in the treatment zones on Camp, Devils, and Twenty Mile creeks.*

	No. Placed in Treatment Zone*			
Structure	**Camp Creek**	**Devils Creek**	**Twenty Mile Creek**	**All**
Bank cover log**	15	3	11	29
Channel constrictor	2	1	3	6
Cross-channel log/bank revetment	5	–	3	8
K dam	2	–	–	2
Tip deflector	2	–	1	3
Wedge dam	2	–	1	3
Whole log cover	3	4	4	11
Wing deflector**	3	3	4	10
Total	34	11	27	72
No./mile	142	110	208	153 (average)

* Installation dates: Camp Creek, July 1984; Devils Creek, September-October 1985; Twenty Mile Creek, July-August 1985.
** These 2 structure types are often used in combination.

* Reference to commercial names of products and equipment used in the construction of trout habitat improvement structures does not represent official endorsement of these products or equipment by the DNR.



At Camp Creek, the crew used heavy equipment to slope and stabilize eroded stream banks and move materials used to construct trout habitat improvement structures.

Postinstallation Assessment of In-channel Structures

The functional quality of the in-channel structures in the treatment zones was assessed 4 years after installation (Table 2). This assessment was based on visual inspection by the author to determine performance in improving trout habitat, particularly resting/security cover and pool habitat useable by adult (age I+) trout. Four quality categories were used: (1) "excellent," a 75-100% performance level, (2) "good," a 50-75% performance level, (3) "fair," a 25-50% performance level, and (4) "poor," a < 25% performance level.

Inventories of Standing Stocks of Trout

Standing stocks of trout in the study zones were inventoried with 2 types of DC electrofishing units. At Camp and Twenty Mile creeks, stream channels were narrow enough and shallow enough to allow operators to collect almost all trout present with 2 individually operated back-pack units (350-v maximum output, 12-v motorcycle battery). Operators worked in tandem, one a few steps behind the other as they proceeded upstream. Two such successive removal runs were made through each zone (Zippin 1958). Few trout were collected on the second removal effort, providing in essence "virtual" population inventories when added to those collected on the first removal sweep. Trout collected on the removal runs were temporarily placed in a tub of water at the upstream end of the study zone.

At Devils Creek, a shallow draft electrofishing boat with a metal cathode bottom was pulled upstream by one crew member, while 2 other crew members operated anode probes connected to the 250-v generator (T & J Model 1736) through retracting reels. The boat-puller also carried a collecting anode probe. Stunned fish were netted and deposited in a tub of water on the boat just behind the boat-puller.

In all study zones of the 3 creeks, captured trout were retained until the entire reach of the TZ or RZ had been electrofished again. Trout in the tub were then removed, anesthetized, measured to the nearest 0.1 inch, and weighed to the nearest gram. All trout from a given zone were then released at the lower boundary of that zone. In the study zones on Camp and Twenty Mile creeks, captured trout were processed at intervals within each study zone, whenever enough trout had been collected to warrant processing.

Abundance and biomass of trout present in each zone at the time of each electrofishing collection were calculated by inch group and species, based on the actual numbers collected on the first sweep through a study zone plus those collected on the second sweep. Estimates of the number and biomass of trout in each inch group were combined in a variety of ways to describe portions of the total standing stock.

On Camp Creek, 4 population characteristics were tracked for brown trout during April and September before (1984) and after (1985-89 avg.) installation of trout habitat improvement structures in the TZ: total number of trout, number of trout $\geq$ 9.0 inches (legal-sized), number of trout $\geq$ 12.0 inches, and biomass. Data cited for the September 1984 preinstallation phase were actually collected in July 1984 because installation work began in July-August 1984. Inventories of standing stocks in July 1984 included age 0. These preinstallation estimates were compared with later estimates of age 0 and older trout from September 1985-89. Although this 2-month adjustment "fudges" the time series comparisons reported in the Results section, the adjustment is conservative in terms of evaluation of benefits resulting from placing structures in the TZ. By late September 1984, preinstallation standing stocks would have been lower due to natural and angling mortality during August and September. Postinstallation inventories of the standing stocks of brown trout in the TZ and RZ on Camp Creek were made each April and September 1985-89.

On Devils and Twenty Mile creeks, a minimum size limit of 6 inches applied to the trout sport fisheries, so densities of trout $\geq$ 6 inches were an important criterion to quantify for these standing stocks. Three characteristics of the standing stocks of brook and brown trout were tracked in the study zones of these 2 creeks: September abundance of trout of all sizes (age 0+), September abundance of trout $\geq$ 6.0 inches, and biomass of all trout of each species in September. At Devils and Twenty Mile creeks, 3-year preinstallation (1983-85) and 4-year postinstallation (1986-89) periods were established to monitor standing stocks of brook and brown trout each September. Structures were installed in Devils Creek during September-October 1985 and in Twenty Mile Creek in July-August 1985. I assumed that the standing stocks present in the study zones at Twenty Mile Creek in September 1985 represented preinstallation conditions, even though the structures had been in place for a few weeks.

Table 2. *Postinstallation performance of trout habitat improvement structures installed in the treatment zones, summarized by structure type and 4 performance categories.**

	Camp Creek TZ				Devils Creek TZ				Twenty Mile Creek TZ				All Treatment Zones				Total No.
Structure	Excel.	Good	Fair	Poor	Excel.	Good	Fair	Poor	Excel.	Good	Fair	Poor	Excel.	Good	Fair	Poor	Structures
Bank cover log	2**	8	3	2	–	1	–	2	1	7	1	2	3(10.3)[a]	16(55.2)	4(13.9)	6(20.6)	29
Channel constrictor	2	–	–	–	1	–	–	–	2	1	–	–	5(83.3)	1(16.7)	–	–	6
Cross–channel log/bank revetment	3	1	1	–	–	–	–	–	2	1	–	–	5(62.5)	2(25.0)	1(12.5)	–	8
K dam	–	1	–	1	–	–	–	–	–	–	–	–	–	1(50.0)	–	1(50.0)	2
Tip deflector	–	–	2	–	–	–	–	–	–	–	–	1	–	–	2(66.7)	1(33.3)	3
Wedge dam	–	–	–	2	–	–	–	–	1	–	–	–	1(33.3)	–	–	2(66.7)	3
Whole log cover	1	–	1	1	–	1	–	3	1	2	1	–	2(18.2)	3(27.3)	2(18.2)	4(36.3)	11
Wing deflector	1	1	1	–	–	1	–	2	–	3	–	1	1(10.0)	5(50.0)	1(10.0)	3(30.0)	10
Total	9	11	8	6	1	3	–	7	7	14	2	4	17(23.6)	28(38.9)	10(13.9)	17(23.6)	72(100.0)

* Performance categories were based on subjective visual inspection of structures in relation to functional performance in providing improved trout habitat. Excel. = 75-100% performance, Good = 50-75% performance, Fair = 25-50% performance, Poor = 0-25% performance.

** Number of structures in treatment zone.

[a] Values in parentheses = percent of total.

RESULTS

Physical Changes in Stream Morphometry

The most dramatic documented physical change in the TZs was the increase in bank cover for trout—from 23.3 ft to 329.3 ft in the TZ at Camp Creek, from only 11.5 ft to 141.4 ft in the TZ at Devils Creek, and from 17.0 ft to 268.5 ft in the Twenty Mile Creek TZ (Append. Table A.2). In the RZs, the amount of bank cover had decreased during the postinstallation period, probably because of decreased stream flow (see Discussion). Reduced stream flow in September 1988 undoubtedly influenced the reductions in average channel width and average water depth observed in the RZs, too.

In-channel structures reduced average channel width of all 3 TZs. However, an increase in average depth of water was detected only in the TZ on Camp Creek (Append Table A.2). At 10 nonrandom transect points in the TZ on Camp Creek, average stream width decreased by 58%, average water depth increased by 126%, and average stream flow velocity decreased slightly (Append. Table A.3). These physical changes show an increase in pool habitat created by the structures. Similar indications of increased pool habitat (increased depth, reduced water velocity) were also associated with the transect sites in the TZs on Devils Creek (Append. Table A.4) and Twenty Mile Creek (Append. Table A.5).

Stream Flow

The best series of stream-flow measurements in September was obtained at Twenty Mile Creek, where only the September 1985 flow reading was missed during the 7-year 1983-89 period. At Camp Creek and Devils Creek, 2 of 7 flow measurements in September were missed (Append. Table B.1). Among the measurements made, however, lowest discharges for all 3 streams were all in the 1987-89 period, the last 3 years of the postinstallation phase. Stream flow data for the same period (1983-89 for 2 other trout streams in Wisconsin corroborate the pattern for below-normal flow measurements (Append. Table B.2).

Minimum recorded flow at the lower boundary of the TZ on Camp Creek was only 1.2 cfs in September 1988, 50% less flow than the September average for 1984-86. Lowest discharge at Twenty Mile Creek, at the boundary of the study zones, was also 1.2 cfs in September 1988, a 56% decline from the 1983-86 series of measurements. Minimum flow measured at Devils Creek, at the lower boundary of the RZ, was 5.2 cfs in September 1989, a decline of 60% from the average of 1983-85. The below-normal streamflow measurements were accompanied by above-normal summer air temperatures in 1988.

Performance of Structures

Camp Creek

Of the 34 structures installed in Camp Creek, only one failed completely. A wedge dam was obliterated by a flood exceeding bank-full stage in October 1984, about 3 months after installation. The dam was partially destroyed and covered over by rubble deposition. Structural failure may have been partly due to poor siting. The other wedge dam in the Camp Creek TZ was not damaged, but throughout the postinstallation period, it provided only poor trout habitat. Only a shallow scour pool developed below the wedge, and the pool did not extend under the wedge logs. (See Append. Table B.3. for details of performance by individual structures.)

Four other structures in the Camp Creek TZ received a poor functional performance ranking—2 bank cover logs, 1 of 2 K dams and 1 of 3 whole log covers (Table 2). Nine (26%) of the 34 devices were ranked as excellent and 11 more (32%) as good in terms of bolstering trout habitat. Both channel constrictors and 3 of 5 cross-channel log/bank revetment devices were ranked as excellent. Both tip deflectors received only a fair ranking, providing shallow scour pools below the channel-constricting tips but little pool habitat beneath the cover portion of each tip.

At Camp Creek, an excellent channel constrictor reinforced with large quarry stones produced one of the best pools in the treatment zone.

Devils Creek

At Devils Creek, only the single channel constrictor was ranked as excellent 4 years after installation. Three structures—a bank cover log, a whole log cover, and a wing deflector—were ranked as good. Seven of the 11 devices evaluated were poor producers of additional trout carrying capacity.

This wedge dam was effective in the treatment zone on Twenty Mile Creek.

Twenty Mile Creek

In the TZ on Twenty Mile Creek, 7 (26%) of 27 structures provided excellent habitat for adult trout and 14 more (52%) provided good quality habitat. Only 4 structures were in poor condition after 4 years of operation. Channel constrictors and cross-channel log/bank revetment devices were the most consistently beneficial. The single wedge dam installed in the TZ produced excellent trout habitat—a high quality scour pool below the device and adequate depth beneath the wedge logs and lateral log extensions edging the pool. Placement was at a clear breakpoint in stream gradient.

For all 3 TZs combined, 45 (63%) of the 72 structures still provided good or excellent trout habitat after 4 years. Evaluation of performance at that time coincided with lower stream flow than when the structures were installed, reducing the quality ranking given to each structure. Two structure types stood out as best: the channel constrictor and the cross-channel log/bank revetment. Only 1 of 14 of these devices received a fair ranking and none were categorized as poor. The tip deflector and wedge dam structures were the least effective types. Two of 3 tip deflectors were ranked as fair and the other as poor. Two of 3 wedge dams were ranked as poor and the other as excellent.

Installation Costs

The average cost of the three stream channel modification projects was $42,620/mile or $286/structure (Table 3). Costs were highest for the work done in the TZ on Devils Creek, the widest of the 3 TZs, and lowest for the construction work at Twenty Mile Creek, where hand tools and streamside rocks and logs were utilized entirely.

Table 3. *Installation costs for the structures in the treatment zones on Camp, Devils, and Twenty Mile creeks.*

Stream	Total Cost (dollars/mile)	% of Total Cost				Average Cost/Structure (dollars)
		Field Crew Wages	Field Crew Expenses*	Equipment Operation**	Structural Supplies[a]	
Camp Creek	37,987	47	5	36	12	275
Devils Creek	54,633	80	4	14	2	497
Twenty Mile Creek	35,238	55	5	38	2	176
Average	42,620	61	5	29	5	286[b]

* Reimbursement for meals in the field.
** Vehicle mileage to and from work sites; hourly reimbursement for use of heavy equipment from DNR motor pool.
[a] Geoweb, typar, reinforcement rods, rock, logs (Camp Creek only), nails.
[b] Average project cost/mile ($42,620) ÷ average no. structures/mile (149).

Trout Population Changes

Camp Creek

April Values. Positive changes occurred among all 4 characteristics of the wild brown trout population in the TZ during the 5-year postinstallation period. Average abundance of age I+ trout in April increased 271% ($P = 0.05$) (Fig. 2).

The average number ≥ 9.0 inches (legal size) in the TZ increased by 59% ($P = 0.03$) in April. In the RZ the average number ≥ 9.0 inches declined 64% in April ($P = 0.03$) (Fig. 3). The number of legal-sized trout peaked at 457/mile in the TZ in April 1989, a 120% increase over the preinstallation density and a 195% increase over the coexisting density of such trout in the RZ (Append. Table C.1).

Average abundance of brown trout ≥ 12.0 inches ("quality size") in April increased by 88% ($P = 0.48$) in the TZ, from 16/mile in April 1984 to 30/mile during 1985-89. In the RZ the average abundance of such quality-sized trout declined from 73/mile in April 1984 to an average of only 20/mile ($P = 0.32$) for the 1985-89 period (Fig. 4). During 1988-89, abundance of quality-sized trout in April declined in the TZ from the 41/mile average density for 1985-87; simultaneously, declines were sharper in the RZ, which held no brown trout ≥ 12.0 inches in April 1989 (Append. Table C.1).

Biomass accumulated significantly in the TZ during the postinstallation period—from 123 lb/mile in April 1984 to an average of 267 lb/mile for April of 1985-89 (117% gain, $P = 0.02$) (Fig. 5). Biomass increased in the TZ for 4 successive Aprils (1985-88), peaking at 344 lb/mile, a 180% improvement from the preinstallation base (Append. Table C.1). In April 1984 biomass in the RZ exceeded that in the TZ by 76%. In April 1988, when measured biomass peaked in both study zones, the RZ held 31% less biomass/mile than did the TZ.

September Values. Average abundance of brown trout in September (including age 0) increased in the TZ by 59% over the preinstallation density (Fig. 2). Peak measured density in the TZ was reached in September 1987—5,200/mile (Append. Table C.1). RZ density also peaked then at 7,091/mile. The 1987 year class, the strongest of 6 recruited during the study period, was a major factor accounting for the peak densities observed in September 1987 (Append. Table C.2). In both study zones, standing stocks collapsed during 1989 to their lowest densities recorded during the study—to 457/mile in the TZ and only 200/mile in the RZ (App. Table C.1). The 1989 year

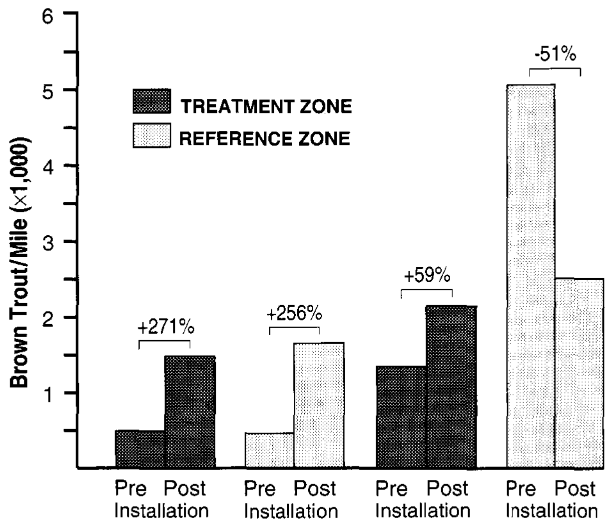


Figure 2. *Number of brown trout/mile in the treatment and reference zones at Camp Creek in April and September before (1984) and after (1985-89 average) installation of trout habitat improvement structures in the treatment zone.*

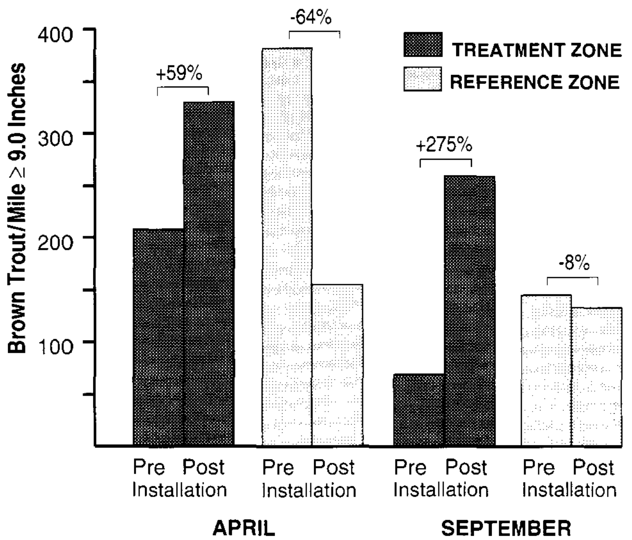


Figure 3. *Number of brown trout/mile ≥ 9.0 inches in the treatment and reference zones at Camp Creek in April and September before (1984) and after (1985-89 average) installation of trout habitat improvement structures in the treatment zone.*

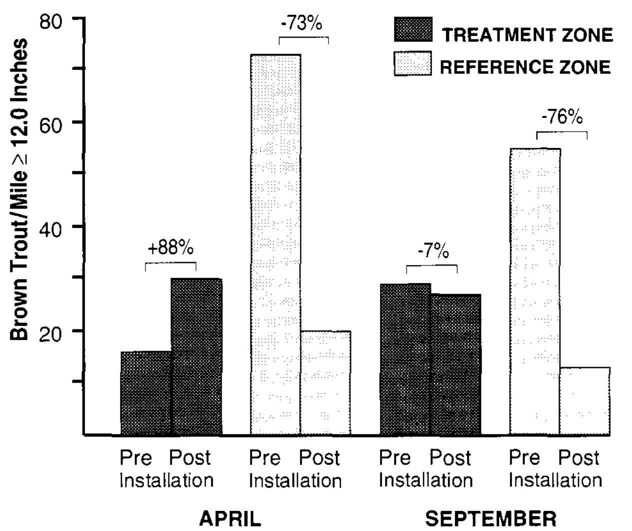


Figure 4. *Number of brown trout/mile ≥ 12.0 inches in the treatment and reference zones at Camp Creek in April and September before (1984) and after (1985-89 average) installation of trout habitat improvement structures in the treatment zone.*

class was totally absent in the RZ (Append. Table C.2) and present in the TZ at a density of only 8/mile. (In absolute terms, only 2 age 0 were present in 1,323 ft of stream in the TZ in September 1989 vs. 1,071 age 0 in that same reach in September 1987.)

Legal-sized trout in the TZ near the close of the fishing seasons increased from only 69/mile in 1984 to a postinstallation average of 259/mile ($P < 0.01$) (Fig. 3). Peak density of 286/mile was reached in September 1987, a value 314% greater than the preinstallation density. In the RZ, abundance of legal-sized trout declined from 145/mile in September 1984 to an average of 133/mile for September 1985-89, a reduction of 8% (Fig. 3). Every fall, except in 1984, the TZ held more legal-sized brown trout than did the RZ (Append. Table C.1).

Abundance of brown trout $\geq$ 12.0 inches in the TZ reached a peak density of 53/mile in September 1986, 2 years after completion of the habitat enhancement project. Over the 5-year postinstallation period, however, average density of such trout was about the same as the preinstallation density (27/mile vs. 29/mile). In the RZ, highest density of quality-sized brown trout was observed in September 1984 (55/mile). During the following 5 years, this study zone never held more than 27 trout/mile $\geq$ 12.0 inches in September and no trout of this size were present in the fall of 1989 (Append. Table C.1). The September 1985-89 average of 13/mile represents a 76% decline from the peak fall density in 1984 (Fig. 4).

Preinstallation biomass in the TZ in September 1984 was only 82 lb/mile, less than one half that present in the RZ at the same time. Following installation of structures in the TZ, biomass in September increased for 3 successive years to a peak of 348 lb/mile, an increase of 324% over the preinstallation value. Biomass also peaked in the RZ in September 1987 (at 287 lb/mile), but at a value only 37% greater than that observed in the RZ in the fall of 1984 (Append. Table C.1).

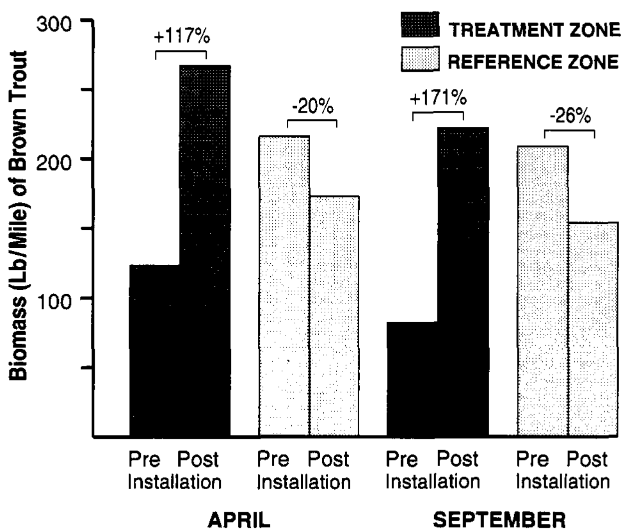


Figure 5. *Biomass (lb/mile) of brown trout in the treatment and reference zones at Camp Creek in April and September before (1984) and after (1985-89 average) installation of trout habitat improvement structures in the treatment zone.*

Average biomass in the fall during the postinstallation phase increased by 171% in the TZ ($P = 0.06$) and declined by 26% in the RZ ($P = 0.55$) (Fig. 5).

Devils Creek

In both study zones, 3 characteristics of the standing stocks of brook trout showed average postinstallation (1986-89) increases over average preinstallation (1983-85) values, but in all cases the percentage increases were greater in the RZ than in the TZ (Figs. 6-8) (Append. Table C.3).

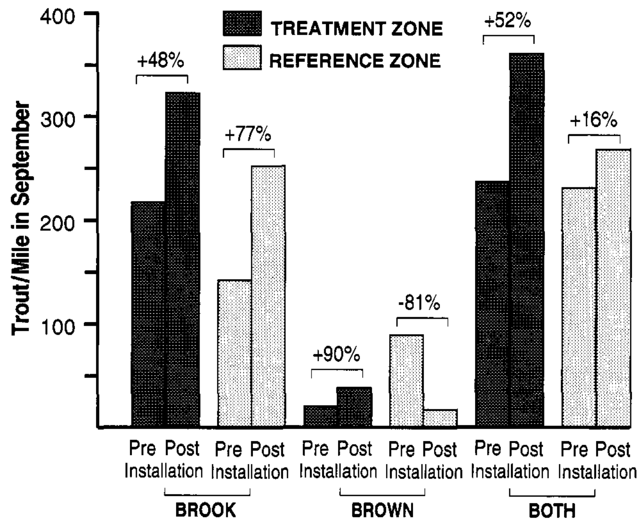


Figure 6. *Number of brook trout/mile and brown trout/mile in the treatment and reference zones at Devils Creek in September before (1983-85 average) and after (1986-89 average) installation of trout habitat improvement structures in the treatment zone.*

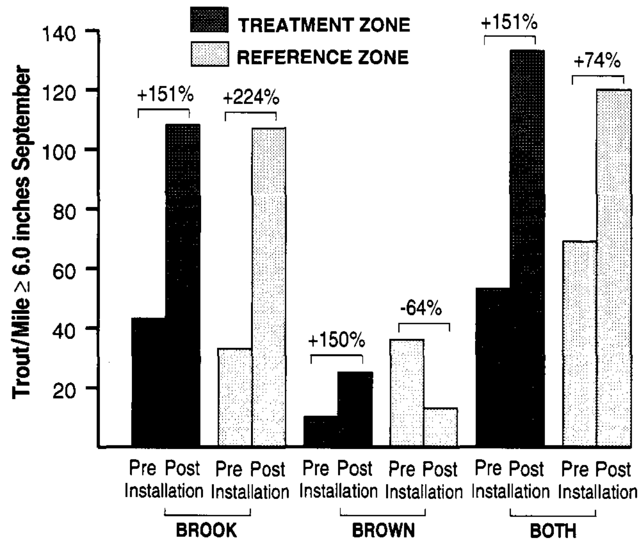


Figure 7. *Number of brook trout/mile and brown trout/mile $\geq$ 6.0 inches in the treatment and reference zones at Devils Creek in September before (1983-85 average) and after (1986-89 average) installation of trout habitat improvement structures in the treatment zone.*

For the standing stocks of brown trout a different pattern emerged, suggesting some benefits from placement of the habitat improvement structures in the TZ. Brown trout of all sizes in September increased an average of 90% in the TZ and declined an average of 81% in the RZ (Fig 6). Legal-sized browns in September increased by 150% in the TZ and declined by 64% in the RZ (Fig. 7). Brown trout biomass in September improved by 47% in the TZ and declined by 49% in the RZ (Fig. 8).

Although none of the proportional gain or loss shifts within a study zone had a statistically significant probability, the probability tests for the shifts in "remainder" values (TZ value minus RZ value) were strong enough to suggest that increased density and biomass for brown trout in the TZ were influenced by the structures placed in the zone (Append. Table C.3). Before habitat improvement structures were added, the RZ tended to hold more brown trout than the TZ. After addition of structures, the relationship reversed, i.e. "remainders" were now positive, not negative ($P = 0.11$ for brown trout of all sizes, $P = 0.06$ for legal-sized brown trout, and $P = 0.29$ for differences in biomass).

Parameters representing average changes in the standing stocks of brook and brown trout combined increased in both study zones during the postinstallation phase. Percentage gains were greater in the TZ than in the RZ but not significantly greater. Trout of all sizes increased an average of 52% in the TZ vs. 16% in the RZ (Fig. 6). Legal-sized trout increased an average of 151% in the TZ vs. 74% in the RZ (Fig. 7). Fall biomass of brook and brown trout combined rose an average of 53% in the TZ and only 16% in the RZ (Fig. 8).

Twenty Mile Creek

Average abundance of age 0+ brook trout present in September declined by 32% in both study zones during the postinstallation period. Average postinstallation abundance of age 0+ brown trout also declined in both study zones—by 15% in the TZ and by 49% in the RZ (Fig. 9). Peak densities of brook trout were observed in both study zones in 1983, the first year of the study (Append. Table C.4). Peak density of brown trout was measured in 1988 in the TZ (3 years after habitat improvement) and in 1983 in the RZ. Brook trout were several times more numerous than brown trout in the RZ all 7 years of monitoring. A similar situation existed in the TZ, except in the fall of 1988, when the ratio of brook trout to brown trout was only 1.7:1.

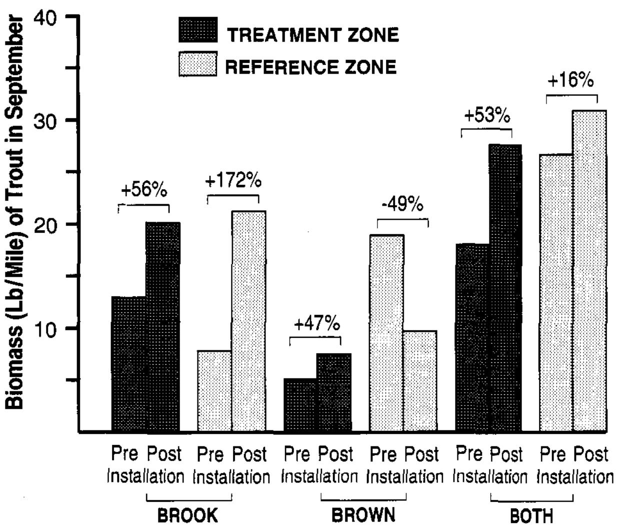


Figure 8. *Biomass (lb/mile) of brook trout and brown trout in the treatment and reference zones at Devils Creek in September before (1983-85 average) and after (1986-89 average) installation of trout habitat improvement structures in the treatment zone.*

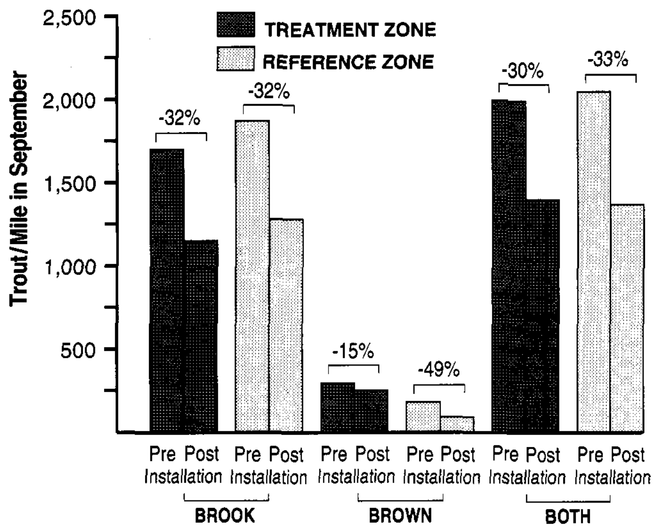


Figure 9. *Number of brook trout/mile and brown trout/mile in the treatment and reference zones at Twenty Mile Creek in September before (1983-85 average) and after (1986-89 average) installation of trout habitat improvement structures in the treatment zone.*

Reduced recruitment of age 0 trout of both species was the primary reason for the average declines in the total number of trout present in the study zones during the 1986-89 period. Average abundance of age 0 brook trout in the fall was 45% less in the TZ and 39% less in the RZ during 1986-89 than during 1983-85 (Append. Table C.5). The 1985-89 year classes of brown trout were 29% weaker in the TZ and 64% weaker in the RZ than were the 1983-85 year classes.

Despite reduced age 0 recruitment in the TZ after structures were installed in 1985, subsequent abundance of legal-sized trout increased. Postinstallation abundance of brook trout ≥ 6.0 inches increased an average of 118% in the TZ ($P = 0.16$). There was no change in the average number of legal-sized brook trout in the RZ (Fig. 10). Legal-sized brown trout showed a 48% average gain in the TZ vs. a 34% average decline in the RZ from the preinstallation period to postinstallation period. For both species combined, there was a 93% average increase ($P = 0.16$) in legal-sized trout remaining in the TZ near the close of the postinstallation seasons. The comparable change in the RZ was a 5% decline.

Densities of legal-sized trout peaked in both study zones in 1986 at 500/mile. The RZ maintained a higher density of legal-sized brook trout every fall except in 1989, when the negative impacts of low stream flow were most severe (see Discussion). For all 7 study years, the TZ held higher densities of legal-sized brown trout than did the RZ, which had no brown trout ≥ 6.0 inches in the falls of 1988-89. During these years, the densities of brown trout in the TZs were 54/mile and 38/mile, respectively (Append. Table C.4).

Increased biomass of legal-sized trout more than offset decreased biomass of age 0 stocks in the TZ during the postinstallation period, such that a modest 13% average increase in biomass of all brook trout and a 27% average increase in biomass of all brown trout occurred (Fig. 11). Although these modest gains were not significant, they were paired with average declines of 16% in the biomass of brook trout and 33% in the average biomass of brown trout in the RZ. Pairing these trends suggests biological benefit from placement of structures that increased pool habitat and hiding cover habitat in the TZ.

Biomass of all trout in the RZ in September exceeded that in the TZ all 3 of the preinstallation years. During 3 of the 4 postinstallation years (1987-89), biomass of trout was greater in the TZ than in the RZ. In this small infertile stream the difference in biomass between zones shifted from 10 lb/mile more in the RZ before habitat improvement to 11 lb/mile more in the TZ after habitat improvement (Append. Table C.4). These average remainders differ significantly ($P = 0.03$).

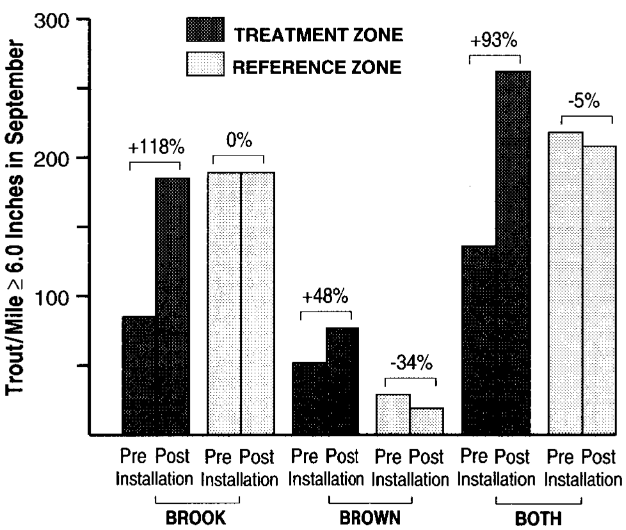


Figure 10. *Number of brook trout/mile and brown trout/mile ≥ 6.0 inches in the treatment and reference zones at Twenty Mile Creek in September before (1983-85 average) and after (1986-89 average) installation of trout habitat improvement structures in the treatment zone.*

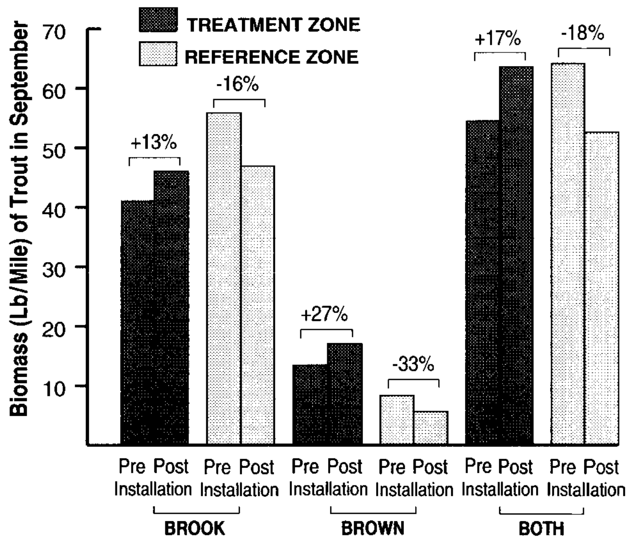


Figure 11. *Biomass (lb/mile) of brook trout and brown trout in the treatment and reference zones at Twenty Mile Creek in September before (1983-85 average) and after (1986-89 average) installation of trout habitat improvement structures in the treatment zone.*

DISCUSSION

Importance of Resting/Security Cover

At Camp, Devils, and Twenty Mile creeks, the addition of resting/security cover for adult trout was the primary accomplishment of the trout habitat improvement projects. All 8 test structures were chosen with this goal in mind. Resting/security cover (providing at least 6 inches of overhead shelter coupled with at least 6 inches of water beneath) increased by factors of 12-15 times the preinstallation quantities, despite reduced stream flow when postinstallation measurements were taken. Concurrently, there were natural declines of 8% (Devils Creek), 16% (Twenty Mile Creek) and 52% (Camp Creek) in the amount of permanent overhead cover in the 3 reference zones.

The prominent contribution of such resting/security cover to trout carrying capacity of a stream reach is now well established in the fisheries literature. Numerous field and laboratory studies have documented direct relationships between natural variations in quantities of such cover and abundance of adult trout (see reviews by White [1986], Hunt [1988], and the case history study by Thorn [1988]).

Resting/security cover may be especially important in determining trout carrying capacity during the stressful winter period (Bustard and Narver 1975; Heifitz et al. 1986; Cunjak and Power 1986, 1987). The only study zones where I could quantitatively assess the relationship between cover and overwinter mortality were the TZ and RZ at Camp Creek. There, during 5 successive overwinter periods (September-April of 1984-89), abundance of wild brown trout declined an average of 14% in the TZ vs. 46% in the RZ (calculated from standing stock data in Append. Table C.1).

The annual values for the TZ obviously do not represent "closed population" changes, since during the winter of 1984-85 there was an increase of 4% in the number of trout in the TZ, and the next winter there was essentially no change in abundance. Volitional movement of trout into the TZ must have occurred from fall to spring, which more than offset natural mortality in the TZ, although its magnitude each winter was unknown.

Whether or not such overwinter recruitment also occurred in the RZ is unknown, but what is evident is that in the RZ, where cover for adult trout is sparse, outmigration plus within-zone natural mortality far surpassed any recruitment that may have occurred. The worst rate of decline in abundance of trout from September to April was 67% in the RZ vs. a worst case decline of only 36% in the TZ.

Impacts of Low Stream Flow

During the last 3 years of the postinstallation period, below-normal stream flow measurements were observed in all 3 study streams. Stream-flow data for 2 other trout streams in Wisconsin, where continuous recording stations are maintained by the U.S. Geological Survey, reflect the same pattern of below-normal flow measurements (Append. Table B.2).

Despite abnormally low stream flow, biomass and abundance of legal-sized trout improved in the TZs on all 3 study streams. At Camp and Twenty Mile creeks, these gains were paired with concurrent declines in biomass and number of legal-sized trout in the RZs. At Devils Creek, biomass and number of legal-sized trout (brook and brown combined) increased in the RZ during the postinstallation phase, but the increases were proportionately less than those measured in the TZ.

Trout Population Changes in the Study Streams

Camp Creek

Overall Results. The most impressive postinstallation responses of standing stocks occurred in the TZ at Camp Creek, the most fertile of the study streams (247 mg/L total alk.). For example, postinstallation biomass in September averaged 222 lb/mile (up 171%) at Camp Creek vs. 63 lb/mile (up 17%) for Twenty Mile Creek (59 mg/L total alk.) and 28 lb/mile (up 53%) at Devils Creek (55 mg/L total alk.).

At Camp Creek, the significant spring and fall biomass gains for wild brown trout in the TZ, and the significant numerical increase in age I+ trout in April, rank among the highest percentage increases quantified for trout habitat improvement projects evaluated in Wisconsin. Thirty-three such published evaluations involve wild brown trout in allopatry and 13 involve evaluations of wild brown and wild brook trout stocks in sympatry (Hunt 1988). The positive responses observed in the Camp Creek TZ were most similar in magnitude to those associated with intensive installation of Wisconsin-style bank cover/current deflector structures, the most consistently effective type of in-channel trout habitat improvement technique tested to date in Wisconsin (Hunt 1971, 1976, 1988). Moreover, if the prolonged drought of 1988-89 had not occurred, average postinstallation increases in the number and weight of brown trout in the TZ probably would have been even more dramatic.

At its peak, the standing stock in the Camp Creek TZ reached 348 lb/mile (414 lb/acre) in the fall of 1987, after steadily building to that level during the first 3 years of the postinstallation period.

Biomass. Biomass peaked in Spring 1988 before declining to 210 lb/mile in the fall of 1988, rising a bit the next spring and then crashing during the April-September period of 1989 to only 145 lb/mile, when the last postinstallation assessment of standing stocks was made (Append. Table C.1). From September 1987 to September 1989, therefore, biomass declined by 58% in the TZ during the period of prolonged drought.

The concurrent 2-year decline in biomass in the RZ, however, was much more severe—an 82% reduction to only 53 lb/mile. When measured biomass was at its highest in both study zones (September 1987), the TZ had a 21% greater biomass than did the RZ. Two years later, when biomass in each zone reached the lowest measured value, the TZ held a 174% greater biomass than did the RZ.

This combination of greater accumulation of biomass in the habitat-enhanced TZ and less severe decline in biomass during low flow years suggests that the habitat improvement structures became increasingly valuable as environmental conditions became more harsh.

One can only speculate how much higher the biomass of wild brown trout might have risen in the TZ in 1988 and 1989, if more normal stream flow regimes had occurred. At Lawrence Creek, in central Wisconsin, biomass of brook trout during the first 3 postinstallation years improved by 86% (Hunt 1976). During the next 3-year period, biomass continued to improve by an additional 94% over the preinstallation average and by 50% over the first 3-year postinstallation average. Transferring these kinds of proportional gains to the Camp Creek TZ would translate into an average biomass for years 4 and 5 of approximately 378 lb/mile (450 lb/acre) in September, rather than the observed average biomass of 178 lb/mile. This lower value, representing a 53% reduction, is attributable in part to loss of trout carrying capacity due to reduced stream flow.

Abundance of Legal-sized Trout. Perhaps the most impressive and managerially important postinstallation trend in the TZ at Camp Creek was the April to April pattern of abundance of legal-sized trout—the "bottom line" goal of most stream improvement projects. Density of this size class ($\geq$ 9.0 inches) increased from a low of 163/mile in April 1985 to a peak of 457/mile in April 1989 (Fig. 12). The only April in which density of such trout was greater in the RZ than in the TZ was in 1984, before placement of structures in the TZ. Peak density in the TZ in April 1989 was reached despite deteriorating environmental conditions during 1988.

A major factor contributing to the peak density of legal-sized trout in April 1989 was the exceptionally strong 1987 year class recruiting into the legal-sized component of the standing stock as age II in 1989. In spring 1989, 40% of the age II brown trout in the TZ were $\geq$ 9.0 inches, and they accounted for 67% of all such trout in the study zone. A few age II individuals even exceeded 11.0 inches by April, exhibiting exceptionally good growth for wild brown trout in Wisconsin streams.

The 1987 year class was also a very strong one in the RZ; in fact, its density in September of that year exceeded age 0 density in the TZ by 36% (7,091/mile vs. 5,200/mile in the TZ). However, as this year class reached age II in the RZ, it lost its numerical superiority (423/mile vs. 768/mile in the TZ). Its contribution of legal-sized trout was also less (154/mile vs. 308/mile in the TZ). I suggest, therefore, that the structures added to the TZ provided trout habitat that was better suited to accommodate a strong year class when its survivors had grown to legal size.

White (1986) proposed that summarization of trout biomass data according to a scale of body lengths—which he termed "lineal standing crop"—could provide especially vivid portrayals of the beneficial consequences of trout habitat improvement projects. He illustrated the concept with biomass data for stocks of wild brown trout in 4 study zones on Cress Spring Creek in Montana. Trout habitat had been intensively improved in one of the zones with bank cover/deflector devices the previous year. Biomass of brown trout in the 12-22 inch range was 9.2 times greater than average biomass of trout in this length range in 3 control zones.

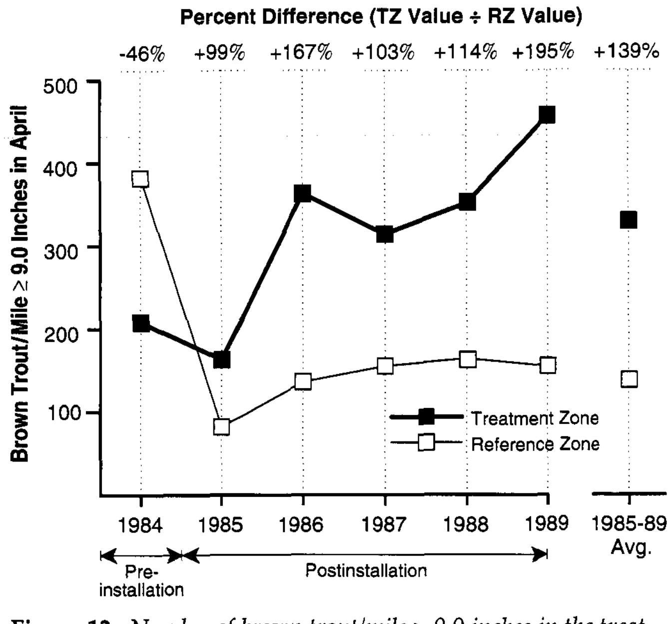


Figure 12. *Number of brown trout/mile $\geq$ 9.0 inches in the treatment and reference zones at Camp Creek in April of 1984-89. Trout habitat improvement structures were installed in the treatment zone in July 1984.*

A similar summary of changes in the lineal distribution of biomass of wild brown trout in the TZ on Camp Creek is illustrated in Figure 13. Although total average biomass in April 1985-89 was only 2.2 times greater in this study zone than in April 1984, average postinstallation biomass was greater in 14 of 16 inch groups, including the 13-16 inch groups. There was no biomass contribution from trout in these 4 inch groups for the preinstallation phase.

Devils Creek

At Devils Creek, there were 2 consistent trends within the data collected on standing stocks of trout in the study zones. First, in both zones, brook trout increased in number and biomass during the postinstallation period, and average gains were proportionately greater in the RZ than in the TZ. The second trend involved brown trout that increased in number and biomass in the TZ and decreased in number and biomass in the RZ from the preinstallation to postinstallation phase. Although only the 172% average increase in biomass of brook trout in the RZ was statistically significant (Append. Table C.3), the pattern of increased abundance and biomass of brown trout in the TZ, coupled with concurrent decreases in the RZ, could be interpreted as a pattern having biological significance, though unsupported by strong statistical inference.

The actual numbers of trout composing the standing stocks in the study zones on this stream all indicated low densities at best. Absolute abundance in the study zones in September 1983-89 ranged from 19 trout to 45 trout in the TZ and from 23 trout to 48 trout in the RZ. A random or even causal addition of only 10 or 12 trout to one of the study zones would have changed the observed low densities by 40-60% and the observed high densities by 20-25%.

As expected, the TZ in Devils Creek served more to assess functional performance of the test structures than to document changes in the standing stocks of trout in the TZ. Continued lack of recruitment from within the study zones or from elsewhere kept standing stocks at low levels throughout the evaluation. Installation of only 11 structures in the TZ also reduced its potential to sustain substantially more trout after installation than before. This would have been true even if greater recruitment had materialized or long-term survival of the sparse stock in the TZ had dramatically improved.

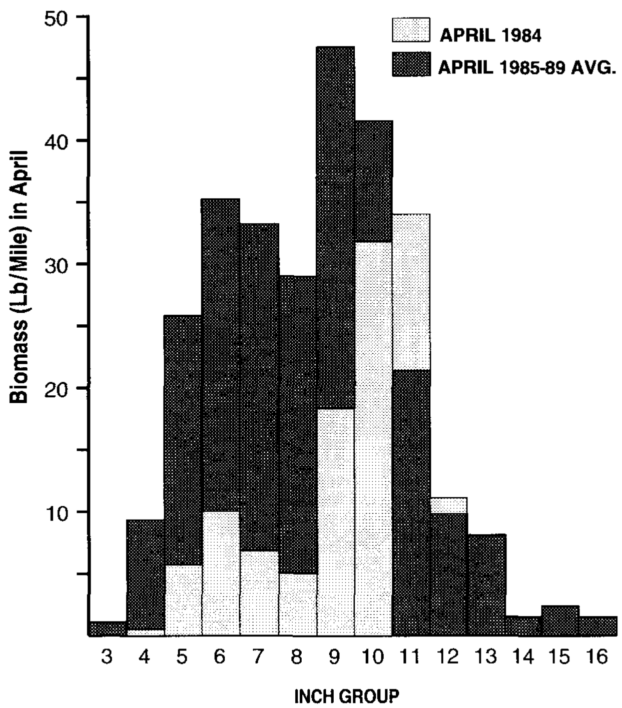


Figure 13. *Lineal distribution of the biomass of brown trout in the treatment zone at Camp Creek before (April 1984) and after (April 1985-89 average) installation of trout habitat improvement structures.*

Twenty Mile Creek

In 9 of 10 previous evaluations of trout habitat improvement on streams in Wisconsin that supported sympatric stocks of wild brook trout and wild brown trout, the brown trout stock usually benefitted more than the brook trout from the habitat enhancement effort (Hunt 1988). This tendency was especially true for trout of legal size. I suggested that the superior performance by wild brown trout reflected at least 2 factors: direct interspecific competition favoring brown trout and lower angler exploitation of brown trout.

Within the TZ at Twenty Mile Creek, which sustained a sympatric stock of brook and brown trout, it was not evident during the first 4 postinstallation years whether brown trout outperformed brook trout. Brook trout of all sizes (age 0+) and of legal size (Figs. 14, 15) continued to outnumber brown trout, and the average percentage increase in legal-sized brook trout for the postinstallation period substantially exceeded the average gain made by brown trout (118% vs. 48%) (Fig. 10). However, based on relative changes in total number of trout (age 0+) present in September and their total biomass, brown trout showed a smaller average percentage decline in one case (Fig. 9) and a greater average percentage increase (Fig. 11) in the other. Only longer monitoring of standing stocks in this TZ will reveal whether brown trout will eventually become the dominant salmonid by number, average size, and biomass.

Deficiencies in Study Design

My study design did not include creel surveys in the study zones before or after habitat improvement projects. Consequently, no data were collected to document changes in angler use or to assess potential impacts of harvest on standing stocks. The DNR made visible improvements in the TZs that would have attracted the attention of anglers and probably increased postinstallation use and harvest. In 4 TZs on other trout streams in Wisconsin where creel surveys were conducted as part of habitat evaluations, angler use increased an average of 79% and harvest increased an average of 41% (Hunt 1988).

If greater, but unaccounted for, harvest also occurred in the TZs on Camp, Devils, and Twenty Mile creeks, postinstallation trout carrying capacity was enhanced more than was reflected by observed improvements in standing stocks. Increased, but unmeasured, harvest would have been particularly detrimental to the evaluation process in the 2 relatively infertile TZs (Devils and Twenty Mile creeks), where the inherent ability of the standing stocks to increase was less than in the fertile TZ on Camp Creek.

Better collections of physical data from the study zones would also have been helpful, especially year-round stream discharge data, rather than relying on sporadic instantaneous determinations of stream flow made on the days when trout population surveys were carried out. And even on some of those occasions, discharge readings were cancelled because discharge was fluctuating due to recent rains.

In retrospect, more effort to document in-channel features influenced by the habitat improvement structures would also have been useful. Area and depth of pool habitat in particular should have been quantified to augment efforts made to measure changes in resting/security cover.

I expected to find that the average depth of the TZs increased after installation of the structures. This did not occur in 2 of the 3 TZs (Devils and Twenty Mile creeks), based on the frequency of cross-channel transects. Whether such unexpected physical change was real (due to reduced stream flow) or spurious (due to imprecise sampling) is speculative. Cross-channel transects were taken at approximately the same points, but not exactly. Permanent transect site stakes were not placed along the stream when the first series of width measurements was made. A tape-measured 50-ft midcourse distance up the stream channel was repeated to set up cross-channel transects, but this procedure was not as accurate as use of a series of permanent stakes would have been to precisely relocate transect points.

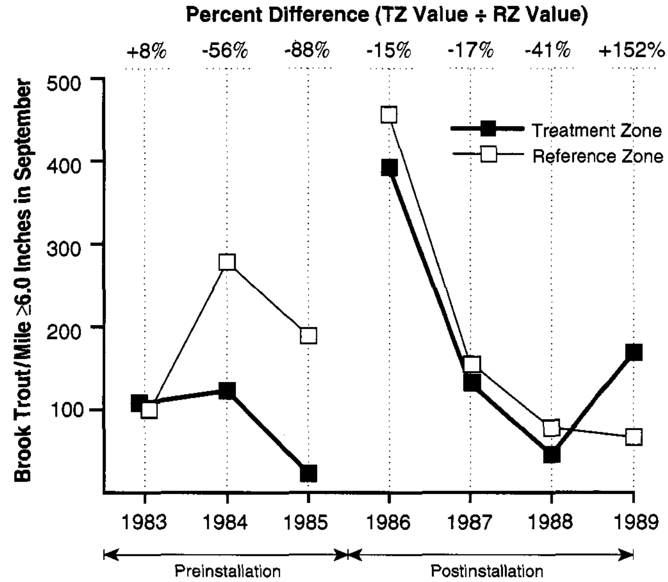


Figure 14. *Number of brook trout/mile ≥ 6.0 inches in the treatment and reference zones at Twenty Mile Creek in September of 1983-89. Trout habitat improvement structures were installed in the treatment zone in July-August 1985.*

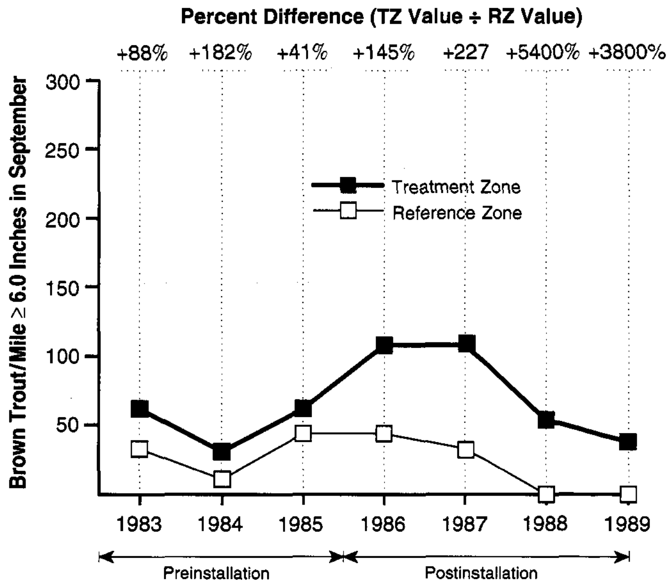


Figure 15. *Number of brown trout/mile ≥ 6.0 inches in the treatment and reference zones at Twenty Mile Creek in September 1983-89. Trout habitat improvement structures were installed in the treatment zone in July-August 1985.*

FISHERY MANAGEMENT IMPLICATIONS AND SPECULATIONS

1. All but one (tip deflector) of the 8 experimental structures tested is recommended to upgrade trout habitat in reaches of other Wisconsin trout streams with gradients exceeding 1%, if normal baseflow in summer does not usually exceed 5 cfs or stream channel width does not exceed 15 ft. I recommend the channel constrictor for straight reaches and the cross-channel log/bank revetment structure for natural bends. Where bends are infrequent, the combination of wing deflectors and bank cover logs is recommended to enhance trout carrying capacity. K dams or wedge dams should be installed at obvious breaks in the stream channel profile, preferably at the downstream end of riffle reaches.

2. In reaches of high-gradient streams where channel width is 15-25 ft and/or where normal summer baseflow is usually 5-10 cfs, I recommend only 3 of the 8 structures tested—the channel constrictor, the combination of a wing (current) deflector and bank cover log, and the cross-channel log/bank revetment.

3. For high-gradient streams having widths $\geq$ 25 ft and/or with normal summer baseflows $\geq$ 10 cfs (such as Devils Creek), I hesitate to recommend any of the 7 fabricated devices to enhance trout carrying capacity. Large whole log covers, well anchored with rebars, would be worth trying and least expensive. Additional experimentation is recommended to assess ways of enhancing trout carrying capacity in the few trout streams in Wisconsin fitting these physical criteria.

4. As expected, the test structures benefitted adult trout more than subadults, a common phenomenon where the changes in trout carrying capacity are primarily due to increased pool area, increased depth, and more resting/security cover.

5. Habitat improvement structures appeared to become increasingly valuable determinants of trout carrying capacity as environmental conditions deteriorated due to declining stream flow. More long-term monitoring studies that span greater variations in stream flow regimes are recommended to validate this important management attribute of habitat improvement structures.

6. Average cost of the structures placed in the 2 smaller streams was approximately $230/structure. Density of installation was approximately 165 structures/mile. This level of intensity was not overdone, if the goal was to provide consistent opportunities to fish throughout a reach of developed stream. Cost to duplicate such work would be approximately $38,000/mile, making this kind of trout habitat improvement one of the most expensive techniques tested to date in Wisconsin. As DNR crews become more experienced at installing such structures, however, cost per structure should decline. Integration of volunteer labor in the construction process is also an option to substantially economize on future projects. Use of streamside rocks and logs also reduces construction cost.

7. Aesthetic appearance as well as functional performance of the test structures deteriorated with an increase in stream channel width and discharge. After 4-5 years, most of the structures in all 3 streams needed maintenance to replace riprap or rock fill. Habitat improvement projects involving placement of in-channel structures will require more frequent attention as gradient and channel width increase. The desirability of using synthetic materials in these situations should be evaluated further.

8. Additional testing of Geoweb is needed to assess its usefulness to retain coarse fill material. When such fill is lost, as happened for about half of the structures using Geoweb, the synthetic Geoweb is exposed and the result is aesthetically displeasing.

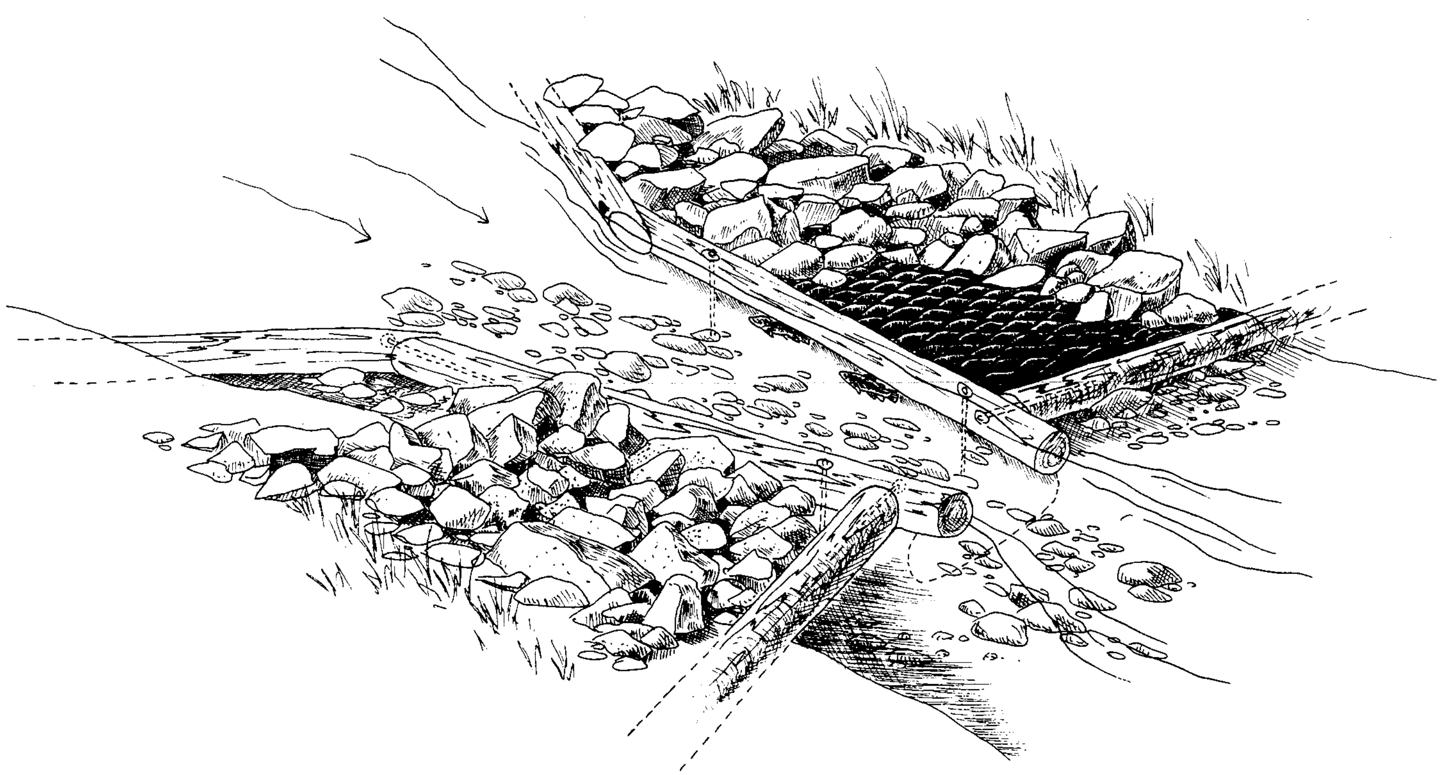
GLOSSARY OF HABITAT DEVELOPMENT TECHNIQUES

Channel Constrictor

This structure is placed in straight reaches of stream channels. The confined channel is pinched in at the downstream end of the structure to create a partial dam effect and deepen pool depth between the face-logs. Additional pool depth can be created by placing a large rock or 2 in midchannel below the structure (not shown).

Use large (≥ 20-inch diameter) rough logs, if available, for the 2 main face-logs. These logs may be partially notched-out to increase underlog cover for trout, or they may be left in their natural form.

Pin the upstream brace-logs at 45° angles to the face-logs, and extend them back 2-3 ft into stream-bank trenches. Stabilize the ends of the brace-logs with riprap. Also add riprap behind the face-logs using Geoweb for a support base or place riprap in a downstream, sloping, shingle-like pattern.



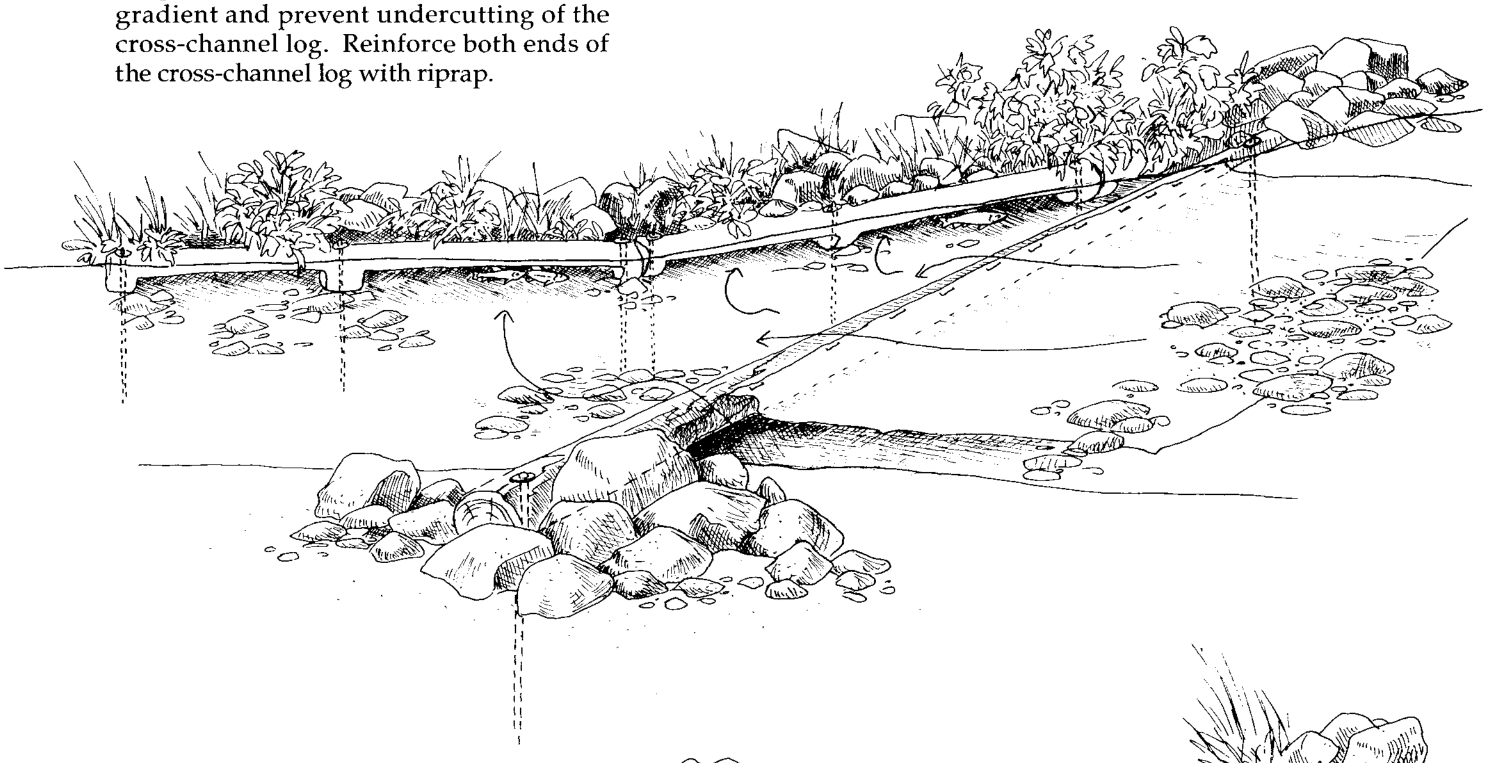
Cross-channel Log/Bank Revetment

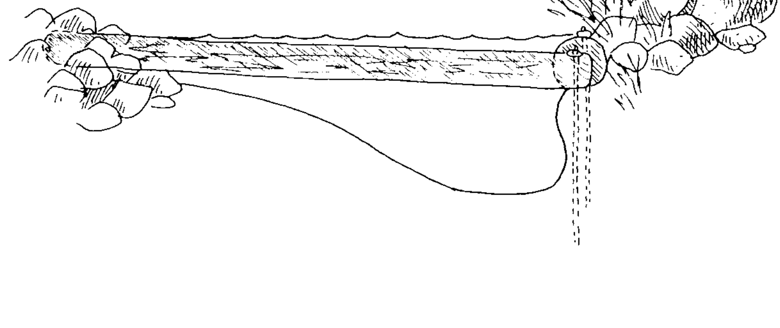
This is an excellent structure to install at natural bends that lack underbank cover and/or just at the downstream end of obvious breaks in stream gradient (end of a riffle).

Position the bank revetment log along the outside bend. Notch out the revetment log to increase underlog cover for trout. Add riprap behind the bank revetment log to improve bank stability. Install the end of the cross-channel log on the shallow side of the stream several inches higher than the opposite end that joins the bank revetment log. Position the cross-channel log at a 30-45° downstream angle and partially bury it. This angular deflection of flow, plus the elevated tilt to the cross-channel log, concentrates flow toward the bank revetment regardless of flow stage. Maximum depth of the lateral scour pool is at the apex of the structure.

Staple roadbase filter fabric to the cross-channel log, extend the fabric sheet upstream for several feet; bury and cover it with heterogeneous substrate to restore natural gradient and prevent undercutting of the cross-channel log. Reinforce both ends of the cross-channel log with riprap.

On Twenty Mile Creek, this cross-channel log/bank revetment structure provided an excellent pool and resting/security cover for trout in the treatment zone.

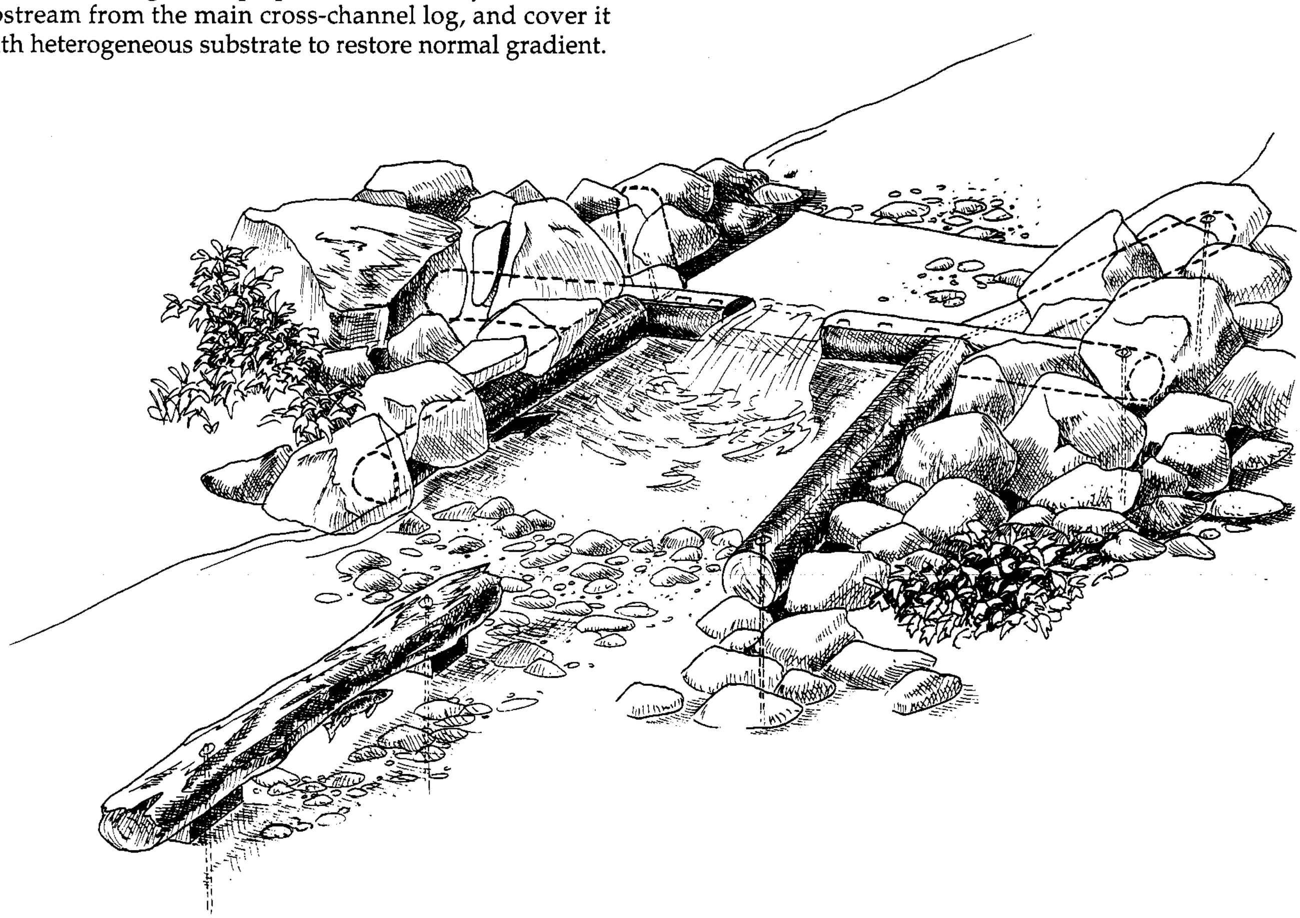




K Dam

This structure consists of a main cross-channel log and downstream extension brace-logs. Upstream brace-logs are optional but recommended. Best placement is in straight reaches where obvious breaks in stream gradient occur. A midchannel scour pool is created below the structure and ideally beneath the downstream brace-logs of the K dam too. The scour pool can be excavated initially, but periodic high flow stages will determine its long-term dimensions and depth. If depth is adequate, a half-log or whole log cover can be added in or below the scour pool to provide additional cover for trout.

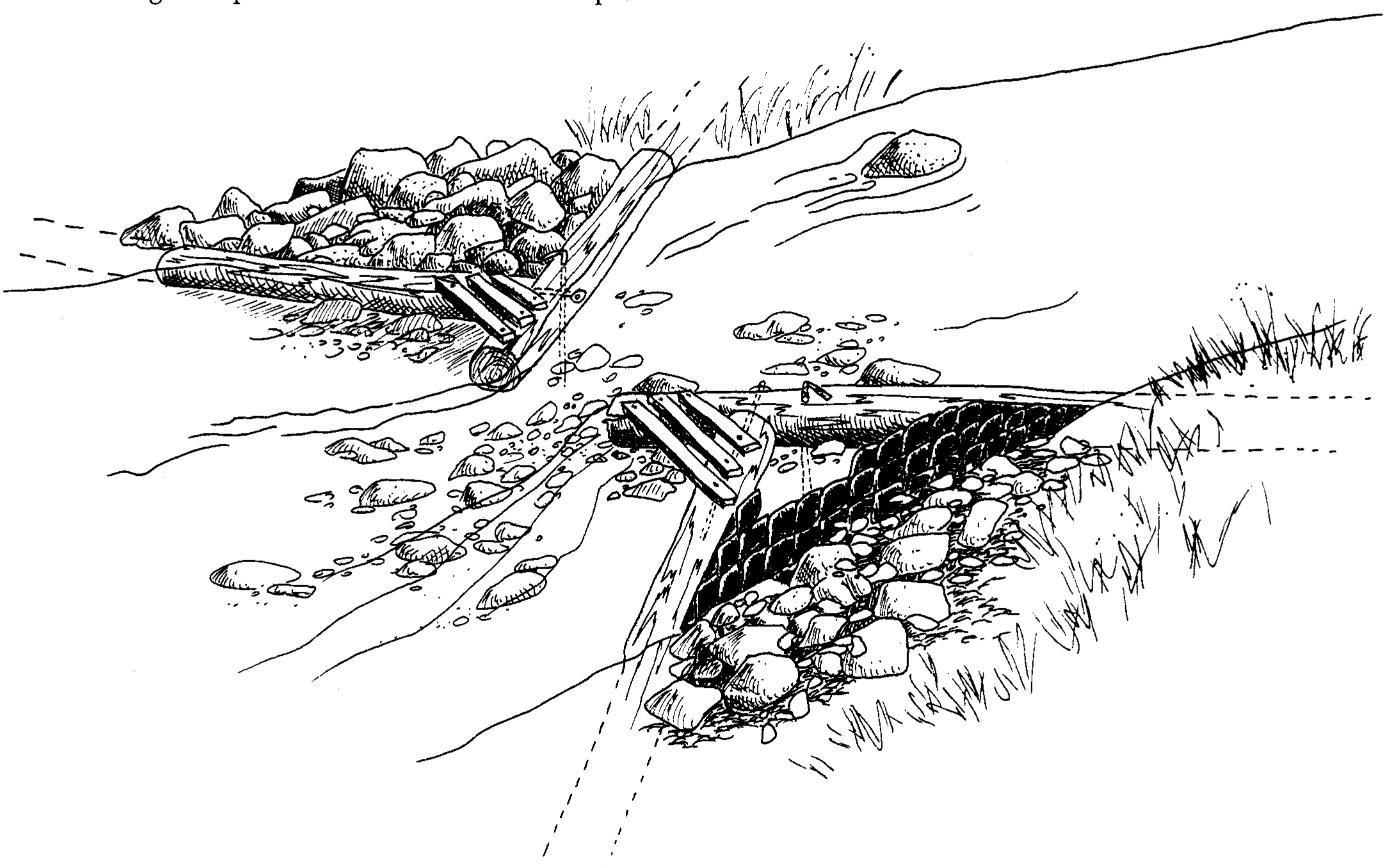
If upstream brace-logs are added, extend them well back into each stream bank at a 45° angle from the cross-channel log. Armor the ends of all brace-logs and the cross-channel log with riprap. Attach and bury filter fabric upstream from the main cross-channel log, and cover it with heterogeneous substrate to restore normal gradient.



Tip Deflector (paired)

This structure can be installed in pairs in straight reaches to provide midchannel cover and encourage development of a plunge pool or as a single structure to provide cover under the tip and redirection of flow toward another structure or naturally good habitat for adult trout.

Extend butt ends of the deflector logs into streambank trenches and stabilize with large riprap. Use of Geoweb to retain riprap is optional. (Functional performance of this structure to date in Wisconsin has not been good. Too much work and material is required for the small gain in pool habitat beneath the cover tips.)

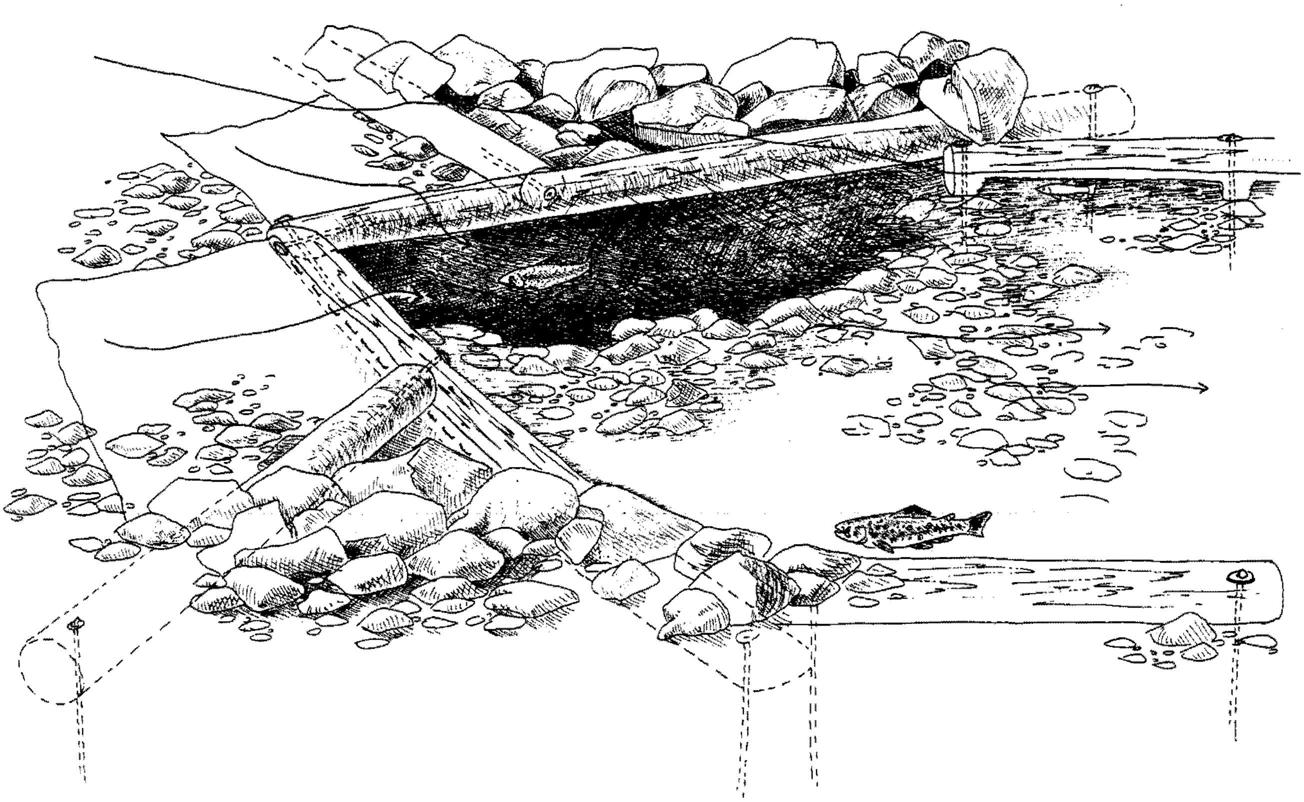


Wedge Dam

This structure consists of 2 sturdy logs that join in mid-stream to form an upstream-pointing wedge, a pair of brace-logs positioned on the upstream side of the wedge, and optional (but highly recommended) bank cover logs below the wedge. The upstream configuration of the wedge focuses stream flow toward the center of the wedge at all flow stages. The concentrated flow scours out a plunge pool below the wedge, and ideally along and under the attached bank cover logs. The initial depth and configuration of the plunge pool can be created by excavation after the logs are in place; however, long-term depth and area of the pool will depend on periodic high flow stages.

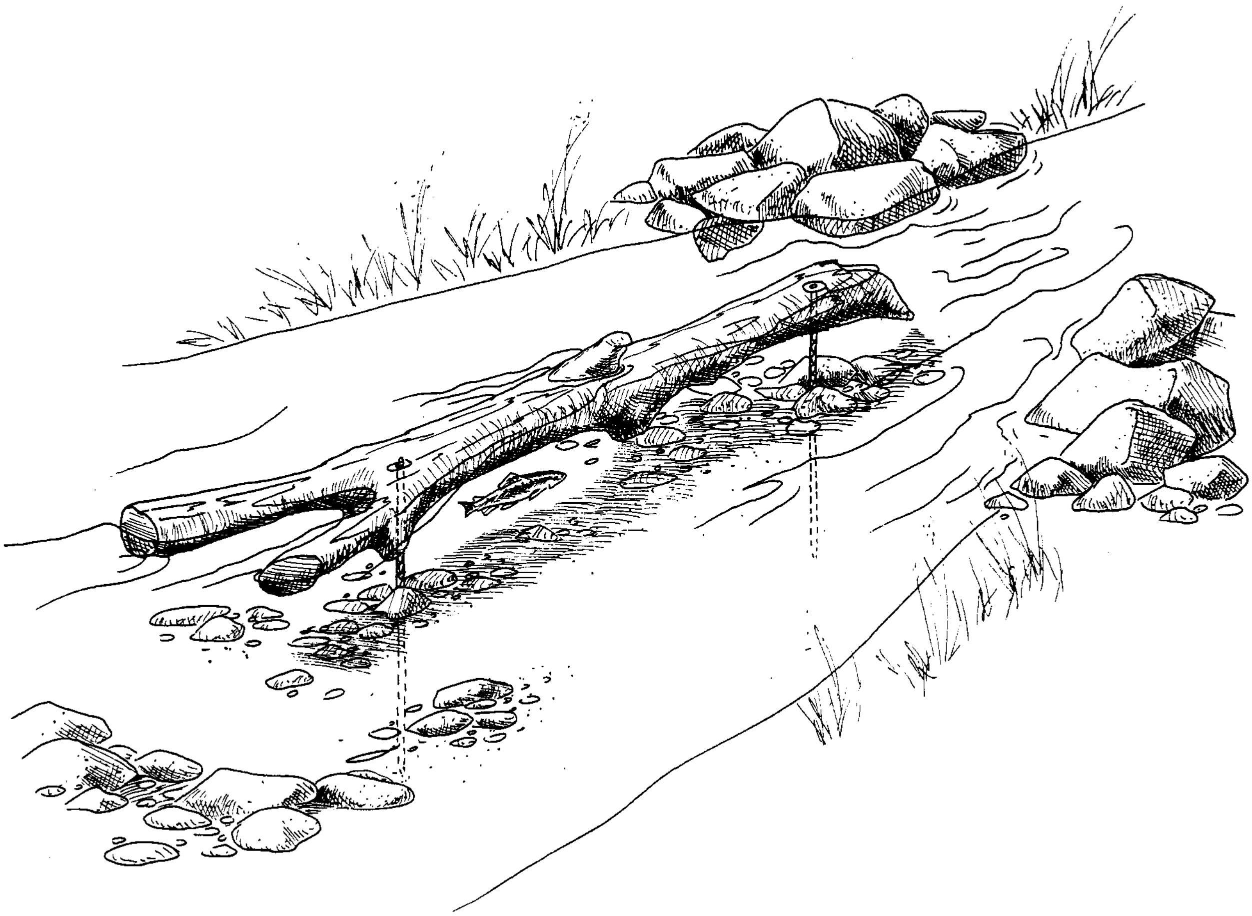
Dig out trenches in the stream bottom so the 2 wedge logs can be partially buried. Keep the butt end of each wedge log several inches higher than the apex junction of the 2 wedge logs by tapering the depth of the trenches. Dig the trenches deep enough to bury the apex. The wedge logs should join at a 45° angle. Attach roadbase fibermat to the wedge logs, extend the fibermat sheet upstream, and cover it with substrate material to prevent undercutting of the wedge.

Attached the brace-logs at 90° angles to the wedge logs. Extend the butts of the brace-logs and wedge logs well back into the stream banks. Excavate trenches if necessary. Use ample riprap at the butt ends of the brace-logs to prevent end-cutting by stream flow during floods.



Whole Log Cover

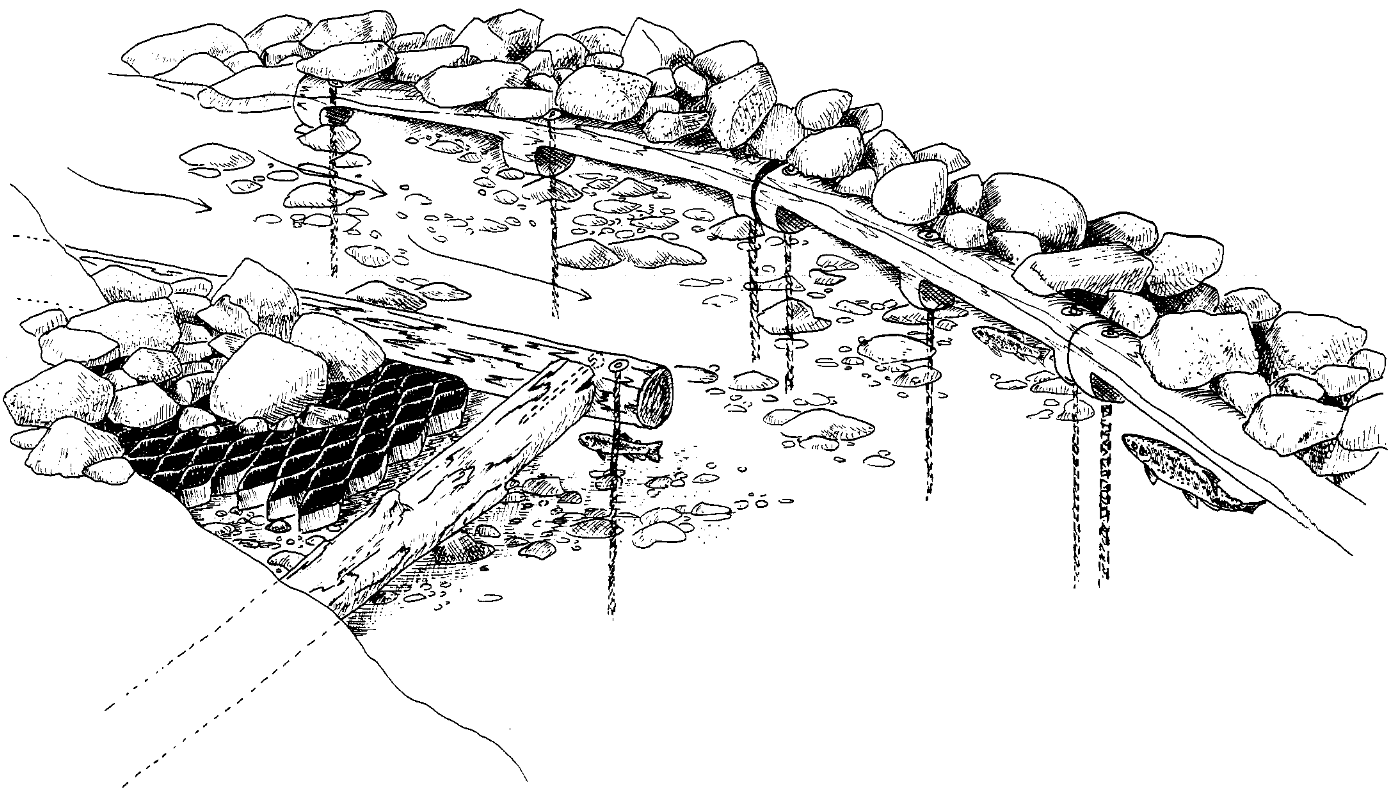
This structure is created by placing a large, crooked section of a whole log in a stream approximately parallel to the flow. Position the log over stable gravel/cobble substrate where the water is deep enough to cover the entire log most of the time. I also recommend placing this structure in or near the tails of pools and in runs of uniformly deep water that lack cover.



Wing (Current) Deflector and Bank Cover Logs

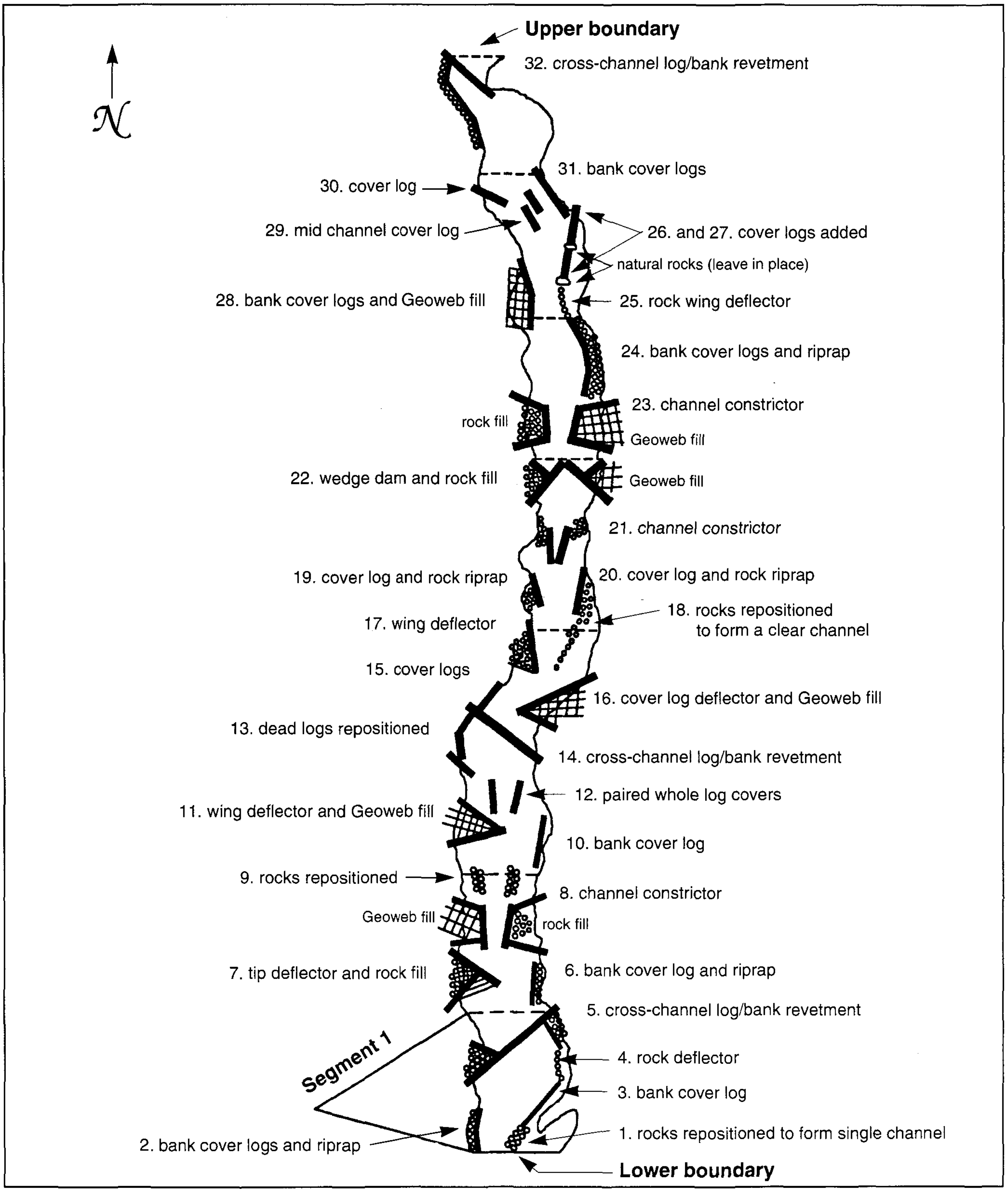
This combination of structures is used in straight reaches of high-gradient streams or at natural bends. Pin bank cover logs in place along the outside bend or against one bank in straight reaches. Partially notch out bank cover logs to increase underlog cover for trout. Add riprap behind the bank cover logs to enhance stream-bank stability and reduce erosion. Position the wing deflector on the opposite bank (inside bend) and upstream from the bank cover logs. Place the deflector so that redirected flow does not intercept the opposite bank upstream from the bank cover logs. Geoweb can be incorporated into the deflector to enhance long-term retention of the cobble/rock fill, but this is optional. To date, use of Geoweb has not been a consistently substantial improvement over fill material that is shingled into place in a downstream pattern.

On Twenty Mile Creek, a wing deflector guided stream flow toward a bank cover structure made from 2 large logs cut nearby.

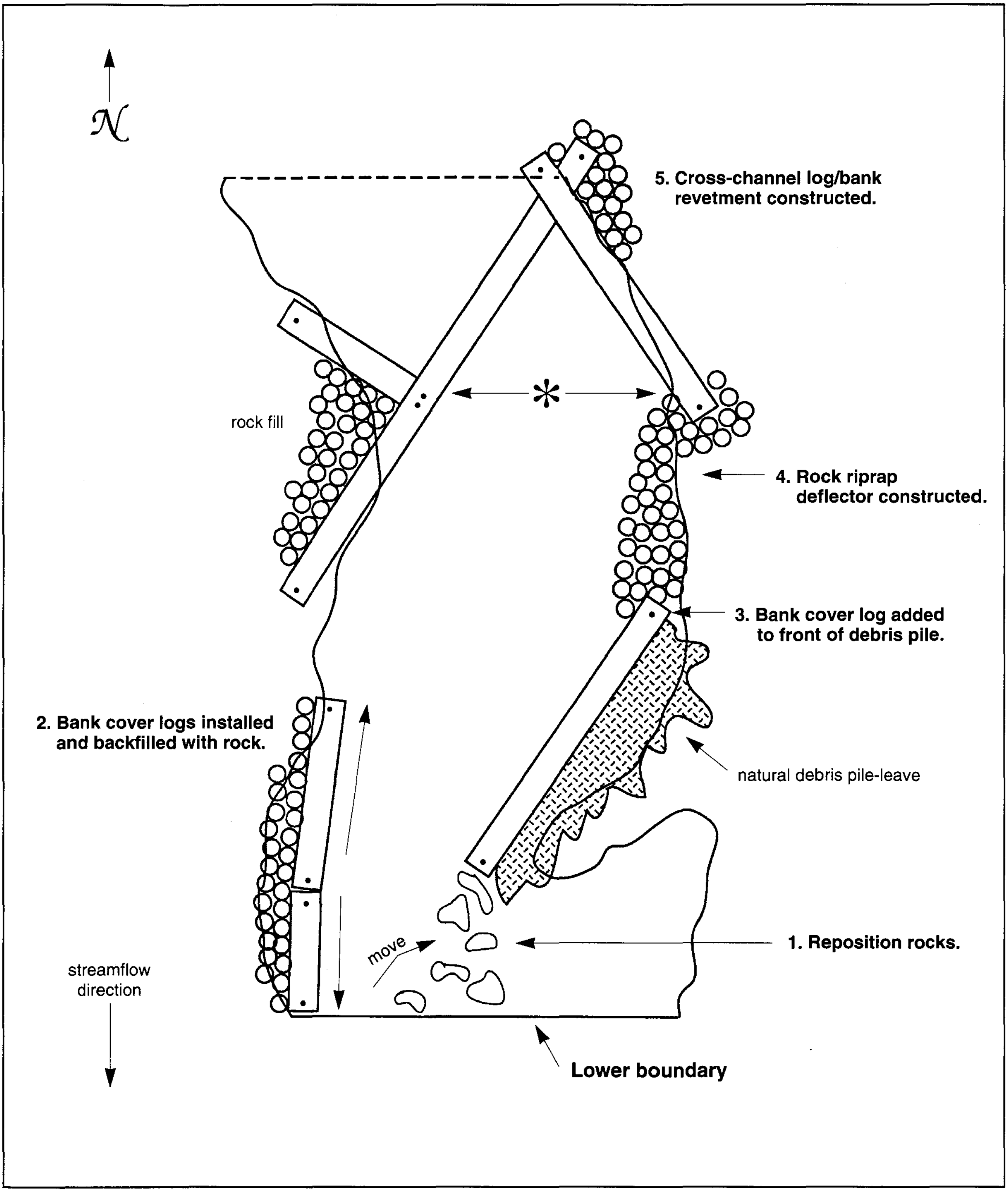


APPENDIXES

Appendix A. Physical Characteristics of the Treatment and Reference Zones in the Study Streams



Appendix Figure A.1. *Schematic layout of trout habitat improvement structures installed in the treatment zone at Twenty Mile Creek during July-August 1985 (not to scale).*



Appendix Figure A.2. *Schematic layout of trout habitat improvement structures installed in Segment 1 of the treatment zone at Twenty Mile Creek during July-August 1985 (not to scale). Approximate dimensions of structures are included, plus the cross-channel location (*) at which width, depth, and velocity measurements were made before and after structures were installed.*

Appendix Table A.1. *Physical characteristics of the treatment and reference zones established on Camp, Devils, and Twenty Mile creeks before trout habitat improvement structures were installed in the treatment zones.*

Stream	Date	Study Zone	Midchannel Length (ft)	Midchannel Length (miles)	Avg. Wetted Channel Width (ft)	Avg. Wetted Channel Depth (inches)	Surface Area (acres)	Substrate Composition (%)* Silt	Sand	Gravel	Cobble	Rock	Bank Cover** (ft)	Bank Cover** % of Bank	Gradient (ft/mile)	Baseflow (cfs)
Camp Creek	Apr 1984	Upper Treatment	968	0.18	7.8	5.6	0.17	6	7	38	39	9	16.8	0.9	71	2.5[b]
		Lower Treatment	325	0.06	14.0	3.6	0.10	5	15	34	33	13	6.5	1.0	71	2.7[b]
		Combined Treatment[a]	1,293	0.24	9.4	4.8	0.27	6	10	37	37	10	23.3	0.9	71	
		Reference	562	0.11	8.2	5.7	0.11	12	11	23	21	33	63.3	5.6	71	2.6
Devils Creek	Sep 1983	Treatment	550	0.10	23.5	7.2	0.30	–	7	29	32	32	–	–	53	12.1
		Reference	770	0.15	28.3	7.8	0.50	<1	10	42	31	17	–	–	23	12.6
Twenty Mile Creek	Sep 1983	Treatment	700	0.13	13.5	5.1	0.22	–	7	27	24	42	–	–	72	2.5
		Reference	500	0.09	13.9	6.7	0.16	–	22	37	17	24	–	–	63	2.7

* Based on following particle size categories: silt (fines) = <0.06 mm, sand = 0.06-2.0 mm, gravel = 2.0 mm - 5 cm, rubble = 5-10 cm, rock = >10 cm

** Stream bank providing at least 6 inches of overhang with at least 6 inches of water beneath overhang. Bank cover was not measured in the study zones on Devils and Twenty Mile creeks before structures were installed.

[a] Upper TZ + Lower TZ = Combined TZ.

[b] Baseflow discharge in September 1984.

Appendix Table A.2. *Physical characteristics of the treatment and reference zones on Camp, Devils, and Twenty Mile creeks after trout habitat improvement structures were installed in the treatment zones, and the percentage change in these characteristics.**

	Camp Creek				Devils Creek				Twenty Mile Creek			
	Treatment		Reference		Treatment		Reference		Treatment		Reference	
Characteristic	**Value**	**% Change**	**Value**	**% Change**	**Value**	**% Change**	**Value**	**% Change**	**Value**	**% Change**	**Value**	**% Change**
Midchannel length (ft)	1,323	+2	549	-2	550	0	770	0	700	0	500	0
Avg. wetted channel width (ft)	6.9	-27	8.7	+7	14.7	-37	21.6	-24	8.6	-36	11.9	-14
Avg. wetted channel depth (inches)	5.8	+21	5.1	-11	4.4	-39	5.7	-27	4.1	-20	4.0	-40
Surface area (acre)	0.21	-25	0.11	0	0.19	-37	0.38	-24	0.14	-36	0.14	-12
Substrate composition (%)												
Silt (fines)	27	+350	24	100	5	+500	<1	0			12	+1,200
Sand	10	0	10	-9	13	+86	14	+40	5	-29	15	-32
Gravel	24	-35	21	-9	34	+17	31	-26	40	+48	40	+8
Cobble	22	-41	22	+5	29	-10	33	+6	38	+58	20	+18
Rock	17	+70	23	-30	19	-41	21	+24	17	-60	13	-46
Bank cover												
Linear ft	329.3	+1,313	30.7	-52	141.4	+1,130	34.0	-8	268.5	+1,479	29.4	-16
% of bank edge	12.4	+1,278	2.8	-50	12.9	+1,136	2.2	-12	19.2	+1,500	2.9	-17

* Preinstallation measurements: Camp Creek, April 1984; Devils Creek, September 1983; Twenty Mile Creek, September 1983.
Postinstallation measurements: Camp Creek, September 1988; Devils Creek, August 1989; Twenty Mile Creek, August 1989.

Appendix Table A.3. *Physical characteristics at 10 nonrandom stream channel transect sites in the treatment zone on Camp Creek before and after installation of trout habitat improvement structures at those sites.**

	Stream Width (ft)			Avg. Water Depth (inches)			Wetted Area Cross Section (ft²)			Avg. Water Velocity (ft/sec)		
Structure Type	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**
Bank cover logs	24.5	5.0	-80	1.9	5.3	+179	3.9	2.2	-44	1.03	0.77	-25
Bank cover logs	24.8	7.8	-69	4.1	4.5	+10	8.5	2.9	-66	0.77	0.64	-17
Wing deflector	16.0	6.2	-61	3.4	11.2	+229	4.5	5.8	+29	0.52	0.40	-23
Channel constrictor	13.0	5.1	-61	6.9	12.8	+86	7.5	5.4	-28	0.29	0.36	+24
Cross-channel log/bank revetment	9.0	5.3	-41	8.1	10.2	+26	6.1	4.5	-26	0.43	0.53	+23
K dam	7.6	5.2	-32	1.7	5.1	+200	1.1	2.2	+100	0.77	1.07	+39
Cross-channel log/bank revetment	6.7	5.2	-22	8.6	12.2	+42	4.8	5.3	+10	0.42	0.54	+29
Double wing deflector	7.3	2.3	-68	1.7	18.9	+1,012	1.1	3.6	+227	0.89	0.91	+2
Wedge dam	7.3	5.2	-29	3.2	3.6	+13	1.9	1.6	-16	0.97	1.10	+13
Cross-channel log/bank revetment	10.1	5.1	-50	2.5	11.0	+340	2.1	4.7	+124	1.26	0.63	-50
Average	12.6	5.2	-58	4.2	9.5	+126	4.2	3.9	-7	0.73	0.70	-4

* Preinstallation measurements taken 25 June 1984, when stream discharge at the upper boundary of the TZ was 2.5 cfs. Postinstallation measurements taken 29 August 1988, when stream discharge was 2.2 cfs. Structures were installed during July 1984.

Appendix Table A.4. *Physical characteristics at 4 nonrandom stream channel transect sites in the treatment zone on Devils Creek before and after installation of trout habitat improvement structures at those sites.*

	Stream Width (ft)			Avg. Water Depth (inches)			Wetted Area Cross Section (ft²)			Avg. Water Velocity (ft/sec)		
Structure Type	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**
Wing deflector/bank cover log	15.0	11.6	-23	4.7	7.0	+49	5.9	6.8	+15	1.16	0.84	-28
Wing deflector/bank cover log	14.0	7.5	-46	4.7	8.1	+72	5.5	5.1	-7	1.17	0.65	-44
Wing deflector/bank cover log	20.0	11.5	-42	5.0	5.6	+12	8.3	5.4	-35	0.77	0.72	-6
Channel constrictor	28.0	9.0	-68	6.1	6.9	+13	14.2	5.2	-63	0.56	0.76	+36
Average	19.2	9.9	-42	5.1	6.9	+35	8.2	5.7	-30	0.92	0.74	-20

* Preinstallation measurements taken 17 June 1985; postinstallation measurements taken 10 August 1989. Structures were installed during August-September 1985.

Appendix Table A.5. *Physical characteristics at 7 nonrandom stream channel transect sites in the treatment zone on Twenty Mile Creek before and after installation of trout habitat improvement structures at those sites.**

	Stream Width (ft)			Avg. Water Depth (inches)			Wetted Area Cross Section (ft^2)			Avg. Water Velocity (ft/sec)		
Structure Type	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**
Cross-channel log/bank revetment	9.4	8.3	-12	6.7	7.8	+16	5.2	5.4	+4	0.56	0.28	-50
Channel constrictor	12.0	5.6	-53	3.6	9.6	+167	3.6	4.5	+25	0.84	0.22	-74
Bank cover log/wing deflector	15.5	8.2	-47	3.6	6.4	+78	4.6	4.4	-4	0.65	0.32	-51
Bank cover log/wing deflector	12.5	6.5	-48	9.1	8.2	-10	9.5	4.4	-54	0.29	0.27	-7
Wedge dam	11.9	8.6	-28	4.4	6.7	+52	4.4	4.8	+9	0.38	0.30	-21
Channel constrictor	15.0	5.3	-65	4.3	6.0	+40	5.4	2.7	-50	0.45	0.37	-18
Cross-channel log/bank revetment	9.0	4.8	-47	4.8	8.5	+77	3.6	3.4	-6	0.96	0.39	-59
Average	12.2	6.8	-44	5.2	7.6	+46	5.3	4.3	-19	0.59	0.31	-47

* Preinstallation measurements taken 18 June 1985. Postinstallation measurements taken 17 August 1989. Structures were installed during July-August 1985.

Appendix B. Supporting Data on Stream Flow Measurements and Performance of Structures

Appendix Table B.1. *Periodic instantaneous measurements of stream flow at boundaries of the study zones on Camp, Devils, and Twenty Mile creeks.*

September of Year	Camp Creek Lower TZ	Devils Creek Lower TZ	Twenty Mile Creek TZ/RZ Boundary
1983	–*	12.6	2.6
1984	2.7	12.2	2.7
1985	2.2	13.8	–*
1986	2.3	–*	2.9
1987	–*	10.9	2.1
1988	1.2	–*	1.2
1989	2.0	5.2	1.8

* Discharge not taken because stream flow was not stable due to runoff from recent rains.

Appendix Table B.2. *Average daily discharge of two reference trout streams monitored continuously during 1983-89.*

	Average Daily Discharge (cfs)	
Year	**White River***	**Black Earth Creek****
1983	320	35
1984	321	43
1985	306	51
1986	320	50
1987	225	39
1988	223	34
1989	232	28

* U.S.G.S. Station No. 040275 on the White River near Ashland, WI, and approximately 20 miles from Twenty Mile Creek, a tributary of the White River.
** U.S.G.S. Station No. 05406500 on Black Earth Creek, approximately 50 miles from Camp Creek.

Appendix Table B.3. *Postinstallation performance of structures installed in the treatment zones on Camp, Devils, and Twenty Mile creeks.*

Stream	Assessment Date	Structure No.	Structure Type	Assessment Comments
Camp Creek	Sep 1988	1	bank cover logs	good, some riprap lost
		2	bank cover logs	good, some riprap lost
		3	bank cover logs	good, some riprap lost
		4	bank cover logs	poor, backfill washed out, underlog cover sparse
		5	tip deflector	fair, shallow pool, especially under cover tips
		6	channel constrictor	excellent pool and cover
		7	whole log cover	fair, cover for adult trout under one side only
		8	channel constrictor	excellent pool and cover
		9	bank cover log	good
		10	wing deflector	fair, inadequate extension
		11	cross-channel log/bank	excellent lateral scour pool and cover revetment
		12	whole log cover	poor, little cover for adult trout
		13	K dam	poor, shallow scour pool, little lateral cover
		14	bank cover log	excellent
		15	bank cover logs	good, some riprap lost
		16	K dam	good, moderate scour pool, some lateral cover
		17	whole log cover	excellent cover both sides
		18	cross-channel log/bank revetment	excellent lateral scour pool and cover
		19	bank cover logs	fair, only half of length provides cover
		20	bank cover logs	poor, only 10% provides cover
		21	tip deflectors	fair, shallow scour pool but no depth under tips of deflectors
		22	wedge dam	poor scour pool, poor cover, poor site selection
		23	bank cover logs	excellent
		24	cross-channel log/bank revetment	excellent pool and cover combination
		25	bank cover logs	good, some loss of cover and backfill riprap
		26	cross-channel log/bank revetment	fair, lateral scour pool partially clogged with rubble
		27	bank cover logs	good, 50% cover and depth for adult trout
		28	wing deflector	good deflection, but needs to be extended
		29	bank cover logs	fair, only 25-30% functional
		30	wedge dam	total failure, washed out, poor location
		31	bank cover logs	good
		32	cross-channel log/bank revetment	good lateral scour pool, about 60% underbank cover
		33	wing deflector	excellent
		34	bank cover logs	fair, about 30% functional cover
		35*	constructed meander	excellent
Devils Creek	Aug 1989	1	wing deflector	good, wood deflector solid, but one third Geoweb fill lost
		2	bank cover logs	good cover, half of riprap lost
		3	wing deflector	poor, most of riprap lost
		4	bank cover logs	poor, most of cover filled in with rubble, logs too small
		5	wing deflector	poor, one half Geoweb fill lost

(continued on next page)

Appendix Table B.3. *Continued.*

Stream	Assessment Date	Structure No.	Structure Type	Assessment Comments
Devils Creek *(cont.)*	Aug 1989	6	bank cover log	poor, less than 25% cover remaining
		7	bank cover log	same as 6
		8	bank cover log	same as 6
		9	bank cover logs	good, about 70% functional
		10	bank cover logs	poor, almost entirely filled in with cobble
		11	channel constrictor	excellent cover and pool depth, little loss of riprap
		12*	channel block	poor, most of riprap washed away
Twenty Mile Creek	Aug 1989	1*	rocks relocated	excellent
		2	bank cover logs	excellent cover, some riprap lost
		3	bank cover logs	poor, only 10% functional, underlog cover filled with cobble
		4	wing deflector	good
		5	cross-channel log/bank revetment	excellent cover & pool, some loss of riprap
		6	bank cover log	good, some loss of riprap
		7	tip deflector	poor, shallow pool, no cover
		8	channel constrictor	excellent pool and cover both sides
		9*	rocks relocated	excellent
		10	bank cover logs	good
		11	wing deflector	good deflection of flow, Geoweb fill partially lost
		12	whole logs cover	good, about 50-60% cover remaining
		13*	repositioned log	excellent
		14	cross-channel log/bank revetment	good pool under half of revetment, cross-channel log should be higher
		15	bank cover logs	good
		16	wing deflector	good, some loss of Geoweb fill
		17	wing deflector	poor, needs to be extended
		18*	rocks relocated	excellent
		19	bank cover logs	good, about 60-70% functional
		20	bank cover logs	same as 19
		21	channel constrictor	good cover and pool on one side only, riprap needs replacing
		22	wedge dam	excellent scour pool and lateral cover, some loss of riprap
		23	channel constrictor	excellent pool and cover on both sides, some loss of riprap
		24	bank cover logs	good cover under 50-60% of length, some loss of riprap
		25*	rocks relocated	excellent
		26	whole log cover	excellent cover along both sides
		27	whole log cover	good cover on one side, partial filling on other side
		28	bank cover logs	good cover, Geoweb ripped and exposed
		29	whole logs cover	fair, one buried, one partly functional
		30	bank cover log	poor, cover space filled in
		31	bank cover logs	fair, about 30% functional, cover space partially filled
		32	cross-channel log/bank revetment	excellent cover and long, deep pool; excellent site

* Structures not included in Table 2 summaries.

Appendix C. Trout Population Changes in the Study Streams

Appendix Table C.1. *Standing stocks of brown trout in the treatment and reference zones on Camp Creek before (1984) and after (1985-89 average) installation of trout habitat improvement structures in the treatment zone.*

		Study Phase										
		Preinstall.	Postinstallation						% Difference *			
Population Characteristic and Month	Study Zone	1984	1985	1986	1987	1988	1989	Postinstall. Avg.	Absolute	Percent	P Value**	P Value[a]
Trout/mile in April												
No. of age I+	TZ	490	1,404	1,163	1,714	3,331	1,482	1,819	1,329	271	0.05	
	RZ	464	1,682	836	1,218	3,455	1,073	1,653	1,189	256	0.13	
	Remainders[b]	26	-278	327	496	-124	409	166				0.73
No. ≥ 9.0 inches	TZ	208	163	363	314	351	457	330	122	59	0.39	
	RZ	382	82	136	155	164	155	138	-244	-64	0.03	
	Remainders	-174	81	227	159	187	302	192				0.02
No. ≥ 12.0 inches	TZ	16	41	41	41	16	12	30	14	88	0.48	
	RZ	73	55	9	27	9	0	20	-53	-73	0.32	
	Remainders	-57	-14	32	14	7	12	10				0.02
Biomass in April (lb/mile)[c]	TZ	123	210	245	287	344	251	267	144	117	0.02	
	RZ	216	206	127	186	236	111	173	-43	-20	0.50	
	Remainders	-93	4	118	101	108	140	94				0.03
Trout/mile in September[d]												
No. of age 0+	TZ	1,347	1,167	2,261	5,200	1,657	457	2,148	801	59	0.87	
	RZ	5,064	1,255	1,691	7,091	2,291	200	2,506	-2,558	-51	0.43	
	Remainders	-3,717	-88	570	-1,891	-634	257	-358				0.03
No. ≥ 9.0 inches	TZ	69	269	253	286	241	245	259	190	275	<0.01	
	RZ	145	145	155	136	127	100	133	-12	-8	0.62	
	Remainders	-76	124	98	150	114	145	126				<0.01
No. ≥ 12.0 inches	TZ	29	12	53	24	8	37	27	-2	-7	0.75	
	RZ	55	9	18	27	9	0	13	-42	-76	0.26	
	Remainders	-26	3	35	-3	-1	37	14				0.14

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Appendix Table C.1. *Continued.*

Population Characteristic and Month	Study Zone	Study Phase: Preinstall. 1984	Postinstallation 1985	1986	1987	1988	1989	Postinstall[c] Avg.	% Difference * Absolute	Percent	P Value**	P Value[a]
Biomass in September	TZ	82	173	235	348	210	145	222	140	171	0.06	
(lb/mile)[b]		RZ	209	122	146	287	164	53	154	-55	-26 0.55	
	Remainders	-127	51	89	61	46	92	68				<0.01

* % difference = (1985 - 89 average) - (1984 value)
1984 value

** Probability that postinstallation average is significantly different from the preinstallation value (log-transformed observations).

[a] Probability that postinstallation average remainder is significantly different from the preinstallation average remainder.

[b] Remainders = TZ value minus RZ value.

[c] Biomass values rounded to nearest whole number.

[d] Data cited for the September 1984 preinstallation phase were actually collected on 27 July 1984. No reduction adjustments were made for natural and angling mortality during August and September.

Appendix Table C.2. *Densities of age 0 brown trout in the treatment and reference zones on Camp Creek in September 1984-89.*

Study Phase	Year	No./mile TZ	RZ
Preinstallation	1984	1,208	4,864
Postinstallation	1985	708	918
	1986	1,829	1,445
	1987	4,462	6,818
	1988	688	1,609
	1989	8	0
	1985-89 Average	1,539	2,158

Appendix Table C.3. *Standing stocks of age 0 and older brook and brown trout in the treatment and reference zones on Devils Creek in September before (1983-85 average) and after (1986-89 average) installation of trout habitat improvement structures in the treatment zone.*

Population Characteristic	Study Zone	Preinstallation			Postinstallation				Preinstall. Average	Postinstall. Average	Difference		P Value**	P Value[a]
		1983	1984	1985	1986	1987	1988	1989			Absolute	%		
Total no./mile														
Brook trout	TZ	210	150	290	200	430	300	360	217	322	105	48	0.16	
	RZ	93	133	200	267	347	147	246	142	252	110	77	0.06	
	Remainders*	117	17	90	-67	83	153	114	75	70				1.0
Brown trout[b]	TZ	10	40	10	20	20	60	50	20	38	8	90	0.15	
	RZ	227	20	20	20	0	33	13	89	17	-72	-81	0.27	
	Remainders	-217	20	-10	0	20	27	37	-69	21				0.11
All	TZ	220	190	300	220	450	360	410	237	360	123	52	0.11	
	RZ	320	153	220	287	347	180	259	231	268	37	16	0.50	
	Remainders	-100	37	80	-67	103	180	151	6	92				0.16
No./mile ≥ 6.0 inches														
Brook trout	TZ	80	30	20	40	210	70	110	43	108	65	151	0.16	
	RZ	67	13	20	113	180	53	80	33	107	74	224	0.06	
	Remainders	13	17	0	-73	30	17	30	10	1				0.37
Brown trout[b]	TZ	0	20	10	10	10	30	50	10	25	15	150	0.27	
	RZ	67	20	20	13	0	27	13	36	13	-23	-64	0.15	
	Remainders	-67	0	-10	-3	10	3	37	-26	12				0.06
All	TZ	80	50	30	50	220	100	160	53	133	80	151	0.11	
	RZ	134	33	40	126	180	80	93	69	120	51	74	0.29	
	Remainders	-54	17	-10	-76	40	20	67	-16	13				0.29

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Appendix Table C.3. *Continued.*

Population Characteristic	Study Zone	Preinstallation			Postinstallation				Preinstall. Average	Postinstall. Average	Difference		P Value**	P Value[a]
		1983	1984	1985	1986	1987	1988	1989			Absolute	%		
Biomass (lb/mile)														
Brook trout	TZ	16.0	9.6	13.2	8.5	33.7	12.9	25.3	12.9	20.1	7.2	56	0.72	
	RZ	10.7	5.3	7.5	22.9	34.1	13.1	14.7	7.8	21.2	13.4	172	0.03	
	Remainders	5.3	4.3	5.7	-14.4	-0.4	-0.2	10.6	5.1	-1.1				0.29
Brown trout[b]	TZ	2.7	8.4	4.1	2.9	4.5	11.2	11.4	5.1	7.5	2.4	47	0.29	
	RZ	35.8	11.2	9.8	6.5	15.9	10.7	5.8	18.9	9.7	-9.2	-49	0.29	
	Remainders	-33.1	-2.8	-5.7	-3.6	-11.4	0.5	5.6	-13.8	-2.2				0.29
All	TZ	18.7	18.0	17.3	11.4	38.2	24.1	36.7	18.0	27.6	9.6	53	0.29	
	RZ	46.5	16.5	17.3	29.4	50.0	23.8	20.5	26.7	30.9	4.2	16	0.29	
	Remainders	-27.8	1.5	0.0	-18.0	-11.8	0.3	16.2	-8.7	-3.3				0.72

* Remainders = TZ value minus RZ value.

** Probability that postinstallation average is significantly different from the preinstallation average.

[a] Probability that postinstallation average remainder is significantly different from the preinstallation average remainder.

[b] Domestic brown trout stocked annually as yearlings in the spring, just prior to the fishing season.

Appendix Table C.4. *Standing stocks of age 0 and older brook and brown trout in the treatment and reference zones on Twenty Mile Creek in September before (1983-85) and after (1986-89) installation of trout habitat improvement structures in the treatment zone.*

Attribute	Study Zone	Preinstallation 1983	1984	1985	Postinstallation 1986	1987	1988	1989	Preinstall. Average	Postinstall. Average	Difference Absolute	%	P Value**	P Value[a]
Total no./mile														
Brook trout	TZ	2,262	1,754	1,085	1,554	1,492	877	677	1,700	1,150	-550	-32	0.16	
	RZ	2,422	1,989	1,200	2,033	1,355	911	822	1,870	1,280	-590	-32	0.29	
	Remainders*	-160	-235	-115	-479	137	-34	-145	-170	-130				0.50
Brown trout	TZ	238	269	377	185	162	508	154	295	252	-43	-15	0.29	
	RZ	311	78	156	156	78	67	67	182	92	-90	-49	0.15	
	Remainders	-73	191	221	29	84	441	87	113	160				1.00
All	TZ	2,500	2,023	1,462	1,739	1,654	1,385	831	1,995	1,402	-593	-30	0.16	
	RZ	2,733	2,067	1,356	2,189	1,433	978	889	2,052	1,372	-680	-33	0.29	
	Remainders	-233	-44	106	-450	221	407	-58	-57	30				0.72
No./mile ≥ 6.0 inches														
Brook trout	TZ	108	123	23	392	131	46	169	85	185	100	+118	0.16	
	RZ	100	278	189	456	156	78	67	189	189	0	0	0.50	
	Remainders	8	-155	-166	-64	-25	-32	102	-104	-4				0.29
Brown trout	TZ	62	31	62	108	108	54	38	52	77	25	+48	0.47	
	RZ	33	11	44	44	33	0	0	29	19	-10	-34	0.47	
	Remainders	29	20	18	64	75	54	38	23	58				0.03
All	TZ	170	154	85	500	239	100	307	136	262	126	+93	0.16	
	RZ	133	289	233	500	189	78	67	218	208	-10	-5	0.60	
	Remainders	37	-135	-148	0	50	22	140	-82	54				0.16

(continued on next page)

Appendix Table C.4. *Continued.*

Attribute	Study Zone	Preinstallation 1983	1984	1985	Postinstallation 1986	1987	1988	1989	Preinstall. Average	Postinstall. Average	Difference Absolute	%	*P* Value**	*P* Value[a]
Biomass (lb/mile)														
Brook	TZ	48.1	50.4	24.5	75.5	48.2	25.9	36.4	41.0	46.5	5.5	+13	0.72	
	RZ	55.9	66.1	45.4	87.3	44.6	30.4	25.3	55.8	46.9	-8.9	-16	0.29	
	Remainders	-7.8	-15.7	-20.9	-11.8	3.6	-4.5	11.1	-14.8	-0.4				0.06
Brown	TZ	15.7	10.5	13.9	18.0	22.0	17.0	11.1	13.4	17.0	3.6	+27	0.16	
	RZ	15.8	3.4	5.6	10.9	5.9	1.3	4.1	8.3	5.6	-2.7	-33	0.72	
	Remainders	-0.1	7.1	8.3	7.1	16.1	15.7	7.0	5.1	11.4				0.37
All	TZ	63.8	60.9	38.4	93.5	70.2	42.9	47.5	54.4	63.5	9.1	+17	0.50	
	RZ	71.7	69.5	51.0	98.2	50.5	31.7	29.4	64.1	52.5	-11.6	-18	0.29	
	Remainders	-7.9	-8.6	-12.6	-4.7	19.7	11.2	18.1	-9.7	11.0				0.03

* Remainders = TZ value minus RZ value.
** Probability that postinstallation average is significantly different from the preinstallation average.
[a] Probability that postinstallation average remainder is significantly different from preinstallation average remainder.

Appendix Table C.5. *Densities of age 0 brook and brown trout in the treatment and reference zones on Twenty Mile Creek in September 1983-89.*

Study Phase	Year	No./Mile TZ Brook Trout	TZ Brown Trout	TZ Total	RZ Brook Trout	RZ Brown Trout	RZ Total
Preinstallation	1983	1,857	83	1,940	1,947	53	2,000
	1984	1,248	195	1,443	1,368	46	1,410
	1985	917	256	1,173	811	105	916
	1983-85 Average	1,341	178	1,519	1,375	67	1,442
Postinstallation	1986	910	7	917	1,253	0	1,253
	1987	1,113	45	1,158	937	42	979
	1988	624	406	1,030	579	53	632
	1989	300	45	345	558	0	558
	1986-89 Average	737	126	863	832	24	856

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Approximate Metric-English Equivalents

1 ha = 2.48 acres
1 m = 3.28 ft
1 cm = 0.39 inches
1 km = 0.62 miles
1 m^2 = 1.20 yd^2
1 L = 1.06 qt
1 g = 0.035 oz
1 kg = 2.21 lb
1 metric ton = 1.10 tons

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