1996

Impacts of Water idversion on Floodplain Structure Hydrology and Riparian Vegetation and Possible Mitigation Cascade River Banff National Park

Richard J. McCleary
The University of Montana

Recommended Citation

McCleary, Richard J., "Impacts of Water idversion on Floodplain Structure Hydrology and Riparian Vegetation and Possible Mitigation Cascade River Banff National Park" (1996). *Graduate Student Theses, Dissertations, & Professional Papers*. 5673.
https://scholarworks.umt.edu/etd/5673

IMPACTS OF WATER DIVERSION ON FLOODPLAIN STRUCTURE, HYDROLOGY AND RIPARIAN VEGETATION, AND POSSIBLE MITIGATION, CASCADE RIVER, BANFF NATIONAL PARK

by

Richard J. McCleary

B.S. The University of Montana, 1993

Presented in partial fulfillment of the requirements

for the degree of

Master of Science

The University of Montana

1996

Approved by:

Committee Chairperson

Dean, Graduate School

5-16-96

Date

McCleary, Richard J., M.S., May 1996 Forestry

Impacts of water diversion on floodplain structure, hydrology and riparian vegetation, and possible mitigation, Cascade River, Banff National Park (139 pp.)

Director: Robert D. Pfister

Abstract

Due to power production which began in 1941, total annual discharge in a section of the Cascade River was reduced by 99 percent. Significant losses of aquatic habitat resulted. With existing structural limitations, flow can be increased up to three percent of the historic total annual discharge. By adapting techniques used to assess effects of forestry practices on streams, I explored the possibility of improving aquatic habitat within these structural constraints.

Analysis of aerial photography revealed that the lowest portion of the historic river has completely dried and been replaced by upland vegetation. Throughout the rest of the study area, upland type ecosystems have encroached and largely replaced the historic floodplain and river ecosystems.

For the first three kilometers downstream from the dam, several tributaries contribute flow. Below this point, Cascade Creek surface flow diminishes as losses to subsurface flow occur. With the alluvial landform, significant recharge of groundwater will be required to restore and maintain surface flow in the lower reaches.

Structurally, Cascade Creek is typified by an extremely wide and shallow channel. Pools are scarce below the three kilometer point. Natural channel forming processes are absent throughout. Computer modeling revealed that increasing flow from one to three percent of historic discharge will not restore channel forming processes, nor change the configuration of the wetted channel. Flows of a much greater magnitude are required.

Along the stream banks, riparian willow communities are progressing into spruce forests. Within the channel, lentic wetland communities are developing. In some reaches, grass species dominate the banks. Decreased shading by shrubs over flowing water and poor bank protection during high water are the implications.

With the high degree of degradation in this system, restoration efforts should focus on the upper reaches. I discuss possibilities of improving aquatic and riparian habitat and re-establishing native species in these reaches. With existing constraints, restoring aquatic habitat in the lower reaches is not feasible. A study of minimum instream flows has never been done and would be required to restore aquatic habitat throughout the study area.

ACKNOWLEDGMENTS

My Graduate Committee provided guidance, and critical reviews of the study plan and thesis drafts. This committee included Professor Pfister as my main advisor, along with Professors Zuuring, Hansen, Callaway and Potts. Peter Achuff, of Parks Canada, also provided valuable input as a committee member.

Several people outside my graduate committee also made important contributions. Paul Kemp, a professional engineer in Calgary, reviewed the hydrology chapter prior to defense. Greg McCleary produced all maps contained in this report. A fellow student, Todd Caplan, critiqued Chapter 4, and my presentation prior to the public defense. Jim Rennels volunteered with field and air photo work. Jack and Christopher McCleary assisted with the field work.

Both Parks Canada and TransAlta Utilities provided support for this project. Charlie Pacas of Parks Canada provided the initial idea and helped to secure funding for the project. Joanne Cairns of Parks Canada helped to obtain necessary field equipment. TransAlta Utilities supplied a surveyor, Alan Canuel, who worked in the field for several days.

TABLE OF CONTENTS

Chapter

Chapter

Appendix

LIST OF TABLES

Table

Table

LIST OF ILLUSTRATIONS

Figure

CHAPTER 1

INTRODUCTION

In 1992, the original licence for TransAlta Utilities to generate electricity at the Cascade Plant within Banff National Park expired. Before the licence would be renewed, Parks Canada required that an independent consultant complete an environmental assessment. In their 1992 report, the consultants described impacts from the existing operation and suggest mitigation. Based on these recommendations, the licence was renewed for the next 40 years. Mitigation included studying the feasibility of increasing the flow in a section of the Cascade River downstream of the dam at Lake Minnewanka as a means to rehabilitate lost aquatic habitat (Dames and Moore 1992). Addressing this requirement of the environmental assessment is the purpose of this thesis. The study area is the 8 km of historic river channel between the main dam on Lake Minnewanka and the power plant near Anthracite (Fig. 1). This section of river has been subject to large scale water diversion since 1941.

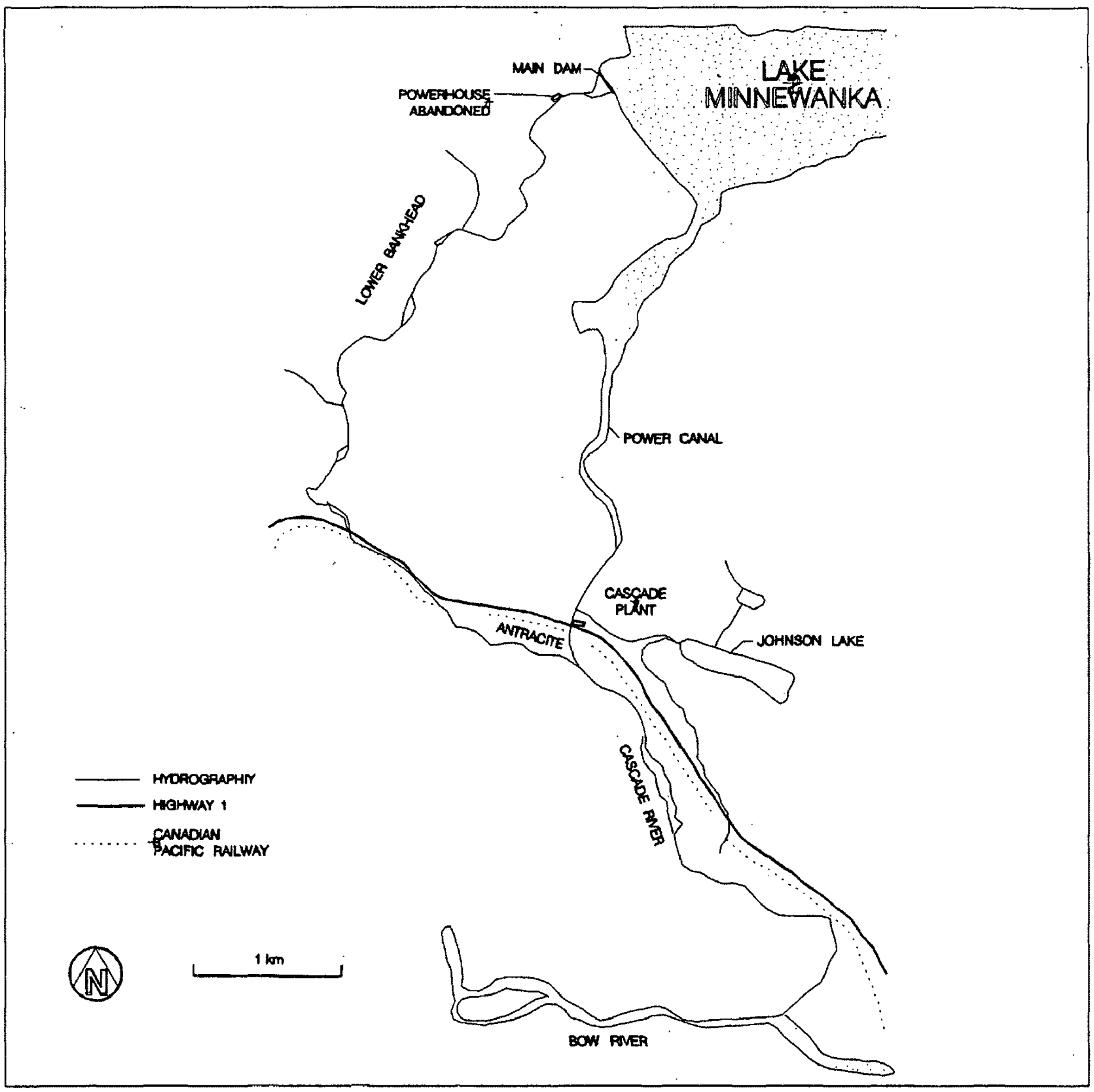


Figure 1. Map of historic sites within study area

The total annual discharge immediately downstream of Lake Minnewanka has been reduced by more than 99 percent since dam construction (Table 1). The remnant stream in the historic channel is herein referred to as Cascade Creek.

Table 1. Total annual discharge and percentage of historic flow diverted for a section of the Cascade River downstream of Lake Minnewanka before and after dam construction

Date	Mean total annual discharge (dam^3)	% of water diverted
1911-1941	252 000[1]	0
1942-1993	1 300[2]	99.5
1994-1995	3 200[3]	99

1. Records from Station No. 05BD002 (Environment Canada 1991)
2. Based on 5 months of discharge at 0.1 m^3/s
3. Based on year round discharge at 0.1 m^3/s

This thesis was funded by Parks Canada. TransAlta Utilities did not contribute direct funding, but provided valuable resources including maps, aerial photographs and personnel (a surveyor). These two proponents have different values and motivations for involvement in this thesis.

From the Banff National Park perspective, investigation into rehabilitation is warranted by the following policies and management plans:

1) 3.2 *Ecosystem-Based Management* in *National Parks Policy* (Parks Canada 1994):

> Sec. 3.2.3 National park ecosystems will be managed with minimal interference to natural processes. However, active management may be allowed when the structure or function of the ecosystem has been seriously altered and manipulation is the only alternative available to restore ecological integrity.

> Note: this document defines **ecological integrity** as a condition where the structure and function of an ecosystem are unimpaired by stresses induced by human activity and are likely to persist.
>
> Sec. 3.2.5 Where manipulation is necessary, it will be based on scientific research, use technology that duplicates natural processes as closely as possible and be carefully monitored.

2) *Minnewanka Area Plan* draft (Banff National Park 1992):

> 5.2.2 Aquatic Ecosystem Protection and Management Objectives:
> -To rehabilitate and restore historic natural aquatic habitats.
> -To assess the ecological implications and feasibility of habitat restoration of the Cascade River channel.

In addition, the extirpation of native fish species from portions of their historic ranges has occurred in Banff National Park. Species of concern include the westslope cutthroat trout (*Salmo clarki lewisi*) and bull trout (*Salvelinus confluentus*). Prior to 1941, both species occupied the study area but due to large scale water diversion, suitable habitat for these species no longer exists. Based on the above Parks Canada policy, restoring habitat within Cascade Creek capable of supporting these species is an ultimate goal.

TransAlta Utilities' interest in this thesis originates in the *Environmental Assessment for Renewal of the Water Power Licence for the Cascade Power Facility and Operation* (Dames and Moore 1992), which recommended studying the feasibility of increasing the flow in the Cascade River. This public company approaches this issue of any flow increase very conservatively, for two reasons. First, any water flowing through the historic channel bypasses the Cascade

Power facility and represents lost hydroelectric generating potential and therefore lost revenue.

Secondly, an international review of the effectiveness of water release from hydroelectric projects as a mitigation strategy to protect fish habitat judged 28 cases and found only 12 (43 percent) effective (Lewis and Mitchell 1994). Three conclusions from this review are related to this study. First, it is impossible to determine the success of a project without a well thought-out monitoring program. Secondly, larger processes such as geomorphic change and the role of flushing flows have not been significantly addressed. Third, the social value of an intact ecosystem is increasing and this extends beyond the value of fish and fish habitat. In this thesis, I attempted to address these short comings when I designed my study. A well though out monitoring program was developed. I evaluated the potential for geomorphic change and expanded the study to include the riparian area.

Riparian areas are located between aquatic and upland environments. The soils in these areas are saturated for at least a portion of the year and support plants adapted to these conditions (Hansen and others 1995). The riparian area performs several functions that link uplands to the adjacent aquatic ecosystem. Functions of the riparian vegetation include: trapping sediment and protecting stream banks during high flows; and regulating water temperatures in small streams as shrubs overhang and shade the flowing water. Therefore, successful restoration of the aquatic system requires simultaneous restoration of the riparian area.

The 1992 environmental assessment clearly specifies the mechanisms for and magnitude of potential flow increases. Currently, water is released into the historic river channel through a pipeline running under the main dam at Lake Minnewanka. The flow is regulated by a valve (herein called the riparian flow valve) which presently releases water at a rate of 0.11 m^3/s and has a maximum capacity of 0.3 m^3/s. The historic river channel (which forms the study area), also serves as the emergency spillway channel. The environmental assessment states that this spillway was designed strictly for emergency use and should not be used to augment flows.

Beside the engineering constraints, human changes to the landscape during the last 125 years limit the rehabilitation options. A brief review of this history establishes the extent and context of these human changes.

RECENT HUMAN HISTORY

The lower Cascade River landscape contains the history of the major human events in Banff National Park (Fig. 1). In the 1880's Canadian Pacific Railway (CPR) surveyors laid the route for Canada's transcontinental railway, following the Bow River corridor upstream from Calgary (Gadd 1986). Near Banff, they encountered the first challenge of mountain topography and a tunnel was proposed through Sleeping Buffalo Mountain. Engineers renamed Sleeping

Buffalo Mountain to Tunnel Mountain but eventually selected an alternative route (Gadd 1986). The railroad would push through a canyon in Devil's Head Creek to the north and eventually reconnect with the Bow River valley (Department of Mines and Technical Surveys 1870). Devil's Head Creek has since been renamed the Cascade River. With the construction of the CPR mainline in 1883, the Cascade River corridor became part of Canada's coast-to-coast transportation system.

In 1885, the popularity of nearby hot springs led to the designation of Banff as Canada's first national park (Gadd 1986). Coal discoveries along the lower reaches of the Cascade River led to the establishment of the town of Anthracite in 1887 (Department of Mines and Technical Surveys 1887). Trains crossing the prairies were fueled primarily by wood and coal from Anthracite provided a more efficient source of fuel. Rip-rap placed along the historic river bank to protect the town remains visible today.

Geologists discovered additional coal seams near the Cascade River and in 1903 the CPR built the mining town of Bankhead (Gadd 1989). Coal from Bankhead fueled steam turbines that produced electricity for the growing town of Banff. However, the coal lacked resin to form cohesive lumps and the mine produced more dust than usable fuel. In 1906, CPR constructed a briquette plant that mixed the fine coal with coal tar and pressed the mixture into lumps. The coal tar arrived in wooden barrels from Pennsylvania by the train load. The briquettes heated homes and fired locomotives. In 1922 the mine became unprofitable and the operation shut down over night. Coal tar residue persists throughout the Lower Bankhead and Cascade River floodplain. In 1994 Banff National Park initiated investigations into the contamination.

The first dam on Lake Minnewanka built before 1912 raised the lake level by 1.2 meters (Canadian Parks Service 1992). At this time the Cascade River bypassed Lake Minnewanka entirely and the outlet stream of the lake was a tributary to the Cascade River. In 1912, the Calgary Power Company constructed a dam on Lake Minnewanka, raising the lake level another 4 meters.

When Bankhead and its power house closed in 1922, a new generating facility was constructed several hundred meters downstream from the dam at Lake Minnewanka. With the conversion to hydro power in 1922, the Calgary Power Company regularly applied to increase water storage and develop more power within Banff National Park. In 1929, with redrawn park boundaries, power development began in the nearby Spray and Kananaskis watersheds. However, park managers denied permission to expand the facilities at Lake Minnewanka.

In 1939, Canada went to war and industrial power demands increased in western Canada. On November 18, 1940, the Calgary Power Company resubmitted applications to develop power on the Cascade River. Under the authority of the War Measures Act, legislation was changed and the company received the licence to undertake the project.

The dam raised the lake level by 24.8 meters from its historic elevation. A diversion canal and penstock rerouted the water to Cascade Plant for power generation. Water bypassed nine kilometers of the historic river channel. The brick power several hundred meters downstream of the present dam was closed in 1941. The turbines were removed and sold, however the brick building still stands (Fig. 1).

The canyon that had originally deterred railroad engineers, now dry, provided the route for the TransCanada Highway. In the 1980's the highway width was doubled through this canyon. The historic river bed, now also mostly dry, provided a source of gravel for the expansion. Several gravel pits were reclaimed for recreation following completion of that phase of the highway expansion project. One pit remains operational.

This thesis consists of four additional chapters. In the next three chapters, I describe the abiotic and biotic components of the Cascade Creek ecosystem. First in Chapter 2, I describe historical changes to the Cascade Creek floodplain using air photo analysis. In Chapter 3, using natural streams and their processes as ideal models, I describe existing hydrology and channel morphology in Cascade Creek. In Chapter 4, I compare the riparian plant communities along Cascade Creek with other plant communities from similar environments. Each of these chapters is organized as an independent scientific paper, with an introduction, description of methods, results and discussion, and conclusions. The final chapter reviews the findings of Chapters 2-4, and presents three options for managers.

CHAPTER 2

FLOODPLAIN DECLINE FOLLOWING DAMMING

INTRODUCTION

Due to frequent disturbance, riparian zones support a variety of types and ages of plant communities. With this large number of habitat patches, riparian areas are important in the maintenance of regional biodiversity (Naiman and others 1993). National Park policy requires the preservation of ecological integrity and restoration where structure or function of an ecosystem has been seriously altered (Parks Canada 1994). Describing the degree of change in the structure of the Cascade River riparian ecosystem is an important first step in restoration planning.

Large scale diversions and impoundments occur throughout western North America. Stream reaches and their associated riparian vegetation are known to respond individually to these water diversions (Harris and others 1987, Friedman and others 1995, Stevens and others 1995). However, the effects of water diversion on floodplain structure have rarely been quantified (Miller and others 1995). In this chapter, I measure the changes to the Cascade River floodplain that occurred between 1943 and 1985.

METHODS

Procedures to evaluate changes to streams over time using air photos are adapted from Grant (1988). Air photos from September 1943 (1:16 000 scale) and May 1985 (1:10 000 scale) cover the 8.3 km of Cascade River subject to water diversion. Although dam completion and diversion occurred in 1942, neither logging or nor wildfire influenced the floodplain between 1942 and 1943. Therefore, 1943 photos are suitable for historical landscape analysis. 1985 photos obtained from TransAlta Utilities were the most recent photos of a scale suitable for stream channel and floodplain measurement.

Photo scale determination followed procedures in Lillesand and Kiefer (1994). I stratified the 1943 Cascade River and the 1985 Cascade Creek on the air photos using a stream classification technique developed by Buffington and Montgomery (1993). Measurements of non-vegetated channel width and floodplain width were made with an 8X magnifier graduated to 0.1 mm. The variables used in this analysis were:

1) <u>non-vegetated stream channel width</u>: This is a measure of the aquatic ecosystem. It is the distance between discernible vegetation on the left and right banks and was taken perpendicular to the main channel.

2) <u>floodplain width</u>: This is a combined measure of the aquatic and riparian ecosystems. It is the width of the area where vegetation or landform show evidence of elevated water table or flood disturbance. This measurement was also taken perpendicular to the main channel.

3) riparian zone width: This is a measure of the riparian ecosystem. It was calculated by subtracting the non-vegetated stream channel width from the floodplain width.

Where an active stream channel was observable, data were taken at a ground distance interval of approximately 100 meters. A similar frequency of measurements was taken on 1943 and 1985 photos, but data points are not paired. All photo distances were converted to ground distance.

Since water diversion in 1942, activities including highway expansion, gravel extraction and recreation development, reshaped much of the landscape in the historic river channel. However, the upper 3.6 km of the 8.3 km study area was not disturbed. Within this pristine reach, where diversion of water is the only visible human influence on the vegetation and stream channel, statistical analyses were used to test the following hypotheses:

1) H_o: μ non-vegetated stream channel width 1943 $\leq$ μ non-vegetated stream channel width 1985.

H_1: μ non-vegetated stream channel width 1943 $>$ μ non-vegetated stream channel width 1985. $\alpha = 0.05$

2) H_o: μ floodplain width 1943 $\leq$ μ floodplain width 1985.

H_1: μ floodplain width 1943 $>$ μ floodplain width 1985. $\alpha = 0.05$

3) H_o: μ riparian zone width 1943 $\leq$ μ riparian zone width 1985.

H_1: μ riparian zone width 1943 $>$ μ riparian zone width 1985. $\alpha = 0.05$

The data were transformed using natural logarithms to achieve a normal distribution. Hypotheses testing followed standard procedures for two samples with unpaired data, including a preliminary test to determine if population variances were equal (Zuuring 1992).

At the 3.6 km mark, Cascade Creek flows into a diversion ditch skirting a large gravel pit and eventually empties into three reclaimed gravel pits called Cascade Ponds. Data downstream beyond the 3.6 km mark were excluded from the statistical analysis due to the confounding factors beyond water diversion that have created the new landscape.

RESULTS AND DISCUSSION

Removal of water from Cascade River is associated with significant decreases in width of terrestrial and aquatic ecosystems in the top 3.6 km of Cascade Creek (Table 1).

Table 1. Summary statistics for three traits observed at two different years

variable	1943		1985		t value
	$\bar{x}$	s	$\bar{x}$	s	
floodplain width (m)	96.4	11.0	24.0	1.7	9.936*
channel width (m)	23.6	1.6	7.7	0.6	9.498*
riparian zone width (m)	72.9	10.9	16.3	1.9	6.849*

* Indicates 1943 value > 1985 value with 95 percent confidence using t test (unpaired) following preliminary test on population variances (n = 39).

The combination of water diversion, gravel extraction and highway construction has decreased aquatic and riparian habitat along the entire 8.3 km of the historic Cascade River channel (Table 2).

Table 2. Changes in floodplain characteristics from 1943 to 1985

variable	1943	1985
length of active channel (km)	8.3	5.5
floodplain area (ha)	128.1	9.8
channel area (ha)	26.3	4.0
riparian zone area (ha)	101.8	5.9

Estimates of area were calculated by multiplying the average width for each reach by its length and summing them for each year.

Active stream channel length was reduced from 8.3 km to 5.4 km between dam construction and 1985 (Table 2). This loss occurs in two places. During the reconstruction of the TransCanada Highway in the early 1980's, portions of the floodplain and historic river channel were mined for gravel. Several gravel pits have been reclaimed as ponds for recreation. These ponds replace 1 km of stream channel. An active stream channel extends for 0.16 km downstream of the ponds and intermittent flows extend for several hundred meters further. The lowest reach, beginning near the 7-km mark, lacks any sign of flowing water and flow becomes entirely sub-surface. Whereas most streams flow into larger streams, Cascade Creek is isolated from the upper Cascade River by the dam and from the lower reaches of the Cascade River by a section of dry channel. Reductions in floodplain width and disruptions of the active channel are illustrated in Figure 2.

According to the statistical analysis, the 1943 mean stream channel width is greater than the 1985 mean stream channel width at a 95 percent confidence level. Width measurements show the 1985 floodplain is confined within the banks of the historic river channel.

Floods shape streamside terraces, recharge aquifers, and clear sites for vegetation colonization. In contrast, fires are the dominant disturbance in adjacent uplands. Such variations in disturbance and physical environment result in habitat diversity at a landscape scale. A comparison of floodplain area from 1943 to 1985 shows a decrease from 128.1 ha to 9.84 ha (Table 2). The extent of the decrease in area is illustrated in Figure 2.

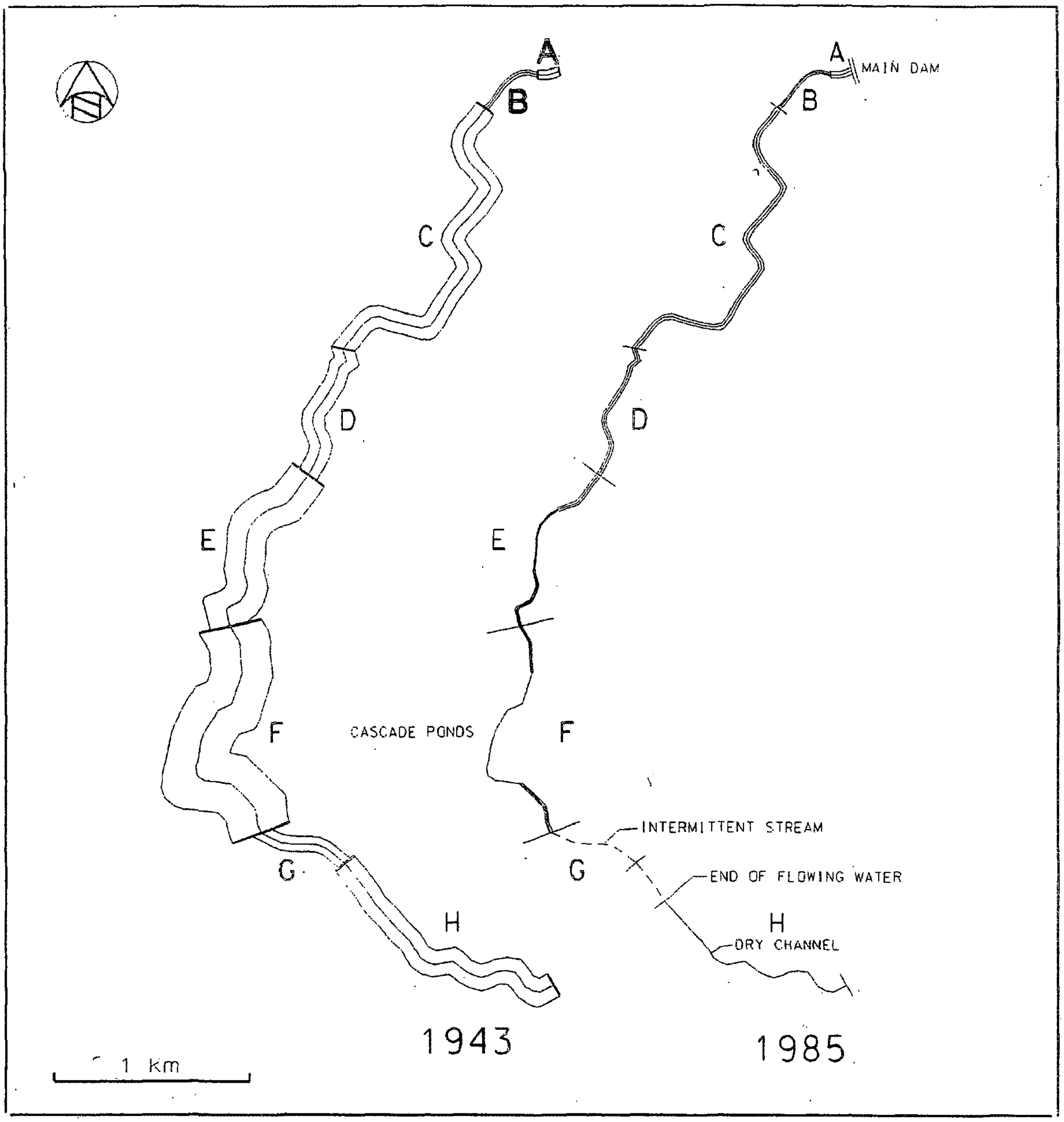


Figure 1. Changes in floodplain following water diversion

CONCLUSIONS

Rivers carry sediment, water, nutrients and seed downstream, while allowing fish and aquatic insects to travel both upstream and downstream. Adjacent riparian areas form natural corridors with improved cover and abundant food for amphibians, birds and mammals. The narrowing of the floodplain represents loss of both aquatic and riparian habitat and therefore the loss of biodiversity within the study area. The disruption of the flowing stream creates a barrier in a natural corridor and represents a threat to biodiversity on a regional scale.

Floodplain changes following water diversion have been reported by other researchers (Yorke 1979, Harris and others 1987, Rood and Heinze-Milne 1989, Miller and others 1995). However, complete disruption of flow and conversion of aquatic and the associated riparian ecosystem to upland ecosystems is rare.

Although resources for restoration are limited, connecting Cascade Creek with the Cascade River downstream of Cascade Plant may facilitate movement of both terrestrial and aquatic biota in this portion of the landscape. The following chapter on hydrology examines feasibility of achieving this goal.

CHAPTER 3

HYDROLOGY OF CASCADE CREEK

INTRODUCTION

From restoration efforts on two major rivers in California, Reiner and Griggs (1989) learned that establishing a natural hydrologic cycle is a prerequisite to any other activity in riparian rehabilitation. However, the option of restoring the historic hydrology of Cascade River (Fig. 1) does not have merit worth pursuing (Canadian Parks Service 1992) and is not the intention of this study.

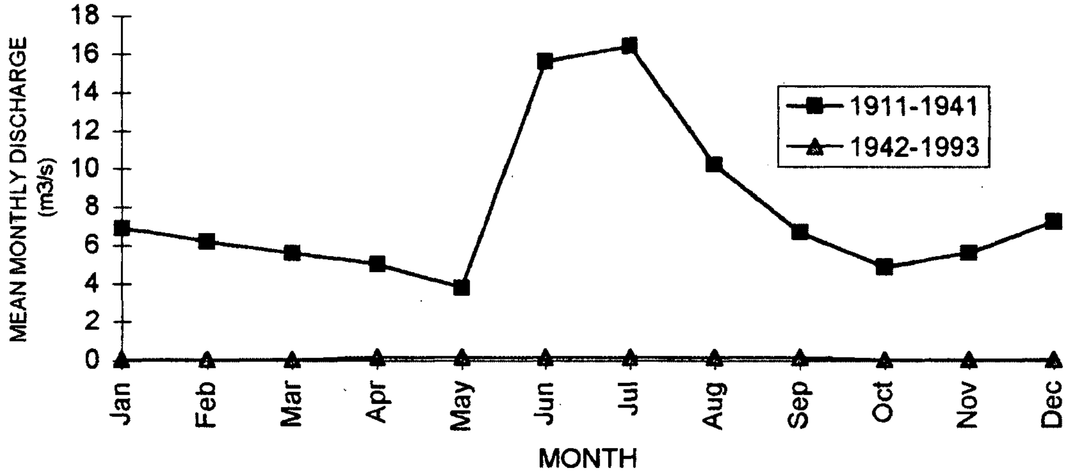


Figure 1. Mean monthly discharge for Cascade River downstream of Lake Minnewanka before and after dam construction.

In such situations where it is impossible to restore historic conditions, Parks Canada policy recommends duplicating natural processes as closely as possible (Parks Canada 1994). Therefore in this chapter, I compare the hydrology of Cascade Creek with the hydrology of natural streams. I begin with the annual hydrograph and utilize Johnson Creek, a first order stream located within 5 km of Cascade Creek, to provide a model of a potential natural hydrograph.

Secondly, I compare the channel of Cascade Creek with other natural stream channels. The shape of the channel cross section is a function of: the flow; the amount and type of sediment in motion; and the character of the material (including the vegetation) comprising the banks and the bed (Leopold 1994). In addition, as rivers grow larger, the width of the channel increases faster than the depth and whereas small streams typically have trapezoidal channels, larger rivers have more rectangular channels (Leopold 1994). The goal of this study is to determine the potential of creating a functioning small stream within a larger channel. Therefore it is important to consider these natural changes in stream channels along the continuum from a small stream to a large river.

Physical characteristics of the channel determine the stream velocity and width/depth ratio. In combination with shading from streamside vegetation, these three factors largely determine water temperature. This easily measured indicator of water quality is also examined.

Third, I examine two hydrologic processes: disturbance of the stream bed during flood events; and over-bank flooding. Disturbance of the stream bed is a natural process resulting from downstream transportation of sediment. The channel bed resists scour and channel structure remains stable until larger clasts are mobilized (Grant 1986). A commonly used size class for this threshold where channels become unstable is d_{84} (size class for which 84 percent of bed material particles have a smaller diameter). Change in channel structure creates a variety of terrestrial and aquatic habitats (Naiman and others 1993). Willows and other colonizers establish on new gravel bars as peak flows recede. High flows undercut banks and topple large trees into the channel, allowing light and large woody debris to enter the stream channel. Certain invertebrate species require recently disturbed substrate for habitat (Reice 1994).

Periodic alteration of channel structure is a natural process. However, an increase in frequency of channel bed disturbance is associated with increases of sediment production and decreases of habitat diversity and associated diminishing biodiversity. Similarly, elimination of channel bed disturbance results in the loss of recently disturbed sites within the habitat matrix and subsequent decreases in biodiversity.

Over-bank flooding usually occurs during peak spring flows. The high water recharges aquifers, and assists in cycling of nutrients between the aquatic and terrestrial systems. These floods may also trigger reproductive, physiological and behavioral responses for fish and aquatic invertebrates (Resh and others 1988).

METHODS

In July 1994, staff-gauging stations were established at six locations along Cascade Creek (Fig. 2). These stations were located to capture the variation in discharge along the length of Cascade Creek that occurs with inputs from tributaries and losses to groundwater. In June 1995, one station was installed on Johnson Creek. This station provides a model hydrograph of a natural stream.

Staff gauge measurements were taken weekly during the rising and falling limbs of the hydrograph and also during peak runoff events. After mid July, measurements were taken once every two weeks until September 1995. Stream flow measurements were taken between 3 and 5 times at various discharge levels for each station. I used a wading rod and AA current meter. The recently calibrated current meter was borrowed from Water Resources Branch of the Water Survey of Canada. Procedures for discharge measurement and equipment maintenance followed Lane (1989). Stage-rating curves were calculated using regression analysis (Appendix 1) and annual hydrographs were produced.

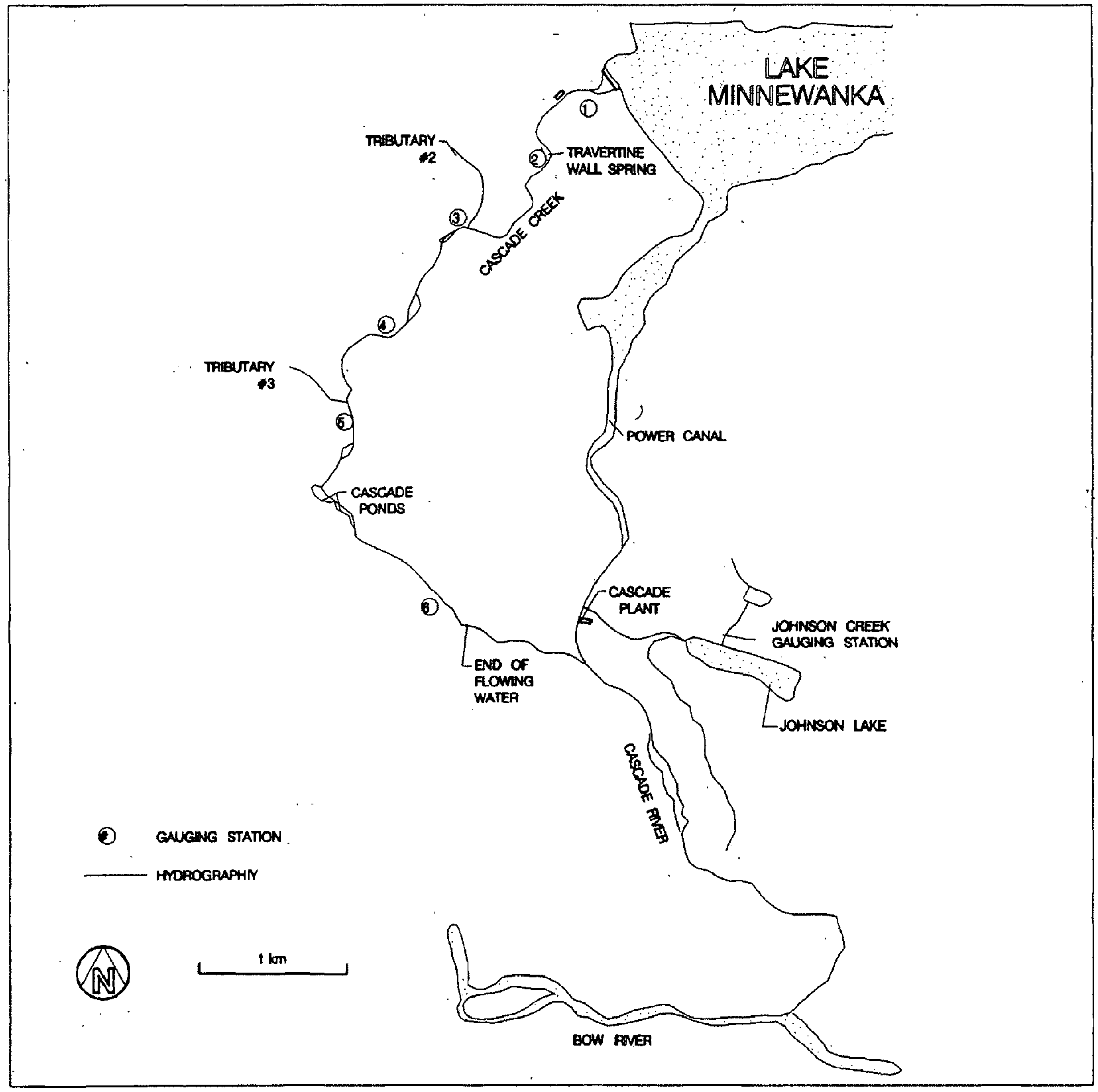


Figure 2. Map of gauging stations within the study area

Channel classification followed Rosgen (1994). Channel cross-sections were surveyed in representative and critical reaches using methods consistent with Harrelson and others (1994).

Water temperatures were measured using remote electronic sensors suspended in the water at Stations 1, 3 and 4 (Fig. 2). Sensors were operational from June 18 until September 10, 1995. These devices logged water temperature 10 times/day at regular intervals. I determined the maximum daily water temperature from these records. Air temperature measurements are from the daily fire weather records at the Banff Warden Station located at similar elevation within 10 km of the study area. These daily measurements were taken each day at noon from the remote weather station. I used regression analysis with air temperature as the independent variable to attempt to explain water temperature at Stations 3 and 4.

Determination of critical velocity for bed movement followed Costa (1983):

$$v_c = 0.18d^{0.49} \quad (50 \leq d \leq 3200 \text{ mm})$$

where: v_c is the mean flow velocity (m/s)

d is d_{84} which is the size class for which 84 percent of the bed particles are smaller

Although this formula was developed and tested for particles > 50 mm in diameter, it was applied in three instances where d_{84} was < 50 mm. Recent use of these methods developed by Costa include Grant (1986) and Wohl (1995).

To model flow velocity within individual cross-sections, I utilized software developed by Grant and others (1992). This software supports three different sets of resistance equations for estimating mean velocity. I chose equations developed by Thorne and Zevenbergen because they use substrate size to estimate channel roughness. The stage and discharge values generated during this modeling exercise were several magnitudes greater than any flows I recorded in the field and therefore could not be verified.

This modeling approach for determining critical velocity for bed movement has limitations. One researcher suggests that in steep mountain streams, reach-scale controls and woody debris have greater influence on bed load movement than channel cross-sectional flow characteristics (Adenlof and Wohl 1994). Other researchers suggest that bed structure and stability, particularly the presence of coarse surface bed armor, control bed load transport (Powell and Ashworth 1995). However, stream power is mainly a function of slope and this variable is important in the model I choose for analysis. Another computer model, HEC RAS, developed by the US CORPS of Engineers, is commonly used for similar modeling exercises. However, the methods I selected for this study remain reasonable and prudent for evaluating potential for large scale disturbance.

Another objective of this chapter was to evaluate the effects of increasing discharge into Cascade Creek through the riparian flow valve from 0.1 to 0.3 m^3/s. To determine the extent of over-bank flooding and changes in width/depth ratios from these flow increases , I also utilized the software developed by Grant and others (1992). First, I estimated stage and discharge with this software using equations developed by Thorne and Zevenbergen. When these estimates were inaccurate, I switched to the Manning's Resistance Equation. This formula allows the user to specify a roughness coefficient, Manning's "N". The program was run repeatedly with various Manning's "N" values until computer generated values resembled measured values of stage and discharge.

RESULTS AND DISCUSSION

Description of Existing Hydrology

TransAlta Utilities controls water release from Lake Minnewanka into Cascade Creek through the riparian flow valve. The 1995 release rate, measured at Station 1 (Fig. 2), was 0.1 m^3/s. Prior to 1994, TransAlta Utilities closed the valve during winter months. The primary purpose of the annual summer release was to fill Cascade Ponds with water for recreation. In 1994, TransAlta Utilities left the riparian flow valve remained open year round to maintain viable winter fish habitat.

One kilometer downstream from the dam, a spring flows into Cascade Creek. The spring originates at the top of a cliff wall on the east side of the creek. Travertine, a calcium carbonate mineral, covers the cliff and nearby hillside. This feature is locally known as the travertine wall. The flow measured at Station 2, the first suitable spot for discharge measurement downstream of the spring, remained steady at 0.18 m^3/s throughout summer and winter months. Figure 3 shows hydrographs from Stations 1 and 2, with Johnson Creek for reference.

Beaver dams moderate flow of Johnson Creek and as a result, flows of Johnson Creek are less flashy than other small snow melt fed streams in the area. Yet, seasonal variation in flow of Johnson Creek strongly contrasts the steady flow of Cascade Creek.

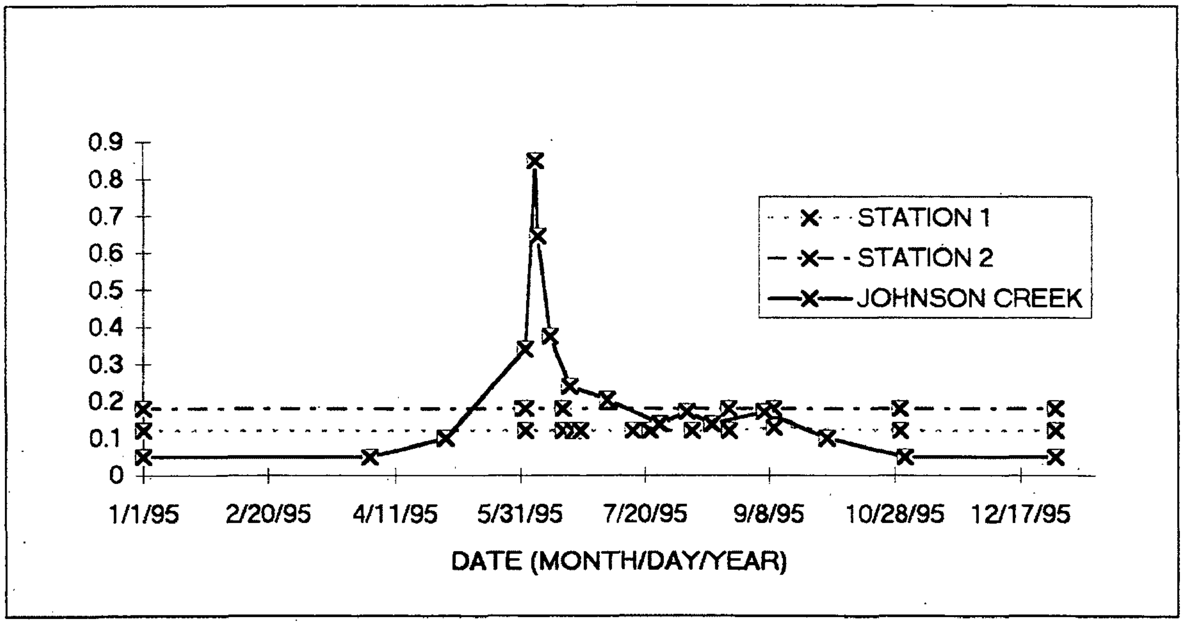


Figure 3. Hydrographs for Cascade Creek Stations 1 and 2, and Johnson Creek

Flow remains stable from the travertine wall downstream to the 2-km point where a second tributary enters. This tributary originates at the base of a hill slope approximately 500 meters upstream of its confluence with Cascade Creek. Station 3 was established at the first suitable point for discharge measurement downstream of this tributary. Maximum discharge occurs in July, and tapers slowly throughout the summer.

Typically, stream surface flow is linked to subsurface flow or groundwater. Gaining or effluent streams acquire surface flow from groundwater sources, whereas losing or influent streams lose surface flow to groundwater (Brooks and others 1992). Downstream of Station 3, the landform changes from a confined river valley to an alluvial fan. Between Stations 3 and 4, surface flow decreases by approximately 50 percent (Fig. 4). These losses to subsurface flow occur across the coarse gravel deposits of Lower Bankhead.

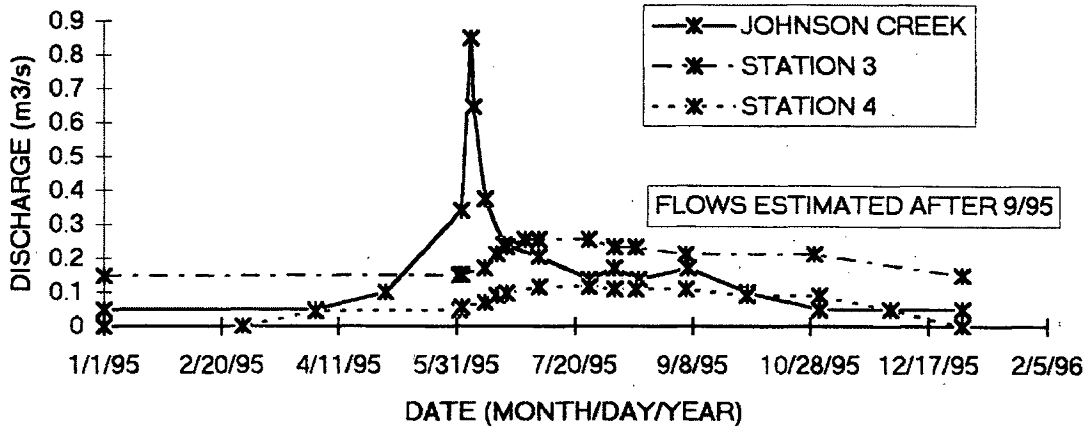


Figure 4. Hydrographs for Cascade Creek Stations 3 and 4, and Johnson Creek

A large active gravel pit begins between Stations 3 and 4 at the 4-km mark and water flows through a diversion ditch skirting the perimeter of the pit. Although the bottom elevation of the pit is 15 m below the riverbed (TransAlta Utilities 1986), the pit remains dry. The dry pit indicates that through Lower

Bankhead, the elevation of surface flow in Cascade Creek is well above the local water table. The rate of loss is likely regulated by fine textured materials in the riverbed. A major disturbance of the streambed, such as a mechanical excavation of the stream bed to create addition pools, may result in further loss of flow to groundwater.

In contrast to Stations 1 and 2, the hydrographs of Station 3 and 4 show increase in peak flow during the summer months (Fig. 4). However, in comparison to Johnson Creek, at Stations 3 and 4 the peak is delayed and the maximum discharge remains much lower.

Near the 5-km mark, a third tributary enters Cascade Creek. This intermittent stream carries snow melt runoff during May and June down the east face of Cascade Mountain. Flow peaks each afternoon and tapers off through the night. The stream also flowed during rainy periods of July and August. The estimated peak discharge of 1.7 m^3/s at Station 5, occurred on June 6, 1995. Figure 5 shows that this discharge exceeds the maximum estimated discharge of Johnson Creek by 100 percent.

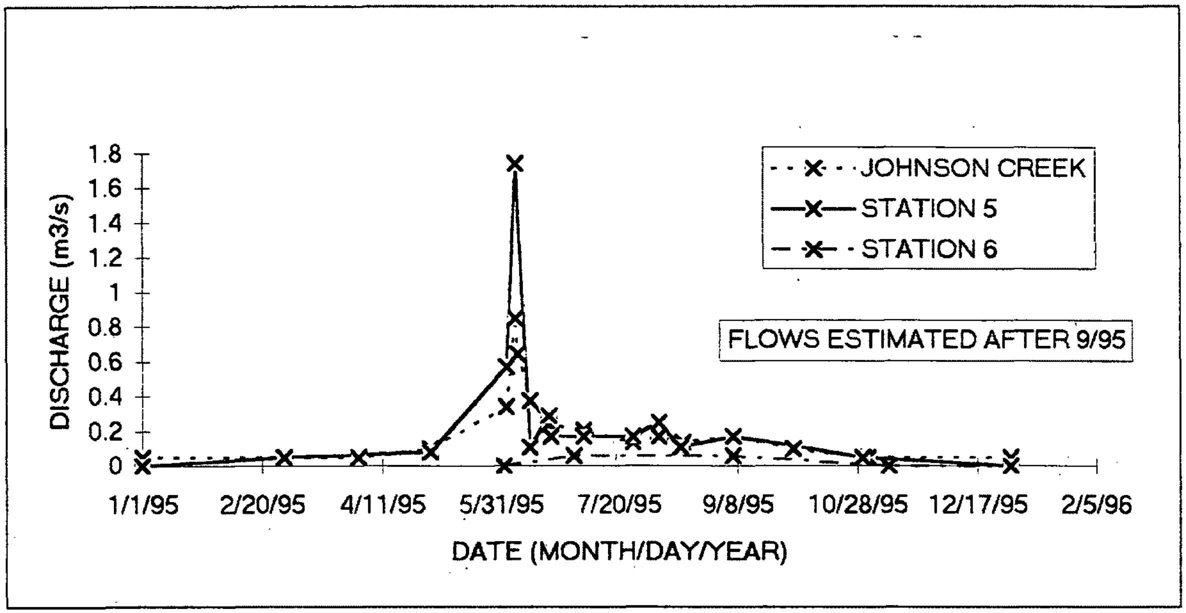


Figure 5. Hydrographs for Cascade Creek Stations 5 and 6, and Johnson Creek

Near the 5.5-km mark, Cascade Creek empties into Cascade Ponds. The ponds dry completely during the winter months and fill again in the month of June. In late June, 1995, the ponds began to spill over. Water flowed to near the 7-km mark before emptying into a small burrow pit. Water disappears underground into a hole on the perimeter of the pit. In comparison to Johnson Creek, flow at Station 6, located downstream of Cascade Ponds, is intermittent and lacks any peak in discharge (Fig. 5). From the 7-km mark to the Cascade River, downstream of Cascade Plant, the channel shows no sign of recent water transport.

Channel Profile and Configuration

The gradient of Cascade Creek averages 0.9 percent. Although few changes in slope occur, channel configuration varies throughout the study area. A classification system of natural rivers developed by Rosgen (1994) provides a tool to compare Cascade Creek with other natural streams. This classification system divides streams into six main channel types. Dominant bed material and slope split these six channel types into subtypes. Appendix 2 contains diagrams of this system for reference.

To describe the channel profile and configuration, Cascade Creek is divided into four sections. Each section is subdivided into stream reaches, based on the Rosgen classification. A representative cross section illustrates the configuration of each reach. All other surveyed cross sections are diagrammed in Appendix 3.

Section 1 extends from the dam for 2.5 kilometers to the second tributary, near Lower Bankhead. The steepest section of Cascade Creek, with a 3 percent slope, occurs in Reach A (Fig. 6). The gradient through Reach B averages 0.9 percent.

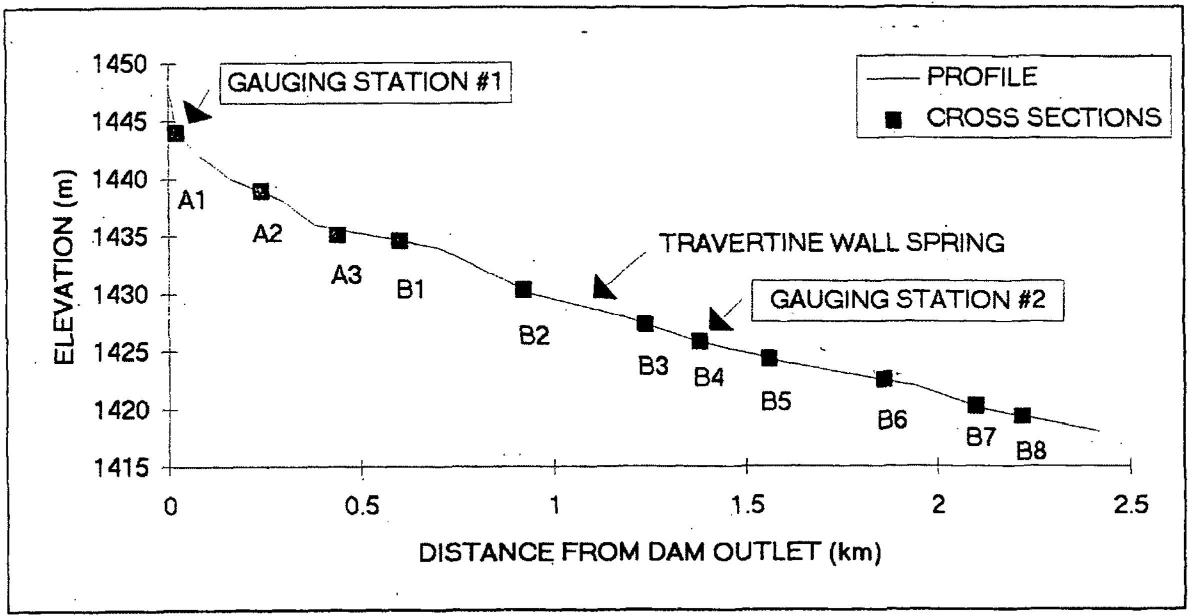


Figure 6. Downstream Profile of Section 1

A gravel bottom, meandering (Rosgen C4) channel occurs through cross-section A1 (Fig. 7). With a steep often undercut bank opposite to a gradually sloping lateral bar for the other bank, the meandering stream provides excellent salmonid habitat. Although less than 100 meters in length, this reach resembles a natural stream more closely than any other reach of Cascade Creek. This reach could serve as a model for other reaches in Cascade Creek where channel manipulation may be recommended.

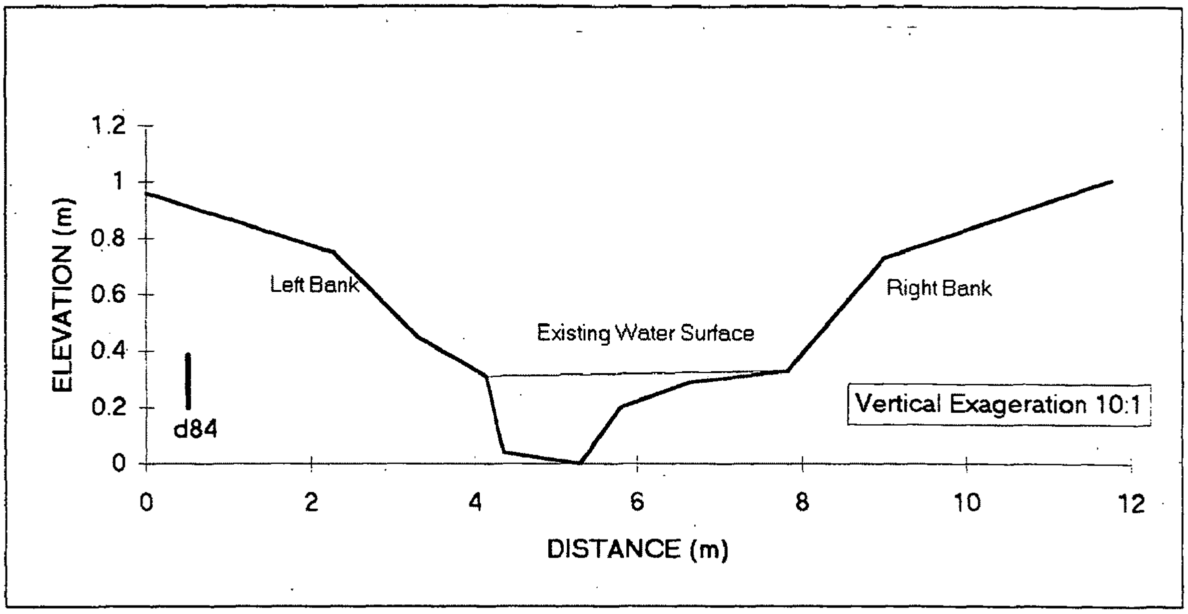


Figure 7. Cross section A1, Cascade Creek

Note: Using the measurement scale on y-axis, the height of the vertical bar labeled d84 provides a measure of the bed particle size in the area of the cross-section. The d84 is the size class for which 84 percent of the bed particles in the area of the cross-section are smaller.

In the remainder of Reach A, including cross-sections A2 and A3, the creek flows through a series of bedrock steps and pools (Rosgen B1 stream type). With the absence of annual flushing flows, deep accumulations of organic matter occur in all pools. The historic channel is visible between cross sections A2 and A3.

Reach B, is a braided, cobble bottom stream (Rosgen type D3). Historic river banks are readily discernible well outside the present channel (Fig. 8). The channel braids in many locations as water flows around the larger clasts from the historic channel. The width/depth ratio for cross-section B1 is 150:1 and averages 75:1 for the eight cross-sections surveyed within Reach B. The wide shallow channel and high surface roughness create very low velocities. The channel remains confined through this reach and deep pools form on outside corners against exposed bedrock cliffs. These pools provide over wintering habitat for a brook trout population.

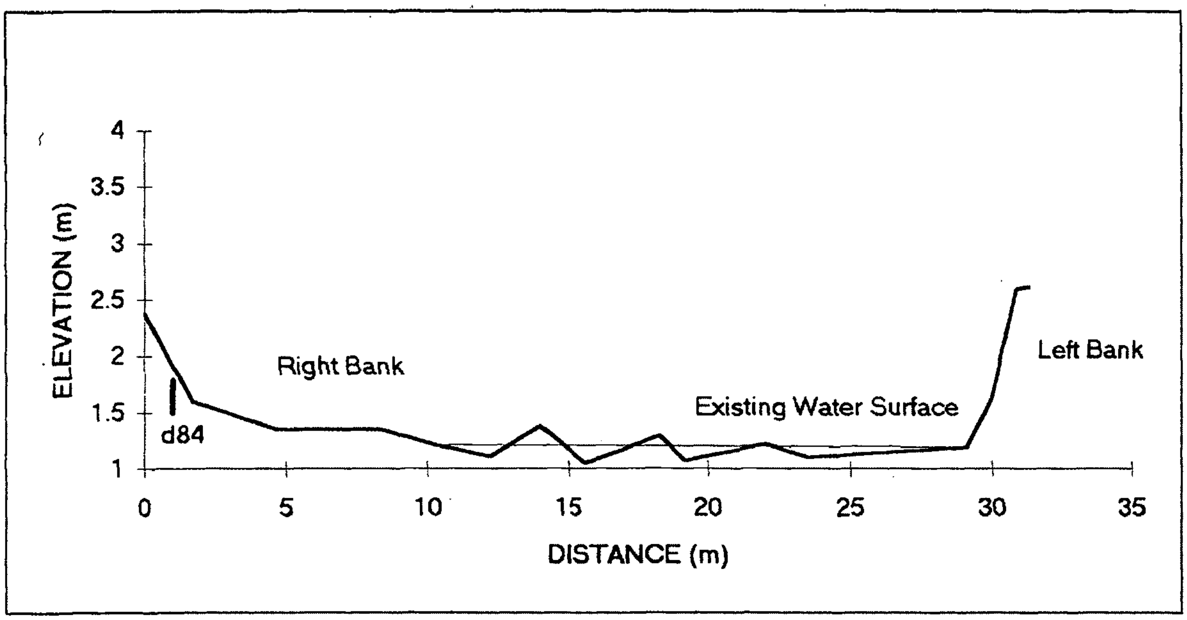


Figure 8. Cross section B1, Cascade Creek

A slump enters the channel on an outside corner near the 2 km mark. In contrast to the average 305 mm d_{84} for the other cross sections found in Reach

B, fine gravel inputs from this erosion event change the d_{84} at cross section B7 to 23 mm.

Section 2 extends from the second tributary near Lower Bankhead to the third tributary near the gravel pit access road. The average gradient of this section decreases to 0.7 percent slope (Fig. 9).

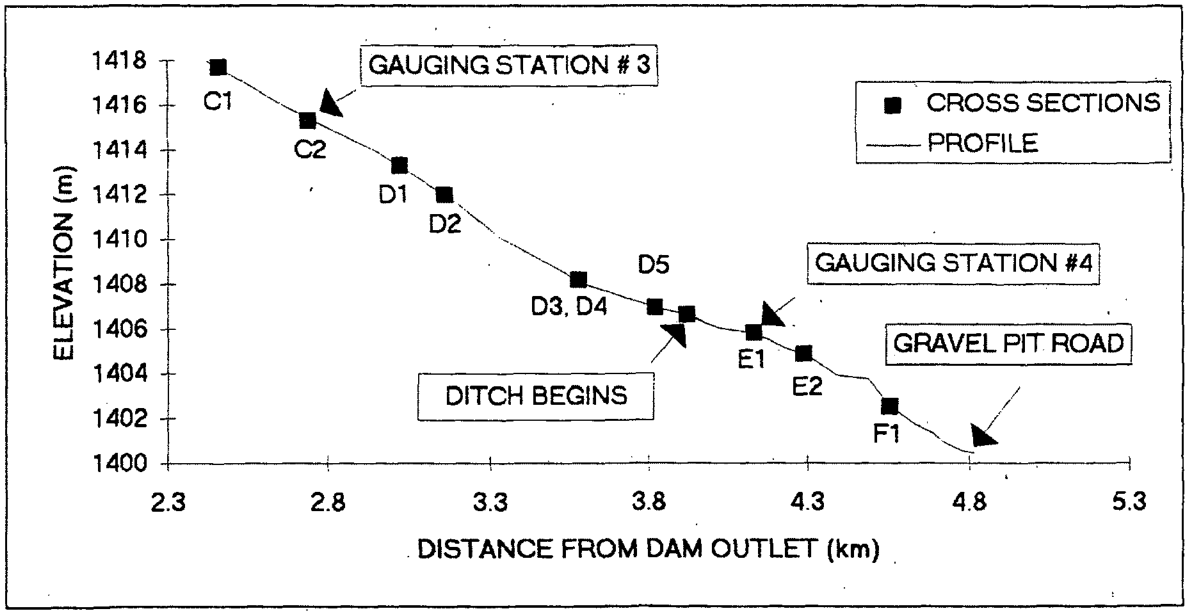


Figure 9. Downstream profile of Section 2

A braided, cobble bottom stream (Rosgen type D3) extends through Reaches C and D. Cliff walls confine Reach C and create two deep pools where trout over-winter. At cross-section C2, the creek narrows and deepens, providing a suitable location for discharge measurement. Width/depth ratios increase to 100:1 through reach D (Fig. 10).

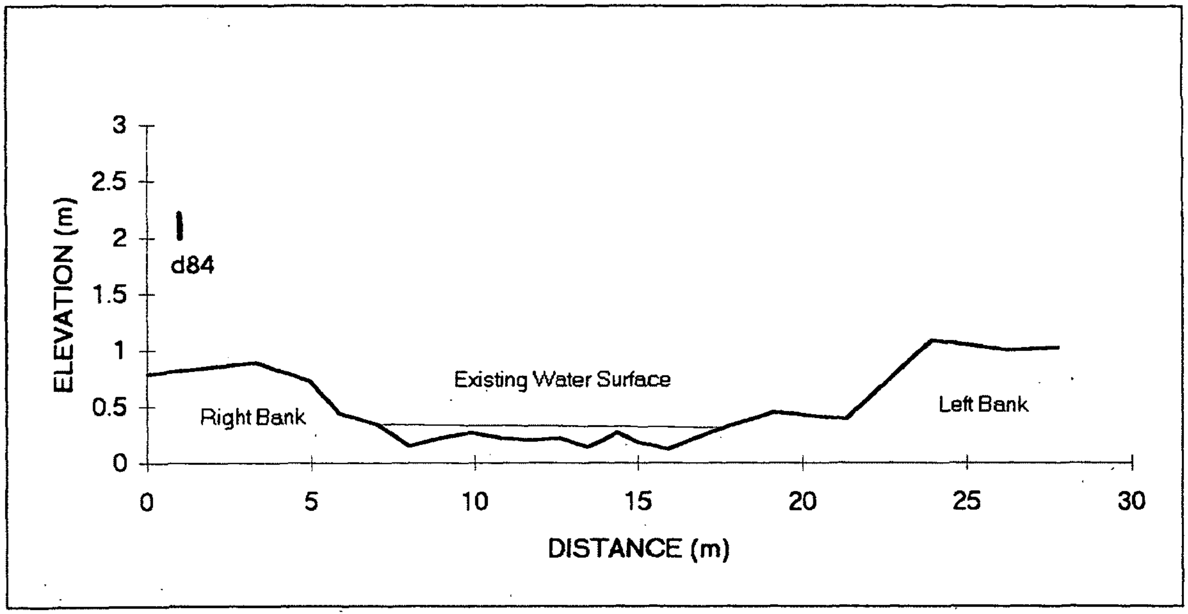


Figure 10. Cross section D2, Cascade Creek

Other than an absence of meandering, the diversion ditch which forms Reach E, possesses many criteria of a natural meandering stream (Rosgen type C). Width/depth ratio at cross section E2 (Fig. 11), decrease to 21:1 from the values of 100:1 found in reach D.

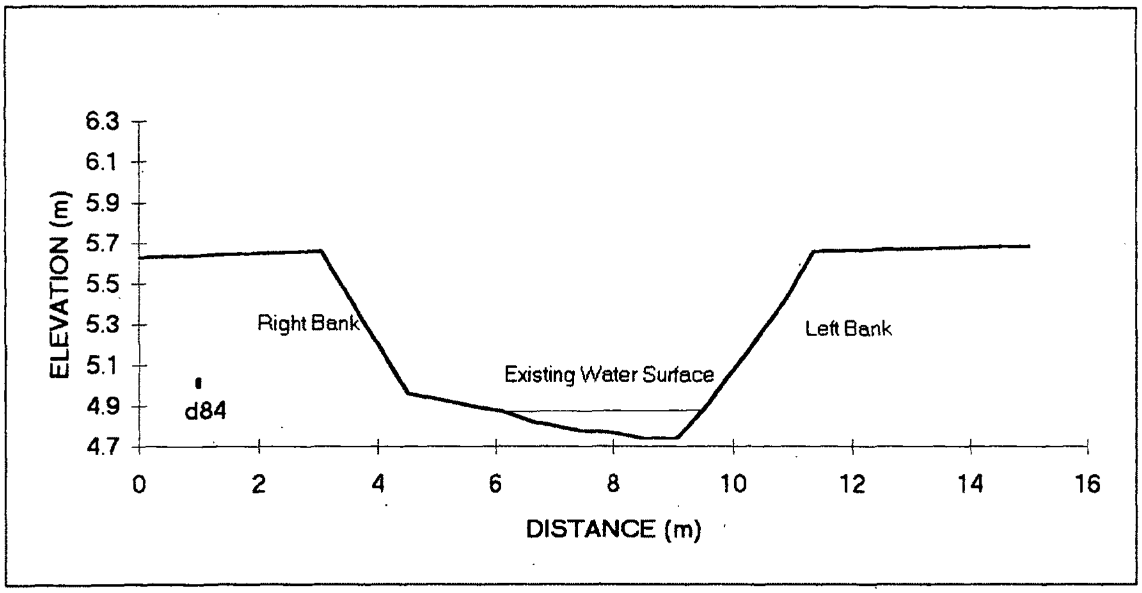


Figure 11. Cross section E2, Cascade Creek

Through Reach F, water flows through a historic side channel. This reach, 150 m long, possess all criteria of a meandering stream (Rosgen type C) including high sinuosity.

Section 3 extends from the third tributary, near the 5-km mark, to the railroad tracks near the 7-km mark. Highway and railroad construction, as well as gravel extraction have removed the historic channel in much of Section 3. The gradient averages 1.5 percent upstream of the ponds and 0.7 percent downstream of the ponds (Fig. 12).

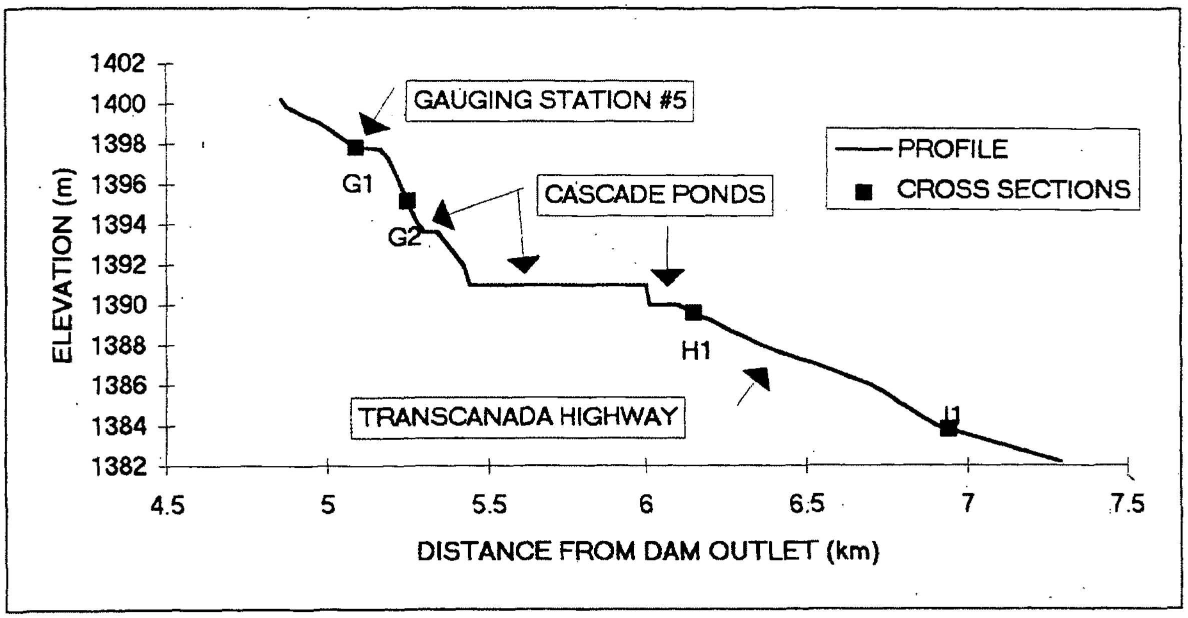


Figure 12. Downstream profile of Section 3

Reach G receives sediment from the Cascade Mountain tributary upstream of Cascade Ponds and shows evidence of recent aggradation and degradation. Erosional features include the bars and headcuts seen in cross section G1 (Fig. 13). A braided, gravel bottom stream (Rosgen D4 type) is found at cross section G1. As the gradient increases and channel constricts at cross section G2, the stream changes to a cobble bottom, riffle dominated stream type (Rosgen B3).

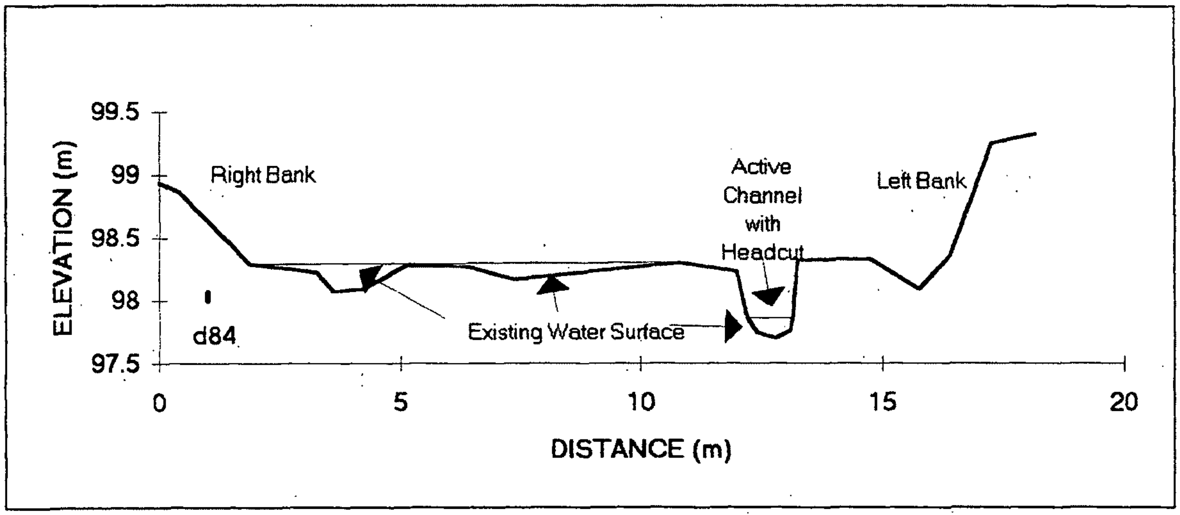


Figure 13. Cross section G1, Cascade Creek

The historic channel features including banks and bed remains intact at cross section H1 (Fig. 14). Downstream from the TransCanada Highway, Cascade Creek appears as a roadside ditch with grasses covering the channel bed. Cross section I1 resembles a braided, sand bottom (Rosgen D5) stream type.

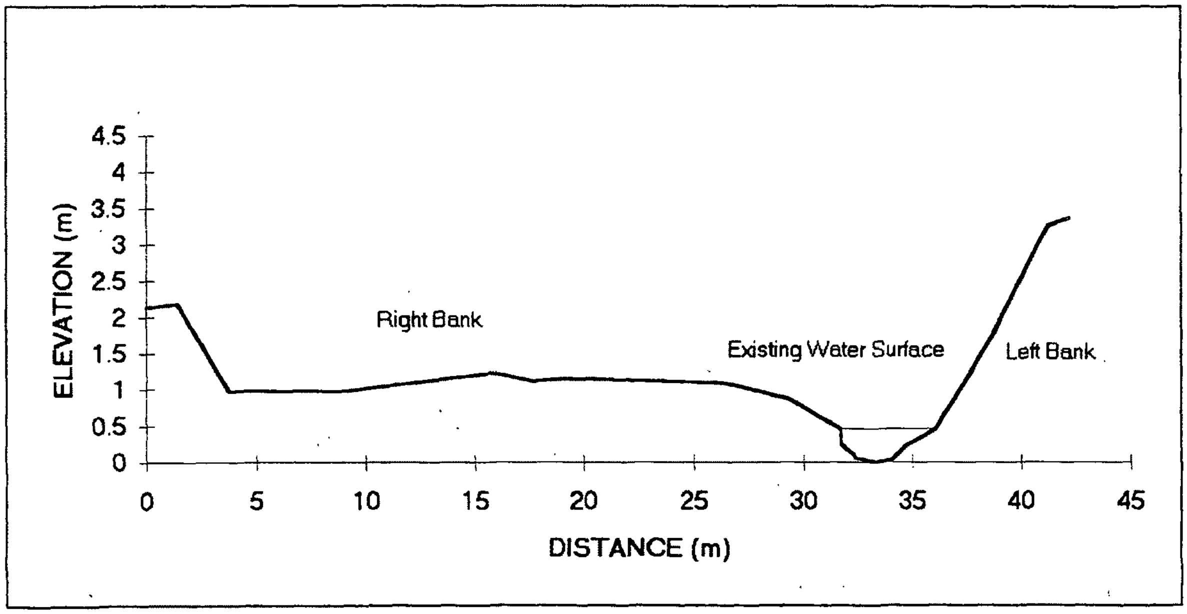


Figure 14. Cross section H1, Cascade Creek

Section 4 extends from the railway crossing to the tailrace, downstream of the power plant (Fig. 15). The gradient from the beginning of this section to cross section I4 averages 0.5 percent.

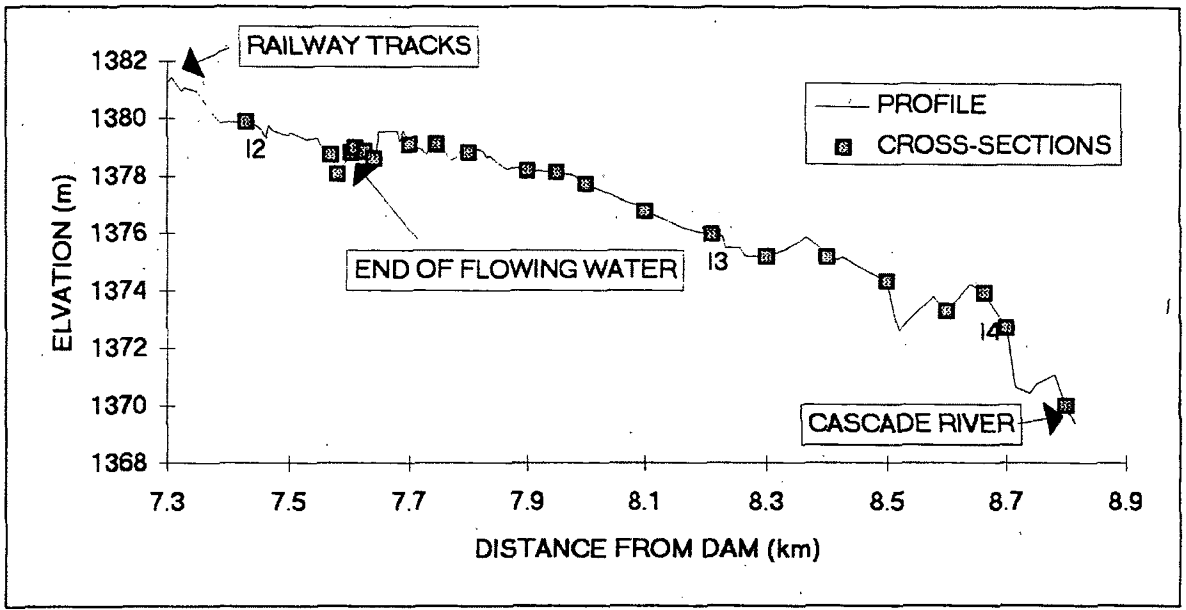


Figure 15. Downstream profile of Section 4

An elevated road bed blocks flow near the 7.6-km mark. This is the end of intermittent flow in the lower study area. Sediment from hill slope erosion along the outside corners of the dry channel blocks potential downstream flow in two other places (Fig. 15). In order for water to flow through this section and join Cascade River, these obstructions will have to be removed and down slope gradient restored.

The two main channel configurations in Section 4 include the excavated ditch of cross section I2 (Fig. 16) and the historic channel of cross section I3 (Fig. 17). The ditch contains several deep pools suitable for fish habitat, but lacks the sinuosity of a natural channel.

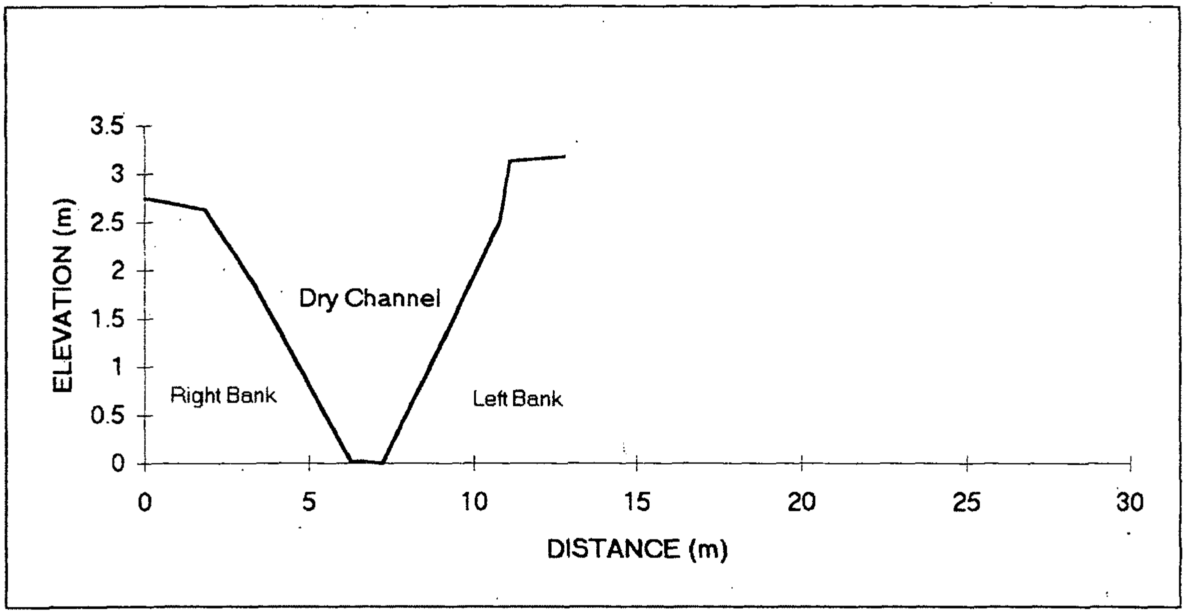


Figure 16. Cross section I1, Cascade Creek

The lower one kilometer of Section 4 remains dry throughout the year. The channel at cross section I3 is wide and flat bottom (Fig. 17), and strongly contrasts the trapezoidal shape of small meandering (Rosgen type C) stream channels.

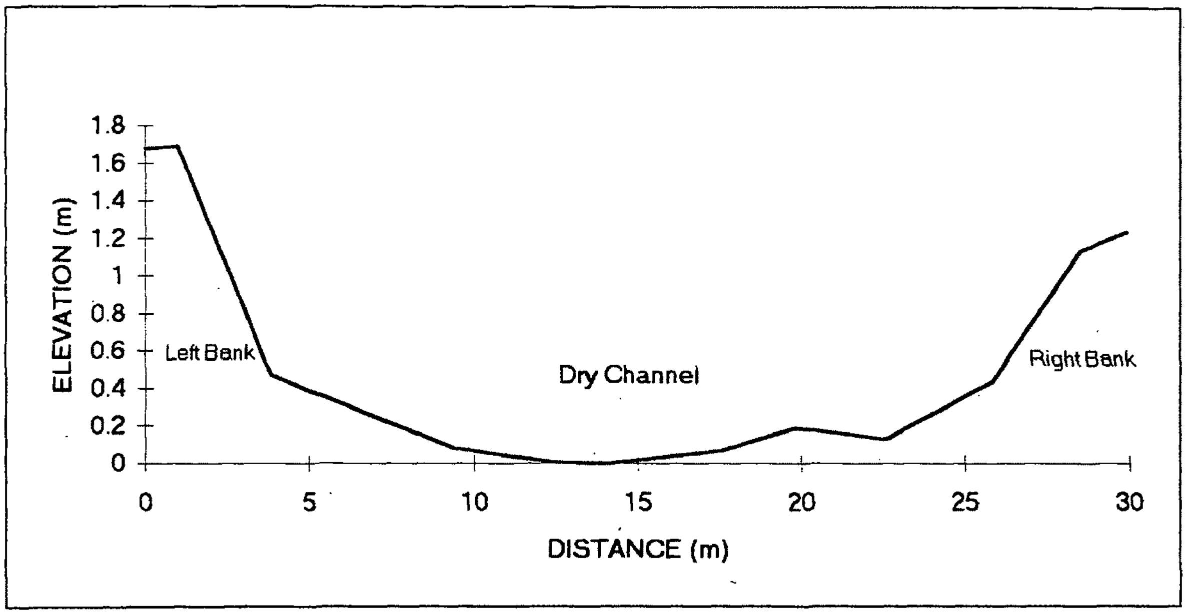


Figure 17. Cross section I3, Cascade Creek

In addition, vegetation in the historic floodplain of section 4 closely resembles adjacent upland vegetation, meaning there is no water table within the rooting depth of trees growing on the floodplain. In Chapter 2, Floodplain Decline Following Damming, I suggested returning surface flow throughout the historic channel as a step towards restoring lost biodiversity. However, with the alluvial landform and depth to water table indicated by the vegetation, flows several magnitudes greater than the present flow capacity of the riparian flow valve are likely required to achieve this goal.

Water Temperature as an Indicator of Water Quality

The optimal temperature range for most salmonids is approximately 12-15°C with temperatures between 20 and 25°C are generally lethal to adult salmonids (MacDonald and others 1991). During an extended warm period in the summer of 1994, I recorded a water temperature of 24°C in the Cascade Creek near Station 4. However, the summer of 1995 was one of the coolest summers on record. At the nearby Banff Warden Office, the highest measured noon air temperature was 23.7°C. In 1995, the highest recorded water temperature in Cascade Creek was 18.3°C. This occurred on June 23 when the noon air temperature in Banff was only 21.1°C. As a result of these cool temperatures, water quality problems relating to temperature were not readily apparent. With the limited variation in values, regression analyses, using noon air temperature at the Banff Warden Office were poor predictors of water temperatures in Cascade Creek. None the less, several patterns with management implications were observed.

First of all, optimal temperatures for salmonids are found throughout the summer months in Cascade Creek from the dam downstream for 3 km to Station 3, at lower Bankhead (Fig. 18). The two spring type tributaries that enter this reach help to maintain these optimal conditions.

Secondly, over the next 1.4 km stretch between Stations 3 and 4, water temperatures increased rapidly on warm days. For example, on June 23, 1995 water temperatures increased from 13.4 to 18.3°C (4.9°C) between Stations 3 and 4. Loosing stream reaches, such as this one, have been found to be susceptible to increases in water temperature (MacDonald and others 1991).

Water temperature is a function of several variables including velocity and shading. The potential to reduce the rate of temperature increase by increasing flow and therefore velocity is examined later in this chapter.

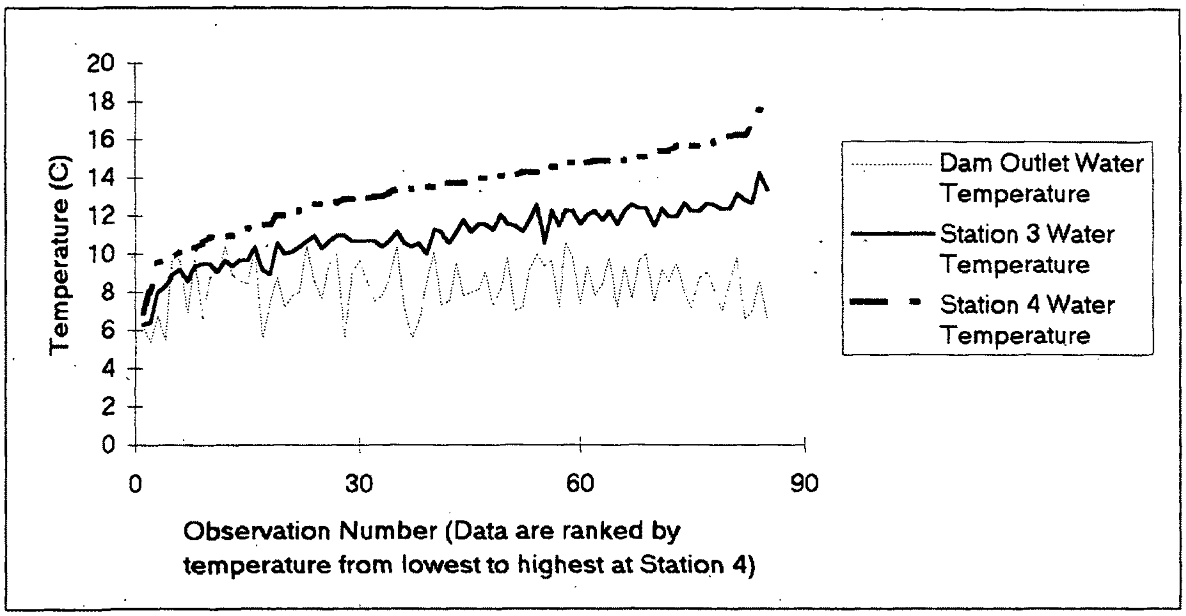


Figure 18. Cascade Creek water temperatures (June 18-September 10, 1995) from Stations 1, 3 and 5

Requirements for Channel Bed Disturbance

Discharge modeling revealed three general patterns. First, only reaches subject to natural or human channel alteration since dam construction show potential of bed disturbance if flows from the riparian flow valve from 0.1 to 0.3 m^3/s. Movement of some bed material can be expected at cross sections A1, B7, E2 (Table 1). However, de-stabilization of the channel is predicted only at cross section F1.

Second, several cross-sections located in unaltered reaches of the historic channel (D1 and D5), showed potential of channel bed disturbance within the magnitude of historic floods. Prior to completion of the dam in 1942, stream flow records were maintained through Lower Bankhead near the site of Gauging Station #3 (Environment Canada 1991). The maximum daily discharge of 73.9 m^3/s occurred on June 28, 1915. Flows greater than 45 m^3/s occurred during 8 of 28 years of records prior to diversion, indicating the magnitude of events that shaped the present channel.

Third, flow at critical velocity often exceeds channel capacity (Table 1, last column) and there are two possible explanations for these results. First, for cross sections with very large d_{84} values (Table 1, cross sections A3 and B1), only over-bank flood events may have had the energy to disturb the historic channel bed. Second, efforts were made to include the historic channel banks when surveying. However, encroachment of vegetation into the historic channel often restricted surveying to within the historic channel (Table 1, cross sections B3 and B4).

Table 1. Critical velocity and flow for surveyed cross-sections, Cascade Creek.

Cross Section	d_{84} (mm)	V_c (m/s)[1]	Q_{max} (m^3/s)[2]	Q at V_c (m^3/s)
A1	185	2.32	11.05	8
A2	bedrock	--	72.30	*
A3	450	3.59	46.80	*
B1	285	2.87	52.90	*
B2	550	3.96	16.07	*
B3	310	2.99	2.72	*
B4	240	2.64	4.94	*
B5	250	2.69	10.26	*
B6	240	2.64	4.85	*
B7	23	0.84	6.34	1.5
B8	260	2.75	102.89	102.9
C1	225	2.56	7.54	*
C2	176	2.27	9.68	*
D1	215	2.5	85.82	33.8
D2	215	2.5	28.86	*
D3	180	2.29	18.13	*
D4	135	1.99	8.31	*
D5	190	2.35	74.79	74.8
E1	55	1.28	2.83	*
E2	30	0.95	9.44	1.4
F1	17	0.72	2.00	0.25
G1	65	1.39	18.56	10.2
G2	135	1.99	66.47	5.3

1. $v_c = 0.18d^{0.49}$
2. Q_{max} = maximum discharge within surveyed cross section
* = channel capacity of surveyed cross section exceeded before v_c reached

Physical Effects of Flow Augmentation

Flow from the riparian flow valve may be increased to 0.3 m^3/s from 0.1 m^3/s with existing structures (Dames and Moore 1992). Expansion of channel width, changes in width/depth ratio and increases in velocity from such increases in flow are shown in Table 2. Increases in channel width between one and two meters are expected. The increased velocities associated with augmented flows may remove some of the organic matter accumulations from the channel bottom. This material will deposit along the margins of the channel where velocity decreases. Disturbance of the organic material on the channel bed occurs during annual peak flows in natural streams and establishment of this process in Cascade Creek may be considered an improvement from present conditions.

Changes in width/depth ratio with augmentation of present flow will not occur in the braided (Rosgen D3) stream type found in reach B (Table 2). High summer water temperatures that occur in Cascade Creek downstream of Station 3 are partially a function of the slow velocity in the wide shallow channel and are likely to persist.

Table 2. Channel characteristics with increased flow, Cascade Creek.

Cross Section	Stage (m)	Flow (m^3/s)	Width (m)	$Depth_{avg}$ (m)	W/D Ratio	V_{avg} (m/s)
A1: July 1994	0.33	0.12	3.4	0.1	34	0.23
Modeled	0.45	0.4	4.8	0.2	24	0.4
B1: July 1994	0.16	0.12	15.4	0.1	154	0.15
Modeled	0.20	0.4	18.0	0.1	180	0.18
B4: July 1994	0.27	0.18	5.5	0.1	55	0.33
Modeled	0.36	0.5	6.7	0.2	39	0.42
C2: July 1994	0.33	0.28	6.6	0.2	33	0.19
Modeled	0.44	0.5	8.3	0.3	28	0.22
E1: July 1994	0.19	0.08	3.3	0.1	33	0.2
Modeled	0.28	0.2	3.6	0.2	18	0.3

CONCLUSIONS

Parks Canada policy requires that natural processes be duplicated as closely as possible when undergoing restoration. Disturbance in both aquatic and terrestrial ecosystems creates a variety of physical environments and therefore habitats for different organisms. As a result, disturbance is one factor important to maintaining biodiversity. Stream environments are inherently rich in biodiversity because of frequent disturbance. Annual over bank floods rearrange portions of the stream bed. Ice flows with spring runoff disturb banks. 10 or 25 year floods events may possess enough energy to cause instability of entire stream reaches. This goal of duplicating natural processes was examined throughout this chapter.

Johnson Creek provided a model of an annual hydrograph for a natural stream. The comparison revealed that the first 2 km of Cascade Creek show a steady spring like flow and lack any increase in peak discharge during early summer. A delayed peak occurs between the 3 and 5-km marks of Cascade Creek, however, the magnitude of increase is much less than seasonal variation observed in Johnson Creek. Beyond the 7-km mark, there is no water and therefore no aquatic or riparian ecosystem present. However, the restrictions to flow increase and the present landform were found to preclude the restoration of a natural flow regime throughout the length of Cascade Creek.

The Rosgen (1994) classification of natural rivers provided examples of the physical characteristics of natural streams. Much of Cascade Creek resembles a braided stream, however the processes of central and lateral bar development, characteristic of braided streams (Leopold and others 1964,) are absent. Such natural channel development is partially dependent on the stream's sediment regime. Sediment sources for natural streams include hill slopes, stream banks and entrained sediment. The present creek downstream of the dam does not have access to upstream sources or the historic stream banks. Sediment sources for Cascade Creek are restricted to hill slopes on several outside corners bends. As a result, the potential for natural channel adjustment due to sediment input is limited.

Analysis of water temperatures revealed that optimal temperatures for salmonids exist in the top 3 km of Cascade Creek. During warm periods, the inflow from the dam and several tributaries will help to maintain these temperatures. However, downstream from the 3-km mark, the stream is highly susceptible to water temperature increases to levels that are less than optimal and possibly lethal to salmonids.

Channel adjustment is also dependent on streamflow (power). Modeling of power revealed that potential for stream bed disturbance within the braided cobble-bottom channel requires flows similar to those that created the historic channel. These flows are well above the proposed augmented releases into Cascade Creek. Only in the reaches altered by human activities since dam construction is there potential for stream bed disturbance.

Computer modeling also revealed that increasing release of water from the riparian flow valve to 0.3 m^3/s will increase stream width between one and two meters. However, stream depth will remain shallow and very high width/depth ratios will persist. Even with these augmented flows, high water temperatures during summer months are likely to persist in the lower reaches. The main benefit from augmented flows may be to remove deep accumulations of organic matter from pools in the upper reaches that provide the best salmonid habitat. Augmented flows may redistribute this material along channel margins. Eventually stream banks formed from organic material may develop.

In conclusion, whereas the hydrology and stream channel are closely linked in natural streams, there is little relation between the hydrograph and stream channel of Cascade Creek. The differences vary between reaches and are most severe in loosing reaches of the stream. Parks Canada policy requires that where possible, natural processes should be restored. However, increasing flows to 0.3 m^3/s will not restore the natural processes that define fluvial systems, including bar formation and channel bed disturbance. With this discrepancy between what is desired and what is possible, the new challenge is to identify some achievable target.

Spring creeks, with very little variation in seasonal flow and infrequent bed disturbance are rare but do exist. The North Raven River, a spring-fed stream in central Alberta provides excellent brown trout habitat (Konynenbelt 1994). Bull trout also inhabit such streams. These streams, with a flattened hydrograph may provide the most realist natural model for rehabilitation of Cascade Creek. However the riparian vegetation, examined in the next chapter, is another vital component of natural streams. In the final chapter, an integrated approach, using the knowledge of floodplain structure, hydrology and riparian vegetation is to identify achievable goals.

CHAPTER 4

RIPARIAN PLANT COMMUNITIES

INTRODUCTION

Stream reaches and their associated riparian vegetation respond individually to water diversion (Harris and others 1987, Friedman and others 1995, Stevens and others 1995). In Chapter 3--Hydrology, using the stream reach as the basic unit, I described the changes in channel morphology and natural hydrologic processes that resulted from water diversion and other human disturbances. In this chapter, I again use the stream reach as the basic unit and explore the influence of these human activities on the riparian vegetation of Cascade Creek. I also compare plant communities of Cascade Creek with other plant communities in the region to predict successional trends and evaluate ecological functioning.

Functions of riparian vegetation vary along the continuum from small streams to large rivers. It is the small streams that are most closely tied to their terrestrial environment through the vegetation (Cummins 1980). Headwater streams are heterotrophic systems, as riparian vegetation typically restricts light penetration to the stream bottom, thereby largely preventing within-stream primary production (Vannote and others 1980). These narrow shaded waterways may derive more than 90 percent of their carbon from their terrestrial environment

(Cummins 1980). In the Alaskan coastal rainforest, both foliage cast by trees onto the floodplain and litter dropped by shrubs directly into the stream were considered important carbon sources for small streams (Alaback and Sidle 1986). Overhanging shrubs, which shade a large percentage of the stream surface, also function to maintain cool water temperatures. Maintenance of these cool temperatures is critical for salmonid survival (Platts and Nelson 1989, Li and others 1994).

In contrast, in mid-sized rivers a large area of the stream bed receives direct light, allowing primary productivity. In these larger rivers, riparian vegetation has a decreased importance as an instream energy source (Cummins 1980). On the other hand, high levels of organic inputs have been observed in mid-sized rivers bordered by deciduous cottonwood forests (Delong and Brusven 1994).

Other important functions of riparian plant communities include generating large woody debris, an important structural component of small streams (Trista and Cromack 1980, Bilby and Ward 1989), and maintaining bank integrity during floods.

Through a portion of the study area, the pre-disturbance channel from the mid-sized Cascade River remains intact. However, this mid-sized channel only supports the flow of a small stream. Even with potential flow increases into this channel from 0.1 m^3/s to 0.3 m^3/s, a small stream will remain. Therefore, as with other natural small streams, the riparian vegetation of Cascade Creek has several important ecological functions.

The vegetation classification of Banff and Jasper National Parks was partially based on plant community structure (Achuff 1982). Such a structurally based classification may be useful when studying ecological processes and functions of riparian communities (Wayne and Bazzaz 1991, Boutine and Keddy 1993).

METHODS

The Ecological Land Classification (ELC) of Banff and Jasper National Parks (Holland and Coen 1982), and its component vegetation classification (Achuff 1982) are valuable tools for regional ecological studies. The ELC vegetation classification includes both a key and descriptions for 85 common vegetation types (Achuff 1982). However, the high degree of human disturbance along Cascade Creek is uncharacteristic of most sites within the national parks. Colonization of the historic riverbed began roughly 50 years ago. Other sites have been more recently disturbed. Such early successional stands are often unstable and heterogeneous and there is a low probability that similar physical environments were sampled during the ELC vegetation classification (Achuff 1982). Therefore, it is not surprising that I found the majority of plant communities along Cascade Creek were not referable to one of the ELC vegetation types. Other classification efforts in the Rocky Mountains describe plant communities associated with human disturbances (Hansen and others 1988) and in this chapter I also describes communities associated with human disturbances.

To develop a vegetation classification suitable for Cascade Creek, I adapted methods from the ELC vegetation classification. The use of similar methodologies allowed me to use some of the vegetation data and information from this past study to predict successional trends.

Field Sampling

In the ELC vegetation classification, the study area was divided into alpine, subalpine and montane regions (Achuff 1982). Researchers used a relevé method (Mueller-Dombois and Ellenburg 1974) where within the major regions, polygons of relatively homogeneous landform and vegetation were identified on air photos and then selected polygons were sampled in the field (Achuff 1982). Plot size within polygons varied from 20m x 20 m to 1m x 1m, depending on the type of plant community sampled. When placing quadrats within polygons, researchers avoided obvious ecotones. Canopy cover was estimated within quadrats using methods described by Daubenmire (1959). The following layers were recognized:

1) tree layer: all woody plants > 5 m tall.
2) tall shrub layer: all woody plants 2 to 5 m tall.
3) low shrub layer: all woody plants 0.5 to 2 m tall.
4) herb-dwarf shrub layer: all woody plants < 0.5 m and all herbs regardless of height.
5) bryoid layer: terrestrial lichens and bryophytes.

For this study, I also followed the relevé concept of vegetation sampling (Mueller-Dombois and Ellenberg 1974). Instead of using broad ecological regions, I first broke Cascade Creek into reaches of similar morphology using a natural river classification (Rosgen 1994). Then, I identified reference sites (100 m in length) within each reach type that were representative of the entire reach. I only sampled along the perennial stream in the top half of the study area. The intermittent stream below Cascade Ponds lacks riparian vegetation and was not sampled. The four reference site locations are shown in Figure 1.

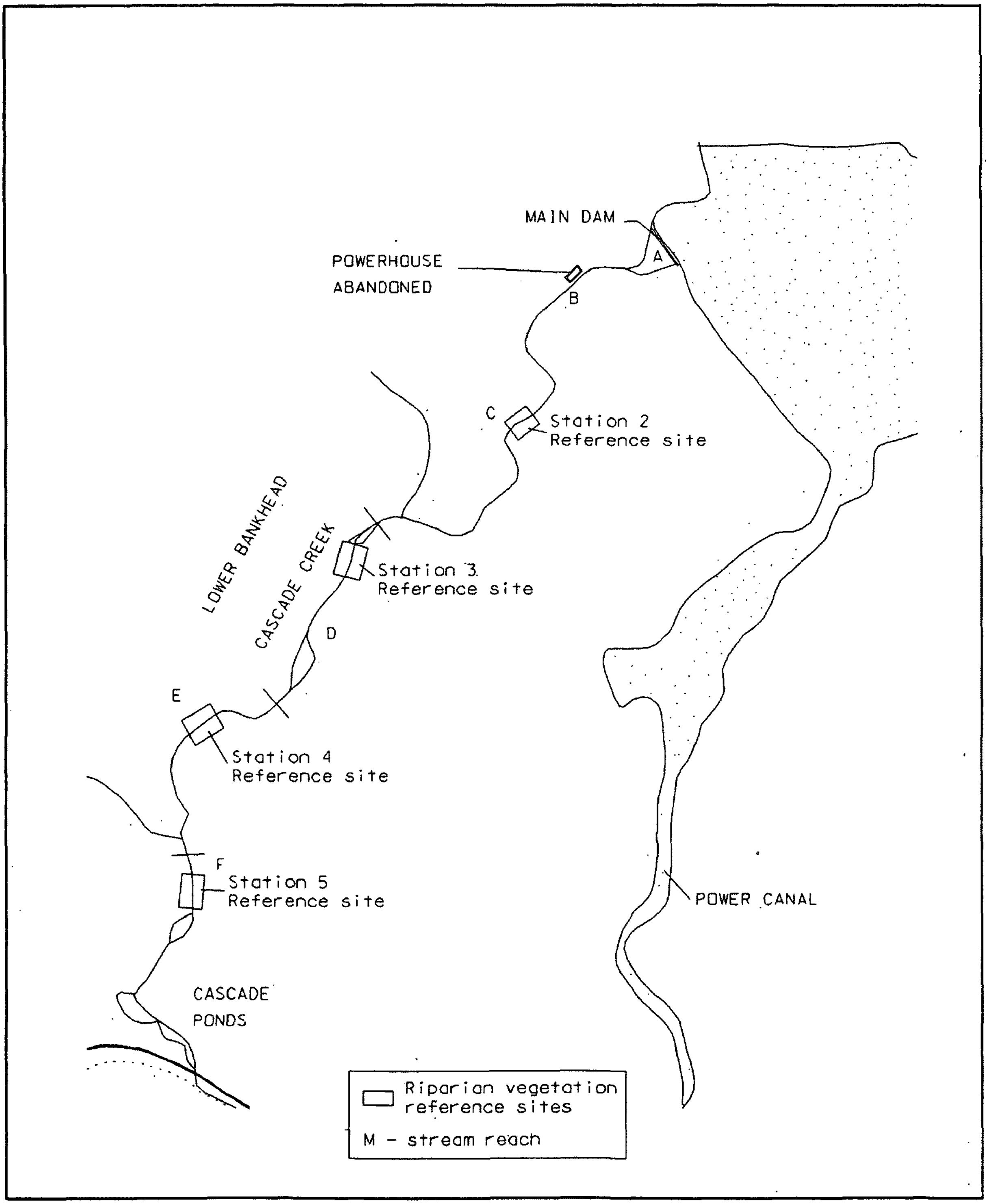


Figure 1. Cascade Creek riparian vegetation reference site locations

While on the ground at each reference site, I mapped polygons of homogeneous structure (2 m minimum width). I placed quadrats within these polygons and avoided obvious ecotones. Due to the long narrow nature of the polygons along Cascade Creek, shrub communities were sampled using 2 x 1 m quadrats. The perimeter of the 2 m^2 quadrat was marked and used to project a grid with 0.2 m increments into the quadrat (Fig. 2). Canopy cover was estimated to the nearest 2 percent within the 50 cell grid.

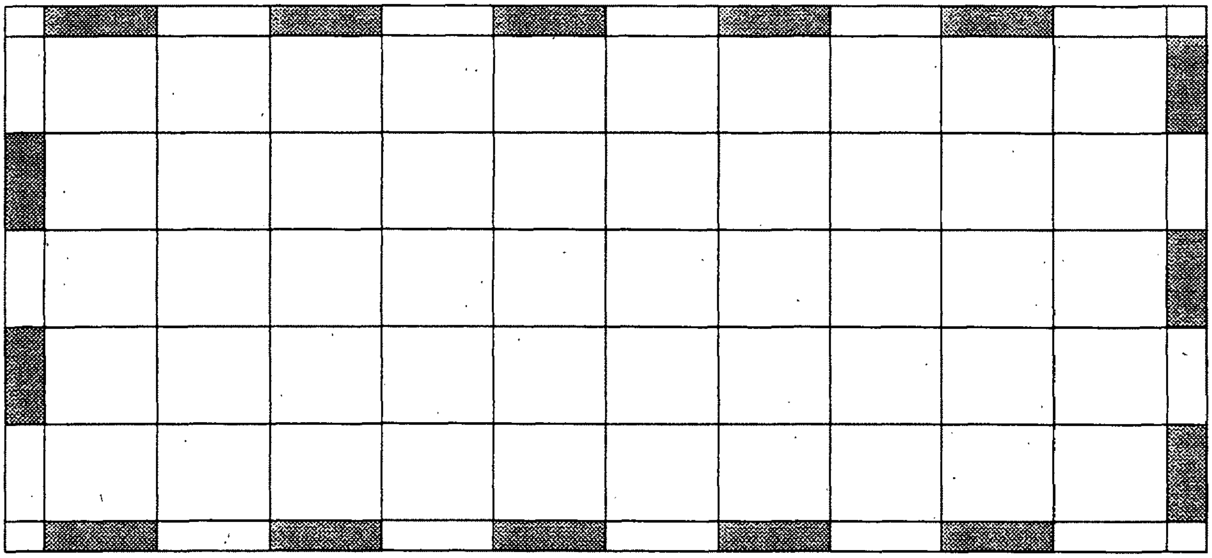


Figure 2. Diagram of the 2x1 m plot frame showing 0.2m perimeter markings and projected grid

Canopy cover for species was recorded separately for the tree (>5 m), tall shrub (2-5 m), shrub (0.5-2 m) and dwarf shrub (<0.5 m) structural classes. Two 0.1 m^2 plots were systematically nested within each larger plot to measure canopy cover for herbaceous species. Canopy cover for herbs was estimated to the nearest 5 percent. Because of inherent variation in early successional riparian communities, sampling within each polygon was repeated until the running mean of dominants stabilized (Mueller-Dombois and Ellenburg 1974) or additional quadrats could not be placed within the polygon. The number of plots required to stabilize the running mean of the dominants within each polygon sample site are shown in Appendix 4. In contrast to the ELC vegetation classification, I did not sample terrestrial lichens and bryophytes.

I collected, identified and then verified unknown species at the University of Calgary Field Station herbarium. As with the ELC classification (Achuff 1982), nomenclature of vascular plants followed Hitchcock and Cronquist (1991) and Moss (1992). However, in comparison to Achuff (1982), I used the more recent versions of these texts. Appendix 5 contains a species list of plants identified within Cascade Creek stands.

The one physical environmental factor that I estimated was the ecological moisture regime (Table 1). This subjective rating was based on a combination of soil texture (as an indicator of soil water holding capacity) and soil moisture.

Table 1: Ecological moisture regime classes (Achuff 1982).

Class	Code	Soil Drainage
xeric - very dry, very low available water storage capacity (AWSC)	1	very rapid
subxeric - dry, low AWSC	2	rapid
mesic - moist, intermediate to high AWSC	3	well to moderately well
subhygric - moist to wet, variable AWSC, seasonal seepage	4	imperfect
hygric - wet, variable AWSC, permanent seepage	5	poor
subhydric - wet, variable AWSC, excess water most of the time	6	very poor
hydric - very wet, standing water constantly	7	-

Data Preparation and Analyses

In the ELC vegetation classification, stands were grouped into units called vegetation types (VTs)(Achuff 1982). The VTs were viewed as "noda" along a "vegetational gradient" consistent with the 1962 theories of Poore and 1967 theories of Whitaker (Achuff 1982). For consistency with previous work, I used the same approach.

I analyzed data from 23 different stands from within the four reference sites on Cascade Creek. Two or three indicator species were identified in each of these stands. Using Parks Canada computer programs (VEG2DBASE and VEGINFO), the database from the ELC vegetation classification was queried. 87 stands containing the indicator species combinations were present. To truncate the data set to a manageable size (1649 plants included in the biophysical) all species with cover less than 5 percent were deleted from the analysis.

The data for 23 Cascade stands and 87 similar biophysical stands was combined into four different matrices based on composition and structure. Individual matrices were then analyzed using two modules within PC-ORD (McCune 1993). Two way indicator species analysis (TWINSPAN) was used to classify plots into cover types. This analysis hierarchically splits the matrix into groups of stands based on information from all of the species (Moore and Chapman 1980). The end result is a five level hierarchical classification without a measure of similarity between stands. Detrended Correspondence Analysis (DCA), a second module within PC-ORD, provides information on similarity between stands on arbitrary axes (indirect ordination) or an environmental continuum (direct ordination). DCA also generates an eigenvalue, which is the variance explained by a particular axis (Hamilton 1992). The information from TWINSPAN and DCA was used together to group stands into vegetation types.

RESULTS

Eight different vegetation types (VTs) were identified using classification and ordination analyses (Table 2).

Table 2. Cascade Creek vegetation types

Vegetation Type	Cascade Stands	Total Stands	% of Total
Shrub Layer (0.5-5m in height) Dominant			
Shrub 1: *Picea glauca / Salix drummondiana* (white spruce / Drummond willow)	9	11	82
Shrub 2: *Ribes oxyacanthoides / Rubus ideaus* (northern gooseberry / red raspberry)	1	1	100
Shrub 3: *Salix spp. / Rosa acicularis / Equisetum arvense* (willow / prickly rose / horsetail)	1	4	25
Total for shrub types	11	16	80
Dwarf Shrub Layer (<0.5m) Dominant			
Dwarf Shrub 1: *Dryas drummondii* (yellow dryad)	2	7	29
Herb Layer Dominant			
Herb 1: *Carex aquatilis* (water sedge)	1	6	17
Herb 2: *Deschampsia cespitosa / Epilobium latifolium* (tufted hairgrass / willow-herb)	4	9	44
Herb 3: *Equisetum variegatum / Tofieldia glutinosa* (northern scouring rush / sticky asphodel)	2	4	50
Herb 4: *Agrostis exarata* (spike redtop)	3	3	100
Total for dwarf shrub and herb types	12	29	50

The procedure used to group the stands in the **Shrub 1**, *Picea glauca / Salix drummondiana* (white spruce / Drummond willow) VT is illustrated in Figures 3 and 4. The same procedure was used to group stands into the other seven VTs.

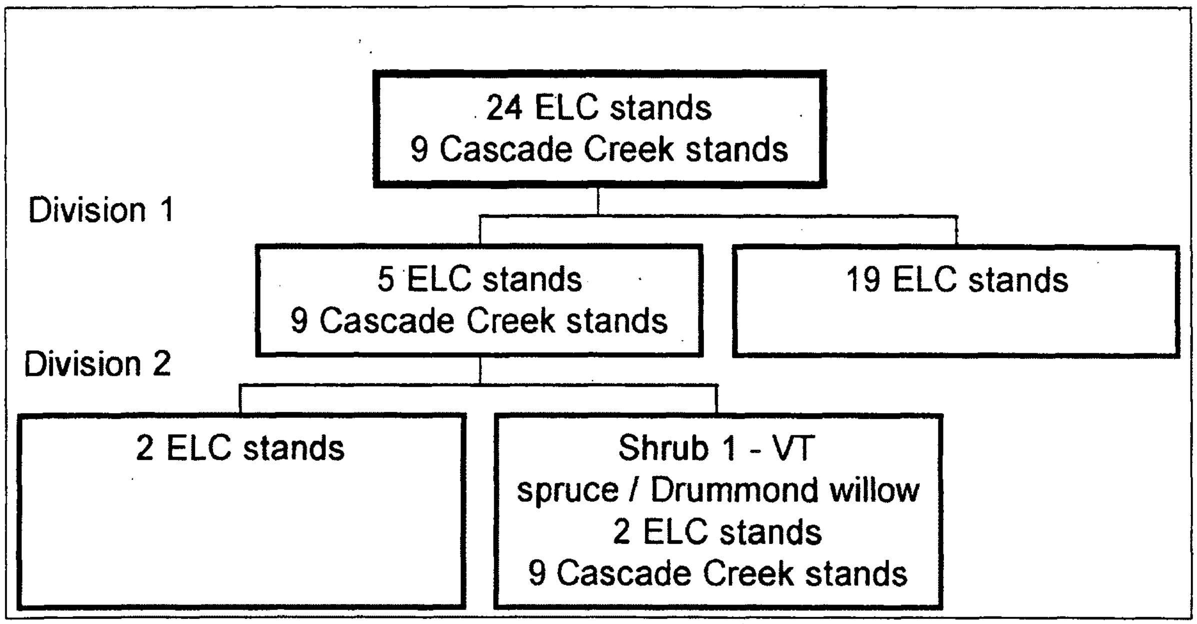


Figure 3. Schematic of two way indicator species analysis (TWINSPAN) for stands with both spruce and willow present

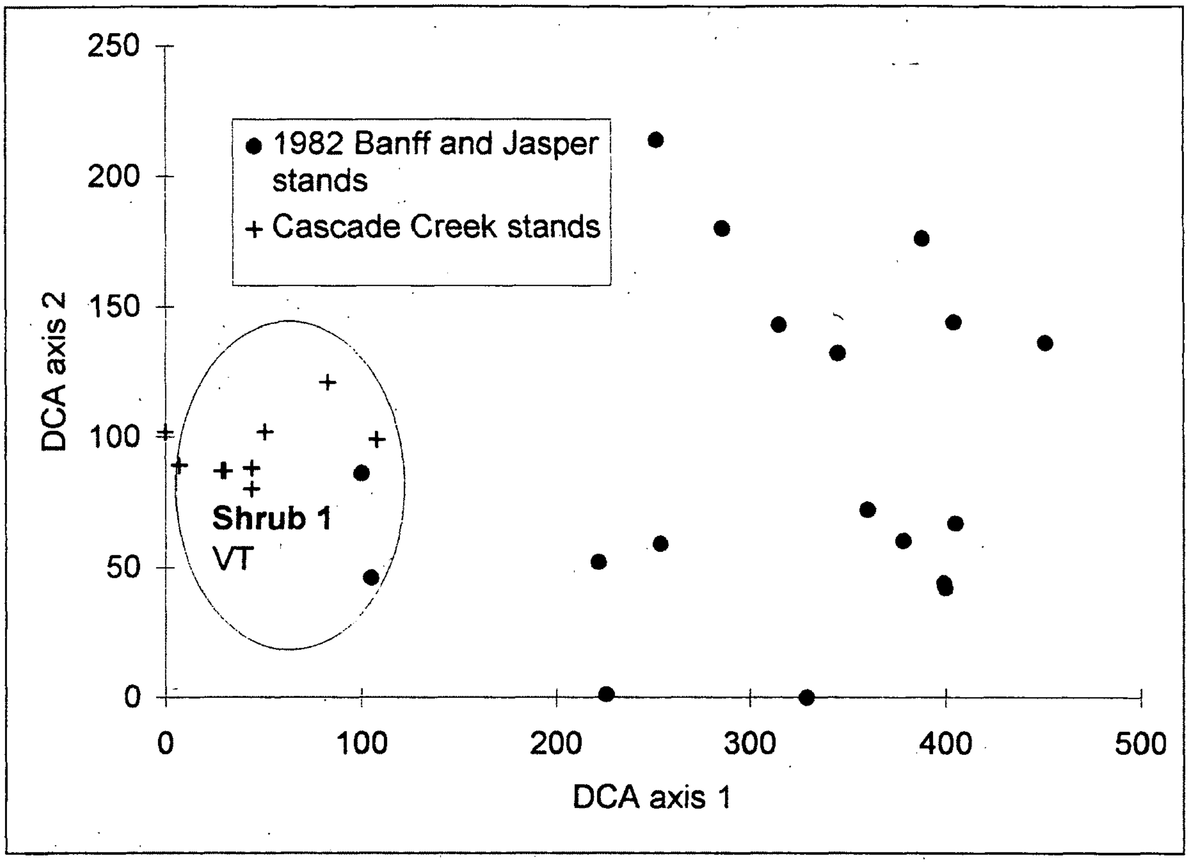


Figure 4. Detrended Correspondence analysis (DCA) ordination of plots with both spruce and willow present, for the first two DCA axes. Eigenvalue for Axis 1 and Axis 2 were 0.76 and 0.29 respectively

Vegetation Type Descriptions

Shrub 1 *Picea glauca / Salix drummondiana* (white spruce / Drummond willow) vegetation type--These stands developed on the bare gravel and cobbles of the historic river bed following the 1941 water diversion. This VT occurs on subhygric and hygric sites either adjacent to the present creek or separated from the flowing water by a herbaceous community (Fig. 5 and 6). *Picea glauca* (white spruce) individuals dominate both the tall shrub and shrub layers (Table 3) indicating good recruitment of this species. In contrast, although *Salix drummondiana* (Drummond willow) is codominant, it appears to be an early seral species in decline. Mature individuals occur within the shrub (0.5-2 m) layer. Vigorous willows of any species within the tall shrub (2-5 m) layer are rare and willow seedlings are largely absent from the dwarf shrub (<0.5 m) layer. Further discussion on the successional trend of this VT is contained later in this chapter.

Note regarding table format: Two different table formats are used to present information on the various VTs. The format depends on the number of stands within the VT. Where the number of stands is <5, the table shows % canopy cover by species for each stand (Tables 4 and 5). Where the number of stands is >4, the % canopy cover by species for all stands is summarized using average, range and constancy (Table 3). Only non-zero % canopy cover values are used to calculate average and constancy.

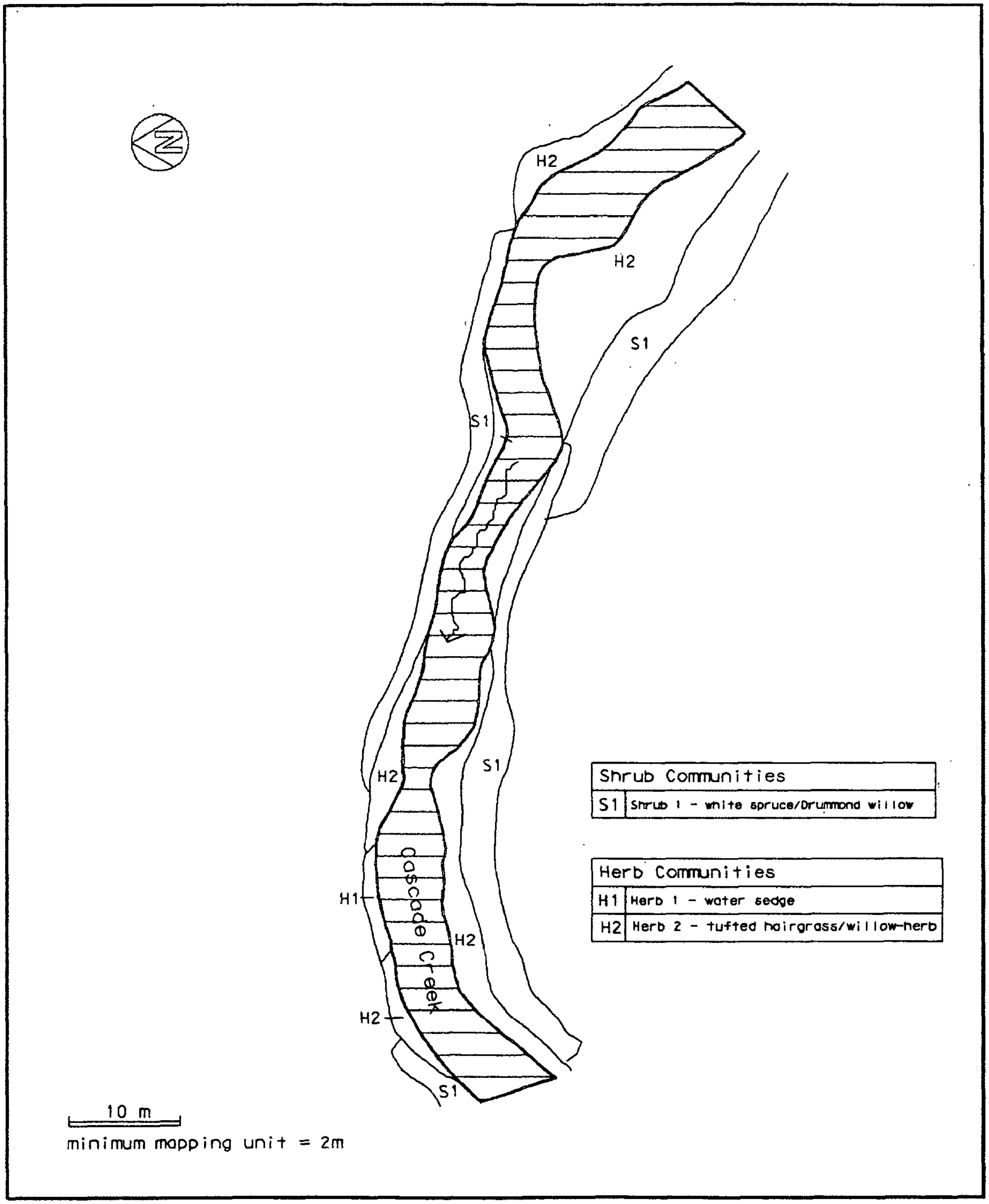


Figure 5. Station 2 (Reach C) riparian vegetation reference site map

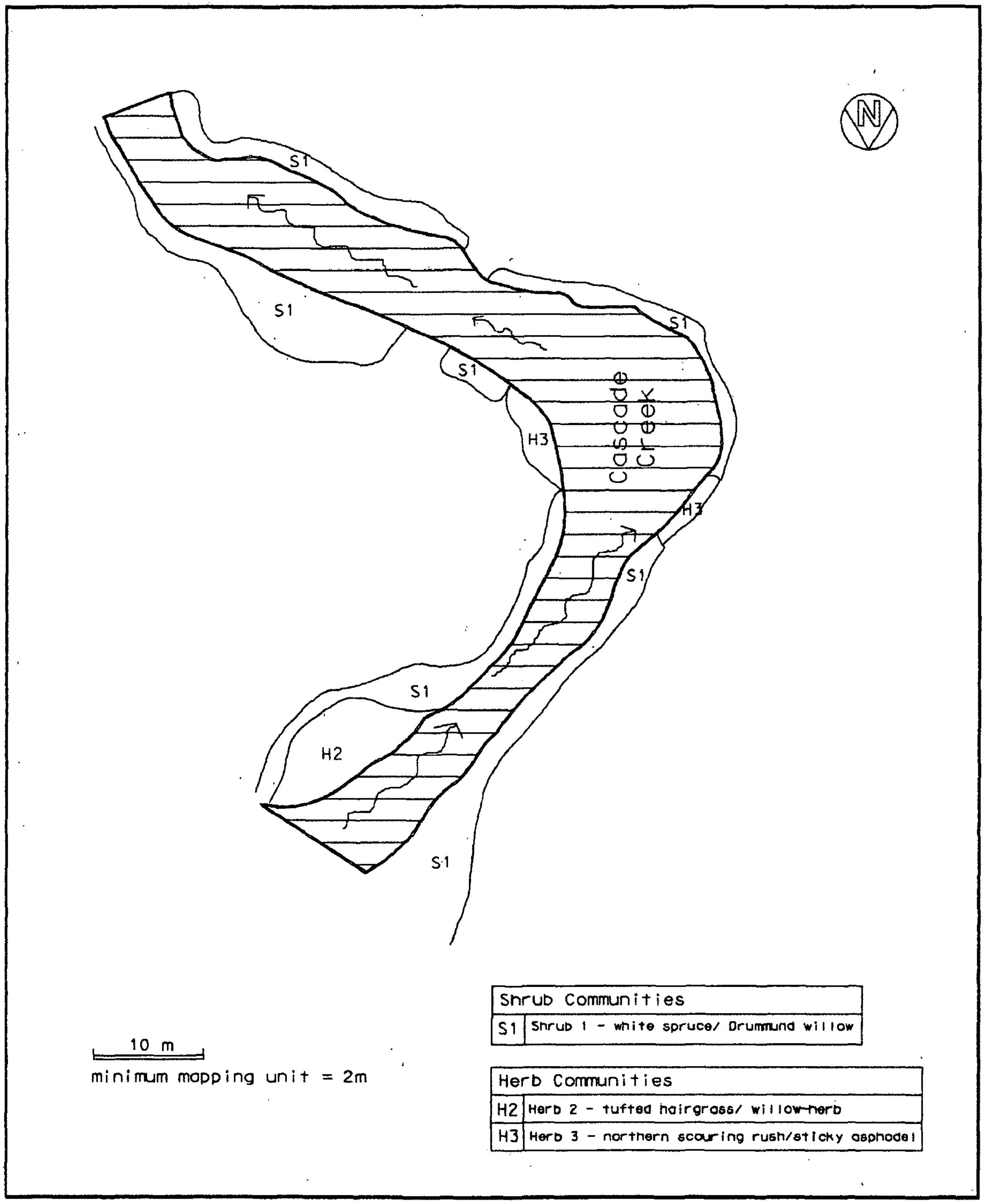


Figure 6. Station 3 (Reach D) riparian vegetation reference site map

Table 3. Average canopy cover, range of canopy cover and constancy for species of the **Shrub 1** *Picea glauca / Salix drummondiana* (white spruce / Drummond willow) vegetation type by structural layer (number = 11 stands)

	% Canopy Cover		
	Average	Range	Constancy (%)
Tree Layer (>5m)			
Picea glauca	38	0-60	18
Tall Shrub Layer (2-5m)			
Elaeagnus commutata	9	0-9	18
Picea glauca	27	0-67	73
Salix bebbiana	5	0-8	18
Shrub Layer (0.5-2m)			
Elaeagnus commutata	15	0-21	27
Picea glauca	25	0-40	82
Potentilla fruticosa	10	0-21	36
Salix barclayi	6	0-6	9
Salix bebbiana	13	0-25	45
Salix drummondiana	21	0-41	91
Salix glauca	15	0-15	9
Salix melanopsis	12	0-24	36
Salix pseudomonticola	17	0-25	18
Shepherdia canadensis	25	0-25	9
Dwarf Shrub Layer (<0.5m)			
Arctostaphylos uva-ursi	12	0-15	18
Dryas drummondii	11	0-16	18
Elaeagnus commutata	5	0-5	9
Juniperus communis	9	0-12	27
Linnaea borealis	54	0-54	9
Picea glauca	7	0-7	18
Populus balsamifera	20	0-20	9
Potentilla fruticosa	5	0-5	9
Herb Layer			
Anemone parviflora	12	0-18	27
Aster conspicuus	5	0-5	9
Carex spp.	11	0-22	36
Deschampsia cespitosa	8	0-10	18
Elymus innovatus	15	0-15	9
Epilobium latifolium	12	0-13	36
Equisetum variegatum	5	0-5	9
Fragaria virginiana	11	0-20	27
Hedysarum alpinum	12	0-18	18
Pyrola asarifolia	9	0-17	36
Taraxacum officinale	8	0-8	9
Species Totals (all layers)			
Elaeagnus commutata	17	0-30	36
Picea glauca	48	10-139	100
Potentilla fructicosa	9	0-21	45
Salix spp.	35	10-57	100

Shrub 2 *Ribes oxyacanthoides / Rubus ideaus* (northern gooseberry, red raspberry) vegetation type--This VT is defined by a single stand located in the diversion ditch adjacent to Cascade gravel pit (Fig. 7) on a subhygric site. The weedy species of this early seral community (Table 4) established naturally within the last 15 years following excavation of the ditch.

Table 4. Canopy cover for species of the **Shrub 2** *Ribes oxyacanthoides / Rubus ideaus* (northern gooseberry, red raspberry) vegetation type by structural layer (number = 1 stand)

	% Canopy Cover
Stand Number	CAS 44
Shrub Layer (0.5-2m)	
Ribes oxyacanthoides	35
Rosa acicularis	30
Rubus ideaus	35
Herb Layer	
Galium boreale	5
Cirsium arvense	5
Smilacina stellata	7
Equisetum arvense	20

Shrub 3 *Salix spp. / Rosa acicularis / Equisetum arvense* (willow / prickly rose / horsetail) vegetation type--The single Cascade Creek stand with this VT occurs on a subhygric site. As with stand CAS 44 (Table 4), this stand established on the banks of the diversion ditch that was excavated in the early 1980's (Fig. 7).

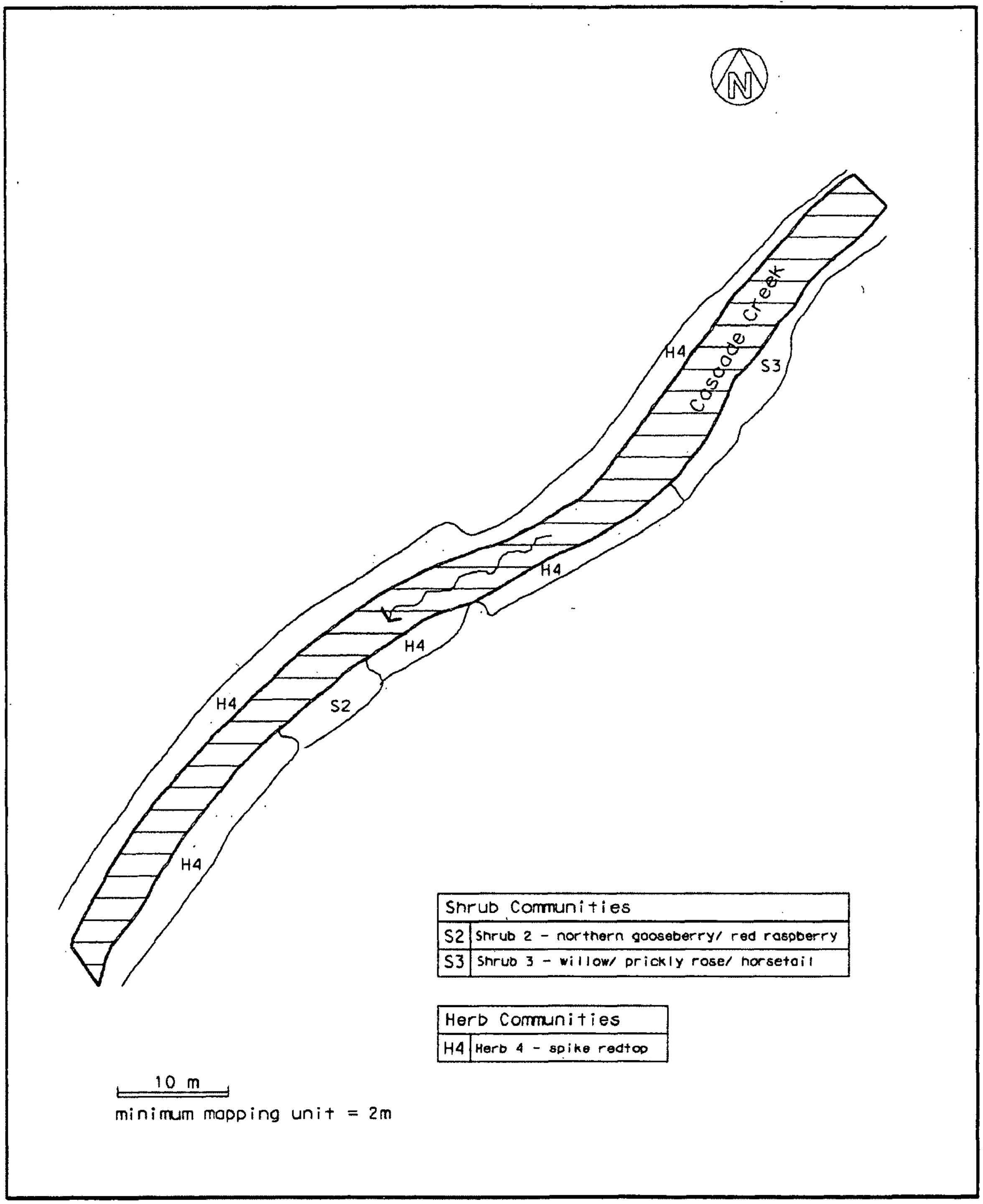


Figure 7. Station 4 (Reach E) riparian vegetation reference site map

This early seral stand was grouped with three stands in various stages of development from the ELC vegetation classification (Table 5). Although these stands have contrasting structures, they have several similar species in the layers below 2m. This high degree of similarity between shrub dominated stands of the Cascade Creek study and the ELC vegetation classification is unique.

Table 5. Canopy cover for species of the **Shrub 3** *Salix spp. / Rosa acicularis / Equisetum arvense* (willow / prickly rose / horsetail) vegetation type by structural layer (number = 4 stands)

	% Canopy Cover			
Stand Number	JD 8090	KS 5158	PA 7194	CAS 41
Tree Layer (>5m)				
Picea glauca	0	90	45	0
Tall Shrub Layer (2-5m)				
Picea glauca	0	10	5	0
Salix glauca	30	0	0	0
Shrub Layer (0.5-2m)				
Picea glauca	0	10	0	0
Rosa acicularis	5	18	0	19
Salix bebbiana	0	0	0	6
Salix boothii	15	0	0	0
Salix glauca	40	5	20	0
Dwarf Shrub Layer (<0.5m)				
Rosa acicularis	0	0	5	0
Herb Layer				
Aster ciliolatus	30	0	0	0
Calamagrostis canadensis	0	3	5	16
Carex scirpoidea	0	0	0	6
Deschampsia cespitosa	30	0	0	0
Elymus innovatus	0	0	5	0
Equisetum arvense	10	40	40	53
Equisetum pratense	0	15	0	0
Equisetum scirpoides	0	8	0	0
Juncus drummondii	5	0	0	0
Juncus filiformis	0	0	0	14
Mitella nuda	0	10	0	0
Pyrola asarifolia	0	0	0	12
Pyrola secunda	0	6	0	0
Species Totals (all layers)				
Picea glauca	0	110	50	0
Salix glauca	70	5	20	0
Salix spp.	85	5	20	6
Rosa acicularis	5	18	5	19

Note: Cascade Creek stands are abbreviated CAS, all other stands are from ELC vegetation classification (Achuff 1982)

Dwarf Shrub 1 *Dryas drummondii* (yellow dryad) vegetation type--Two Cascade Creek stands from the reference site at Station 5 were grouped with five stands from the ELC vegetation classification to form the **Dwarf Shrub 1** VT (Table 6). Site moisture regime varies from xeric to subhygric. The two Cascade Creek stands are located on a site disturbed in the early 1980's for gravel extraction (Fig. 8). *Dryas drummondii* (yellow dryad) frequently colonizes gravel sites such as glacial moraines and gravel bars and is one of the few nitrogen fixers in the family Rosaceae. With the key to the ELC vegetation classification (Achuff 1982), all seven stands keyed out to the *Dryas drummondii-Epilobium latifolium* (yellow dryad-willow herb) VT. In comparison, the Cascade Creek stands in the **Shrub 1-3** VTs would not key out using the ELC vegetation classification.

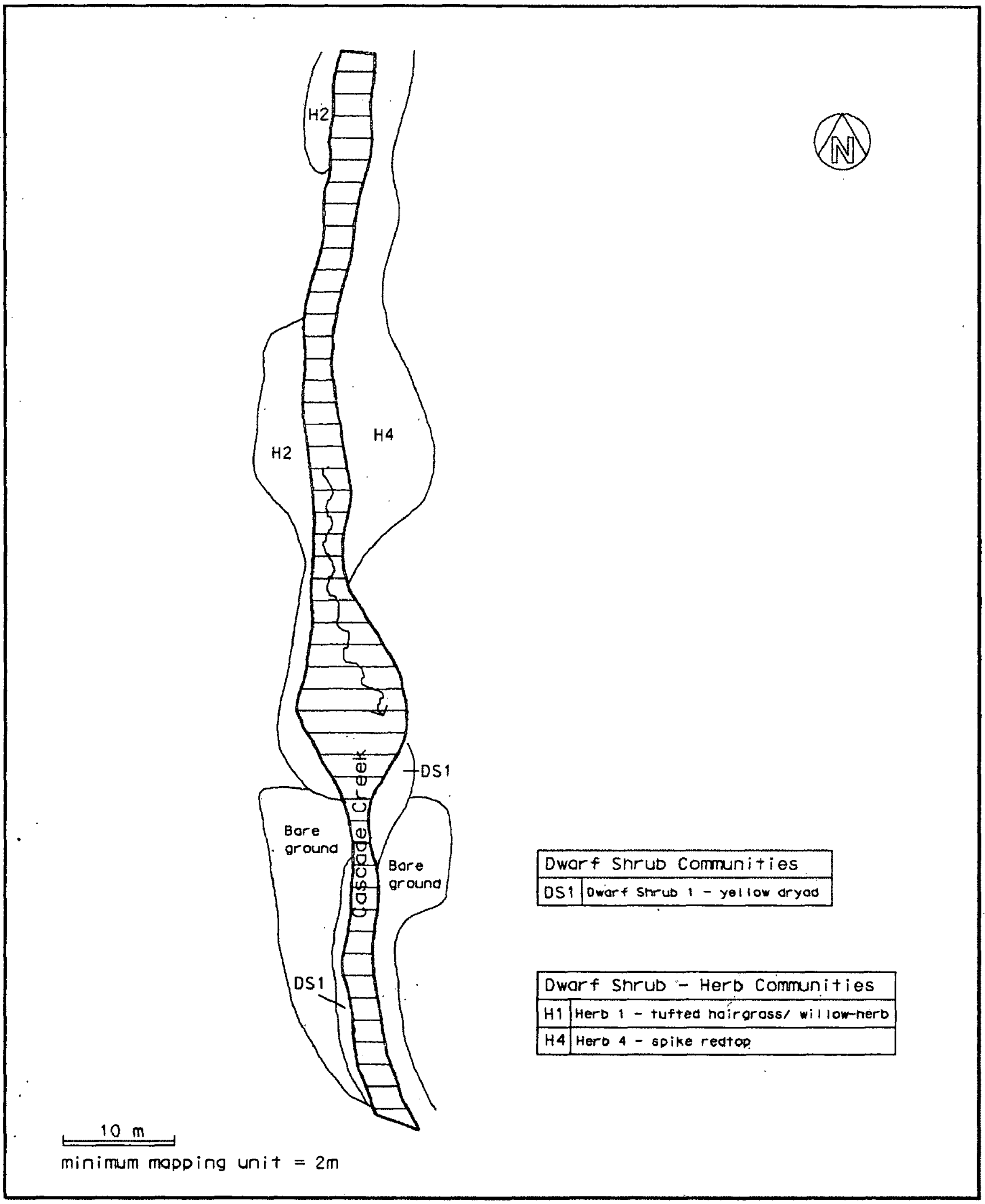


Figure 8. Station 5(Reach F) riparian vegetation reference site map

Table 6. Average canopy cover, range of canopy cover and constancy for species of the **Dwarf Shrub 1** *Dryas drummondii* (yellow dryad) vegetation type by structural layer (number = 7 stands)

	% Canopy Cover		
	Average.	Range.	Constancy (%)
Tree Layer (>5m)			
Picea engelmannii	8	0-8	17
Tall Shrub Layer (2-5m)			
Picea engelmannii	5	0-5	17
Shrub Layer (0.5-2m)			
Salix brachycarpa	20	0-20	17
Shepherdia canadensis	14	0-14	17
Dwarf Shrub Layer (<0.5m)			
Dryas drummondii	37	10-60	100
Herb Layer			
Agrostis stolonifera	10	0-10	17
Arctostaphylos uva-ursi	5	0-5	17
Aster modestus	5	0-5	17
Epilobium latifolium	12	0-12	17
Senecio canus	5	0-5	17
Species Totals (all layers)			
Picea engelmannii	13	0-13	17

Herb 1 ***Carex aquatilis*** **(water sedge) vegetation type**--A single **Herb 1** stand was described in standing water at the Station 2 reference site (Fig. 5). Similar to Cascade Creek stands in the **Dwarf Shrub 1** VT, this herbaceous stand keys out well using the ELC vegetation classification. The other five stands in this grouping were from the ELC vegetation classification (Table 7). All 6 stands in

Herb 1 key out to a *Carex aquatilis / Carex rostrata* (water sedge-beaked sedge) VT (Achuff 1982).

Table 7. Average canopy cover, range of canopy cover and constancy for species of the **Herb 1** *Carex aquatilis* (water sedge) vegetation type by structural layer (number = 6 stands)

	% Canopy Cover		
	Average	Range	Constancy (%)
Shrub Layer (0.5-2m)			
Betula glandulosa	5	0-5	17
Dwarf Shrub Layer (<0.5m)			
Salix nivalis	5	0-5	17
Herb Layer			
Carex aquatilis	76	70-85	100
Deschampsia cespitosa	5	0-5	17
Glyceria striata	20	0-20	17

This VT is successionally mature on a 200 year time scale, however over a period of several hundred years, the accumulation of organic matter may eventually allow the invasion of shrubs and trees (Achuff 1982). Thick accumulations of organic matter are common in slow moving pools of Cascade Creek and this fen-like succession can be expected in these locations.

Herb 2 *Deschampsia cespitosa / Epilobium latifolium* (tufted hairgrass / willow herb) vegetation type--This community is found along the stream margins in three of the four reference sites (Fig. 5, 6 and 8). The stands have subhygric or hygric moisture regimes. At Station 5, where periodic flooding and sediment deposition occur, some tree regeneration is evident. However, most stands lack any sign of developing tree or shrub components (Table 8). With this herbaceous community structure and the lack of periodic disturbance, most stands resemble still water (lentic) more than flowing water (lotic) wetlands.

Table 8. Average canopy cover, range of canopy cover and constancy for species of the **Herb 2** *Deschampsia cespitosa / Epilobium latifolium* (tufted hairgrass / willow-herb) vegetation type by structural layer (number = 9 stands)

	% Canopy Cover		
	Average	Range	Constancy (%)
Shrub Layer (0.5-2m)			
Betula glandulosa	5	0-5	11
Populus balsamifera	8	0-8	11
Salix glauca	10	0-10	11
Dwarf Shrub Layer (<0.5m)			
Betula glandulosa	20	0-20	11
Salix barrattiana	30	0-30	11
Salix glauca	10	0-10	11
Salix nivalis	10	0-10	11
All Herbs			
Arnica latifolia	5	0-5	11
Anemone parviflora	9	0-20	33
Carex aquatilis	25	0-30	22
Carex scirpoidea	18	0-35	33
Carex spp.	31	0-60	33
Deschampsia cespitosa	19	0-55	67
Epilobium latifolium	22	0-44	56
Festuca rubra	65	0-65	11
Kobresia simpliciuscula	10	0-10	11
Polygonum viviparum	8	0-15	56
Saxifraga aizoides	15	0-15	11
Selaginella densa	10	0-10	11
Ranunculus occidentalis	5	0-5	11

Festuca rubra dominates a single stand where the adjacent uplands were planted with this species following gravel mining.

Herb 3 *Equisetum variegatum / Tofieldia glutinosa* (northern scouring rush / sticky asphodel) vegetation type--The reference site at Station 3 contains the two Cascade Creek stands in the **Herb 3 VT** (Fig. 6). Cascade Creek **Herb 3** stands lack any shrub species (Table 9) and with the consistent hygric environment at Station 3, shrub recruitment may not occur. With this structure and the absence of periodic sediment deposition, **Herb 3** also most closely resembles a still water (lentic) wetland.

Table 9. Canopy cover for species of the **Herb 3** *Equisetum variegatum / Tofieldia glutinosa* (northern scouring rush / sticky asphodel) vegetation type by structural layer (number = 4 stands)

	% Canopy Cover			
Stand Number	JD 7079	KS 6025	CAS 33	CAS 38
Shrub Layer (0.5-2m)				
Betula glandulosa	5	0	0	0
Picea glauca	5	2	0	0
Dwarf Shrub Layer (<0.5)				
Dryas drummondii	0	0	0	8
Herb Layer				
Anemone parviflora	5	0	0	0
Antennaria lanata	15	0	0	0
Aster conspicuus	0	0	0	8
Carex spp.	0	25	0	8
Carex gynocrates	0	3	6	0
Carex livida	0	10	0	0
Carex microglochin	0	10	0	0
Carex pauciflora	0	0	0	16
Carex scirpoidea	25	0	0	0
Equisetum variegatum	10	4	45	4
Eriophorum angustifolium	0	10	0	0
Fragaria virginiana	0	0	0	8
Juncus balticus	20	5	0	0
Pedicularis bracteosa	5	0	0	0
Scirpus caespitosus	0	15	0	0
Tofieldia glutinosa	2	3	8	20

Note: Cascade Creek stands are abbreviated CAS, all other stands are from the ELC vegetation classification (Achuff 1982)

Herb 4 ***Agrostis exarata*** **(spike redtop) vegetation type**--This community is found on recently disturbed subhygric sites. No similar stands were described in the ELC vegetation classification (Table 10). Following excavation of the diversion ditch around 1980, the banks were likely seeded with a grass mix that included several introduced species and *Agrostis exarata* (spike redtop). This disturbance community covers much of the stream banks in the Station 4 reference site (Fig. 7) and may be acting as a seed source for similar downstream communities at the Station 5 reference site (Fig. 8).

Seedling recruitment is absent in two of the three stands (Table 10) and it is difficult to predict the successional development of these two early seral stands.

Table 10. Canopy cover for species of the **Herb 4** *Agrostis exarata* (spike redtop) vegetation type by structural layer (number = 3 stands)

	% Canopy Cover		
Stand Number	CAS 42	CAS 43	CAS 56
Shrub Layer (0.5-2m)			
Populus balsamifera	20	0	0
Dwarf Shrub Layer (<0.5m)			
Linnaea borealis	0	6	0
Herb Layer			
Agropyron repens	0	0	11
Agrostis exarata	20	17	22
Agrostis stolonifera	0	0	11
Fragaria virginiana	0	0	24
Hedysarum alpinum	10	0	0
Poa compressa	0	0	5
Trifolium repens	0	0	11

Note: Cascade Creek stands are abbreviated CAS

Successional Trends

Cascade Creek plant communities are recent, as most have established on the bare substrate of the historic river bed following the 1941 water diversion. Others have colonized the banks of the diversion ditch excavated during the 1980's. Most shrub communities have established on moist stable sites. The majority of the herbaceous communities are situated on wetter stable sites. Models were produced to illustrate possible successional trends for these two lifeform groups. To produce these models, I arranged shrub types and herbaceous types from driest to wettest based on moisture regime. Next, I identified similar communities from the ELC vegetation classification (Achuff 1982) and the classification of Montana's riparian and wetland communities (Hansen and others 1995). By using the keys from these classifications and also by noting common understory and overstory species in the community composition tables, possible trends towards climax communities became apparent.

Shrub Vegetation Types--In contrast to other fluvial sites subject to frequent disturbance, the Cascade Creek sites within the historic channel are stable (Chapter 3). Sites for colonization along streams typically form as point bars develop on the inside bank of meander bends (Leopold 1994). Over time, with periodic sediment deposition, a floodplain develops. Eventually the site may become stable. A corresponding trend in vegetation for Banff and Jasper region described by Achuff (1982) is shown in Figure 9. Typically, a mix of these vegetation types would be expected down the length of the stream when viewing both left and right banks through a series of meanders. Each vegetation type would represent a various stage of floodplain development, creating a mosaic of habitats. The intermediate stage with periodic sediment deposition in the Banff and Jasper region is associated with the *Salix spp. / Equisetum arvense* (willow / horsetail) VT (Achuff 1982).

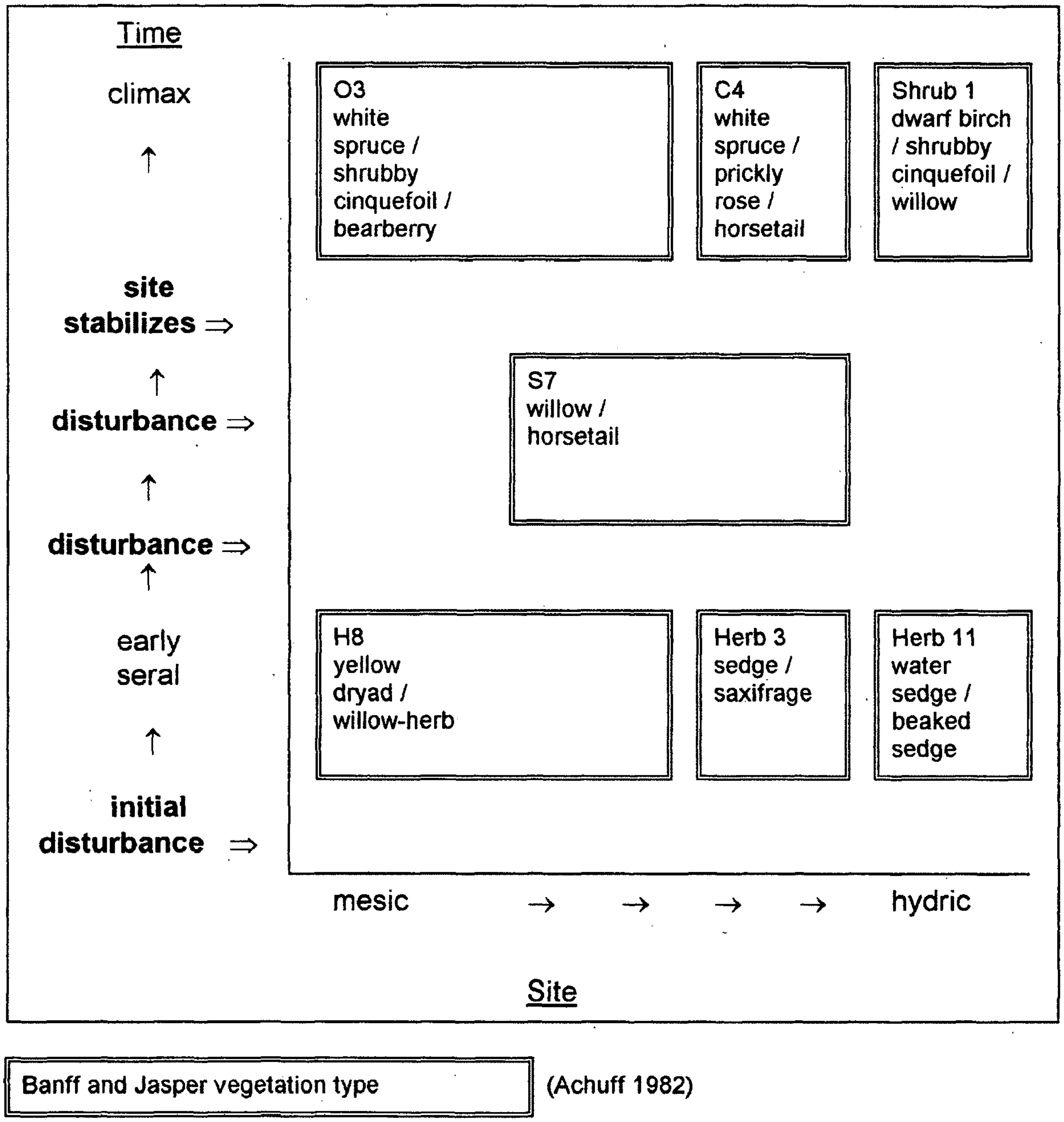


Figure 9. Plant succession trends for moist and wet fluvial sites in the montane region of Banff and Jasper (adapted from Achuff 1982).

Some minor lateral shifts in moisture regime and understory species of Cascade Creek stands may occur over time. Regardless, the **Shrub 1** - *Picea glauca / Salix drummondiana* (white spruce / Drummond willow) stands within the historic channel appear to be developing into closed canopy, spruce forests (Fig 10). This progression is further illustrated at cross section C2 located within the reference site at Station 3 (Fig. 11).

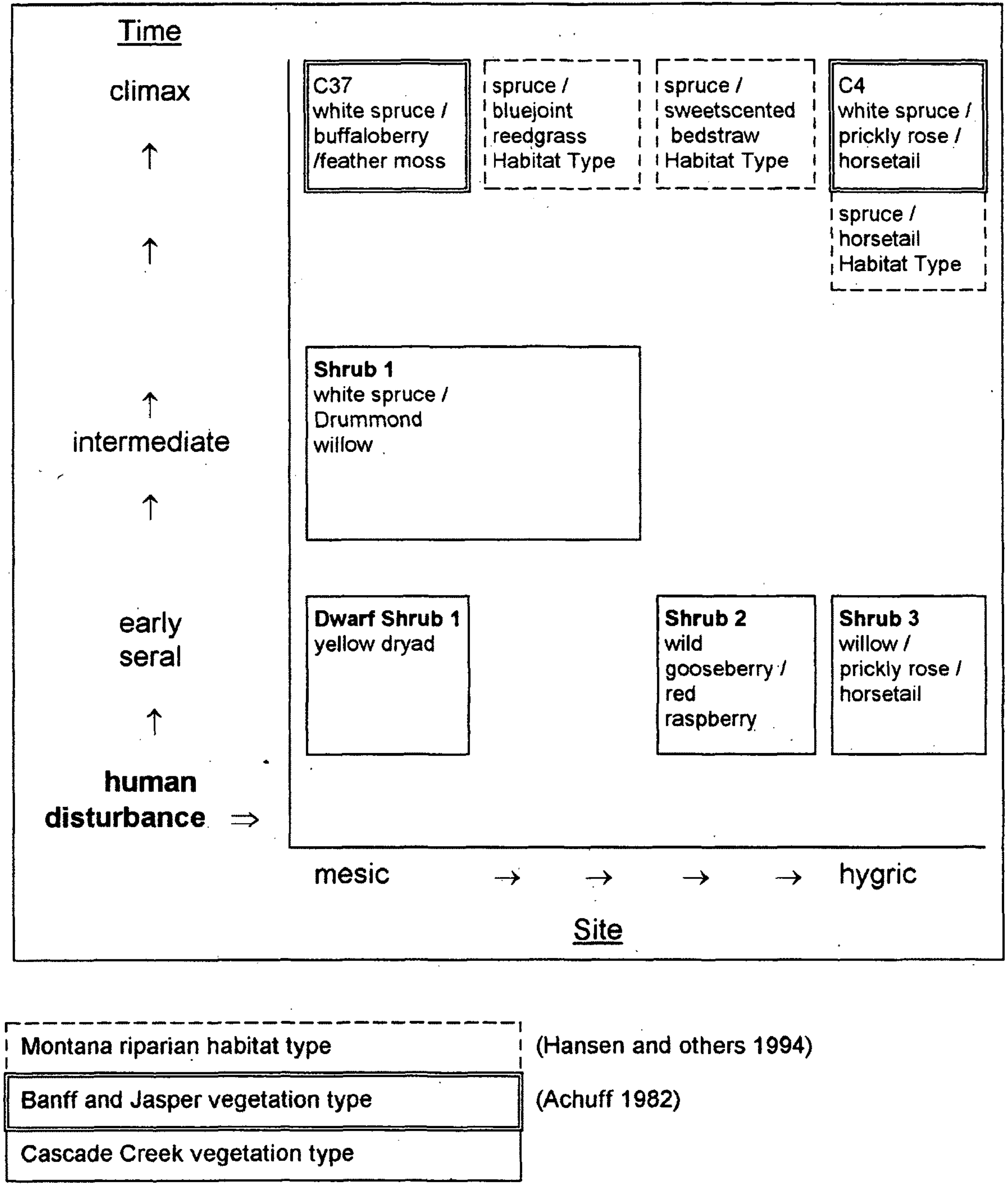


Figure 10. Plant succession trends for Cascade Creek shrub communities

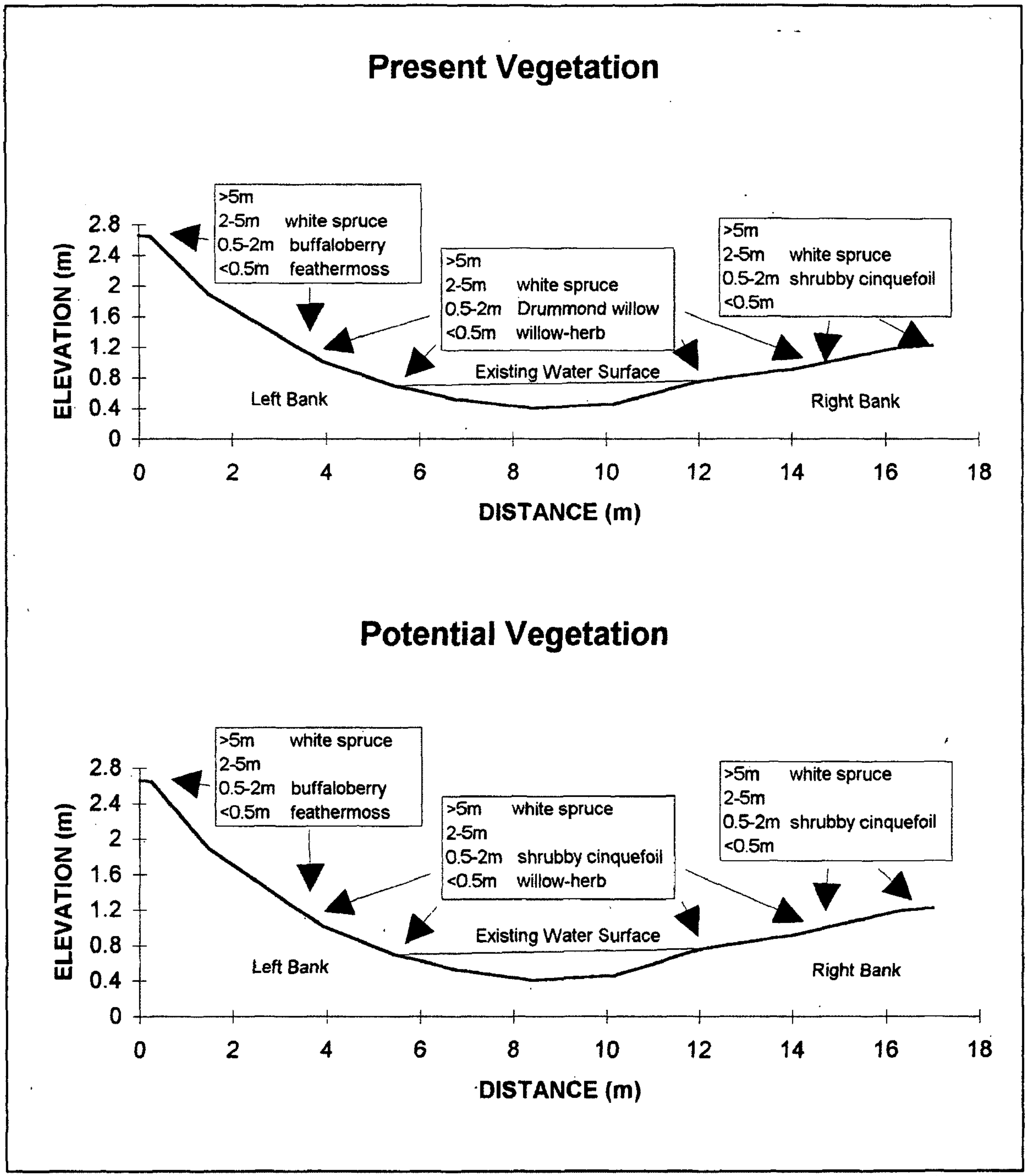


Figure 11. Present and potential vegetation at cross section C2, showing dominant species in each structural layer

The **Shrub 1** *Picea glauca / Salix drummondiana* (white spruce / Drummond willow) VT lines most of the historic channel at Station 2 and 3 (Fig. 5 and 6). Simultaneously, these stands appear to be progressing towards climax spruce stands lacking a willow component. This contrasts with most active floodplains, which support a diverse array of seral stages. This transient increase in reproduction of early seral willow and cottonwoods on bare moist areas of former channel bed followed by their slow decline has been observed elsewhere (Johnson 1994, Miller and others 1995).

This decline may be related to a number of factors. Willow seedlings of certain species have been observed to be intolerant of shade (Johnson and others 1976). Therefore under the dense spruce canopy found in Cascade Creek stands, willows may be unable to reproduce. A recent experiment supports a second cause of decline--that the decline of willows and cottonwoods on meandering channels results from the decreased formation of moist open sites suitable for seedling establishment (Friedman and others 1995). A similar increase in percentage of older riparian stands has been observed on the North Platte River in Wyoming following water diversion during the last century (Miller and others 1995).

Other possible explanations for a decline in reproduction include: decreased in vigor of adults, leading to lower seed production; changes in patterns of grazing or fire; and competition from exotic species (Friedman and others 1995). During the last decade, a large elk herd has congregated in the Banff town site vicinity (which includes the Cascade Creek area) during the winter months (Hurd 1995). Heavy winter utilization of willow by these ungulates may also be contributing to the decline in willow reproduction and importance in the Shrub 1 VT. Local experiments will be required to determine the exact causes of the demise of the willow component.

In Banff, most of the surrounding uplands are also closed canopy spruce forests. The trend of Cascade Creek shrub stands towards spruce forests represents an amalgamation of the riparian vegetation types with these adjacent uplands, resulting in further loss of habitat biodiversity at the landscape level.

Herb Vegetation Types--Although most Cascade Creek herbaceous vegetation types border onto shrub communities, these VTs lack evidence of a developing shrub component and appear likely to remain as herbaceous communities. This shrub-herbaceous ecotone in other gently sloping sites has been attributed to depth to the water table (Groenveld and Or 1994). Due to the flood frequency, productive fluvial marshes have also developed along regulated canyon rivers, including the Colorado downstream of Glen Canyon dam (Stevens and others 1995). In Cascade Creek, the lack of shrub regeneration may be related to the anaerobic conditions in the saturated environment, absence of flood disturbance or lack of viable seeds. Experimentation is required to determine exact cause. With a stable physical environment and these successional trends, these systems resemble still water (lentic) wetlands more than flowing water (lotic) wetlands (Fig 12). The trends from this model are also illustrated at cross section B4 from within the Station 2 reference site (Fig. 13).

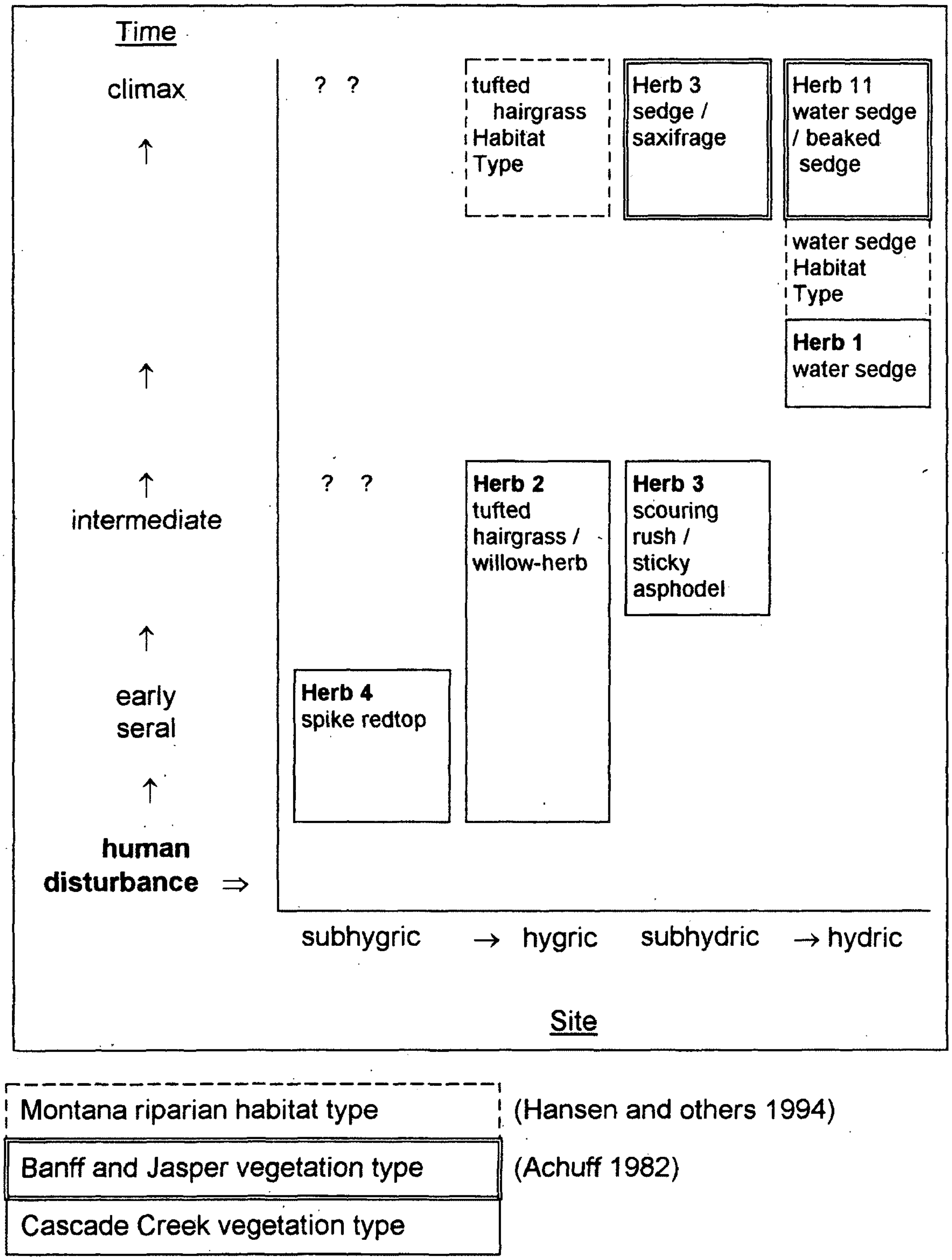


Figure 12. Plant succession trends for Cascade Creek herb communities

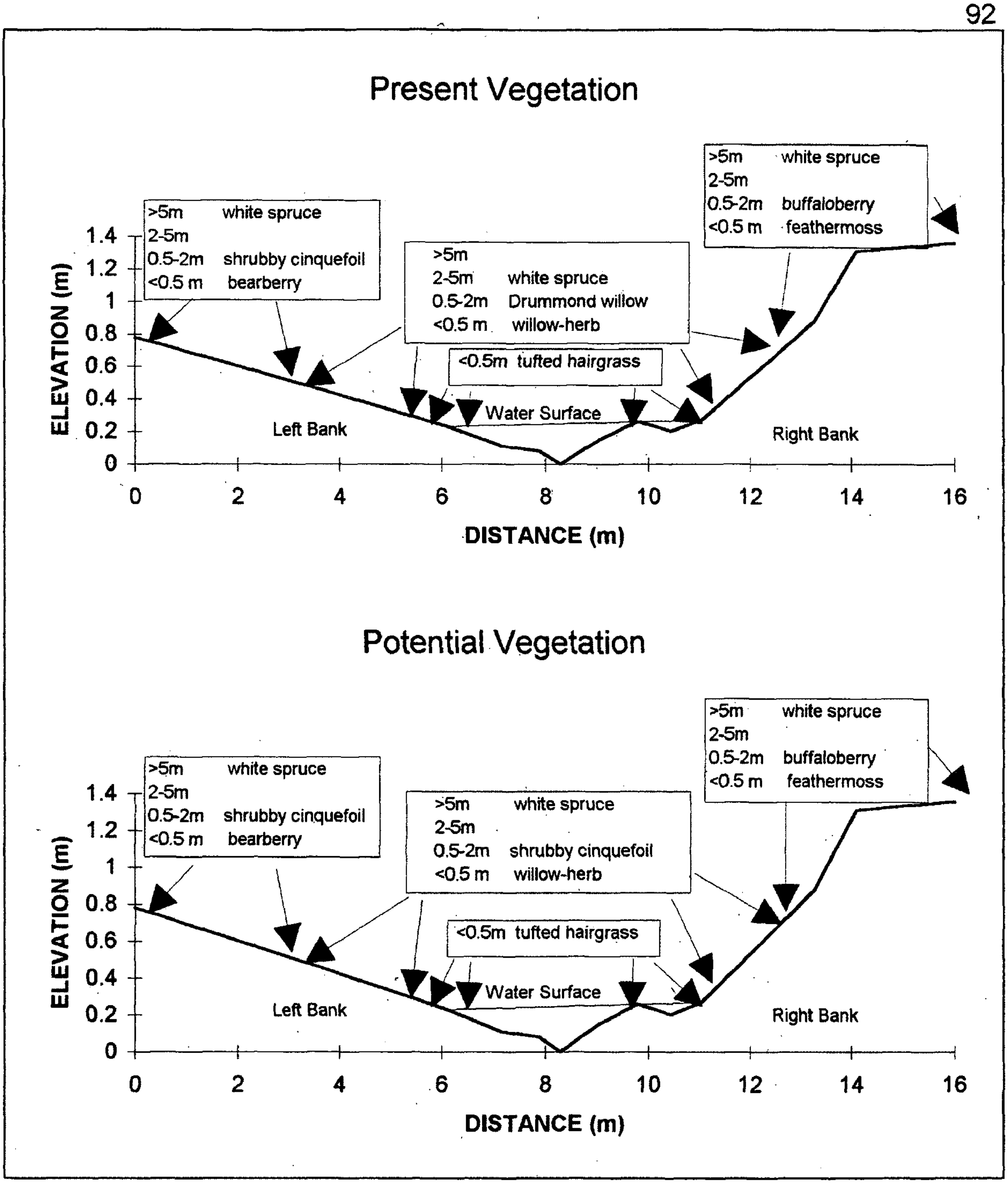


Figure 13. Present and potential vegetation at cross section B4, showing dominant species in each structural layer

The Herb 4 *Agrostis exarata* (spike redtop) VT may be the exception to these trends resembling still water wetlands. This vegetation type established on sites as recent as the early 1980's and with the dominance of it is difficult to predict stand development. In situations (such as Cascade Creek) where the frequency or intensity of natural disturbance is decreased, or where human disturbance increases, the invasion of competitively superior non-native species may be promoted (Hobbs and Huenneke 1992). When comparing seed size, germination and growth requirements of native and non-native riparian plants, introduced species may be adapted to a greater variety of conditions than native species. These factors explained the success of introduced species *Elaeagnus angustifolia* (Russian olive) where the natural flow and disturbance regime of a river has been altered (Shafroth and others 1995). In the lower portion of the study area where upstream communities contain non-native species and the nearby highway and railroad act as a seed source, special considerations for the establishment of native shrubs may be required.

Ecological Functioning of the Cascade Creek Vegetation Types

These ratings are based on several important functions of riparian vegetation in naturally occurring small streams. The importance of vegetation for shading, carbon production and bank protection was established in the introduction of this chapter. By site, existing and potential vegetation were rated using a key (Table 11).

Table 11. Key to ecological function rating by dominant lifeform

Structure (by dominant layer)	**Function**		
	Shading	Carbon Production	Bank Protection
Tree Layer (> 5m)			
i) deciduous trees dominant	good	good	good
ii)conifers dominant	good	poor	good
Tall Shrubs Layer (2-5 m)			
i) deciduous shrubs dominant	good	good	good
ii) conifers dominant	fair	poor	good
Shrub Layer (0.5-2m)			
i) deciduous shrubs dominant	fair	good	good
ii) conifers dominant	fair	poor	good
Dwarf Shrub Layer (<0.5m)	poor	poor	fair
Herbs	poor	poor	poor

Most Cascade Creek herbaceous communities show poor shading and bank protection for both existing and potential VTs (Table 12). However, the thick root mass of the *Carex aquatilis* (water sedge) community may help to maintain bank integrity during a flood event.

Elevated water temperatures during summer months are a problem in Cascade Creek resulting largely from the wide and shallow stream channel (Chapter 3). Shrub VTs 1-3 lack a dominant deciduous tall shrub (2-5 m) component required to hang over the flowing water and therefore receive a fair rating for shading (Table 12). However, even with a dominant deciduous tall shrub layer, the vegetation cannot compensate for the existing physical problem with the channel.

Table 12. Ecological function ratings for existing and potential vegetation types

Vegetation Type	Shading	Carbon Production	Bank Protection
Shrub 1: *Picea glauca / Salix drummondiana* (white spruce / Drummond willow)	fair → fair	good → fair	good → good
Shrub 2: *Ribes oxyacanthoides / Rubus ideaus* (northern gooseberry / red raspberry)	fair → good	good → good	good → good
Shrub 3: *Salix spp. / Rosa acicularis / Equisetum arvense* (willow / prickly rose / horsetail)	fair → good	fair → good	fair → good
Dwarf Shrub 1: *Dryas drummondii* (yellow dryad)	poor → good	fair → good	fair → good
Herb 1: *Carex aquatilis* (water sedge)	poor → poor	fair → fair	good → good
Herb 2: *Deschampsia cespitosa / Epilobium latifolium* (tufted hairgrass / willow-herb)	poor → poor	fair → fair	poor →poor
Herb 3: *Equisetum variegatum / Tofieldia glutinosa* (northern scouring rush / sticky asphodel)	poor → poor	fair → fair	poor →poor
Herb 4: *Agrostis exarata* (spike redtop)	poor → ??	fair → ??	poor → ??

(→) indicates rating for site in 50 years

CONCLUSIONS

There are three major differences between riparian communities of Cascade Creek and plant communities of naturally occurring small streams. These differences are primarily the result of human disturbances including the large-scale diversion of water since 1941 and ditch excavation of the early 1980's.

The first difference is the simultaneous progression of most Cascade Creek shrub communities toward closed canopy spruce forests. In most natural fluvial environments, a mix of seral stages and therefore habitats occur down the length of a stream when viewing the left and right banks through a series of meanders. Each seral stage represents a particular point in floodplain development. However, the entire Cascade River channel became stable when water diversion began in 1941 and this variety of habitat patches is absent along the remnant Cascade Creek. The trend of Cascade Creek shrub stands towards spruce forests represents an integration of the riparian vegetation types with adjacent spruce uplands, resulting in further loss of habitat diversity.

The second difference is the development of herbaceous communities resembling still water (lentic) wetlands. These communities are developing along the margins of the historic river channel. In comparison to typical flowing water (lotic) wetlands, these communities show poor ecological functioning for shading. In addition, should flood disturbances return, these communities would provide poor bank protection.

Development of plant communities dominated by grasses including several introduced species is the third difference. These communities cannot perform the important ecological functions of streamside vegetation that include shading and maintaining bank integrity. In comparison to tree and shrub communities with more complex structural diversity, these graminoid communities also provide fewer habitat niches for wildlife.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

Parks Canada's new ecosystem based management policy requires the restoration of habitat that has been lost as a result of human activities. In several local reports which incorporated this objective, investigating the potential of restoring lost aquatic habitat in Cascade Creek was recommended. Accomplishing such goals of preservation and restoration of biodiversity requires that ecosystems and the processes that maintain them be viewed at a variety of scales (Noss and Cooperrider 1994). When viewing aquatic systems, the watershed scale is an appropriate starting place.

From this broad perspective, the Cascade River at Lower Bankhead, a fourth order stream, drained an area of 664 km^2 (Environment Canada 1991). The river flowed uninterrupted from its headwaters to the Bow River. The river skirted Lake Minnewanka, transporting water, sediment, nutrients and debris into the larger rivers downstream. Historic stream flow and sediment loads shaped the river and floodplain. In the first chapter of this thesis, I described how human activities during the last century have reshaped this historic landscape downstream of Lake Minewanka and created constraints to restoring lost aquatic habitat.

In Chapter 2, **Floodplain Decline Following Damming**, I identified two important landscape level changes that have occurred since dam construction in 1941. First, whereas most small streams flow into larger streams, Cascade Creek ends two kilometers from the Cascade River (Fig. 1). The end of this stream represents a terminus in the river continuum. Second, the present flow regime has not maintained the historic floodplain. Upland ecosystems have replaced a major part of the former riparian ecosystems. The historic river channel largely contains the existing channel and its floodplain.

From this larger perspective, Cascade Creek could now be considered a first or second order stream with its own watershed. Its drainage basin area is greatly reduced from the area of the original Cascade River watershed. With this viewpoint, one goal for restoration becomes apparent--to recreate a perennial stream within the dry relic channel (Fig. 1, Reach H) and allow the movement of water, nutrients and biota between Cascade Creek and the lower watershed.

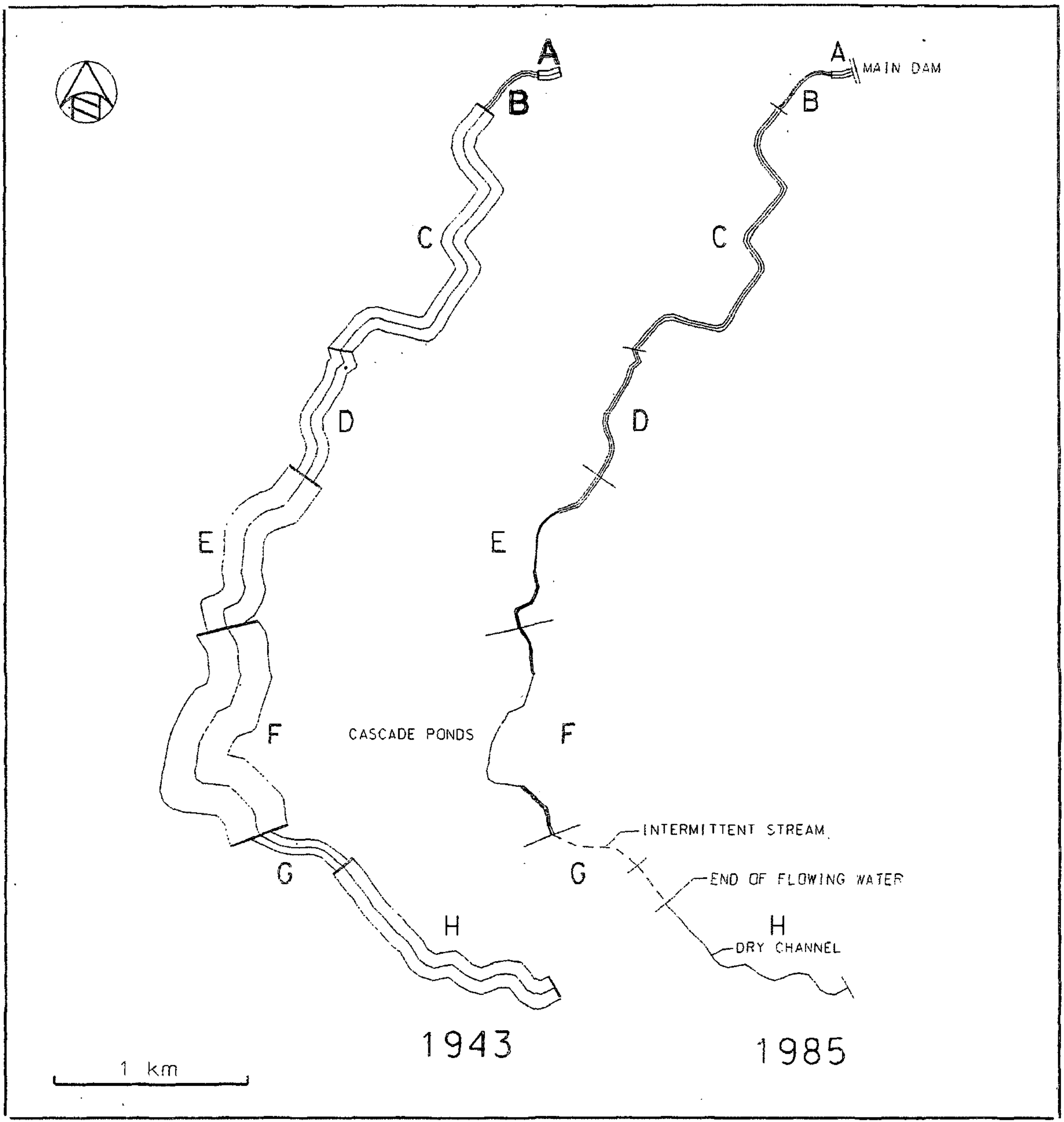


Figure 1. Changes in floodplain following water diversion

In Chapter 3, **Hydrology**, I used a detailed perspective to compare Cascade Creek with natural streams. Johnson Creek provided a model of an annual hydrograph for a natural stream. The comparison revealed that the first 2 km of Cascade Creek show a steady spring like flow and lack any increase in peak discharge during early summer. A delayed peak occurs between the 3 and 5-km marks of Cascade Creek, however, the magnitude of increase is much less than seasonal variation observed in Johnson Creek. Beyond the 7-km mark, there is no water and therefore no aquatic or riparian ecosystem present. The restrictions to flow increase and the present landform were found to preclude the restoration of a natural flow regime throughout the length of Cascade Creek, which was the desired goal identified in Chapter 2.

In a comparison of Cascade Creek and natural stream types, the first 500 m of Cascade Creek resemble a meandering, then a bedrock step and pool stream. Below this point, Cascade Creek resembles a braided stream. Large scale water diversion has eliminated sediment sources and greatly reduced stream power--thereby excluding natural channel adjustment. As a result, throughout most of the study area, the hydrology of Cascade Creek most closely resembles a spring type creek or slow moving pond.

Analysis of summer water temperatures revealed that optimal temperatures for salmonids exist in the top 3 km of Cascade Creek. During warm periods, the inflow from the dam and several tributaries help to maintain these temperatures. However, downstream from the 3-km mark, the stream is highly susceptible to water temperature increases to levels that are less than optimal and possibly lethal to salmonids.

The results from a fisheries inventory conducted during September 1995, relate to these description of flow, stream type and water temperature. Meandering stream types typically provide excellent salmonid habitat. In Cascade Creek, the meandering and bedrock step and pool reaches immediately downstream of the dam support a healthy brook trout population (Lethbridge College 1995). Normal fish food sources at this site are supplemented by mysis, a cold water shrimp, which likely enters Cascade Creek through the riparian flow valve from Lake Minnewanka (Lethbridge College 1995). At the 3-km mark, a healthy brook trout population persisted (Lethbridge College 1995). The cool water temperatures found at this site are maintained by various upstream inputs. However, at the 4-km mark, which is susceptible to water temperature increases, fish were present but below levels for estimating the population (Lethbridge College 1995). Downstream of Cascade Ponds, no fish were found (Lethbridge College 1995).

Modeling of stream power revealed that potential for stream bed disturbance within the braided cobble-bottom channel requires flows similar to those that created the historic channel. These flows are well above the proposed augmented releases into Cascade Creek. Only in the reaches altered by human activities since dam construction is there potential for stream bed disturbance.

Computer modeling also revealed that by increasing water release to the capacity of the riparian flow valve, stream depth in the braided channel will remain shallow and very high width/depth ratios will persist. Even with these augmented flows, high water temperatures during summer months are likely to occur in the lower reaches. Augmented flows may serve mainly as a means of removing accumulations of organic matter from pools in the upper reaches (important for the maintenance of deep water habitat for salmonids).

These descriptions and modeling exercises revealed that in order to achieve the goal of restoring flows and reintroducing natural processes (channel alteration and seasonal streambank inundation), flows greatly exceeding the capacity of the riparian flow valve are required. Recommending possible mechanisms to permit flows of this magnitude is not the intent of this study.

In Chapter 4, **Riparian Plant Communities**, I revealed three major differences between Cascade Creek riparian plant communities and other streamside communities. First, shrub communities in the historic channel (Reaches C and D) are simultaneously progressing into closed canopy spruce forests. This trend represents a loss of variety in habitat patches both within the riparian area and within the watershed. The second difference is the evolution of herbaceous lentic (still water) wetland communities both within the channel and along the channel margins. These two occurrences may be related to absence of flood-related disturbance, or the lack of variation in the length of time sites are inundated during high flows.

Development of plant communities dominated by weedy grass species is the third difference between Cascade Creek and other natural vegetation communities. These communities have developed as a result of recent human disturbances including gravel extraction and associated reclamation practices.

These three factors result in a decreased ability of Cascade Creek vegetation to perform the normal ecological functions of riparian vegetation. These functions include shading the flowing water, acting as an instream carbon source and protecting banks during high flows. The degree of impairment varies between reach.

RECOMMENDATIONS

With this highly altered system, the greatest challenge is to identify achievable objectives. In an evaluation of artificial stream restoration efforts, widespread project failure was observed and related to several factors (Beschta and others 1994). Often times, short term objectives resulted in simple and artificial manipulations of selected components of the system. These approaches neglected the complex functions of the aquatic and its associated riparian ecosystem. Self-regulating communities that resemble natural systems were not created and degraded systems continued to persist. Pouring time and money into a degraded system where continuous human perturbations exist was largely futile and also raised false public expectations that aquatic conditions would be improving. The first step to success is to treat the cause of the problem rather than the symptoms (Beschta and others 1994).

In the case of Cascade Creek the cause of the problem is large scale water diversion. Therefore the approach recommended in the environmental assessment, where large scale water diversion is allowed to continue largely unchanged, is flawed from the onset. Clearly, Parks Canada policy recommends restoration of systems impacted by human activities. If present park managers are serious about this attaining this goal with Cascade Creek, then a study of minimum instream flows required to recreate a wetland ecosystem throughout the historic channel should be undertaken. Based on the recommendations of such a study, engineers then could redesign the Lake Minnewanka dam to allow sufficient flows to enter the historic channel.

Regardless of whether this recommendation is implemeted, some possibilities of improving the present system exist. Reintroducing the native salmonid, westslope cuttroat trout, appears possible within the top 3 km of the creek. Due to the superior competitive ability of eastern brook trout, removal of this non-native species is required prior to this reintroduction experiment (Lethbridge College 1995). Suitable over-wintering habitat can limit fish survival. Therefore, prior to implementing this project, TransAlta Utilities should guarantee adequate winter discharge through the riparian flow valve to provide over-wintering habitat in the pools of the top 3 km of Cascade Creek. With this guarantee, a plan for removal and reintroduction could then be developed and implemented.

Concerning physical habitat restoration, in such cases where degradation of aquatic habitat is severe, efforts should focus on streams or stream reaches where potential to return to a near natural state is possible (Platts and Rinne 1985). In other restoration efforts, successful projects were designed by using a natural stream as a template (Newbury and Gaboury 1993). However, within the historic channel, reintroducing the full complexity of natural fluvial processes found in most streams in the region is impossible. A more reasonable goal is to mimic the steady spring like flow regime found in streams such as the North Raven River (Konyenbelt 1994). In the reach by reach summary (Table 1) priority areas for restoration become apparent.

Table 1. Summary of differences between Cascade Creek and natural streams, recommended changes, and engineering problems, by stream reach

Reach	Flow Type	Wetland Type	Stream Type	Model Stream	Main Differences	Suggested Changes	Engineering Problems	Engineering Solutions
A	perennial	lotic (flowing water)	meandering	meandering	**Flow Regime** -steady flow seasonally	-seasonal increase to 0.3 m^3/s through riparian flow valve	-poor worker access at tunnel entrance to riparian flow valve -high velocity from pipeline discharge	-improve access with wooden structure -install remote flow valve -rip-rap pipeline outlet to dissipate energy
					-absence of disturbance	-periodic flushing flows greater than 0.3 m^3/s	-not in present spillway design	-explore structural changes to dam
					Channel -none	-none	-none	-none
					Vegetation -none	-none	-none	-none
B	perennial	lentic (still water)	bedrock step and pool	bedrock step and pool	**Flow Regime** -see Reach A	-see Reach A	-see Reach A	-see Reach A
					Channel - infilling of pools with organic matter	-introduce periodic flushing flows	-may require flows greater than 0.3 m^3/s	-explore structural changes to dam
					Vegetation -none	-none	-none	-none

Table 1 (continued). Summary of differences between Cascade Creek and natural streams, recommended changes, and engineering problems, by stream reach

Reach	Flow Type	Wetland Type^{3}	Stream Type	Model Stream	Main Differences	Suggested Changes	Engineering Problems	Engineering Solutions
C	perennial	lentic (still water)	braided	meandering	**Flow Regime** -see Reach A	-substantial flow increases required	-may require flows greater than 0.3 m^3/s	-explore structural changes to dam
					Channel -very high width to depth ratios -low sinuosity	-flow increase -channel modification	-see Reach B -poor equipment access	-see Reach B -focus channel modifications on other reaches
					Vegetation -tall shrubs absent	-experimental planting with tall shrub species	-none	-none
D	intermittent (winter freezing)	lentic (still water)	braided	perennial meandering	**Flow Regime** -see Reach A	-see Reach A	-Bankhead contamination -loosing reach with surface flow perched well above water table	-consult site experts -minimal disturbance of channel bed
					Channel -very high width to depth ratios causing high water temperatures -low sinuosity -very few pools	-channel modification -channel modification	-see above	-minimal disturbance of channel bed
					Vegetation -tall shrubs absent	-experimental planting with tall shrub species	-none	-none

Table 1 (continued). Summary of differences between Cascade Creek and natural streams, recommended changes, and engineering problems, by stream reach

Reach	Flow Type	Wetland Type	Stream Type	Model Stream	Main Differences	Suggested Changes	Engineering Problems	Engineering Solutions
E	intermittent (freezing)	lentic (still water)	meandering	perennial meandering	**Flow Regime** -see Reach A	-see Reach A	-Bankhead contamination	-consult site experts
					Channel -low sinuosity -absence of pools	-channel modification	-none	-none
					Vegetation -non-native riparian plants associated with poor shading and bank protection	-experimental planting of tall shrub species	-none	-none
F	intermittent (freezing)	lotic (flowing water)	braided, riffle	perennial meandering	**Flow Regime** - seasonal and annual fluctuations with Cascade Mountain snow melt runoff	-none	-inadequate culverts on gravel pit access road for 0.3 m^3 /s or flushing flows	-replace culverts
					Channel -very active channel	-allow natural adjustment	-plugging of Loop Road culverts with sediment requiring annual clearing	-replace three small culverts with a single larger culvert to allow sediment passage
					Vegetation -see Reach E	-See Reach E	-none	-none

Table 1 (continued). Summary of differences between Cascade Creek and natural streams, recommended changes, and engineering problems, by stream reach

Reach	Flow Type	Wetland Type	Stream Type	Model Stream	Main Differences	Suggested Changes	Engineering Problems	Engineering Solutions
G	ephemeral	lentic (still water)	braided	perennial meandering	**Flow Regime** -ephemeral stream flow	-flow increase	-surface flow tied to seasonal groundwater	-groundwater recharge required
					Channel -very high width to depth ratios -low sinuosity	-channel modification	-see above	-see above
					Vegetation -non-native grasses dominant -tall shrubs absent	-experimental planting of tall shrub species	-none	-none
H	dry	none	braided	perennial meandering	**Flow Regime** -no stream flow	-flow increase greater than $0.3\ m^3/s$ required to create perennial flow	-surface flow tied to seasonal groundwater	-groundwater recharge required
					Channel -lack of downstream gradient -very high width to depth ratios, low sinuosity,	-restore downstream gradient -channel modification	-none	-none
					Vegetation riparian vegetation absent	-experimental planting of tall shrub species	-none	-none

Stream Reaches A-E have the greatest potential to return to a near natural state. With the high degree of degradation downstream of Cascade Ponds and the limited water, restoration efforts in the lower reaches (G-H) will be both expensive and very risky.

Thick organic accumulations in the pools in Reach A could be removed by hand or flushed out in order to provide deep water habitat. I also recommend some work in Reaches B and C. From personal observation, fish concentrate in the pools found in these reaches. These pools are widely spaced and often lack overhanging shrubs for cover. The experimental plantings recommended in Table 1 could concentrate around these deep water areas and utilize species including river alder (*Alnus tenuifolia*) and river birch (*Betula glandulosa*), as these species are generally less palatable than willow. I collected seeds from these two species during the fall of 1995 from the vicinity for this purpose.

Reaches D and E are located adjacent to the coal tar contaminations at Lower Bankhead. Implementing the following recommendations is contingent upon approval from the experts on the contamination problem.

In Reach D, I recommend decreasing the width of the existing channel. By reducing the width, the depth and velocity will increase. Besides providing more suitable physical habitat, these changes may help to reduce the rate of water temperature increases in this reach.

NOVA corporation has developed and demonstrated techniques for pipeline reclamation (Hunter 1994) that could be utilized in this situation. Recommended changes in channel cross-section for Reach D are illustrated in Figure 2.

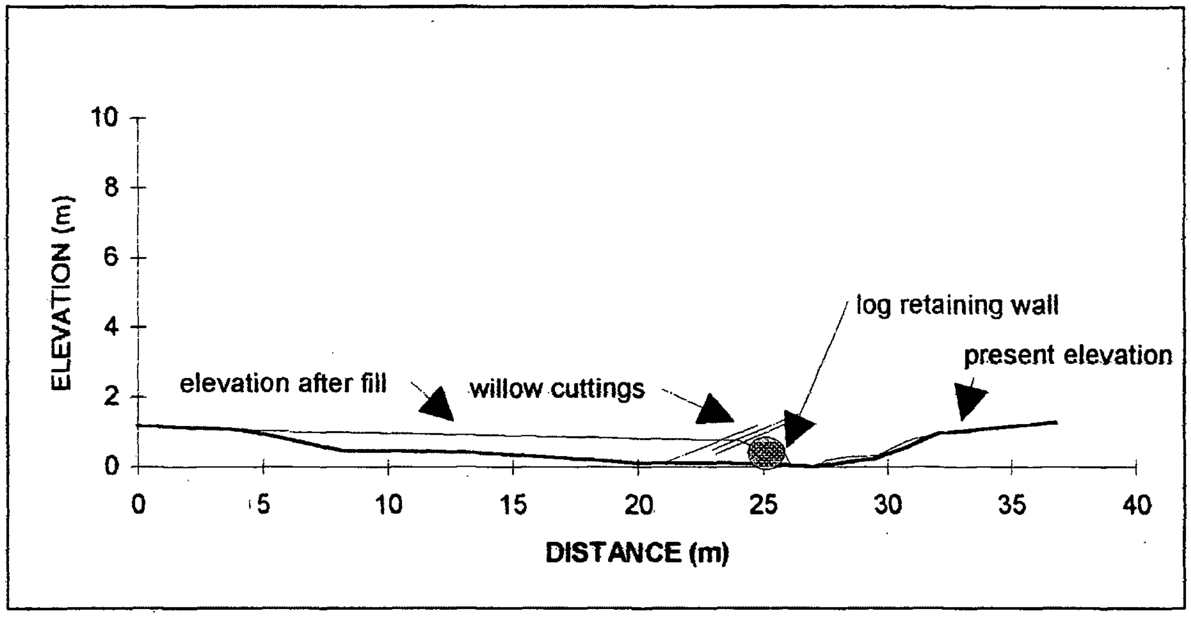


Figure 2. Creating a meandering stream channel at cross section D1

In Reach E, the diversion ditch, the channel lacks sinuosity and variation of depth. In several areas meanders could be created. Variation in the downstream profile could be introduced by excavation or damming with wooden or rock structures. Active management of the vegetation in this reach is required to re-establish native shrub communities. This includes planting shrubs and cutting back streambank grasses during summer months to reduce competition between these grasses and native shrubs. An experimental ungulate exclosure in this reach is also recommended to determine the influence of ungulate use on shrub establishment.

Although measurements of large woody debris are not presented in this report, I observed that this important structural component of small streams is largely absent throughout Cascade Creek. Increasing levels of instream woody debris is also recommended.

Should these recommendation be implemented, the process should be viewed as a natural experiment. Both Parks Canada and TransAlta Utilities are interested in such projects as public relations tools. However, this project should be presented in a manner that will increase public support for restoration of the entire study area. This larger project will require costly structural modifications to the dam and other facilities. If this project is presented without this larger context, the publicity would simply raise false public expectations that lost aquatic habitat in Banff National Park is being recovered.

Other human disturbances to streams in Banff National Park will occur. For example, as the reconstruction of the TransCanada highway occurs, streams will be impacted. Where mitigation is required, a reach based evaluation of the flow regime, stream channel and riparian vegetation can provide a framework for evaluation and planning.

LITERATURE CITED

Achuff, P.L. 1982. Chapter 3 Vegetation. *In:* Ecological (biophysical) land classification of Banff and Jasper National Parks. Volume II: Soil and vegetation resources (Holland, W.D. and G.M. Ceon, editors). Alberta Institute of Pedology Publications No. SS-82-44.

Adenlof, K.A. and E.E. Wohl. 1994. Controls on bedload movement in a subalpine stream of the Colorado Rocky Mountains, U.S.A.. Arctic and Alpine Research, 26: 77-85.

Alaback, P.B. and R.C. Sidle. 1986. Biomass, structure, and nutrients of riparian vegetation on a small watershed on Chichagof Island, Southeast Alaska. *In*: Watershed research perspectives (Correll, D.L., editor). Smithsonian Environmental Research Center, Edgewater, MD.

Banff National Park.1992. Minnewanka Area Plan (draft). Written by Susan Haid, School of Community and Regional Planning, University of British Columbia.

Beschta, R.L., W.S. Platts, J.B. Kauffman and M.T. Hill. 1994. Artifical stream restoration -- money well spent or an expensive failure? *In*: Environmental Restoration, Proceedings of the Universities Council on Water Resources 1994 Annual Meeting. p. 76-104.

Bilby, R.E. and J.W. Ward. 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. Transactions of the American Fisheries Society 118: 368-378.

Boutine, C. and Keddy, P.A. 1993. A functional classification of wetland plants. Journal of Vegetation Science 4: 591-600.

Brooks, K.N., P.F. Ffolliot, H.M. Gregersen and J.L. Thames. 1992. Hydrology and the Management of Watersheds. Iowa State University Press. Ames, Iowa. 392 p.

Canadian Parks Service. 1992. Draft of Abandonment Option Analysis, Cascade Hydropower Development, Banff National Park. Environmental Assessment Division, Western Region.

Costa, J.E. 1983. Paleohydraulic reconstruction of flash-flood peaks from boulder deposits in the Colorado Front Range. Geological Society of America Bulletin 94: 986-1004.

Cummins, K.W. 1980. The multiple linkages of forests to streams. *In:* Forests: fresh perspectives from ecosystem analysis, proceedings of a symposium (R.H. Waring, editor). 37th Ann. Biol. Colloq., Oregon State Univ., Corvallis, OR. p. 191-197.

Dames and Moore. 1992. Environmental Assessment for renewal of final water power licence for the Cascade power facility and operation. August 1992. Prepared for TransAlta Utility Corporation. Calgary.

Daubenmire, R.F. 1959. A canopy-coverage method of vegetation analysis. Northwest Science 33: 43-64.

Delong, M.D. and Brusven, M.A. 1994. Allochtonous input of organic matter from different riparian habitats of an agriculturally impacted stream. Environmental Management 18: 59-71.

Department of Mines and Technical Surveys. 1870. Plan 5533 C.P.R. Right of Way. Copy of original plan provided by Natural Resources Canada, Legal Surveys Division, Alberta Regional Office, Edmonton, Alberta.

Department of Mines and Technical Surveys. 1887. Plan 42382 Plan of the town of Anthracite. Copy of original plan provided by Natural Resources Canada, Legal Surveys Division, Alberta Regional Office, Edmonton, Alberta.

Environment Canada. 1991. Historical streamflow summary for Alberta to 1990. Environment Canada Inland Waters Directorate. Ottawa.

Friedman, J.M., M.L. Scott and W.M. Lewis, Jr. 1995. Restoration of riparian forest using irrigation, artificial disturbance, and natural seedfall. Environmental Management 19: 547-557.

Gadd, B. 1986. Handbook of the Canadian Rockies. Corax Press. Jasper, Alberta. 876 p.

Gadd, B. 1989. Bankhead, The Twenty Year Town. The Friends of Banff Park and Canadian Parks Service. 75 p.

Grant, G.E. 1986. Assessing effects of peak flow increases on stream channels: a rational approach. California Watershed Management Conference, West Sacramento, California. 142-149.

Grant, G. 1988. The RAPID technique: a new method for evaluating downstream effects of forest practices on riparian zones. USDA Forest Service, General Technical Report PNW-GTR-220. Pacific Northwest Research Station, Portland, OR. 36 p.

Grant, G.E., J.E. Duval, G.J. Koerper, and J.L. Fogg. 1992. XSPRO: a channel cross-section analyzer. USDI Bureau of Land Management Technical Note 387.

Groenveld, D.P. and D. Or. 1994. Water table induced shrub-herbaceous ecotone: hydrologic management implications. Water Resources Bulletin 30: 911-920.

Hamilton, L.C. 1992. Regression with graphics: a second course in applied statistics. Belmont, California: Brooks/Cole Publishing Company.

Hansen, P.L., S.W. Chadde, R.D. Pfister. 1988. Riparian dominance types of Montana. Miscellaneous Publication No. 49, June 1988. Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana, Missoula, MT. 411 p.

Hansen, P.L., R.D. Pfister, K. Boggs, B.J. Cook, J. Joy, D.K. Hinckley. 1995. Classification and management of Montana's riparian and wetland sites. Miscellaneous Publication No. 54, May 1995. Montana Forest and Conservation Experiment Station, School of Forestry, The University of Montana. Missoula, MT. 646 p.

Harrelson, C.C., C.L. Rawlins and J.P. Potyondy. 1994. Stream channel reference sites: an illustrated guide to field technique. USDA Forest Service General Technical Report RM-245. Rocky Mountain Forest and Range Experiement Station, Fort Collins, CO.

Harris, R.R., C.A. Fox and R. Risser. 1987. Impacts of hydroelectric development on riparian vegetation in the Sierra Nevada Region, California, USA. Environmental Management 11: 519-527.

Hitchcock, C.L. and A. Cronquist. 1991. Flora of the Pacific Northwest. University of Washington Press, Seattle, WA. 730 p.

Hobbs, R.J. and L.F. Huenneke. 1992. Disturbance, diversity and invasion: implications for conservation. Conservation Biology 6: 324-337.

Holland, W.D. and G.M. Coen (editors). 1982. Ecological (biophysical) land classification of Banff and Jasper National Parks. Volume II: Soil and vegetation resources. Alberta Institute of Pedology Publications No. SS-82-44.

Hunter, R. 1994. A photo guide to biostabilization methods used in pipeline reclamation. Unpublished report prepared by NOVA Gas Tranmissions Ltd.

Hurd, T. 1995. Personal communication. Banff National Park Warden Office.

Lane, R.J. 1989. Principles of discharge measurement. Water Resources Branch, Water Survey of Canada. Fredericton, New Brunswick. 1989_05_05.

Leopold, L.B. 1994. A View of the River. Harvard University Press, Cambridge. 298 p.

Leopold, L.B. and M.G. Wolman and J.P. Miller. 1964. Fluvial processes in geomorphology. W.H. Freeman and Company. San Francisco, CA. 522 p.

Lethbridge College. 1995. Interm report on fish and invertebrate distributions in select streams, Banff National Park.

Lewis, A.F. and A.C. Mitchell. 1994. Evaluation of the effectiveness of water release as a mitigation to protect fish habitat. Prepared for the Canadian Electrical Association, Power System Planning and Operation Section. Toronto, Canada.

Li, H.W., G.A. Lamberti, T.N. Pearsons, C.K. Tait , J.L. Li and J.C. Buckhouse. 1994. Cumulative effects of riparian disturbance along high desert trout streams of the John Day Basin, Oregon. Transactions of the American Fisheries Society 123: 627-640.

Lillesand, T.M. and R.W. Kiefer. 1994. Remote Sensing and Image Interpretation. 3rd ed. John Wiley and Sons, Inc. New York.

Johnson, W.C. 1994. Woodland expansion in the Platte River, Nebraska: patterns and causes. Ecological Monographs 64: 45-84.

Johnson, W.C., R.L. Burgess and W.R. Keammerer. 1976. Forest overstory vegetation and environment on the Missouri River floodplain in North Dakota. Ecological Monographs 46: 59-84.

Konynenbelt, R.D. 1994. Stream habitat restoration along the North Raven River, Alberta. *In:* Proceedings of the 9th International Trout Stream Habitat Improvement Workshop. Trout Unlimited Canada. Calgary, Alberta.

Lewis, A.F. and A.C. Mitchell. 1994. Evaluation of the effectiveness of water release as a mitigation to protect fish habitat. Prepared for the Canadaian Electrical Association, Power System Planning and operation Section. Toronto, Canada.

MacDonald, L.H., A.W. Smart and R.C. Wissmar. 1990. Monitoring guidelines to evaluate effects of forestry activities in the Pacific Northwest. Report No. EPA 910/9-91-001. U.S. Environmental Protection Agency, Region 10, NPS Section. Seattle, Washington.. 166 p.

McCune, B. 1993. Multivariate analysis on the PC-ORD system. Biology Program, Oregon State University, Corvallis, OR. 139 p.

Miller, J.R., T.T. Schulz, N. Thompson Hobbs, K.R. Wilson, D.L. Schrupp, and W.L. Baker. 1995. Changes in landscape structure of a southeastern Wyoming riparian zone following shifts in stream dynamics. Biological Conservation 72: 371-379.

Moore, P.D. and S.B. Chapman (editors).1986. Methods in Plant Ecology. Oxford: Blackwell Scientific Publications.

Moss, E.H. 1992. Flora of Alberta. University of Toronto Press. Toronto. 687 p.

Mueller-Dombois, D. and H. Ellenburg. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York. 547 pp.

Naimin, R.J., H. Decamps and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3: 209-212.

Newbury, R.W. and M.N. Gaboury. 1993. Stream analysis and fish habitat design - a field manual. Newbury Hydraulics Ltd., Gibsons, British Columbia. 256 p.

Noss, R.F. and A.Y. Cooperrider. 1994. Saving Nature's Legacy: Preserving and Restoring Biodiversity. Island Press, Covelo, California.

Parks Canada. 1994. Guiding Principles and Operational Policies. Minister of Supplies and Services Canada. Cat. No. R62-275/1994E. 125 p.

Platts, W.S. and J.N. Rinne. 1985. Riparian and stream enhancement management and research in the Rocky Mountians. North American Journal of Fisheries Management 5: 115-125.

Platts, W.S. and R.L. Nelson. 1989. Stream canopy and its relationship to salmonid biomass in the Intermountain West. North American Journal of Fisheries Management 9: 446-457.

Powell, D.M. and P.J. Ashworth. 1995. Spatial pattern of flow competence and bed load transport in a divided gravel bed river. Water Resources Research, 31: 741-752.

Reice, S.R. 1994. Nonequilibrium determinants of community structure. American Scientist 82: 424-435.

Reiner, R. and T. Griggs. 1989. The Nature Conservancy undertakes riparian restoration projects in California. Restoration Management and Notes 7: 3-8.

Resh, V.H., A.V. Brown, A.P. Covich, M.E. Gurtz, H.W. Li, G. Wayne Minshall, S.R. Reice, A.L. Sheldon, J.B. Wallace and R.C. Wissmar. 1988. The role of disturbance in stream ecology. Journal of the North American Benthological Society 7: 433-455.

Rood , S.B. and S. Heinze-Milne. 1989. Abrupt downstream forest decline following river damming in southern Alberta. Canadian Journal of Botany 67: 1744 - 1749.

Rosgen, D.L. 1994 (in press). A classification of natural rivers. Submitted to Catena. Catena, Elseiver Publications, Amsterdam.

Shafroth, P.B., G.T. Auble and M.L. Scott. 1995. Germination and establishment of the native plains cottonwood (*Populus deltoides* Marshall subsp. *monilifera*) and the exotic Russian -olive (*Elaeagnus angustifolia* L.). Conservation Biology 9: 1169-1175.

Stevens, L.E., J.C. Schmidt, T.J. Ayers and B.T. Brown. 1995. Flow regulation, geomorphology, and Colorado River marsh development in the Grand Canyon, Arizona. Ecological Applications 5: 1025-1039.

Stromberg, J.C. and D.T. Patten. 1990. Riparian vegetation instream flow requirements: A case study from a diverted stream in the Eastern Sierra Nevada, California, USA. Environmental Management 14: 185-194.

TransAlta Utilites. 1986. Cascade storage and power development map series, Cascade River, Bankhead to Banff Interchange. Scale 1:2 000. Map No. Co.17391.

Trista, F.J. and K. Cromack, Jr. 1980. The role of wood debris in forests and streams. *In:* Forests: fresh perspectives from ecosystem analysis, proceedings of a symposium (R.H. Waring editor) . 37th Ann. Biol. Colloq., Oregon State Univ., Corvallis, OR. p. 171-190.

Vannote, R.L., GW. Minshall, K.W. Cummins, J.R. Sedell and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130-137.

Wayne, P.M. and F.A. Bazzaz. 1991. Assessing diversity in plant communities: the importance of within species variation. TREE 6: 400-403.

Wohl, E.E. 1995. Estimating flood magnitude in ungauged mountain channels, Nepal. Mountain Research and Development, 15: 69-76.

Yorke, T.H. 1978. Impact assessment of water resource development activities: A dual matrix approach. FWS/OBS-78/82.

Zuuring, H. 1992. Research Methods Handbook. School of Forestry, University of Montana. 89 p.

APPENDIX 1. REGRESSION ANALYSIS AND STAGE RATING CURVES

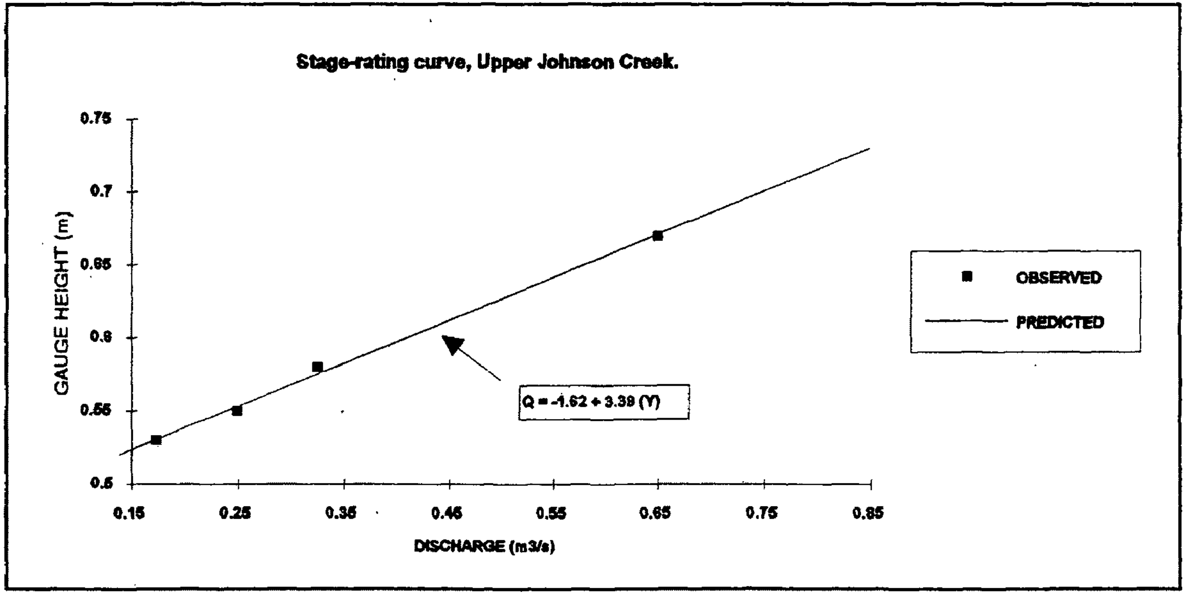
Table 1. Regression Statistics for Johnson Creek Stage-Rating Curve

Multiple R	0.9986
R Square	0.9972
Adjusted R Square	0.9958
Standard Error	0.0137
Observations	4

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*P-value*
Regression	1	0.1317	0.1317	705.6534	0.0014
Residual	2	0.0004	0.0002		
Total	3	0.1321			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.6242	0.0746	-21.7703	0.0002	-1.9452	-1.3032
Gauge Height (m)	3.3880	0.1275	26.5641	0.0001	2.8393	3.9368



note: in the regression equation, Q represents discharge

Table 2. Regression Statisitcs for Station 3 Stage-Rating Curve

Multiple R	0.8649
R Square	0.7480
Adjusted R Square	0.6640
Standard Error	0.0262
Observations	5

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*P-value*
Regression	1	0.0061	0.0061	8.9037	0.0584
Residual	3	0.0021	0.0007		
Total	4	0.0082			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.3061	0.1744	-1.7549	0.1541	-0.8612	0.2490
Gauge Height ^{2}	2.1603	0.7240	2.9839	0.0406	-0.1437	4.4644

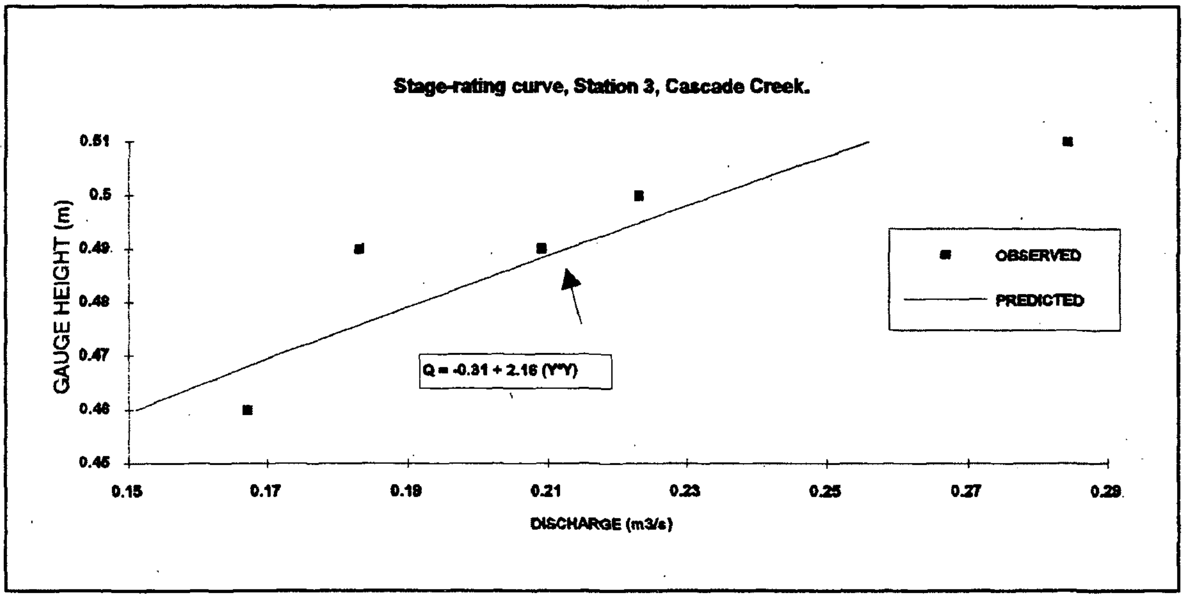


Table 3. Regression Statisitcs for Station 4 Stage-Rating Curve

Multiple R	0.8693
R Square	0.7557
Adjusted R Square	0.6743
Standard Error	0.0152
Observations	5

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*P-value*
Regression	1	0.0021	0.0021	9.2813	0.0556
Residual	3	0.0007	0.0002		
Total	4	0.0028			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.5143	0.2005	-2.5650	0.0623	-1.1524	0.1238
Sqrt (Gauge Height)	0.9007	0.2956	3.0465	0.0382	-0.0402	1.8415

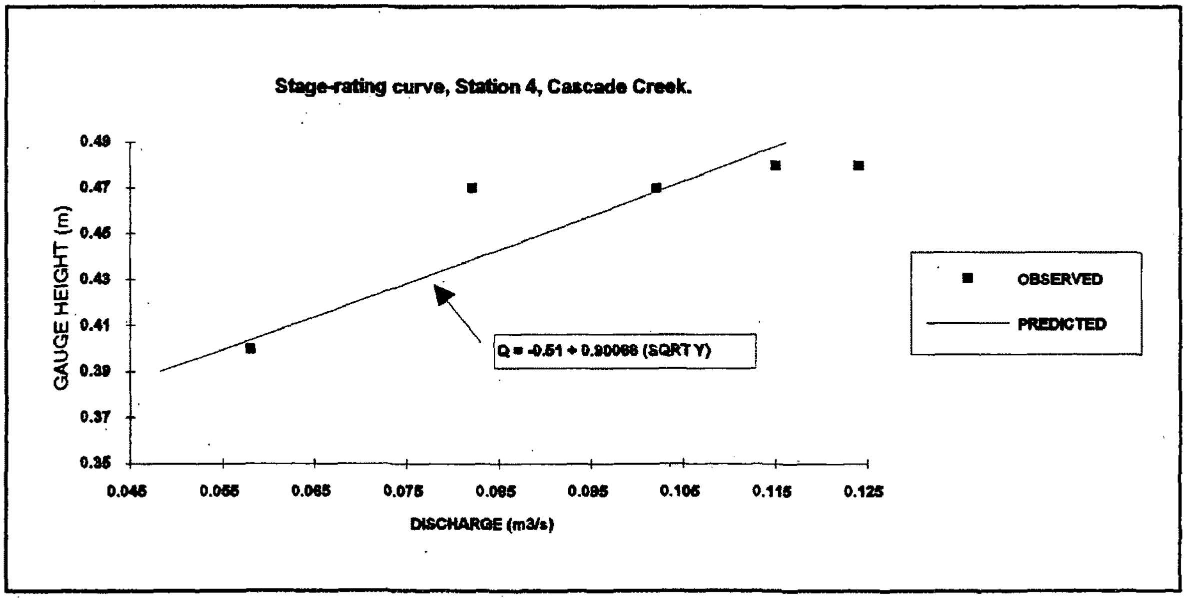


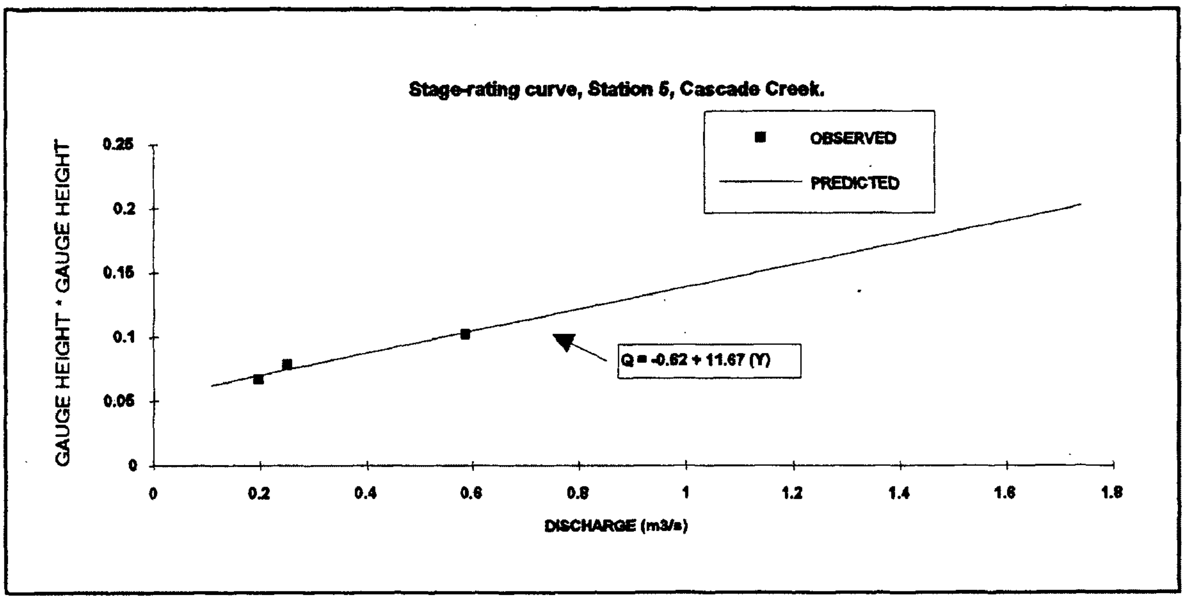
Table 4. Regression Statisitcs for Station 5, Stage-Rating Curve

Multiple R	0.9838
R Square	0.9678
Adjusted R Square	0.9356
Standard Error	0.0536
Observations	3

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*P-value*
Regression	1	0.0864	0.0864	30.0793	0.1148
Residual	1	0.0029	0.0029		
Total	2	0.0893			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.6224	0.1789	-3.4793	0.0736	-2.8953	1.6505
Gauge Height ^{2}	11.6700	2.1278	5.4845	0.0317	-15.3666	38.7066



APPENDIX 2. ROSGEN STREAM TYPES AND CROSS SECTIONS

(photocopied from Harrelson and others 1994)

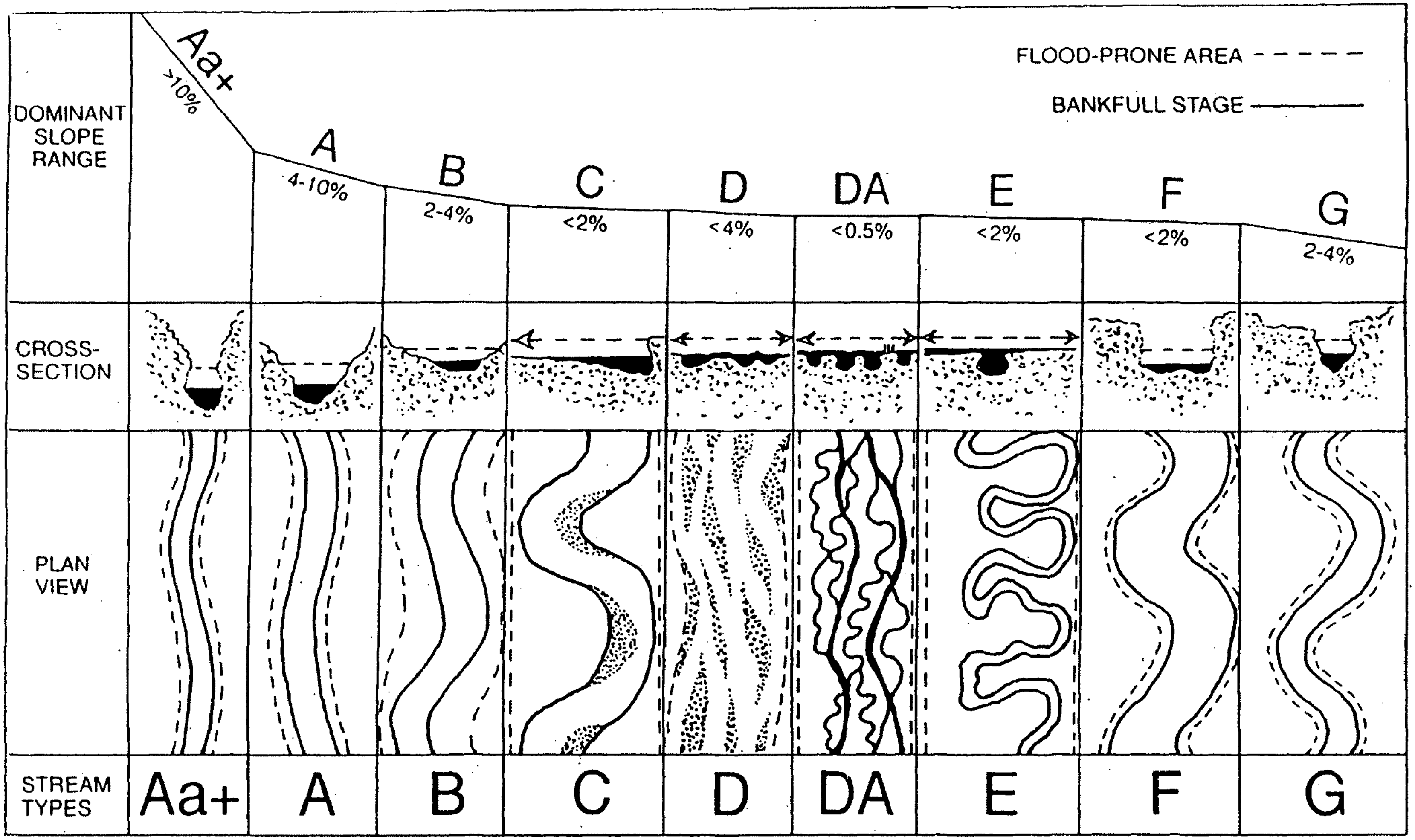
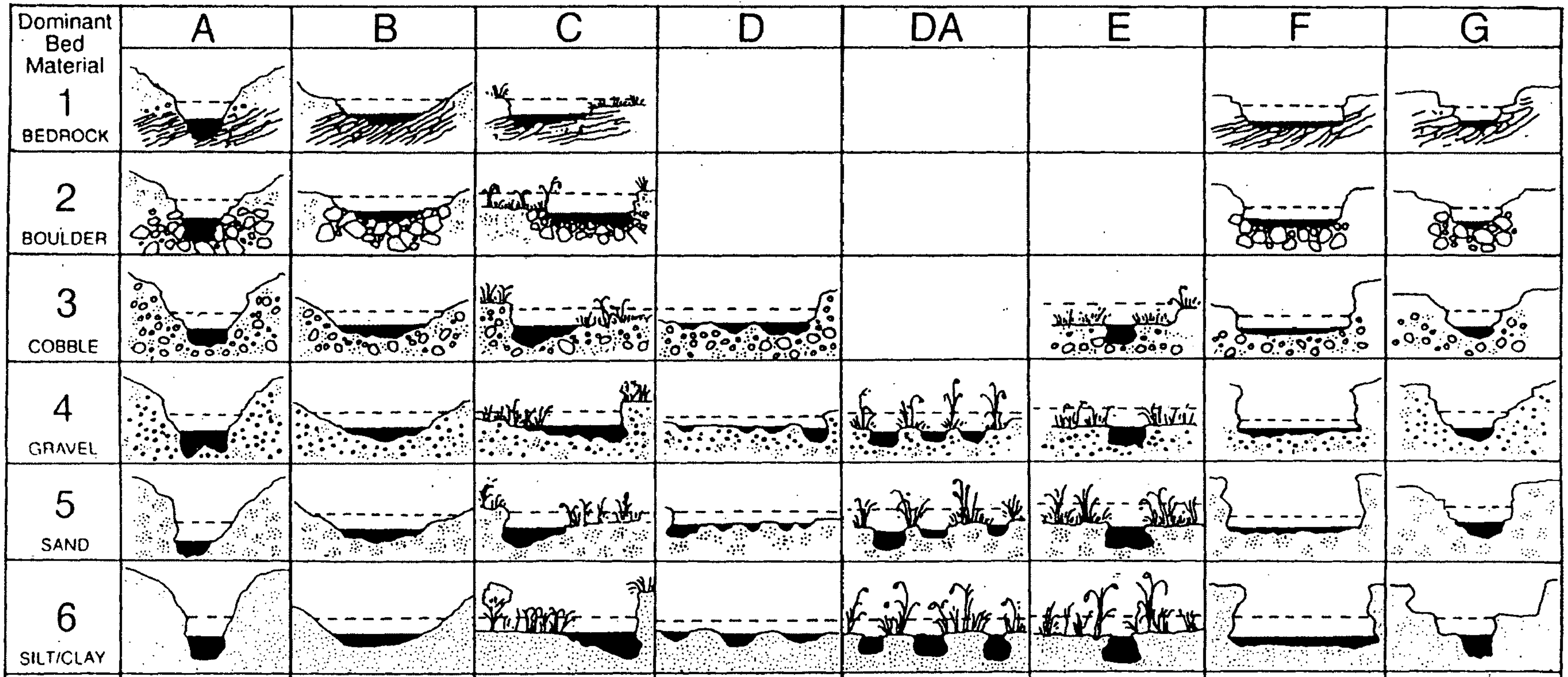


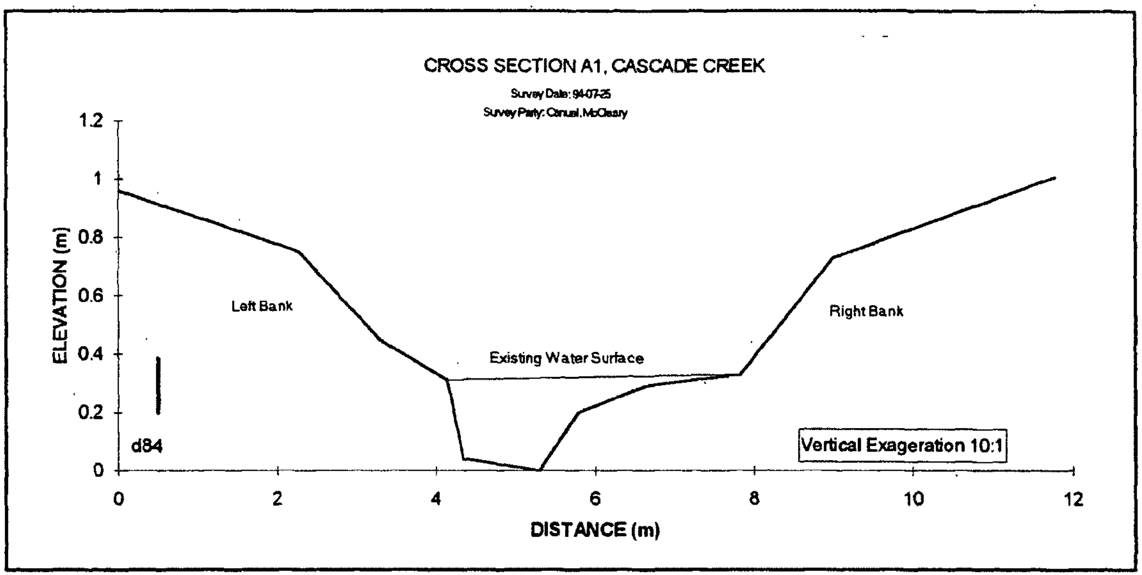
Figure 2. – Stream types: gradient, cross-section, plan view (adapted from Rosgen 1994). Original drawings by Lee Silvey. Courtesy of Catena Verlag.

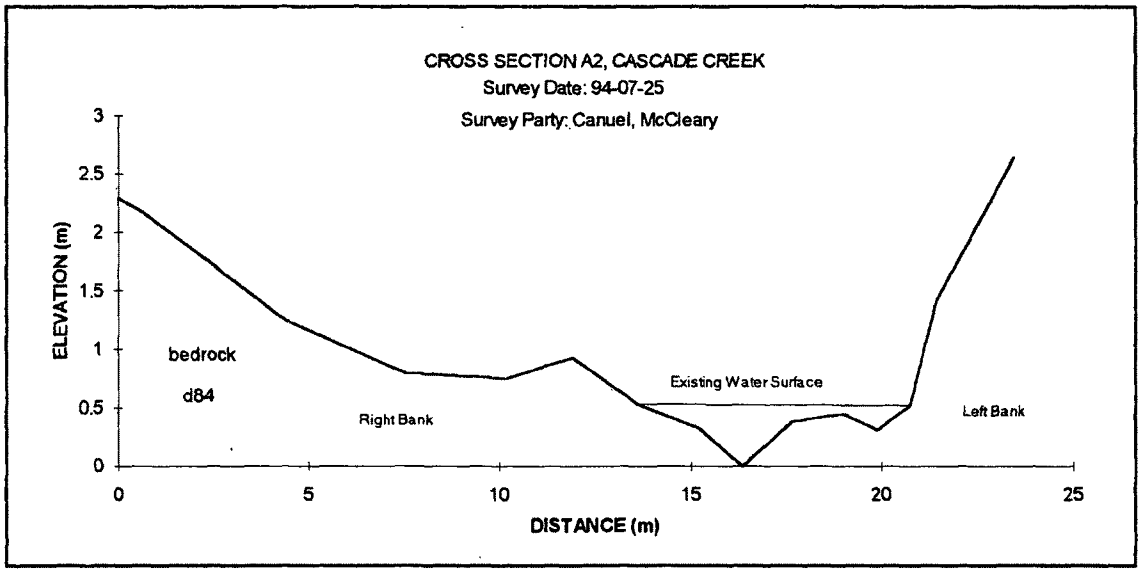


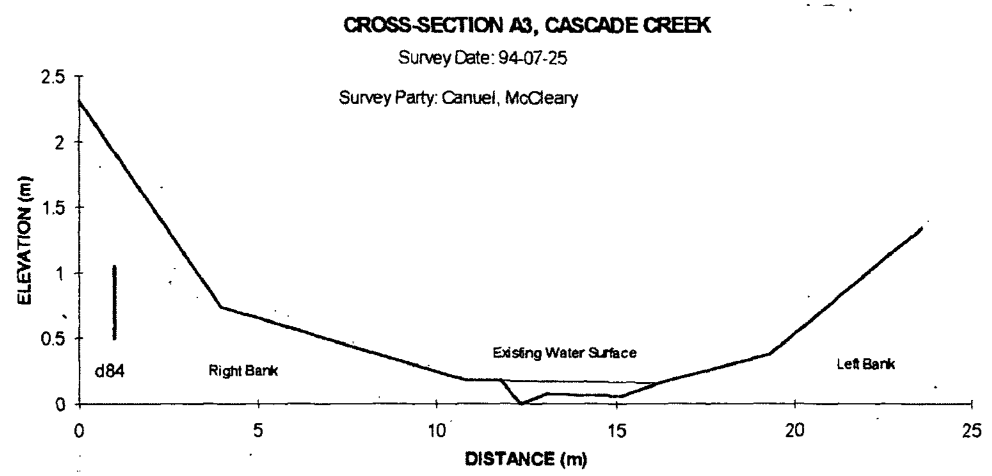
	A	B	C	D	DA	E	F	G
ENTRH.	<1.4	1.4-2.2	>2.2	N/A	>2.2	>2.2	<1.4	<1.4
SIN.	<1.2	>1.2	>1.4	<1.1	1.1-1.6	>1.5	>1.4	>1.2
W/D	<12	>12	>12	>40	<40	<12	<12	<12
SLOPE	.04-.099	.02-.039	<.02	<.04	<.005	<.02	<.02	.02-.039

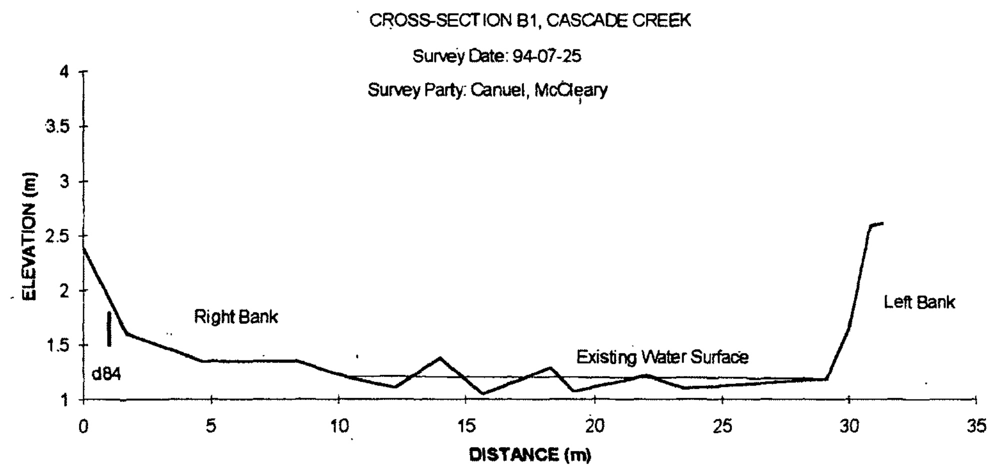
Figure 3. – Cross-section view of stream types (adapted from Rosgen 1994). Original drawings by Lee Silvey. Courtesy of Catena Verlag.

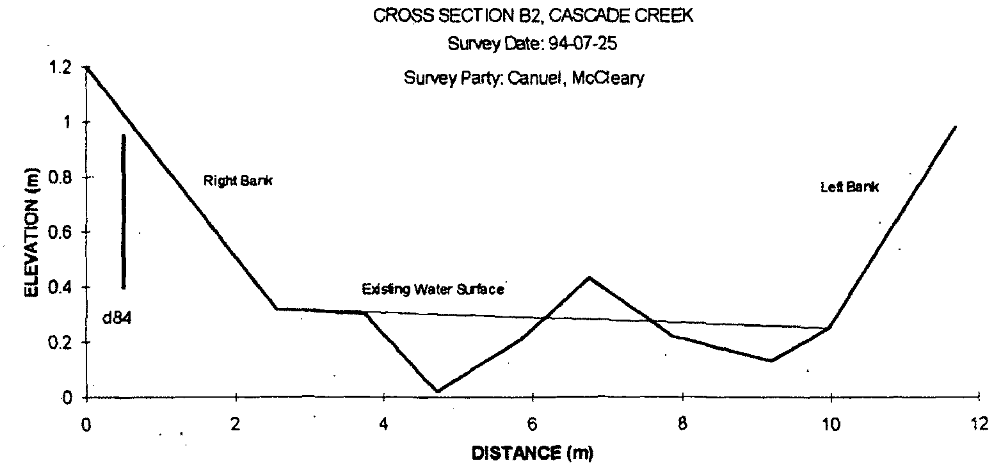
APPENDIX 3. CASCADE CREEK CROSS SECTIONS

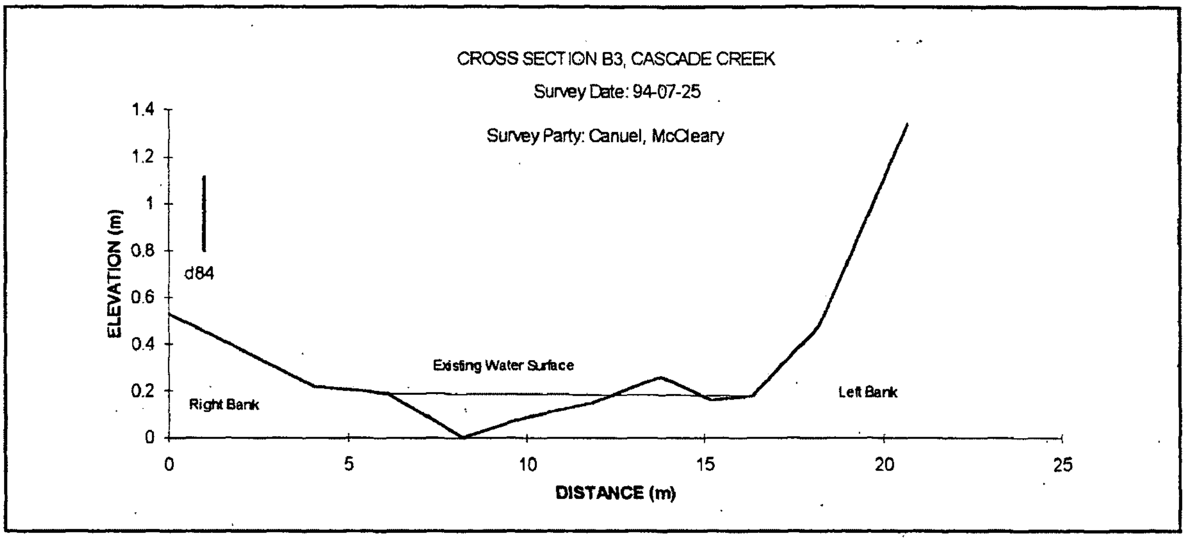


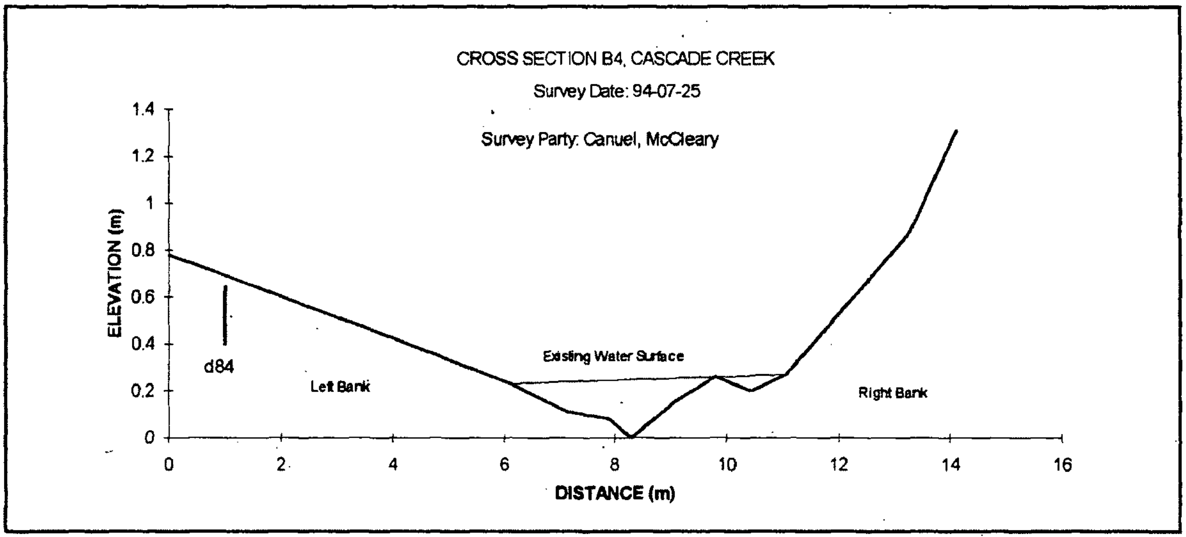


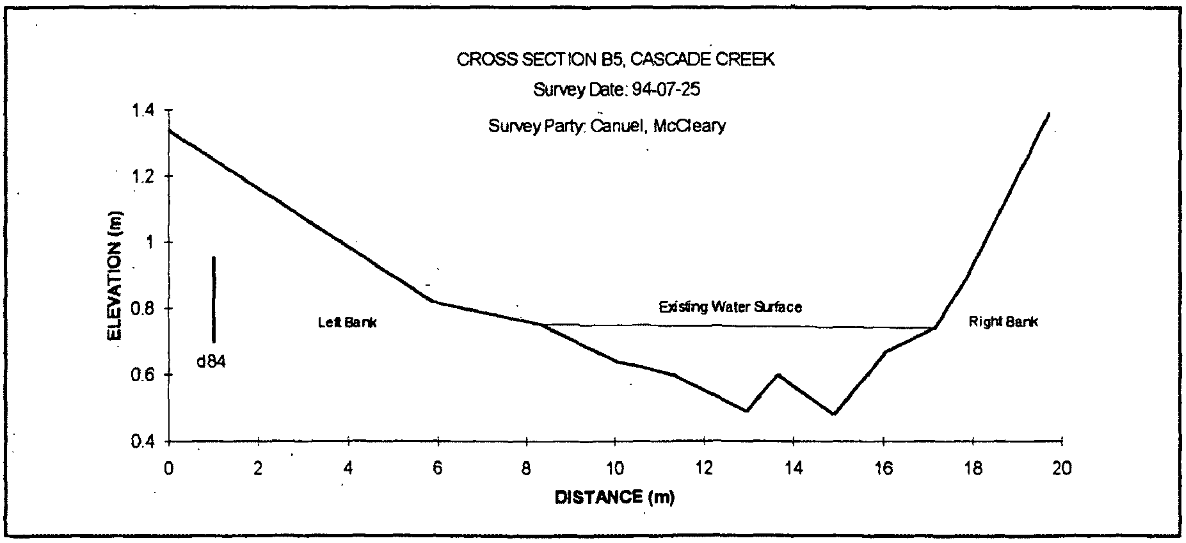

CROSS-SECTION A3, CASCADE CREEK
Survey Date: 94-07-25
Survey Party: Canuel, McCleary
ELEVATION (m)
2.5
2
1.5
1
0.5
0
d84
Right Bank
Existing Water Surface
Left Bank
0
5
10
15
20
25
DISTANCE (m)

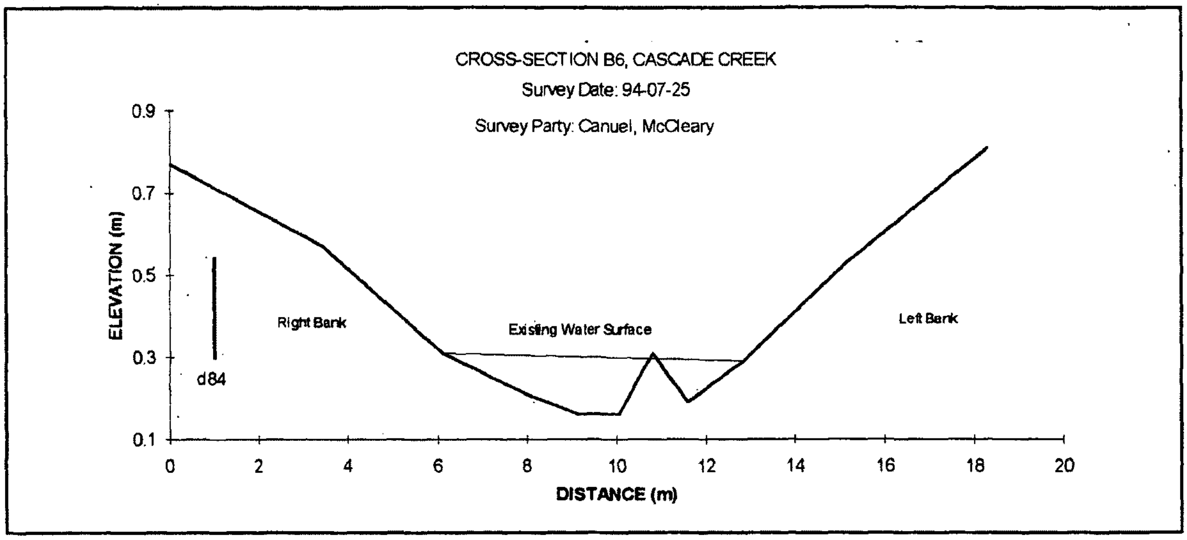

CROSS-SECTION B1, CASCADE CREEK
Survey Date: 94-07-25
Survey Party: Canuel, McCleary
ELEVATION (m)
4
3.5
3
2.5
2
1.5
1
Right Bank
Left Bank
Existing Water Surface
d84
0
5
10
15
20
25
30
35
DISTANCE (m)

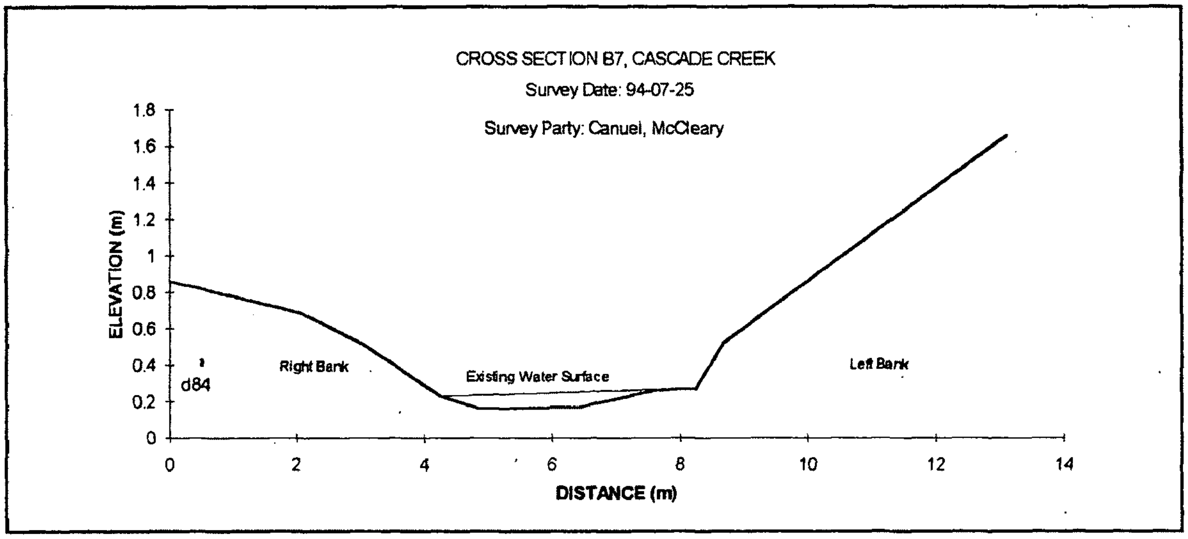

CROSS SECTION B2, CASCADE CREEK
Survey Date: 94-07-25
Survey Party: Canuel, McCleary
ELEVATION (m)
1.2
1
0.8
0.6
0.4
0.2
0
Right Bank
Left Bank
Existing Water Surface
d84
0
2
4
6
8
10
12
DISTANCE (m)

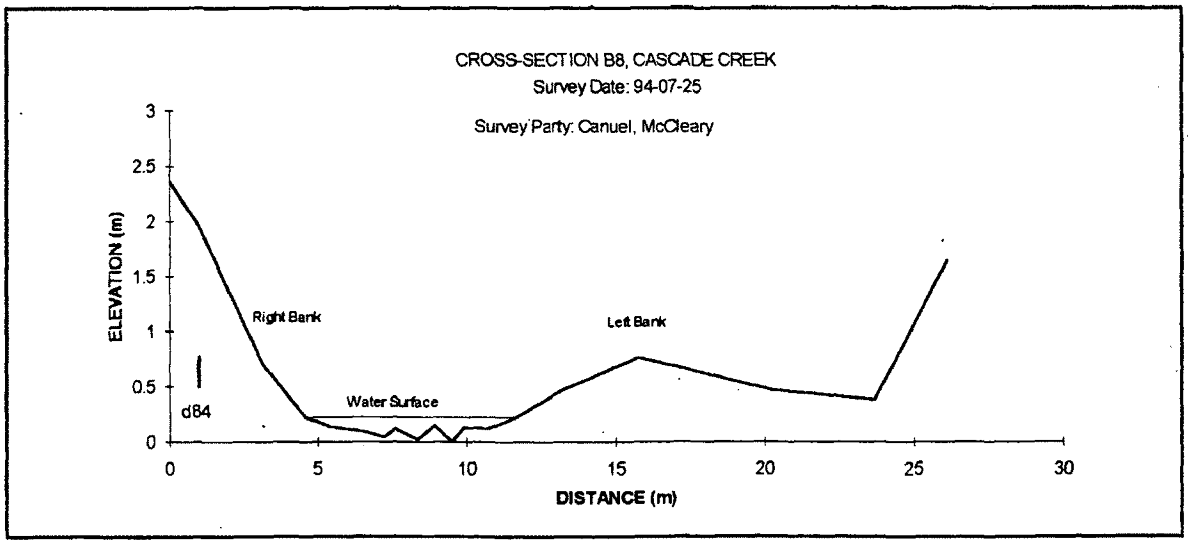

CROSS SECTION B3, CASCADE CREEK
Survey Date: 94-07-25
Survey Party: Canuel, McCleary
ELEVATION (m)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
d84
Existing Water Surface
Right Bank
Left Bank
0
5
10
15
20
25
DISTANCE (m)

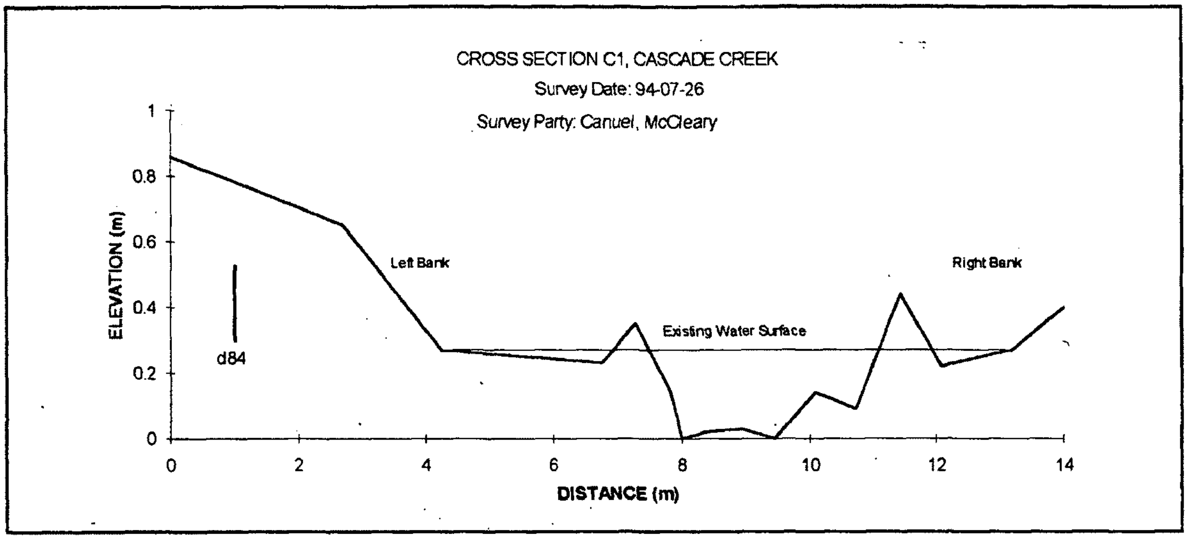

CROSS SECTION B4, CASCADE CREEK
Survey Date: 94-07-25
Survey Party: Canuel, McCleary
ELEVATION (m)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
d84
Existing Water Surface
Left Bank
Right Bank
0
2
4
6
8
10
12
14
16
DISTANCE (m)


CROSS SECTION B5, CASCADE CREEK
Survey Date: 94-07-25
Survey Party: Canuel, McCleary
ELEVATION (m)
1.4
1.2
1
0.8
0.6
0.4
d84
Existing Water Surface
Left Bank
Right Bank
0
2
4
6
8
10
12
14
16
18
20
DISTANCE (m)

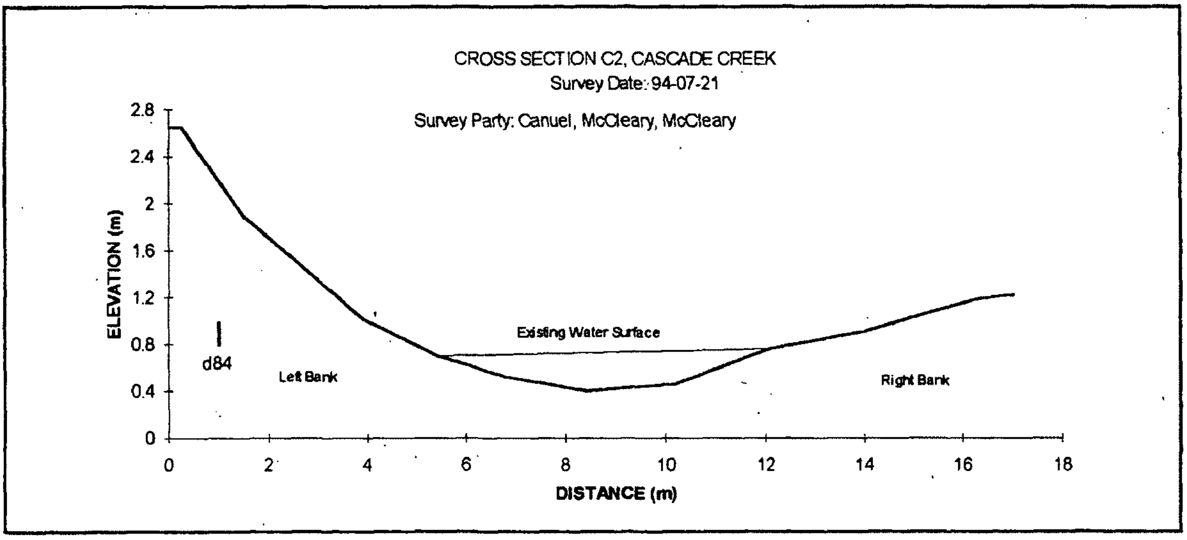

CROSS-SECTION B6, CASCADE CREEK
Survey Date: 94-07-25
Survey Party: Canuel, McCleary
ELEVATION (m)
0.9
0.7
0.5
0.3
0.1
d84
Right Bank
Existing Water Surface
Left Bank
0
2
4
6
8
10
12
14
16
18
20
DISTANCE (m)


CROSS SECTION B7, CASCADE CREEK
Survey Date: 94-07-25
Survey Party: Canuel, McCleary
ELEVATION (m)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
d84
Right Bank
Existing Water Surface
Left Bank
0
2
4
6
8
10
12
14
DISTANCE (m)

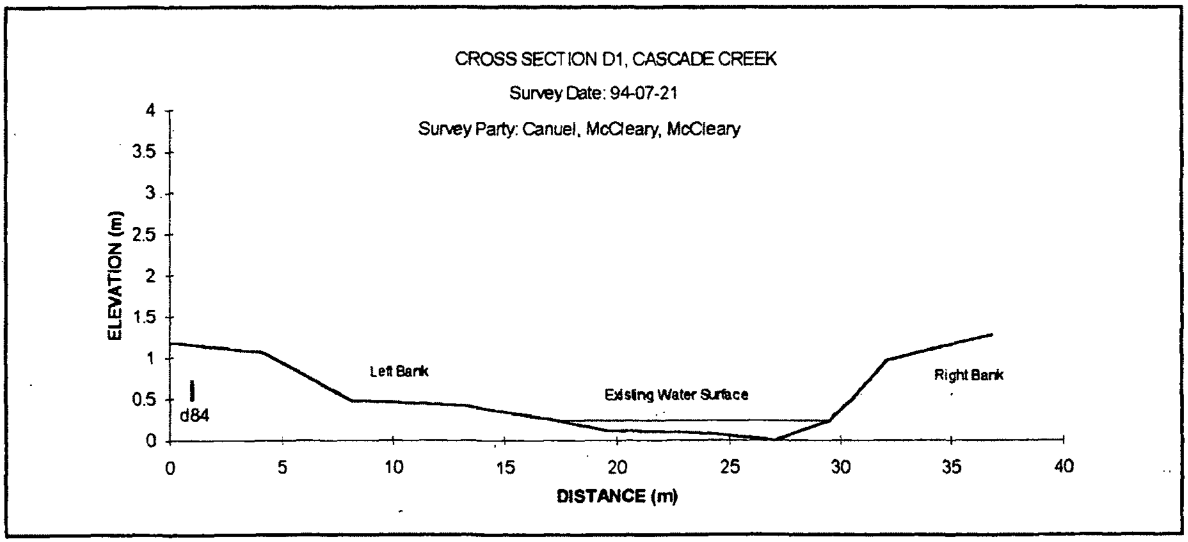

CROSS-SECTION B8, CASCADE CREEK
Survey Date: 94-07-25
Survey Party: Canuel, McCleary
ELEVATION (m)
3
2.5
2
1.5
1
0.5
0
d84
Right Bank
Left Bank
Water Surface
0
5
10
15
20
25
30
DISTANCE (m)



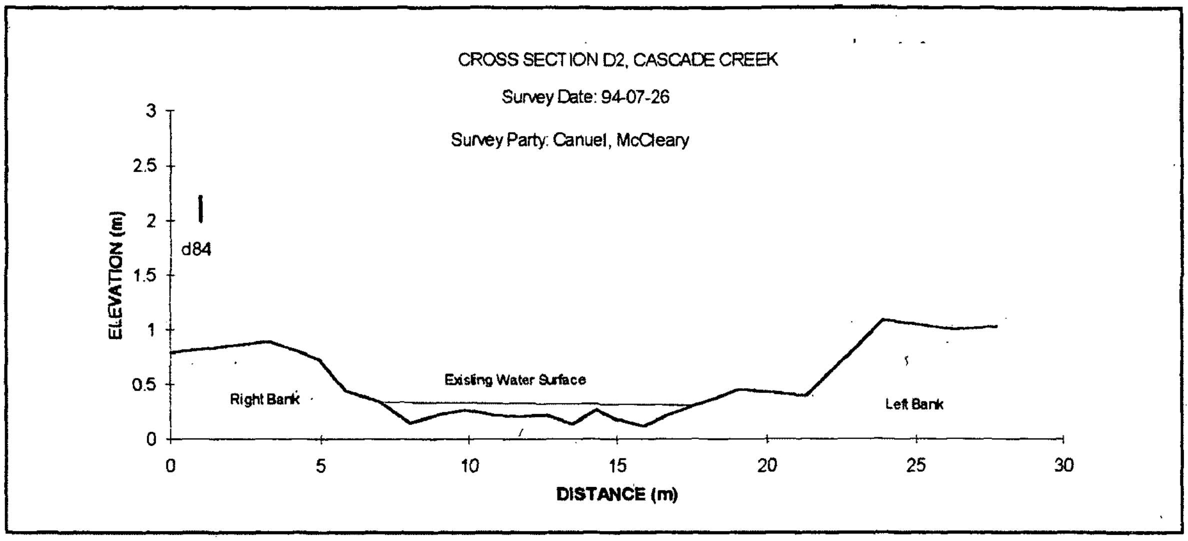
CROSS SECTION C1, CASCADE CREEK
Survey Date: 94-07-26
Survey Party: Canuel, McCleary

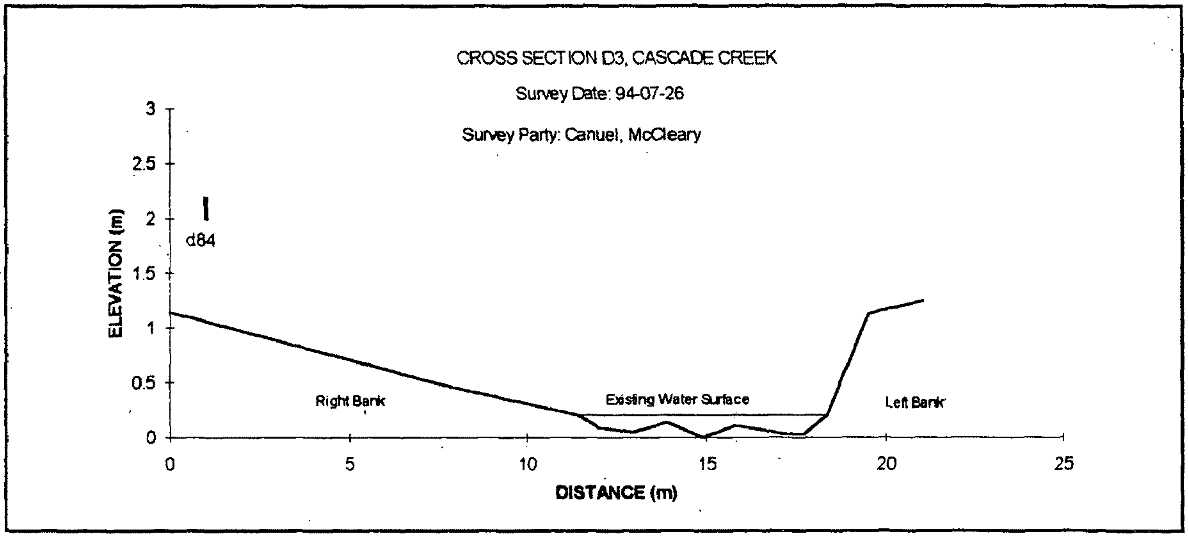


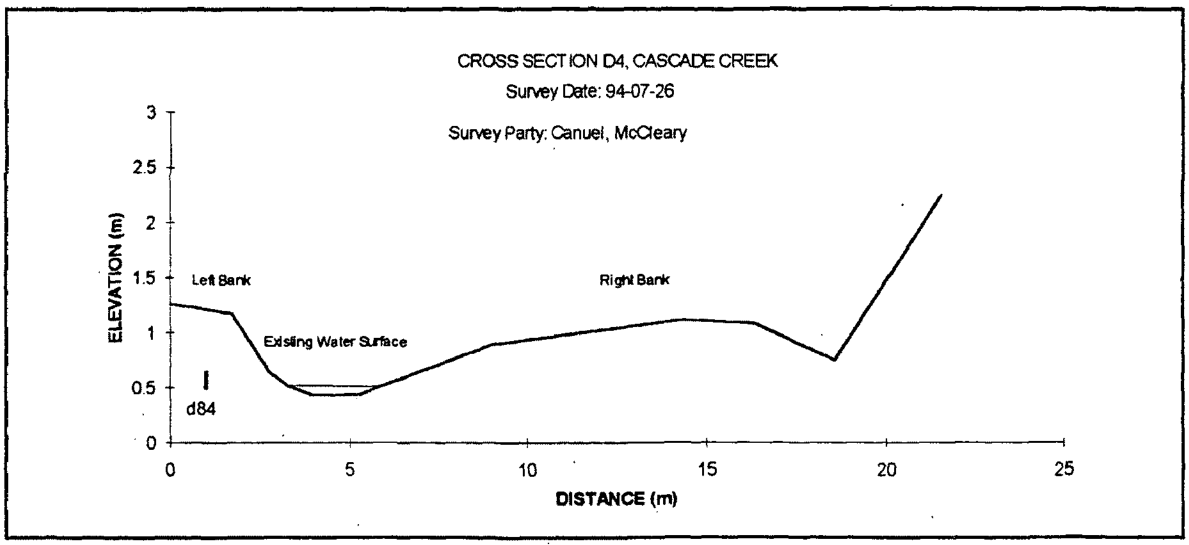
CROSS SECTION C2, CASCADE CREEK
Survey Date: 94-07-21
Survey Party: Canuel, McCleary, McCleary

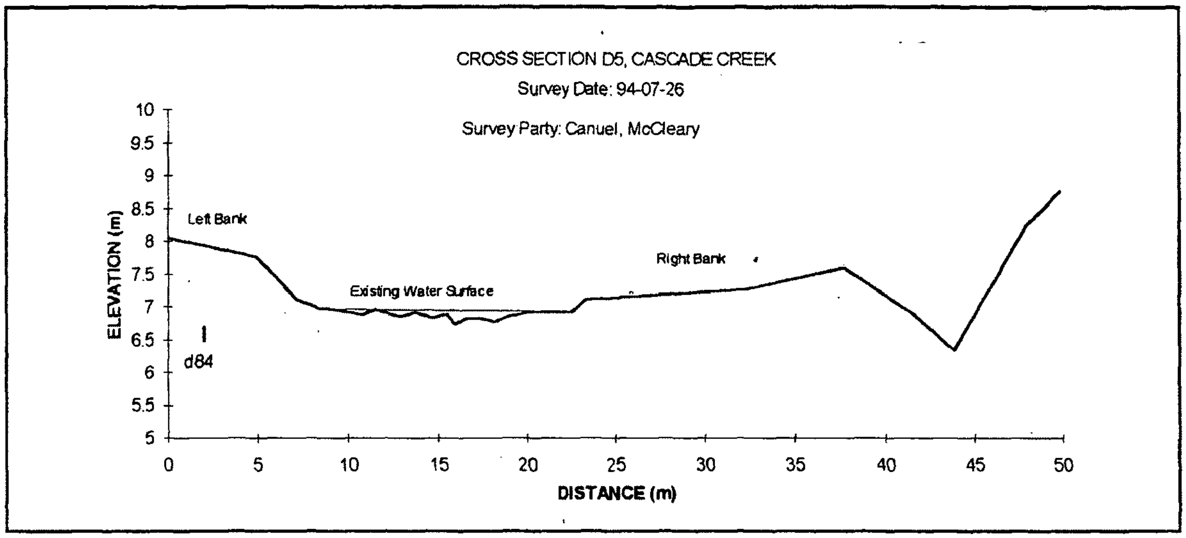


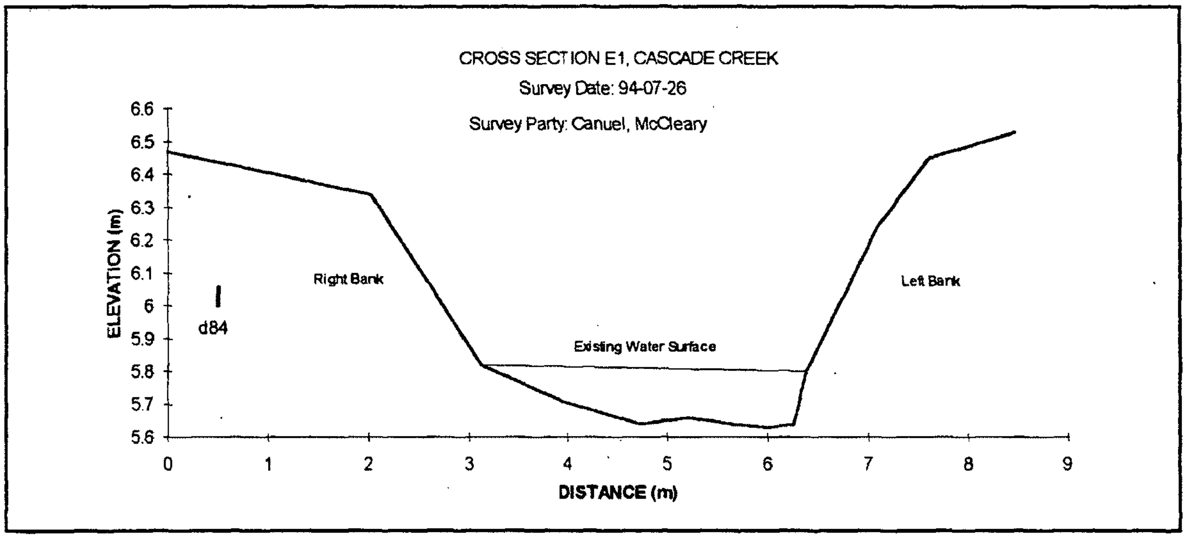
CROSS SECTION D1, CASCADE CREEK
Survey Date: 94-07-21
Survey Party: Canuel, McCleary, McCleary

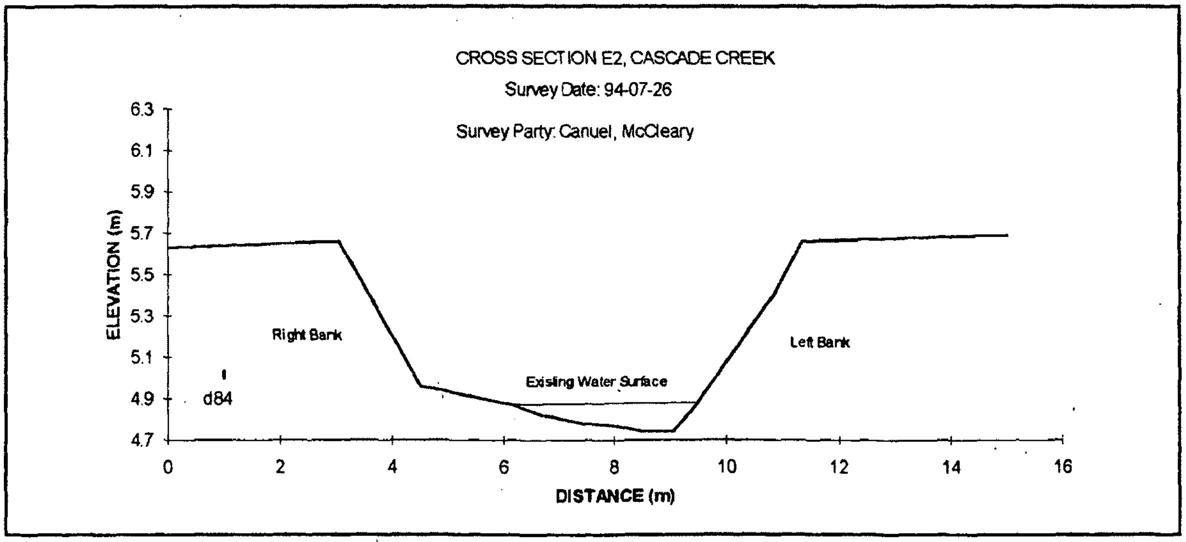

CROSS SECTION D2, CASCADE CREEK
Survey Date: 94-07-26
Survey Party: Canuel, McCleary
ELEVATION (m)
DISTANCE (m)
d84
Right Bank
Existing Water Surface
Left Bank
0
0.5
1
1.5
2
2.5
3
0
5
10
15
20
25
30

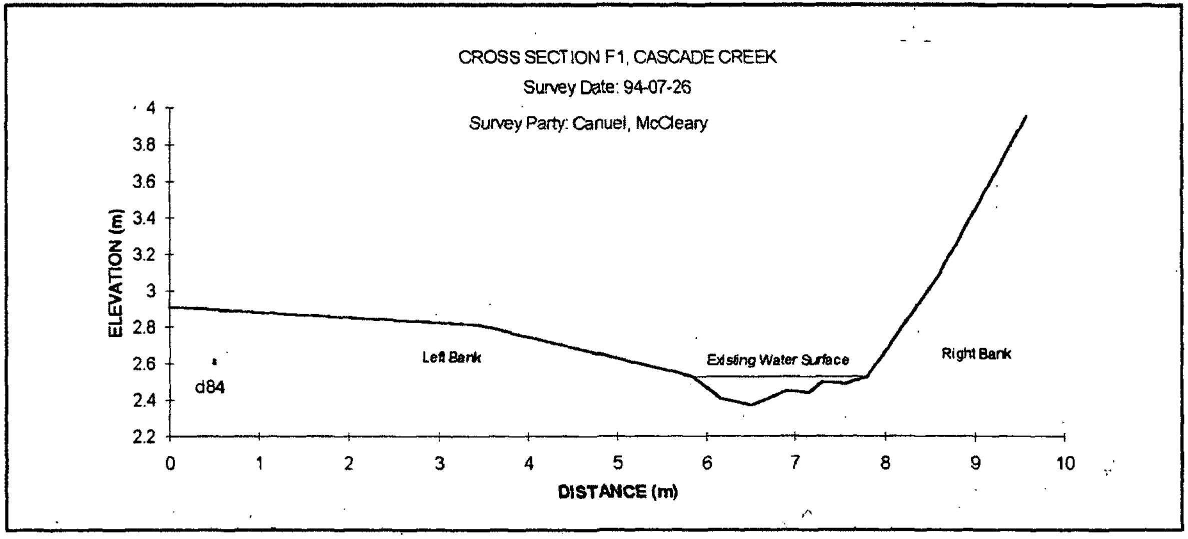

CROSS SECTION D3, CASCADE CREEK
Survey Date: 94-07-26
Survey Party: Canuel, McCleary
ELEVATION (m)
DISTANCE (m)
d84
Right Bank
Existing Water Surface
Left Bank
0
0.5
1
1.5
2
2.5
3
0
5
10
15
20
25

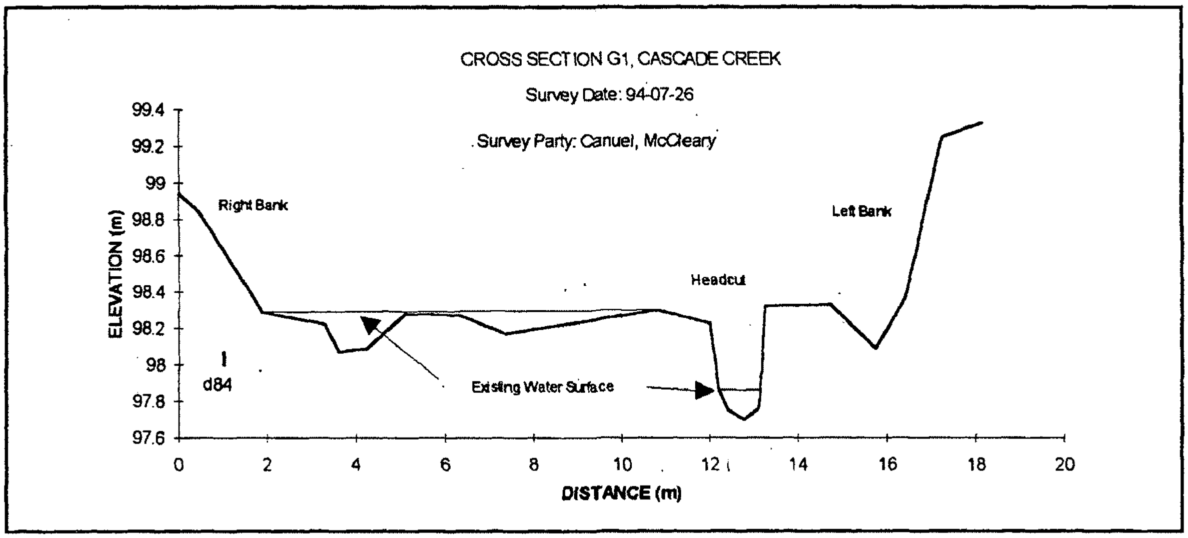

CROSS SECTION D4, CASCADE CREEK
Survey Date: 94-07-26
Survey Party: Canuel, McCleary
ELEVATION (m)
DISTANCE (m)
Left Bank
Right Bank
Existing Water Surface
d84
0
0.5
1
1.5
2
2.5
3
0
5
10
15
20
25

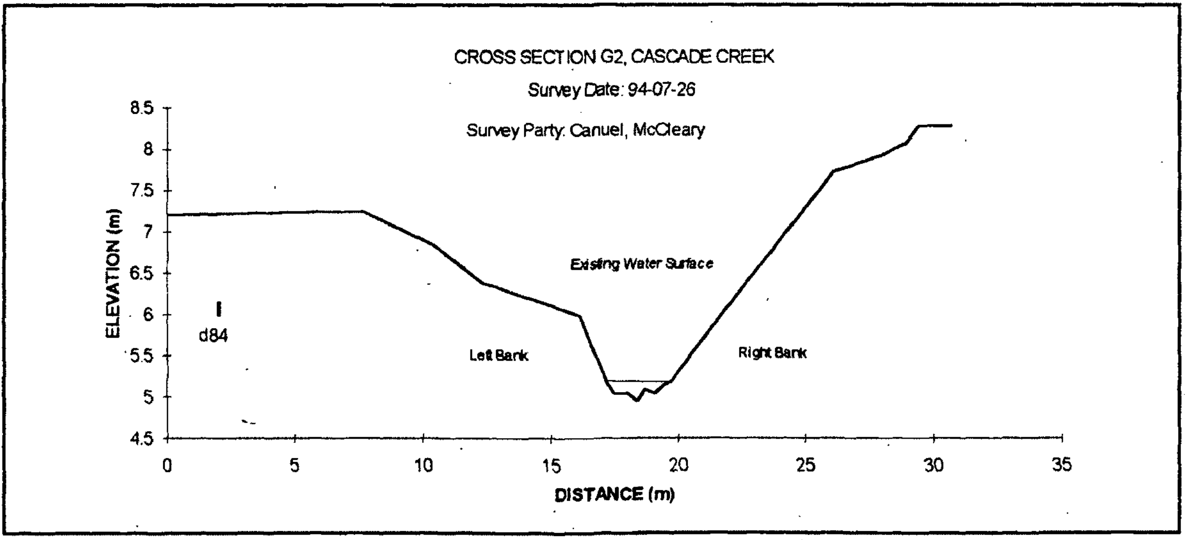

CROSS SECTION D5, CASCADE CREEK
Survey Date: 94-07-26
Survey Party: Canuel, McCleary
ELEVATION (m)
DISTANCE (m)
Left Bank
Right Bank
Existing Water Surface
d84
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
0
5
10
15
20
25
30
35
40
45
50

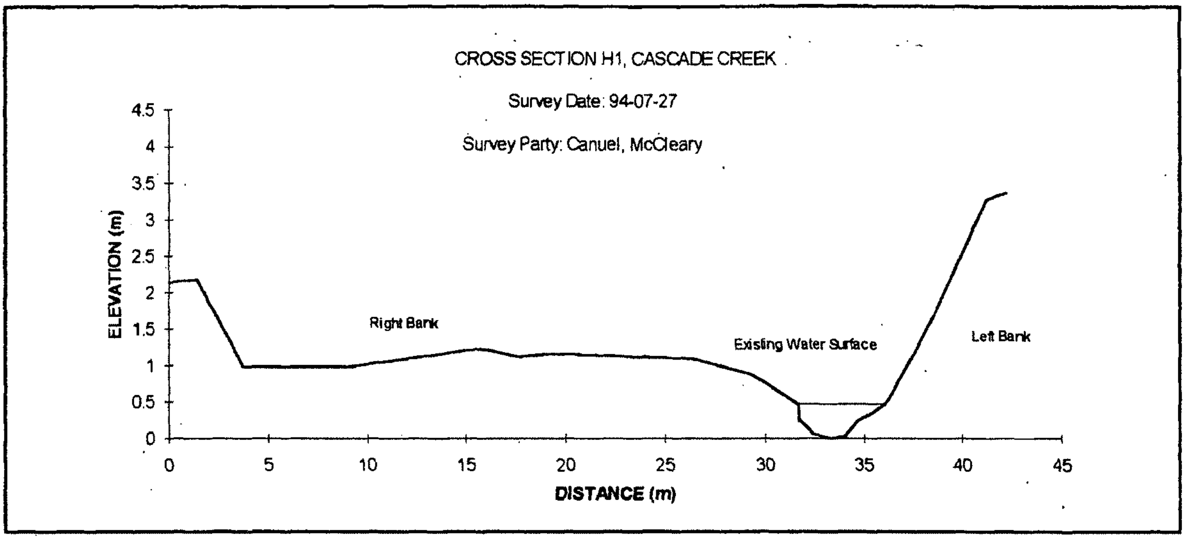

CROSS SECTION E1, CASCADE CREEK
Survey Date: 94-07-26
Survey Party: Canuel, McCleary
ELEVATION (m)
DISTANCE (m)
Right Bank
Left Bank
Existing Water Surface
d84
6.6
6.5
6.4
6.3
6.2
6.1
6
5.9
5.8
5.7
5.6
0
1
2
3
4
5
6
7
8
9

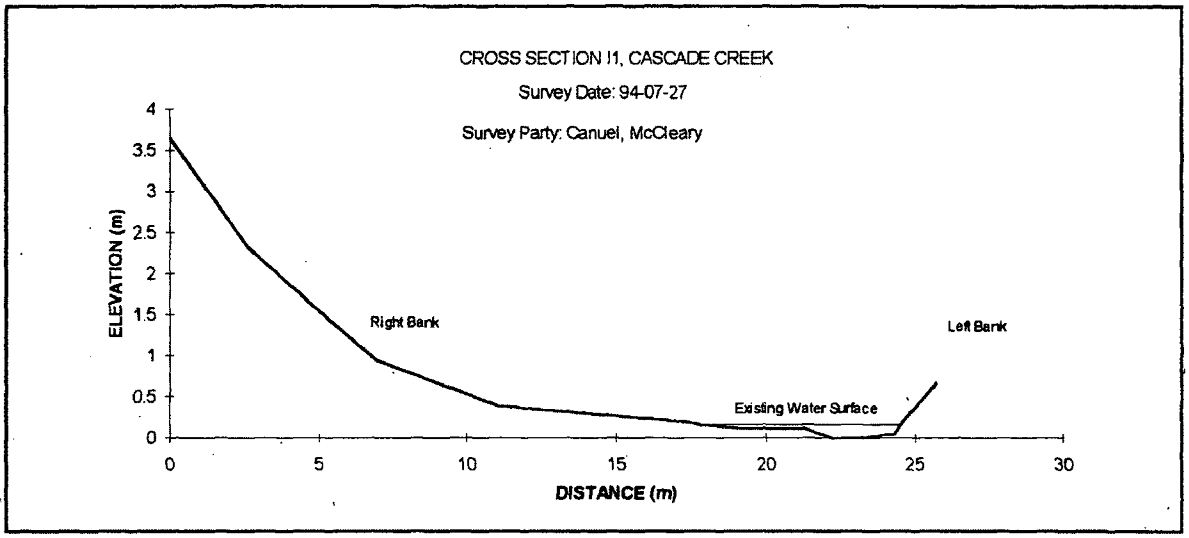

CROSS SECTION E2, CASCADE CREEK
Survey Date: 94-07-26
Survey Party: Canuel, McCleary
ELEVATION (m)
DISTANCE (m)
Right Bank
Left Bank
Existing Water Surface
d84
6.3
6.1
5.9
5.7
5.5
5.3
5.1
4.9
4.7
0
2
4
6
8
10
12
14
16

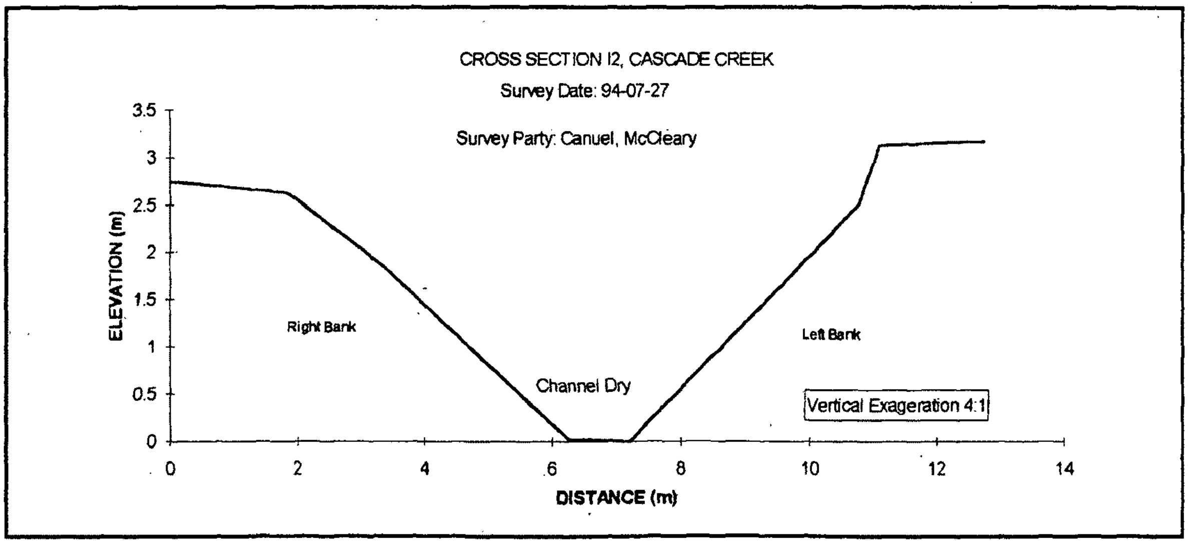

CROSS SECTION F1, CASCADE CREEK
Survey Date: 94-07-26
Survey Party: Canuel, McCleary
ELEVATION (m)
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
d84
Left Bank
Existing Water Surface
Right Bank
0
1
2
3
4
5
6
7
8
9
10
DISTANCE (m)

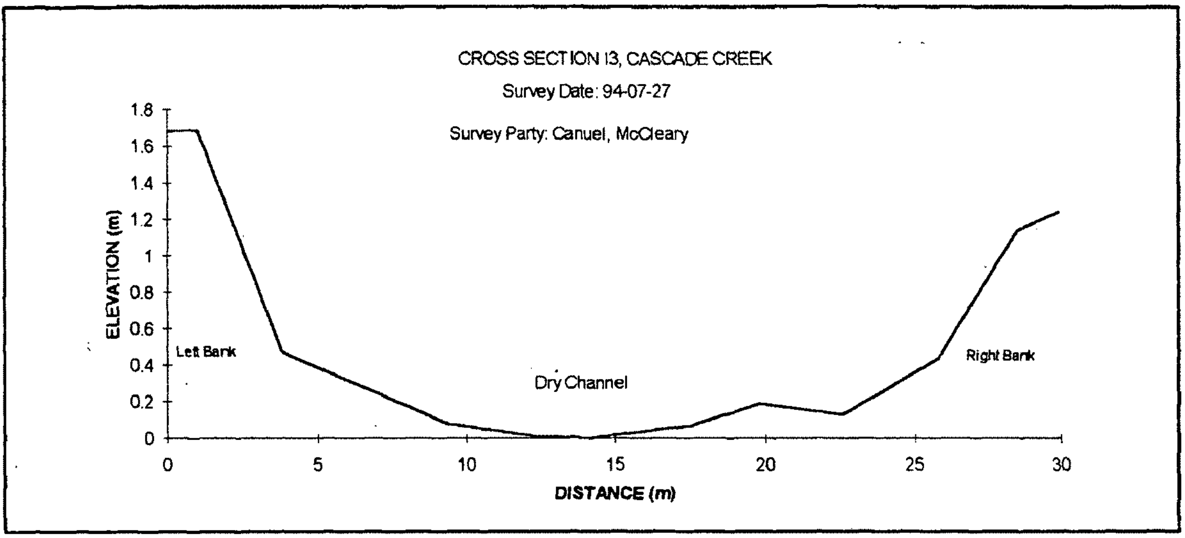

CROSS SECTION G1, CASCADE CREEK
Survey Date: 94-07-26
Survey Party: Canuel, McCleary
ELEVATION (m)
99.4
99.2
99
98.8
98.6
98.4
98.2
98
97.8
97.6
Right Bank
Left Bank
Headcut
d84
Existing Water Surface
0
2
4
6
8
10
12
14
16
18
20
DISTANCE (m)

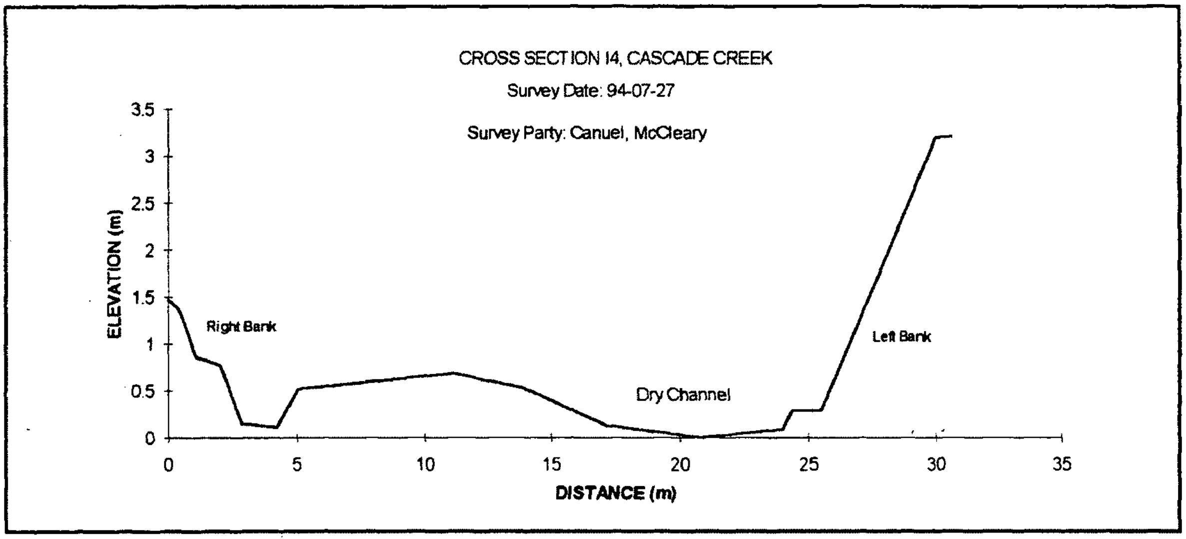

CROSS SECTION G2, CASCADE CREEK
Survey Date: 94-07-26
Survey Party: Canuel, McCleary
ELEVATION (m)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
Existing Water Surface
d84
Left Bank
Right Bank
0
5
10
15
20
25
30
35
DISTANCE (m)


CROSS SECTION H1, CASCADE CREEK
Survey Date: 94-07-27
Survey Party: Canuel, McCleary
ELEVATION (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Right Bank
Existing Water Surface
Left Bank
0
5
10
15
20
25
30
35
40
45
DISTANCE (m)


CROSS SECTION I1, CASCADE CREEK
Survey Date: 94-07-27
Survey Party: Canuel, McCleary
ELEVATION (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
Right Bank
Left Bank
Existing Water Surface
0
5
10
15
20
25
30
DISTANCE (m)


CROSS SECTION I2, CASCADE CREEK
Survey Date: 94-07-27
Survey Party: Canuel, McCleary
ELEVATION (m)
0
0.5
1
1.5
2
2.5
3
3.5
Right Bank
Channel Dry
Left Bank
Vertical Exageration 4:1
0
2
4
6
8
10
12
14
DISTANCE (m)


CROSS SECTION I3, CASCADE CREEK
Survey Date: 94-07-27
Survey Party: Canuel, McCleary
ELEVATION (m)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Left Bank
Dry Channel
Right Bank
0
5
10
15
20
25
30
DISTANCE (m)


CROSS SECTION I4, CASCADE CREEK
Survey Date: 94-07-27
Survey Party: Canuel, McCleary
ELEVATION (m)
3.5
3
2.5
2
1.5
1
0.5
0
Right Bank
Dry Channel
Left Bank
0
5
10
15
20
25
30
35
DISTANCE (m)

APPENDIX 4. SAMPLE SIZE SUMMARY FOR RIPARIAN POLYGONS

Station #	Polygon #	Vegetation Type	# of Plots	Area Sampled (m^2)
2	2-1	Shrub 1	1	2
	2-2	Herb 1	1	1
	2-3	Shrub 1	1	2
	2-4	Shrub 1	2	4
	2-5	Herb 2	1	1
3	3-1	Shrub 1	4	8
	3-2	Shrub 1	3	6
	3-3	Herb 3	4	2
	3-4	Shrub 1	1	2
	3-5	Shrub 1	3	6
	3-6	Herb 2	1	0.25
	3-7	Shrub 1	3	6
	3-8	Herb 3	1	0.25
	3-9	Shrub 1	4	8
4	4-1	Shrub 3	3	6
	4-2	Herb 4	1	2
	4-3	Herb 4	4	8
	4-4	Shrub 2	1	2
5	5-1	Dwarf Shrub 1	1	1
	5-2	Herb 2	1	1
	5-3	Herb 2	1	1
	5-4	Dwarf Shrub 1	1	1
	5-5	Herb 4	4	4

Scientific and Common Names of Vegetation Types
Shrub 1: *Picea glauca / Salix drummondiana* (white spruce / Drummond willow)
Shrub 2: *Ribes oxyacanthoides / Rubus ideaus* (northern gooseberry / red raspberry)
Shrub 3: *Salix spp. / Rosa acicularis / Equisetum arvense* (willow / prickly rose / horsetail)
Dwarf Shrub 1: *Dryas drummondii* (yellow dryad)
Herb 1: *Carex aquatalis* (water sedge)
Herb 2: *Deschampsia cespitosa / Epilobium latifolium* (tufted hairgrass / willow-herb)
Herb 3: *Equisetum variegatum / Tofeildia glutinosa* (northern scouring rush / sticky asphodel)
Herb 4: *Agrostis exerata* (spike redtop)

APPENDIX 5. CASCADE CREEK PLANT LIST

Note: The primary authority is Hitchcock and Cronquist (1991), except where (**M**) follows the name. In that case, Moss (1992) is primary authority.

EQUISETOPHYTA	
EQUISETACEAE	
Equisetum arvense	common horsetail
Equisetum variegatum	northern scouring rush
PINOPHYTA	
CUPRESSACEAE	
Juniperus communis	common juniper
PINACEAE	
Picea glauca	white spruce
Pinus contorta	lodgepole pine
Pseudotsuga menziesii	Douglas fir
MAGNOLIOPHYTA	
MAGNOLIATAE	
CAMPANULACEAE	
Campanula rotundifolia	Scotch bluebell
COMPOSITAE	
Achillea millefolium	common yarrow
Aster conspicuus	showy aster
Aster modestus	few-flowered aster
Cirsium arvense	Canada thistle
Taraxacum officinale	common dandelion
CORNACEAE	
Cornus canadensis	bunchberry
ELAEAGNACEAE	
Elaeagnus commutata	silverberry
Shepherdia canadensis	Canada buffalo-berry
ERICACEAE	
Arctostaphylos uva-ursi	kinnickinnick
Pyrola asarifolia	common pink wintergreen
LEGUMINOSAE	
Astragalus eucosmus	elegant milk vetch
Hedysarum alpinum	American hedysarum

Lathyrus ochroleucus	cream-flowered peavine
Oxytropis campestris	slender crazyweed
Trifolium repens	white clover
Vicia americana	American vetch
Vicia cracca	tufted vetch
LENTIBULARIACEAE	
Pinguicula vulgaris	common butterwort
ONAGRACEAE	
Epilobium latifolium	red willow-herb
POLYGONACEAE	
Polygonum viviparum	alpine bistort
RANUCULACEAE	
Anemone multifida	cliff anemone
Anemone parviflora	small-flowered anemone
Thalictrum occidentale	western meadow rue
ROSACEAE	
Amelanchier alnifolia	western serviceberry
Dryas drummondii	yellow dryad
Fragaria virginiana	strawberry
Potentilla fruticosa	shrubby cinquefoil
Rosa acicularis	prickly rose
Rubus ideas	red raspberry
RUBIACEAE	
Galium boreale	northern bedstraw
SALICACEAE	
Populus balsamifera (**M**)	balsam poplar (**M**)
Populus tremuloides	trembling aspen
Salix barclayi	Barclay's willow
Salix bebbiana	Bebb willow
Salix drummondii	Drummond willow
Salix melanopsis (**M**)	dusky willow
Salix myrtillifolia	blueberry willow
Salix pseudomonticola	mountain willow
SAXIFRAGACEAE	
Heuchera cylindrica	roundleaf alumroot
Ribes oxyacanthoides (**M**)	northern gooseberry

SCROPHULARIACEAE	
Castilleja miniata	common paintbrush
Pedicularis groenlandica	elephant's head
Rhinanthus crista-galli	yellow rattle
LILIATAE	
CYPERACEAE	
Carex aquatilis	water sedge
Carex gynocrates (**M**)	yellow bog sedge
Carex pauciflora	few-flowered sedge
Carex scirpoidea	Canada single-spike sedge
GRAMINEAE	
Agropyron repens	quack grass
Agropyron dasystachyum	thick-spiked wheatgrass
Agropyron trachycaulum (**M**)	slender wheatgrass
Agrostis exarata	spike redtop
Agrostis stolonifera	redtop
Calamagrostis canadensis	bluejoint reedgrass
Calamagrostis inexpansa	narrow-spiked reedgrass
Deschampsia cespitosa	tufted hairgrass
Elymus innovatus (**M**)	hairy wild rye (**M**)
Festuca rubra	red fescue
Glyceria pulchella (**M**)	manna grass (**M**)
Glyceria striata	fowl mannagrass
Hierochloe odorata	holy grass
Phleum pratense	common timothy
Poa compressa	Canada bluegrass
Poa pratensis	Kentucy bluegrass
JUNCACEAE	
Juncus balticus	Baltic rush
Juncus bufonius	toad rush
Juncus filiformis	thread rush
LILIACEAE	
Smilacina stellata	star-flowered Solomon's-seal
Tofieldia glutinosa	sticky asphodel
ORCHIDACEAE	
Habenaria hyperborea	northern green bog-orchid