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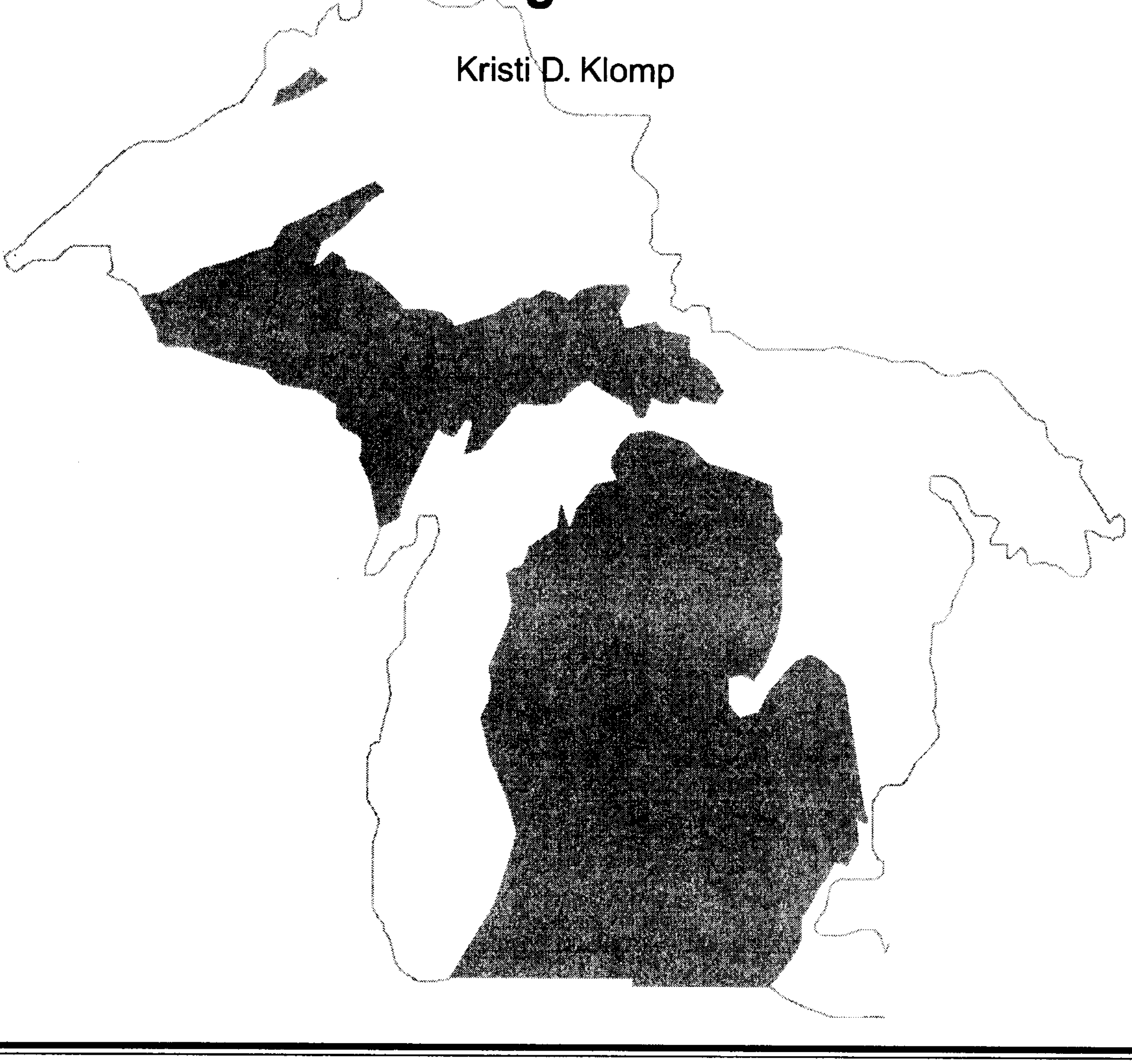
An Initial Evaluation of the Habitat and Fisheries Resources Associated with a Dam Removal in a Michigan Coldwater Stream

Kristi D. Klomp



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RESEARCH REPORT

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AN INITIAL EVALUATION OF THE HABITAT AND FISHERIES RESOURCES ASSOCIATED WITH A DAM REMOVAL IN A MICHIGAN COLDWATER STREAM

By

Kristi D. Klomp

A THESIS

Submitted to
Michigan State University
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ABSTRACT

AN INITIAL EVALUATION OF THE HABITAT AND FISHERIES RESOURCES ASSOCIATED WITH A DAM REMOVAL IN A MICHIGAN COLDWATER STREAM

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Stronach Dam was built in 1912 as a hydroelectric dam on the Pine River, Manistee County, Michigan. A high sand bedload contributed to the filling of the 26-hectare reservoir and led to the decommissioning of the dam in 1953. In 1996, a staged drawdown (2 feet/year) of the dam was initiated, and is expected to be complete by 2003. A 1995 pre-removal habitat assessment of a 9.2 km stretch of stream adjoining Stronach Dam indicated that habitat quality is degraded below the dam and for 3.8 km upstream from the dam where gradient and streambed particle size are reduced. In 1996, 31 permanent transects were surveyed to establish initial streambed elevations. Slight changes in elevation were detected in 1997 after lowering the dam 2 ½ feet. Abundance of rainbow trout, brook trout, brown trout, and white suckers was quantified using a multi-pass depletion method of electrofishing. White suckers were found to outnumber trout 9 to 1 in the habitat downstream from the dam; trout and sucker densities were nearly equal in the upstream reach impacted by the dam; while trout were 11 times more abundant than suckers upstream from the dam's influence. Growth analysis of white suckers, rainbow trout, and brown trout did not exhibit differences related to location within the study reach. Habitat and fish populations will continue to be monitored annually to determine the long-term impacts of the dam removal.

ACKNOWLEDGEMENTS

This study was funded by the Michigan Department of Natural Resources and Michigan State University.

I am grateful for the guidance and helpful suggestions provided by my advisor, D. Hayes, and my graduate committee members, R. Batie, T. Burton, and N. Kevern.

My undergraduate interns, J. Lessard, J. Spoelstra, and B. Thompson, and lab technician, S. Pauley, deserve special recognition for their hard work and commitment.

I would like to thank T. Rozich (Michigan Department of Natural Resources), B. Stuber (United States Forest Service), T. Moris (United States Forest Service), and D. Battige (Consumers Energy Co.) for their cooperation, advice, and for providing assistance in the field.

Thanks goes to V. Nelson and the Pine River Association, R. Schmidt from Schmidt Outfitters, E. Youngblood from Pine River Chapter Trout Unlimited, and the West Michigan Chapter Trout Unlimited, all who graciously volunteered their time or financial support.

I also extend my deepest appreciation to my husband, Brad, for his ongoing support.

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INTRODUCTION

More than 68,000 dams obstruct streams in the United States (Haberman 1995). Many of these are privately owned dams, built 50 to 150 years ago, and fall under the jurisdiction of the Federal Energy Regulatory Commission (FERC). It is FERC's responsibility to issue licenses stipulating conditions under which these dams may operate. These licenses are issued for periods of 30 to 50 years (Bowers and Bowman 1995). Since the average age of dams in the U.S. is 40 years (Shuman 1995a), licenses will expire on nearly 500 of these dams by the year 2010 (Bowers and Bowman 1995). As these dams come up for relicensing, managers look for alternatives in situations where aging hydroelectric dams are either unsafe or no longer operate efficiently. Dam removal will increasingly become an option as managers look for strategies which promote river restoration. Despite the decades of research documenting effects that dam placement has on the morphology and ecology of rivers, the literature is scant with information regarding effects of dam removal. A planned, staged dam removal offers a unique opportunity to study the effects on the fish and the stream's physical attributes that impact the biota.

Stronach Dam was built in 1912 as a hydroelectric facility on the Pine River, Manistee County, Michigan. The Pine is a coldwater stream, valued for its resident populations of rainbow, brown, and brook trout. Because of logging activities during the late 1800's, many of the banks along the river were denuded of vegetation and became unstable. Consequently, the Pine carries a high bedload of sand. When the dam was operational, this sand perpetually interfered with the efficient operation of the turbines.

When first built, Stronach Dam created a 26 hectare reservoir. The high sand bedload started filling in the reservoir almost immediately and attempts to dredge the area upstream were unsuccessful. Subsequently, the dam was decommissioned as a power-generating plant in 1953. In the absence of the reservoir, the water flows over the dam with virtually no retention time in the backwater area.

The removal of Stronach Dam was proposed as part of a FERC agreement to relicense the Tippy Dam hydroelectric project on the Manistee River. The decision was made to remove Stronach Dam in a controlled, staged process. In 1996, a water control device was installed and the drawdown began. The dam is lowered six inches every three months, so that the water level at the dam is lowered two feet per year. The removal is expected to be complete in the year 2003.

Hansen (1971) estimated that the annual discharge of sediment at Stronach Dam is 50,000 tons (70 percent of which is sand; 30 percent silt and clay). Kenny (1968) suggests that two years' worth of sediment is held in Stronach's backwater area. Hansen (1971) purports that the dam, acting as a sediment trap over the years, has impacted a 2.8 mile stretch of stream upstream from the dam. It is predicted that the removal of Stronach Dam will cause downcutting of the streambed, exposing a gravel/cobble substrate in the process. The uncovering of a gravel/cobble substrate will increase suitable habit for aquatic invertebrates, provide increased cover for fish and create a more diverse hydraulic condition favorable for efficient resting and feeding behavior of fish. It is anticipated that the increase in gravel/cobble substrate, with it's associated increased invertebrate numbers, will ultimately allow greater growth rates and abundance of trout in sections of the stream presently providing suboptimal habitat conditions. Additional benefits of removing the dam include restoration of the river to a free-flowing state attractive to canoeists and other recreationalists, public safety issues, and aesthetic benefits.

This study is the first phase of a long-term project to determine the effects that the dam's removal will have on the ecology of the river. Because the dam has impacted a length of stream equivalent to 3.8 kilometers upstream from the dam, I postulate that an investigation into the habitat and fish population upstream from this impacted area will offer clues regarding the response of fish to habitat changes resulting from the dam removal.

The overall, long term goal of this project is to determine if the dam removal, and the subsequent potential for fish migration from Tippy Reservoir, will have a significant impact on salmonid populations in the Pine River. This research will include the study of the physical environment and the biotic community before the intended changes within the river occur. In addition to the potential to relate the present fish assemblage to habitat conditions, this study will provide the basis for subsequent monitoring of change over the long term. Even though the actual removal process will only take 5 or 6 years, it may take several years after the dam is removed for the river channel to reach some equilibrium state. The rate and extent of the geomorphic changes can only be quantified if baseline conditions are measured before changes occur. Likewise, changes in the biotic communities resulting from habitat alteration will be detected only if populations are documented before habitat conditions change.

The three major objectives of this study were to 1) document the current habitat conditions within the 9.2 kilometer study stretch of the Pine above and below Stronach

Dam, 2) to estimate the abundance of the rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), and white suckers (*Catastomus commersoni*) within the study stretch and, 3) to analyze and compare growth rates of rainbow trout, brown trout, and white suckers, between the impacted zones and the non-impacted zones of the river.

Study Area

The Pine River is located in Michigan's lower peninsula and is a tributary to the Manistee River (Figure 1). The Pine is located in an area of sandy, glacial outwash moraine and is deeply entrenched into the terrain with many banks elevated more than 30 meters (100 feet) above the water surface. As is typical of streams in this area, it has a stable flow dominated by groundwater input. The Pine drains a 686 square-kilometer (265 square mile) watershed above Stronach Dam (Hansen 1971) and has an annual mean discharge of 8.18 m^3/s (289 cfs) (Blumer et al. 1998) based on 31 years of record at a U.S. Geological Survey gaging station located about 13 kilometers upstream from Stronach Dam.

Stronach Dam is located approximately 5 kilometers upstream from the convergence of the Pine River with the Manistee River. Another 1.7 kilometers downstream from where these two rivers meet, lies Tippy Dam. Tippy Dam supports a 400 hectare reservoir whose backwaters extend up into the Pine. Tippy Dam reservoir sustains a coolwater fishery, including populations of yellow perch (*Perca flavescens*), northern pike (*Esox lucius*) and walleye (*Stizostedion vitreum*). Currently, these fish have access to the Pine River but cannot migrate upstream past Stronach Dam.

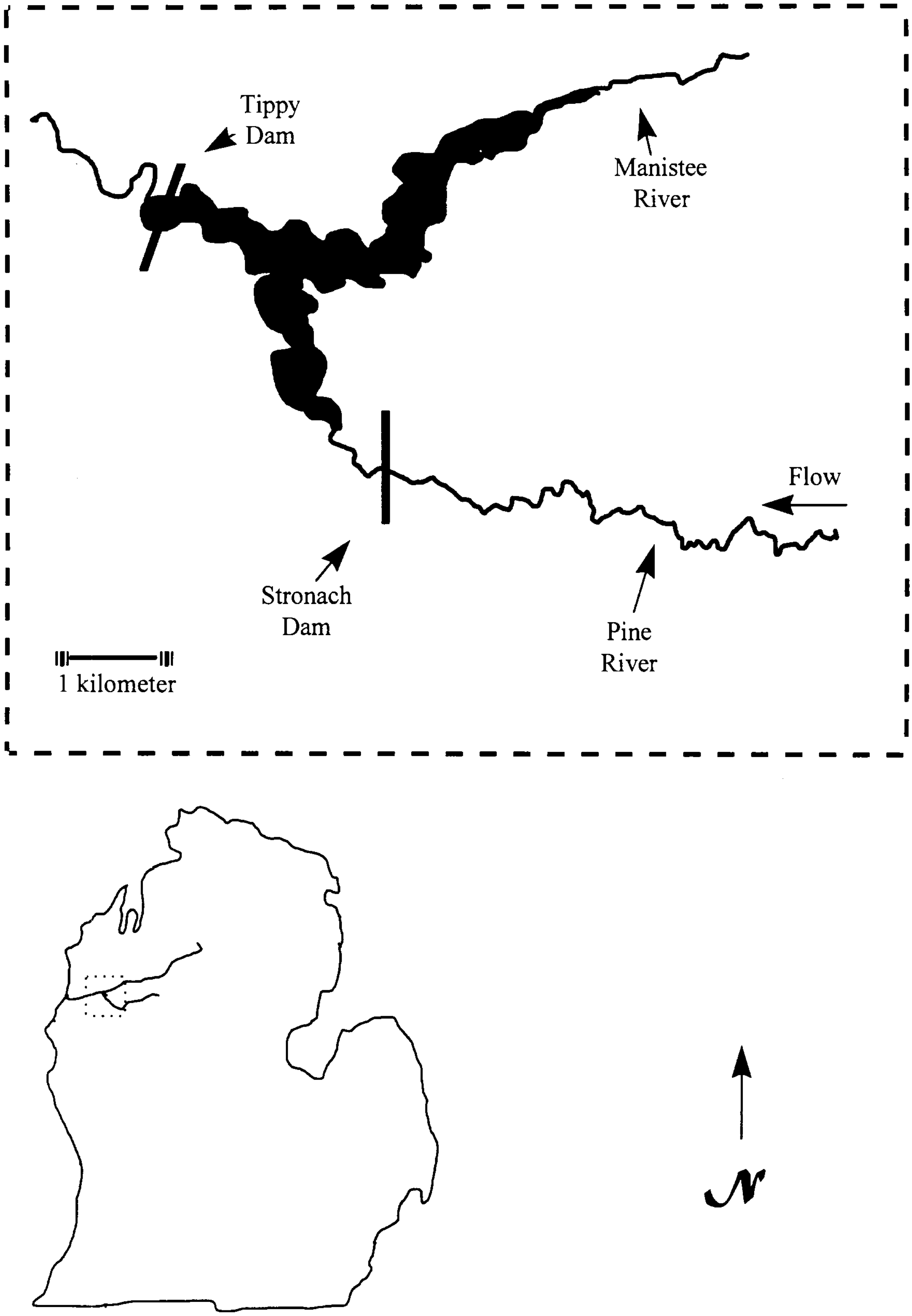


Figure 1. Location of Stronach Dam on the Pine River

For this study I selected a 9.2 kilometer length of stream encompassing a stretch from 1.1 kilometers downstream from Stronach Dam to a point 8.2 kilometers upstream from the dam (Figure 2). The study section is located in a relatively remote area of the Huron-Manistee National Forest. Forty-two kilometers (twenty-six miles) of the Pine River have been designated by the United States Congress as a National Scenic River under the Michigan Rivers Act of 1992. Four kilometers (2 ½ miles) lie within the upstream boundary of the study area. As part of its management plan (Stuber 1994), the U.S. Forest Service has implemented a plan to reduce sediment bedload. The removal of Stronach Dam will complement these efforts.

For sampling purposes, we divided our study area into three different zones: the downstream zone, the 1.1 kilometer reach downstream from Stronach Dam; the impacted zone, the 3.8 kilometer stretch directly upstream from Stronach Dam; and the non-impacted zone, the 4.3 kilometer reach beyond the influence of the dam.

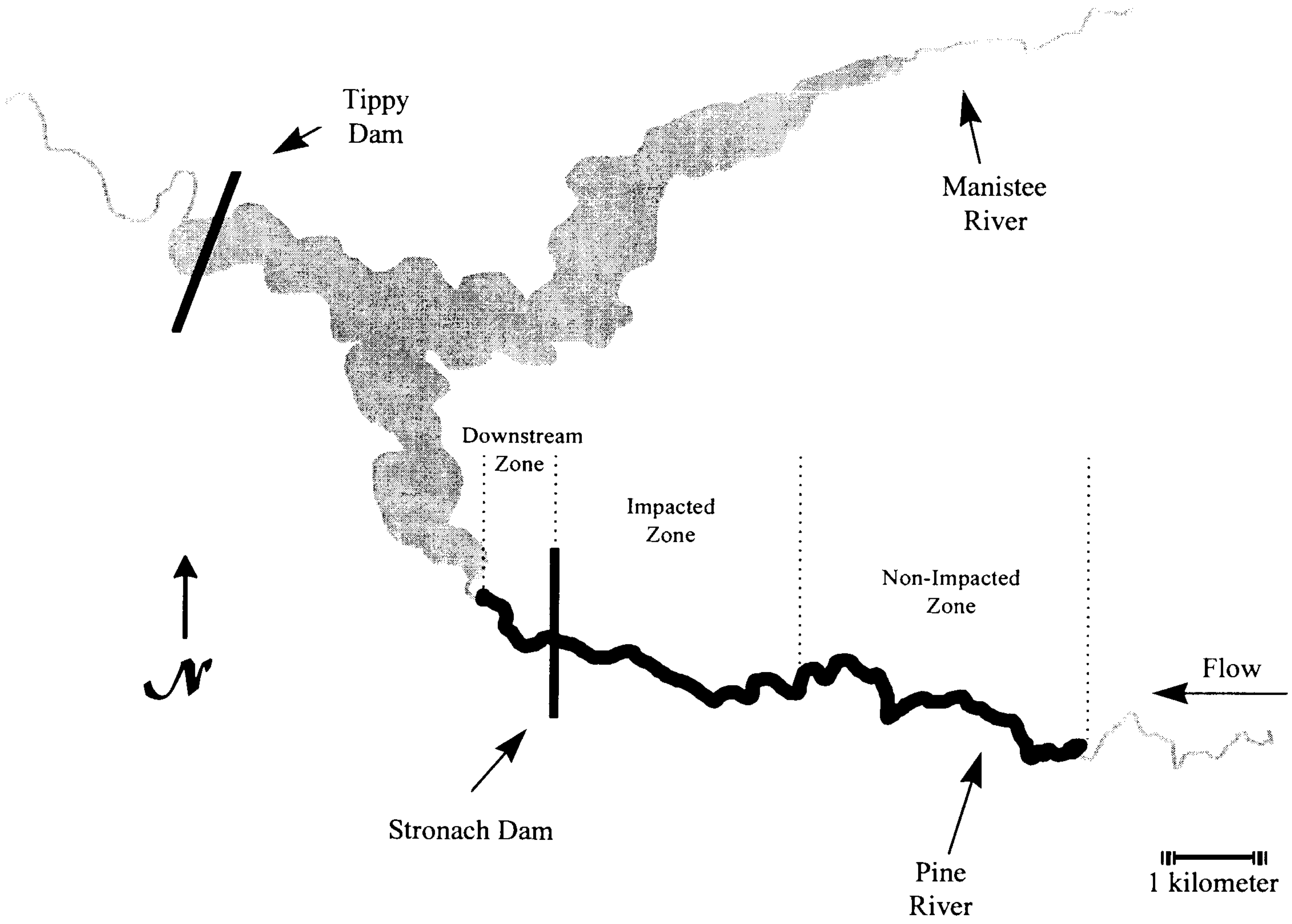


Figure 2. Location of study area shown in black.

METHODS

Habitat

Initial measurements of stream width and depth were taken during the summer of 1995. Substrate types were visually estimated at this time using a modified Wentworth scale (Table 1). These measurements were taken along 278 transects set perpendicular to the flow at 20 to 50 meter intervals, spanning the entire length of the 9.2 kilometer study stretch. Additionally, the habitat was delineated into meso-scale habitat types following criteria developed by Hicks and Watson (1985). Units of stream were categorized as runs, riffles, pools, or rapids on the basis of the dominant characteristics of water velocity, depth, substrate, and surface turbulence (Table 2). In addition, a designation of complex was given where more than one habitat category applied.

Table 1. Classification of substrate for initial assessment.

Substrate Class	Particle size (diameter in millimeters)
organic debris	visually estimated
clay	visually estimated
silt	visually estimated
sand	>silt-2
small gravel	3-10
large gravel	11-100
cobble	101-300
boulder	>300

Table 2. Classification of meso-scale habitat types (Hicks and Watson 1985).

Habitat Unit	Depth (meters)	Appearance of Water Surface	Substrate
Run	0.5-1.5	Moderate current, unbroken water	Sand or small gravel
Riffle	0.1-1.0	Swift current, turbulent, broken water	Gravel or cobble
Pool	1.5-4.0	Slow or no current, unbroken water	Sand or clay
Rapid	0.1-1.5	Swift current, very turbulent, white-water	Large cobble or boulders
Complex	0.1-4.0	Variable	Variable

Independent of the 278 transects placed to evaluate habitat on a coarse scale in 1995, 31 permanent survey transect stations were established in 1996 to measure streambed elevation before and during the course of the dam's removal. Twenty-nine of these transects were placed upstream from the dam, in series of three to six transects, and two of them were placed downstream from the dam (Figure 3). These sites were measured again in 1997, after the dam's removal had been initiated. Elevations were assumed for all transects except for the six transects proximal to the dam. I was able to tie these six transects into USGS datum allowing actual elevation to be determined at these sites. The streambed profiles developed from this survey will be used to detect changes in channel morphology over the long term of this study. Discharge was measured in cubic feet/second at one of the survey transects within each series in 1996 and 1997 using a Marsh-McBirney Model 201 portable current meter.

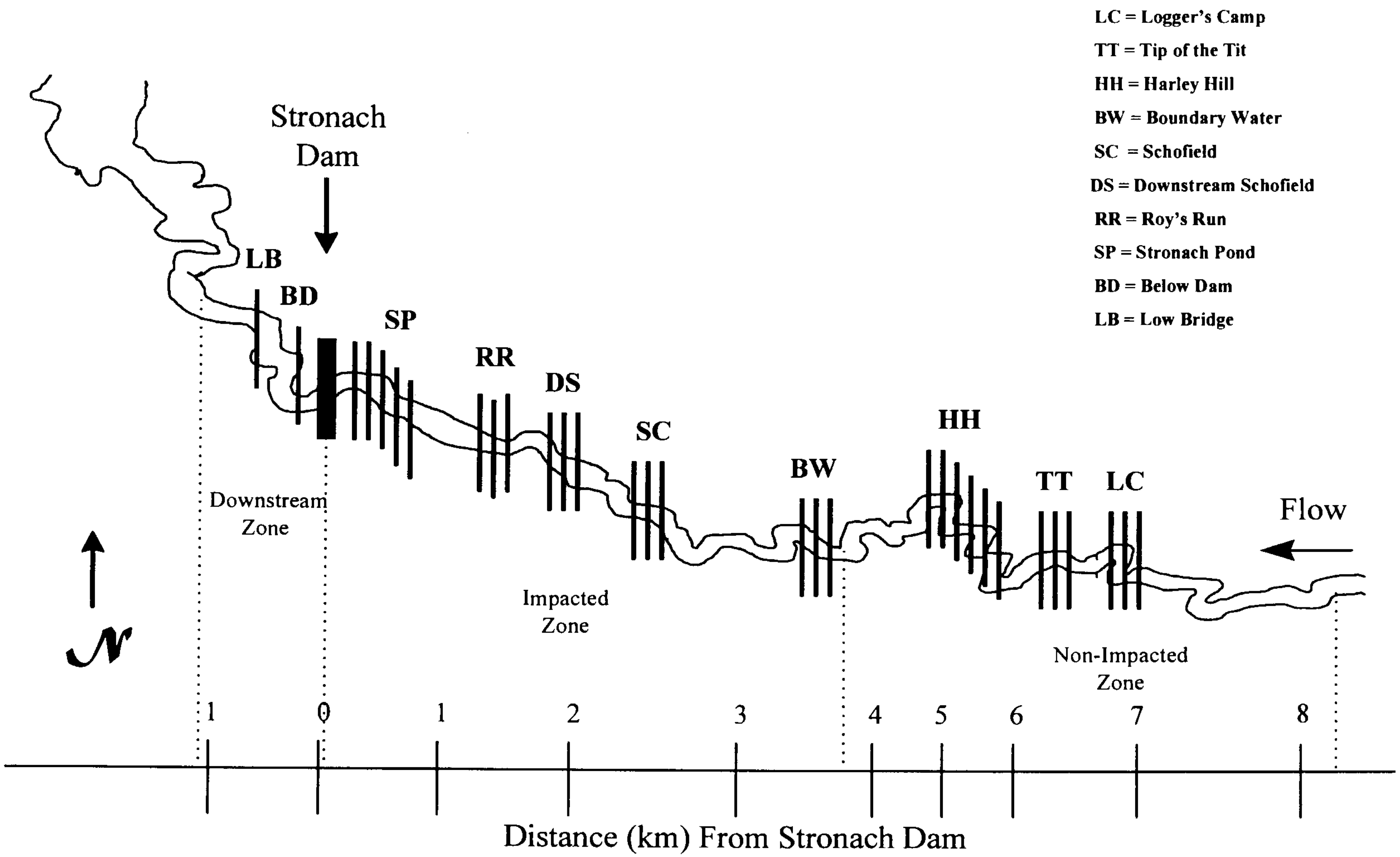


Figure 3. Cross-sectional survey sites.

A pebble count, as described by Kondolf and Li (1992), was done at one transect within each series in 1996, and at each transect in 1997. The pebble count involved randomly selecting and measuring 100 streambed particles along a transect. Substrate particle size was categorized at a finer scale than it was for the initial habitat assessment done in 1995 (Table 3). A chi-square analysis was performed to detect differences in particle size distribution at each site that had been sampled in 1996 and 1997.

Additionally, photo documentation of each transect and it's associated banks were catalogued and are archived in the Department of Fisheries and Wildlife at Michigan State University.

Table 3. Classification of substrate for pebble count assessment (Platts et al. 1983).

Substrate Class	Particle size (diameter in millimeters)	Classification Code
medium boulder	512-1,024	13
small boulder	256-512	12
large cobble	128-256	11
small cobble	64-128	10
very coarse gravel	32-64	9
coarse gravel	16-32	8
medium gravel	8-16	7
fine gravel	4-8	6
very fine gravel	2-4	5
sand	0.062-2.000	4
silt	0.004-0.062	3
clay	0.00034-0.004	2
organic		1

Fish Abundance

Abundance of trout and white suckers was estimated at 10 sites during the summer of 1997. Block nets were placed at the upstream and downstream boundary to enclose each sampling site. A Smith-Root 17-foot CataRaft was used with a multi-pass depletion method of sampling. At least three successive electrofishing passes in a single day were made at each site. Ten sites (Figure 4), totaling 207 meters downstream from the dam and 2,057 meters upstream from the dam, were sampled within block nets. Sites ranged in length from 75 meters to 428 meters. Microfish (Van Deventer and Platts 1985), a software program using the Burnham maximum-likelihood estimator (Van Deventer and Platts 1983), was used to calculate abundance estimates and their confidence intervals. Abundance estimates were converted to density estimates (fish/hectare) using measurement taken of lengths and widths of the river at each site. Analysis of fish abundance was performed using an analysis of variance (ANOVA) according to the GLM procedure of SAS (SAS Institute 1988) on untransformed white sucker densities and log-transformed trout densities to compare density between the three habitat zones.

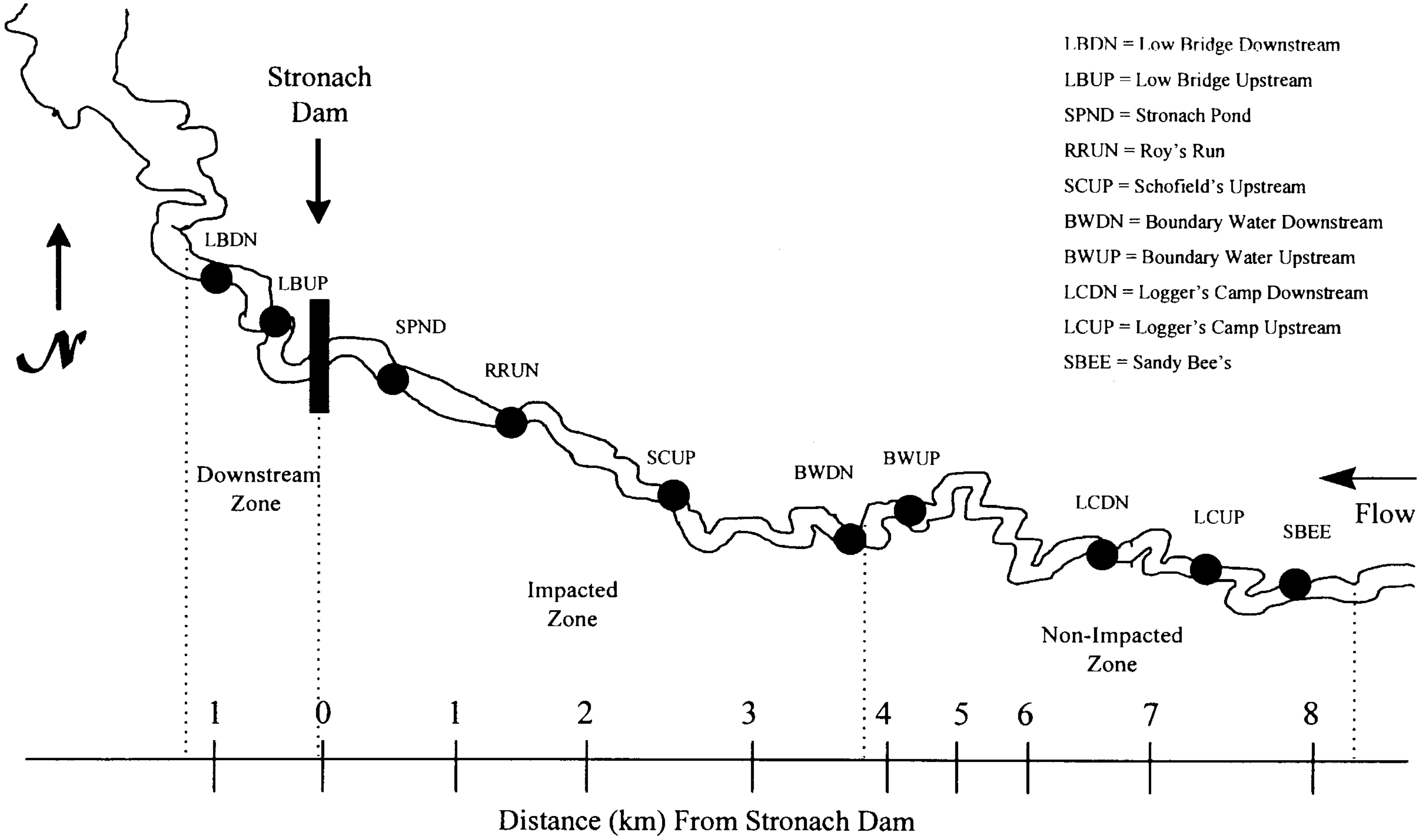


Figure 4. Fish abundance sampling sites.

Fish Growth

Trout and suckers were captured for age determination and growth analysis during the summer of 1996 using a backpack electrofishing unit, during the spring of 1997 using fyke nets, and during the summer of 1997 using an inflatable electrofishing boat. The electrofishing equipment consisted of a 12 V battery powered backpack unit made by University of Wisconsin Instrumentation Systems Center, model ABP-450-1QT. This unit was set to deliver pulsed DC (10% duty cycle) at 250-450 V. The electrofishing boat was a Smith Root-17 CataRaft set to deliver pulsed DC (40% duty cycle) at 50-500 V. Total length (TL) was measured for each fish and recorded to the nearest millimeter. Scales were taken from the trout and pectoral fin rays were taken from the white suckers.

Rainbow Trout and Brown Trout. Scales from rainbow trout and brown trout were mounted between glass slides and were analyzed using a magnified image projected onto a digitizing tablet. Radii and interannular distances were measured to the nearest .001 millimeter on three to five scales (or as many as were necessary to distinguish a consistent pattern in annuli distance) from each fish. Distance was measured in millimeters from the focus to each annulus and to the edge of the scale.

White Suckers. A Minitom precision cutting machine was used to section white sucker fin rays. Transverse sections of various widths were taken from the base of the first fin ray from each sucker. Fin rays were coated with clear epoxy in instances where the ray was not rigid enough to withstand the blade of the saw. At least three sections were taken from each sucker; more were taken when necessary to get a clear image of annuli. Sections were mounted on glass slides and coated with glycerin. An Optimas imaging system was used to measure the distance from the focus to each annulus and to the edge of the fin ray (to the nearest .001 millimeter).

Growth Analysis. A linear regression was performed to obtain an equation relating total length to scale/ray radius. The y-intercept from this equation was used to back-calculate lengths at previous ages for each fish using the Fraser-Lee formula,

$$L_i = k + [(L_c - k)\ S_i/S_c]$$

where k=length at inital scale/ray formation, L_c= length at capture, S_i=scale increment length, and S_c=scale radius (Francis 1990). From these back-calculated lengths, growth increments were determined for the year 1996 from fish captured in 1997 and for the year 1995 from fish captured in 1996.

A general linear regression was performed to determine if length at previous age could be a factor affecting fish growth. Differences in annual incremental growth between the three different habitat zones were evaluated with analysis of covariance (ANCOVA), using annual incremental growth as the response variable, habitat zone as the main effect, and length at previous age as the covariate. All analyses were performed on untransformed data according to the GLM procedure of SAS (SAS Institute 1988). Significance tests were performed at an alpha of 0.05.

RESULTS

Habitat

In categorizing the river into mesohabitats, most (73%) of the study area was classified as runs having an average depth of 0.86 meters, with sand being the predominant substrate (Table 4). Fifteen percent of the study site is classified as riffles, which are mostly located upstream from the influence of the dam (only 0.8% of the riffles appear within the impacted zone). Riffles have a mean depth of 0.66 meters and the substratum is most often composed of large gravel. Pools and rapids occur less frequently and each category occupies three percent of the study site. Pools are on average 1.56 meters deep with a sandy bottom. Rapids in the Pine have a mean depth of 0.81 meters and the substrate in these rapids is most commonly boulders and cobble. Six percent of the study stretch is classified as complex, all of which occurs upstream from the dam's influence, with a gravel streambed and a mean depth of 0.90 meters. Additional analyses suggest that the complex habitat consists primarily of riffles (48.4%), combined with runs (29.5%) and pools (22.1%). On average the Pine is nineteen meters wide throughout the study site. The river narrows where rapids occur (mean width = 17 meters). The distribution of these mesohabitat types and their proximity to the dam are visually displayed in Figure 5. Figure 5 also shows how the study region was divided into three distinct stretches based on the level of impact the dam has had on the diversity of habitat as detected from the mesohabitat delineation.

Table 4. Habitat assessment characteristics - 1995.

Habitat Type	Total Length (meters)	Percent Length of Study Area	Mean Width (meters)	Mean Depth (meters)	Primary Substrate
Run	6734	73	19	.86	Sand
Riffle	1409	15	19	.66	Large gravel
Pool	239	3	19	1.56	Sand
Rapid	277	3	17	.81	Boulder/Cobble
Complex	570	6	19	.90	Large gravel

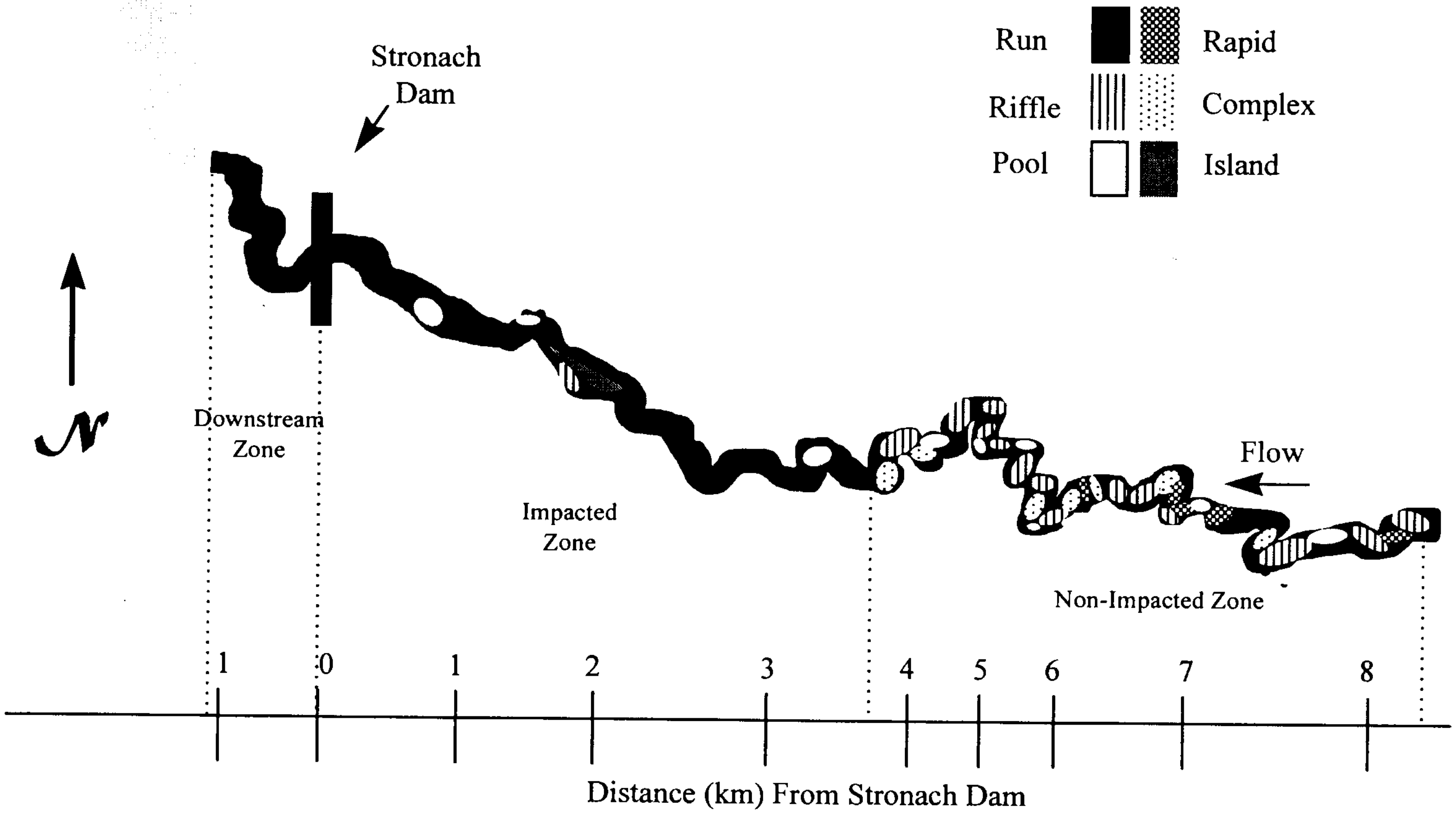


Figure 5. Study region delineated into zones by distribution of habitat types.

Profiles showing streambed elevations for each individual transect surveyed are provided in Figures 6 through 14. Maximum elevation changes for each site are reported in Table 5. Some of the changes (particularly those at sites proximal to the dam, e.g. SP #'s 1-5 and BD #1) are probably related to the initiation of the dam removal. The profiles developed from the sites in the non-impacted zone (Figures 6, 7 and 8), do not show large changes in streambed elevation. Many of the changes in streambed morphology that were observed (e.g. LC #2, LC #3, TT #1) in the non-impacted zone could be linked to naturally occurring events such as newly fallen trees. The profiles of transects from sites in the impacted zone (Figures 9, 10, 11, 12, and 13) also show little change in streambed elevation with the exception of those transects most proximal to the dam (SP #2, SP #3, SP #4, SP #5). These transects show some degradation in streambed elevation which in some cases may be due to the lowering of the dam, and in other cases (SP #5) is attributable to construction of the water control structure and excavation of the soil in that area. Downstream from the dam, measurements suggest that the streambed is aggrading (Figure 14), particularly at the transect directly downstream from the dam.

Gradients from the eight stations upstream and one station downstream from Stronach Dam are reported in Table 6. These were determined from the change in water surface elevation from the upstream-most transect at a station to the downstream-most transect at the same station. Gradients are highest (> 2m/km) at sites upstream from the dam's influence, and lowest (< 1m/km) at sites within the impacted zone and downstream from the dam.

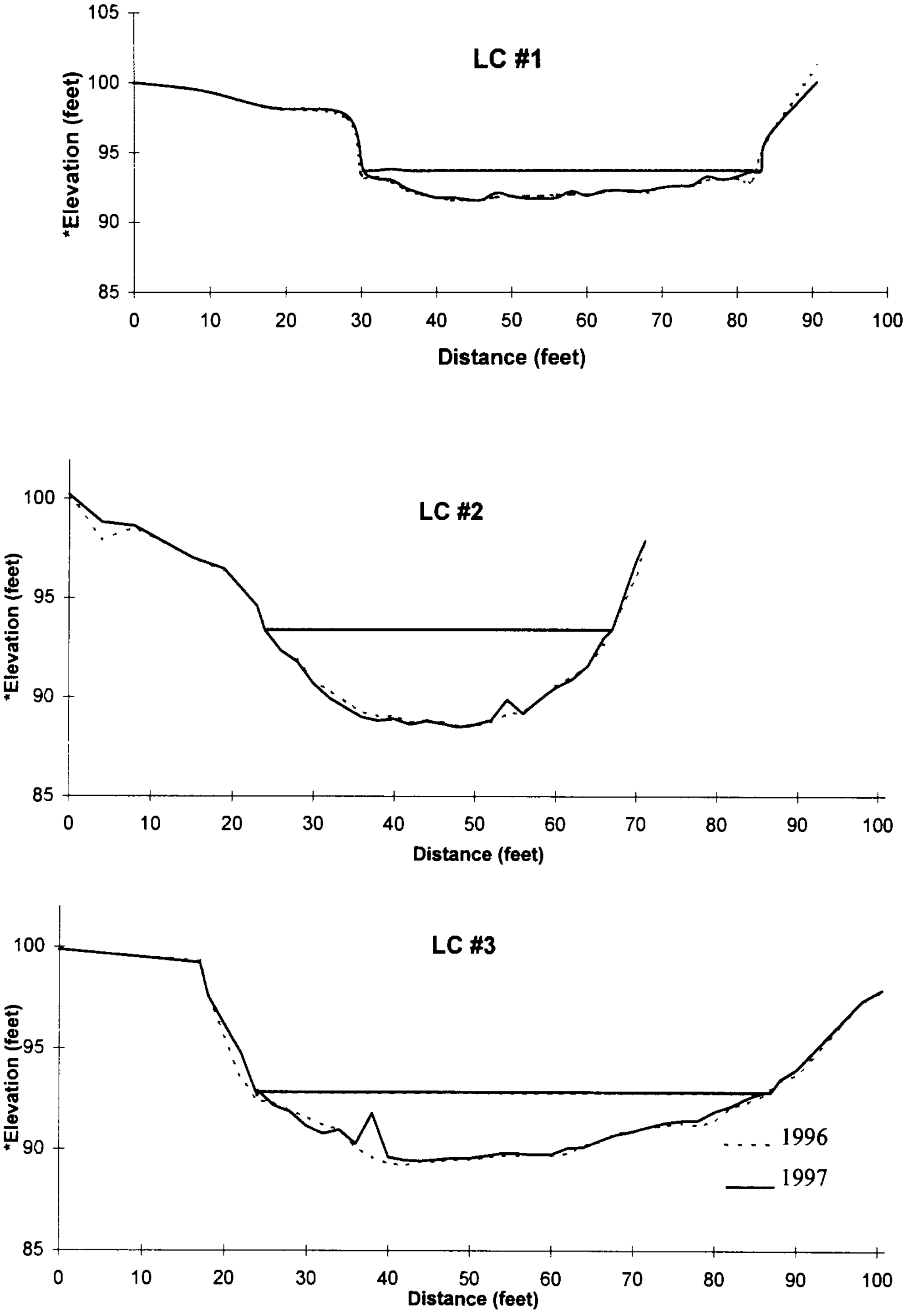


Figure 6. Streambed profiles of the Logger's Camp (LC) series for 1996 and 1997. These transects are located approximately 7.0 km upstream from Stronach Dam, within the non-impacted zone. *Assumed elevations where USGS datum not available.

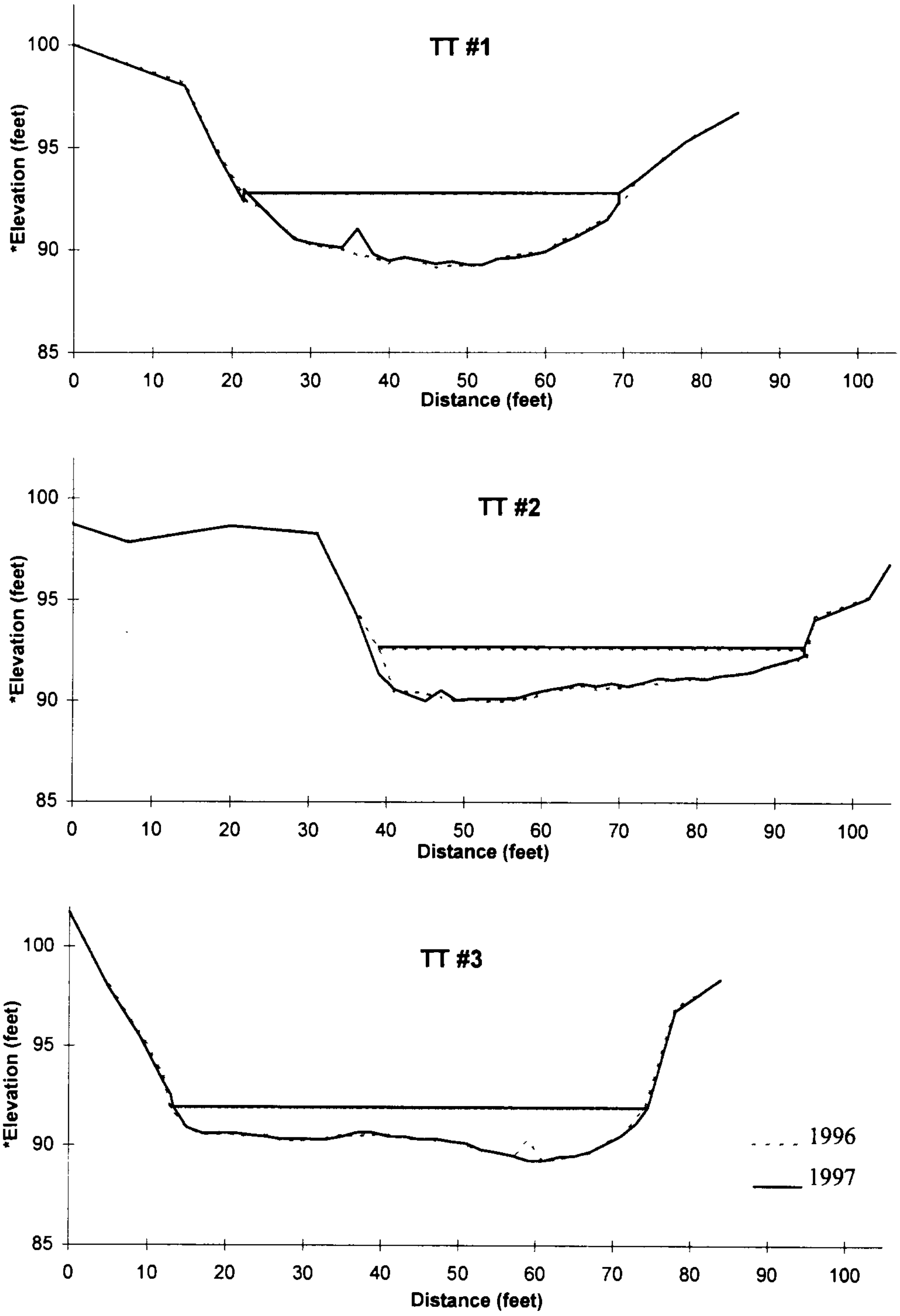


Figure 7. Streambed profiles of the Tip of the Tit (TT) series for 1996 and 1997. These transects are located approximately 6.3 km upstream from Stronach Dam, within the non-impacted zone. *Assumed elevations where USGS datum not available.

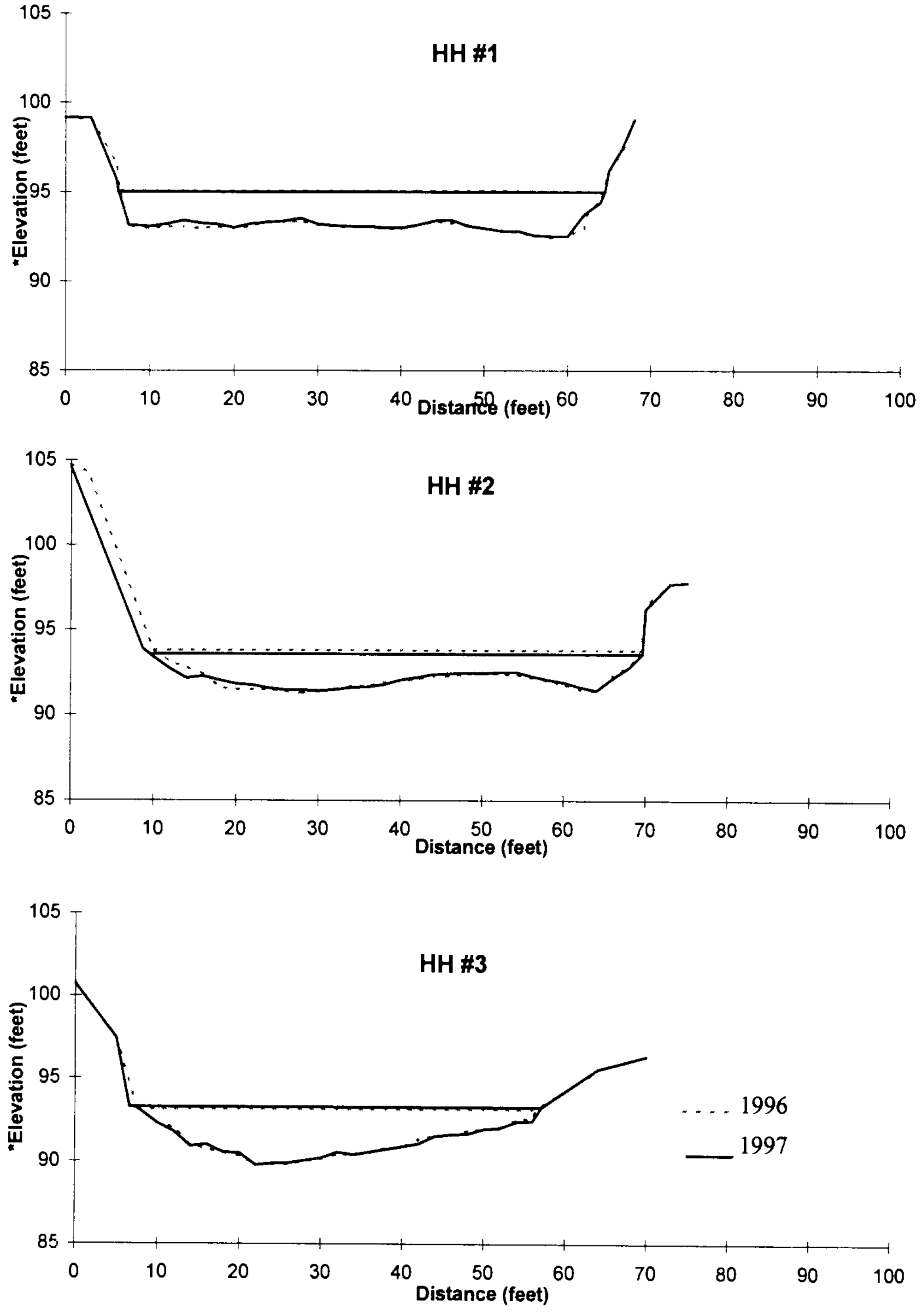


Figure 8. Streambed profiles of the Harley Hill (HH) series for 1996 and 1997. These transects are located approximately 5.3 km upstream from Stronach Dam, within the non-impacted zone. *Assumed elevations where USGS datum not available.

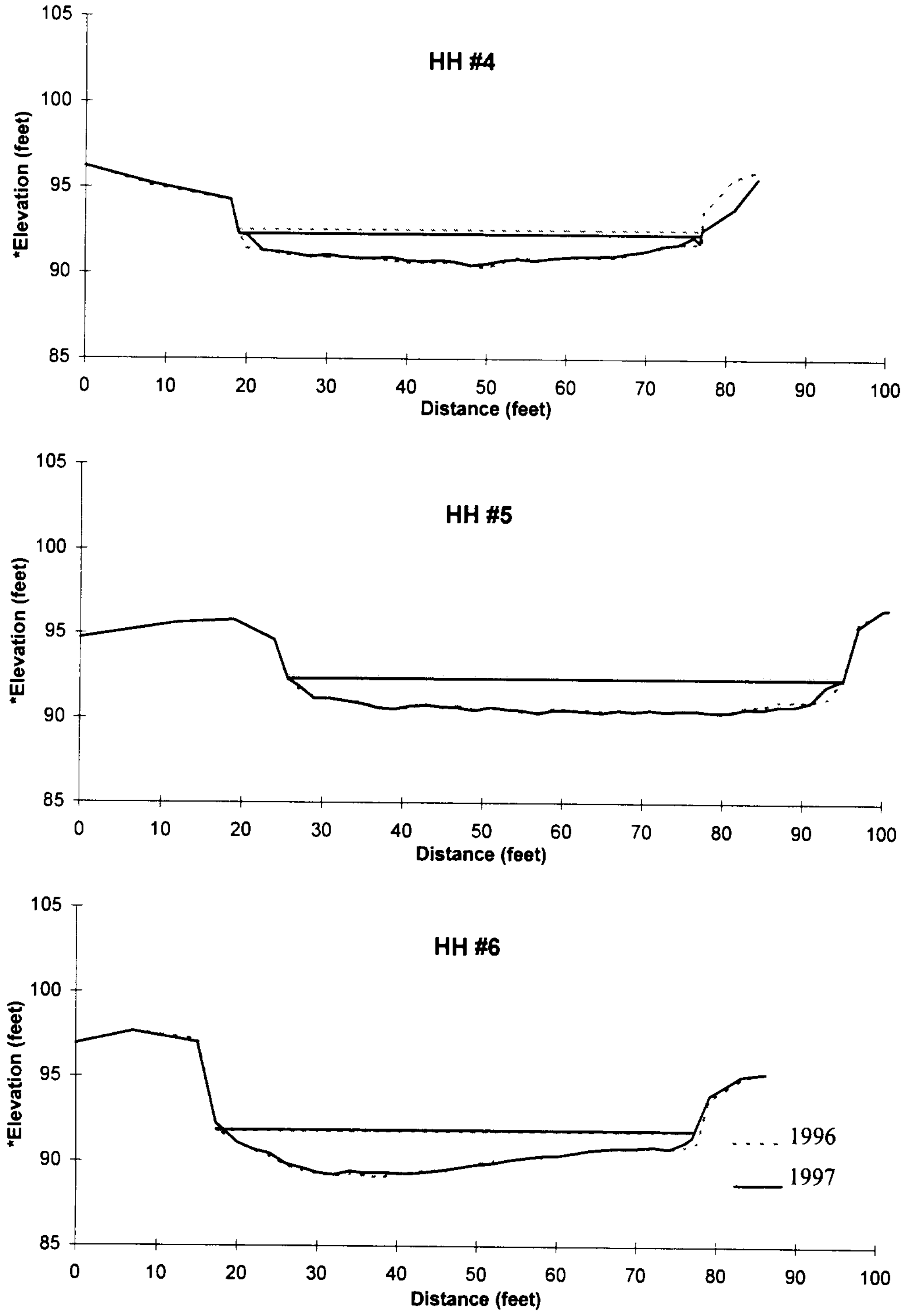


Figure 8 (cont'd.). Streambed profiles of the Harley Hill (HH) series for 1996 and 1997. These transects are located approximately 5.3 km upstream from Stronach Dam, within the non-impacted zone. *Assumed elevations where USGS datum not available.

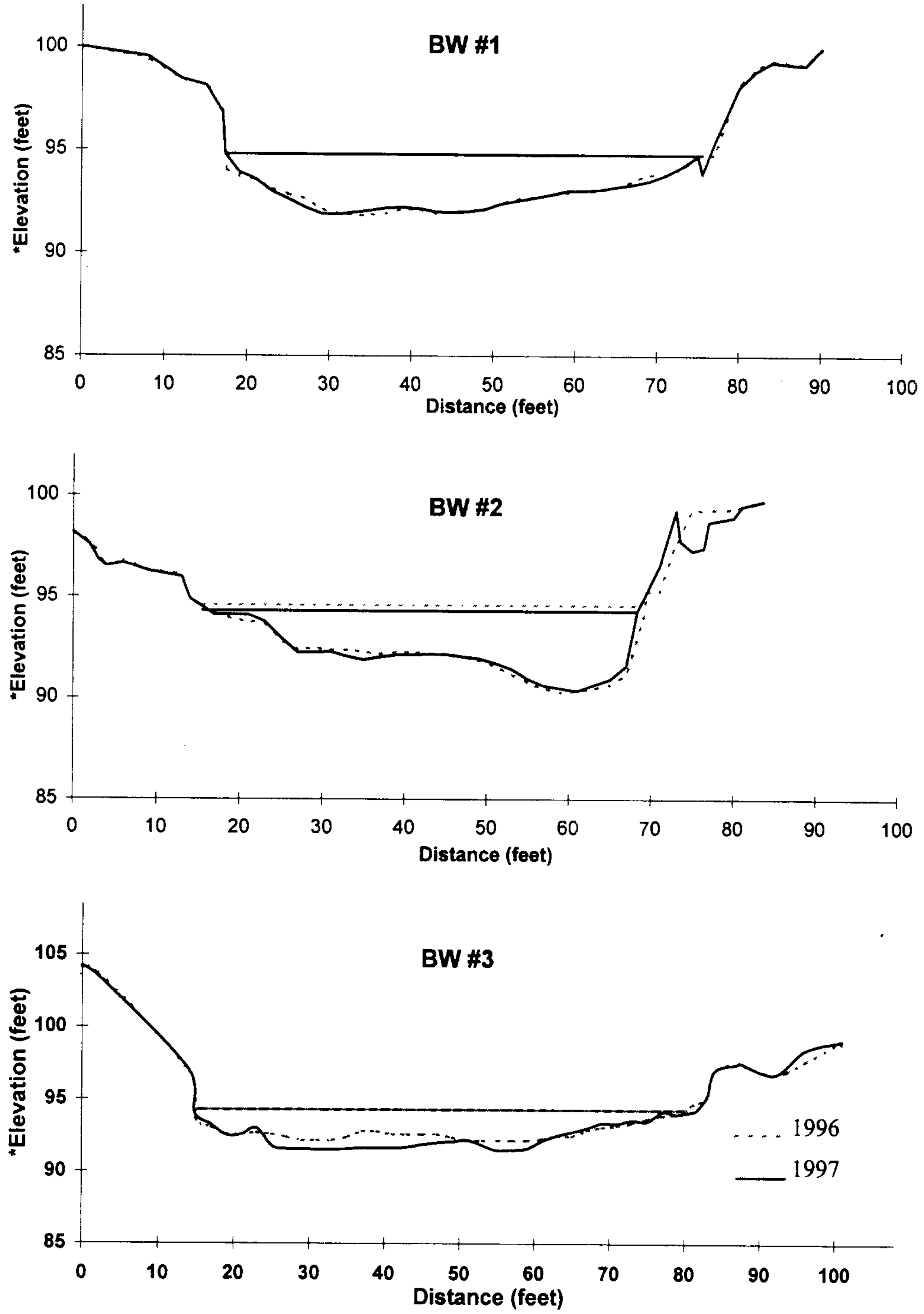


Figure 9. Streambed profiles of the Boundary Water (BW) series for 1996 and 1997. These transects are located approximately 3.5 km upstream from Stronach Dam, within the impacted zone. *Assumed elevations where USGS datum not available.

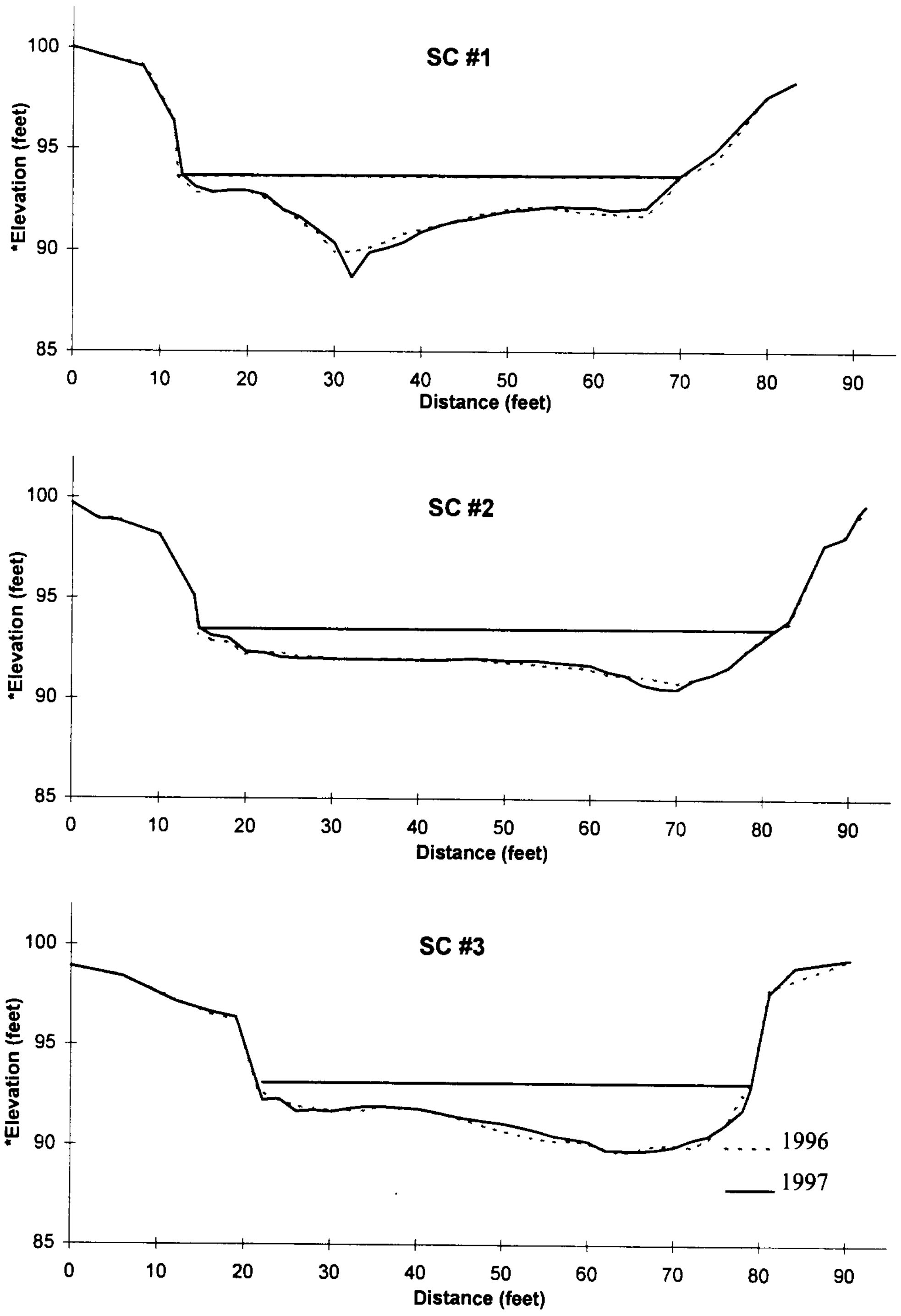


Figure 10. Streambed profiles of the Schofield (SC) series for 1996 and 1997. These transects are located approximately 2.4 km upstream from Stronach Dam, within the impacted zone. *Assumed elevations where USGS datum not available.

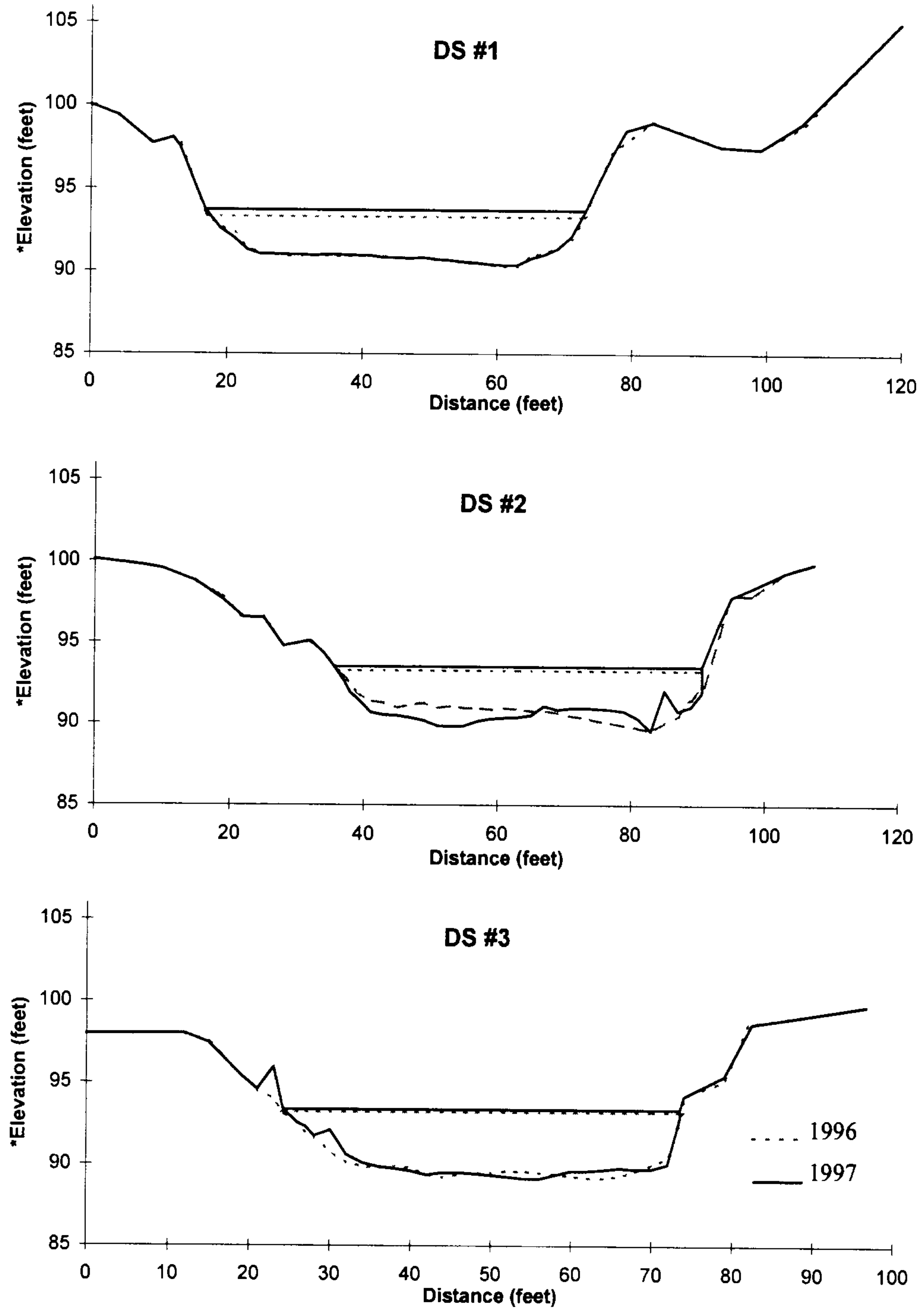


Figure 11. Streambed profiles of the Downstream Schofield (DS) series for 1996 and 1997. These transects are located approximately 1.6 km upstream from Stronach Dam, within the impacted zone. *Assumed elevations where USGS datum not available.

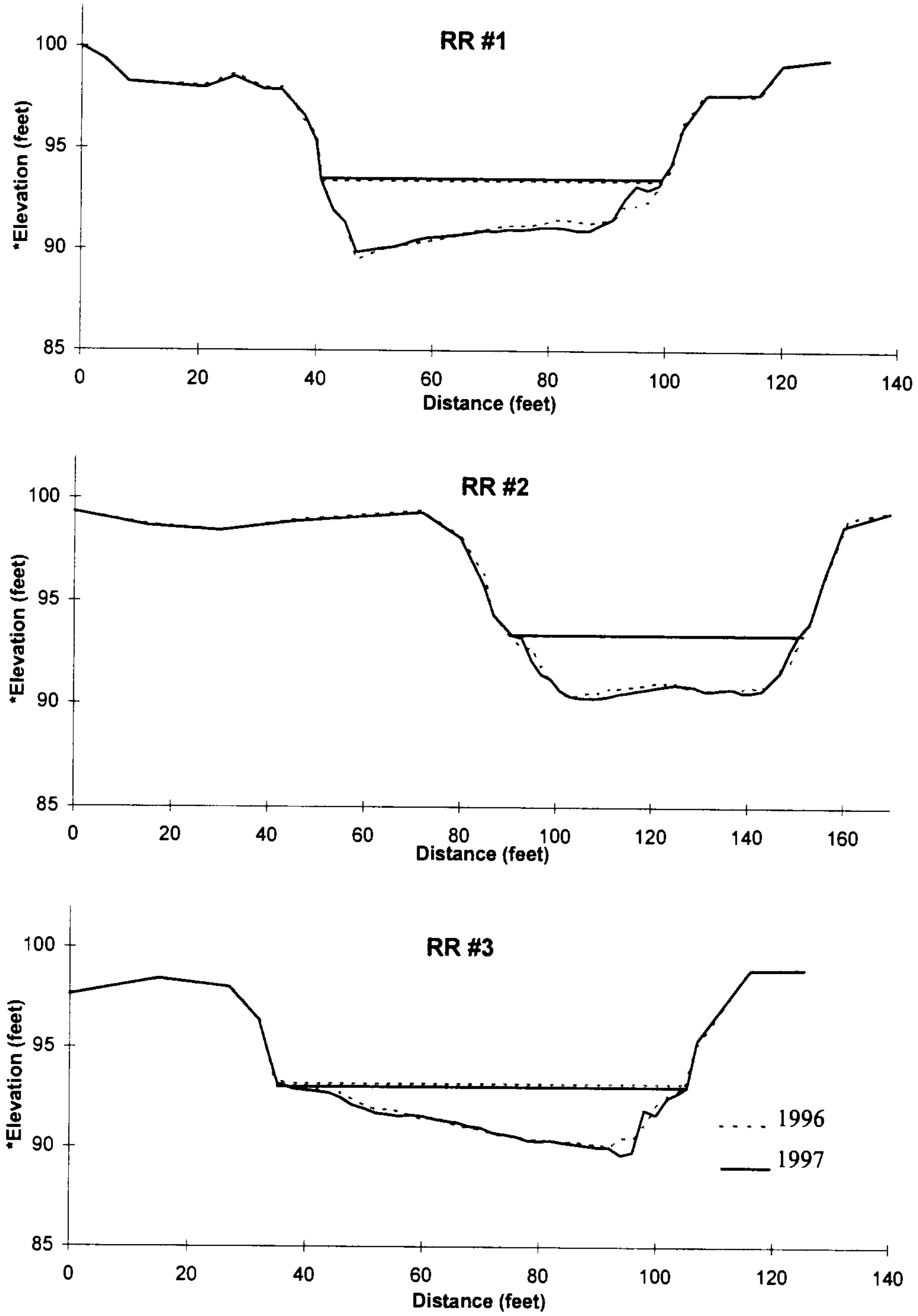


Figure 12. Streambed profiles of the Roy's Run (RR) series for 1996 and 1997. These transects are located approximately 1.1 km upstream from Stronach Dam, within the impacted zone. *Assumed elevations where USGS datum not available.

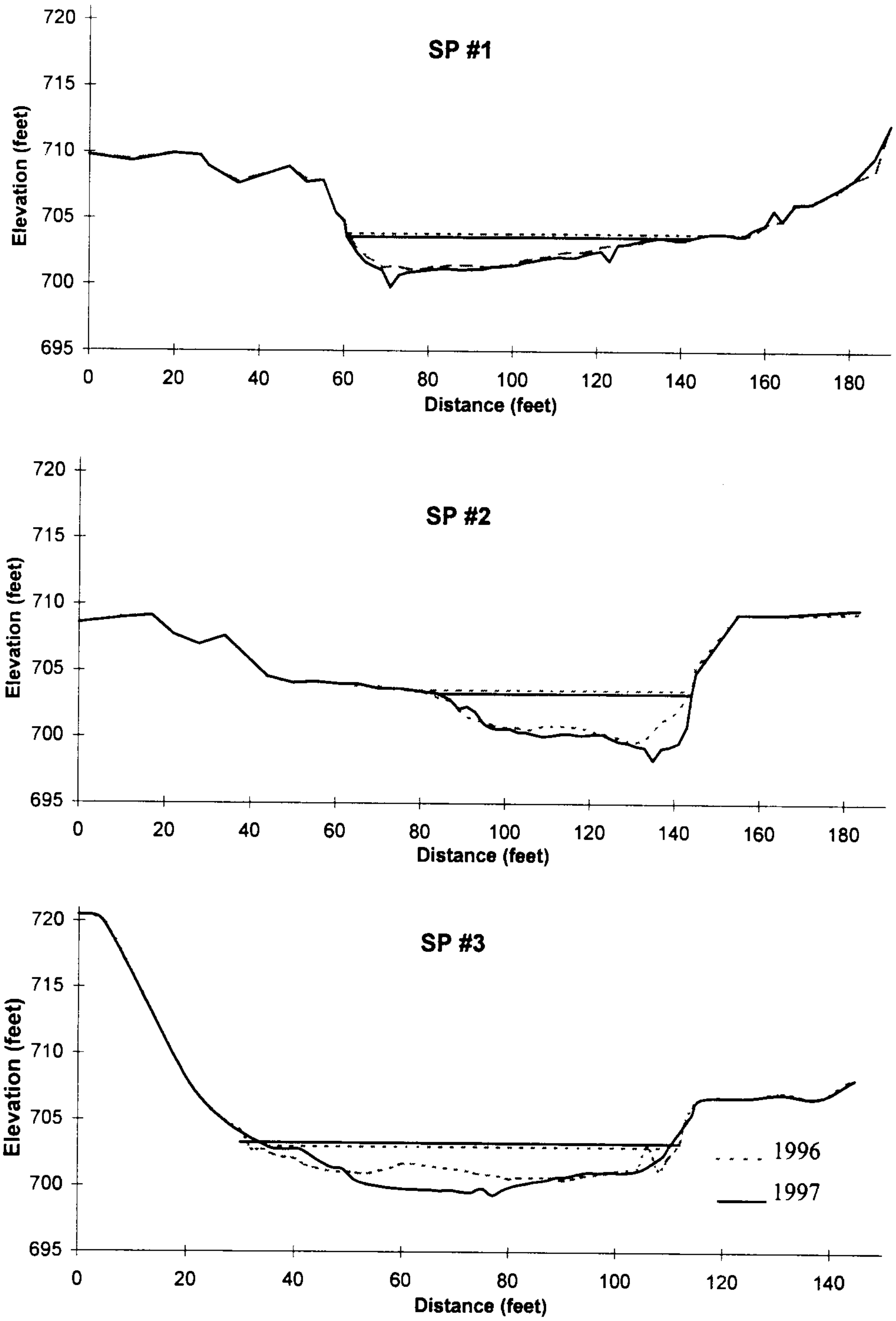
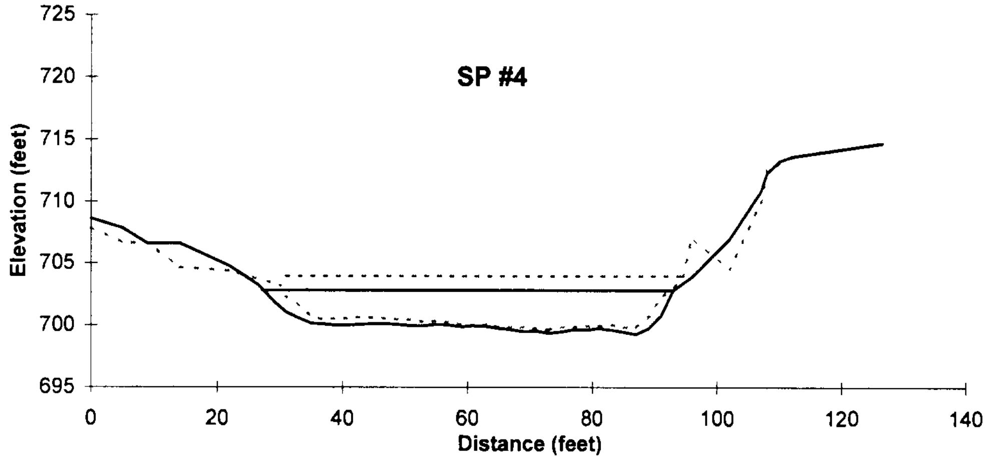


Figure 13. Streambed profiles of the Stronach Pond (SP) series for 1996 and 1997. These transects are located within approximately 0.6 km of, and upstream from, Stronach Dam, within the impacted zone. (Actual elevations from USGS.)



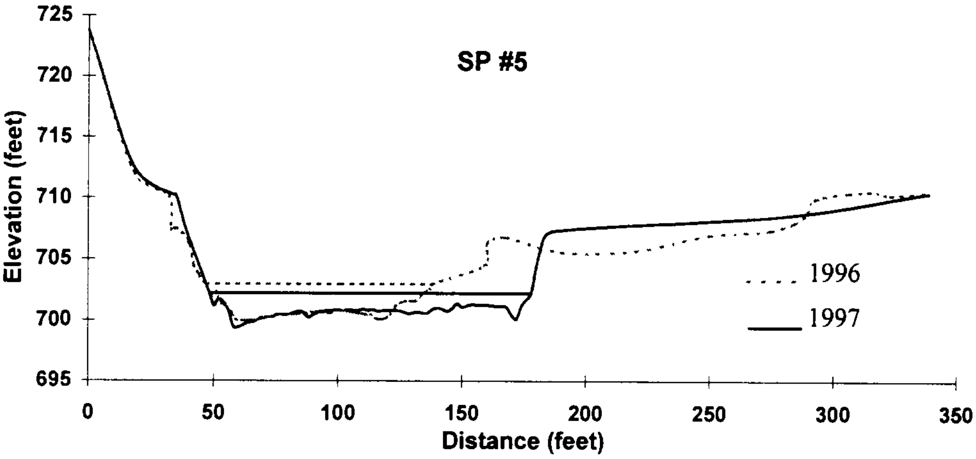


Figure 13 (cont'd.). Streambed profiles of the Stronach Pond (SP) series for 1996 and 1997. These transects are located within approximately 0.6 km of, and upstream from, Stronach Dam, within the impacted zone. (Actual elevations from USGS.)

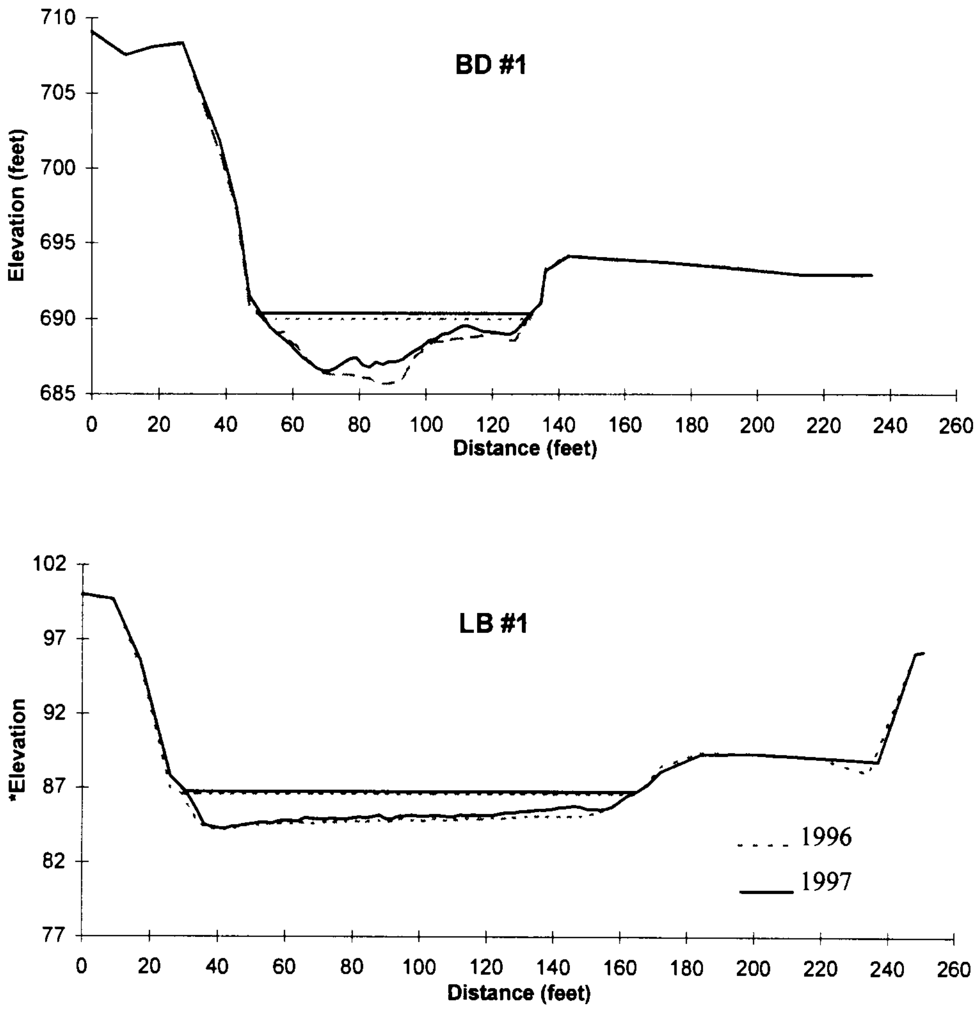


Figure 14. Streambed profiles of the Below Dam (BD) transect located approximately 100 meters downstream from Stronach Dam, and the Low Bridge (LB) transect located 0.8 km downstream from the dam. Elevations are actual for the BD transect and assumed for the LB transect.

Table 5. Streambed elevation changes from 1996 to 1997. Negative values indicate degradation of the streambed; positive values indicate aggradation.

Habitat Zone	Site	Maximum Elevation Change (feet)
Non-impacted	LC #1	0.23
Non-impacted	LC #2	0.72
Non-impacted	LC #3	2.19
Non-impacted	TT #1	1.28
Non-impacted	TT #2	-0.36
Non-impacted	TT #3	0.08
Non-impacted	HH #1	-0.04
Non-impacted	HH #2	-0.13
Non-impacted	HH #3	-0.06
Non-impacted	HH #4	-0.09
Non-impacted	HH #5	-0.07
Non-impacted	HH #6	-0.07
Impacted	BW #1	-0.07
Impacted	BW #2	-0.01
Impacted	BW #3	-1.15
Impacted	SC #1	-1.25
Impacted	SC #2	-0.44
Impacted	SC #3	-0.22
Impacted	DS #1	-0.03
Impacted	DS #2	-1.24
Impacted	DS #3	-0.45
Impacted	RR #1	-0.44
Impacted	RR #2	-0.39
Impacted	RR #3	-0.88
Impacted	SP #1	-1.60
Impacted	SP #2	-2.29
Impacted	SP #3	-1.93
Impacted	SP #4	-0.57
Impacted	SP #5	-5.49
Downstream	BD #1	1.46
Downstream	LB #1	0.68

Table 6. Gradient from eight stations upstream and one station downstream from Stronach Dam. The first three are from survey sites located in the non-impacted zone, the next four are located in the impacted zone, and the last is from a site downstream from the dam.

Site	Gradient (%)	Gradient (m/km)	Gradient (ft/mile)
LC	0.21	2.14	11.28
TT	0.26	2.59	13.67
HH	0.22	2.20	11.61
BW	0.09	0.92	4.85
SC	0.06	0.64	3.39
DS	0.04	0.39	2.07
RR	0.07	0.67	3.54
SP	0.04	0.41	2.15
LB	0.04	0.40	2.11

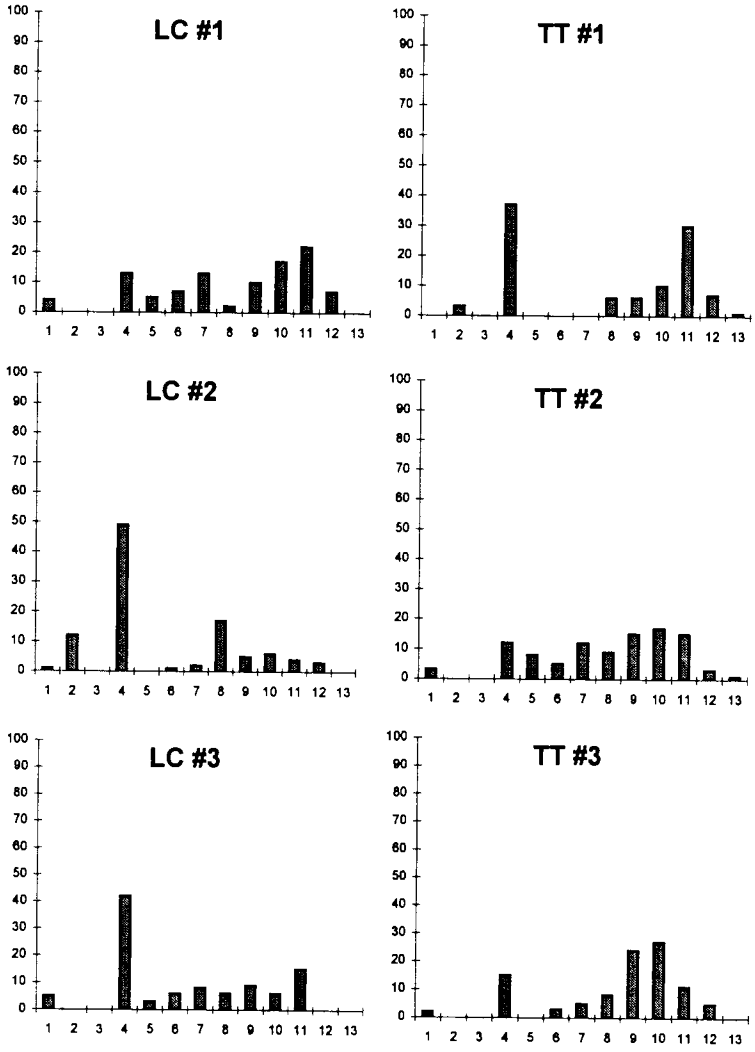
Flow measurements taken at 10 different transects during June of 1996 and July of 1997 are reported in Table 7. The average 1996 flow (273 cfs or 7.73 m^3/s) that I measured was 10% greater than the average discharge (248 cfs or 7.02 m^3/s) reported for the Pine River in July, while the average 1997 flow (268 cfs or 7.59 m^3/s) measured was 4% less than the average discharge (278 cfs or 7.87 m^3/s) reported for the month of June (Blumer et al. 1998). Flow was relatively greater in 1996 than in 1997 due to elevated rainfall in 1996.

Results of the pebble count analysis are shown graphically in Figures 15 through 20. Large substrate particle sizes, such as boulders, generally occur only in the non-impacted zone as seen in Figures 15 and 16. Gravel-size substrate particles are more prevalent in the non-impacted zone and in the upstream-most stretches of the impacted zone (Figures 15, 16, 17, and 18). Sand, which is present throughout the study section, becomes the dominant substrate type at sites near the dam (Figure 19) and at sites downstream from the dam (Figure 20). Results of the pebble count analysis from the 10 sites evaluated in 1996 are shown along side 1997 results at the same 10 sites in Figure 21. A chi-square analysis suggests a significant difference in the distribution of particle size at sites LC #1, BW #3, RR #3, and SP #5. Additional results, displaying dominant and subdominant substrate type at each transect, are given in Figure 22 for 1996 and in Table 8 for 1997.

Mean particle size of the substrate shows a general decrease in size where the gradient of the stream channel also decreases (Figure 23).

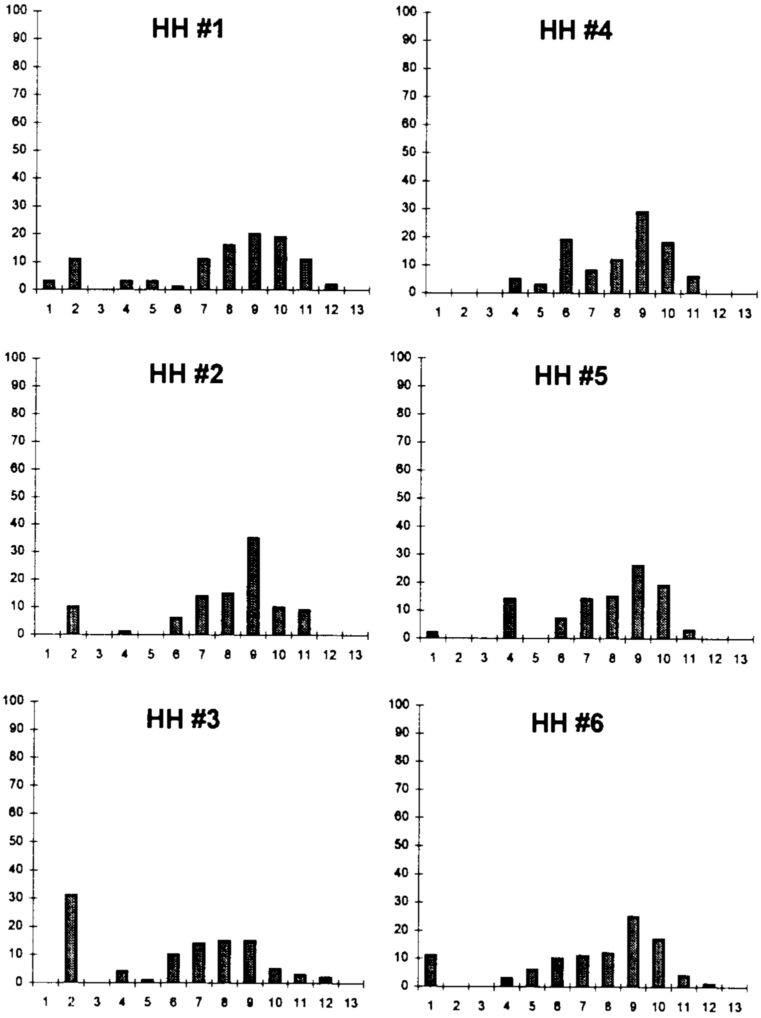
Table 7. Flow measurements at survey stations.

Site	Discharge (cfs) 1996	Discharge (cfs) 1997
LC	261	244
(m^3/s)	(7.39)	(6.91)
TT	251	259
(m^3/s)	(7.11)	(7.33)
HH	285	270
(m^3/s)	(8.07)	(7.65)
BW	268	263
(m^3/s)	(7.59)	(7.45)
SC	281	263
(m^3/s)	(7.96)	(7.45)
DS	281	298
(m^3/s)	(7.96)	(8.44)
RR	261	277
(m^3/s)	(7.39)	(7.84)
SP #1	277	280
(m^3/s)	(7.84)	(7.93)
SP #5	259	275
(m^3/s)	(7.33)	(7.79)
LB	309	253
(m^3/s)	(8.75)	(7.16)



Substrate Code
1 = organic
2 = clay 0.00024-0.004mm
3 = silt 0.04-0.062mm
4 = sand 0.062-2.000mm
5 = very fine gravel 2-4mm
6 = fine gravel 4-8mm
7 = medium gravel 8-16mm
8 = coarse gravel 16-32mm
9 = very coarse gravel 32-64mm
10 = small cobble 64-128
11 = large cobble 128-256mm
12 = small boulder 256-512mm
13 = medium boulder

Figure 15. 1997 substrate particle size distributions at LC and TT transects located 7.0 km and 6.3 km upstream from Stronach Dam, respectively, within the non-impacted zone.


HH #1

HH #4

HH #2

HH #5

HH #3

HH #6

Substrate Code
1 = organic
2 = clay
0.00024-0.004mm
3 = silt
0.04-0.062mm
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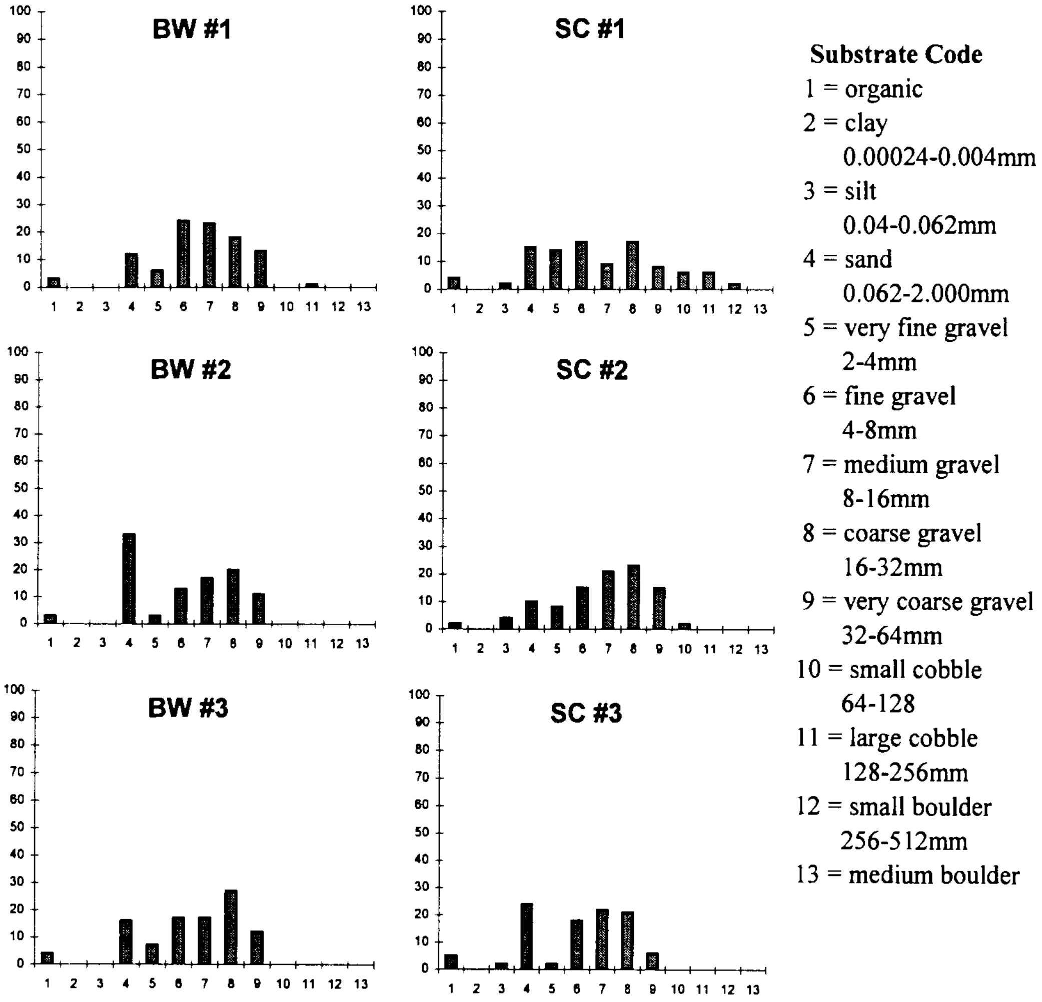
6 = fine gravel
4-8mm
7 = medium gravel
8-16mm
8 = coarse gravel
16-32mm
9 = very coarse gravel
32-64mm
10 = small cobble
64-128
11 = large cobble
128-256mm
12 = small boulder
256-512mm
13 = medium boulder

Figure 16. 1997 particle size distributions at HH transects located approximately 5.3 km upstream from Stronach Dam, within the non-impacted zone.



Substrate Code
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2 = clay
0.00024-0.004mm
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4 = sand
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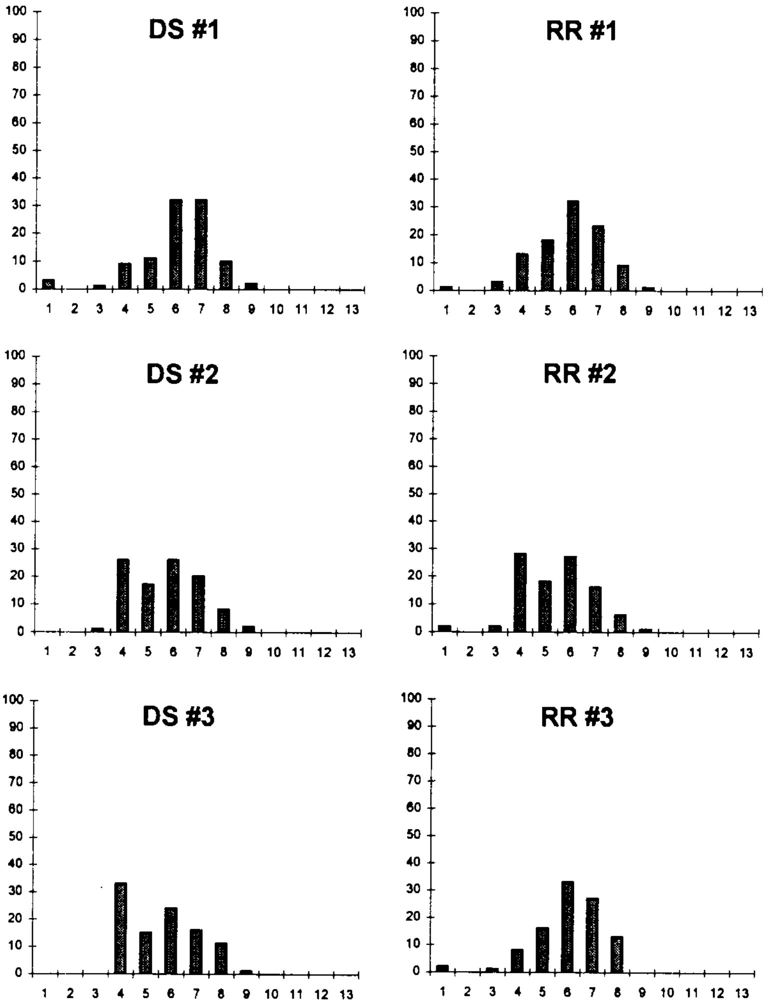
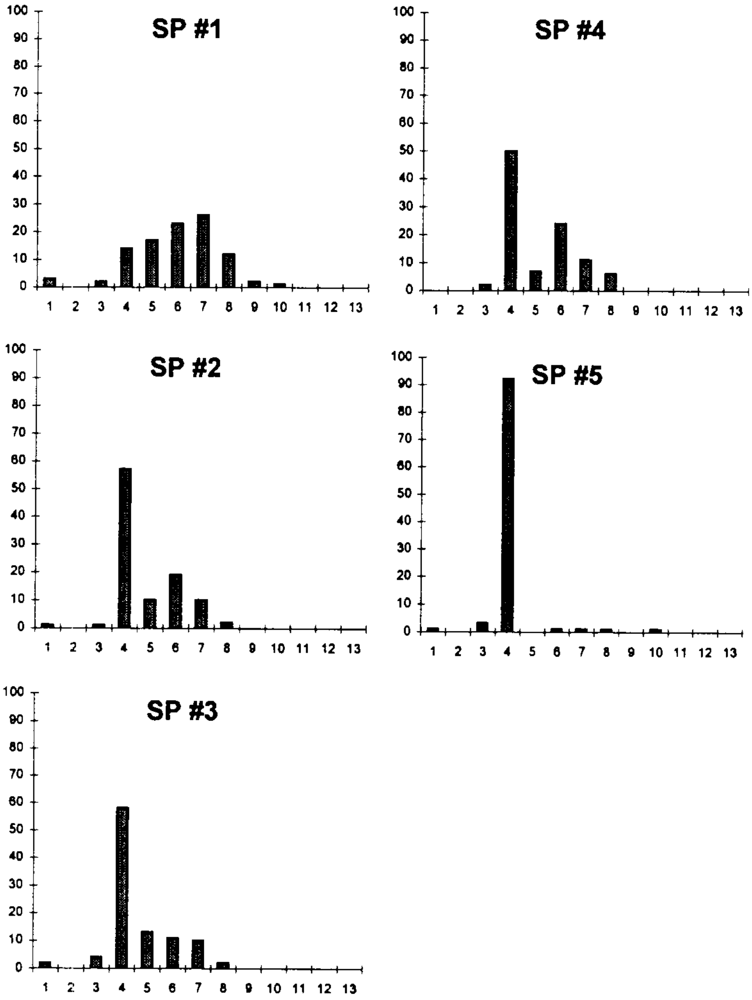
6 = fine gravel
4-8mm
7 = medium gravel
8-16mm
8 = coarse gravel
16-32mm
9 = very coarse gravel
32-64mm
10 = small cobble
64-128
11 = large cobble
128-256mm
12 = small boulder
256-512mm
13 = medium boulder

Figure 17. 1997 substrate particle size distribution at BW and SC transects located 3.5 km and 2.4 km upstream from Stronach Dam, respectively, within the impacted zone.



Substrate Code
1 = organic
2 = clay
0.00024-0.004mm
3 = silt
0.04-0.062mm
4 = sand
0.062-2.000mm
5 = very fine gravel
2-4mm
6 = fine gravel
4-8mm
7 = medium gravel
8-16mm
8 = coarse gravel
16-32mm
9 = very coarse gravel
32-64mm
10 = small cobble
64-128
11 = large cobble
128-256mm
12 = small boulder
256-512mm
13 = medium boulder

Figure 18. 1997 substrate particle size distributions at DS and RR transects located 1.6 km and 1.1 km upstream from Stronach Dam, respectively, within the impacted zone.



Substrate Code

1 = organic

2 = clay
0.00024-0.004mm

3 = silt
0.04-0.062mm

4 = sand
0.062-2.000mm

5 = very fine gravel
2-4mm

6 = fine gravel
4-8mm

7 = medium gravel
8-16mm

8 = coarse gravel
16-32mm

9 = very coarse gravel
32-64mm

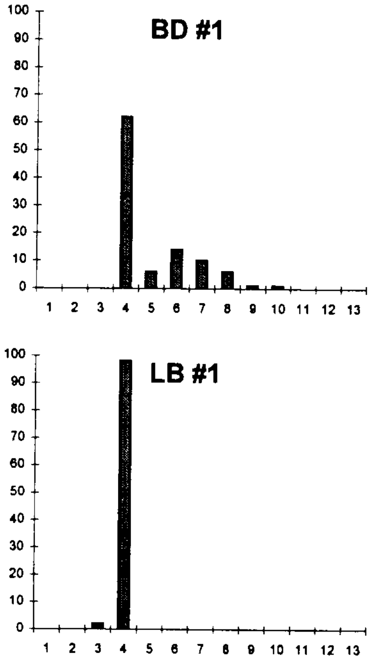
10 = small cobble
64-128

11 = large cobble
128-256mm

12 = small boulder
256-512mm

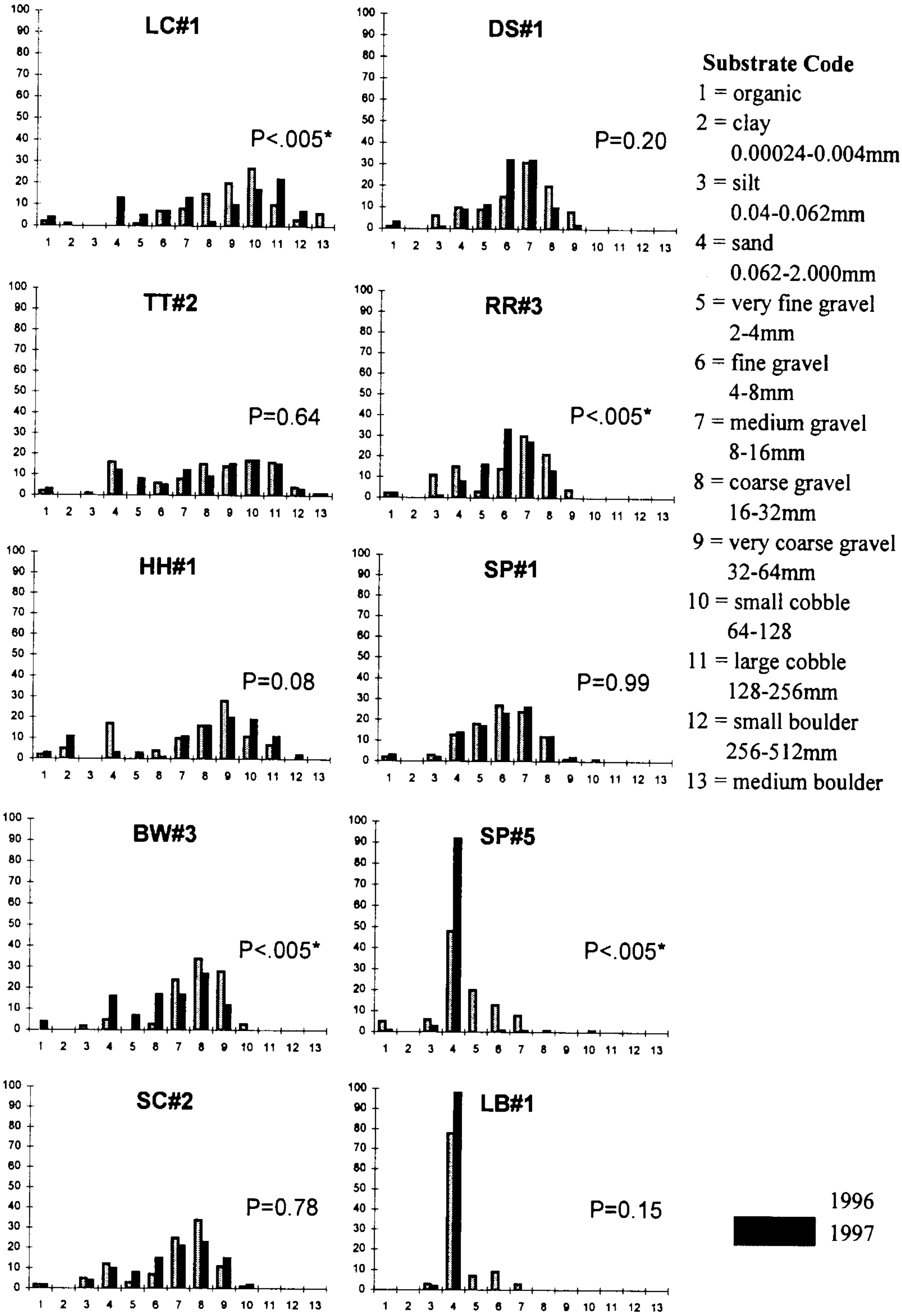
13 = medium boulder

Figure 19. 1997 substrate particle size distributions at SP transects located within 0.6 km of, and upstream from Stronach Dam, within the impacted zone.



Substrate Code
1 = organic
2 = clay
0.00024-0.004mm
3 = silt
0.04-0.062mm
4 = sand
0.062-2.000mm
5 = very fine gravel
2-4mm
6 = fine gravel
4-8mm
7 = medium gravel
8-16mm
8 = coarse gravel
16-32mm
9 = very coarse gravel
32-64mm
10 = small cobble
64-128
11 = large cobble
128-256mm
12 = small boulder
256-512mm
13 = medium boulder

Figure 20. 1997 substrate particle size distributions from transects downstream from Stronach Dam. BD transect is located approximately 100 meters downstream from the dam and LB is located 0.8 km downstream from the dam.



Substrate Code

1 = organic
2 = clay
0.00024-0.004mm
3 = silt
0.04-0.062mm
4 = sand
0.062-2.000mm
5 = very fine gravel
2-4mm
6 = fine gravel
4-8mm
7 = medium gravel
8-16mm
8 = coarse gravel
16-32mm
9 = very coarse gravel
32-64mm
10 = small cobble
64-128
11 = large cobble
128-256mm
12 = small boulder
256-512mm
13 = medium boulder

Figure 21. 1996 and 1997 substrate particle size distribution. A significant difference was detected between the results of 1996 and 1997 for sites: LC #1, BW #3, RR #3, and SP #5.

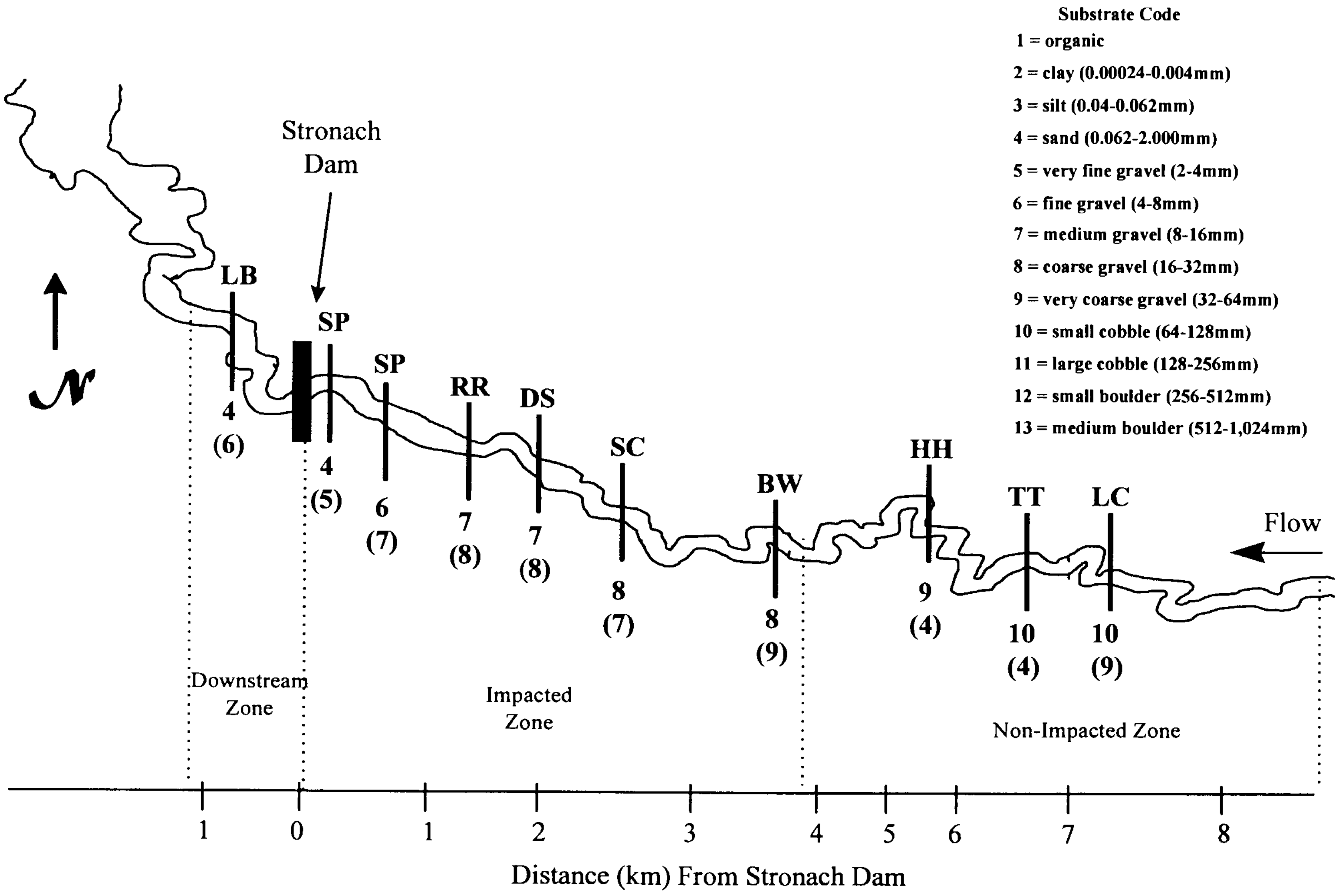


Figure 22. Primary and secondary substrate types in 1996.

Table 8. 1997 pebble count summary.

Site	Dominant Substrate Category	Subdominant Substrate Category
LC #1	11	10
LC #2	4	8
LC #3	4	11
TT #1	4	11
TT #2	10	9
TT #3	10	9
HH #1	9	10
HH #2	9	10
HH #3	2	9
HH #4	9	6
HH #5	9	10
HH #6	9	10
BW #1	6	7
BW #2	4	8
BW #3	8	6
SC #1	6	8
SC #2	8	7
SC #3	4	7
DS #1	6	7
DS #2	4	6
DS #3	4	6
RR #1	6	7
RR #2	4	6
RR #3	6	7
SP #1	7	6
SP #2	4	6
SP #3	4	5
SP #4	4	6
SP #5	4	3
BD #1	4	6
LB #1	4	3

Substrate Code

1 = organic
2 = clay (0.00024-0.004mm)
3 = silt (0.04-0.062mm)
4 = sand (0.062-2.000mm)
5 = very fine gravel (2-4mm)
6 = fine gravel (4-8mm)
7 = medium gravel (8-16mm)
8 = coarse gravel (16-32mm)
9 = very coarse gravel (32-64mm)
10 = small cobble (64-128mm)
11 = large cobble (128-256mm)
12 = small boulder (256-512mm)
13 = medium boulder (512-1,024mm)

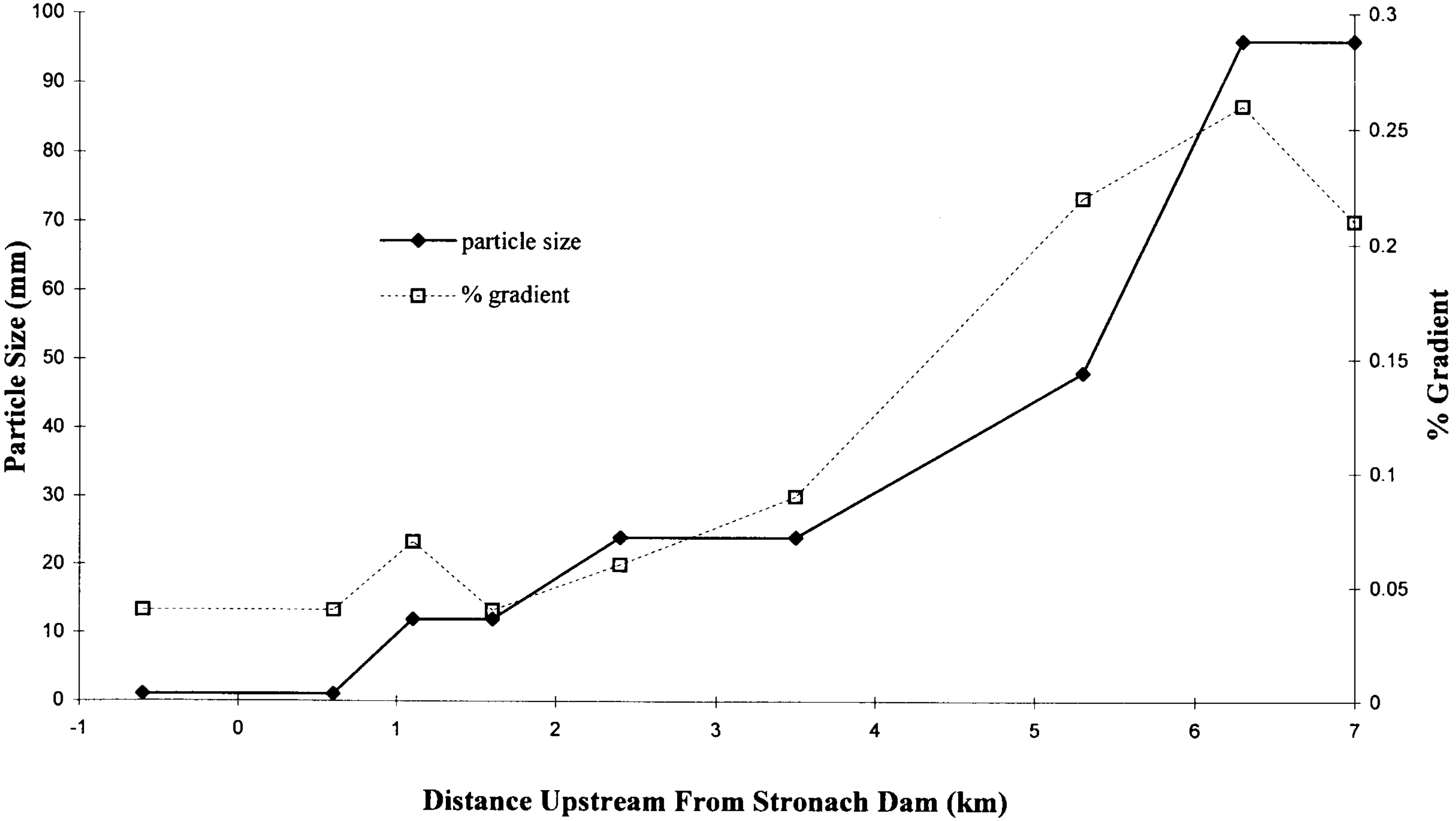


Figure 23. Longitudinal trends in particle size and gradient in the Pine River, 1996.

Fish Abundance

Fish densities (number/hectare) and their associated confidence intervals for rainbow trout, brook trout, brown trout, and white suckers are reported for each of the ten sampling sites in Table 9. The density estimates in each of the three zones were combined to determine mean density of each species by zone. These figures along with associated standard deviations are reported in Table 10 and graphically in Figure 24. Comparison of fish abundance between the three zones shows mean density of brown trout increases in the direction from downstream to upstream (Table 10); mean density of brook trout also increases; mean density of rainbow trout is higher upstream from the dam than downstream, but densities are similar between the impacted and non-impacted zone; and white sucker density decreases (Table 10) in the direction from downstream to upstream.

Another comparison was made between the three zones after combining the three species of trout into a single category (Figure 25). The trend becomes more apparent with the trout grouped together. Numbers of trout steadily increase in an upstream direction, while numbers of white suckers decrease. An analysis of variance (ANOVA) was performed on log-transformed data to determine if trout densities were statistically different between the three habitat zones. When trout are combined into a common category, differences in trout densities were detected between the three zones at a significance level of p=.0548. An ANOVA performed on white suckers concluded that white sucker density between the three zones is significantly different (p=.001).

Table 9. 1997 fish density with 95% confidence intervals by site.

Site	Zone	Rainbow Trout number/ha	Brook Trout number/ha	Brown Trout number/ha	White Sucker number/ha
SBEE	Non-impacted	62	88	40	0
CI		(57, 84)	(84, 106)	(39, 49)	-
LCUP	Non-impacted	6	25	19	22
CI		(5, 69)	(20, 67)	(17, 22)	(20, 25)
LCDN	Non-impacted	0	8	16	17
CI		-	-	(15, 47)	(15, 30)
BWUP	Non-impacted	14	28	53	3
CI		(12, 15)	(27, 30)	(50, 62)	-
BWDN	Impacted	20	11	21	44
CI		(15, 37)	(10, 22)	(20, 27)	(27, 89)
SCUP	Impacted	27	13	38	48
CI		(27, 32)	(12, 15)	(37, 47)	(47, 52)
RRUN	Impacted	8	3	61	37
CI		(7, 20)	-	(20, 378)	(37, 42)
SPND	Impacted	24	8	19	118
CI		(20, 37)	(7, 10)	(17, 25)	(84, 153)
LBUP	Downstream	0	0	20	154
CI		-	-	(17, 20)	(96, 319)
LBDN	Downstream	9	0	4	160
CI		-	-	-	(108, 286)

Table 10. Average fish density by zone shown with standard deviations.

Zone	Rainbow Trout number/ha	Brook Trout number/ha	Brown Trout number/ha	White Sucker number/ha
Non-impacted	19	36	39	8
SD	28.0	34.8	17.6	10.7
Impacted	21	9	30	70
SD	8.4	4.4	19.6	37.6
Downstream	5	0	11	157
SD	6.1	0	10.5	4.2

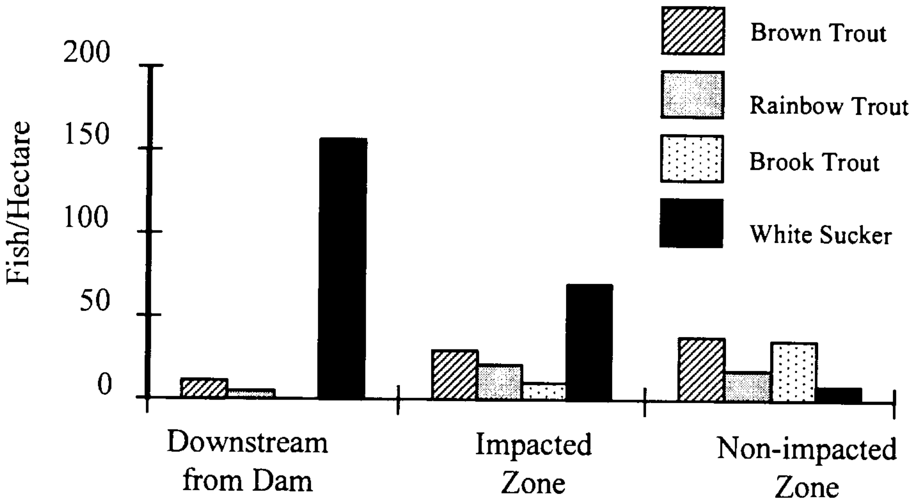


Figure 24. Fish density by zone.

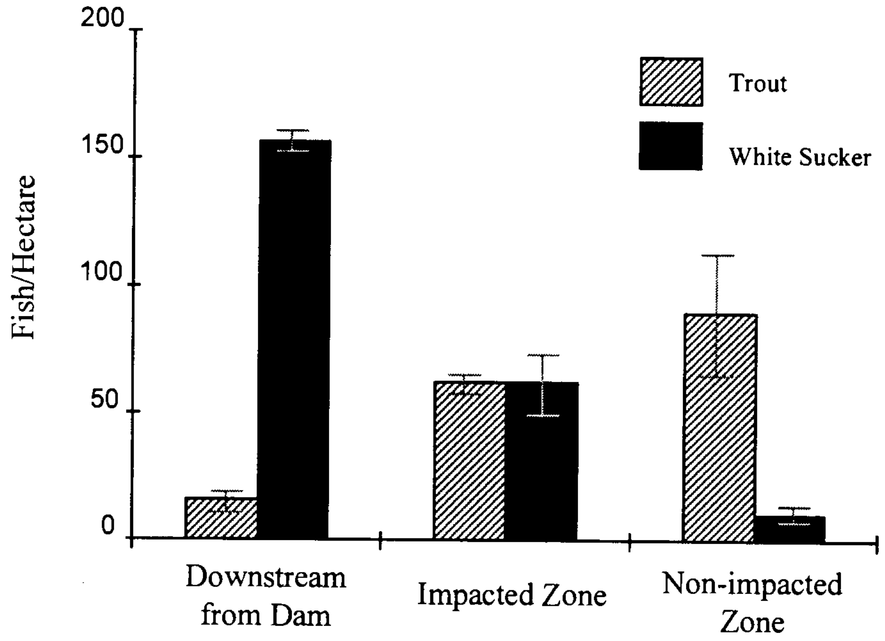


Figure 25. Fish density (± 1 SE) by zone with all three species of trout combined into a common category.

Relative age distribution of rainbow trout as they appear within the three zones are shown in Figure 26. Few young of the year rainbow trout were captured during the population census, and most of the fish were age one or two. A chi-square test suggests that the age structure is significantly different for rainbow trout among all three zones (p=.012). Brown trout age distributions can be seen in Figure 27. Young of the year brown trout were evident upstream from the dam, but no young of the year brown trout were encountered downstream from the dam. Age three and age four brown trout were encountered more frequently downstream from the dam than younger brown trout. The opposite was true for brown trout upstream from the dam; here it was more common to encounter brown trout younger than age 3. A chi-square analysis of brown trout age distribution suggests no significant difference (p=.368) between the impacted and non-impacted zone, but the age distribution for brown trout downstream from the dam is significantly different (p=.001) from brown trout upstream from the dam. White suckers were most commonly age zero or age one throughout the study reach (Figure 28). There was no significant difference detected in age distribution for white suckers among the three zones (p=.365).

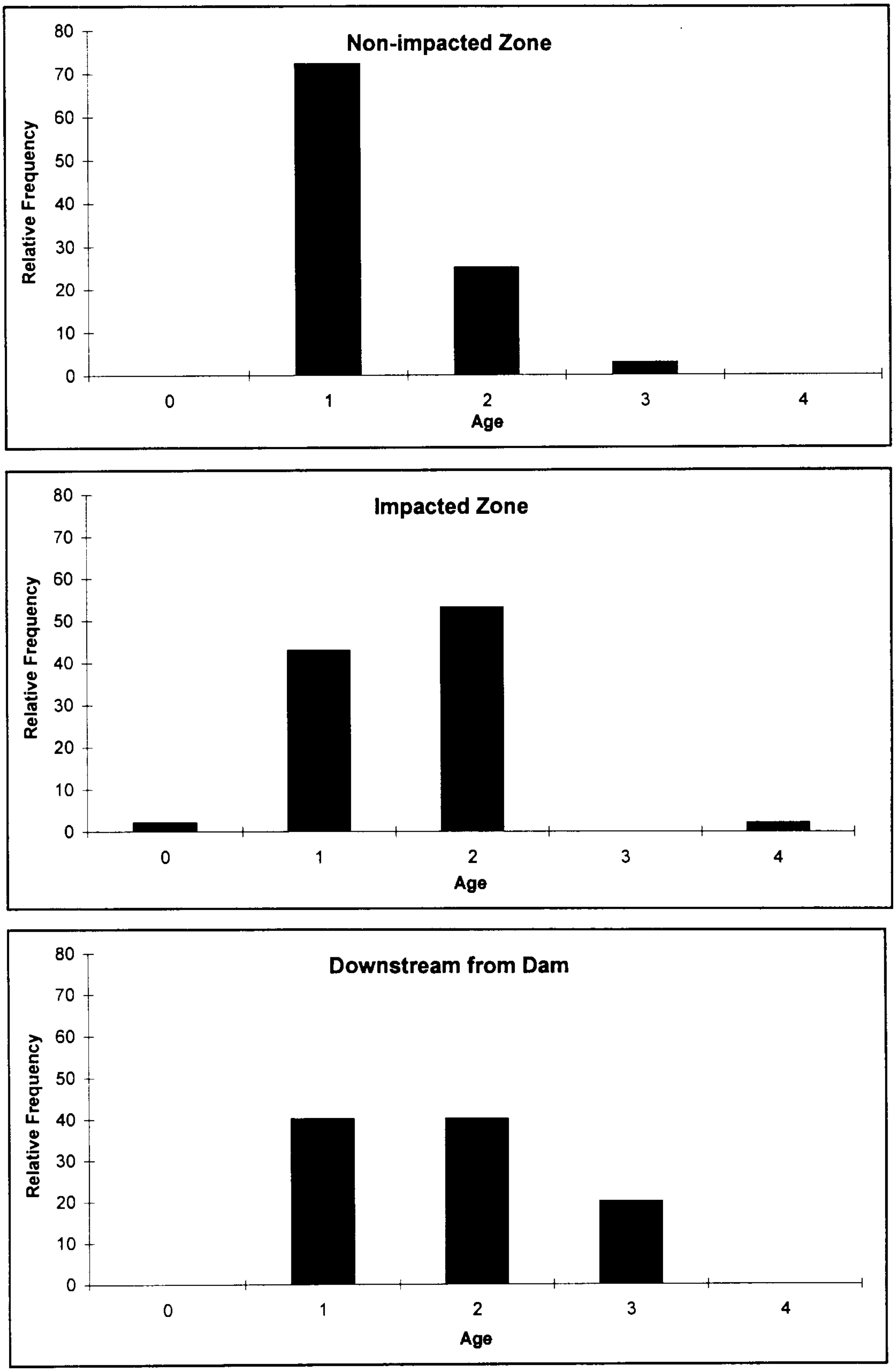


Figure 26. 1997 rainbow trout age distribution by zone.

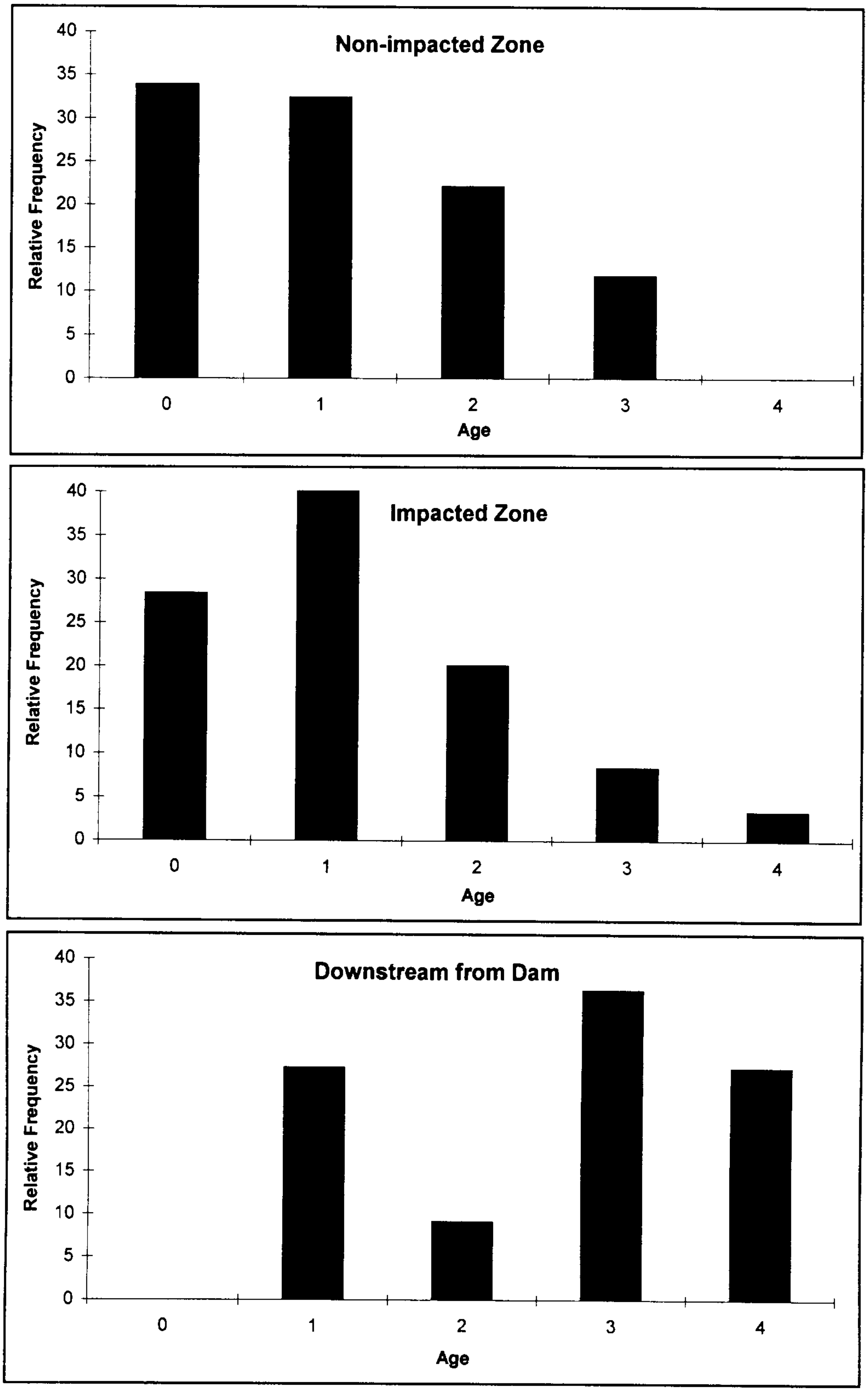


Figure 27. 1997 brown trout age distribution by zone.

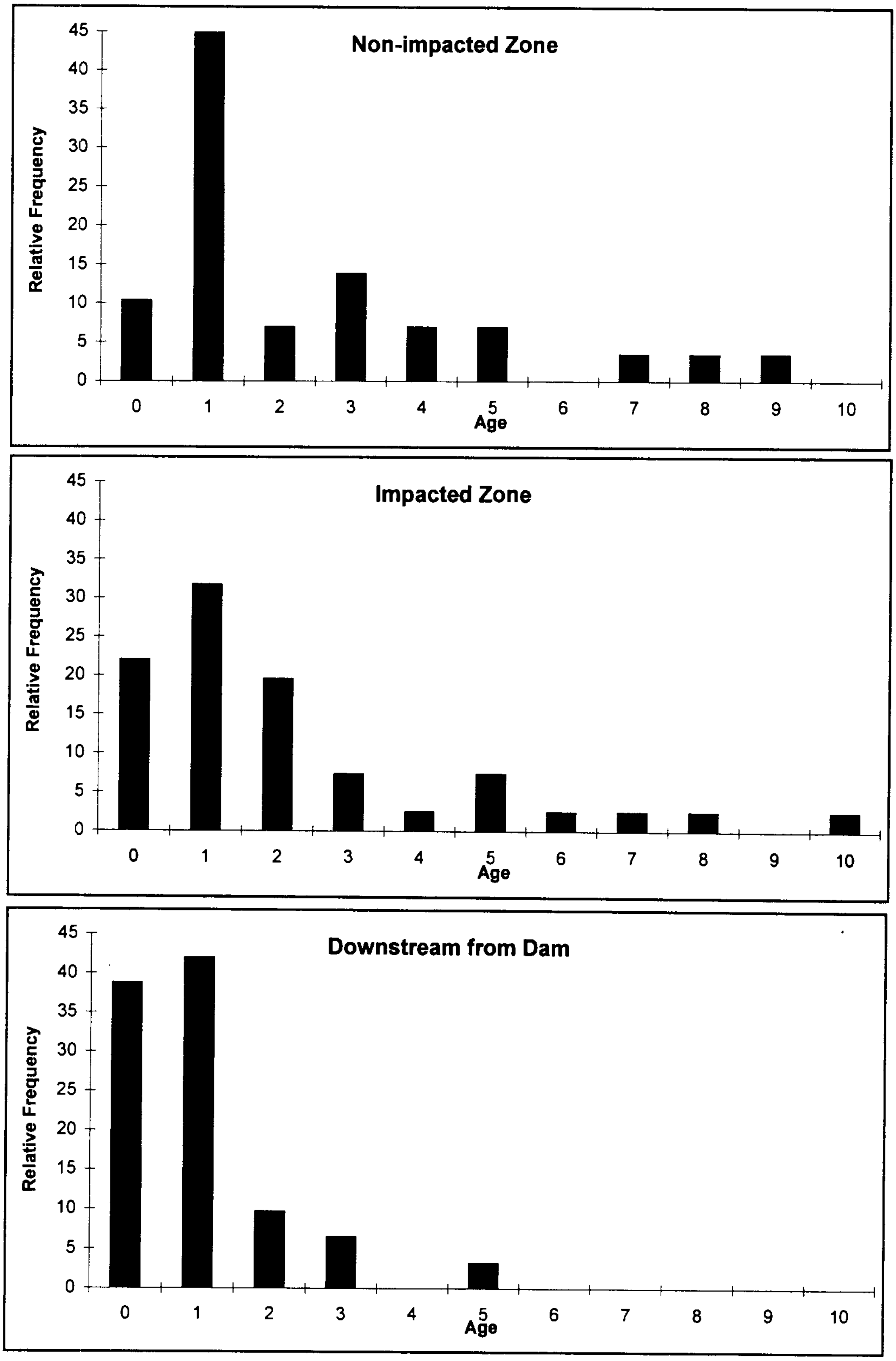


Figure 28. 1997 white sucker age distribution by zone.

Fish Growth

Rainbow Trout. The linear regression relating fish total length to scale radius is shown in Figure 29 for rainbow trout. The y-intercept determined from this regression is 32.75 mm. This was used to back-calculate rainbow trout length using the Fraser-Lee equation (Francis 1990), $L_i = 32.75+[(L_c-32.75)\ S_i/S_c]$. The analysis was performed on 151 rainbow trout captured in 1996 and 1997. Rainbow trout ranged in age from 0 to 4 years, with most fish being age 1 and age 2 (Figure 26). Annual growth increments and mean lengths determined from back-calculations for these fish are given in Table 11.

Table 11. Rainbow trout annual growth.

Age	Mean Growth Increment (mm)	Average Total Length (mm)	(n)
1	105.4	105.4	67
2	106.6	213.1	67
3	76.3	286.9	5
4	29.3	336.2	1

A regression of annual incremental growth on length at previous age was computed for rainbow trout in each zone (Figure 30). A signifcant relationship between these two variables (downstream zone, p=0.019; impacted zone, p=0.081; non-impacted zone, p=0.032) suggests that length accounts for some of the difference in incremental growth. An ANCOVA, using length at previous age as a covariate, indicated no significant difference (p=0.225) in incremental growth between the three zones.

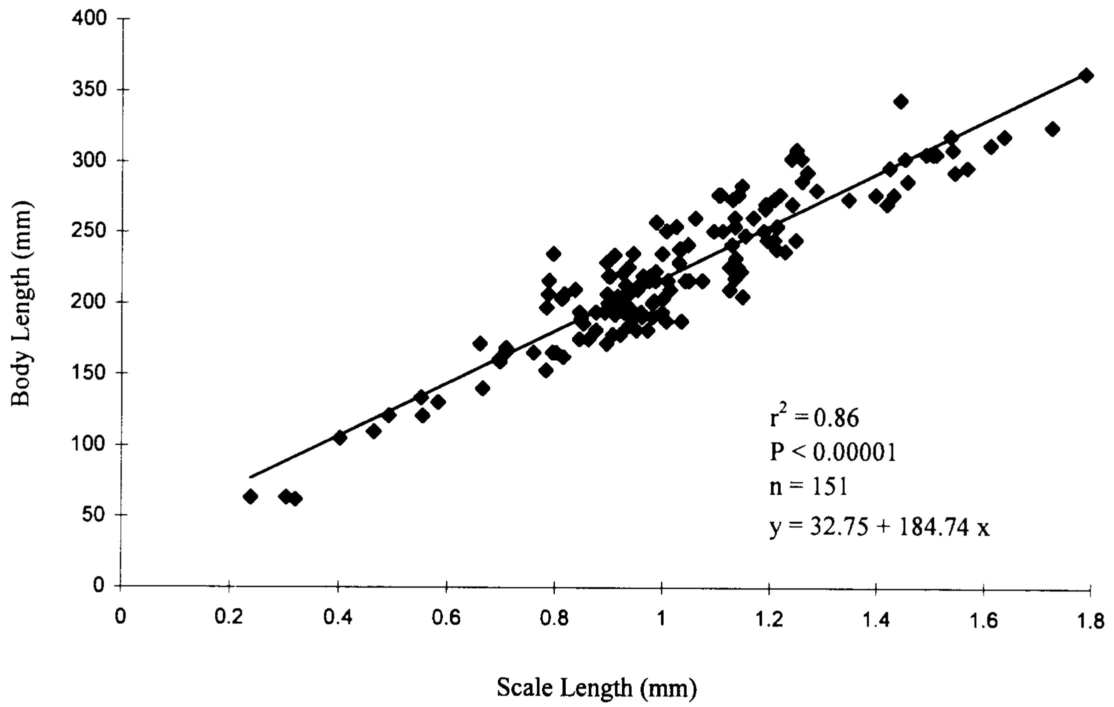


Figure 29. Rainbow trout regression showing body-scale relationship pooled from 1996 and 1997.

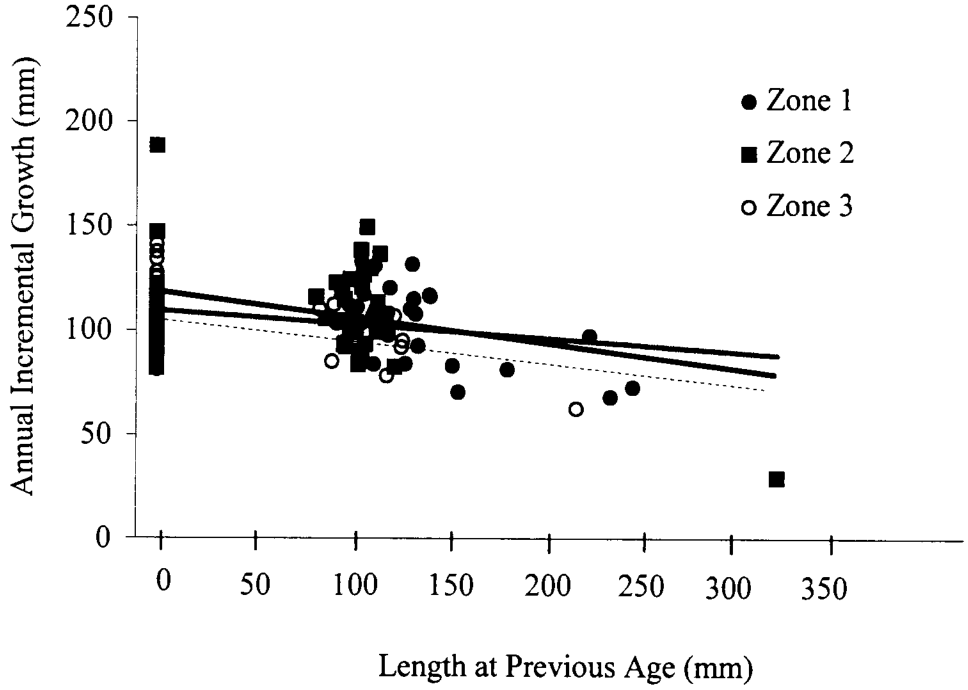


Figure 30. Rainbow trout incremental growth regressed on length at previous age for each zone. Zone 1 represents fish downstream from dam, Zone 2 represents fish within the impacted zone, and Zone 3 represents fish in the non-impacted zone.

Brown Trout. A linear regression relating fish total length to scale radius was done on 256 brown trout captured in 1996 and 1997. This is shown graphically in Figure 31. For brown trout the y-intercept was calculated to be -6.98 mm. However, since -6.98 mm was not found to be significantly different than zero, zero was used as the y-intercept. The equation used to back-calculate brown trout length was, $L_i= 0+[(L_c-0)\ S_i/S_c]$. Brown trout ranged from age zero to age four, with the majority of fish being age one and numbers steadily declining with each age class (Figure 27). Annual growth increments and mean lengths determined from back-calculations for these fish are reported in Table 12.

Table 12. Brown trout annual growth.

Age	Mean Growth Increment (mm)	Average Total Length (mm)	(n)
1	120.3	120.3	84
2	134.4	256.8	49
3	89.8	367.6	27
4	71.4	451.2	10

A regression of annual incremental growth on length at previous age was computed for brown trout in each zone (Figure 32). The relationship between these two variables (downstream zone, p=0.006; impacted zone, p=0.058; non-impacted zone, p=0.006) suggests that length at age accounts for some of the difference in incremental growth.

An ANCOVA, using length at previous age as a covariate, indicated no significant difference (p=0.252) in incremental growth between the three zones.

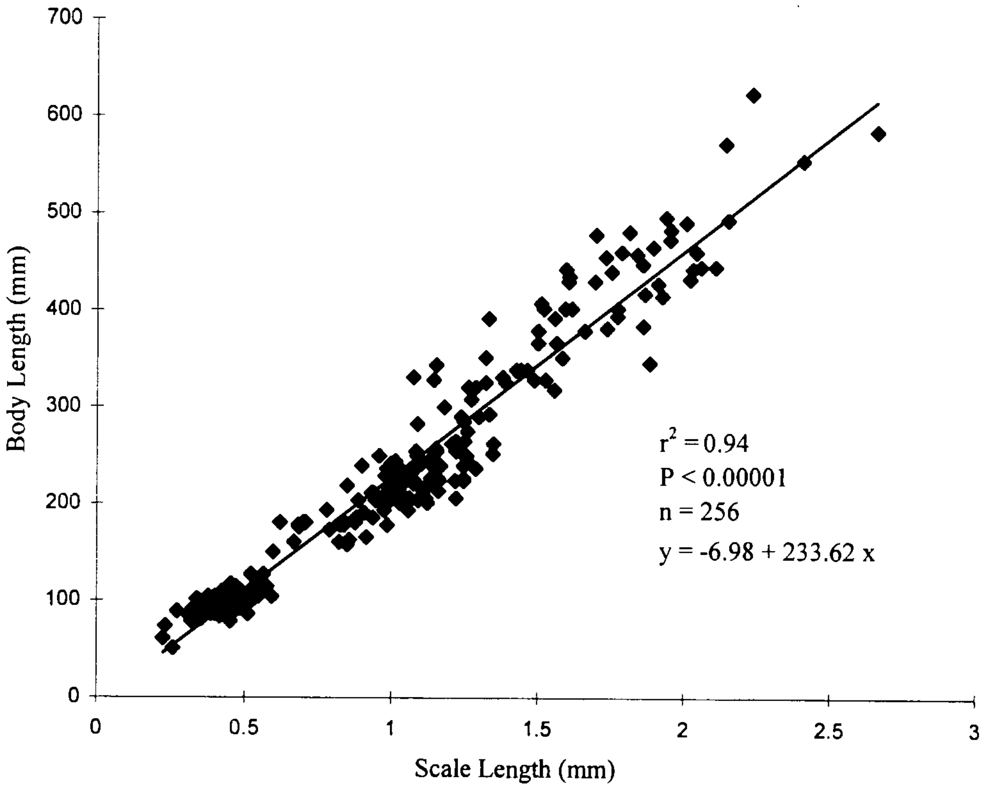


Figure 31. Brown trout regression showing body-scale relationship pooled from 1996 and 1997.

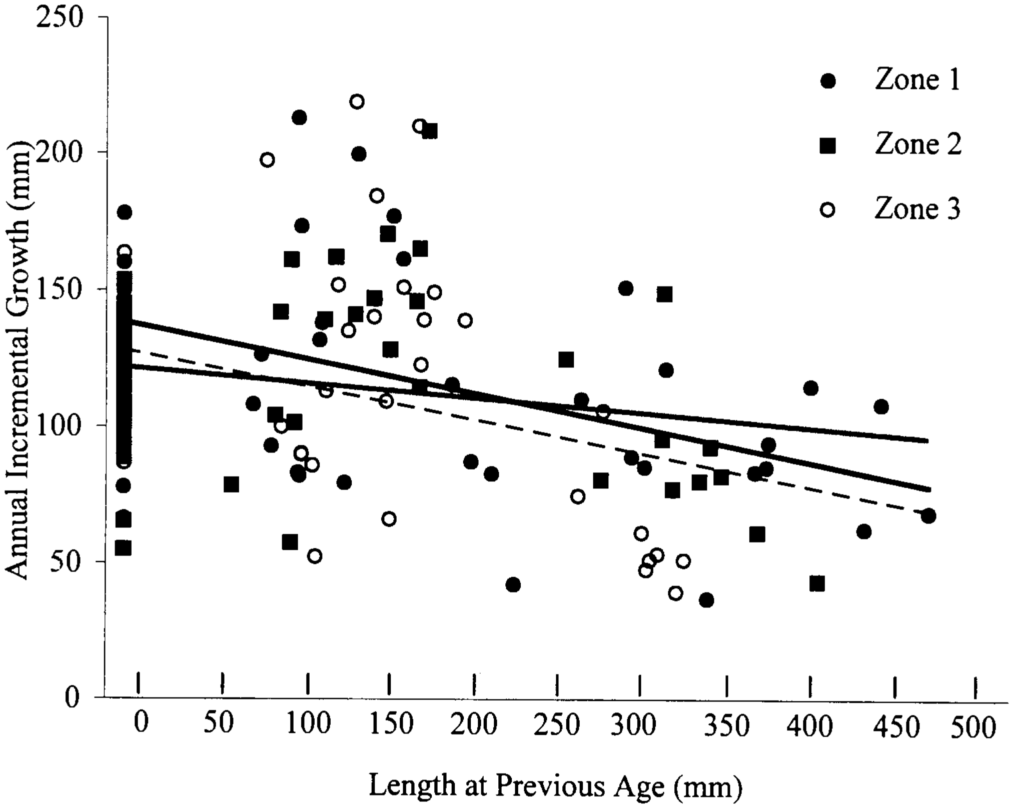


Figure 32. Brown trout incremental growth regressed on length at previous age for each zone. Zone 1 represents fish downstream from the dam, Zone 2 represents fish in the impacted zone, and Zone 3 represents fish in the non-impacted zone.

White Suckers. A linear regression relating fish total length to fin-ray radius was performed on 149 common white suckers captured in 1997. This is shown graphically in Figure 33. For white suckers the y-intercept was calculated to be 67.33 mm. The equation used to back-calculate white sucker lengths was, $L_i = 67.33 + [(L_c - 67.33)\ S_i/S_c]$. White suckers ranged from age zero to age twelve, with the majority of fish being age one (Figure 28). Annual growth increments and mean lengths determined from back-calculations for these fish, ages one to ten are reported in Table 13.

Table 13. White sucker annual growth.

Age	Mean Growth Increment (mm)	Average Total Length (mm)	(n)
1	143.6	143.6	46
2	55.1	199.8	33
3	63.7	266.7	16
4	62.7	300.5	8
5	36.9	379.0	10
6	30.5	412.2	3
7	65.8	490.2	3
8	25.5	448.3	5
9	34.9	456.3	5
10	18.2	462.4	4

A regression of annual incremental growth on length at previous age was computed for white suckers in each zone (Figure 34). The relationship between these two variables ($p<0.00001$ in all three zones) suggests that length at age accounts for some of the difference in incremental growth.

An ANCOVA, using length at previous age as a covariate, indicated incremental growth was similar ($p=0.615$) between the three zones.

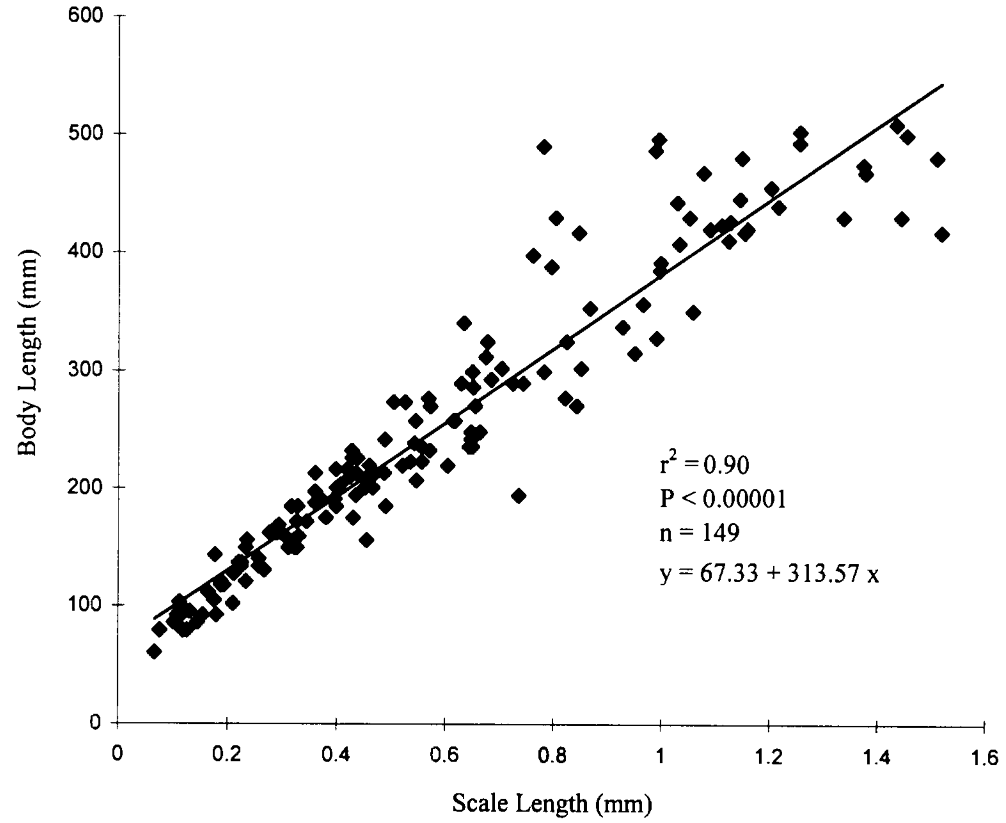


Figure 33. White sucker regression showing body-fin ray relationship from fish captured in 1997.

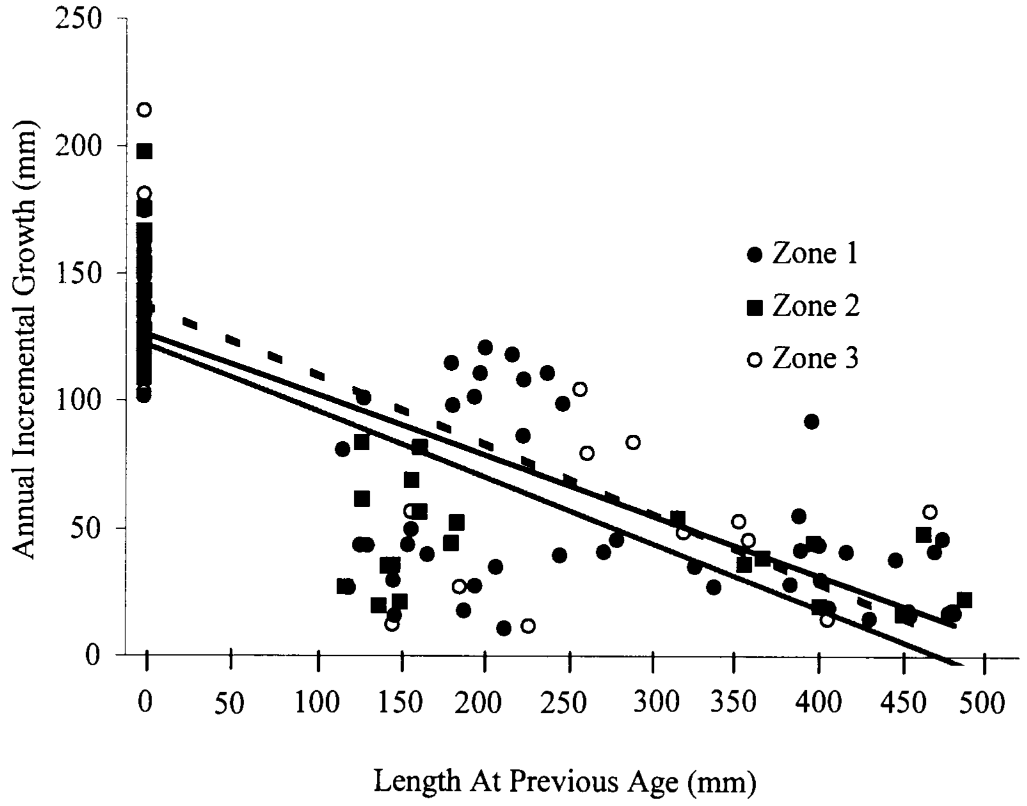


Figure 34. White sucker incremental growth regressed on length at previous age for each zone. Zone 1 represents fish downstream from the dam, Zone 2 represents fish in the impacted zone, and Zone 3 represents fish in the non-impacted zone.

Although, differences in growth determined from back-calculated lengths within habitat zones was not detected in either of the trout species, their length at capture is greater than average for Michigan trout (Tables 14 and 15). Conversely, the white suckers in the Pine River are not growing as well as the average white sucker in Michigan as indicated by lengths at capture, except for the age zero and age seven fish (Table 16).

Table 14. 1996 and 1997 Pine River rainbow trout length (mm) at capture compared to Michigan state averages for stream-dwelling rainbow trout (Laarman et al. 1981). All fish were captured during the growing season.

Age	Pine River	Michigan State Average
0	61	56
1	201	160
2	279	213
3	323	262
4	363	--

Table 15. 1996 and 1997 Pine River brown trout length (mm) at capture compared to Michigan state averages for stream-dwelling brown trout (Laarman et al. 1981). All fish were captured during the growing season.

Age	Pine River	Michigan State Average
0	72	76
1	218	163
2	341	229
3	434	292
4	542	384

Table 16. 1997 Pine River white sucker length (mm) at capture compared to Michigan state averages for lake-dwelling white suckers (Laarman et al. 1981). All fish were captured during the growing season.

Age	1997 Length (mm)	Michigan State Average (mm)
0	107	89
1	191	218
2	244	305
3	312	363
4	394	414
5	419	429
6	439	460
7	493	460

DISCUSSION

The impacts of dams on river ecosystems have been studied extensively (Brune 1953, Hammad 1972, Lignon et al. 1995, Parker 1980, Petts 1980, Ward and Stanford 1989, Williams and Wolman 1984). Most of these studies concentrate on aspects affecting a river downstream from a dam. Little attention has been given to impacts a dam might have in the situation of an impoundment silted in. Yet, by their nature, all dams will eventually become obsolete for hydropower operations. In the situation of Stronach Dam, the one-time 26 hectare reservoir, has essentially served as a sediment trap over the years with the effects seen for 3.8 kilometers upstream from the dam. Hydrologic changes have occurred within the greater Manistee River system (e.g. Tippy Dam) since the closure of Stronach Dam, that make restoration of the Pine River to pre-dam conditions impossible. Nonetheless, understanding the processes which explain the morphologic characteristics of a river aids in evaluating the complex changes in species interactions which may occur as a result of a dam removal.

In the few documented cases where dams have been deliberately removed, e.g. Fort Edward Dam on the Hudson River, NY in 1973, Newaygo Dam on the Muskegon River, MI 1969, Woolen Mills Dam on the Milwaukee River, WI in 1988, Salling Dam on the AuSable River, MI in 1992, Columbia Falls Dam on the Pleasant River, ME in 1989 (Shuman 1995a), few studies have investigated the response of fish to the removal. As many hydroelectric dams come up for relicensing, it is expected that an increasing number of them will be scheduled for removal. Management decisions regarding dam removals need to give consideration to the ecological impacts a removal may have. This requires pre-planning to include a baseline evaluation of the physical and biological aspects of the system. While each dam presents a unique set of circumstances, the Stronach Dam project is an attempt to comprehensively document the ecological impacts a dam removal will have, and serves as a reference for managers who are faced with dam removals in the future.

Habitat. Initial measurements of meso-scale habitat types made in 1995 clearly show a difference between the three habitat study zones: non-impacted, impacted, and downstream zones (Figure 5). The diversity of habitat types increases at a point approximately 3.8 kilometers upstream from the dam. These findings agree with those described by Hansen (1971), who noted that Stronach Dam had influenced the stream channel with an increase in sediment occurring up to 2.8 miles upstream from the dam.

The pebble count analysis shows an overall trend for particle size to decrease from upstream to downstream (Figures 15-20). Sand, which is prevalent throughout the river, becomes the dominant substrate type near the dam and downstream from the dam. A chi-square analysis suggests that differences in the distribution of particle size occurred between 1996 and 1997 at sites: LC #1, BW #3, RR #3, and SP #5. At two of these sites (BW #3 and RR #3), trees had fallen into the river upstream from the transect which may account for the differences. Site SP #5 is the site directly upstream from the dam. The changes in substrate size at this site may be due to the installation of the water control structure and the excavation that was involved in that process. Any changes in streambed particle size, however, may be due to natural variation which occurs in a dynamic fluvial system.

Hansen's (1971) study of sediment transport along a 26-mile stretch of the Pine River reported a relationship between major classes of sediment on the streambed to the slope of the water surface. My study shows a similar trend (Figure 23). As gradient decreases from the upstream sites to sites within the impacted zone, substrate particle size also decreases. This can be attributed to the high-energy water, associated with the higher gradient, being able to transport small and less stable particles. This supports the assumption that when the dam is removed, a coarsening of the substrate will result within the impacted zone, as sediment moves downstream.

The streambed at sites within the non-impacted zone is well armored with gravel or cobble. Therefore, I did not expect to detect changes in streambed elevation between years 1996 and 1997 at these sites (Figures 6-8). It is unlikely that these sites will change in response to the dam removal. Major changes that can be directly related to the dam removal are not evident from the streambed profiles of the impacted zone (Figures 9-13). However, within the impacted zone, small differences in streambed elevation can be seen in some of the Stronach Pond series' transects (Figure 13). It should be noted that at the time the 1997 survey was completed, the dam had been lowered 2 ½ feet. Therefore, we wouldn't expect any changes in elevation greater than 2 ½ feet to be associated with the dam removal. Indeed, elevation changes larger than 2 ½ feet were not detected (Table 5) at any sites except at SP #5. This site is upstream from, and adjacent to the dam. The degradation of the streambed by 5.49 feet at this site is associated with excavation and installation of the water control device. Sites downstream from the dam (Figure 14 and Table 5), have begun to show some aggradation. This is the response we would expect as sediment is moved downstream with the lowering of the dam. It is important to recognize, however, that there are indications that the streambed downstream from the dam is influenced by hydro operations at Tippy Dam. Most notably, in a 1992-93 incident, where the water level at Tippy Dam was lowered 8 to 10 feet for repairs, surface water elevation in the tailrace waters at Stronach Dam lowered in elevation by 2.7 feet (Battige 1996). Simultaneously, about a kilometer downstream from Stronach Dam, fish habitat enhancement structures that had been submerged several feet below the water surface were exposed by the subsequent decrease in streambed elevation. Understanding that the elevation of the streambed downstream from Stronach Dam is partially influenced by activity at Tippy Dam, reduces the degree of certainty we can ascribe changes detected in streambed elevation to the lowering of Stronach Dam.

Expected Long-term Changes to Habitat. Geomorphological changes that occur as a result of the dam removal, may take years, even decades, after the dam is removed before reaching a state of equilibrium. It will take even longer to be reflected in fish populations. Equilibrium has been described as a state when the average elevation of the streambed is maintained over a period of time because the inflow of sediment is equal to the outflow (Frenette and Harvey 1973). Under this definition, the Pine River at Stronach Dam has been in a state of equilibrium since 1950. Sedimentation models estimate that conditions of sediment transport equilibrium had been reached at that time and that the sediment trapping efficiency of Stronach Pond has since been reduced to zero (LMSE 1992a). Frenette and Harvey also explain that true equilibrium is rarely achieved in natural rivers since rivers tend to continually wear the land surface down to a base level (which is ultimately sea level), and that these changes typically occur on a geologic time scale. Activities induced by man can result in sudden changes so that it is unfitting in the case of a dam removal to consider equilibrium occurring only at a geologic time scale. The term 'dynamic equilibrium' is a more appropriate term in considering the processes involved with a dam removal. Dynamic equilibrium can be explained ecologically as the succession corresponding to the re-establishment of the substratum by organisms. Amoros and Wade (1996) suggest this re-establishment time could take weeks to several years depending on the magnitude of the disturbance and the regeneration time for the taxa involved. This ecological succession can be complicated by the random occurrence of a large flood event. It should be recognized that the situation of a large flood event increases potential for increased sediment transport from bed and bank erosion which could further delay the re-establishment of instream fauna.

In a study done to evaluate the effects of sediment following a dam removal in 1969 on the Muskegon River, Michigan, it was estimated that about 40% of the impounded sediment was washed downstream immediately after the removal while the rest of the sediment moved downstream at a rate of 1.6 km per year (Shuman 1995a). Similarly, the removal of the Woolen Mills Dam on the Milwaukee River resulted in most of the sediment within the 2.4 kilometer stretch of former impoundment to be scoured downstream within six months. After this scouring, the streambed uncovered a gravel and rubble substrate (Shuman 1995a). Shuman (1995b) suggests that following a dam removal, it may take 50 to 80 years for the sediment to totally flush through the river system.

The changes in channel morphology associated with the Stronach Dam removal are expected to cause downcutting and change the slope of the channel where deposition has occurred through the years. This will, consequently, increase the velocity of water in the affected areas. In turn, a dynamic series of streambed aggradation and degradation processes along the river can be expected as sediment is transported. Under these environmental circumstances, the biotic community will not comprehensively reflect the impacts of the disturbance until the river channel physically adjusts into a stable structure (Petts 1987).

Fish Abundance. The detection of trout abundance increasing in an upstream direction corresponds to the observation that habitat quality increases for trout in that same direction. The effects of sand, as found in the impacted and downstream zones, is well-documented (Cordone and Kelley 1961, Everest et al. 1987, Hansen 1971, Waters 1995). Sediment can reduce spawning success by covering gravel, decreasing food supplies for fish due to scouring aquatic insects from substrate or burying desirable substrate, reducing pool depths thereby decreasing carrying capacity of the stream for larger fish, reducing survival rates of eggs, decreasing vertical relief associated with the streambed used by fry as cover, and by changing the albedo of the streambed making fish more vulnerable to predation (Alexander and Hansen 1986).

The conjecture that numbers of trout will diminish in response to reduced habitat quality is substantiated by previous studies. Alexander and Hansen (1983, 1986) found sand deposition in Hunt Creek, Michigan, was related to decreased abundance of trout in all size and age groups. Five years after the removal of the Woolen Mills Dam in Wisconsin, Kanehl et al. (1997) noted improvement in fish habitat quality in the area that had been impounded and an increase in abundance of smallmouth bass (*Micropterus dolomieui*). Similarly, Hunt (1976) found that numbers and biomass of brook trout in a Wisconsin stream increased and peaked six years after a stream habitat enhancement project. This substantiates the need for long-term monitoring following the dam removal. Alexander and Hansen hypothesized that the mechanism responsible for increased densities of trout was the effect that sand had on the microhabitat and the resulting reduced survival of early life stages. In spite of increased abundance of trout, Alexander and Hansen found growth rate was not affected by sand deposition. They suggest that the decrease in benthos production associated with sandy substrate is negated by the decreased number of trout competing for that resource. It is possible that the same phenomenon is taking place in the Pine River. The fact that there was no difference detected in trout growth rate, in spite of differences in trout densities between the three habitat zones, indicates a decrease in competition for food due to lower abundance of trout in the areas were habitat is affected by sand.

It is likely that movement of sand and sediment from the impacted zone, as is expected with the dam removal, will increase the carrying capacity of the Pine River. In a Minnesota stream, Elwood and Waters (1969) reported a sharp decrease in a brook trout population after a severe flood filled pool areas with sand, decreasing space suitable for trout.

The presence of rainbow trout and brown trout throughout the study stretch suggests that environmental and habitat conditions are not limiting. The lack of brook trout downstream from the dam indicates a less than optimal habitat in that zone. It is reasonable to believe that the sandy substrate is not conducive to support the benthos these fish require. However, if benthos were the limiting factor, it would follow that brown trout and rainbow trout, which exhibit similar feeding behavior as brook trout (Bowlby and Imhof 1989, Carlander 1969), would also be absent downstream from the dam. It is possible that brook trout are limited by resting space downstream from the dam. Brook trout young-of-the-year are generally found in shallow riffles and as they increase in size they seek cover in deeper pools with undercut banks (Saunders and Smith 1962). Downstream from the dam, where the river is considerably wider, cover in the form of overhead shade and undercut banks is limited. If brook trout were to occupy the downstream zone, they would have to compete with other trout for available cover. Fausch and White (1981) demonstrated that brown trout were able to outcompete brook trout for resting positions associated with available cover in a Michigan stream.

In addition, the substrate downstream from the dam is not suitable for brook trout spawning. Brook trout require gravel substrate for spawning with gravels 30-80 mm being considered optimal (Raleigh 1982). This coincides with substrate particle size categories 9 and 10 on the measuring scale that we used. From Figure 22, it is evident that this substrate type is not prevalent except in the area not impacted by the dam. In contrast, optimal substrate size for brown and rainbow trout spawning includes smaller particle sizes than that for brook trout. Brown trout prefer gravel 10-70 mm, but will utilize substrate 3-100 mm in size (Raleigh et al. 1986). This corresponds to substrate categories 5-10 with preference for 7-10 in Figure 22. Rainbow trout <500 mm (as found in the Pine River), on average prefer substrate particle size in the 15-60 mm range (Raleigh et al. 1984). This is represented in Figure 22 by substrate categories 7-9. Under these conditions, brown trout and rainbow trout are able to utilize habitat both in the impacted zone and the non-impacted zone for spawning.

Brook trout abundance throughout the study area is inversely related to the presence of white suckers. This may be a reflection of the autoecology of these fish and their specific habitat requirements, but it may also be a result of a competitive interaction between these two species. Magnan (1988) and Tremblay and Magnan (1991) reported that the presence of white sucker had an impact on brook trout in terms of changes in food habits (a shift from benthic invertebrates to zooplankton) and a decrease in mean annual yield. He attributed these effects to the intensity of competition between these species. Flick and Webster (1992) found that elimination of white suckers from Adirondack waters improved brook trout standing crop from 0.3 lb./acre to 8-10 lb./acre.

White suckers appear to thrive in the downstream reaches of the Pine River. Compared to the upstream zones, they face the least potential of competition from trout here. White suckers are morphologically better adapted to feed on zoobenthos than trout (Magnan 1988) and, being opportunistic feeders, are less limited by the degraded habitat downstream from the dam.

White suckers prefer gravel substrate for spawning with relatively swift, shallow (20 to 30 cm) water. Spawning in rivers has been reported at current velocities between 14 cm/sec to 90 cm/sec. However, current velocities between 30 to 59 cm/sec are considered excellent for spawning white suckers (Twomey et al. 1984). Given the velocity readings I measured (Figure 35), the white suckers may find currents sub-optimal for spawning in the upper reaches of our study area. It should be noted that we took our velocity measurements midsummer when water depth and flow is lowest. White suckers spawn in April and May when water depth and current velocity may be considerably higher. Additionally, the velocity measurements I've reported are the mean values for an entire transect. Within a given transect there are pockets of slower water near the margins of the stream which, if the substrate were suitable, may be used for spawning.

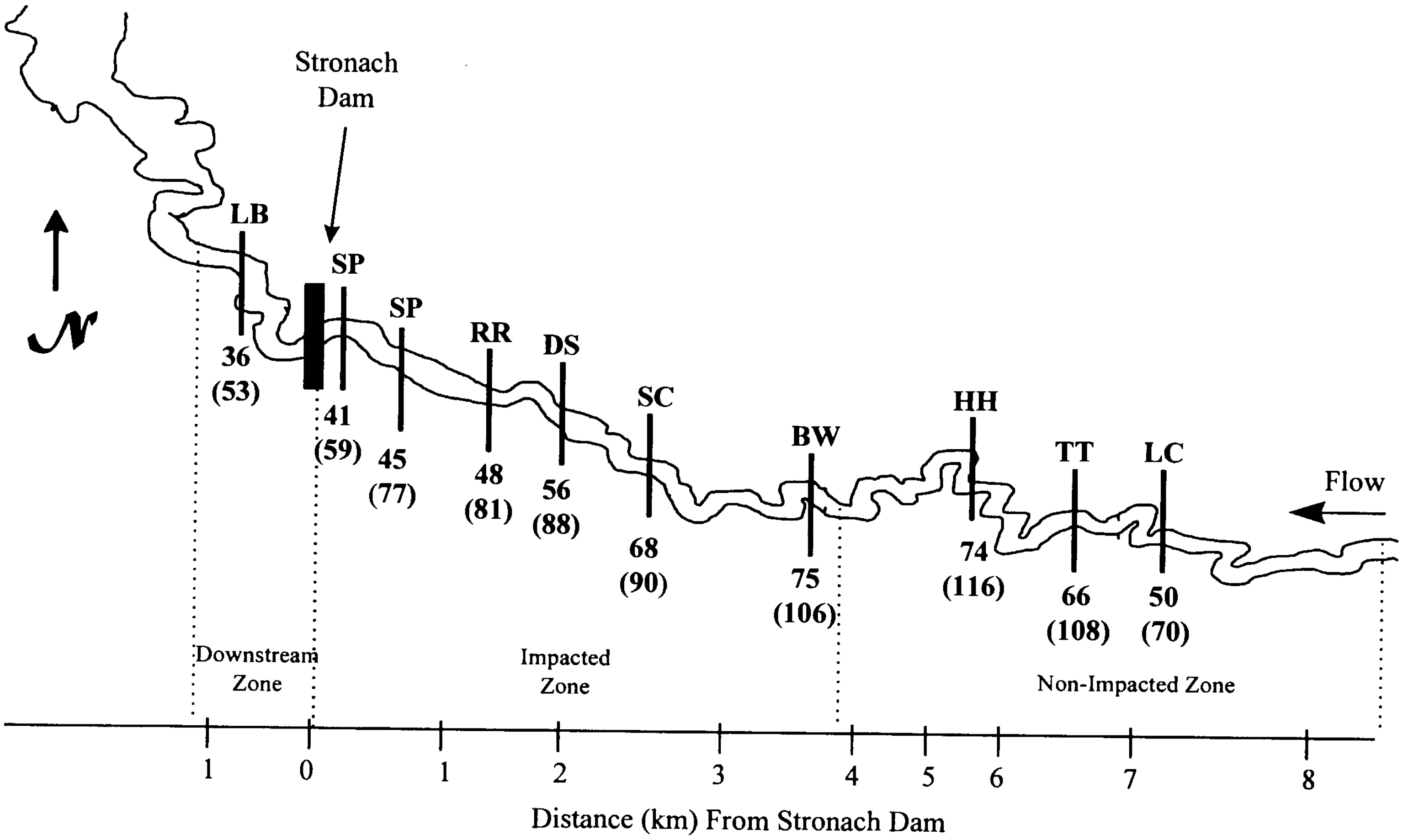


Figure 35. 1996 (pre-dam removal) average velocities (cm/sec) with maximum velocities shown in parentheses.

The question remains whether suckers, after using a particular habitat for spawning, would remain in an area of swift water. White sucker abundance was reported to decrease in response to an increase in water velocity as a result of a habitat restoration project on Rapid Creek, South Dakota. Brown trout abundance simultaneously increased. Initially, the suckers outnumbered the trout nine to one. Four years after the restoration work, brown trout outnumbered suckers nine to one (Ford 1984).

It has been observed that white suckers have a hard time maintaining stability in fast or turbulent water and that adults primarily inhabit areas of slow to moderate velocity (approximately 40 cm/sec). Though smaller fish (<150 mm) occupy a wider variety of habitats than adults (Twomey et al. 1984). These slower (40 cm/sec) current velocity conditions were only encountered within 4.0 meters of the stream edge in transects upstream from the impacted zone, within 8 meters of the stream edge in the impacted zone and within 14 meters of the stream edge downstream from the dam. Relative widths of transects having velocities less than 40 cm/sec are shown in Figure 36. Based on these observations and the contention that white suckers are primarily found in velocities < 40 cm/sec, the amount of space suitable for white suckers becomes very limited in the upstream, non-impacted stretch of the Pine. Given that gradient is expected to increase as the dam is removed, and that velocities will consequently increase, it is unlikely that large numbers of white suckers will seek residence in the rehabilitated waters of the Pine.

Age Distribution of Fish. Age distribution of rainbow trout between the three zones (Figure 26) reveals that the majority (91 percent) of rainbow trout are age one and two. Young of the year rainbows were rarely encountered. A possible explanation for this is that these fish were not susceptible to the electrofishing equipment due to their

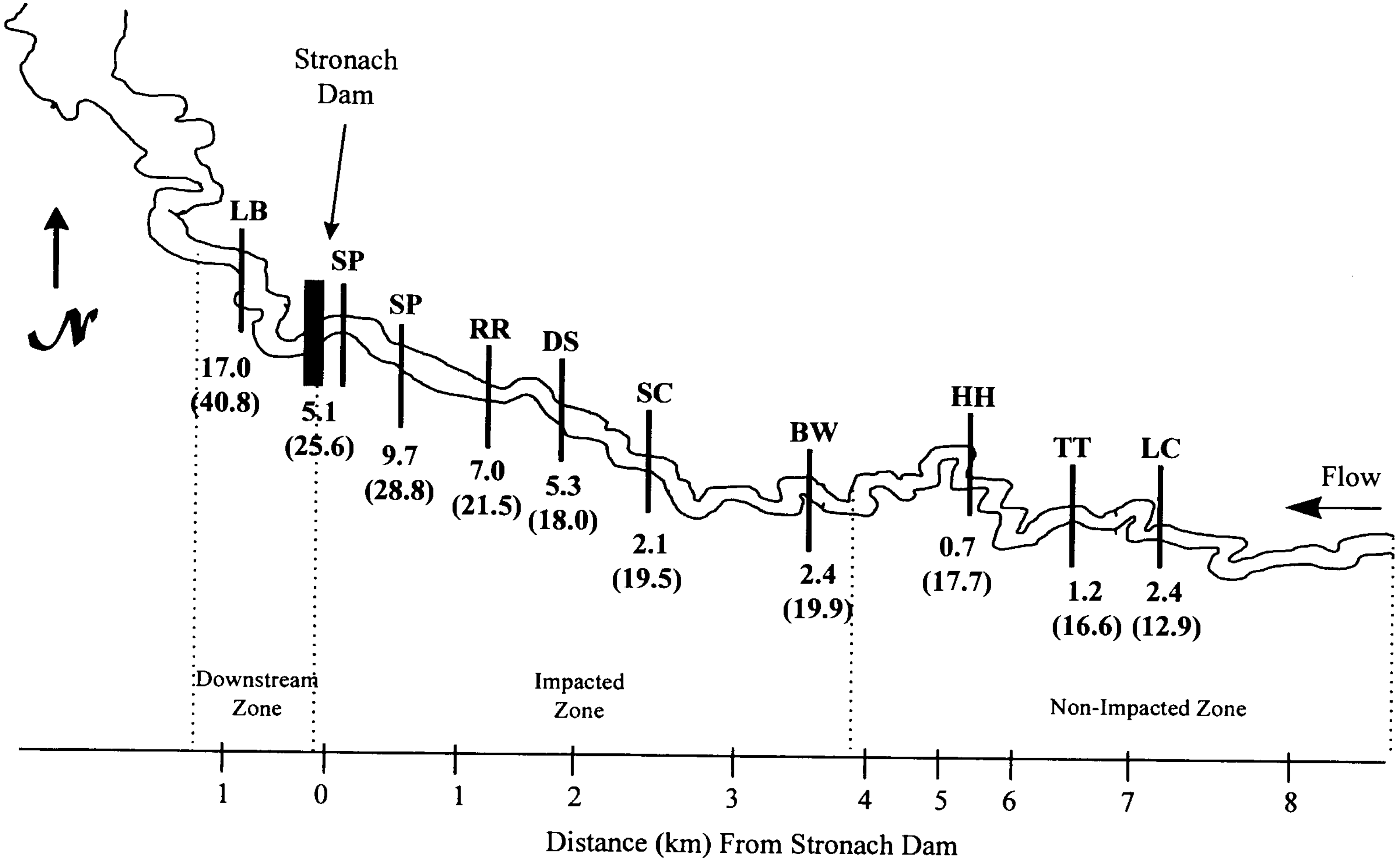


Figure 36. Top figures are the widths (meters) of stream having current velocities <40 cm/sec. Total stream width (meters) is the figure shown in parentheses (1996 conditions).

small size. Of the species studied, rainbow trout are the smallest at the time of year (July/August) we sampled. Alternatively, they may not be present in the mainstem of the Pine at this age. They may be seeking refuge in one of the wetlands or side channels that adjoin the river.

Brown trout young of the year were susceptible to the electrofishing gear. Age zero fish made up 31 percent of the fish upstream from the dam (Figure 27). Age zero and age one fish comprised the majority (67 percent) of the fish upstream from the dam. Conversely, downstream from the dam age zero brown trout were absent and 63 percent of the fish were age three and four. This raises a question as to suitability of the downstream zone for young of the year brown trout and the upstream zones for suitability for age three and age four fish. A possible explanation for the upstream/downstream discrepancy in age distributions may lie in the forage base available in these zones. Many resident fish in Tippy Reservoir use the stretch of the Pine River downstream from the dam, for their spawning migrations. I witnessed seasonal migrations en masse of redhorse suckers (*Moxostoma macrolepidotum* and *M. anisurum*), rock bass (*Ambloplites rupestris*), northern pike (*E. lucius*), trout perch (*Percopsis omiscomaycus*), and white suckers (*C. commersoni*) during their spawning seasons. It is likely that this spawning production creates a forage base suitable for larger trout. If young of the year brown trout do occur downstream from the dam, they may be included in this forage base. During the three years of this study, we did not encounter any redhorse sucker, rock bass, northern pike or trout perch upstream from the dam. It is likely that the age zero brown trout fall prey to these predators downstream from the dam. That an abundance of smaller fish as forage is not available to brown trout upstream from the dam, may preclude these fish from reaching age three and four.

The age distribution of white suckers (Figure 28) suggests that most (63 percent) of the resident white suckers are age zero and age one. These two age groups account for 55 percent of the suckers in the non-impacted zone and a comparable 54 percent of the suckers in the impacted zone. Eighty-one percent of the white suckers downstream from the dam fell into the age zero and age one cohorts while the remaining 19 percent of the downstream white suckers were ages two to five. In the non-impacted and impacted zone the ages two to five fish accounted for 35 percent and 36 percent (respectively) of the suckers. The remaining 8 percent of the suckers upstream from the dam were ages six to ten. While white suckers, ages six to ten were encountered downstream from the dam during the spring spawning season, we did not capture any resident white suckers in this age class during the July/August survey. Because these fish have access to Tippy Reservoir, I speculate that they are seeking more suitable conditions away from the swift current of the Pine and are foraging in the backwater of Tippy Dam during the growing season.

Fish Growth. Fish growth did not vary between the three habitat zones. Even though it is recognized that fish move freely within the river's impacted and non-impacted zones, I anticipated that the differences of habitat quality in the two upstream zones and the isolation of the downstream zone would manifest itself to some degree in fish growth. It should be recognized, however, that the growth increment that I examined, was the most recent 'full' year of growth. Therefore, the growth attained during the season of capture, is not accounted for in the growth increment that I analyzed.

Thus, it is unlikely that a given fish was captured in the same locale that it established its last annual growth increment.

Water temperature often plays a major influence on fish growth. The thermal impact of Stronach Dam has been evaluated (LMSE 1992b) and water temperature is monitored continuously by the Michigan Department of Natural Resources (Krueger 1998). Water temperature data collected from sites within the three habitat zones suggest that Stronach Dam does not impact water temperature since there is no retention time in the backwater area and, that water temperatures do not fluctuate between the three zones represented in the study reach.

An alternative explanation for the undifferentiated growth may be that, because trout are found in higher densities in the non-impacted zone, density dependent effects may be strong enough upstream to negate any additional growth that could be attributed to better habitat conditions.

Overall, the trout are growing well compared to other stream-residing trout in Michigan (Tables 14 and 15). This may suggest that they are not limited by food or space. White suckers, on the other hand, are not growing as well as the average white sucker in Michigan (Laarman et al. 1981), except at ages zero and seven (Table 16). This may suggest that forage is limiting, or that other environmental conditions are not optimal for them. If forage is limiting sucker growth, due to benthos abundance being reduced by the sand in this stream, it is not apparently affecting trout growth. This might be explained by rainbow and brown trout relying more heavily on drift, terrestrials, and fish for their diet. However, we can not state this conclusively without diet and benthos data to support it. Alternatively, the white suckers in the Pine may be expending more energy resisting stream current or competing with trout for optimal space than the average white sucker. It must be noted that the average lengths reported by Laarman et al. (1981) for white suckers in Michigan are not solely based on stream-dwelling fish. Growth differences could be explained by the variation of environmental conditions suckers are exposed to. The higher than average growth of age zero white suckers may be due to the ability of these younger fish to occupy a wider array of habitat (Twomey et al. 1984), and being able to outcompete young of the year trout for optimal foraging ground by virtue of their size advantage at that age. The difference in length of age zero fish may also be a reflection of whether these fish were captured early or late in the growing season. The age seven length estimate is probably a reflection of small sample size in that age category (n=3). It might also be noted that when fish get older, fin rays get difficult to read. The darker zones between annuli become more narrow and annuli merge toward the edge of the ray. This observation is supported by others (Quinn and Ross 1982).

SUMMARY AND CONCLUSIONS

The contrast of higher gradient water with its stable streambed in the upstream reaches of the study area to the sand-covered low gradient channel near the dam is evidence that Stronach Dam has had an impact on habitat quality throughout the years. It is reasonable to believe that as the dam is removed and sediment moves downstream, the gradient will increase in the impacted zone resulting in the uncovering of a gravel/cobble substrate. This will create greater diversity in hydraulic conditions and generate more habitat suitable for trout.

Fish growth was not significantly different between zones of varying habitat quality for any of the fish species (rainbow trout, brown trout, and white suckers) investigated. This suggests that where these species occur, they are able to use the available forage base to the same level of efficiency as conspecifics in other areas of the river. However, free movement of fish throughout the study area confounds growth results when comparing fish from various areas. Given that fish growth differences were not detected across the variable habitat conditions and fish densities that were observed, it is unlikely that changes in fish growth associated with the dam removal will be detected.

An examination of age distribution among fish suggests that the majority of white suckers are ages zero and one with some reaching age 10. Most of the trout were ages zero, one, and two, with no trout found older than age four. However, downstream from the dam, brown trout were most commonly ages three and four, and age zero brown trout were not encountered. The predominance of older year classes of brown trout downstream from the dam suggests that a food source may be present there, allowing them to make an ontogenetic shift to larger prey, a resource not available to trout upstream from the dam. The absence of age zero brown trout downstream from the dam suggests that predation by foraging species common to Tippy Reservoir, or by other trout, may be a factor in controlling age structure of Pine River fish. An investigation into the diet of these fish may help explain the differences in age/size distribution between the zones and provide a basis for comparison after the dam is removed. If the forage base is a factor in structuring the age/size distribution of fish, the dam removal may increase the number of fish reaching a larger size or may affect recruitment of trout if age zero fish are lost to predation.

Fish densities responded to the degree of impact that Stronach Dam has had on habitat and the isolation of fish downstream from the dam. The upstream-most reaches of our study section, where the habitat has been least influenced by the dam, had the highest average abundance of trout. Trout densities tend to diminish in a downstream direction with fewest numbers of trout found downstream from the dam. White sucker abundance, in contrast, was lowest in the upstream, non-impacted zone and highest downstream from the dam. It is expected that densities of trout will increase where the gradient of the stream channel increases as a result of the dam removal.

It is important to recognize that streambed elevation in the Pine River is partially controlled by hydropower operations at Tippy Dam. This limits the certainty with which we can attribute downstream streambed elevation changes during the removal of Stronach Dam. Furthermore, the presence of Tippy Dam and the fact that its backwaters currently extend into the Pine River creates additional uncertainty regarding the extent of habitat restoration we can expect after Stronach Dam is removed. The impact that this could have on stream gradient, water temperature, and fish community structure remains questionable.

The biotic structure of the river will not reach a state of equilibrium until after the stream channel becomes stable, which may be years after the dam is removed. Therefore, in order to detect the full effect of the dam removal, it is essential that the stream's physical and biological attributes continue to be monitored for a long period (years to decades) after the removal is completed.

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