WISCONSIN DEPARTMENT OF NATURAL RESOURCES
RESEARCH REPORT 167
April 1995

Effects of Streambank Riprapping On Physical Features and Brown Trout Standing Stocks In Millville Creek

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Abstract

This study determined impacts of intensive streambank rock riprapping upon the physical environment and standing stocks of brown trout (*Salmo trutta*) in a southwestern Wisconsin stream. A 4-mile reach of lower Millville Creek was riprapped in the summer of 1990. Essentially all trout water received some riprap work and therefore negated establishment of a "reference zone" and limited comparisons to "before" versus "after" in 2 representative stream reaches. Physical characteristics were measured during spring 1990 and spring 1992. Annual trout population estimates were made during 1988-89 and 1992-93.

Severe streambank erosion was effectively curtailed throughout both study reaches of Millville Creek by intensive streambank riprapping. Mean stream width, predicted to decrease, remained unchanged in both stream reaches while mean stream depth increased significantly as predicted. The number of pools ≥ 3 ft deep increased 57% and 97% in the 2 stream reaches while length of thalweg ≥ 3 ft deep increased 416 ft or 58% in both study reaches combined. Incidence of gravel substrates, hypothesized to increase after riprapping, did not change in 1 stream reach and declined a small but significant amount in the other stream reach after riprapping. Overhead bank cover (defined as ≥ 6 inches of overhang with ≥ 12 inches of water beneath) was rare initially and declined 88% and 50% in the 2 study reaches. Significant interactions between time period (before versus after riprapping) and the 2 stream reaches studied were evident for number/mile ($P = 0.03$) and lb/acre ($P = 0.05$) of brown trout. In the 2 study reaches combined, mean densities of Age 0, Age 1 and older, legal size (i.e., ≥ 12 inches), and all brown trout increased significantly following streambank riprapping (i.e., no overlap of 95% confidence intervals). Even though post-treatment brown trout populations were significantly greater, mean densities were too low to be of management significance and could not justify the $26,800/mile expenditure for the riprap work.

Streambank riprapping done in concert with other habitat improvement techniques designed to increase amounts of overhead bank cover is recommended to maximize the probability of meaningful gains in standing stocks of brown trout while abating severe streambank erosion. Further evaluations of streambank riprapping alone are also recommended but only if they include "reference zones" to fully identify the cause-and-effect relationships.

Contents

Introduction

Rock riprap revetments are a simple and effective method of stabilizing stream banks and reducing erosion due to poor land use practices in the watershed. Conservation departments in the United States and Canada invariably include riprap revetments in their published guidelines for the restoration of trout habitat in streams (White and Brynildson 1967, Helfrich et al. 1985, Binns 1986, Paquet 1986).

Although generally considered a useful trout stream habitat improvement technique, riprap revetments have usually been applied in conjunction with other stream enhancement techniques. Singular benefits of riprapping alone upon physical and biological characteristics of the receiving stream have seldom been quantified.

Exclusive use of rock riprapping on Wisconsin trout streams has been common practice in the past, with more than 25 miles of stream riprapped since 1978 (L. E. Claggett, Wisconsin Department of Natural Resources, pers. commun.). Despite a strong history of trout habitat evaluations in Wisconsin (Frankenberger and Fassbender 1967; Frankenberger 1968; Hunt 1971, 1978, 1979, 1982, 1988; Lowry 1971; White 1972), in only 2 instances have specific impacts of riprap projects been evaluated. Approximately 0.7 mile of riprapping along Willow Creek in Richland County resulted in a 35% increase in wild brown trout (*Salmo trutta*) 6 inches and larger, and a 86% increase in trout 12 inches and larger (Hunt 1988). Unfortunately results were based on single-run electrofishing surveys and no biomass measurements or changes in the physical parameters of the stream were made. At Doc Smith Branch, located in Grant County, 1.4 miles of riprapping failed to improve standing stocks of stocked brown trout and spring to fall survival declined (Hunt 1988). No physical parameters were measured and no information on angler use or catch were collected. Further evaluation of riprapping as a trout habitat development technique was recommended by Claggett (1990) following a statewide trout habitat development program review.

The purpose of this study was to take advantage of a 1990 fisheries management riprap project on Millville Creek to document changes in both the physical environment and standing stocks of brown trout resulting from this type of instream habitat manipulation.

The general hypothesis was that riprapping would reduce streambank erosion, decrease stream width, increase stream depth, create better pools, expose additional gravel substrate, and increase the standing stock of brown trout present.

Study Area

Millville Creek is located in the unglaciated or driftless region of southwestern Wisconsin in Grant County (Fig. 1). This region is characterized by steep-walled, narrow, river valleys and contains more than 1,700 miles of trout streams. Although often badly abused by the pasturing of dairy cattle, trout streams in the driftless region merit rehabilitation efforts because they are among the most fertile streams in Wisconsin and have the potential for sustaining some of the highest standing stocks of trout.

Millville Creek, like most trout streams in southwestern Wisconsin, is subject to (1) extreme and rapid water level fluctuation following storm events, (2) free access and heavy grazing by livestock, primarily dairy cattle, and (3) intensive row crop farming in the riparian zone. The synergistic effects of these activities contribute to the near absence of riparian woody vegetation, unstable streambanks, and extreme streambank erosion (Figs. 2, 3). Loss of pool habitat, sparse overhead bank cover, and siltation of gravel spawning areas are major deleterious impacts on trout carrying capacity.

Normal summer flows of Millville Creek range from 7-10 cfs. Alkalinity and pH average 220 ppm $CaCO_3$ and 8.1, respectively. The lower 5.5 miles of Millville Creek are Class II trout water (Wis. Dep. Nat. Resour. 1980) and is typically stocked each fall with 1,000-2,000 fingerling brown trout (Table 1). The study area included a 0.9-mile upper Treatment Zone (TZ1) and a 1.1-mile lower Treatment Zone (TZ2) located within a 4-mile reach scheduled for intensive streambank riprapping (Fig. 1).

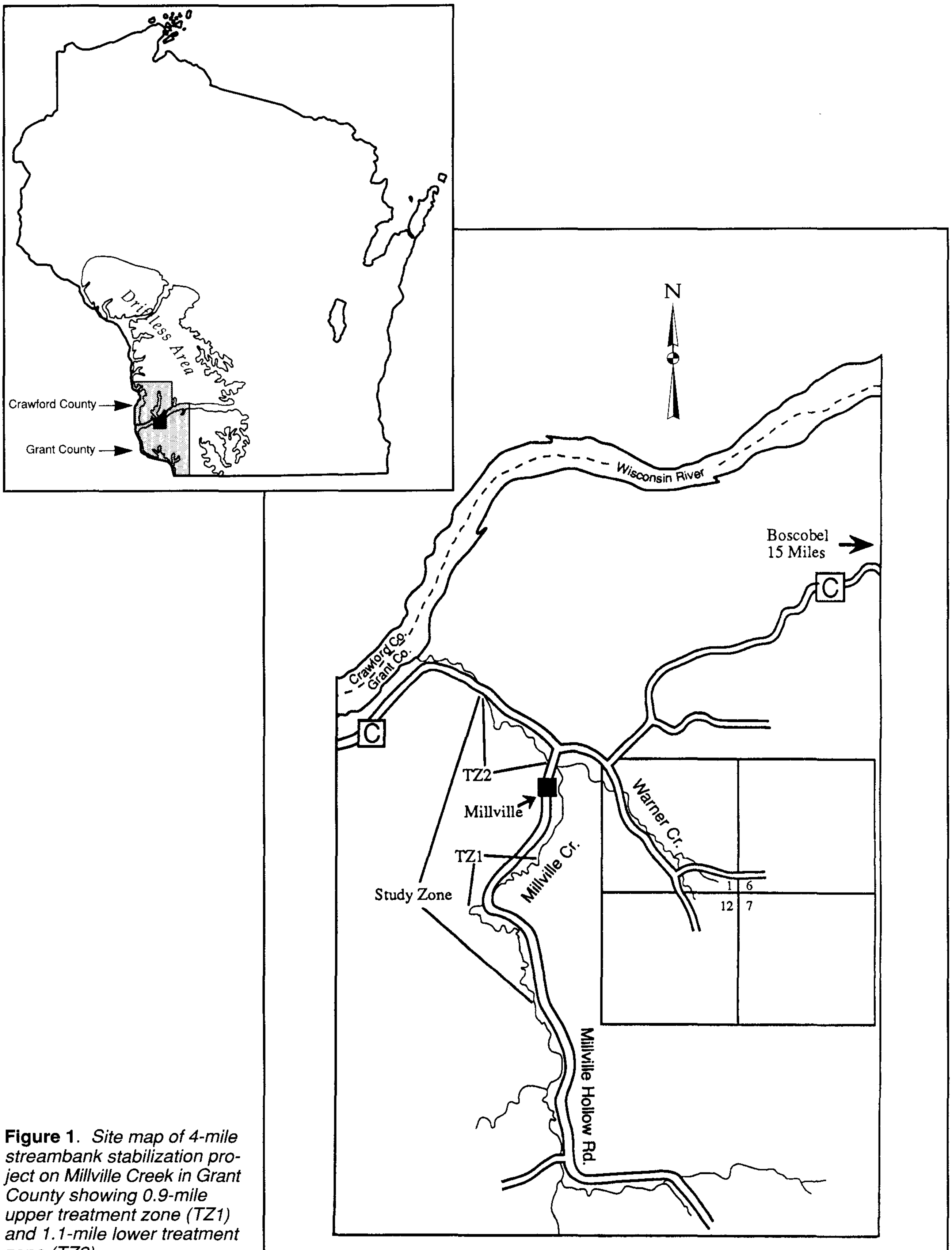

Figure 1. *Site map of 4-mile streambank stabilization project on Millville Creek in Grant County showing 0.9-mile upper treatment zone (TZ1) and 1.1-mile lower treatment zone (TZ2).*

Methods

Streambank Riprapping

During July through mid-September 1990, approximately 14,780 ft of streambank were intensively riprapped throughout the 4-mile reach of lower Millville Creek (Fig. 4). All comparable trout water received some riprap work and therefore negated establishment of a "reference zone" and limited comparisons to "before" versus "after" in TZ1 and TZ2. All unstable, nonvegetated, and often vertical streambanks were riprapped. Riprap was trucked to the site, dumped, and pushed over the streambank; banks were not sloped prior to riprapping. Cost of the project, including time, labor, and materials, was $75,000 (approximately $5.00/ft or $26,800/mile).

Physical Characteristics

Physical measurements of Millville Creek were made in May 1990 and in May 1992. Beginning at the lower end of each TZ, a 4-ft electric fence rod was driven into the substrate in the thalweg. A 100-ft nylon line (marked off in 1-ft intervals) was attached to the exposed portion of the rod and stretched upstream following the thalweg. Additional fence rods were placed into the substrate at various intervals along the thalweg to help guide the nylon line. The line was attached to a second fence rod at its upstream end and the rod was driven into the substrate. Stream width was measured at 25-ft intervals perpendicular to the nylon line. Water depth and the presence or absence of gravel (0.1- to 1.0-inch diameter) were recorded at 1-ft intervals across the width transects. After completion of 5 transects (0, 25, 50, 75, and 100 ft), I returned to the downstream fence rod. Between each width transect, I measured length of thalweg $\geq$ 3 ft deep, maximum depth, and length of overhead bank cover (OBC), (i.e., undercut banks, logs, and debris jams, having a minimum width of 6 inches in association with a water depth of at least 12 inches). When measurements were completed, the 100-ft nylon line was moved upstream following the thalweg and the process repeated.

A Pygmy Gurley meter and top-set wading rod were used to measure discharge of Millville Creek each time physical measurements were taken. Discharge was also determined when trout population surveys were conducted. Procedures followed were those described by Trihey and Wegner (1981).

Within TZ1 and TZ2, stream width and depth were compared between time periods (before and after riprapping) using 2-sample *t* tests (1 observation for each transect). Incidence of gravel substrate, based on presence or absence at each site in all transects, was compared between time periods in TZ1 and TZ2 using chi-square tests. Differences were considered significant at $P < 0.05$. Other physical parameters were measured completely and were not statistically tested.

Trout Population Surveys

Stream electrofishing gear included a towed stream shocker boat equipped with a 220 V DC generator, 3 anodes, and a cathode of sheet metal which protected the boat bottom from abrasion. Mark and recapture electrofishing surveys of TZ1 and TZ2 were made between late August and late September 1988, 1989, 1992, and 1993, except in 1989 when only a marking run was conducted in TZ1. Mark and recapture electrofishing surveys were separated by approximately 24 hours. Trout were measured to the nearest 0.1 inch on marking surveys and to within inch groups on recapture surveys. Wild Age 0 trout captured in 1988 and 1992 were given characteristic fin clips to help distinguish between naturally produced and stocked trout in subsequent electrofishing surveys. Individual trout weights (to the nearest gram) were recorded only during 1988 and 1992. Age 0 trout produced in the stream and all Age 1 and older trout were distinguished using length-frequency distributions and were virtually discrete. Population estimates were made for both Age 0 and Age 1 and older trout and apportioned to inch groups based on the

Table 1. *Trout stocking records for Millville Creek, Grant County, Wisconsin, 1987-92.*

Date	Species	Number Planted	Average Size (inches)
2 Jun 1987	Brown trout	4,000	3.0
21 Sep 1987	Brown trout	2,000	5.0
18 Feb 1988	Rainbow trout	10,000	3.0
18 Oct 1988	Brown trout	2,000	5.0
5 Oct 1989	Brown trout	1,000	5.0
4 Oct 1990	Brown trout	1,000	5.0
30 Sep 1991	Brown trout	2,000	5.0
15 Sep 1992	Brown trout	2,000	5.0

Figure 2. *Excessive stream width, channel braiding, and filling of pools with sediment all result from heavy livestock grazing in the riparian zone—Millville Creek, May 1990.*

Figure 3. *Unstable, vertical streambanks and massive soil loss following thunderstorms often result from over grazing and rowcropping in the riparian zone—Millville Creek, May 1990.*

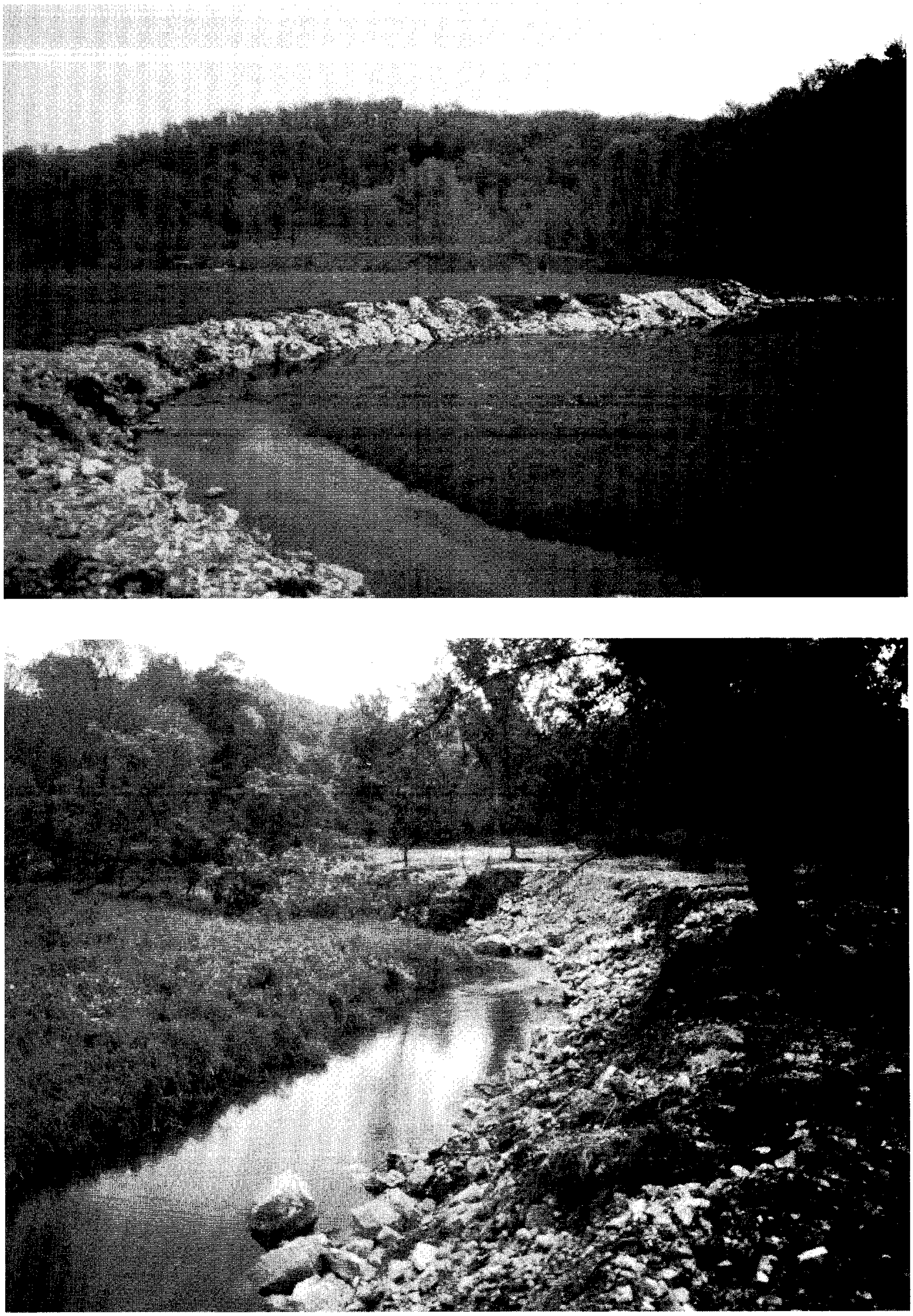

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Figure 4. *Intensive streambank riprapping stabilizes eroding streambanks, encourages downward streambed scour, and ultimately creates a deeper stream—Millville Creek, May 1991 (upper), and August 1990 (lower).*

relative proportions of trout captured in the various inch groups during both electrofishing runs. Population estimates and sampling variances were computed using the Bailey modification of the Petersen formula and large-sample sampling variance formula, respectively (Ricker 1958). Estimates and their variances were combined to determine total population parameters. Differences were considered significant when 95% confidence intervals did not overlap. In 1989, a population estimate in TZ1 (where only a single marking run was conducted) was based upon corresponding recapture efficiencies observed in TZ2.

The total brown trout population, number of trout ≥ 12 inches, number of trout ≥ 15 inches, and total trout biomass were compared using 2-way analysis of variance (ANOVA) with time period, zone, and their interaction as factors in the model. Trout densities were first log-transformed to make variance more homogeneous. Repeated observations on the same zone were treated as independent observations. Differences were considered significant at $P < 0.05$. All statistical computing was done with SAS (SAS Institute Inc. 1989).

Results

Changes in Physical Characteristics

In May 1992, discharge of Millville Creek in TZ1 and TZ2 was 2.0 and 1.8 times greater, respectively, than when initial streamflows were measured in May 1990 (Table 2). Streamflows recorded in May 1990 reflected 3 previous years of below-average precipitation and severe drought conditions prevalent throughout 1988 and 1989, whereas streamflows measured in 1992 followed 2 years of above-average precipitation (U.S. Geological Survey 1987-91).

Mean stream width was relatively unchanged following streambank riprapping while mean stream depth increased (Table 2). Mean widths in TZ1 and TZ2 were within 0.3 ft and 0.1 ft of their original measurements, respectively, and were not significantly different. Mean stream depths increased 0.1 ft in TZ1 and 0.3 ft in TZ2 and were both significantly different ($P < 0.001$).

The most striking physical change following streambank riprapping was in the amount of water ≥ 3 ft deep. The number of pools ≥ 3 ft deep in TZ1 increased from 14 to 22 or 57% (Table 2). Total increase in thalweg length ≥ 3 ft was only 35 ft, however. In TZ2, the number of pools ≥ 3 ft deep increased from 29 to 57 for a 97% gain. There was an increase of 381 ft in thalweg length ≥ 3 ft deep. Combining both TZ1 and TZ2, the number of pools ≥ 3 ft deep increased from 43 to 79 or 84%. Length of thalweg ≥ 3 ft deep increased by 416 ft, a 58% increase which represented a 4% increase in the total amount of water ≥ 3 ft deep in both study zones.

The percentage of cross-channel transects with gravel in TZ1 increased from 63% in 1990 to 72% in 1992, suggesting an increase in gravel substrates following streambank riprapping (Table 2). However, the percentage of gravel at individual sites across transects increased only from 26% to 28% and did not represent a significant change. In TZ2, the percentage of cross-channel transects with gravel increased from 71% in 1990 to 74% in 1992, suggesting little change after riprapping. The percentage of gravel at individual sites across transects declined from 34% to 27%, however, and represented a small, but significant decline ($P < 0.001$).

OBC was sparse in Millville Creek both before and after streambank riprapping. In TZ1, only 20 ft of OBC was present before riprapping and most of this was associated with a fallen tree that had sloughed in on a steep outside bend (Table 2). Following riprapping, only 2.5 ft of OBC was present. This represented an 88% decline. The fallen tree present before riprapping had disappeared. In TZ2, 127 ft of OBC occurred prior to riprapping and only 64 ft remained after riprapping. This represented a 50% decline. Three log/debris areas providing OBC before riprapping had either been removed or significantly reduced in extent during periods of high stream discharge.

Changes in Brown Trout Populations

Prefatory Assumptions

A temporary 50% reduction in fingerling brown trout stocked in Millville Creek occurred in 1989 and 1990 between pre- and post-riprap trout population surveys (Table 1). The normal stocking quota was resumed in 1991, almost a year before the first post-riprap population survey was completed in 1992. The temporary reductions in trout stocked were assumed to have little effect upon brown trout population comparisons before and after riprapping.

Rainbow trout (*Oncorhynchus mykiss*) populations averaging 115 fish/mile in 1988 (mean length 8.7 inches) and 8 fish/mile in 1989 (mean length 13.8 inches) were survivors from a 1-time release of fingerlings in February 1988 (Table 1). Effects of these rainbow trout upon pre-riprap brown trout populations were considered negligible. No rainbow trout remained in Millville Creek following streambank riprapping.

A drought during 1989 and 1990 resulted in poor natural recruitment and reduced brown trout populations in many southwestern Wisconsin trout streams. Because natural reproduction was negligible in Millville Creek and annual stocking of fall fingerlings was maintained, effects of the drought upon brown trout populations were considered minimal.

Confidence Interval Approach

In TZ1, a mean, late-summer, trout density of 18/mile during 1988-89 increased to 109/mile during 1992-93 and represented a significant increase in the brown trout population following streambank riprapping (Table 3). Mean biomass of brown trout increased from 6 lb/acre before riprapping to 23 lb/acre following riprapping. A wild 1992 year class equal to 119/mile accounted for 80% of the brown trout population in 1992 and was solely responsible for a significant increase in mean density of Age 0 fish before versus after riprapping, i.e., from 0 to 60/mile. Mean density of the Age 1 and older trout was also significantly greater after riprapping (18/mile versus 49/mile). Survivors of the 1992 year class comprised 13% of the Age 1 and older trout present in 1993 and contributed to the mean population increase. Mean density of legal-size brown trout, i.e., ≥ 12 inches, increased significantly from 3/mile before riprapping to 12/mile after riprapping while mean number of large brown trout, i.e., ≥ 15 inches, remained at or below 1/mile throughout the study (Table 4).

In TZ2, a mean density of 104/mile during 1988-89 was not significantly different from a mean density of 97/mile during 1992-93 and suggested little response in the trout population following streambank riprapping (Table 3). Mean biomass increased from 18 lb/acre to 31 lb/acre. A mean year-class strength of 50/mile before riprapping (1988-89) was not significantly different from a mean year-class strength of 38/mile during 1992-93. Likewise, a mean of 54 Age 1 and older trout/mile before riprapping was not significantly different from a corresponding mean of 60/mile after riprapping. Brown trout populations were strongly influenced by wild year classes in 1988 and 1992. Wild Age 0 fish comprised 79% of the trout population in 1988 and surviving wild yearlings comprised 47% of Age 1 and older trout present in 1989. Similarly, wild Age 0 fish comprised 53% of the trout population in 1992 and surviving wild yearlings comprised 32% of the Age 1 and older trout present in 1993. Mean number of legal-size brown trout, i.e., ≥ 12 inches, increased significantly from 23/mile before riprapping to 55/mile after riprapping. Mean number of trout ≥ 15 inches increased from 5/mile to 12/mile during the same time period but did not represent a significant change (Table 4).

Trout data from both TZ's were combined to better represent changes occurring throughout the entire study area following riprapping (Table 5). Mean density of brown trout increased significantly from 65/mile before riprapping to 102/mile following riprapping. Mean total biomass increased from 14 lb/acre to 27 lb/acre during the same period. Mean year-class strength (Age 0) increased significantly from 27/mile before riprapping to 47/mile after riprapping. Mean density of Age 1 and older brown trout also increased significantly from 38/mile before riprapping to 54/mile after riprapping. The latter was largely the result of the increase in mean year-class strength. Mean density of legal-size trout, i.e., ≥ 12 inches, increased significantly from 15/mile to 36/mile (Table 6). Mean density of brown trout ≥ 15.0 inches increased from 3/mile to 7/mile but was not significant.

Analysis of Variance Approach

Significant interactions between time period and zone were evident for number/mile ($P = 0.03$) and lb/acre ($P = 0.05$) of brown trout. That is, the effect of time period (before versus after riprapping) differed between TZ1 and TZ2. For each of the 2 variables there was a larger increase from 1988-89 to 1992-93 in TZ1 than in TZ2. Interactions between time period and zone were not significant for either number/mile ≥ 12 inches or number/mile ≥ 15 inches. In both TZ1 and TZ2, a significant difference between time periods for brown trout ≥ 12 inches ($P = 0.02$) was evident with greater numbers present following streambank riprapping. Significant differences were not apparent between comparisons of other population parameters and time period.

Discussion

Following intensive streambank riprapping on Millville Creek, mean stream depth increased significantly, as predicted, as did the number of pools ≥ 3 ft deep and length of thalweg ≥ 3 ft deep. Mean stream width, predicted to decrease, remained unchanged. Riprap greatly reduces lateral streambed scour and expansion of stream width, and forces downward streambed scour (Stern et al. 1980). Stream discharge was almost double when post-treatment physical measurements were made and undoubtedly accounted for some of the observed increases in both mean stream depth and amount of water ≥ 3 ft deep. However, the

Table 2. *Physical attributes of the 0.9-mile upper treatment zone (TZ1) and 1.1-mile lower treatment zone (TZ2) on Millville Creek before and after streambank riprapping.*

	TZ1			TZ2		
Physical Attribute	**1990**	**1992**	**Change**	**1990**	**1992**	**Change**
Discharge (cfs)[a]	4.0	8.1	+4.1	6.9	12.6	+5.7
Mean width (ft)[b]	14.6	14.3	-0.3	19.4	19.5	+0.1
Mean depth (ft)[b]	0.8	0.9	+0.1[c]	0.9	1.2	+0.3[c]
Thalweg ≥ 3 ft (ft)[a]	225	260	+35	493	874	+381
Deepest pool (ft)[a]	4.3	5.5	+1.2	5.3	6.0	+0.7
Number pools ≥ 3 ft[a]	14	22	+8	29	57	+28
Gravel: % transects[a]	63	72	+9	71	74	+3
% sites[b]	26	28	+2	34	27	-7[c]
OBC (ft)[a]	20.0	2.5	-17.5	127	64	-63

[a] Enumerated.
[b] Statistically tested.
[c] Significantly different (*t* test, $P < 0.001$).

Table 3. *Brown trout populations (number/mile) and 95% confidence intervals in TZ1 and TZ2 of Millville Creek before and after streambank riprapping (lb/acre in parentheses).*

Before Riprapping TZ1				After Riprapping TZ1			
Year	**Age 0[a]**	**Age 1+**	**Totals**	**Year**	**Age 0[a]**	**Age 1+**	**Totals**
1988	0	18+6	18+6	1992	119±15	29±0	148±15
		(6)	(6)		(9)	(13)	(22)
1989	0	18±6[b]	18±6	1993	0	69±7	69±7
		(5)	(5)			(24)	(24)
Means	0	18±6	18±6	Means	60±11	49±5	109±11
		(6)	(6)		(4)	(18)	(23)

TZ2				TZ2			
Year	**Age 0[a]**	**Age 1+**	**Totals**	**Year**	**Age 0[a]**	**Age 1+**	**Totals**
1988	99±16	27±7	126±18	1992	64±8	57±7	121±11
	(3)	(11)	(14)		(3)	(24)	(27)
1989	1	80±8	81±8	1993	11±4	62±11	73±11
	(<1)	(23)	(23)		(<1)	(34)	(34)
Means	50±11	54±7	104±14	Means	38±6	60±9	97±11
	(2)	(17)	(18)		(2)	(29)	(31)

[a] Wild young of the year.
[b] Population estimate based on single-run survey in TZ1 and recapture. Efficiency observed in double-run surveys made in TZ2; assumed same 95% C.I. for population estimate made in 1988.

Table 4. *Brown trout (number/mile) ≥ 12 inches and ≥15 inches in TZ1 and TZ2 of Millville Creek before and after streambank riprapping.*

Before Riprapping TZ1			After Riprapping TZ1		
Year	**>12 Inches**	**>15 Inches**	**Year**	**>12 Inches**	**>15 Inches**
1988	4	1	1992	8	1
1989	2	0	1993	16	1
Means	3±3	1±1	Means	12±4	1±2
TZ2			**TZ2**		
Year	**>12 Inches**	**>15 Inches**	**Year**	**>12 Inches**	**>15 Inches**
1988	16	5	1992	50	7
1989	30	4	1993	60	18
Means	23±6	5±3	Means	55±7	12±5

Table 5. *Brown trout populations (number/mile) and 95% confidence intervals in TZ1 and TZ2 combined, before and after streambank riprapping in Millville Creek (lb/acre in parentheses).*

Before Riprapping				After Riprapping			
Year	**Age 0**	**Age 1+**	**Totals**	**Year**	**Age 0**	**Age 1+**	**Totals**
1988	54±9	23±4	77±10	1992	88±8	44±4	132±9
	(2)	(9)	(11)		(3)	(20)	(23)
1989	1	52±4	53±4	1993	6±2	65±6	71±7
	(<1)	(16)	(16)		(<1)	(30)	(31)
Means	27±6	38±5	65±8	Means	47±6	54±5	102±8
	(1)	(12)	(13)		(2)	(25)	(27)

Table 6. *Brown trout (number/mile) ≥ 12 inches and ≥ 15 inches in TZ1 and TZ2 combined, before and after streambank riprapping in Millville Creek.*

Before Riprapping			After Riprapping		
Year	**>12 Inches**	**>15 Inches**	**Year**	**>12 Inches**	**>15 Inches**
1988	11	4	1992	31	4
1989	18	2	1993	40	10
Means	15±3	3±2	Means	36±4	7±2

magnitude of these desired morphological changes was amplified by the confining effects of the riprap upon the stream channel and by forced downcutting. A stasis in mean stream width, given the substantial increase in stream discharge observed, was certainly the result of the confining effects of the intensive streambank riprapping and suggests that, had discharge been similar, a reduction in mean stream width would have occurred.

In the absence of a "reference zone" for comparison, one can also argue that the observed changes in stream depth and lack of change in stream width were caused by natural hydrologic processes unrelated to streambank riprapping. There is, however, no reasonable logic or data from other studies to support the contention that maintenance of the status quo, in this case severe and continued streambank erosion, leads either to a deeper stream channel or to a greater number of deep pools. In fact, numerous studies (Gunderson 1968, Platts 1981, Platts and Rinne 1982, Meehan 1991) have documented reductions in channel depth and increases in channel width resulting from unabated streambank erosion similar to that observed on Millville Creek prior to riprapping. Common sense again dictates that streambank riprapping was responsible for some of the favorable changes in stream depth and the stasis in stream width observed.

Streambank riprapping reduces energy dissipation laterally and increases stream velocities during periods of increased stream discharge (Stern et al. 1980). Riprapping, therefore, also contributed to the observed "washing out" of some of the large woody debris in Millville Creek, which in turn, reduced the already sparse amount of OBC present.

Lack of a significant quantitative change in gravel present in the upper treatment zone, and a small, but statistically significant, decline in gravel present in the lower treatment zone following streambank riprapping differed from the initial prediction of an increase in streambed gravel. Riprapping stabilized previously unstable streambanks on Millville Creek and, by doing so, reduced sediment inputs. Reductions in sediment input and increased hydraulic energy resulting from stream channel confinement by riprap should have increased the sediment transport capability of the stream. Either streambed composition of Millville Creek did not include substantial amounts of sediment-covered, gravel-size materials, or the separation of gravel from finer sediments requires longer than the 2-year time frame observed.

Statistically significant increases occurred in 4 of 5 population metrics of brown trout examined following streambank riprapping; a smaller, insignificant increase also occurred in the fifth metric. In the absence of a "reference zone" for comparison, the contribution that riprapping made to these population increases is open to debate. This debate has little management relevance, however, because the post-riprap population metrics were all below levels of any management significance. For example, assuming the significant increase in mean density of brown trout observed after riprapping was entirely due to riprapping, the mean density of 102 brown trout/mile (including only 36 legal-size trout/mile) observed after riprapping is meager justification for the $26,800/mile expenditure incurred.

An increase in fishing pressure and trout harvest often occurs following instream habitat improvement projects (Hunt 1971, Larson 1982, Thorn 1988*a*). In the absence of sport fishery data, an increase in harvest is often cited as a possible reason for less-than-expected gains in trout standing stocks after completion of habitat improvement projects (Hunt 1988, Thorn 1988*b*). Creel surveys were not conducted on Millville Creek during my study. However, emergency catch-and-release regulations were legislatively imposed during 1990 and 1991 and eliminated trout harvest during these 2 years. Also, evidence of angling on Millville Creek was seldom observed by DNR personnel during the entire study, further suggesting that harvest was not responsible for the lack of meaningful gains in trout standing stocks.

Wesche et al. (1987) found no relationship between standing stocks of brown trout and either deep-water cover (>1.5 ft) or rubble-boulder cover in small streams in southeastern Wyoming. Thorn (1988*b*) found little relationship between streambank riprapping and population characteristics of brown trout in southeastern Minnesota streams very similar to Millville Creek. Significant correlations between brown trout density or biomass and area of deep water (≥ 3 ft) were also not apparent in the Minnesota study. The greatest amount of variation in the standing stocks of trout present in both the above studies was explained by the amount of OBC present. The prominent contribution of OBC to trout carrying capacity has also been well established in the literature (White 1986; Hunt 1988, 1992). The spartan amount of OBC in Millville Creek (only 147 ft present before and 66.5 ft present following riprapping) was evidently a major environmental factor suppressing brown trout populations that could not be alleviated by the increased water depth and better pool habitat occurring following streambank riprapping.

Management Implications

Physical changes associated with intensive streambank riprapping on Millville Creek failed to produce meaningful increases in the standing stocks of brown trout present even though increased angler harvest was not indicated and stocking quotas remained stable. Riprapping alone on trout streams similar to Millville Creek (characterized by severe streambank erosion, lack of OBC, and a sparse trout population strongly dependent upon stocking) will, therefore, primarily alleviate only the erosion problem. The lack of OBC appears to be a key factor suppressing standing stocks of trout in streams like Millville Creek and riprapping exacerbates rather than ameliorates this inherent deficiency by aiding displacement of scarce supplies of large woody debris during high stream discharge.

Therefore, to correct excessive streambank erosion and maximize the probability of achieving meaningful gains in brown trout populations, I recommend that riprapping be used in concert with other trout habitat improvement techniques specifically designed to increase OBC. "Lunker" structures, cross-channel log/bank revetments, and channel constrictors (Vetrano 1988, Hunt 1993, Seehorn 1992) have achieved the most positive trout population responses to date in the "driftless" region of Wisconsin (Vetrano 1988; Hunt 1992). These structures should be incorporated into future streambank riprapping projects in this region. Further evaluation of streambank riprapping alone is also needed, but must include a "reference zone" to fully identify the cause-and-effect relationships.

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Acknowledgments

My thanks to Gene Van Dyck, Area Fisheries Supervisor, and Roger Kerr, Area Land Agent (former Fish Manager) in the Dodgeville Area for bringing the riprapping project to my attention. My additional thanks to Roger Kerr for his cooperation and assistance in annual electrofishing surveys. Equal appreciation goes to Kent Niermeyer, technician in the Rivers and Streams Research Group, who ably and enthusiastically assisted in all phases of field work and preliminary processing of field data.

I also wish to thank William Thorn, Minnesota Department of Natural Resources; Robert L. Hunt (retired), Wisconsin Cold Water Research Group Leader; Michael Staggs, Fishery Research Section Chief; John Lyons, Rivers and Streams Research Group Leader; and Larry Claggett, Bureau of Fisheries Management, for technical review of the manuscript. Statistical analyses of data were carried out by Paul Rasmussen, biometrician with the Technical Services Section.

This research was supported in part by funds provided by Federal Aid in Sport Fish Restoration Act F-83-R. This report represents the final report for Study No. 418.

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PUBL-RS-567 95