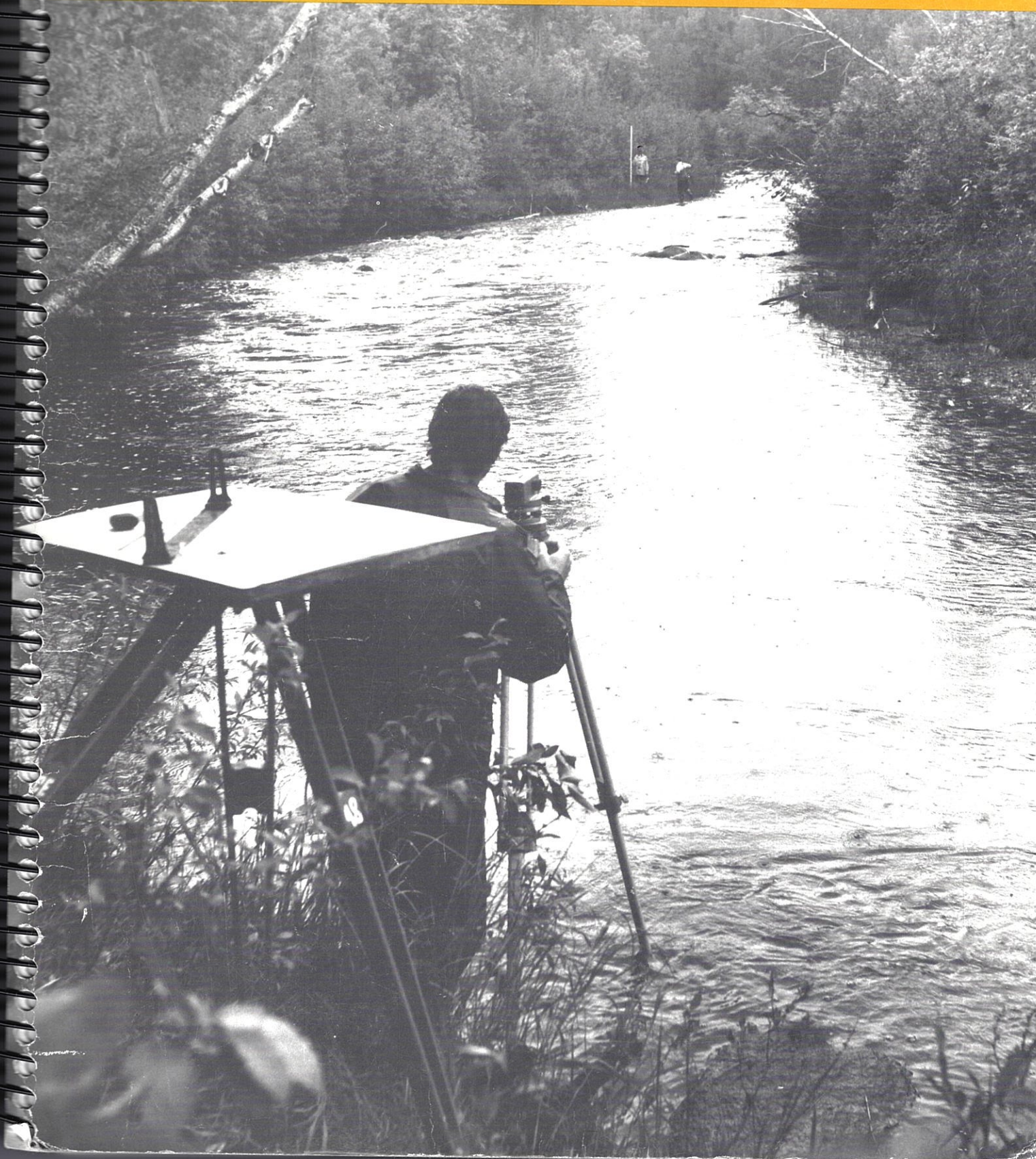


# STREAM ANALYSIS AND FISH HABITAT DESIGN

*A Field Manual*

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## **Chapter 4**

# **Design and Construction of Stream Habitat Works**

### **Design principle**

The design of stream rehabilitation and enhancement works is based on evaluating the present state of the stream and adjusting the channel geometry and slope to a new form that can be maintained by the available streamflow. The biological habitats that are created are a complex combination of the flow hydraulics and physical characteristics of the streambed, banks, and riparian vegetation that defies complete analysis. Where possible, surveys of natural stream reaches with preferred and proven habitats are used as design guidelines that will allow the habitat factors to be re-created naturally. In most cases, the observed design templates and stream construction works must be sized to fit the capability of rehabilitation stream.

### **Ten steps in the design and construction process**

The major stages in designing and constructing stream habitat works have been divided into ten steps (Figure 4-1). The procedures and analyses used in the first six steps are discussed in the preceding chapters of the manual: Planning, Field Surveys, and Evaluation. The last four steps are presented in the following five stream habitat projects:

- Example 1: Hamilton Creek - walleye spawning habitat at a stream crossing,
- Example 2: Mink Creek - walleye spawning habitat and stabilization in a drainage canal,
- Example 3: Wilson River - walleye spawning habitat and stabilization in a channelized river,
- Example 4: Pine River - trout habitat creation in a naturally uniform mobile bed stream,
- Example 5: Whiteshell River - trout habitat enhancement in a bedrock controlled river.

<b>1) Drainage Basin</b>	Trace watershed lines on topographical and geological maps to identify sample and rehabilitation basins.
<b>2) Profiles</b>	Sketch mainstem and tributary long profiles to identify discontinuities which may cause abrupt changes in stream characteristics (falls, former base levels, etc.).
<b>3) Flow</b>	Prepare flow summary for rehabilitation reach using existing or nearby records if available (flood frequency, minimum flows, historical mass curve).
<b>4) Channel Geometry Surveys</b>	Select and survey sample reaches to establish the relationship between the channel geometry, drainage area, and bankfull discharge.
<b>5) Rehabilitation Reach Survey</b>	Survey rehabilitation reaches in sufficient detail to prepare construction drawings and establish survey reference markers.
<b>6) Preferred Habitats</b>	Prepare a summary of habitat factors for biologically preferred reaches using regional references and surveys. Where possible, undertake reach surveys in reference streams with proven populations to identify local flow conditions, substrate, refugia, etc.
<b>7) Selecting and Sizing Rehabilitation Works</b>	Select potential schemes and structures that will be reinforced by the existing stream dynamics and geometry.
<b>8) Instream Flow Requirements</b>	Test designs for minimum and maximum flows, set target flows for critical periods derived from the historical mass curve.
<b>9) Supervise Construction</b>	Arrange for on-site location and elevation surveys and provide advice for finishing details in the stream.
<b>10) Monitor and Adjust Design</b>	Arrange for periodic surveys of the rehabilitated reach and reference reaches to improve the design as planting matures and the re-constructed channel ages.

**Figure 4-1:** Design and construction process for stream habitat projects.

## Design Example 4: North Pine River Trout Habitat Enhancement

**Project background** The Pine River flows from the foot of Baldy Mountain in the Duck Mountain portion of the Manitoba escarpment to Lake Winnipegosis (Figures 1-3 and 1-5). A topographic model of the basin is shown in Figure 1-7.

The Pine River supports one of the few resident rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*) populations in south-western Manitoba. Adult trout are widely distributed in the lower river, particularly in meandering reaches with pools that are greater than 0.7 m deep under low flow conditions. Under higher flow conditions, some trout have been caught in the middle reaches of the stream in tributaries to the main stem, particularly in beaver dam impoundments in Middle Creek and Clearwater Creek. However, with low and moderate flows, there are rapidly-flowing shallow reaches paved with large boulders and cobbles that obstruct fish passage and do not allow meanders or pools to form. A typical straight reach in the Upper Pine River is shown in Figures 2-8 and 4-40. The characteristics of the reach are discussed as survey and evaluation examples in Chapter 2 and Chapter 3.

In 1990, Swan Valley Sport Fishing Enhancement Inc. raised funds to create more trout habitat in the middle reaches of the Pine River. To gather information for designing the enhancement works, the members of the Association described "ideal" trout fishing reaches on the lower Pine and adjacent streams. Based on these initial interviews, probable sites were chosen along several streams for sample fishing. The "trout distribution and catch form" shown in

TROUT DISTRIBUTION AND CATCH  
FORMS FOR  
ANGLING SURVEYS IN ESCARPMENT STREAMS

MANITOBA FISHERIES BRANCH



General Information

This form has been designed to improve our understanding of brook and rainbow trout habitat in Porcupine and Duck Mountain streams. It will also provide information on trout distribution and abundance.

To complete the form, anglers should indicate the date, time period and number of anglers fishing a particular stream site or section. Using a 1:50,000 topographical map anglers should identify their fishing locations by topographical elevation. Long sections of stream that are fished should be limited to an elevation change of no more than 25 ft. For example, a typical stream section on the Pine River would be identified with an elevation between 1600 and 1625 ft. For each trout caught, measure its total length and describe the habitat in which it was found. It is important that a form be completed describing the habitat for each section of stream fished, even though in some cases no fish were caught.

On the opposite page of the form provide your comments on the trout habitat, flow conditions and fishing success. If possible sketch a plan view drawing of the site identifying the characteristics which you feel are key trout habitat components.

Good Luck and Good Fishing!

FIG. 1 - JULY 24th TRIP

TROUT DISTRIBUTION AND CATCH FORM

Stream PINE RIVER  
No. of Anglers reporting on this form 1  
Fished at this site from 1:35 AM/PM to 5:30 AM/PM  
Date JULY 24/90

HABITAT AND CATCH DESCRIPTION

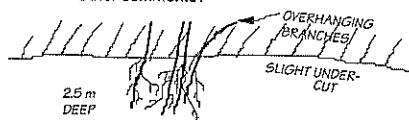
Topographical elevation of fishing site:

at \_\_\_\_\_ ft. or between 1475 and 1550 ft.

SPECIES	LENGTH (cm)	HABITAT				Depth (cm)
		Meander Pool (✓)	Beaver Pond (✓)	Rapids (✓)		
RAINBOW TROUT	30.5 cm	✓				75 cm
RAINBOW TROUT	25 cm	✓				75 cm
BROOK TROUT	36 cm	✓				60 - 90 cm
BROOK TROUT	33 cm	RELEASED				60 cm
RAINBOW TROUT	31 cm	RELEASED				60 cm
5 RAINBOW TROUT	20-29 cm	(RELEASED)				60 cm

Submitted by Terry Scales

Comments: Have you caught fish here before? YES  
Is the water higher or lower than average? AVERAGE  
Is the catch rate at this site today better, worse or the same as usual?  
Is the habitat alternating pools and riffles? YES  
Other comments?



2 BROOK TROUT

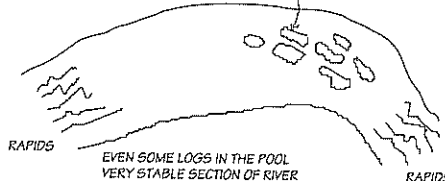
THE RIVER HAS SHOWN VERY LITTLE CHANGE  
SINCE I FISHED 5 YEARS AGO. POOL THE SAME.

Sketch of the site showing pool, rapids, large boulders, undercut banks

12 TROUT (4 BROOK & 8 RAINBOW)  
IN POOLS AS BELOW

100 - 150 cm DEEP

SUBMERGED BOULDERS  
2 FEET ACROSS



EVEN SOME LOGS IN THE POOL  
VERY STABLE SECTION OF RIVER

Figure 4-37: Sample trout distribution and catch forms used by volunteer anglers to identify preferred trout habitats.

Figure 4-37 was completed for each sample reach by the volunteer anglers. Obtaining volunteers was not difficult and the quality of sketching and reporting was outstanding.

The best trout sites occurred in meanders with deep pools and helical flows as shown in Figures 2-10, 3-16, and 3-17. On the lower Pine, two of the sites were surveyed in detail. The characteristics of the pools, riffles, and meanders were then used as design guidelines for constructing two experimental meanders in a straight reach of the North Pine River. The meanders were constructed in November 1990.

The North Pine River project is summarized in the following sections in the design steps presented in Figure 4-1.

## **1) Drainage basin**

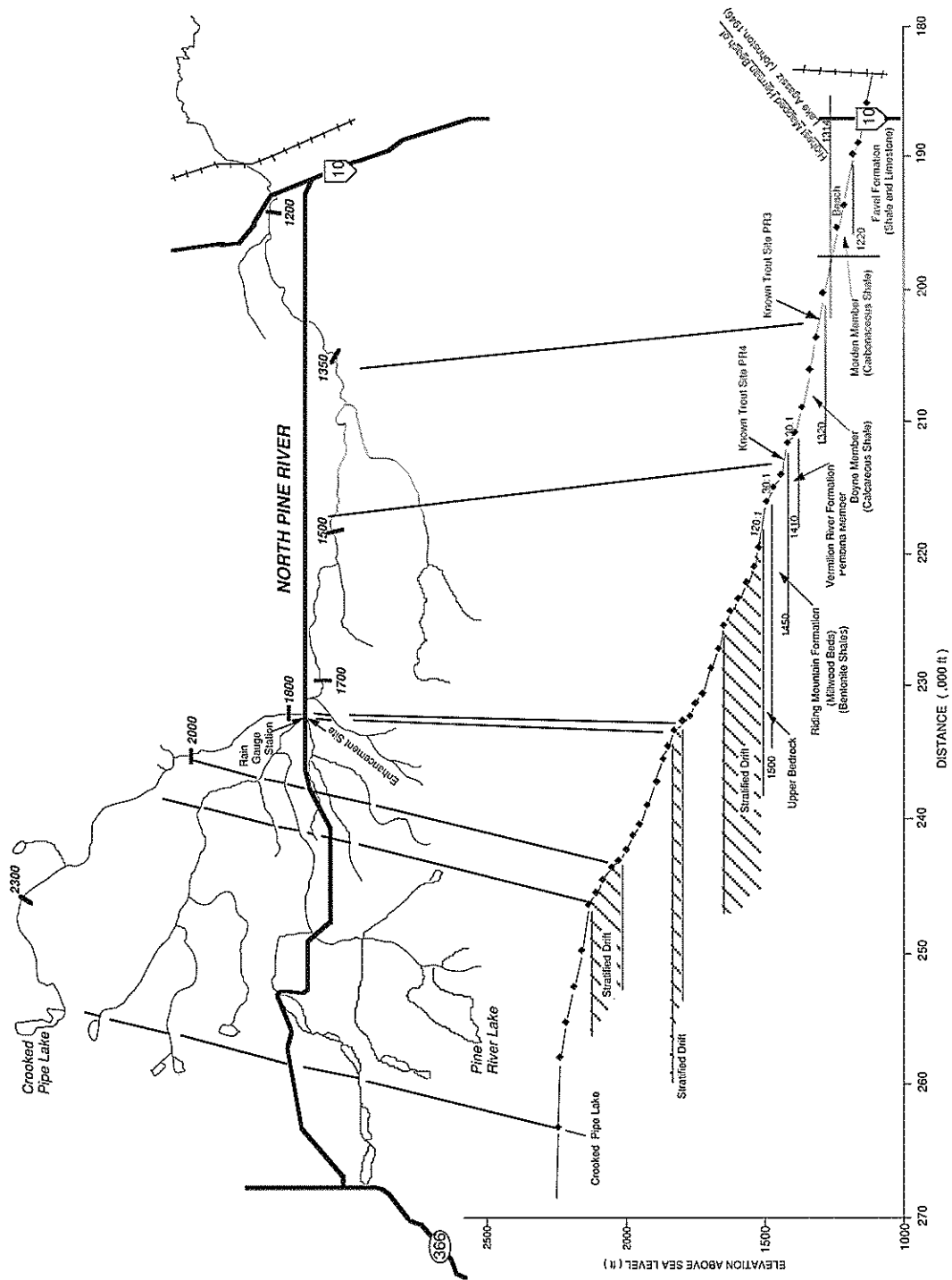
The boundaries of the Pine River drainage basin shown in Figure 1-3 were sketched using 100 ft contours on 1:250,000 NTS Map Sheet 62N. The area of the Pine River basin that is tributary to the gauging station is 210 km<sup>2</sup>. The area tributary to the North Pine sample reach was estimated to be 100 km<sup>2</sup>.

## **2) Profiles**

The general profile shown in Figure 1-3 is concave upwards with three distinct segments on and below the escarpment. To define the cusp segments in more detail, a larger scale profile was prepared using 25 ft contour intervals on 1:50,000 NTS maps. The profile was combined with a geologic cross-section of the escarpment prepared by Klassen (1979) to determine where and at what elevations the streambed intersected different surficial deposits and bedrock formations. The basin plan and cross-section are shown in Figure 4-38.

In the glacial till on top of the escarpment, the bases of local cusps coincide with beds of coarse stratified deposits that are more resistant to erosion than the overlying deposits in the upstream reaches. The stable North Pine River enhancement site flows through a bouldery stratified deposit at elevation 549 ASL (1800 ft). The local slope in this stable reach is 2.2%, about 1.5 times the average slope in the middle segment of the profile.

The elevation of the base of the cusps in the lower half of the profile coincide with the upper bedrock surface and the upper levels of more resistant bedrock units in the geological cross-section. The two



**Figure 4-38:** Plan, long profile, and geologic cross-section of the Pine River basin. Local cusps in the profile are formed as the stream encounters resistant glacial deposits and bedrock outcrops.

preferred trout habitat survey sites occur in meandering reaches of the lower half of local cusps in the profile. The average slope of the profile in this segment of the stream is 1% while the slope of the habitat reaches is only 0.6 %.

### 3) Flow

The Pine River gauging station is located at the base of the escarpment near the town of Pine River. The records are summarized in Table 1-3. Annual flood frequency curves for the gauged site and for the North Pine site were shown as examples in Figure 3-3. Based on the reach surveys presented in Chapter 2, the estimated bankfull flow for the North Pine site was  $6.7 \text{ m}^3/\text{s}$ . On the annual flood frequency curve, this flow represents the average annual flood peak. The estimated bankfull flow was adopted as the design flow for the channel enhancement works.

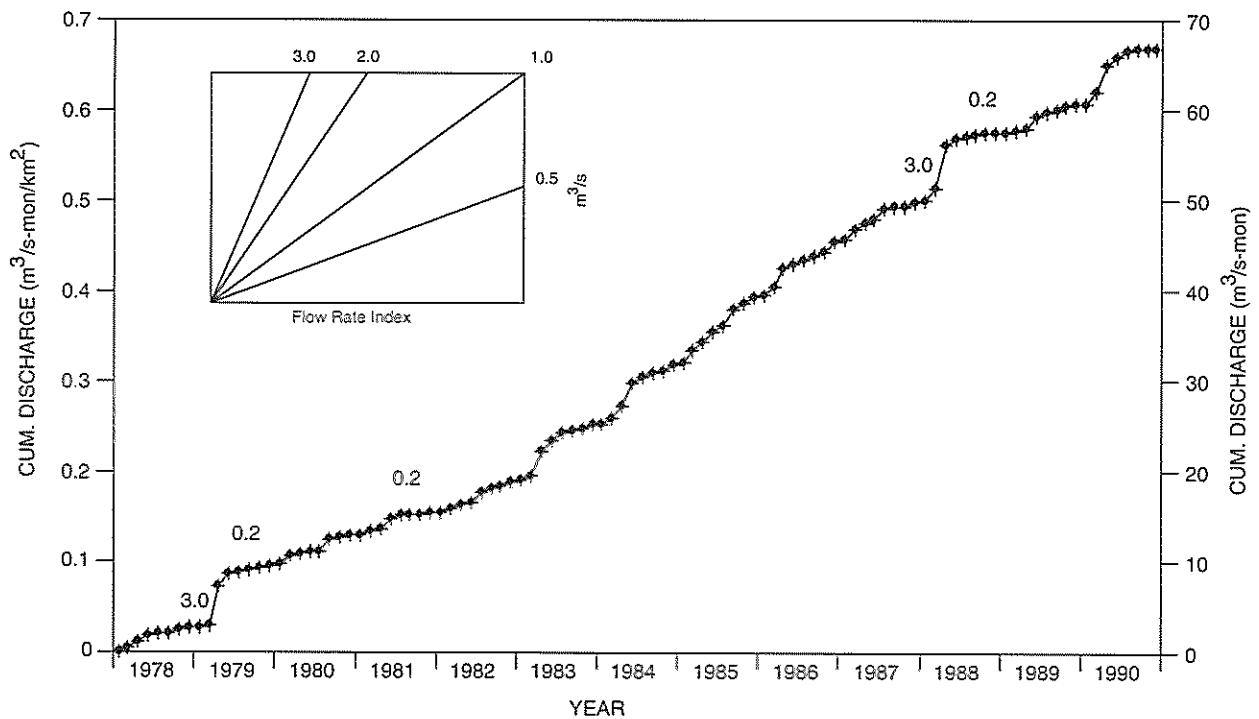


Figure 4-39: Mass curve of monthly flows for the North Pine River 1978-1990.



The mass curve of monthly flows for the North Pine site is shown in Figure 4-39. The flows are steady in the open-water season because of natural regulation by upstream storage in small lakes and marshes on the top of the escarpment. The average monthly flow for the open water season in the 1978-1990 period was 0.6 m<sup>3</sup>/s. The lowest monthly mid-summer flows were maintained at 0.2 m<sup>3</sup>/s and Spring runoff flows did not exceed 3 m<sup>3</sup>/s. The lowest flow period occurs in mid-winter. During this period, resident fish populations have been observed in beaver ponds above and below the North Pine site. Open water is maintained only in reaches with inflowing groundwater. This condition occurs in the upper half of the North Pine site.

#### 4) Channel geometry surveys

The channel geometry surveys and evaluations for the North Pine site are discussed in Chapters 2 and 3. The characteristics of the channel are summarized in Table 4-14.

In Figure 3-4, the predicted bankfull discharge lies along a general line for the relationship between bankfull discharge and drainage area for small southern Manitoba basins. The bankfull width and depth lie within the range of similar relationships shown in Figure 3-7.

**Table 4-14: North Pine River channel characteristics.**

bankfull width .....	9.7 m
bankfull depth .....	0.84 m
average slope .....	0.022
median bed paving material size. ....	0.45 m
assumed bankfull roughness .....	0.16
predicted bankfull velocity .....	0.83 m/s
bankfull tractive force. ....	18.5 kg/m <sup>2</sup>
bankfull Froude number.....	0.3
bankfull discharge.....	6.7 m <sup>3</sup> /s

The size distribution of the boulders and large cobbles paving the streambed was shown in Figure 2-7. At the bankfull stage, all of the bed paving materials are stable.

#### 5) Enhancement reach survey

The North Pine survey reach and a similar straight segment of the stream above the Beaver Lake Provincial Road crossing was used for the experimental trout habitat meander project. The natural reach prior to construction is shown in Figure 4-40. The plan and profile of the project reaches are shown in the upper diagram in Figure 4-41.

#### 6) Preferred habitats

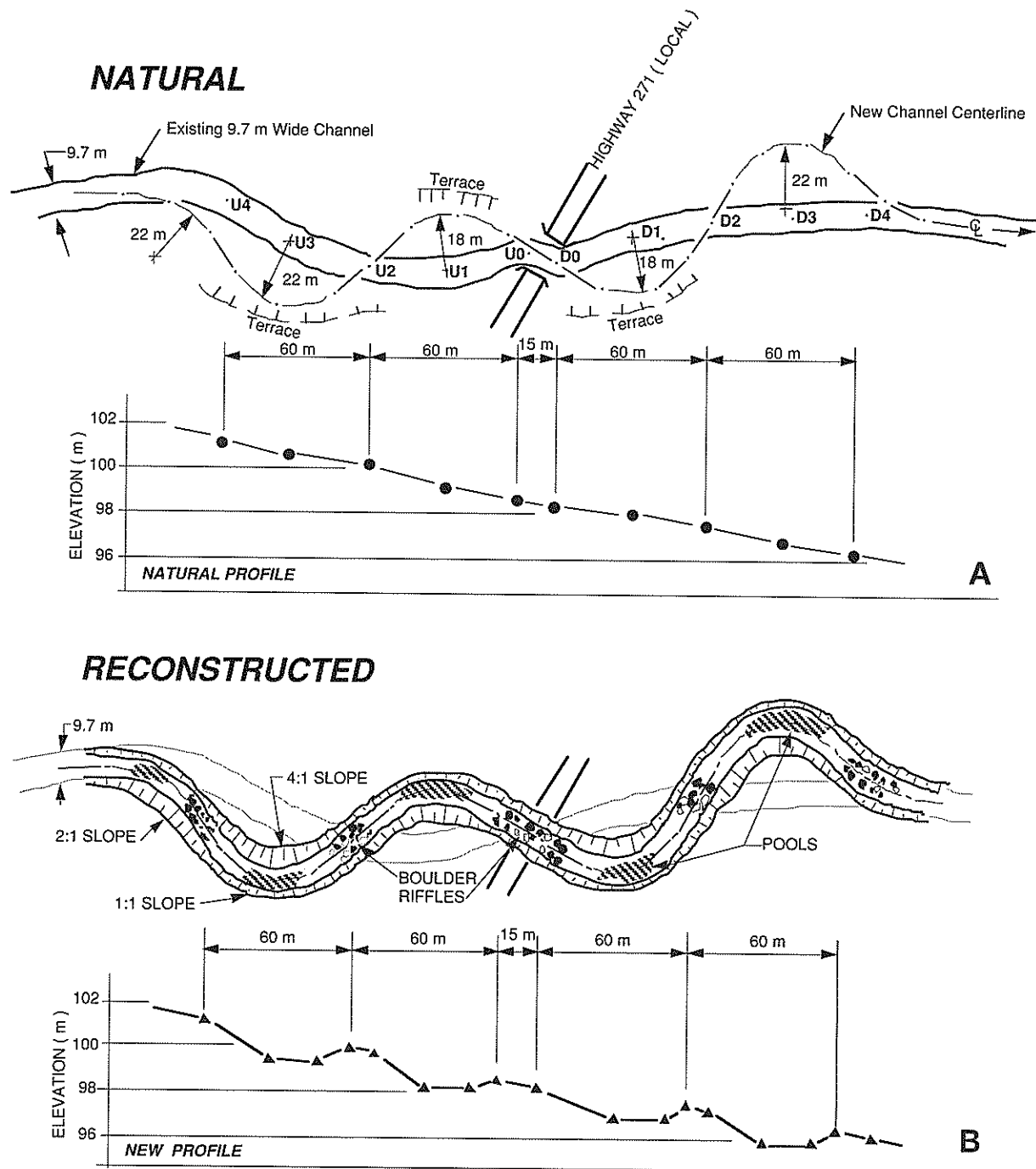
Reference studies of preferred adult trout habitats show the highest probability of use for stream reaches with flow velocities of 0.4 m/s (1.4 ft/s), depths of 0.6 m (2 ft) or more, water temperatures of 13 - 21 °C (55 to 70 °F), and a substrate of gravels, cobbles, and boulders (Bovee 1978). A typical trout habitat reach on the lower Pine was used as a template for the design. The meandering reach is shown as a survey example in Figure 2-10. The pattern and hydraulic habitat characteristics are discussed with Figures 3-16, 3-17, and 3-20 in Chapter 3.

#### 7) Enhancement works

The existing channel alignment in the project reach was determined using baselines and channel cross-sections (see Observation 6, Chapter 2, Figure 2-8). The channel alignment in the reaches

**Figure 4-40:** The uniform straight channel of the North Pine enhancement reach prior to construction. A highway bridge is located in the middle of the reach.





**Figure 4-41:** North Pine trout habitat enhancement reach before (A) and after (B) re-alignment into meanders and excavation of a pool and riffle profile.

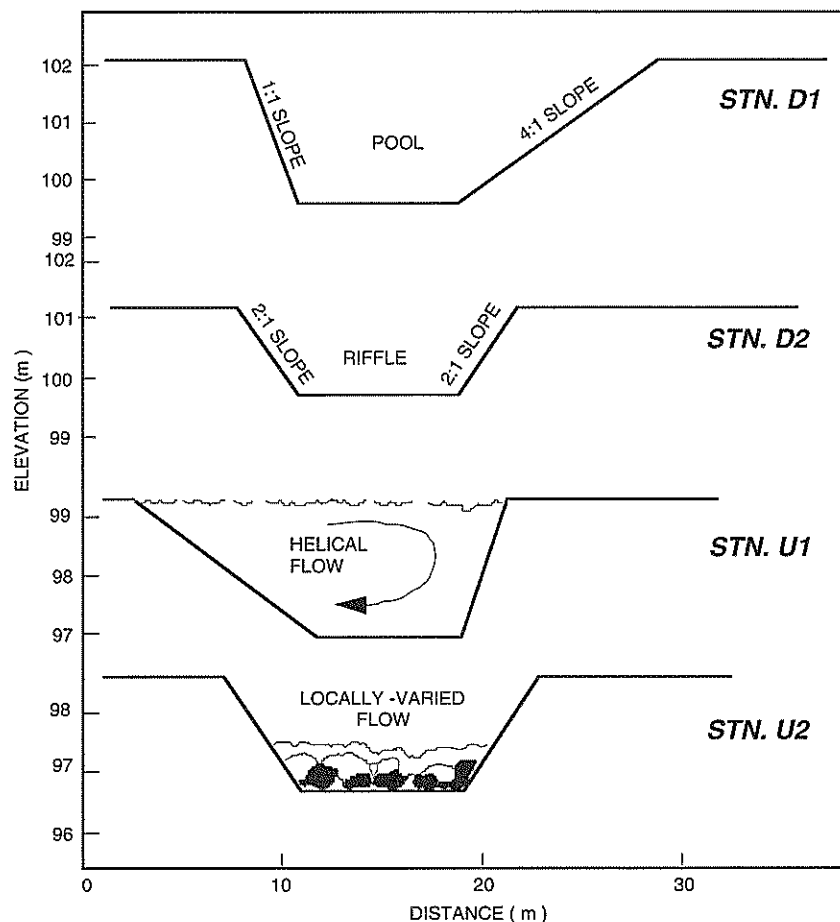
upstream and downstream from the project area was scaled from air photos. Cross-sections of the channel and floodplain were surveyed every 30 m upstream and downstream from the highway bridge. The stations are shown as U0 to U4 upstream and D0 to D4 downstream in Figure 4-41A.

Meanders were designed at a spacing of 120 m, or 12.4 times the bankfull width of 9.7 m. The riffles were spaced at 60 m, or 6.2 times the bankfull width. The ratio of width to depth is slightly greater than the template site shown in Figure 3-16, but close to the average for bedrock and alluvial streams (Evaluation 5, Chapter 3).

The amplitude of the meanders was selected to fit between terraces that rose 1 to 2 m on either side of the existing floodplain. The meander bends were placed to allow undercutting of the terraces similar to that observed at the template site. The radius of curvature of the top of the loop of the meander bends was set at 22 m, or 2.3 times the bankfull width in the first and last bend. The mean radius observed in many meanders is 2.4 times the bankfull width (Chang 1988). The radius was reduced to 18 m in the central bends to produce a straight alignment with the highway bridge. The centreline and geometry of the meander loops are superimposed on the existing channel in Figure 4-41A.

A pool and riffle profile was designed for the meandering channel (Figure 4-41B). The original riffle sections were used as cross-over points for the meanders, although some additional large rocks were added at 0.2 m to 0.5 m spacing to produce chutes at low and intermediate flows. Pools were excavated between the riffles to depths varying from 0.5 m to 0.7 m below the riffle crests. The channel cross-sections were varied as shown in Figure 4-42. In the meander pools, the cross-section is designed with 1:1 slopes on the outside of the bend and 4:1 slopes on the inside of the bend to mimic naturally skewed sections. In the riffle zones, the cross-sections are regular, with 2:1 slopes on both sides of the stream. It is anticipated that the cross-sections will become more continuously rounded as the channel sides erode with subsequent bankfull flows. A short 15 m reach with a regular cross-section was developed in an extended riffle that passes under the highway bridge.





**Figure 4-42:** Variation in excavated cross-sections through the excavated meanders in the North Pine River project.

The natural straight channel was stable at the estimated bankfull flow of  $6.7 \text{ m}^3/\text{s}$ . The constructed meanders in the stream segment decreased the average slope in the reach from .022 to .018, increasing the stability even further. The local slope of the riffle sections was not changed but the average size of the bed paving materials was increased by adding spaced boulders to create aeration zones and diverse local flow conditions.

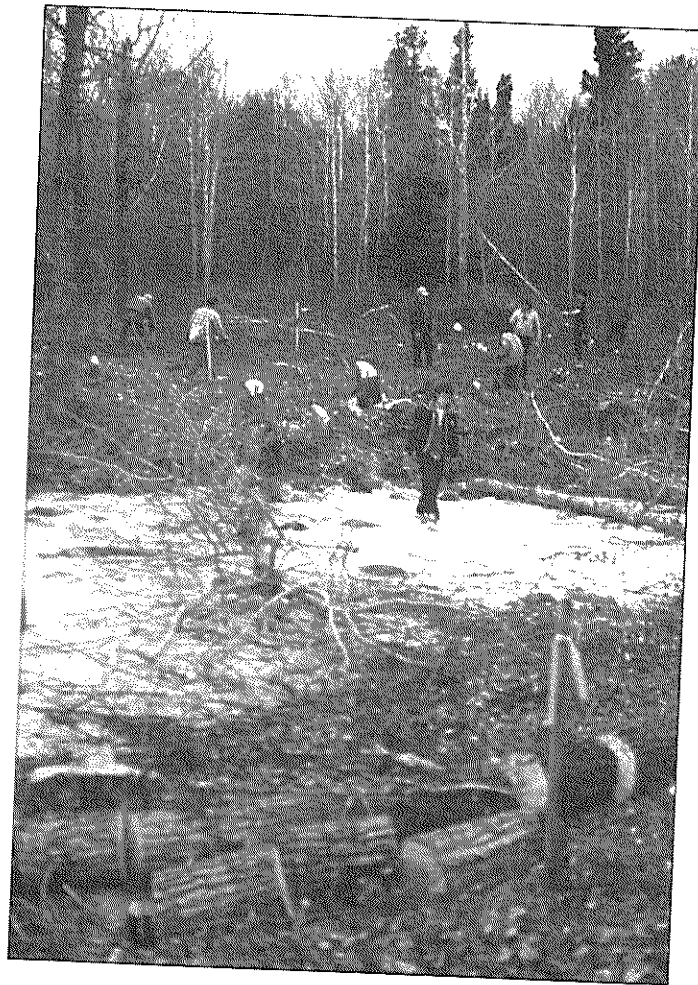
## 8) Instream flow requirements

The existing naturally regulated flow regime of the Pine River (Figure 4-39) presently supports the resident trout population and requires no augmentation (discussed in Section 3). In low-flow years the excavated pools in the meandering reach would decrease to an average depth of 0.6 m. Assuming the beaver population will not be

## 9) Supervise construction

removed, ponds above and below the enhancement reach should continue to act as winter refuge. Fish passage between the ponds has been improved by increasing the mean depth and creating narrow chutes through the riffle sections in the enhanced reach.

The alignment of the new meandering channel was established by measuring offsets from the centre of the existing channel. The tops of the channel banks were marked with survey stakes, allowing for an 8 m base and varying side slopes. The meander path was then cleared by hand by members of the Swan Valley Sport Fishing Enhancement group and students of the Swan Valley Regional High School (Figure 4-43).



**Figure 4-43:** Volunteers clearing the meander path as it crosses the original channel of the North Pine enhancement reach.

The channel was excavated with an 0.5 m<sup>3</sup> bucket track-mounted backhoe assisted with a small bulldozer to infill the old channel (Figure 4-44).

Where possible, existing trees along the new course of the channel were saved, particularly on the outside of the meander bends to provide cover over the newly excavated pools. The completed meander upstream from the highway bridge is shown in Figure 4-45. In 1991, the project reach was re-planted with local trees and shrubs by volunteers from the Swan Valley Regional High School.

Project labour, costs and materials are summarized in Table 4-15.

**Table 4-15: Materials and costs for the North Pine trout habitat project.**

Machine Rental	
96 hours backhoe .....	\$7200.
70 hours bulldozer .....	\$3850.
Labour	
surveys .....	15 pd
design .....	3 pd
clearing .....	15 pd
re-planting .....	5 pd
arrangements .....	2 pd
supervision. ....	11 pd

## 10) Monitor and adjust design

In 1991, a moderate spring flood peak was observed at the Pine River gauging station of 5.74 m<sup>3</sup>/s, equivalent to an annual flood peak frequency of 92 % (Figure 3-3). The flood peak in the excavated meandering reach was estimated to be 3 m<sup>3</sup>/s. Following the peak, a small delta of coarse sands was observed in the upper pools. There was no movement of the cobbles and boulders in the riffle zones. Trout were observed and caught in the project reach in the 1991 open-water season. An aerial view of the excavated meanders under low flow conditions following the first flood peak is shown in Figure 4-46.



**Figure 4-44:**  
Excavation of the first  
upstream meander  
bend above the  
highway bridge in the  
North Pine project  
(Figure 4-40 shows the  
pre-excavation  
channel).



**Figure 4-45:** The  
completed upstream  
meander bend of the  
North Pine River trout  
habitat enhancement  
project (December  
1990).





**Figure 4-46:** Aerial view of the North Pine River trout habitat enhancement reach. The meandering channel mimics successful trout angling reaches surveyed on the lower Pine River and adjacent streams.