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CHARACTER AND CONTROLS OF SUSPENDED-SEDIMENT CONCENTRATION AND DISCHARGE EFFECTIVENESS, FRASER RIVER, BRITISH COLUMBIA, CANADA

by

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B. A., Ed., University of Zambia, 1981

M. Sc., Simon Fraser University, 1986

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

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of

Geography

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Abstract

This study investigates the character of seasonal channel scour and fill regime in relation to suspended-sediment transport in the Fraser River. Magnitude/frequency characteristics of selected flow events are investigated in relation to the roles of effective discharge, threshold discharge for bed scour, and bankfull discharges in transporting suspended-sediment load. The study includes an analysis of the major factors controlling sediment variation for 49 single-valued linear and non-linear (concave and convex) and 122 hysteretic sediment rating curves for single hydrological events. Archival data for sediment, discharge and cross-section form collected by Water Survey of Canada from 1960 to 1988 are used for graphical analysis and for linear, non-linear and stepwise multiple regression models of sediment discharge.

Results of the analyses reveal that the effective discharge and threshold discharge for bed scour, which can be estimated from bankfull discharge or from drainage area, generally are 0.3 and 0.8 times bankfull discharge, respectively. Seasonal scour and fill regime in Fraser River shows a rapid lowering of the bed, caused largely by spring snowmelt, and progressive adjustment of the bed and suspended-sediment transport. A close relationship between scour and filling of the bed and sediment concentration is identified, especially when the threshold discharge and bankfull discharges are exceeded.

Three major factors are shown to control variations of suspended-sediment concentration reflected in sediment rating curves: hydrology, channel hydraulics and meteorological conditions. Hydrologically, variations in linear sediment curves are controlled by mean rising-discharge and rates of flood intensity (rising stage) and by mean falling-discharge and rates of flood recession (falling stage). For non-linear sediment rating curves, sediment concentrations are more related to rates of flood recession than to rates of flood intensity. Under high antecedent moisture conditions, quick runoff tends to rapidly increase sediment concentration closely related to discharge, producing linear curves, while under low antecedent moisture conditions, delayed increases in concentration produce non-linear sediment curves.

Hydraulically, sediment variation for linear rating curves are controlled by scouring of the bed (rising stage) and by channel filling (falling stages); concave curves by scouring in the rising stages and filling and re-scouring in the falling stages; and convex curves by filling and scouring in the rising stages and filling and re-scouring in the falling stages. In winter, timing of scouring and filling approximately coincides with the timing of precipitation, if any, in the rising and/or falling stages under sub-zero and low temperatures ($1 \leq T \leq 9\ ^{O}C$) or under moderate ($10 \leq T \leq 19\ ^{O}C$) temperature conditions.

Concepts of geomorphic and complex response are used to relate factors controlling sediment discharge for single hydrological events in a model predicting forms of sediment rating curves produced under different geomorphologic, hydrologic, hydraulic and meteorologic conditions.

Dedication

To my wife and children

Acknowledgements

I wish to thank my Senior Supervisor, Dr. E. J. Hickin, for his invaluable support and advise during the tedious process of writing this thesis. He provided me with inspiration and encouragement at all stages of my degree programme. Special thanks are due to my external examiner Dr. R. A. Kostaschuk for many enlightening suggestions and ideas of the character of suspended-sediment transport in the Fraser River basin.

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

This study investigates cause and effect relationships between sediment concentration and controlling physical factors on the Fraser River in British Columbia, Canada (Fig. 1.1). It is concerned with the processes governing the transport of suspended-sediment by rivers. In the sense that river scientists have given their attention to these questions of sediment transport for more than a century, the problems are not new (Hey, 1979). However, in the sense that many of the problems remain unresolved, the questions remain current and deserve further attention. Indeed, the slow progress in understanding the nature of sediment transport through rivers suggests that we are asking the wrong questions (The Task Committee for Preparation of Sediment Manual, Committee on Sedimentation of the Hydraulics Division (The Task Committee) ASCE, 1971).

Suspended-sediment transport by rivers is an important phenomenon to both science and river engineering. The science of fluvial geomorphology recognizes that the function of rivers is to transport both water and sediment from the land surfaces they access. In the sense that rivers appear to be adjusted to the imposed load of sediment and water, they are both a morphological expression of those impositions and a certain kind of measure of them. To understand how a river

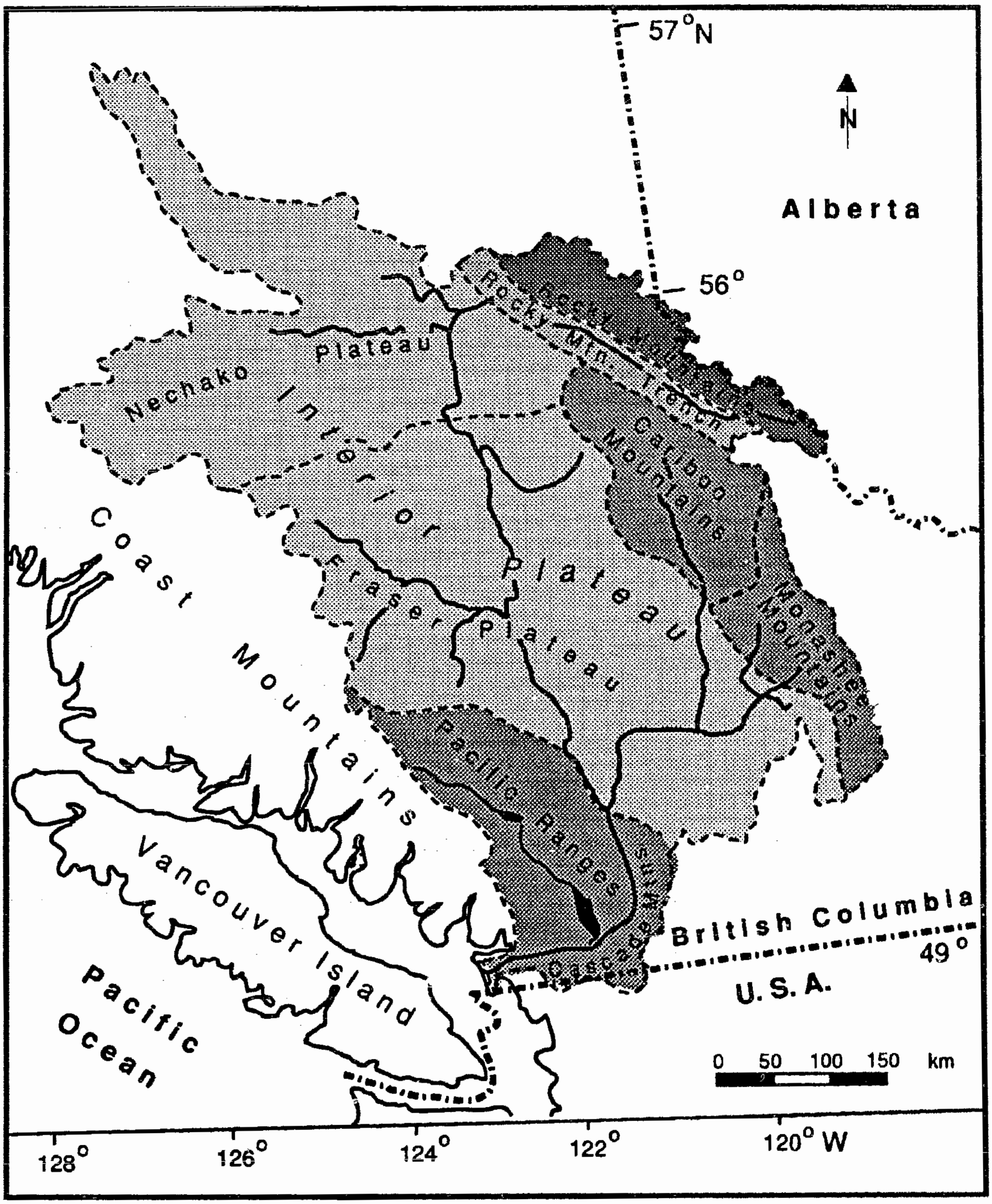


Fig. 1.1. The Fraser River Basin and its physiographic regions

transports sediment is to understand one of the most fundamental causes and effects of fluvial geomorphology.

Many previous studies have investigated relationships between discharge and sediment at annual and seasonal time scales (e.g., Gregory and Walling, 1973; Walling, 1977). In a majority of cases the relationship exhibits a wide scatter of points, especially for temperate streams characterized by snowmelt. In British Columbia, sediment transport is largely supply dependent (Church et al. 1989; Church and Slaymaker, 1990; Slaymaker 1977; 1987; Slaymaker and McPherson, 1977). The pattern of sediment yield in Fraser River reflects a number of controlling factors such as hydrology, geology and climate.

The notions of bankfull and effective discharges are particularly important in the understanding of the role various flow events play in geomorphology. This is because magnitude and frequency characteristics (Wolman and Miller, 1960) of flows are linked to the duration of bankfull discharge (Q_{bf}) as well as effective discharge (Q_{eff}). It is probable that there is a meaningful relationship (not yet established) between sediment transport and bankfull and effective discharge, and threshold discharge that is worthy of investigation. Effective discharge here refers to the mid-point discharge of a class, which, over a period of time transports a greater portion of suspended-sediment load than any other flow event. By threshold discharge is meant that discharge above which scour contributes local boundary sediment directly to suspended load.

The engineering and practical importance of fluvial sediment transport has many dimensions and hardly needs justifying here. For example, rates of river channel erosion and deposition are intimately related to sediment transport rates. The capacity of a river to sustain renewable sand and gravel mining or to fill in a reservoir, is a function of sediment transport. Natural disturbances and manufactured changes such as channelization lead to channel responses communicated from reach to reach by processes of sediment transport. The direct and indirect impacts of sedimentation on riparian activities of humans and their resources such as the fishery are documented elsewhere (ASCE, 1965; 1969; UNESCO, 1985).

It is the assumption of this study that, suspended-sediment transport also is controlled by channel hydraulic factors. Previous studies, for instance, Leopold and Maddock (1953) demonstrated that changes in hydraulic factors of width, depth and velocity with discharge downstream and at-a-station have a tendency of effecting quasi-equilibrium states in rivers transporting both water and sediment. Factors controlling sediment load and discharge are hydrology, geology and other physical characteristics of drainage basins. Accordingly, flood events generally transport relatively larger suspended-sediment loads than low flow events. In this way, channel quasi-equilibrium is maintained due to constant changes in velocity-depth relations and changes in bed roughness which is closely associated with suspended-sediment transport.

Additionally, for a river to remain in equilibrium it makes a wide range of hydraulic adjustments (Maddock, 1969). Better understanding of these adjustments (associated with changes in the size of sediment particles and/or changes in bed forms) demands that we investigate the relations of channel scour and fill and bank erosion with discharge using readily available cross-section data at appropriate space and time scales.

At a cross-section natural rivers maintain a dynamic equilibrium state when the flow along the bed has a sideways component up the channel banks which more or less exactly compensates the tendency of sediment to move downslope under the influence of gravity (Wilson, 1973: 393). Since cross-sections of rivers respond to changes in discharge, Wilson argues that the mean cross-profile (cross-section) of many alluvial rivers approximates equilibrium with the mean flow conditions. This reason could partly explain the equilibrium conditions that obtain in a river during the passage of single hydrological event. But river channel adjustments also depend on amount of sediment available for transport.

Since the Fraser River basin was glaciated, sediment supply in its valley is conditioned by paraglacial processes (Church and Ryder, 1972) which followed the retreat of the Fraser Glaciation and produced a system out-of-phase with present environmental conditions. In the contemporary period, river adjustments are largely controlled by events such as floods which effect erosion of bed and banks as well as causing the deposition of fine and coarse-grained sediments forming gravel bars and eventually islands.

Although hydraulic controls must be important, there also is strong evidence that supply limitations exert important controls on suspended-sediment transport rates. This thesis is concerned particularly with examination of the effects of sediment-supply limitation on the rate of suspended-sediment transport.

In order to enhance our understanding of sediment-supply controls in rivers, three questions are particularly important:

1. What are the general sources of sediment and why does supply vary?

2. What is the appropriate time scale to examine the linkage between suspended-sediment transport rates and controlling factors?

3. If short-term variability in suspended-sediment transport is evident, is it fully integrated at larger time scales so that concepts such as effective discharge remain viable?

1.2 Scope of Study

1.2.1 General Objective

The general objective of this study is to examine the nature of controls on the rate of suspended-sediment transport in rivers, with particular attention focused on the role of sediment supply during single hydrological events. The study is limited largely to reaches of the Fraser River for which suspended-sediment, hydraulic, and geomorphic data have been monitored by Environment Canada (Water Survey of Canada; WSC) for several years. Because of the large data processing task involved in analysing these WSC data, manageable subsets of the highest quality records were extracted in order to address specific issues.

In addition, the general pattern of discharge effectiveness for the reaches in question are examined in the light of findings related to individual hydrological events.

The thesis methodology, detailed in Chapter Three, essentially is inductive and exploratory in character although particular hypotheses are implicit in the examination of the role of channel scour and fill.

1.2.2 Specific Research Questions

In this thesis, the general objectives outlined above are subdivided into several basic research questions:

1. What is the nature of the relationships among discharge, suspended-sediment concentration, and channel scour and fill? The answer to this question involves deriving the scour/fill regime of the reaches in question over time scales from days to years.

2. What are the hydrologic, hydraulic and meteorologic factors that control the form of suspended-sediment rating curves for individual hydrological events? The answer to this question involves developing a classification of rating-curve form and a multivariate statistical analysis of the proposed controlling parameters.

3. If suspended-sediment load is measurably dependent on local scour, what are the frequency statistics of threshold discharge for bed scour? The answer to this question involves determining the discharge threshold and its return period.

4. What are the frequency statistics of effective discharge and how do they relate to the threshold discharge? The answer to this question involves comparing and contrasting the determined frequency statistics of the two concepts.

1.3. Organization of this Study

The following section outlines the theoretical background by reviewing pertinent literature on suspended sediment transport. Chapter Two describes the physical characteristics of the study area. Data and analytical methods employed are the subject of Chapter Three. The results are discussed in chapters Four through Seven. Each chapter deals with a different aspect of sediment transport for seasonal and single hydrological events: (1) the relations of channel bed scour and fill process to suspended-sediment transport in Chapter Four; (2) factors controlling the relationships (linear and non-linear) between suspended-sediment concentration and discharge for single hydrological events in Chapter Five; (3) controlling factors in the variations of suspended-sediment concentration for events exhibiting hysteresis in sediment-discharge relationships (simply referred to as hysteretic events) in Chapter Six; and finally (4) an analysis of the duration of the effective discharge for suspended-sediment transport, and the relationship between bankfull, effective discharges and the threshold discharges for bed scour in Chapter Seven. Chapter Eight summarizes and concludes the study.

1.4. Theoretical Background

1.4.1 River Channel Scour and Fill

Studies of scour and fill in alluvial streams are few and these include work in the Unites States by Leopold and Maddock (1953a; b), Colby (1964) and Andrews (1979), in Hungary by Laczay (1973) and in former Soviet Union by Mirtskhoulava (1973). Experimental streams have been examined by Alvarez and Alfaro (1973). Channel scour, which is the lowering of the stream-bed, is one of the important causes of some sediment related problems in rivers. For instance, scouring of river beds causes local erosion around bridge piers. Little is known about the processes of general scour and fill largely due to paucity of data. But the understanding of scour and fill processes can be enhanced through investigations of hydraulic adjustments to variations in discharge and sediment load (Andrews, 1980).

The basic principles involved in the explanation of scour and fill have been outlined by Colby (1964) for sand-bed streams. One of the principles is the continuity of sediment discharge along a stream reach. For a sand-bed stream, there is a balance between the volume of sand-size particles deposited on and removed from a sand bed. The other principle is that a relation exists among discharge of sand, characteristics of the flow, and the availability of sands. Colby (1964) argues that, if no such relation were to exist, the difference between the discharge of sands into and out of a channel reach would be wholly indeterminate except by measurement.

1.4.2 Relationship Between Suspended-Sediment Concentration and Discharge

Movement of suspended-sediment in rivers is often dependent more on supply than on flow conditions, thus it is not amenable to the application of hydraulic formulas. A graph showing the relationship between sediment concentration (mg L^{-1}) plotted as ordinate, and the river discharge ($m^3 s^{-1}$) plotted as abscissa, is known as a rating curve. In sediment studies, sediment rating curves are used for estimation and prediction of sediment loads in rivers. Previous studies of sediment-discharge relationships have focused on seasonal or annual time scales (Gregory and Walling, 1973; Walling, 1977; Thompson, 1987). However, sediment rating curves of many rivers show a wide scatter of points indicating that suspended sediment concentration is not a single-valued function of discharge. In addition, the relationships between sediment concentration and discharge for most temperate streams with significant snowmelt are generally non-linear.

But the problem of sediment transport in rivers is generally complicated by both lateral and vertical variation of sediments in the cross-section, different rates of transport for different sediment sizes, and large variations in hydraulic factors such as depth, velocity, turbulence, and other flow parameters across a stream. Therefore, single measurements such as average depth, mean velocity or median particle sizes are, to some extent, unsatisfactory indices of conditions for a cross section (Colby, 1964). The bed over which the river flows varies from smooth to rough surfaces, and is generally characterized by dunes and sometimes antidunes; the bed configuration varies laterally, longitudinally and with time.

The processes of erosion and sediment transport are not well understood. In regions where seasonal variations in erosion processes and source areas are controlled by floods generated by spring snowmelt and summer storms, seasonal variation in sediment yields may mask any relationship with discharge (Walling, 1988). As a result, the transport of these sediments is controlled by a host of factors linked to channel conditions and catchment characteristics. Long-term estimates of fluvial sediment yield generally are based on annual records of sediment transport. In the Fraser River basin, however, seasonal and annual rating curves do not adequately characterize suspended-sediment loads (Carson, 1988; Church et al. 1985; Thompson, 1987; Thompson et al. 1988; Zrymiak and Tassone, 1986).

1.4.2.1 Suspended-Sediment Transport for Single Hydrological Events

The major problem of river studies to date is the lack of knowledge of river behaviour and what causes channel changes. This problem may be broken down into a number of specific problems some of which are discussed below. The Task Committee (ASCE, 1971) has asserted that river systems and river processes are so complex that there is not even general accord on which aspects are causes and which are effects. The Task Committee ascribed this confusion to, among other factors, the failure to distinguish between long- and short-term behaviour of rivers and between single-valued and multiple-valued (hysteretic) relationships between sediment concentration and discharge. The understanding of these distinctions and their implications for sediment transport is a prerequisite to increasing knowledge of river channel processes.

Sediment-discharge relationships for single hydrologic events have been previously investigated (Guy, 1964; Wood, 1977; Marcus, 1989; Loughran, 1974; Klein, 1984; Williams, 1989) and variations in sediment concentrations were attributed to exhaustion and replenishment of sediment supplies, differences in travel distances between source areas and locations of measuring stations, locations of sediment source areas, and to the existence of time lag between sediment concentration and discharge peaks.

Examples of single-valued relationships between sediment concentration and discharge have been reported by Arnborg et al. (1967) in Alaska and Wood (1972) in England. Williams (1989) developed models for single-valued relations (linear and curved) for single hydrological events by comparing sediment concentration (C) and discharge (Q) ratios at a given discharge on the rising and falling limbs of discharge hydrographs. Although Williams (1989) summarized the physiographic and hydrological reasons for the existence of each type of single-valued relationships in sediment rating curves, only partial understanding of controlling factors exists. He concluded that C-Q relations are influenced by precipitation intensity and its areal distribution, runoff amount and rate, floodwater travel rates and travel distances, and spatial and temporal storage-mobilization-depletion processes of available sediment.

However, an adequate understanding of the complexity of short-term river processes demands that, channel hydraulic relations associated with single-valued relationships be distinguished from hysteretic relationships between sediment concentration and discharge. Although single hydrological events sometimes lasting from days to weeks have received little attention in the past, their shorter duration and smaller areal coverage involved reveal greater detail of channel processes than events of longer durations and covering much larger areas. Single hydrological events also have the advantage of being able to isolate complex sediment generating and delivery processes observed in events of longer time scales.

In a storm-period time scale, channel variables can be considered as independent of sediment load or of discharge in influencing the hydraulics of the channel (Schumm and Lichty, 1965). However, channel response to changes in discharge even during a brief time span is complicated by short-term changes in variables such as depth or velocity because these variables assume roles of dependent variables at one time and that of independent variables at other times. The effects of such role reversals are complicated sediment-discharge relationships not easily deciphered. Therefore, better understanding of factors controlling sediment variation in single hydrological events is required.

Analyses of the character of suspended sediment transport for individual hydrological events have been reported in many studies (Kennedy, 1965; Carson et al. 1973; Wood, 1977; Walling, 1974; 1982). Paustian and Beschta (1979) and Loughran (1974) found higher concentrations of suspended sediments during rising limbs of storm hydrographs than on the falling limbs. This variation in sediment concentrations was attributed partly to the disturbance of stream-bed armour during the rising and subsequent reformation of armour somewhere near the hydrograph peak (Paustian and Beschta, 1979) and to the exhaustion and replenishment of sediments (Leopold and Maddock, 1953; Wood, 1977) on the rising and falling limbs, respectively. Despite this linkage, no detailed investigation has been specifically conducted to ascertain the relationship between stream-bed scour and sediment transport for single hydrological events.

1.5 Magnitude and Frequency Analysis of Sediment Loads

1.5.1 Patterns of Suspended-Sediment Yields

The literature on patterns of sediment yield is extensive (Milliman and Meade, 1983; Gregory and Walling, 1973) and has been reviewed by Webb and Walling (1983). In Canada, studies on sediment yields include works by Robinson (1972), Stichling (1973) and Dickinson and Wall (1977). For British Columbia, patterns of sediment yields have been investigated by Slaymaker (1972; 1977; 1987), Slaymaker and Mcpherson (1977) and Kellerhals (1979). More recently, Church et al. (1989) and Church and Slaymaker (1989) have analysed the suspended sediment data for British Columbia to test the conventional model of declining sediment yields with increasing drainage area.

The conventional model was found not to be relevant to British Columbian rivers because specific sediment yield increases with drainage area at all scales from 10 000 km^2 up to 30 000 km^2. In the conventional model, sediment yields decline downstream due to deposition along the channels of a portion of the load from erosion of the land surface. But in British Columbia, Church et al. (1989) argued that river sediment is recruited from erosion along the valleys of the rivers and that net recruitment downstream continues at a rate greater than that of the increase in drainage area. Does the effective discharge for suspended-sediment transport reflect this pattern of supply on the Fraser River?

1.5.2 Effective Discharge for Suspended-Sediment Transport

The concept of magnitude and frequency characteristics of river loads was introduced to geomorphology by Wolman and Miller (1960). This classical work was followed by studies which emphasized the effectiveness of fluvial events in modifying landscapes (e.g. Gupter and Fox, 1974; Baker, 1977; Wolman and Gerson, 1978; Anderson and Calver, 1980; Beven, 1981; Sichingabula, 1986; Hickin and Sichingabula, 1988; 1989) rather than their role in removing material from river systems. Some studies investigated the magnitude and frequency characteristics of sediment transport in rivers (Webb and Walling, 1982; 1984).

Wolman and Miller (1960) argued that the amount of sediment transported by flows of a given magnitude depends upon the form of the relationship between discharge and sediment load as well as on the frequency distribution of the discharge events. Using suspended sediment data they showed that the largest portion of the total load is carried by flows that occur once or twice per year on the average. Ashmore and Day (1988) observed that the concept of a simple effective discharge was not applicable to Saskatchewan streams and that, in many cases, the effective discharge histograms were not the simple unimodal distributions envisaged by Wolman and Miller (1960) but rather had complex forms sometimes having peaks of similar magnitude at two or more discharges with quite different durations. Earlier studies which arrived at similar conclusions include Leopold et al. (1964) and Benson and Thomas (1966).

These findings suggest that the concept of effective discharge requires further testing or modification for application to streams in different regions.

1.5.3 Bankfull Discharge

Bankfull discharge, simply defined as the flow which just fills the cross-section of an alluvial channel without overtopping the banks (Richards, 1982), was linked to effective discharge by Woman and Miller (1960) when they defined it as the flow which performs most work in terms of sediment transport. The link between dominant and effective discharge was based on the apparent consistency in the frequency with which bankfull discharge occurs along streams and on the approximate correspondence between the frequency of bankfull discharge and the frequency of that flow which cumulatively transports most sediment (Wolman and Miller, 1960).

The link between bankfull and effective discharge is established by their approximate recurrence intervals of 1 to 2 years. But Knighton (1987: 94) notes that this link is limited in a number of respects which include the lack of a consistent method of specifying the bankfull channel. Bankfull is not necessarily of constant frequency even within a single basin (Leopold et al. 1964) and bankfull discharge may not be the most effective flow for sediment transport (Pickup and Warner, 1976). Therefore, river channel forms must be the product, not of a single formative discharge, but of a range of discharges which may include bankfull and effective discharges.

This brief review of literature on different aspects of sediment transport in rivers has highlighted a number of research problems; contributing to their resolution constitutes the objectives of this study.

CHAPTER TWO

DESCRIPTION OF THE STUDY AREA

2.1 Physical Characteristics of the Fraser River Basin

The Fraser River basin is composed of mountain ranges, plateaus, deep valley floors and coastal lowlands. Descriptions of the geology and geomorphology of these zones are found in various sources, including Holland (1964), Fulton (1969), Janes (1976) and Douglas et al. (1976).

Fraser River flows from the western slopes of the Rocky Mountains and flows northwesterly through the Rocky Mountain Trench, skirts the northern tip of the Columbia Mountains and cuts diagonally southward across the Interior Plateau in a deeply incised channel before turning westward past the southern end of the Coast Mountains to enter the Strait of Georgia at the southwest corner of British Columbia (Fig. 1.1, 2.1). It drains a total area of 219 000 km^2 (reduced from 233 000 km^2 by completion of the Kenney Dam in 1952). The Fraser River basin is characterized by four major physiographic regions, namely: the Coast Mountains to the southwest, the Interior Plateau subdivided into the Fraser Plateau, to the south, and the Nechako Plateau to the north, and the Eastern Mountains consisting of the Rocky and Columbia Mountains (Fig. 1.1) (Holland, 1964).

The Coast Mountains region is characterized by massive granitic plutons or folded volcanic and sedimentary rocks intruded by scattered plutonics. Volcanic activity in this region has produced high-relief and

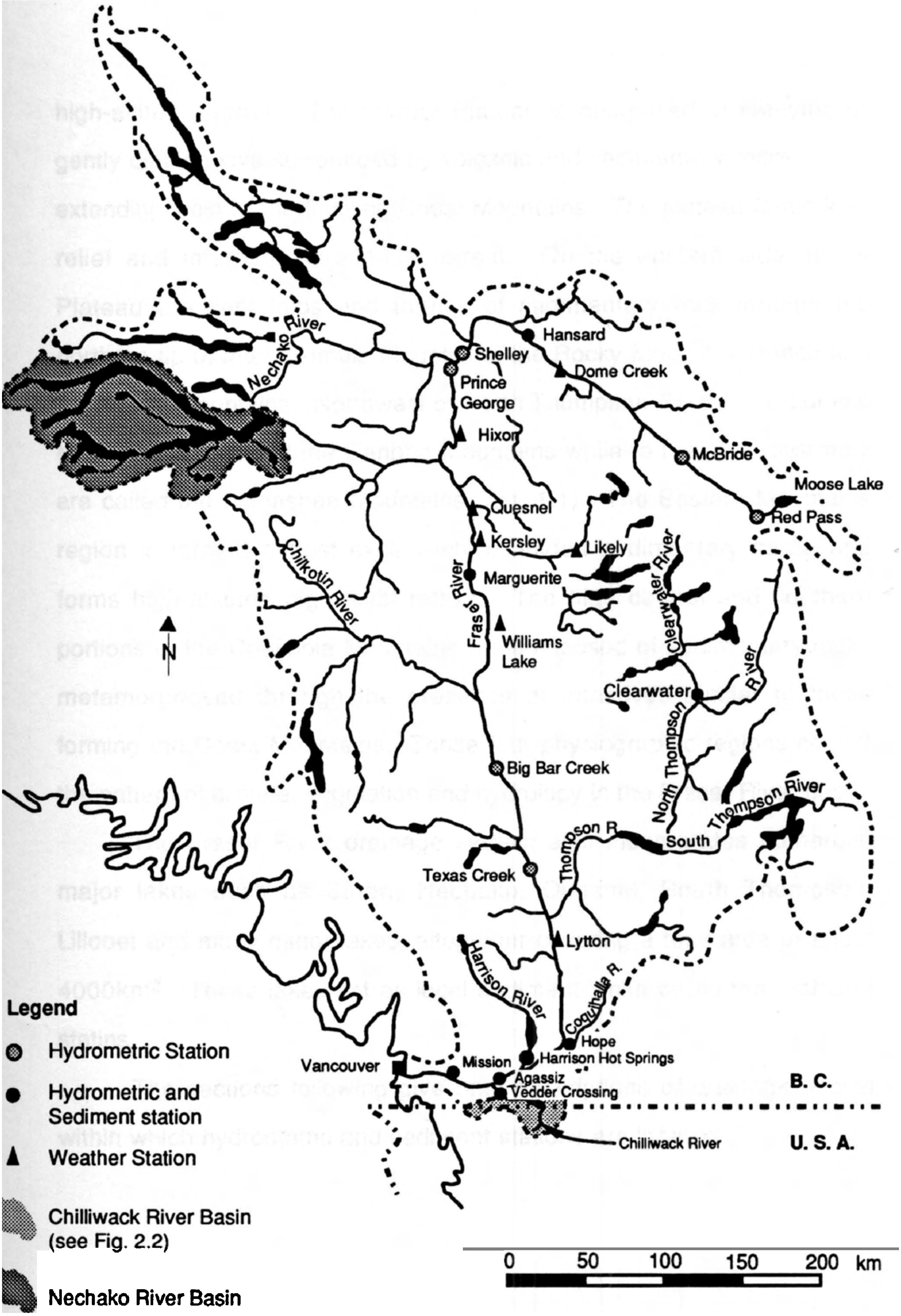


Fig 2.1. Hydrometric and weather stations in the Fraser River basin.

high-altitude terrain. The Interior Plateau is composed of flat-lying or gently dipping lava surrounded by volcanic and sedimentary rocks extending west to the flanking Coast Mountains. The plateau forms low-relief and intermediate-altitude terrain. On the eastern side of the Plateau are vast folds and thrusts of sedimentary rock forming the northern tip of the Columbia Mountains, the Rocky Mountain Trench and the Rocky Mountains. Northwest of North Thompson River the Columbia Mountains are called the Cariboo Mountains while to the southeast they are called the Monashee Mountains (Fig. 1.1). The Eastern Mountains region is formed almost exclusively of folded sedimentary strata and forms high-altitude high-relief terrain. The high central and southern portions of the Columbia Mountains are composed of sedimentary rocks metamorphosed through the presence of intrusives similar to those forming the Coast Mountains. These four physiographic regions control the pattern of climate, vegetation and hydrology in the Fraser River basin.

The Fraser River drainage system also incorporates numerous major lakes such as Stuart, Nechako, Quesnel, South Thompson, Lillooet and many minor lakes, altogether covering a total area of about 4000km^2. These lakes act as local sediment sinks within the drainage statins.

The sections following give brief descriptions of drainage basins within which hydrometric and sediment stations are located.

2.1.1 Fraser River Sub-Basins with Sediment Stations

For the purposes of this study, the main channel of the Fraser River is divided into the upper, middle and lower river sub-basins. The physical characteristics of these basins, including those for Chilliwack and Clearwater River, are discussed below.

2.1.1.1 Upper Fraser River Sub-Basin

The upper Fraser River basin is the catchment upstream of Hansard station (Fig. 2.1). In this region the Fraser River has many meanders as it travels in the northwesterly direction through the Rocky Mountain Trench. draining an area of 2 100 km^2 upstream of Grand Canyon located between Hansard and Shelley stations. The floor of the 3-15 km wide trench is composed of lacustrine silts, outwash and aeolian sands and gravels to great depths. The steep walls are largely composed of folded sedimentary rocks of the Rocky Mountains, except in the eastern portion of the sub-basin where the Fraser River roughly forms the northeastern boundary of the broad region of metamorphic rock extending from its source. Moose Lake with an area of about 1.5 km^2 traps most of the sediment originating from the upstream 100 km of channel. A sediment station in the upper Fraser River basin is located at Hansard.

2.1.1.2 Middle Fraser River Sub-Basin

The middle Fraser River basin, located between Hansard and Hope stations, is drained by the Nechako River which joins the Fraser River at Prince George, Chilkotin, and Thompson Rivers. A portion of the flow from the Nechako River basin has been diverted to the Nass River system after the construction of Kenney Dam. The bedrock of the plateau portion of the Nechako River basin is composed of volcanic and sedimentary rocks which form the greater part of the interior highland while igneous rocks of the Coast batholith form the western fringe.

Other major tributaries in the Middle Fraser River basin include the Quesnel and Thompson rivers which drain the Columbia Mountains and join the Fraser River from the east at central and southern points in the Interior Plateau. The western slopes of the Rocky Mountains are drained by McGregor River which joins the Fraser downstream of Hansard and east of Prince George. The other major tributary in the Middle Fraser River basin which drain the Coast Mountains is the Chilkotin River. The sediment station representative of the middle Fraser River basin is the Marguerite station on Fraser River located between Quesnel and Williams Lake town (Fig. 2.1).

2.1.1.3 Lower Fraser River Sub-Basin

In the lower Fraser River basin, major tributaries include Lillooet-Harrison and Pitt Rivers which drain the Pacific Ranges while the Chilliwack-Sumas River drains the Cascade Mountains. From Hope to the mouth, Fraser River has an average width of 650 m and expands up to about 1 km in some areas. In the lower Fraser Valley, the spring freshet deposit vast amounts of coarse material, creating numerous gravel bars and constantly changing channel conditions, especially downstream of Agassiz (Mclean, 1990). To the north and south of the lower Fraser River are igneous rocks of the Coast and Cascade Mountains. Most of the area is made up of unconsolidated sediments consisting of clays and silts, offshore marine deposits, sands and gravels, which are either outwash or post-glacial stream and river deposits. The tills also found in the area were laid down during advances of Wisconsinan glaciation, of which the last is believed to have receded about 11 000 years BP (Clague et al. 1980; Armstrong, 1981 Saunders et al. 1987).

Sediment stations in the lower Fraser River are located at Hope, Agassiz and Mission on the Fraser River, Harrison Hot Springs on the Harrison River, Silverhope Creek near Hope and at Vedder Crossing on the Chilliwack River (Figs. 2.1; 2.2).

2.1.1.4 Chilliwack River Sub-Basin

The Chilliwack River, located within a humid temperate region, has a drainage basin of 1230 km^2 and is 51 km in length. Its valley is underlain by Triassic and Jurassic pelite and sandstone (Cultas Group), Pennyslvanian and Permian basic rocks such as pelite, sandstone and limestone (Chilliwack Group) as well as Tertiary granodiorite and quartz diorite rocks (Monger, 1970). The surficial geology of the Chilliwack

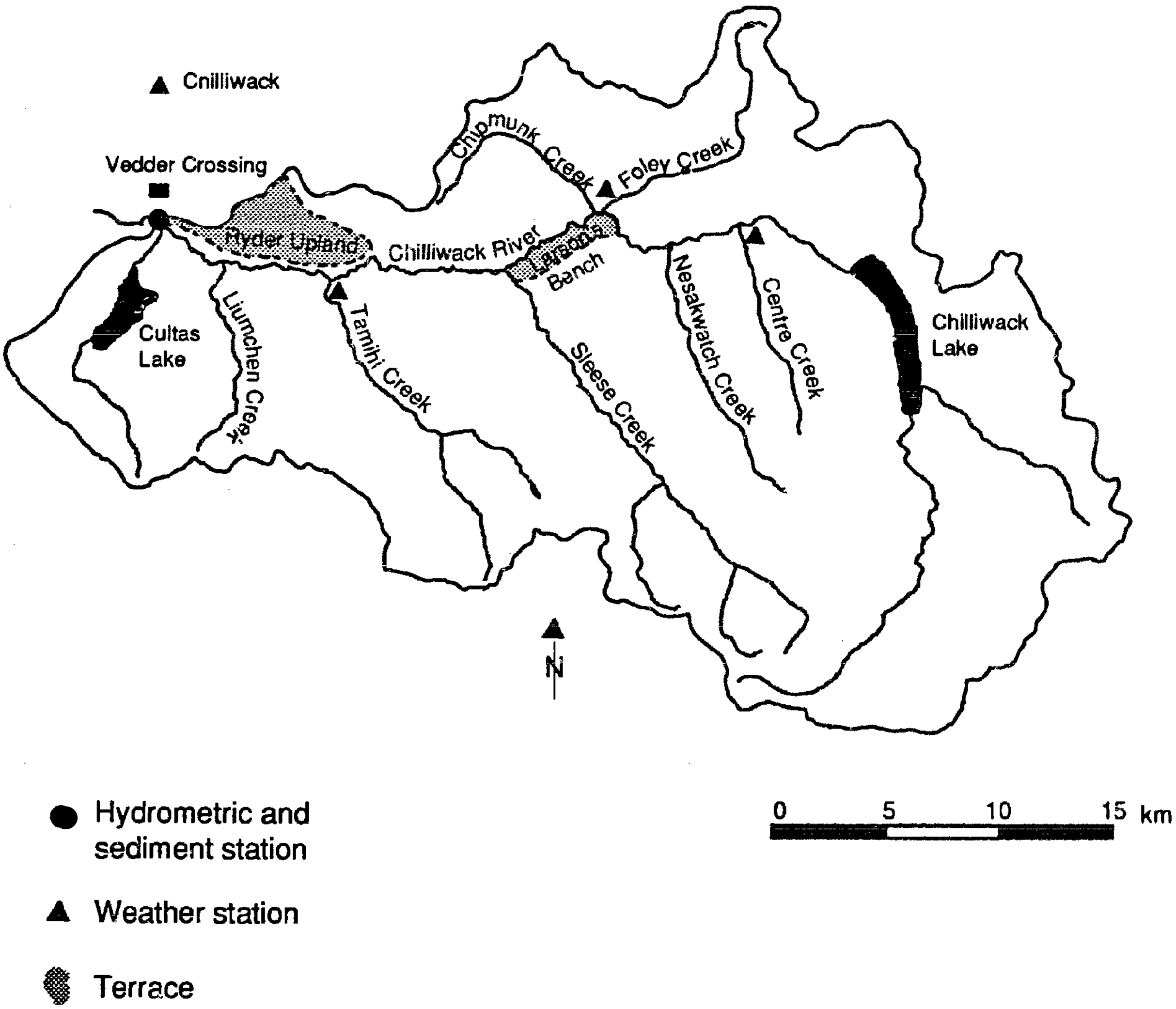


Fig. 2.2. Hydrometric and weather stations in the Chilliwack River basin.

River Valley is composed of glaciofluvial sediments which include gravel, sand and silt and diamicton deposited at the end of the Fraser Glaciation, about 11 000 years BP (Clague et al. 1980; Armstrong, 1981; Clague, 1981; Saunders, 1985; Saunders et al. 1987).

The drainage system of the Chilliwack River includes Chilliwack Lake (621 masl) and several tributary streams such as Foley, and Chipmunck Creeks which join it from the north while Centre, Nesakwatch, Sleese, Tamahi and Liumenchen Creeks enter it from the south (Fig. 2.2). The hydrological regime of the Chilliwack River has a seasonally bimodal distribution of runoff, with the first peak occurring in late spring - early summer (snowmelt) and the second in autumn - early winter (rainfall) (Saunders, 1985). A hydrometric and sediment station on the Chilliwack River is located near the mouth of the basin at Vedder Crossing.

2.1.1.5 Clearwater River Sub-Basin

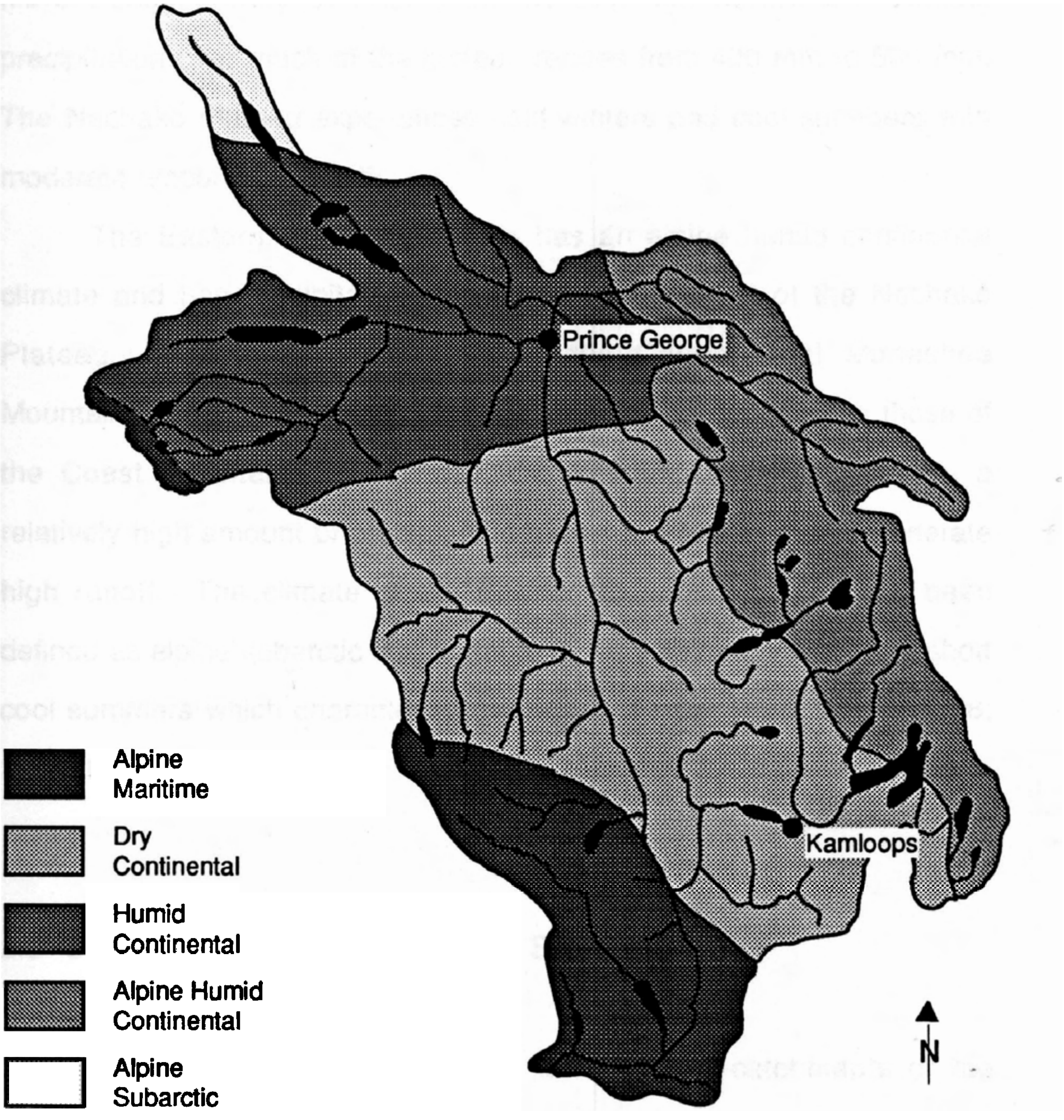
The Clearwater drainage system, which forms part of the headwaters region of North Thompson River, has an area of 1 420 km^2. It is located within Columbia Mountains where lithologies range from metamorphic, through sedimentary and volcanic rocks to granite. The Cariboo Mountains are principally composed of quartzite while in the Monashees foliated gneisses are widespread. The sediment station in this sub-basin is located near Clearwater above the junction of Clearwater and North Thompson Rivers (Fig. 2.1).

2.2 Climate

The climate of parts of the Fraser River basin in British Columbia has previously been described by Kendrew and Kerr (1955), Meteorological Branch (1967), Environment Canada (1982), Hare and Thomas (1974) and Phillips (1990). The varied physiography of this region together with the influence of the prevailing westerly winds and the movement of high and low pressure systems control rainfall distribution. For instance, the western border region receives the highest mean annual precipitation (>3500 mm), interior south-central areas receiving the lowest (<400 mm) while northern plateaus receive moderate amounts (400-1000 mm). The Fraser River basin, like most of British Columbia, lies within the Temperate Zone, at high elevations are found alpine conditions while semi-arid conditions exist in the Central and Southeastern areas. In general, climatic regions of the Fraser River conform to the major physiographic regions, viz.: Coast Mountains, Fraser Plateau, Nechako Plateau and the Eastern Mountains (Fig. 2.3).

The Coast Mountains have an alpine maritime climate characterized by high annual precipitation (greater than 3500 mm) and relatively moderate temperatures at intermediate elevations throughout the year. A large proportion of Fraser River runoff comes from this region and a very heavy snowpack sometimes accumulates in winter. In contrast, based on valley data the Fraser Plateau with a dry continental type of climate receives less than 750 mm of annual precipitation due to the rain shadow effect of the Coast Mountains. The runoff from the Fraser Plateau is small and the area has cold winters and mild summers.

The Nechako Plateau is characterized by a humid continental type



Source: Fraser River Board (1963)

Fig. 2.3. Climatic regions of the Fraser River basin.

of climate. A break in the Coast Mountains, the Skeena Saddle, permits more frequent entry of Pacific storms from the northwest. Annual precipitation over much of the plateau ranges from 400 mm to 500 mm. The Nechako Plateau experiences cold winters and cool summers with moderate amounts of runoff.

The Eastern Mountains region has an alpine humid continental climate and has precipitation much heavier than that of the Nechako Plateau. Substantial snowpacks in the Cariboo and Monashee Mountains occur each winter, although they are not as deep as those of the Coast Mountains. Generally, the Eastern Mountains receive a relatively high amount of precipitation (500 mm-2500 mm) and generate high runoff. The climate of the Eastern Mountains region has been defined as alpine subarctic due to the long, very severe winters and short cool summers which characterize the region (Fraser River Board, 1956: 2-22; 1963).

2.3 Sources of Suspended-Sediment Supply

Major sources of sediment in different sub-catchments of the Fraser River system are cutbanks and landslides which occur along many parts of the Fraser River and its tributaries. Most of the sediments in the valley are glacial deposits. The transport of most of these sediments have been conditioned by paraglacial processes that followed glacial episodes (Clague, 1986; Church and Ryder, 1972). For the purposes of this study only those sites along the main stem of Fraser and Chilliwack Rivers will be briefly discussed below.

2.3.1 Upper Fraser River Sub-Basin

In the upper Fraser sub-basin, most of the sediment coming from upstream is deposited in Moose Lake immediately upstream of Red Pass gauging station (Fig. 2.1). As a result, almost all of the sediment reaching Hansard sediment station is recruited downstream of this lake. Field observations of geomorphological features and information obtained from 1: 250 000 topographical sheets indicates that most of the sediment in the upper Fraser basin comes from the reach located about 12 to 23 km downstream of Moose Lake. Mt. Robson, the highest peak in the Rocky Mountains is located in this reach (hereinafter called "Robson Reach") is a major source of clastic sediments carried by the Fraser River. The evidence for this is in the width of the river which is wider than in the upstream and downstream reaches. The increased width of Robson Reach is due to the deposition of large quantities of bed-material load cascading down Robson River which originates from the flanks of Mt. Robson and Swiftcurrent Creek (another major source of sediment supply. The channel bed of Robson Reach is composed of unconsolidated materials ranging from fines, readily entrained as suspended load, to gravels moved as bedload. Most of these sediments come from landslides and from melting glaciers at high elevations.

Although suspended-sediment continues to be recruited by the Fraser River between Robson Reach and Hansard, due to collapse of cutbanks and bed erosion, it likely is small compared to that coming from upstream. The next major source of suspended-sediment are in the middle Fraser River basin between Hansard and Marguerite sediment stations.

2.3.2 Middle Fraser River Sub-Basin

In the middle Fraser River sub-basin most of the sediment are recruited downstream of Grand Canyon near Giscome located about 40 km upstream of Shelley (Fig. 2.1). In this reach, there are also a number of tributaries which supply large quantities of sand and gravel to the Fraser River. Such tributaries include the McGregor River which joins the Fraser River downstream of McBride, the Salmon River at 10 km upstream of Shelley, and the Nechako River enters the Fraser River at Prince George. All these rivers enter the Fraser from the right bank, facing in the downstream direction. These rivers are excavating deep valley fill.

Perhaps most of the local sources of sediment are extensive cutbanks stretching for about 4 km along Fraser River, located 8 km downstream of Prince George. These cutbanks occur around the confluences of the Haggish and Tabor Creeks and on both banks of the Fraser River. In fact, the entire stretch of the river between Prince George and Quesnel is susceptible to bank erosion because of the existence of large quantities of glacial and glaciolacustrine sediment in the river valleys (Evans, 1982; Clague, 1987; 1988). Some of the sediments originate from a braided reach located upstream of Quesnel. In this reach, the gradient of the river is higher than on the upstream and downstream reaches such that it erodes its bed and banks with vigour as well as transporting large quantities of sediment supplied from the upstream.

The last major local source of suspended-sediment north of Marguerite is the braided reach 23 km in length located 12 km upstream of Marguerite station. This braided reach, with an average width of 790 m, is composed of gravel bars and islands. During rising flows this braided reach is capable of supplying large quantities of sediment deposited by receding flows in the summer and winter months. Consequently, it is expected that sediment concentrations will greatly increase at the onset of snowmelt and during individual hydrological events due to existence of large quantities of unconsolidated sediments within the Fraser River channel.

The character of Fraser River described above remains essentially the same downstream of Marguerite to about Lytton which is upstream of the Fraser River Canyon. The next section discusses source areas of suspended-sediment in the lower Fraser River sub-basin.

2.3.4 Lower Fraser River Sub-Basin

The lower Fraser River sub-basin covers the area downstream of the Hope station (Fig. 2.1). The river from Hope to Mission station is characterized by increased channel width, braided channels, and gravel bars and islands (Mclean, 1990). From Mission to the Strait of Georgia, the river has a single channel and the suspended load consists of sand. Most of the sediment in the lower Fraser River sub-basin originates from erosion of the banks and bed upstream of Hope especially around Boston Bar, Lytton and Lillooet (Fraser River Board, 1963). Local sources of suspended-sediment in the reach are the stream-bed (Kostaschuk et al. 1986). There is only a limited amount of bank erosion due to the fact that river banks have been stabilized in most areas of the lower Fraser reach (Fraser River Board, 1963).

The assessment of suspended-sediment transported by the river is complicated by the dredging of the bed to allow shipping and by mining of gravel for commercial use between Hope and Mission (Kellerhals Engineering Services, 1987). Volumetric estimates of sand and gravel extraction from lower Fraser River between 1973 and 1986 average about 120 000 $m^3 y^{-1}$ (Mclean, 1990). Some of the sediment are supplied by tributary streams such as Chilliwack, Coquihalla, and Thompson Rivers. Retreating Bridge and Bishop Glaciers drained by Bridge and Lillooet rivers also likely supply suspended-sediment to the lower Fraser River. Of the rivers in the lower Fraser Basin only sources of sediment in Chilliwack River will be discussed.

2.3.5 Chilliwack River Sub-Basin

Since Chilliwack River was not deglaciated until about 11 000 years BP, its valley is still filled with unconsolidated glacial sediments in the silts to gravel range. Previous studies (Munshaw, 1976; Saunders, 1985; Saunders et al. 1987) have identified major sources of sediment supplied to the river as originating from glacial sandurs and from tributary streams, especially Sleese, Liumchen and Tamahi Creeks (Fig. 2.2). Since the Chilliwack River is located in an area which receives large amount of precipitation, it experiences mudslides on an annual basis. Mudslides are a major source of suspended-sediment transported by the

Chilliwack River, especially during intense storm events. Some of these are dicussed in Chapters Five and Six.

Overall, the Fraser River system is filled with large quantities of unconsolidated sediments, most of which travels as suspended-sediment load.

The next chapter discusses types of data and analytical methods used in this study.

CHAPTER THREE

DATA AND METHODS OF ANALYSIS

3.1 Types and Sources of Data

3.1.1 Archival Data

This study utilizes archival river discharge and sediment data collected by Water Survey of Canada (WSC) for ten hydrometric stations located on the main channel of the Fraser River and four on its tributaries. Eight of these stations were also sediment stations. The raw data used in this study were of several types. The first included summaries of routinely measured cross-section measurements comprising the date, air and water temperatures, width, cross-section area, mean velocity, gauge height and daily mean discharge collected between 1960 and 1988, inclusive. Average depths of flow not included in WSC compilations were derived as cross-sectional area/channel width. In addition, detailed cross-section measurements of depth and water-surface widths, defining channel cross-section shape, were collected for the period 1965 to 1988. But these data had some gaps.

Secondly, a total of 96 years and 12 seasons (April-October) of paired daily discharge and sediment concentration data for the period 1965-1987 for 9 sediment stations were supplied by the Sediment Branch of Water Survey of Canada in Ottawa on computer tape. These data consisted of measured and estimated values of daily mean discharge and daily mean sediment concentrations were supplemented by published data for 1988 (Inland Waters Directorate, 1990). The decision to restrict the analysis largely to data collected after 1960 was dictated by the availability of suspended-sediment data.

Thirdly, descriptive information of gauging site characteristics were extracted from closed and current station files at the WSC Office in Vancouver. Finally, meteorological data (total daily precipitation and daily mean temperature measurements for selected weather stations within the Fraser River basin; Fig. 2.1) were obtained from the Atmospheric Services of Canada, Vancouver Office, for the period 1965 to 1988 (Table 3.1). Note that the studied weather stations are not representative of the meteorological conditions of the whole Fraser River basin. Only precipitation and temperature data corresponding to the duration of a select number of individual events were used in the analysis.

3.1.2 Field Work

Preliminary field observations of the character of the main channel of Fraser River from the Rockies to the sea were conducted in the summer of 1991. In particular, sites prone to bank erosion (sediment sources) were noted. In March 1992, more detailed surveys were restricted to observations of the composition of bed calibre and clastic suspended-sediments resident in gravel bars near the Marguerite station. The survey involved digging pits on gravel bars and recording particle sizes at a time when the river stage was low and gravel bars were exposed. These data supplemented similar observations

Table 3.1. Weather stations located in the Fraser River basin used in this study.

No.	Station no.	Station Name	Latitude (N) (° ')	Longitude (W) (° ')	Altitude (masl)
1.	1101530	Chilliwack	49 07	122 06	6
2.	1101564	Chilliwack R. Centre Creek	49 06	121 33	488
3.	1101565	Chilliwack R. Foley Creek	49 06	121 38	457
4.	1101567	Chilliwack R. Tamahi Creek	49 04	121 50	137
5.	1100120	Agassiz	49 15	121 46	15
6.	1105190	Mission	49 08	122 18	56
7.	1113540	Hope	49 22	121 29	39
8.	1098940	Williams Lake	52 11	122 04	940
9.	1094616	Likely	52 36	121 32	724
10.	1094125	Kersely	52 49	122 22	671
11.	1096630	Quesnel	53 02	122 31	545
12.	1093474	Hixon	53 25	122 35	587
13.	1096450	Prince George	53 53	122 46	579
14.	1094950	McBride	53 16	120 09	722
15.	1092520	Dome Creek	53 44	120 59	648

documented by Carson (1988).

3.2. Methods of Data Collection used by WSC

Methods of data collection for suspended sediments in Canada previously have been described by Stichling (1969; 1973) and are summarized in the annual sediment publications (e.g. Inland Waters Directorate, 1990). Therefore, a comprehensive description of data collection and compilation procedures used by WSC is unnecessary here, but those methods and techniques that are germane to the understanding of limitations inherent in the discharge and sediment data deserve consideration.

3.2.1 Suspended-Sediment Sampling Methods used by WSC

Three main suspended-sediment sampling procedures are followed by WSC: (1) measuring suspended-sediment load by the depth-integrating method; (2) taking single suspended-sediment samples at a selected vertical of depth in the cross-section; and (3) measuring the suspended-sediment load by the point-integrating method. The depth-integrating method is used for determining the average suspended-sediment concentration in the water column. Sampling at a selected vertical is used for determining the sediment concentration for days when comprehensive suspended-sediment load measurements are not taken. Finally, the limited measurement of suspended-sediment load by the point-integrating method is used for cross-checking depth-integrated measurements. Detailed description of these methods are readily available elsewhere (e.g., Inland Waters Directorate, 1990).

3.2.2 Suspended-Sediment Samplers

Sediment samplers used by WSC in the collection of sediment data in the periods of record for various stations include the USDH-48 (wading-type) and USDH-59 (for handline sampling). The latter is used for depth-integrating sampling on small and medium size streams and during winter months. On medium to large streams whose depths are less than five metres, the USD-59 and USD-74 are used on reel suspensions.

For point-integrating suspended sediment sampling, USP-61, USP-61-A1, USP-63 and the USP-72 have been used, and are also utilized for depth-integrating sampling when depth is over five metres. Lastly, automatic pump samplers were used for unattended sample collection and bottling of individual water samples extracted from a fixed point in a stream. This type of sampler is normally installed at isolated locations where no data otherwise would be available during ice break-up or peak flow periods.

The daily mean sediment concentration is determined by through laboratory analysis of water samples and time-weighted averaging of the suspended-sediment. This is done by computing it from a manually constructed concentration hydrograph using a smooth curve through the concentration points on the water level chart copy (Water Resources Branch, 1983; cited by Carson, 1988: 20) following the pattern of changes in water level. This procedure is also used for interpolating sediment concentrations for unmeasured days at stations where sampling is infrequent. But the daily mean concentration value may be determined arithmetically or graphically (Inland Waters Directorate, 1990).

The sediment program of WSC deals with both suspended and bed load measurements. Since grain sizes for these sediment particles is a continuum, the distinction between suspended and bed-load materials is not well defined. In WSC compilations sediment particles are classified into three: (1) clay: <0.004 mm, (2) silt: 0.004 - 0.062 mm, sand: 0.062 - 2.0 mm and gravel > 2.0 mm. The clay and silt components also known as wash load are transported by turbulent forces and therefore are considered not to be capacity load. But the coarser component of sand which travels also as bed-load by intermittent suspension and saltation on the bed could be considered as capacity at certain flow levels.

Maclean (1990) noted that in the lower Fraser River reach there were no sediments finer 0.177 mm and used this grain size to distinguish bed-material load from the wash load. This study did not analyse particle sizes of the suspended load, but based on the miscellaneous depth-integrated particle-size data compiled by WSC, suspended-sediment data herein include bed sediment particles ranging in size between 0.062 and 2.00 mm. Therefore, in this study suspended-sediment load includes that portion of sand derived from the bed.

Since sediment loads are determined from stream discharge and sediment concentration, salient aspects of discharge measurements are briefly outlined below.

3.2.3 Measurement of River Discharge

Daily mean discharges at measurement sections are computed from a rating curve relating flow to river stage or height. Discharge generally is computed by the velocity-area method which involves field measurements of velocity, depth and width of flow. The frequency of discharge measurements and methods used, especially for determining flow velocity and stage are crucial in assessing the accuracy and reliability of sediment and discharge data and are discussed in the section following.

3.3. Limitations, Accuracy and Reliability of Data

The use of archival data collected by various agencies designed to meet objectives different from those of the present study imposed a number of limitations on analysis and interpretation of results. Firstly, many stations had sediment records of different periods which made comparison of results between stations difficult. Secondly, the length of usable sediment record ranged from six months to twenty-three years. Thirdly, the data collected by WSC were not sufficiently dense for analysis of single hydrological events. This was partly because most of the discharge and sediment measurements did not include the discharge and sediment measurements did not include measurements of water-surface slopes and observations of bed characteristics. Additionally, cross-section measurements were not always made for all days of individual events.

In view of these limitations, the analysis of individual events for specific relationships between discharge and sediment concentration and among discharge and depth, velocity and bed elevations, included some data interpolated for unmeasured days. An understanding of data limitations is important because accuracy and reliability of the data dictates what types of analysis can be undertaken. In the next section possible sources of errors in discharge and sediment data are discussed.

3.3.1 Errors in Discharge Measurements

The precision of discharge data for British Columbia rivers, based on the analysis of Hope, Agassiz and Mission stations, is within ±5% of the actually measured daily values (Mclean and Church, 1986). But the reliability of discharge measurements is affected by a number of factors. The instability of the channel boundary at measurement sections is one possible source of error in the estimation of discharge by the rating curve method, necessitating revision of the rating curve from time to time. Almost all rating curves for stations included in this study were revised many times by WSC in the period of record minimizing errors in the discharge estimates.

The second possible source of error in discharge measurements is the condition of the stream at the time of measurement, such as when there is an ice cover and during break-up and the rating curve is not applicable. The potential for this source of error is higher for streams located in the middle and headwaters regions of the Fraser River in the Rocky Mountain Range which experience colder winters than for stations located in the lower basin with mild winters. However, when discharge measurements are made when there is an ice cover, a description of the hydrological conditions is provided by WSC so that correction of the data may be made.

Errors related to methods and instruments used in measuring flow velocities and for collecting water samples, although they are considered to be negligible in the literature, must be acknowledged. This potential source of error has been investigated previously by Demmet'ev (1962) in the former USSR and Carter and Anderson (1963) and Dickinson (1967a; 1967b) in the United States. With regard to errors in velocity measurements, it is generally known that, velocity fluctuations about the mean at a point in the section are random in time. Furthermore, velocity varies with the logarithm of depth so that the average of the 0.2 and 0.8 velocities closely approximate the mean velocity in the vertical. Carter and Anderson (1963) found that, if single discharge measurements were made at a number of gauging sites by the usual 0.2 and 0.8 method, the errors of two-thirds of the measurements are less than 2.2 percent. Thus, the measurement of stream velocity by the single and two point methods yield similar results without causing significant errors in the discharge measurements obtained.

Therefore, most of the errors present in the discharge data do not arise from velocity measurements, but rather from the type and stability of stage gauge used, accuracy of observation and stage measurement.

According to the Inland Waters Directorate (1990), in British Columbia and Canada as a whole, data collected during open-water periods are more reliable than those collected during periods of ice conditions or those obtained by estimation. Additionally, water level data collected utilizing a water-stage recorder are more reliable and accurate than those using a manual gauge only, especially for small or flashy streams.

3.3.3 Errors in Suspended-Sediment Data

One of the sources of errors in suspended sediment measurements that is not related to the errors in the discharge is the use of different samplers during different times or during the same period for different watersheds. It has been indicated above that at least eight types of samplers have been used at one time or another in the collection of sediment samples for British Columbia rivers. The author is not aware of any investigation in Canada conducted to evaluate the relative performance of suspended sediment samplers. In the United States, Walter and Baird (1970) compared concentrations of suspended sediment collected with depth-integrating (USDH-48) and dip samplers and found greater concentrations for the integrated than dip samples. Consequently, they concluded that for valid comparisons, sediment concentration data obtained with dip and depth-integrating samples during different time periods for a watershed should be adjusted.

In British Columbia, it is not known whether or not different samplers yielded different sediment concentrations for different time periods. Obviously it is the assumption of this study that differences are unimportant. Maclean and Church (1986) estimated the accuracy of daily concentration measurements at Hope, Agassiz and Mission station to be ±10% of the actually measured values. This estimate of the accuracy of concentration measurement on Fraser River also applies to the Chilliwack, Harrison and Clearwater Rivers because similar sampling procedures have been used at all sediment stations (Bruno Tassone, Water Survey of Canada, Vancouver; personal communication). Therefore, by using sediment concentration data collected by WSC it was assumed that the data were reliable, of high accuracy and that it was comparable between different time periods as well as between different river systems. The task of assessing whether or not sediment data for different periods are comparable was outside the scope of this study.

The processing of all data collected for this study is the subject of sections following.

3.4. Processing of Data

In order to prepare the data for analysis the discharge and concentration data were transferred from computer tape to floppy disks for use on a personal computer to facilitate organization, arrangement, and sorting of data for different analyses. The methods of data processing used in the analysis are described below.

3.4.1 Identification of Single Hydrological Events

In order to classify rating curves, single-valued hydrological storm-period events were distinguished from other events. This was done in stages. Firstly, different types of rating curves were identified from plots of daily mean sediment concentration and daily mean discharge for different years at different gauging stations in the Fraser River basin. Secondly, individual hydrological events were identified from graphs of daily mean discharge and daily mean concentration plotted against time in days. Thereafter, the beginning and termination of each event on the Q-graph were determined. The beginning of the event was indicated by the change in discharge from decreasing in the falling stage of a preceeding event to increasing in the rising stage of event being studied, and termination of the event by a change in discharge from decreasing in the falling stage of event in question to increasing discharge in the rising stage of a subsequent event.

Sometimes the termination of an event also was indicated by lack of change in discharge for at least two days at the low flow stage. Overall, the selection of different events for detailed analysis depended on the the ability to identify the beginning of rise and termination of events on the Q-graphs. The method first applied by Williams (1989) in identifying the beginning (Q_1) and termination (Q_2) of the event, was choosing a time of rise during the rising of Q-graph and a termination time during falling stage and finally reading the corresponding (C_1) and (C_2) on the concentration graph (C-graph).

3.4.2 Selection of Single Hydrological Events

A plot of daily mean discharge and time for the period of sediment record revealed a total of 1025 hydrographs of individual events. In order to assess the functional relationship between sediment concentration and discharge sediment rating curves for all the events were constructed for comparison. A total of 49 hydrological events were found to exhibit single-valued sediment-discharge relations and were selected for detailed analysis.

In addition, the timing of the 1025 events were compared with dates of discharge measurements to determine whether or not an event could be considered to have been measured (as opposed to estimated). An event was considered measured if discharge measurements were made at or near the time of discharge rise, at or near the peak and at or near its termination. Based on these criteria, a subset of 12 more events were selected from the 49 events for detailed analysis of channel hydraulic factors controlling variations in sediment concentrations.

However, measurements were rarely made at precise time of rise, peak and at the termination of the events. Such measurements when available were the exception rather than the rule. Consequent upon further processing, the sample of events for hydraulic analysis was reduced to 9 events after eliminating those which had too few discharge measurements on the rising and falling stages. Altogether, a total sample of 49 single hydrological events with single-valued sediment rating curves (31 linear, 18 non-linear) were analyzed and the results are discussed in Chapter Five. The discharge and sediment concentration data for these events are given in Appendix 1.

Lastly, 730 discharge measurements in the period of sediment record for all sediment stations were assessed to determine the number of single hydrological events represented by the measured discharge data collected. It was found that most of sampled discharges were made during the course of 387 hydrological events whose hydrological characteristics are discussed in the next section. Single hydrological events exhibiting hysteresis in the relationship between concentration and discharge were also investigated separately. The discharge and concentration data for 122 hysteretic events (Appendix 2) are analysed in Chapter Six. Of the hysteretic events, 13 were measured.

3.4.3 Determination of Hydrological Factors

A closer examination of the summaries of measured discharge data at various stations revealed that each measurement could be placed either on rising, peak or falling stages of hydrological events whose characteristics could be easily determined. Consequently, an evaluation of hydrological factors (explained in Fig. 3.1) controlling sediment variation in single hydrological events was conducted by combining measured and published daily discharge. These hydrological factors included: (1) measured discharge at time of sampling (Q); (2) discharge preceding storm hydrograph rise (Qpr); (3) an index of flood intensity defined as the ratio of the difference between peak discharge and stormflow preceding the storm to the time of rise (IFI) (Gregory and Walling, 1973: 219); and (4) index of rate of flood recession (IFR) defined as the ratio of the difference between peak discharge and the discharge

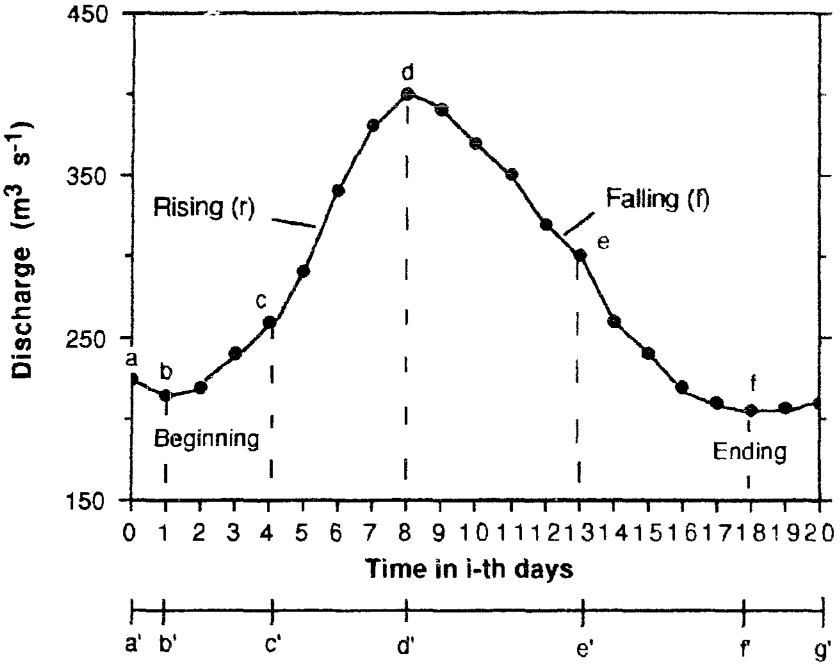


Fig. 3.1. Idealized definitive hydrograph used for determination of hydrological factors explained below.

a	is the discharge for the day before hydrograph rise (Qpr, $m^3 s^{-1}$);
b	is the discharge at beginning of hydrograph rise ($m^3 s^{-1}$);
d	is the discharge at time of peak ($m^3 s^{-1}$);
f	is the discharge at termination of the event ($m^3 s^{-1}$);
d'-b'	is the hydrograph time of rise (days);
f'-d'	is the hydrograph time of recession (days);
c, e	are discharges at time of sampling (c', e') (Q, $m^3 s^{-1}$);
(d-a)/(d'-b')	is the index of flood intensity (IFI);
(d-f)/(f'-d')	is the index of flood recession (IFR);

at the termination of the flood to the time of flood recession (Guy, 1964; Loughran, 1976).

Factors controlling sediment variation for single-valued and hysteretic hydrological events were analysed using the data in Appendices 3 and 4. A discussion of these factors is given in Chapters Five and Six.

3.5. Analytical methods

3.5.1 Computation of Daily Suspended Sediment Load

In this study daily suspended-sediment load is computed as the product of suspended-sediment concentration and river discharge:

$$SSL = 0.0864CQ \qquad (1)$$

where SSL is the suspended sediment load (tonnes per day); C is daily mean sediment concentration (mg L^{-1}); Q is daily mean discharge ($m^3 s^{-1}$) and 0.0864 is a metric conversion factor.

Since sediment loads are the product of discharge and concentration, their accuracy depends on the precision of the discharge and concentration measurements plus that of fine particle size measurements. Based on these three factors, Maclean and Church (1986) estimated that daily suspended-sediment loads are within ±15% of the true values.

3.5.2 Determination of Discharge Threshold for Stream-bed Scour and Filling

Since stream-bed elevation is not normally measured, it was derived as the difference between gauge height (water surface elevation) and flow depth (Leopold and Maddock, 1953b: 30). Thereafter, the discharge thresholds for stream-bed scour and fill at each station were graphically determined from plots of discharge and stream-bed elevations averaged over a period of years. The discharge and stream-bed elevation data for different stations are given in Appendices 5A through 5K. The relations of suspended-sediment concentration to channel scour and fill and factors controlling such relationships are discussed in Chapter Four.

Stream-bed elevations were not determined at Clearwater (08LA001) and at Siverhope Creek near Hope (08MF009), because data are not adequate. On the Harrison River at Harrison Hotsprings sediment station (08MG013) determination of stream-bed elevation is complicated by the fact that, when Fraser River is high, water backs up on Harrison River. As a result, when the river backs-up measurements are made at a location different from one used at low flows. Since it is not always possible to tell, from available data, whether the measurements were obtained under backflow conditions or not, and the fact that measurements at high and low flows are not comparable, computed stream-bed elevations for the Harrison River are not meaningful and have been excluded from the analysis.

In addition, gauge height measurements at Marguerite station on the Fraser River before and after 24th April, 1974 do not belong to the same population. In order to make the measurements comparable, gauge heights after 1974 were adjusted by increasing them by 4.2%. The adjustment factor of 4.2% was the one applied by WSC to the difference in discharges values obtained using Stage-Discharge Rating Table No. 8 for the 24th April, 1974 measurement. No attempt was made to determine the cause of the variations in gauge heights before and after 1974.

3.5.3 Determination of Factors Controlling Sediment Variation in Single Hydrological Events

In order to identify factors that control sediment variation associated with measured discharges and for single-valued and hysteretic events, least squares regressions of discharge and concentration data were used in the derivation of multiple stepwise regression models presented in Chapters Four, Five and Six. The use of ordinary least-squares regression for predicting the dependent variable is an appropriate technique provided the linearity assumption is satisfied. It is widely employed in hydrologic analysis (e.g., Walling ,1971; Troutman and Williams, 1987). Stepwise-multiple regression analysis was used to identify the order in which hydrological factors control variations in suspended sediment concentration. In addition, beta coefficients as suggested by Yevdjevich (1964) were calculated in order to determine the order in which controlling variables were to be entered in multiple regression models predicting sediment concentration for groups of linear and non-linear events.

3.5.4 Justification for Using the Regression Method of Analysis

A functional (regression) analysis approach (Richards, 1982) is used in the evaluation of relationships between suspended-sediment concentration and discharge in rivers for individual hydrological events. Some previous studies have used transfer-function models in explaining variations in sediment concentrations in rivers (Sharma and Dickinson, 1980; Thompson, 1987; Lemke, 1990; 1991). The use of functional analysis for examining single hydrological events can be justified on a number of grounds.

Firstly, unlike the transfer-function models which require differencing of observations, the regression method allows for the evaluation of simultaneous changes in river discharge and sediment concentration for single-valued events for which differencing is inappropriate. Here single-valued-events refer to those hydrological events in which the relationships between discharge and sediment concentration on the rising and falling stages are sensibly or statistically similar so that they can be described by a single overall rating curve. Transfer-function models are inappropriate for analysis of such events because changes in sediment concentration respond immediately to changes in discharge.

Secondly, hydrologic theory suggests that transfer-function models are best suited for analysis of variations in which there is some lag time in the response of sediment concentration to changes in discharge (Lemke, 1990). For these hydrological events sediment concentration does not change instantaneously with river discharge. However, physical reasoning suggests that the differencing of observations in the application of transfer-function models defeats the objective of trying to understand causality. That is, once the observations have been differenced, they cannot be related back to the nature of physical driving processes. On this basis, there is no heuristic value in the transfer-function models when applied to individual hydrological events.

In addition, transfer-function models, unlike the regression method, are not designed for assessing qualitative aspects of scale in space and time (Klemes, 1983). It should be pointed out that this study was designed in such a way that the results and conclusions be arrived at by analysis rather than by postulations which is often the case with transfer-function models. Therefore, in this case, the functional regression method is the appropriate method to use in order to enhance the understanding of the dynamics of suspended-sediment transport and of the relationship between sediment concentration and discharge in rivers. The regression method previously has been applied to the analysis of factors controlling the variations in suspended-sediment concentrations for individual events by Guy (1964) and Gregory and Walling (1973), among others.

In this study, regression analysis is applied to measured concentrations and discharge without log transformation. Although better regression results sometimes can be obtained on log-transformed data the transformation is inappropriate for the river data used. One of the assumptions of the best fit regression method is that values of the dependent variable are normally distributed about the regression line (Chorley and Kennedy 1971: 27) so that it passes through the means of the dependent variable at any value of the independent variable. But this is not true of log-transformed values; alternative approaches are discussed by Jansson (1985). Log transformation generally leads to underestimation of river loads (Fenn et al. 1985; Church et al. 1985) for which Ferguson (1986) has provided a correction factor.

Other reasons for using regression method in the analysis of sediment variation in single hydrological events given by Guy (1964) include the following: (1) Rating curves for particular events are not biased with data observed during other storm events; (2) by using daily discharge and sediment data instantaneous fluctuations are averaged out; (3) adjacent storm events are less likely to be related serially than adjacent instantaneous or daily sediment data; and (4) certain weather and hydrological conditions can be evaluated for correlation with sediment-discharge relation. The major disadvantage of the hydrological event method is that the sequence of weather may be such that the discharge from different storms may overlap each other in some instances.

3.5.4 Interpolation of Unmeasured Depths and Velocities

Evaluation of hydraulic factors controlling variation in suspended-concentration for individual events required the use of channel cross section variables. Since hydraulic data were available for only a few days during individual events, data for unmeasured days could only be obtained by interpolation. The variables that required estimation included average depth and mean velocity for unmeasured days. In the interpolation procedure used, unmeasured depth and velocity were estimated in proportion to discharge if and when measurements were made on the rising, at peak, and on falling, stages of individual events.

Since not all measurements were made exactly at time of rise, at peak, and at termination of events, less satisfactory measurements were also utilized in order to increase the number of events for investigation. The least satisfactory (but acceptable) cases were events for which measurements were made a few days before the time of rise, immediately before or immediately after the peak, and a few days before and after the termination of the event. The unmeasured average depth and mean velocity were interpolated using the procedure given in Table 3.2 for which a diagrammatic illustration is given in Fig. 3.2.

If there were no measurements immediately before and after the beginning and termination of an event, and if there was no change in the rising or falling trend of the discharge, the interpolation procedure described above was continued beyond the measured dates to cover the entire duration of the event. The hydraulic data for single-valued and hysteretic events with interpolated values are given in Appendices VI and VII. Note that the performance of the interpolation procedure is not known since it has not been tested against known or measured events.

3.6 Determination of Effective Discharge and Its Duration

For this study the effective discharge was defined as the mid-point of a range of flows, which, over a period of time transports a greater

Table 3.2. Procedures used for estimating unmeasured average stream velocities and average depths of flow.

$$Vi = Vmr + \left[\frac{Qir - Qmr}{Qmp - Qmr}\right](Vmp - Vmr) \qquad (2)$$

$$Vi = Vmf + \left[\frac{Qif - Qmf}{Qmp - Qmf}\right](Vmp - Vmf) \qquad (3)$$

$$Di = Dmr + \left[\frac{Qir - Qmr}{Qmp - Qmr}\right](Dmp - Dmr) \qquad (4)$$

$$Di = Dmf + \left[\frac{Qif - Qmf}{Qmp - Qmf}\right](Dmp - Dmf) \qquad (5)$$

where Vi is the interpolated i-th mean velocity; Vmr, Vmp and Vmf are measured velocities on rising, at or near peak and on falling stages; Di is the interpolated i-th average depth; Dmr, Dmp and Dmf are measured average depths on rising, at or near peak and on falling stages; Qir and Qif are i-th discharges on rising and falling stages (estimated from stage measurements); Qmr, Qmp and Qmf are measured discharges on rising, at or near peak and falling stages, respectively.

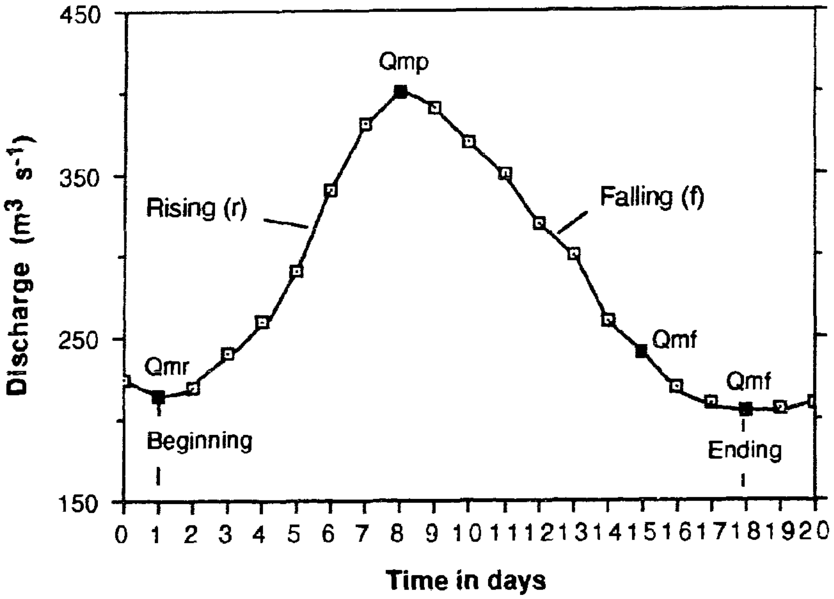


Fig. 3.2. An illustrative idealized hydrograph used for estimating depth and velocity on days when discharge was not measured. The symbols Qmr, Qmp and Qmf stand for discharge measured on rising, at peak and on falling limbs of the hydrograph, respectively.

portion of the suspended-sediment load than any other flow range (Pickup, 1976). Using daily discharge and sediment concentration data in the period of sediment record the effective discharge was determined by dividing the discharge range into approximately 20 equal classes; finding the duration of flows in each class; calculating daily suspended sediment load and multiplying it by duration. Finally, sediment-discharge graphs were constructed for the identification of the most effective discharge class.

In addition, also constructed for analysis were plots of cumulative percentages of daily suspended-sediment loads transported in a given percentage of time, and the cumulative percentages of suspended-sediment loads transported by cumulative percentages of total discharges. The results of these analyses are discussed in Chapter Seven.

3.7 Bankfull Discharge

Bankfull discharge is defined as the flow which just fills the channel without overtopping its banks (Richards, 1982). In this study, statistical bankfull discharge was determined by flood magnitude frequency analysis of the annual series at the various gauging stations (Dalrymple, 1960). Statistical bankfull discharge taken to be the 1.58-year flood (Dury et al. 1963) was used in this study to determine bankfull discharges at various study stations.

Although methods of determining bankfull discharge have been criticized (Harvey, 1969; Kennedy, 1972), especially when they are used to determine the 'dominant' or 'formative' events controlling channel form, they remain widely used as means of characterizing river hydrology. The advantage of using flood frequency analysis methods according to Dury (1973: 109) is that, if natural bankfull discharge on poised streams can be tied to a fixed recurrence interval, comparison among existing streams or between present and former streams would be greatly facilitated.

CHAPTER FOUR

SEASONAL CHARACTER OF CHANNEL SCOUR AND FILL AND SUSPENDED-SEDIMENT TRANSPORT

4.1 The Character of Channel Bed Scour and Fill

4.1.1 Definition of Stream-bed Scour and Fill

For this study, stream-bed scour is defined as the lowering of the stream-bed elevation due to erosion. Conversely, channel filling is defined as the rising of bed elevation due to sediment deposition. In general, channels scour as discharge increases and fill as discharge declines. These definitions are consistent with the definition of scour provided by Laursen (1953: 179), who defined it as the enlargement of a flow section by the removal of material composing the boundary through the action of fluid motion. Implicit in Laursen's definition is the fact that bed lowering is caused by the movement of sediment particles on the stream-bed due to fluid forces.

Although there is a close relationship between bed scour and fill processes and sediment supply and transport, it is not possible with the data available to differentiate between the material supplied and the material scoured. This is largely because the data used for assessing channel scour and fill are at-a-station measurements and not river reaches. In addition, the suspended-sediment load investigated herein is mainly carried by turbulent forces in the flow while materials scoured from the stream-bed include bed material load which moves as bed load.

4.1.2 Temporal Changes in Stream-bed Elevations

Stream-bed elevations determined in this study were based on data records ranging in length from 10 to 28 years for the 11 stations in the Fraser River basin for which appropriate data are available. The number of measurements were variable (3 to 30), averaging about 8 observations per calendar year. The average maximum scour of the bed below the mean was found to be 0.290m while the calculated average maximum elevations of the bed above the mean bed elevation is 0.998m (Table 4.1) (excluding Red Pass station because of uncertainty in the observed lowest bed elevation of -4.371m). For all stations, the average change in bed elevation was found to be 0.447m. Generally, this shows that the average in bed elevation at any station on the main channel of the Fraser and Chilliwack Rivers is less than one metre.

Stream-bed scour and fill are closely related to changes in channel shape caused by seasonal changes in discharge. In order for the river to accommodate the increasing flow of water at the onset of snowmelt the channel changes shape through increases in depth and width. On the Fraser River, channel changes which reflect processes of scour and fill are best illustrated at Marguerite station where measurements are not made from a bridge but from a cable car across the channel. As a result measurements at Marguerite station are free of complicating bridge pier scour effects, such as obstruction to the flow and creation of swirls.

Bed elevations at Marguerite in 1984 were lowered starting from May and reached the maximum depth in early June following the annual discharge peak, before filling commenced (Fig. 4.1). The scour and fill

Table. 4.1. Summary data of average stream-bed elevations at sediment stations on the Fraser and Chilliwack Rivers in British Columbia.

No.	Station no.	River	No. of years	Max. scour below mean (m)	Mean[1] bed elev. (m)	max. elev. above mean (m)
1.	08KA007	Fraser R. at Red Pass	21	-3.060?	1.311	2.044
2.	08KA005	Fraser R. at McBride	19	-1.039	-2.292	0.924
3.	08KA004	Fraser R. at Hansard	13	0.550	-0.612	1.100
4.	08KB001	Fraser R. at Shelley	28	0.822	-0.437	1.114
5.	08MC018	Fraser R. near Marguerite	15	0.817	-2.653	1.088
6.	08MD013	Fraser R. near Big Bar Cr.	12	0.739	1.217	1.434
7.	08MF040	Fraser R. at Texas Creek	26	0.421	1.068	1.031
8.	08MF005	Fraser R. at Hope	14	1.242	3.065	1.303
9.	08MF035	Fraser R. near Agassiz	17	0.635	-0.463	0.573
10.	08MH001	Chilliwack R. at Vedder Crossing	10	-0.644	0.295	0.593
11.	08MH024	Fraser R. at Mission	17	-0.646	7.130	0.817

[1] Bed elevations are based on arbitrary local datum. (?) indicates that the value is not accurately known.

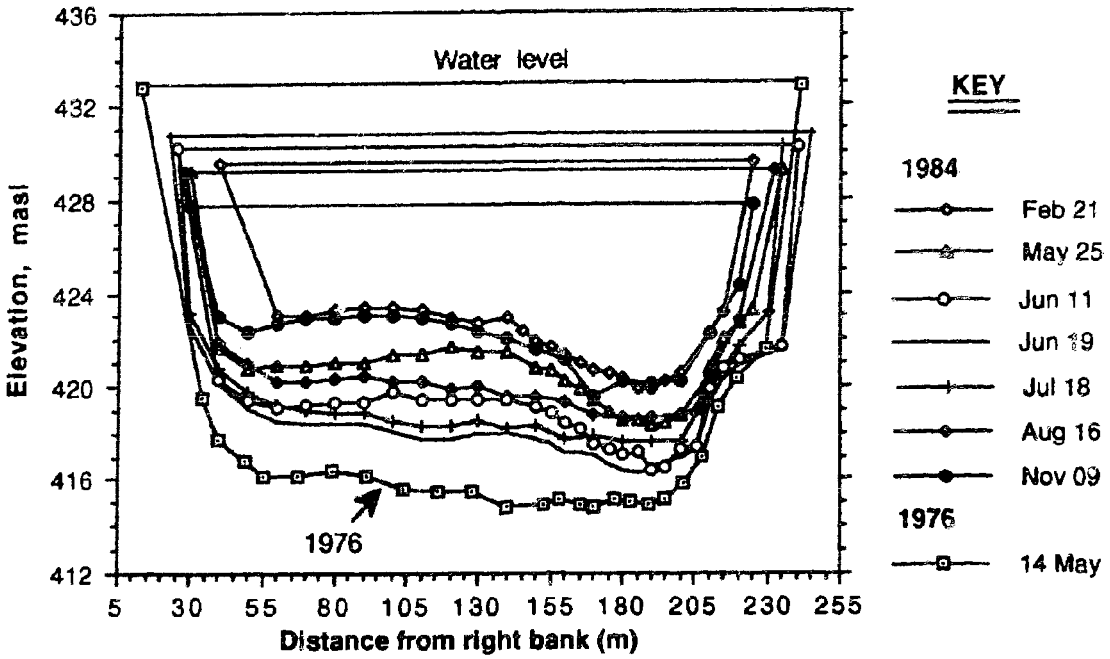


Fig. 4.1. Cross sectional shape of the Fraser River at Marguerite station for different dates in 1984 and in 1976 when the maximum discharge was measured.

cycle was almost complete by November. The channel cross-section for the maximum measured discharge in 1976 corresponds to the maximum possible lowering of the bed (Fig. 4.1). During the lowering of the bed sand-sized sediment stored in gravel bars and bed are accessed by the flow.

At low flow, the river bed surface at Marguerite station is characterized by a coarse layer of imbricated gravel sediment. In the terminology of Bray and Church (1980) the Fraser River reach at Marguerite station is armoured (Fig. 4.2a). Below the surface layer are large quantities of interstitial sand-sized and finer sediments (Fig. 4.2b). Carson (1988: 55) estimated that, at high flows, about 14% of bed sediment moves as suspension, the rest being transported as bed load. Altnough the number of measurements per year varied from station to station, the seasonal scour and fill sequences observed were generally consistent from year to year (Fig. 4.3). Changes in bed elevations were tied to changes in discharge levels, decreasing as the discharge rose from about March through May and reached lowest levels in June at peak discharge. Rises in bed elevations, which marked the onset of progressive filling commenced in July and almost returned to pre-spring level by the end of the winter season.

A fundamental feature of the annual regime of bed elevation is the pattern of sharp drops of the bed at times of major floods. These sharp drops of bed elevations are best illustrated at the Hansard and Mission stations on the Fraser River as well as at Vedder Crossing station on the Chilliwack River (Figs. 4.3a, b, c). Another important feature is the apparent stable stream-bed elevations observed at Hansard station from year to year compared to those for other stations.

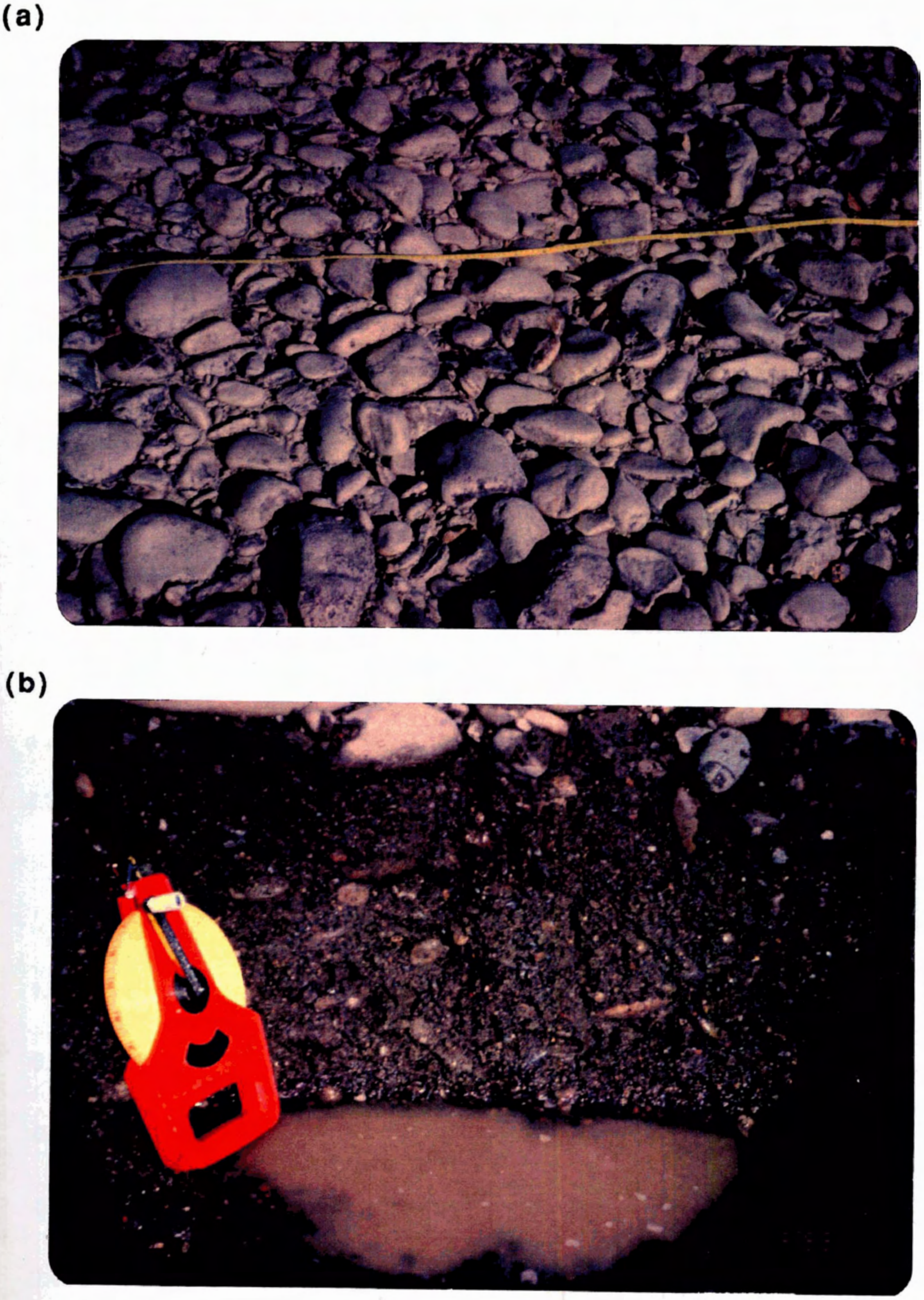


Fig. 4.2. Photograph showing (a) armoured gravel bar surface near the right bank and (b) composition of subsurface clastic sediments at the centre of the gravel bar on the Fraser River at Marguerite station.

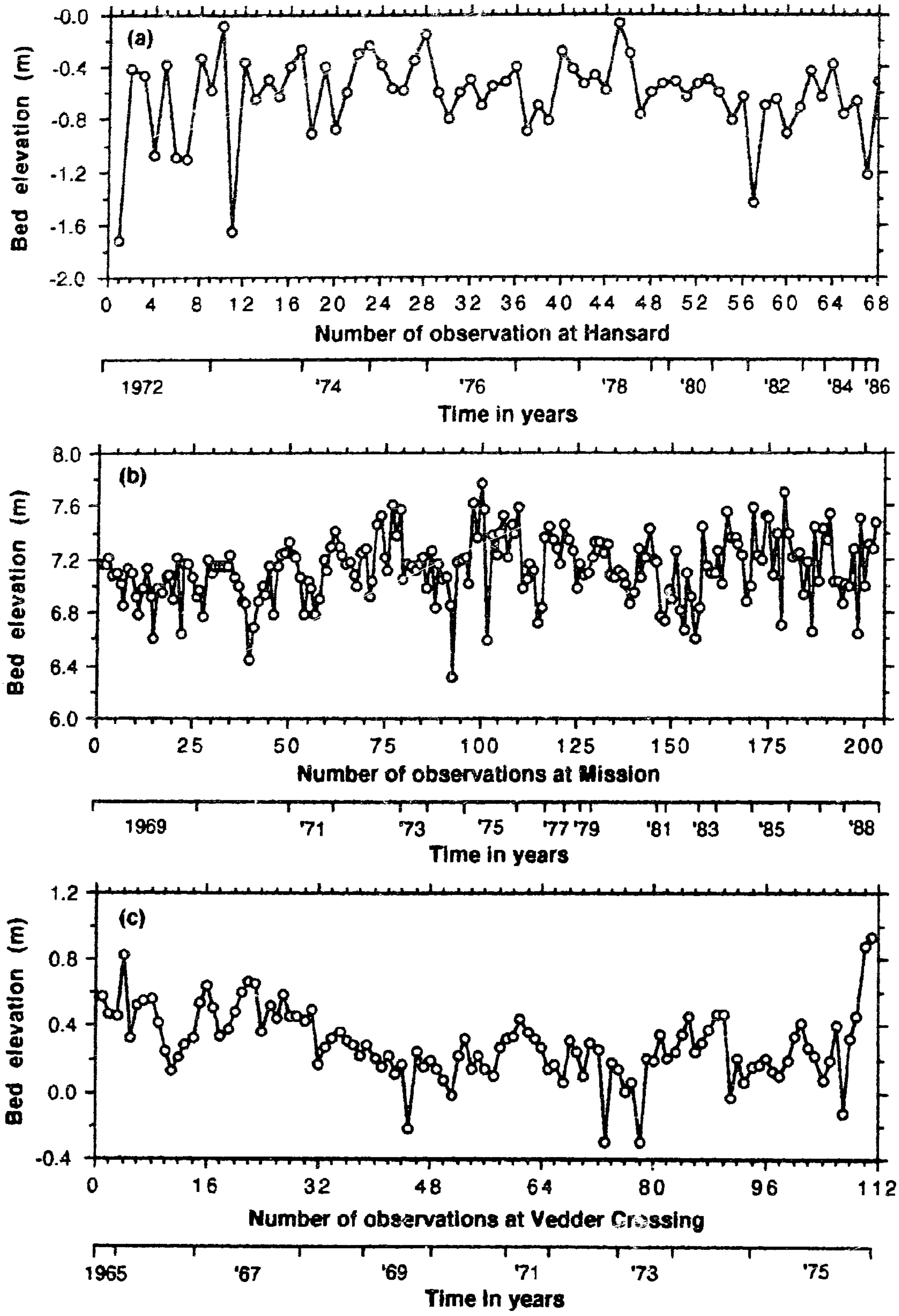


Fig. 4.3. Temporal variation of average bed elevations at (a) Hansard and (b) Mission stations on the Fraser River and (c) at Vedder Crossing station on the Chilliwack River.

Bed elevations at Marguerite station reflect rapid aggradation during 1975 followed by a more gradual phase of degradation until 1986 but without reaching the pre-1974 levels (Fig. 4.4a). This suggests that post-1974 flood events could not mobilize all of the sediment deposited by the 1972 flood of record. It is likely that aggradation also occurred after 1967 when the second highest flood in recorded history occurred. In contrast, bed degradation was observed at the Vedder Crossing station on the Chilliwack River in 1968 when the highest flood since mid-1950s was experienced (Fig. 4.3c). Bed elevations remained low by the 1975 flood, the then third highest recorded flood to the peak in 1917.

Similarly, minor bed aggradation occurred at Hope and Mission stations after the 1972 flood, respectively the highest and second highest in recorded in history. However, elevations of the bed at these stations were compensated by the sharp bed drops that ensued in subsequent years. More corroborative evidence of channel aggradation and or degradation in immediate reaches at each of the studied stations is required to confirm that the observed station changes are general to long reaches of channel. Nevertheless, the findings of this study are useful insofar as they allow inferences to be drawn about the stability of cross sections and for assessing the importance of sediment storage in river channels.

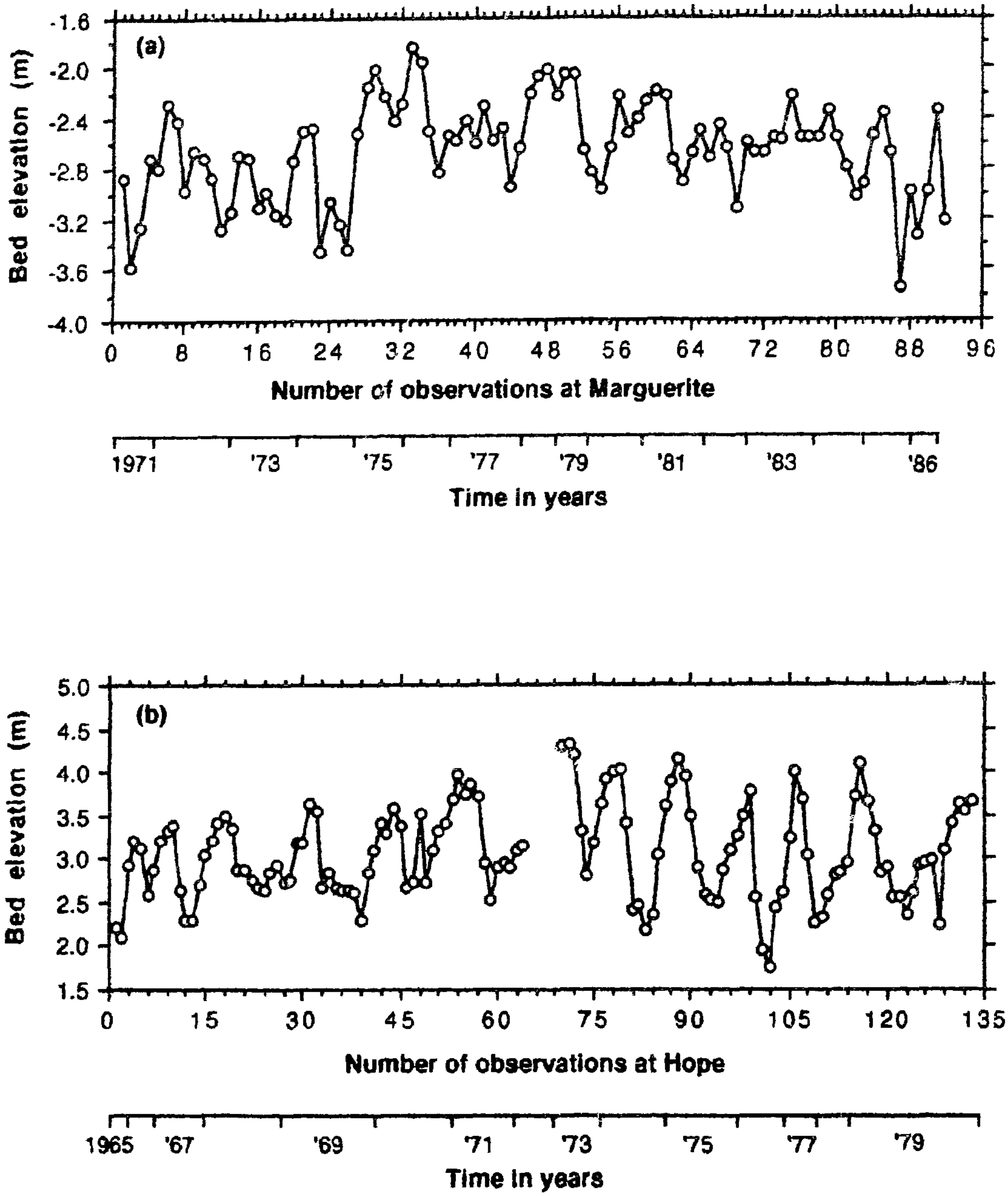


Fig. 4.4. Temporal variation of bed elevations at (a) the Marguerite and (b) Hope stations on the Fraser River. The data for 1972 at Hope station were not available.

4.1.3 Seasonal Sequences of Stream-bed Scour and Fill and Sediment Transport

Sediment transport involving the processes of stream-bed scour and fill is best visualized in terms of a simple sediment budget. Thus, over an arbitrary time interval (Δt) a sediment budget for a river reach can be expressed as:

$$Gi = Go + Gl \tag{6}$$

$$Gl = Gi - Go = \Delta e / \Delta t$$

where Gi and Go are the quantities of sediment entering and leaving the river reach in a given time interval, respectively; Gl or Δe is the quantity of sediment deposited on or eroded from the stream-bed due to filling or scour in the time interval (Δt).

The three quantities in equation (2) can be used in computing the amount of sediments scoured or filled if they are expressed in terms of equivalent volumes of sediment rather than in terms of weight or parts per million. The use of at-a-station data in this study has precluded the computation of volumes of sediment eroded or deposited as required by the sediment budget approach described above.

Otherwise, Colby (1964b: 9) states that, the equivalent volume of a deposit is the weight of sediment divided by a known or assumed weight per unit volume of deposited sediment. If it is assumed that the average elevation of the stream-bed is constant when no net weight of sediment is deposited or eroded in a given time interval, and that the amount of sediment transported at any instant is negligible, depth (D) of scour and fill per unit area can be estimated as:

$$D \quad = \quad Gl/A \quad = \quad (Go - Gi)/A \qquad (7)$$

in which A is the reach wetted area.

In applying equation 3 to real situations, careful consideration needs to be given to the conditions under which different sediment particle sizes are moved. It is best applicable to bed material load which includes sand.

4.1.3.1 Assumptions

In order to evaluate and assess stream-bed scour and fill processes at sediment stations in the Fraser River basin, it was assumed that local rate of scour ($\Delta e/\Delta t$) was equal to the difference between the rate of removal (Go) and the rate of sediment supply (Gl). Under this assumption stream-bed scour ($-\Delta e/\Delta t$) indicated that the rate of removal was greater than the rate of sediment supply ($Go > Gl$) while filling ($+\Delta e/\Delta t$) showed that the rate of deposition was greater than the rate of sediment supply ($Gi > Gl$) in the river reach.

4.1.3.2 Regimes of Stream-bed Scour and Fill Sequences

Assessment of seasonal stream-bed scour and fill involved, firstly, the division of measured discharges and the associated bed elevations into the rising and falling stages. Secondly, plots of stream-bed elevations versus discharge were constructed, but these showed a wide scatter of points. In order to highlight trends in these plots moving averages of bed elevations were computed. A variable number of points was used for averaging stream-bed elevations largely because of differences in number of observations available at various stations. For stations with many observations, trends in stream-bed elevations were revealed with the use of higher averaging points than for stations with smaller numbers of observations. The moving average method was used because it does not require that data observations be made at regular time intervals. Note that the measurements of discharge and channel form used in this study were made at irregular interval intervals. In addition, it should be pointed out that the accuracy of stream-bed elevations in the low flow range at some stations is questionable and were not included in the discussion because most of the measurements were made in winter when the river has an ice-cover.

The results of this analysis showed that, for instance, at Red Pass (Fig. 4.5a) and Marguerite (Fig. 4.5b) stations on Fraser River, scouring occurred at particular discharge thresholds (Q_t) and was generally preceded by filling at lower discharges. Discharge thresholds were determined as the level at which scouring of the bed commenced. But in some instances Qt was taken to be the discharge at which the stream-bed scouring path meets the filling path. The discharge thresholds

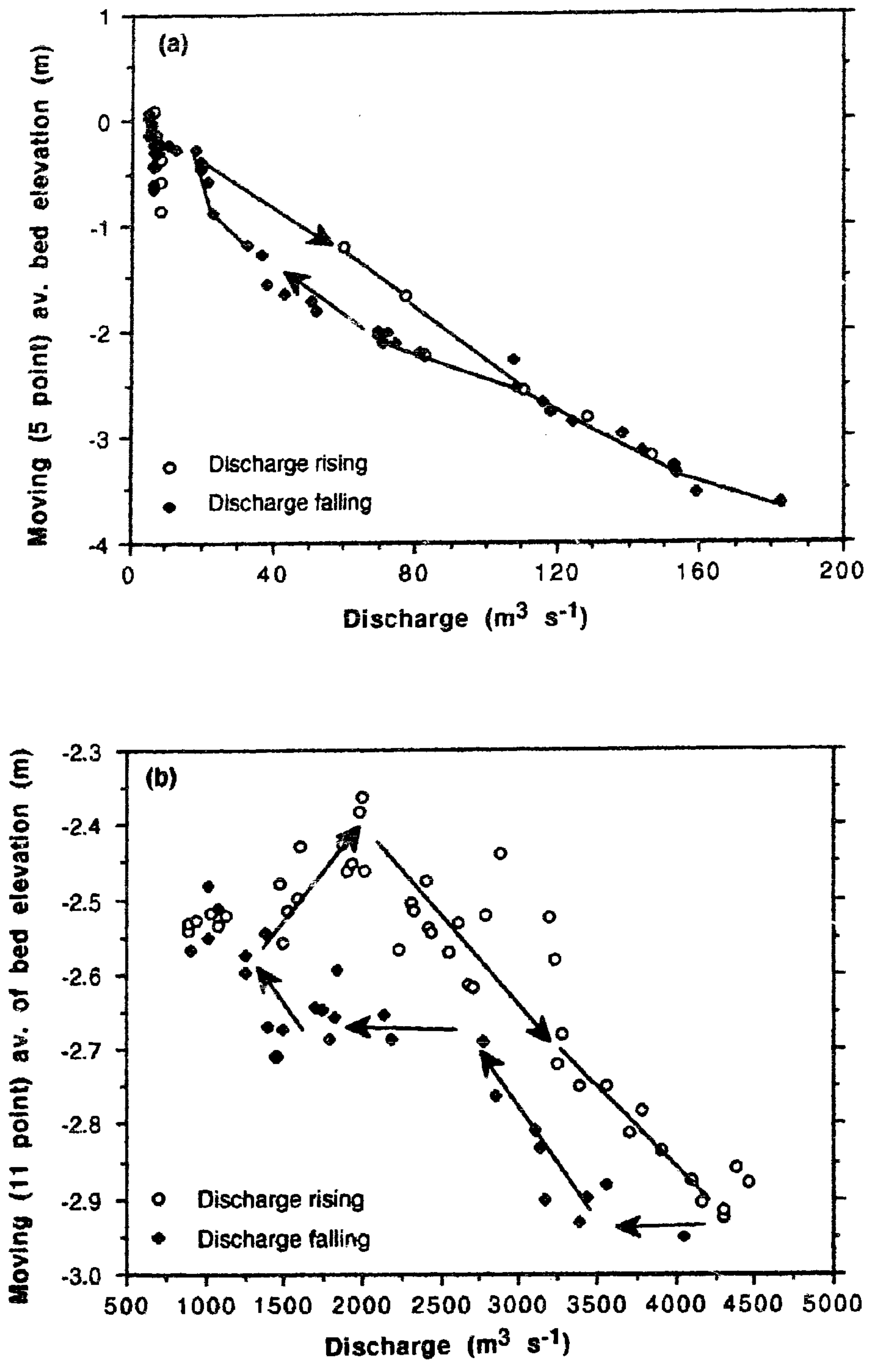


Fig. 4.5. Patterns of bed scour and fill sequences on the Fraser River at (a) Red Pass (1960-1981) and (b) Marguerite station (1971-1986).

determined for a number of stations in the Fraser River basin are shown in Table 4.2 together with the mean annual and bankfull discharges for comparison.

The analysis of seasonal stream-bed scour and fill regimes in the Fraser River basin revealed that bed elevation was highly variable for flows below mean annual discharges and that more intense scouring occurred at bankfull and higher discharges. For the Mission station, discharges lower than 5 500 $m^3 s^{-1}$ were not included in the analysis due to the tidal influence. The selection of 5 500 $m^3 s^{-1}$ as the tidal/fluvial division was based on the fields notes kept by Water Survey of Canada, Vancouver Office, which indicated that the Fraser River at discharges below this level was generally under tidal influence. Also, at Vedder Crossing station on the Chilliwack River three days of discharge and sediment measurements during the 30 November 1975 flood were excluded from the analysis because the associated concentrations (2200-4000 mg L^{-1}) were anomously high and clearly not part of the general population.

In general, for the periods of record the scour and fill regimes for the Fraser and Chilliwack River stations were characterized by alternating phases of rapid lowering of the bed and prolonged periods of filling. But the recovery path due to filling was generally less gradual as discharge decreased than the scouring path of bed elevation because of seasonal hydrological effects. These hydrological effects include prolonged periods of low flows which promote in-channel deposition of sediment from valley slopes and channel banks. In Fig. 4.5b the Marguerite station best illustrates the filling path: bed elevation exhibits step-like patterns of bed scour as discharge decreased. It is interesting

Table. 4.2. Discharge thresholds for stream-bed scour and other flows controlling channel shape in the Fraser River basin.

			Discharge[1]		
No.	Station no.	River	Q_{ma} (m^3s^{-1})	Q_t (m^3s^{-1})	$Q_{1.58}$ (m^3s^{-1})
1.	08KA007	Fraser R. at Red Pass	46.8	35	232
2.	08KA005	Fraser R. at McBride	197.0	100?	818
3.	08KA004	Fraser R. at Hansard	469.0	600	1950
4.	08KB001	Fraser R. at Shelley	814.0	700	3060
5.	08MC018	Fraser R. near Marguerite	1420.0	2000	4200
6.	08MD013	Fraser R. near Big Bar Creek	1520.0	1000	4240
7.	08MF040	Fraser R. at Texas Creek	2500.0	1100	4960
8.	08MF005	Fraser R. at Hope	2720.0	1500?	8000
9.	08MF035	Fraser R. near Agassiz	2880.0	3000	8000†
10.	08MH001	Chilliwack R. at Vedder Crossing	68.0	150	275
11.	08MH024	Fraser R. at Mission	3350.0	6000	8000†

[1] Q_{ma} is the mean annual discharge; Q_t the discharge threshold for bed scour and $Q_{1.58}$ is the bankful discharge. (†) indicates that $Q_{1.58}$ is not accurately known due to short discharge record, value given is for Hope station. (?) indicates that Q_t value is not accurately known.

to note that, these step-like patterns of bed scour resemble similar patterns reported by Dinehart (1992: 64) which he observed to be caused by the passage of low frequency bed waves following transitional phases of bed scour during storm flows. In this case, however, the steps more likely relate to seasonal sediment supply regimes as discharge decreases.

The step-like patterns of bed scour on the Fraser River near Marguerite, which followed the passage of the annual discharge peak, represent different seasonal adjustments of the bed and are characterized by successive stationary, rising, stationary and rising phases. The first stationary phase represents the effects of high discharges and the attendant high velocities immediately following the annual peak discharge which inhibited sediment deposition. The next rising phase as discharge declined normally represents the effects of low discharges in the dry summer months which promoted deposition; another stationary phase is associated with fall storminess representing repeated phases of erosion and deposition. The final rising phase, effected by continued deposition in the winter months, completes the seasonal scour cycle.

The filling phase of the seasonal scour cycle generally tracked lower for a given discharge than the scouring phase when the bed adjusted to its pre-spring level. This hysteretic phenomenon observed at Red Pass (Fig. 4.5a), Marguerite (Fig. 4.5b) and Big Bar Creek (Fig. 4.6a) stations on the Fraser River and at Vedder Crossing station on the Chilliwack River (Fig. 4.6b), suggests that the process of seasonal filling of the bed is much slower than that of bed scour. It is noteworthy that, on the Chilliwack River scour and fill regime exhibited two easily identifiable

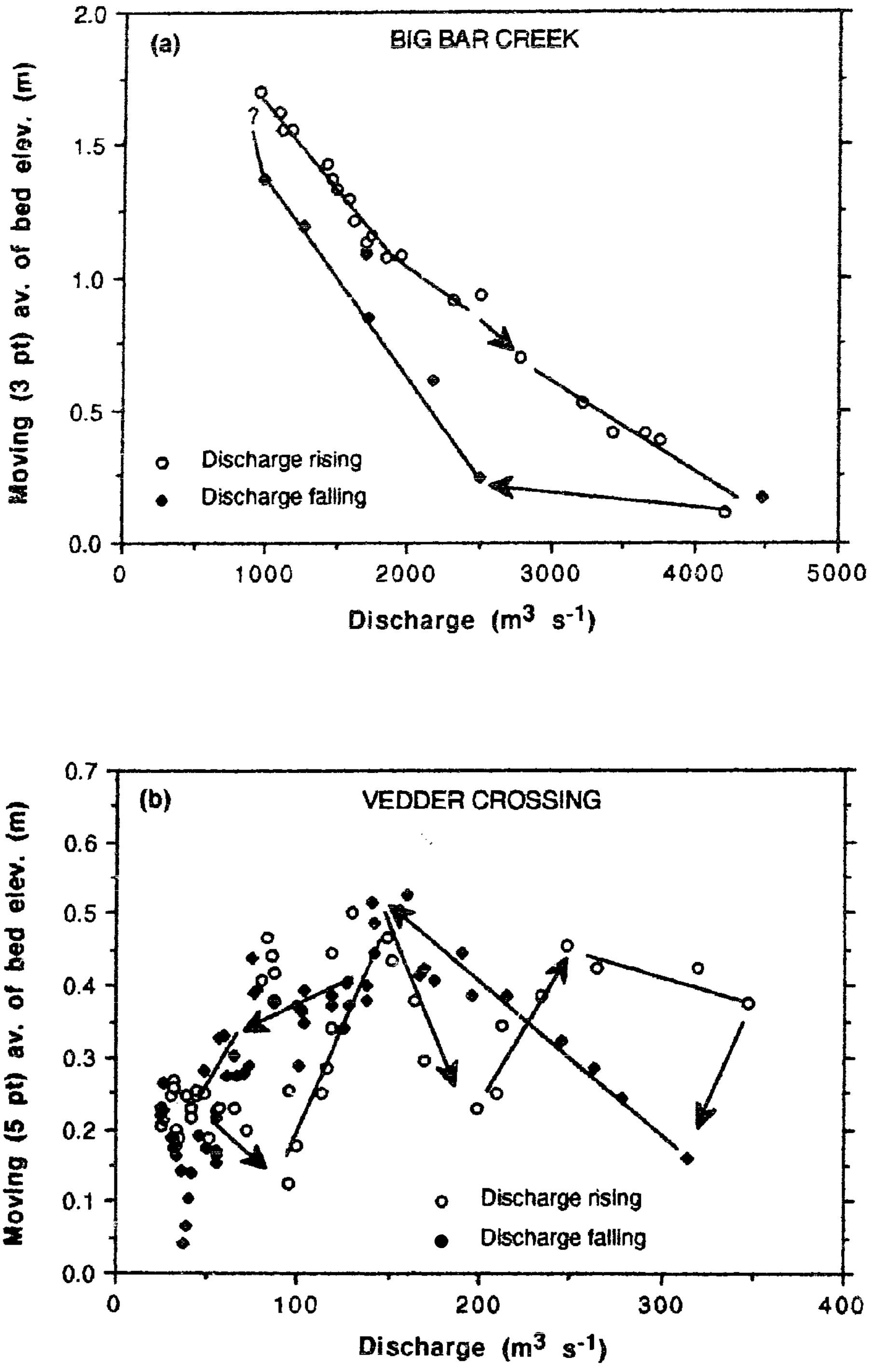


Fig. 4.6. Patterns of bed scour and fill sequences at (a) Big Bar Creek (1960-72) on the Fraser River and (b) Vedder Crossing station (1965-75) on the Chilliwack River. (?) means that path of filling is unknown due to insufficient data.

cycles in concert with the yearly bimodal distribution of discharge. The first peak occurred in June and the second in December.

By contrast, at Agassiz station on Fraser River there are two bed scour cycles for discharges greater and smaller than 5 000 m^3s^{-1} (Fig. 4.7a). In the higher discharge range, the rising discharges in excess of 5000 $m^3 s^{-1}$ up to the peak generally were associated with filling of the channel with sediments while falling discharges scoured the bed as the sediment was remobilized. The scouring and filling phenomenon observed at the Agassiz station were not unique as similar processes were also observed at the McBride, Big Bar Creek and Mission stations.

The observations of scour and fill effects at Agassiz station are important because they help to explain the en masse movement of large quantities of sand immediately following the spring freshet between Agassiz and Mission station located 45 km downstream of Agassiz. At Mission, bed elevations for rising and falling discharges greater than 5500 $m^3 s^{-1}$ were the reverse of those obtained at Agassiz station (Fig. 4.7b). At the Mission station the scour path leads the filling path resulting in an anticlockwise pattern of bed adjustment. This process indicates that the Fraser River at Mission flushes out most of the sediments deposited from upstream by the time of peak flows. Thus, the scour and fill regime represents a process where the rate of sediment supply (Gl) is higher than that of removal (Go) in the period of decreasing discharge. The implication of this is that, at Mission station, the channel likely fills at a time scale of days to weeks after the annual discharge peak has passed.

The bed scour and fill processes observed at Agassiz and Mission stations clearly demonstrate how closely linked these processes are at

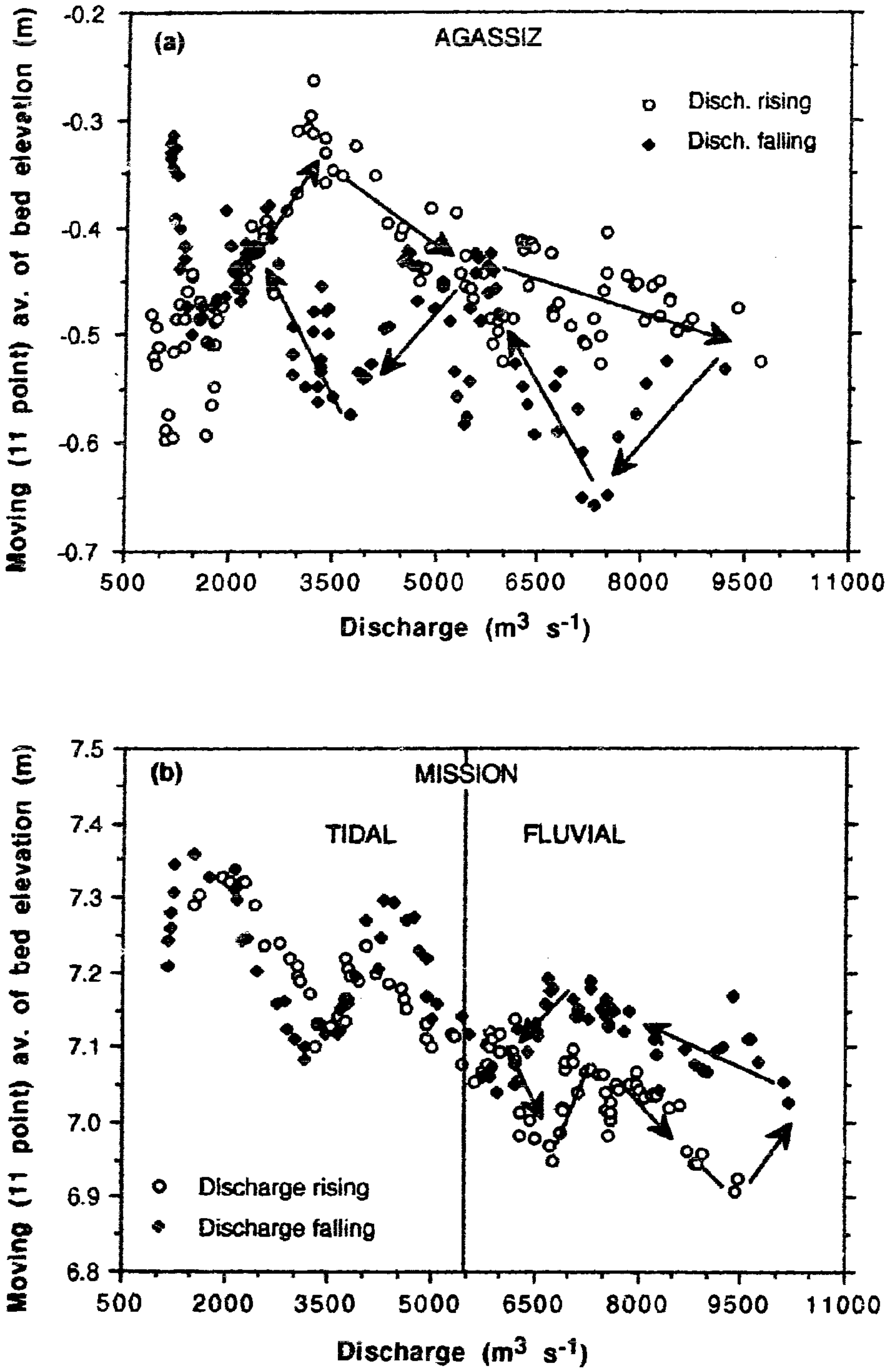


Fig. 4.7. Patterns of bed scour and fill sequences on the Fraser River (a) near Agassiz (1968-1986) and (b) at Mission station (1969-1988).

the two stations. During rising spring flows the Fraser River fills the channel at Agassiz while flushing out all incoming sediments at Mission. During recession flows, sediment deposited by rising high flows at Agassiz are remobilized to fill the channel at the Mission station. The deposition and remobilization of sediments on the Fraser River has been previously demonstrated by Church et al. (1987) who compared average monthly loads between Agassiz and Mission for a number of years. They concluded that substantial quantities of the sand-size fraction were being stored in the Agassiz-Mission reach on the rising limb of the freshet and then deflated from the reach on the failing limb.

In addition to the seasonal clockwise and counterclockwise paths of scour and fill a third pattern was also observed where the filling bed elevations retraced the scouring paths at two sediment stations (Hansard, Fig. 4.8a; Hope, Fig. 4.8b) as well as at other gauging stations (McBride, Fig. 4.9a; Shelley, Fig. 4.9b; Texas Creek, Fig. 4.9c). Note that the determination of the discharge for bed scour at McBride, Texas Creek and Hope stations is not clear cut as there is no marked evidence of filling at lower flows. In addition, note that most of the observations in winter months at flows lower than 250 $m^3 s^{-1}$ were not included in the analysis at Shelley station because most of them were anomalous. These observed bed elevations were lower than those for peak flows because ice conditions that obtain on the river make it difficult to accurately measure flow depths and widths.

The situations in which the filling path retraced that for scouring, physically, implies that, at a given discharge the amount of sediment removed by the rising discharge is equal to the amount of sediment deposited by the falling discharge.

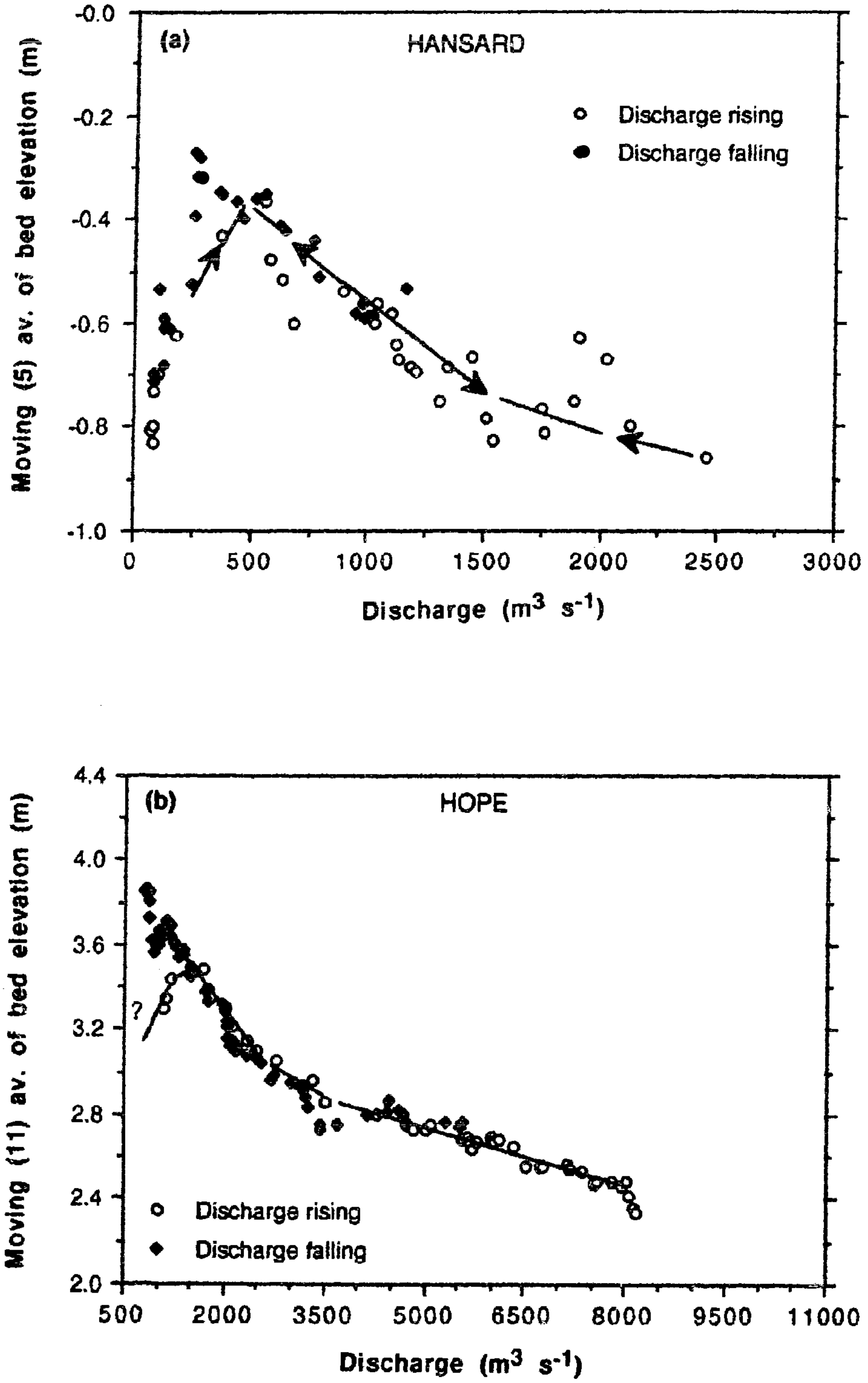


Fig. 4.8. Patterns of bed scour and fill sequences on the Fraser River at (a) Hansard (1972-1985) and (b) Hope (1965-1979) stations. (?) means that filling path is in doubt.

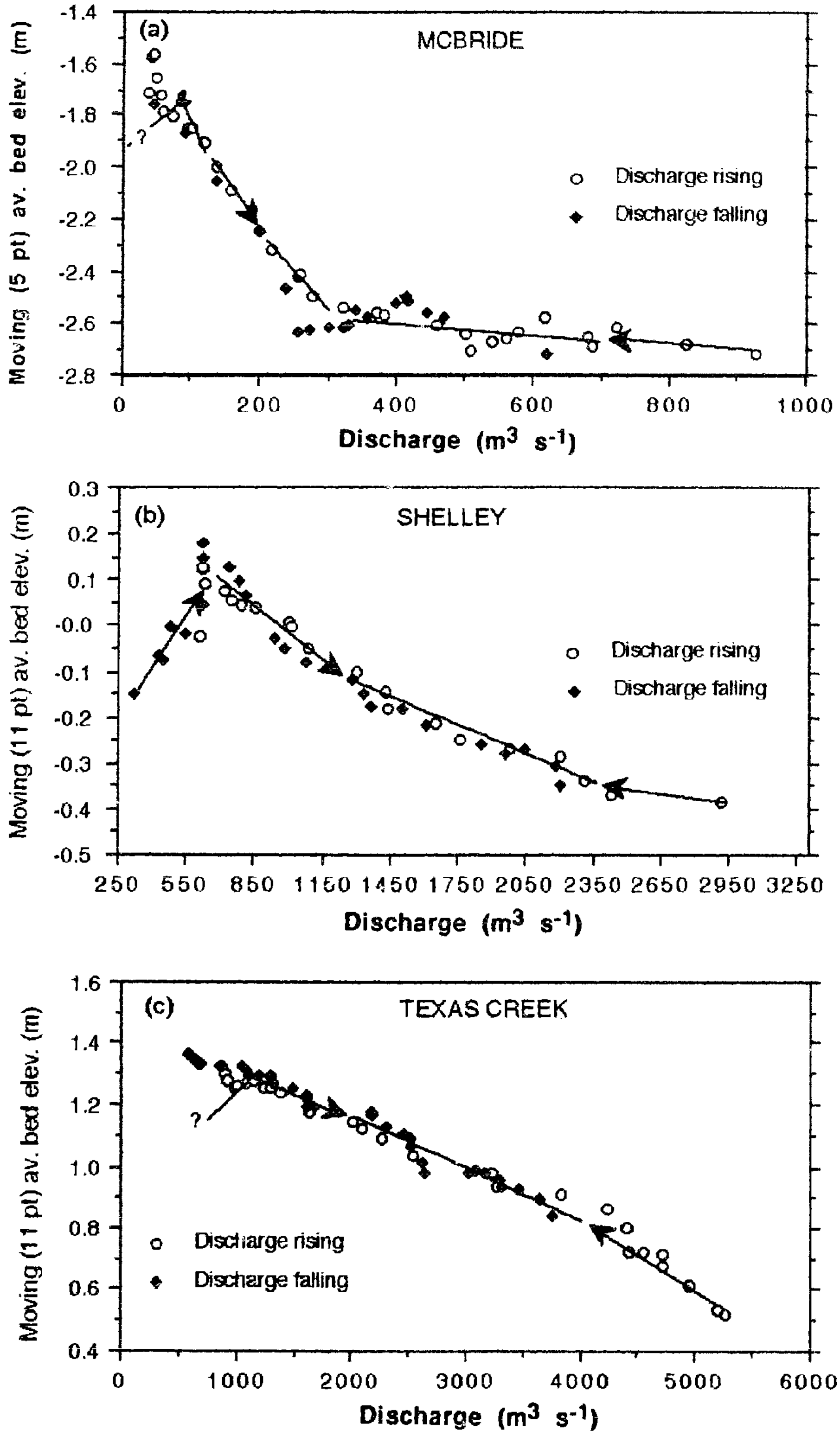


Fig. 4.9. Patterns of bed scour and fill sequences on the Fraser River at (a) McBride (1969-86), (b) Shelley (1960-86) and (c) Texas Creek (1960-86) stations. (?) means that filling path is in doubt.

4.1.4 The Relation of Suspended-Sediment Concentration to Channel Scour and Fill

In order to relate scour and fill processes to changes in sediment concentration, the sediment budget provides a conceptual tool for interpretation. It is conceived that, if Go has a functional linear relationship with discharge, there will be a sudden increase in sediment concentration at the first threshold discharge (Q_{t1}) caused by the scouring of the stream-bed and the liberation of sand-sized clastic sediments as well as at the second discharge threshold (Q_{t2}) when high elevation bars are mobilized at or near the bankfull discharge (Fig. 4. 10). In Fig. 4.10 it is conceived that sediment concentration would increase with increasing discharge even before scouring of the bed begins mainly because fine grained sediment particles stored in channel banks are accessed by the rising discharge and become incorporated into the wash load component (Gi) supplied from upstream reaches. Once scouring begins the increase in sediment concentration is likely to be larger at higher discharges than lower discharges. The model described above applies mainly to the discharges in the rising stages for which channel processes are reasonably predictable.

This conceptualization of suspended-sediment transport was tested in this study with the use of measured discharge and concentration data at several sediment stations in Fraser River basin. The relationship of suspended-sediment concentration to channel scour and fill was assessed graphically from plots of averaged sediment concentration and observed discharge which showed wide scatter of points. As a result, a moving average was applied to the

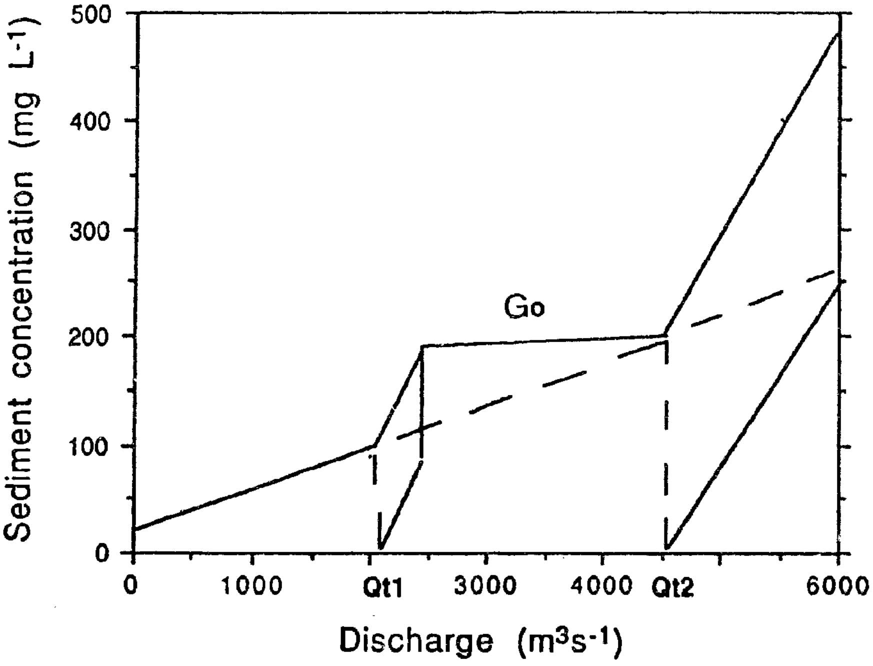


Fig. 4.10. An Idealized plot of sediment concentration and discharge showing relative effects of the exceedance of the discharge for bed scour(Q_{t1}) and bankfull discharge (Q_{t2}) on sediment transport at a scouring river section.

concentration data to help identify discontinuities in the concentration-discharge plots.

Like the plots of moving averages of bed elevation and discharge at Hansard and Hope stations, no distinctive discontinuities were observed in the plots of moving averages for sediment concentration and discharge at these stations. At the Marguerite station, however, discontinuities marking the onset of increases in concentration with discharge were observed at discharge thresholds (Q_t = 2 000 $m^3 s^{-1}$) and at bankfull discharge (Q_{bf} = 4 100 $m^3 s^{-1}$) (Fig. 4.11a), discharge levels identical to those for increased stream-bed scour. Similar discontinuities in sediment concentrations on Chilliwack River were also observed at Vedder Crossing station (Fig. 4.11b). In the low discharge range, on Chilliwack River, the first marked increase in concentration occurs at 75 $m^3 s^{-1}$ (Q_{t1}) when bed scouring commenced and possibly related to wash load mobilization, the second increase occurs at 150 $m^3 s^{-1}$ (Q_{t2}) likely related to bar and dune movement.

At the Agassiz and Mission stations, on Fraser River, major increases in concentrations occurs at discharges corresponding to Q_t and Q_{bf} and 5 500 $m^3 s^{-1}$ and 6 000 and 8 000 $m^3 s^{-1}$, respectively (Fig.4.12a,b). The C-Q graph for Mission station shows that there are at least three increases in sediment concentration and generally it is more complex than those for other stations. The complexity of the C-Q relation is attributed to the tidal influence for flows less than 5 500 $m^3 s^{-1}$. No attempt was made to relate stream-bed scour and fill to sediment concentration in the complex tidal discharge range but in the fluvial regime of Fraser River at Mission, a major increase in C-Q was observed at Q_{t1} = 6 000 $m^3 s^{-1}$ where bed scour commences in earnest (Fig. 4.7b).

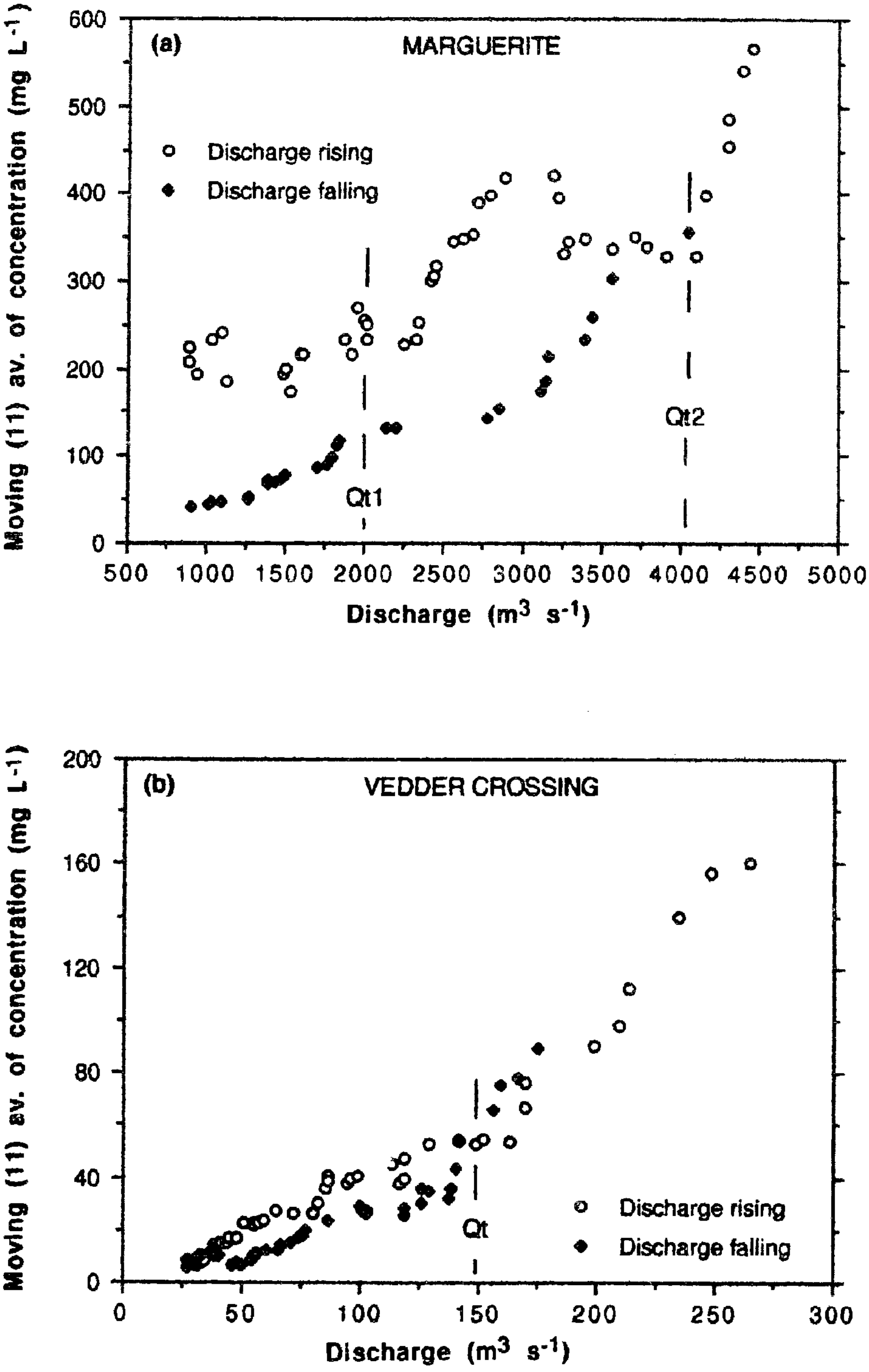


Fig. 4.11. Generalized relations of sediment concentration and discharge (a) on the Fraser River near Marguerite (1971-1986) and (b) on the Chilliwack River at Vedder Crossing (1965-1975).

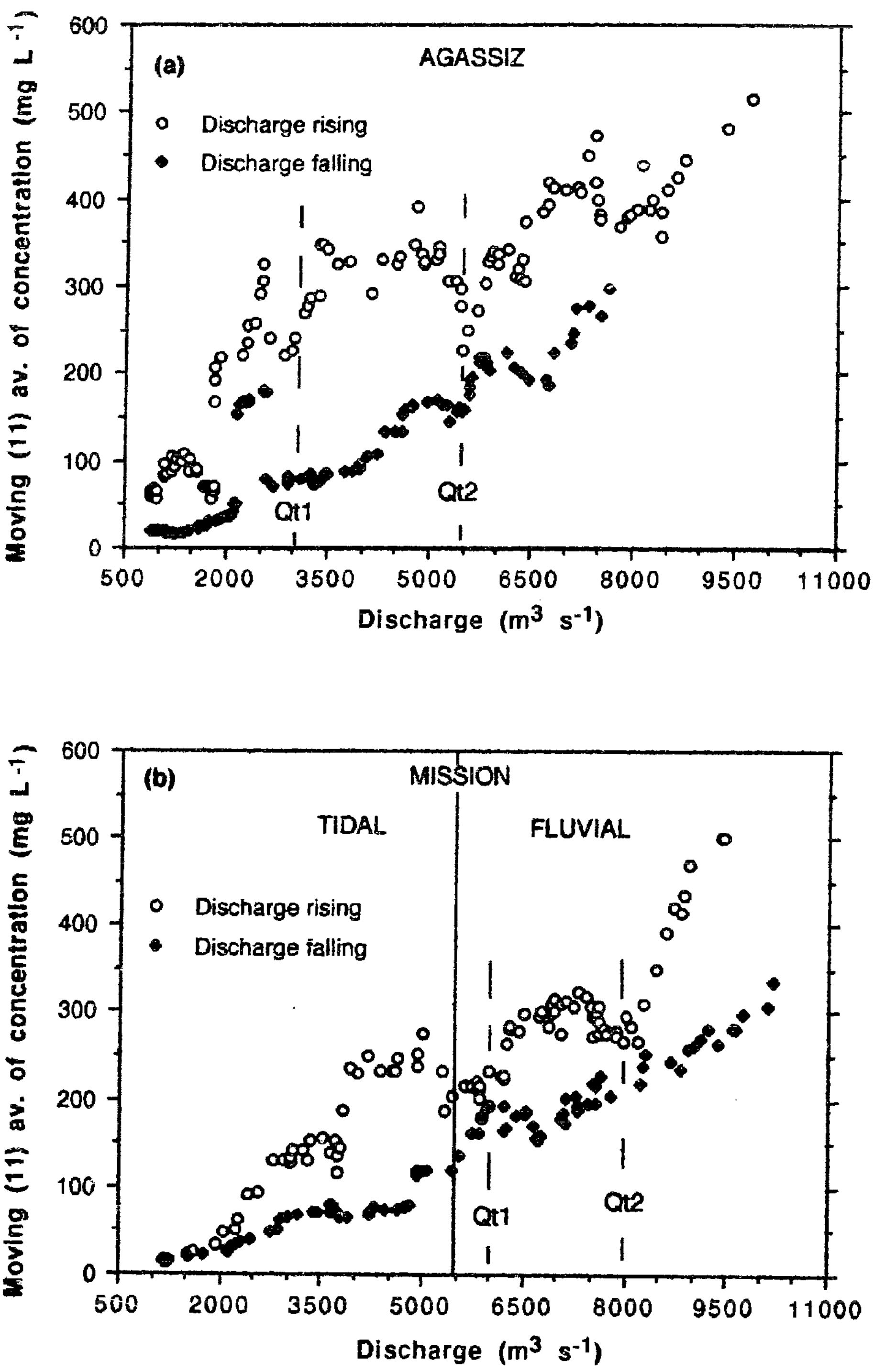


Fig. 4.12. Generalized relations of sediment concentration and discharge on the Fraser River (a) near Agassiz (1968-1986) and (b) at Mission (1969-1988).

A second increase in sediment concentration occurs at Q_{t2} = 8 000 $m^3 s^{-1}$ quite possibly caused by the mobilization of higher elevation bars and dune forms on the bed which release large quantities of interstitial fine-grained sediments into the flow for transport. Evidently, the exceedance of the discharge for bed scour (Q_{t1}) and bankfull discharge (Q_{t2}) partly accounts for the anomalous increases in sediment concentrations at many sediment stations in the Fraser River basin.

In summary, the averaging of sediment concentration in the concentration-discharge plots was useful in demonstrating the importance of suspended-sediment transport due to stream-bed scour. In most cases, a marked increase in concentration was found to occur when the discharge for bed scour and bankfull discharges were exceeded. This observation indicates that the concepts of threshold discharge for bed scour and bankfull discharge have a physical meaning not only to channel forming but also to suspended-sediment transport.

4.1.5 Hysteresis in Seasonal Suspended-Sediment Concentration and Channel Scour and Fill Sequences

Seasonal hysteresis in sediment concentration on Fraser River is best illustrated by using mean monthly sediment and discharge data given in Appendix 6. Fig. 4.13 clearly shows the annual pattern of sediment transport near Marguerite and Hope stations in 1977 through 1979. In a study of relative contribution of channel and slope erosion to suspended sediment load in the Senegal River basin, Kattan et al. (1987) indicated that the cyclical patterns of sediment transport could be

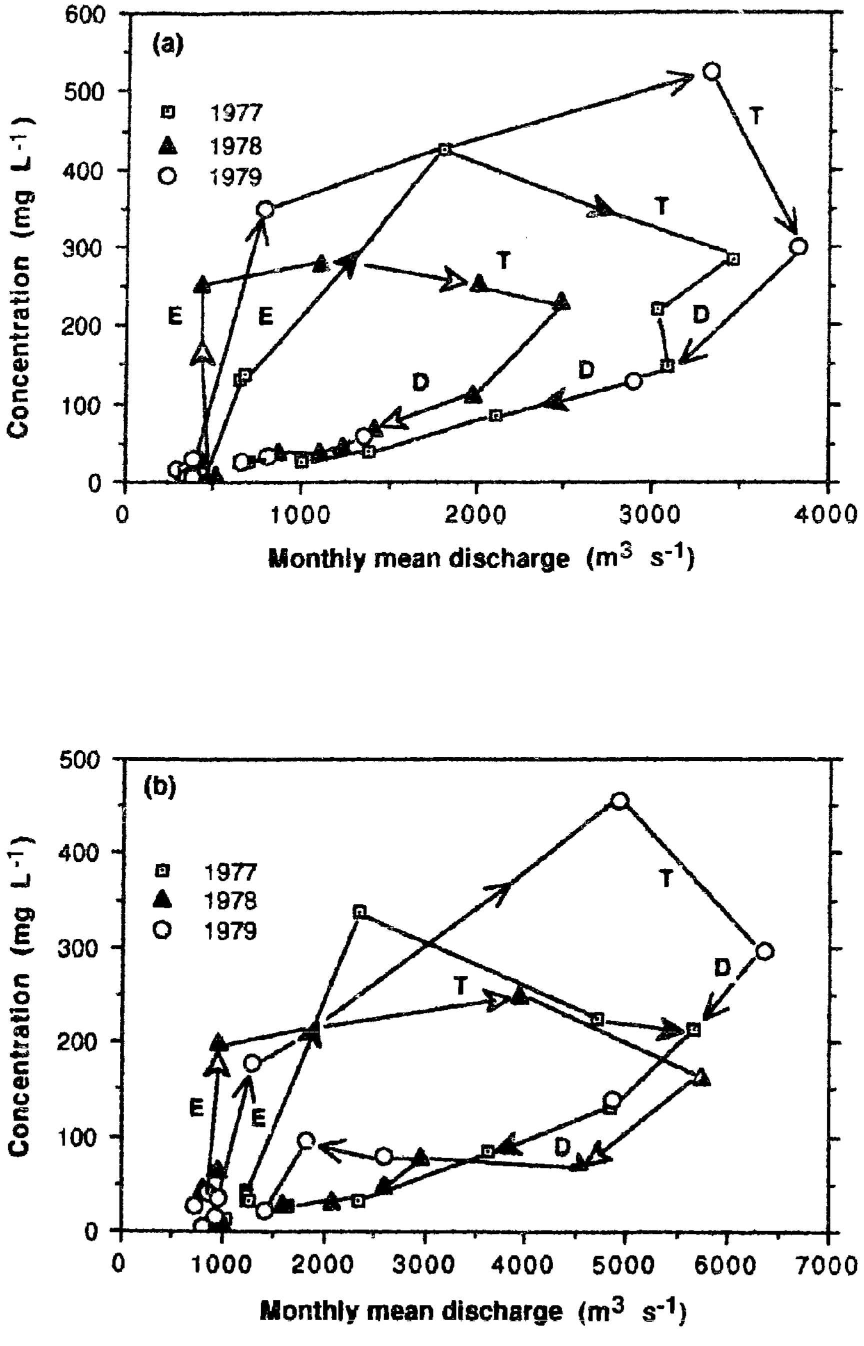


Fig. 4. 13. Pronounced hysteretic loops in the relationships of monthly mean suspended sediment concentration and monthly mean discharge for three years on the Fraser River at (a) Marguerite and (b) Hope stations. Designations (E), (T) and (D) refer to erosion, transport deposition, respectively.

divided into three periods distinguished on the basis of the dominant fluvial processes involved. The three dominant processes conceived for the Fraser River were (1) valley erosion including channel scour (E), (2) sediment transport (T) and (3) deposition by channel filling (D). In this study, hysteresis in the seasonal sediment concentration is related to the seasonal stream-bed scour and fill sequences identified in section 4.1.3.

In this case, the valley erosion phase includes channel scour occurring mainly during snowmelt in the spring months. It is characterized by increased suspended sediment concentration likely caused by the arrival in the channel of suspended sediments produced by rain splash erosion transported by surface runoff. The suspended sediments from valley slopes were augmented by the reworking and remobilization of sediments stored on the river bed during low winter flows.

The transportation phase is similar to the first stationary phase in the bed filling path observed at the Marguerite station in Fig. 4.5b which occurs after the passage of annual discharge peak. It is characterized by a reduction in sediment concentration due to dilution by higher discharges and a low stable stream-bed. The exhaustion of sediment supply from valley slopes and cessation of channel scour marks the onset of deposition and channel fill processes characteristic of the fall and winter months. Overall, the annual sediment discharge process exhibits pronounced hysteresis similar to that observed in the relationships between discharge and stream-bed scour and fill sequences discussed in previous sections.

The analysis of seasonal concentration and stream-bed scour and fill sequences complements Witfield and Schreier's (1981) work which attributes the overall annual hysteresis on the Fraser River to seasonal differences in stream conditions, source area contributions and storage-discharge relationships. Within the overall hysteretic loop they also noted that there exists a system of secondary hysteretic loops caused mainly by individual storms, a matter discussed in Chapter Six.

4.1.6 Summary and Conclusions

In summary, this component of the study has demonstrated that interannual variations of stream-bed elevations in the Fraser River basin varied from station to station and were shown to have been most stable at the Hansard station. In the period of study, the Fraser River at the Marguerite station aggraded following the 1972 flood of record while the Chilliwack River at Vedder Crossing station degraded after the 1968 flood.

The seasonal scour and fill regimes in the Fraser River basin were found to have been characterized by rapid lowering of the bed caused largely by the spring snowmelt and by the progressive adjustment of stream-bed and sediment transport. The spring snowmelt supplied not only discharge but also suspended sediments which were augmented by readily available materials deposited in the channel system during local summer floods (Leopold and Maddock, 1953a: 168-169). The freshet was found to leave river beds at lower elevations than those preceding the spring snowmelt and that the scour cycle was more complete at some stations than at others. Generally, the succession of scour and fill sequences was almost the same from year to year. Sediment concentrations were also found to greatly increase when the discharge for bed scour and bankfull discharges are exceeded as fine sediments trapped in bed forms were accessed by the flow.

CHAPTER FIVE

FACTORS CONTROLLING SINGLE-VALUED SUSPENDED-SEDIMENT RATING CURVES

5.1.1 Assumptions

In order to analyse factors controlling forms of sediment rating curves for single-valued hydrological events, certain assumptions are necessary. The first assumption is that suspended-sediment concentration for single-valued hydrological events is more closely related to the supply of fines (bed-material sediment) from the stream-bed and wash sediment from stream banks than to drainage basin conditions. This assumption is partly supported by Arnborg et al. (1967) and Wood (1972) who observed that bed-material component of suspended-sediment originate from the stream-bed when the rate of change in concentration remains virtually unchanged whether the stage is rising or falling.

The second assumption is that average velocity and average depth are acceptable measures of the non-uniform velocities and depths at measuring stations (Colby, 1964b). Undoubtedly, this assumption is unsatisfactory for some situations given the varied cross-sectional shapes that exist among river reaches and at different stages of flow at the same cross-section.

Thirdly, average velocities and average depths on rising and falling stages in the course of single hydrological events are assumed to change in proportion to discharge. This assumption allows for detailed analysis of the relationships among discharge, depth, and velocity during individual events described in this chapter and in chapters Five and Six.

5.2 Definitions

5.2.1 Single-Valued Sediment Rating Curves

The Task Committee on alluvial streams, ASCE (1971: 110) provided a definition of single-valued relationships:

> "A dependent variable is said to be a single-valued function of a group of independent variables, if for each set of values of the independent variable, the dependent variable takes on one and only one value."

Familiarity with river behaviour and sediment transport processes suggests that single-valued sediment rating curves defined as above would be rare if not non-existent in nature. A more practical operational definition of a single-valued sediment rating curve is one for which concentrations for each value of river discharge on the rising and falling limbs are similar. By this definition, sediment concentrations on the rising and falling stages which are sensibly or statistically similar could be described by an overall linear or non-linear single-valued curve. The diagnostic characteristic used for identification of single-valued sediment rating curves is the lack of moderate to pronounced hysteresis in the sediment-discharge line plot.

5.2.2 Non-linear Sediment Rating Curves

A non-linear curve is one in which the slope of the curve varies over the domain of the function. The graph of a function $f(x)$ is said to be concave if the slope is increasing with x ($f'(x)$ is positive) and convex if the slope is decreasing with x ($f'(x)$ is negative).

An illustration of hydrological events that produce single-valued linear, concave and convex relationships between suspended-sediment concentration and discharge are shown in Fig. 5.1. Note that hydrological events that produce linear, non-linear (concave and convex) rating curves will hereinafter be referred to simply as linear, concave and convex events, respectively.

The use of regression analysis for linear and non-linear sediment-discharge relationships has no physical basis although an implicit assumption of such relations could be made. Linear regression analysis was used mainly as the best tool for quantitative description of the scatter plots of the relations between sediment concentration and discharge for particular hydrological events. Similarly, non-linear polynomial regression analysis was used for some events as the best tool for quantitative description of the relations between sediment concentration and discharge. The polynomial functions were chosen in favour of power functions largely because power functions are best suited for log-transformed data. The data analysed in this study are untransformed sediment concentration and discharge as compiled by Water Survey of Canada. If sediment concentration and discharge data were transformed

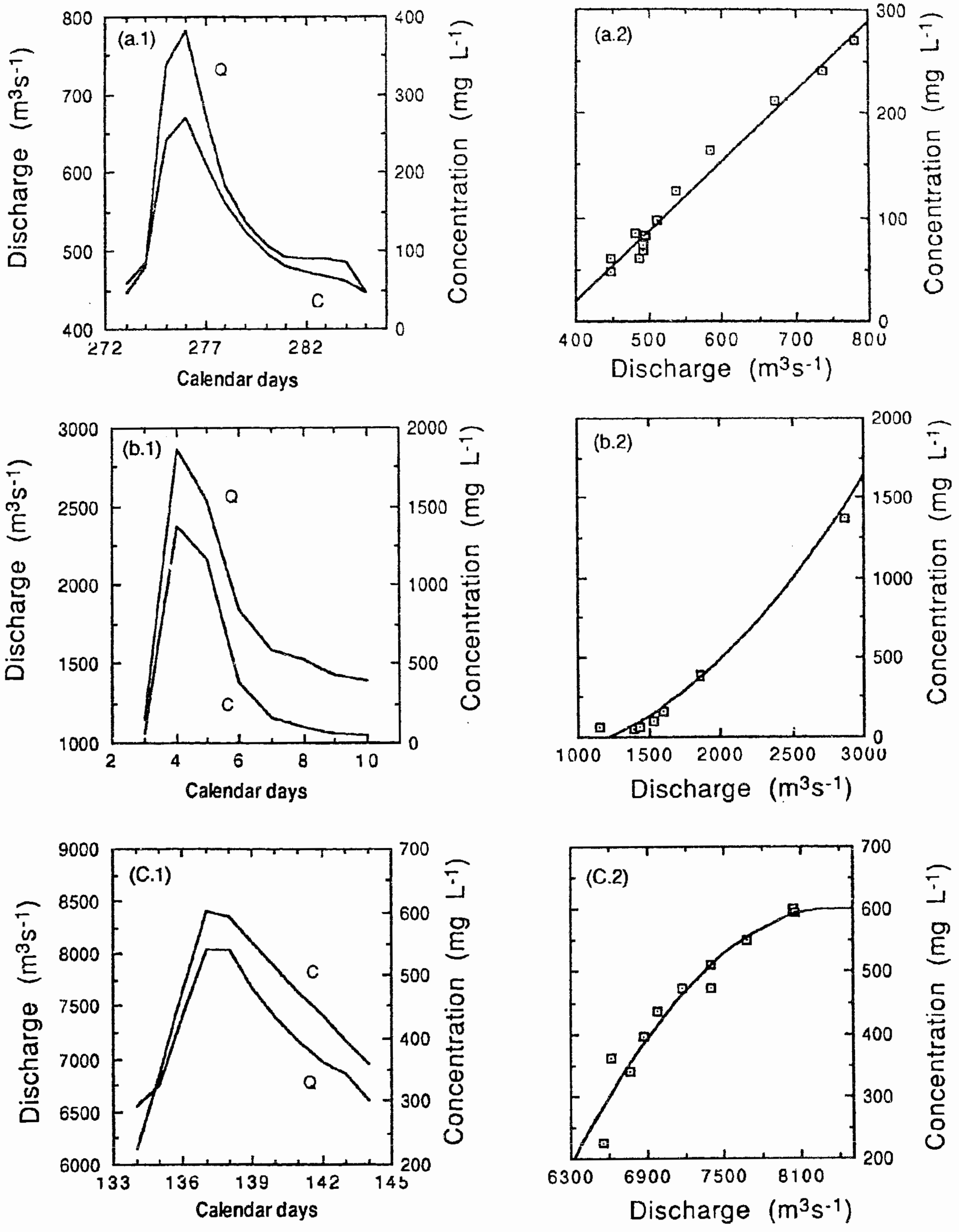


Fig. 5.1. Examples of sediment concentration (C) and discharge (Q) graphs associated with (a) linear, (b) concave and (c) convex, single-valued curves.

to logs and the multiplicative regression power model used, regression lines would have to be corrected due to underestimation of sediment loads (Ferguson, 1986). This would have been an arduous task given the large number of individual hydrological events studied.

However, since polynomial functions behave differently outside the range of the independent variables, each polynomial function used in this study is only valid within the domain of discharge measurements of particular hydrological events.

Using simple linear regression and non-linear polynimial analyses quantitative as well as qualitative characteristics of three types of single-valued sediment rating curves for hydrological events studied are discussed in the sections following.

5.3.1 Description of Linear Single-Valued Sediment Rating Curves

Williams (1989) found that a single-valued linear relationship between sediment concentration and discharge occurs when the C-graph, (a plot of concentration (C) as ordinate and time as abscissa) and the Q-graph (a plot of discharge (Q) as ordinate and time as abscissa) have simultaneous peaks and identical spreads and skewness (Fig. 5.2a, b.1). This study finds, however, that they also can be obtained when C peaks earlier than Q as evidenced by event number 20 of 24 June 1973 on the Fraser River near Agassiz (Table 5.1).

In addition, without attaching any physical meaning to the slopes of the regression lines, it was found that slopes of unity and greater were obtained for linear relationships between sediment concentration and

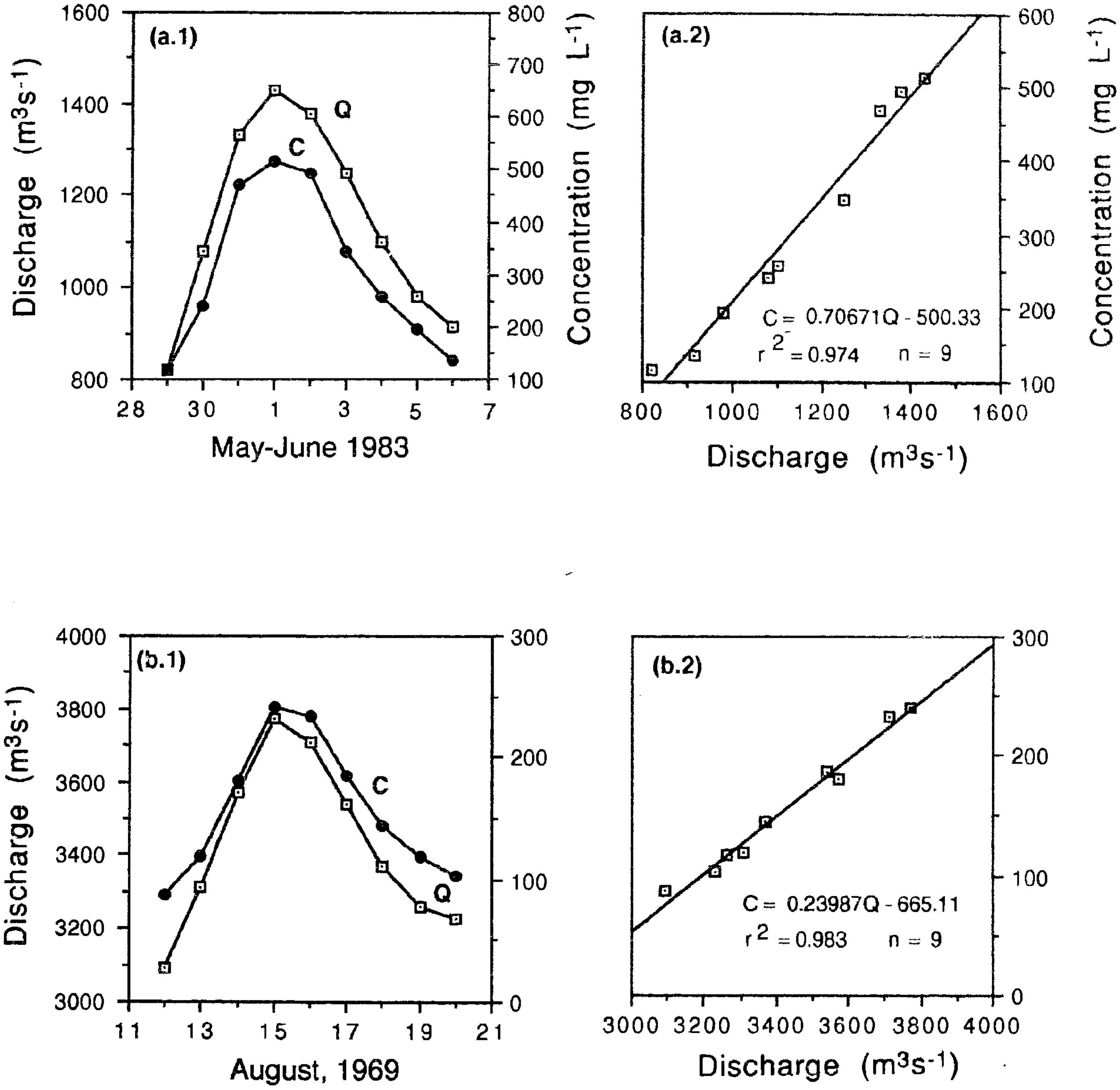


Fig. 5.2. Examples of sediment concentration and discharge graphs for hydrological events with linear sediment rating curves on the Fraser River at (a) Hansard and (b) Hope stations.

Table. 5.1. Summary of qualitative characteristics of temporal graphs for discharge and sediment concentration for storm-period events with linear sediment rating curves in the Fraser River basin.

Event	Station			Peaking first	Skewness	Spread	
no.	no.	River	Period	C or Q	C & Q	C	Q
1.	08KA004	Fraser R. at Hansard	27.09.73 - 12.10.73	Simultaneous	Identical	Narrower	Broader
2.	08KA004	Fraser R. at Hansard	02.06.74 - 09.06.74	Simultaneous	Identical	Narrower	Broader
3.	08KA004	Fraser R. at Hansard	29.09.80 - 11.10.80	Simultaneous	Identical	Narrower	Broader
4.	08KA004	Fraser R. at Hansard	29.05.83 - 06.06.83	Simultaneous	Identical	Narrower	Broader
5.	08KA004	Fraser R. at Hansard	09.06.83 - 14.06.83	Simultaneous	Identical	Narrower	Broader
6.	08KA004	Fraser R. at Hansard	17.06.83 - 24.06.83	Simultaneous	Identical	Broader	Narrower
7.	08LA001	Clearwater R. near Clearwater	27.09.72 - 12.10.72	Simultaneous	Identical	Narrower	Broader
8.	08MC018	Fraser R. near Marguerite	03.06.79 - 11.06.79	Simultaneous	Identical	Narrower	Broader
9.	08MF005	Fraser R. at Hope	09.12.67 - 15.12.67	Simultaneous	Identical	Narrower	Broader
10.	08MF005	Fraser R. at Hope	25.05.69 - 01.06.69	Simultaneous	Identical	Narrower	Broader
11.	08MF005	Fraser R. at Hope	12.08.69 - 20.08.69	Simultaneous	Identical	Narrower	Broader
12.	08MF005	Fraser R. at Hope	21.11.69 - 01.12.69	Simultaneous	Identical	Narrower	Broader

Table 5.1 continued

Event	Station			Peaking first	Skewness	Spread	
no.	no.	River	Period	C or Q	C & Q	C	Q
13.	08MF005	Fraser R. at Hope	31.10.77 - 06.11.77	Simultaneous	Identical	Broader	Narrower
14.	08MF009	Silverhope Cr. near Hope	01.12.68 - 11.12.68	Simultaneous	Identical	Narrower	Broader
15.	08MF009	Silverhope Cr. near Hope	30.09.69 - 07.10.69	Simultaneous	Identical	Narrower	Broader
16.	08MF009	Silverhope Cr. near hope	01.06.70 - 10.06.70	Simultaneous	Identical	Narrower	Broader
17.	08MF035	Fraser R. near Agassiz	23.01.68 - 02.02.68	Simultaneous	Identical	Narrower	Broader
18.	08MF035	Fraser R. near Agassiz	10.08.69 - 21.08.69	Simultaneous	Identical	Narrower	Broader
19.	08MF035	Fraser R. near Agassiz	08.06.73 - 16.06.73	Simultaneous	Identical	Narrower	Broader
20.	08MF035	Fraser R. near Agassiz	24.06.73 - 04.07.73	C	Identical	Narrower	Broader
21.	08MF035	Fraser R. near Agassiz	16.01.86 - 24.01.86	Simultaneous	Identical	Narrower	Broader
22.	08MF035	Fraser R.near Agassiz	22.02.86 - 05.03.86	Simultaneous	Identical	Narrower	Broader
23.	08MG013	Harrison R. near Harrison L.	01.01.70 - 09.01.70	Simultaneous	Identical	Narrower	Broader
24.	08MG013	Harrison R. near Harrison L.	12.03.70 - 23.03.70	Simultaneous	Identical	Narrower	Broader
25.	08MH001	Chilliwack R.at Vedder Crossing	12.01.68 - 18.01.68	Simultaneous	Identical	Narrower	Broader
26.	08MH001	Chilliwack R. at Vedder Crossing	19.01.68 - 23.01.68	Simultaneous	Identical	Narrower	Broader
27.	08MH001	Chilliwack R.at Vedder Crossing	01.02.68 - 09.02.68	Simultaneous	Identical	Broader	Narrower

Table 5.1 concluded

Event	Station			Peaking first	Skewness	Spread	
no.	no.	River	Period	C or Q	C & Q	C	Q
28.	08MH001	Chilliwack R. at Vedder Crossing	30.05.70 - 12.06.70	Simultaneous	Identical	Narrower	Broader
29.	08MH001	Chilliwack R. at Vedder Crossing	19.01.72 - 29.01.72	Simultaneous	Identical	Narrower	Broader
30.	08MH001	Chilliwack R. at Vedder Crossing	30.05.75 - 11.06.75	Simultaneous	Identical	Narrower	Broader
31.	08MH024	Fraser R. at Mission	09.08.69 - 20.08.69	Simultaneous	Identical	Narrower	Broader

discharge on some of the Fraser River stations. Table 5.2 shows that overall slopes of unity and greater were mainly observed on smaller streams such as Silverhope Creek, for storm event 14, 15, and 16; on the Harrison River for storm event number 29, and on the Chilliwack River for storm event number 26. All of these rivers, except for a few exceptional events, generally carried low concentrations of suspended-sediment.

The majority of the linear C-Q relations observed in this study had slopes less than 1 in the overall, rising and falling plots. The overall linear relationships between sediment concentration and discharge were strong, explaining between 91 and 99% of the variation in sediment concentration. The standard errors of estimate generally were higher for larger than smaller rivers. This indicates that, for single-valued events there is a tendency for sediment concentration to be more closely related to discharge on smaller than larger rivers. For instance, the highest overall r^2 of 0.995 was observed on the Silverhope Creek for event number 15 of 30 September 1969, while the lowest overall r^2 of 0.913 was for event number 30 of 9 August, 1969 observed on Fraser River at Mission station. Generally, sediment concentrations were more closely related to discharge in the rising (r^2: 0.931-1) than falling (r^2: 0.880-0.998) stages of single-valued linear curves effected by single hydrological events. But the slopes of the regression lines for the rising stages generally were steeper than those for falling stages (Table 5.2) indicating that sediment concentration increased more rapidly on the rising than it declined on the falling stage.

Note that this observation is based on the comparison of all events in a given category, relations for individual events in the rising and falling stages did not differ significantly for the overall curves not to be

Table. 5.2. Regression correlation coefficients for relationships between sediment concencentration (C) and discharge (Q) for storm-period events with linear single-valued sediment rating curves in the Fraser River basin.

Event	Station			Overall			Rising			Falling		
no.	no.	River	Period	Rating curve	r^2	Se	Rating curve	r^2	Se	Rating curve	r^2	Se
1.	08KA004	Fraser	27.09.73 - 12.10.73	C = 0.807Q - 224.252	0.968	35.309	C = 0.74Q - 175.295	0.993	25.224	C = 0.819Q - 257.741	0.957	34.935
2.	08KA004	Fraser	02.06.74 - 09.06.74	C = 0.497Q - 344.622	0.926	17.984	C = 0.438^{b}Q - 272.539	0.979	17.578	C = 0.664Q - 520.131	0.946	12.611
3.	08KA004	Fraser	29.09.80 - 11.10.80	C = 0.672Q - 247.983	0.978	11.569	C = 0.621Q - 215.891	1	01.894	C = 0.79Q - 310.051	0.969	10.154
4.	08KA004	Fraser	29.05.83 - 06.06.83	C = 0.707Q - 500.331	0.974	26.524	C = 0.686Q - 463.646	0.982	31.13	C = 0.725Q - 530.402	0.978	24.049
5.	08KA004	Fraser	09.06.83 - 14.06.83	C = 0.486Q - 366.397	0.987	06.525	C = 0.465^{b}Q - 332.6	0.973	10.352	C = 0.497^{b}Q - 366.893	0.99	07.207
6.	08KA004	Fraser	17.06.83 - 24.06.83	C = 0.262Q - 161.266	0.968	07.801	C = 0.248Q - 146.62	0.982	06.568	C = 0.352^{b}Q - 247.698	0.982	06.752
7.	08LA001	Clearwater	27.09.72 - 12.10.72	C = 0.091Q - 41.964	0.928	04.045	C = 0.1Q - 48.667	0.994	01.709	C = Q + 0	1	00.000
8.	08MC018	Fraser	03.06.79 - 11.06.79	C = 0.31Q - 818.361	0.929	63.405	C = 0.364Q - 1038.915	0.981	44.042	C = 0.238Q - 508.996	0.948	48.560
9.	08MF005	Fraser	09.12.67 - 15.12.67	C = 0.419Q - 478.301	0.951	15.535	C = 0.528Q - 647.31	1	00.000	C = 0.401Q - 449.119	0.991	06.140
10.	08MF005	Fraser	25.05.69 - 01.06.69	C = 0.264Q - 1374.25	0.967	18.627	C = 0.267Q - 1389.071	0.970	21.078	C = 0.248Q - 1276.91	0.981	17.401
11.	08MF005	Fraser	12.08.69 - 20.08.69	C = 0.24Q - 665.114	0.983	07.852	C = 0.227Q - 624.071	0.981	11.601	C = 0.261Q - 735.28	0.998	02.904
12.	08MF005	Fraser	21.11.69 - 01.12.69	C = 0.208Q - 256.404	0.976	06.751	C = 0.233Q - 408.408	0.999	02.360	C = 0.177Q - 292.391	0.978	05.093

Table 5.2 continued

Event no.	Station no.	River	Period	Overall Rating curve	Overall r^2	Overall Se	Rising Rating curve	Rising r^2	Rising Se	Falling Rating curve	Falling r^2	Falling Se
13.	08MF005	Fraser	31.10.77 - 06.11.77	C = 0.369Q - 500.431	0.965	10.845	C = 0.412Q - 575.246	0.978	15.753	C = 0.32Q - 426.848	0.899	10.246
14.	08MF009	Silverhope	01.12.68 - 11.12.68	C = 1.696 + 0.28Q	0.970	00.911	$C = 2.103 + 0.252^{a}Q$	0.997	00.492	C = 1.266 + 0.305Q	0.970	00.889
15.	08MF009	Silverhope	30.09.69 - 07.10.69	C = 2.543Q - 21.661	0.995	00.815	$C = 2.556^{a}Q - 21.829$	0.997	01.301	C = 2.459Q - 20.781	0.974	00.954
16.	08MF009	Silverhope	01.06.70 - 10.06.70	C = 2.745Q - 41.691	0.950	05.075	$C = 2.684^{b}Q - 44.064$	0.991	04.253	C = 3.323Q - 58.66	0.984	02.494
17.	08MF035	Fraser	23.01.68 - 02.02.68	C = 0.162Q - 214.733	0.948	16.926	C = 0.138Q - 145.845	0.953	14.364	C = 0.184Q - 279.242	0.989	10.512
18.	08MF035	Fraser	10.08.69 - 21.08.69	C = 0.181Q - 508.58	0.970	7.985	C = 0.181Q - 513.271	0.990	06.094	C = 0.167Q - 454.111	0.949	06.095
19.	08MF035	Fraser	08.06.73 - 16.06.73	C = 0.118Q - 525.166	0.971	15.616	C = 0.134Q - 631.415	0.996	08.264	C = 0.102Q - 426.217	0.975	13.518
20.	08MF035	Fraser	24.06.73 - 04.07.73	C = 0.123Q - 592.427	0.927	29.938	C = 0.135Q - 671.164	0.970	25.347	C = 0.087Q - 353.706	0.922	20.631
21.	08MF035	Fraser	16.01.86 - 24.01.86	C = 0.365Q - 341.921	0.943	27.366	$C = 0.35^{a}Q - 319.106$	0.949	42.319	C = 0.492Q - 480.715	0.947	14.682
22.	08MF035	Fraser	22.02.86 - 05.03.86	C = 0.233Q - 187.528	0.959	22.338	C = 0.221Q - 163.555	0.978	30.397	C = 0.271Q - 241.195	0.954	16.731
23.	08MG013	Harrison	01.01.70 - 09.01.70	C = 0.057Q - 29.841	0.941	01.698	C = 0.06Q - 30.773	0.992	00.730	$C = 0.05^{b}Q - 26.999$	0.986	00.911
24.	08MG013	Harrison	12.03.70 - 23.03.70	C = 1.72Q + 100.875	0.968	01.813	C = 0.51Q - 50.576	0.982	00.932	C = 0.467Q - 43.175	0.934	00.592
25.	08MH001	Chilliwack	12.01.68 - 18.01.68	C = 0.688Q - 33.948	0.976	07.147	C = 0.653Q -27.362	0.990	08.408	C = 0.823Q -54.884	0.986	04.862
26.	08MH001	Chilliwack	19.01.68 - 23.01.68	C = 0.779Q - 34.345	0.920	18.366	C = 0.811Q - 51.062	1	01.096	C = 0.688Q - 5.085	0.793	26.951

Table 5.2 concluded

Event	Station			Overall			Rising			Falling		
no.	no.	River	Period	Rating curve	r^2	Se	Rating curve	r^2	Se	Rating curve	r^2	Se
27.	08MH001	Chilliwack	01.02.68 - 09.02.68	$C = 0.319Q - 14.055$	0.956	01.153	$C = 0.304^{a}Q - 12.375$	0.945	01.775	$C = 0.326Q - 14.894$	0.964	00.777
28.	08MH001	Chilliwack	30.05.70 - 12.06.70	$C = 0.55Q - 26.886$	0.959	05.874	$C = 0.604Q - 38.532$	0.998	01.865	$C = 0.477Q - 13.435$	0.958	04.741
29.	08MH001	Chilliwack	19.01.72 - 29.01.72	$C = 0.554Q - 12.304$	0.971	02.565	$C = 0.463^{a}Q - 4.891$	0.999	00.843	$C = 0.667Q - 18.567$	0.998	00.596
30.	08MH001	Chilliwack	30.05.75 - 11.06.75	$C = 1.06Q - 103.223$	0.916	13.529	$C = 1.137Q - 123.681$	0.931	13.668	$C = 1.146Q - 113.761$	0.880	13.856
31.	08MH024	Fraser	09.08.69 - 20.08.69	$C = 0.173Q - 580.437$	0.913	16.602	$C = 0.17Q - 564.165$	0.957	12.883	$C = 0.279Q - 1020.99$	0.979	08.933

NOTES: 1. Superscripts indicate levels of significance for coefficients occurring less frequently: (a) - significant at 95 percent level; (b) - 90 percent level. Where no superscripts are shown the coefficients are significant at the 99 percent level.

2. Se standards for the standard error of estimate (mg L^{-1}).

considered as singue-valued.

5.3.2 Description of Non-linear Single-valued Sediment Rating Curves

This section discusses concave and convex forms of sediment rating curves observed at sediment stations in the Fraser River basin.

5.3.3 Characteristics of Concave Sediment Rating Curves

Williams (1989) notes that the concave rating curve occurs where the spread of the C-graph is less than that of the Q-graph (Fig. 5.1b). The associated rating curve bends upward so that its slope increases with increasing discharge. Examples of the concave C-Q relations observed in the Fraser River basin shown in Fig. 5.3 have similar characteristics to those reported by Williams (1989).

The C-graphs and Q-graphs for different events in the Fraser River basin were characterized by identical skewness and narrower spreads for C-graphs than Q-graphs (Table 5.3). In a majority of cases C and Q peaked simultaneously. However, a concave rating curve was also obtained when Q peaked earlier than C for event number 42 on 20 March 1972 at Mission station on Fraser River.

Differences in the characteristics of individual concave events were reflected in the variable equations shown in Table 5.4, despite very high correlation coefficients obtained between sediment concentration and discharge. The non-linear regression analysis showed that

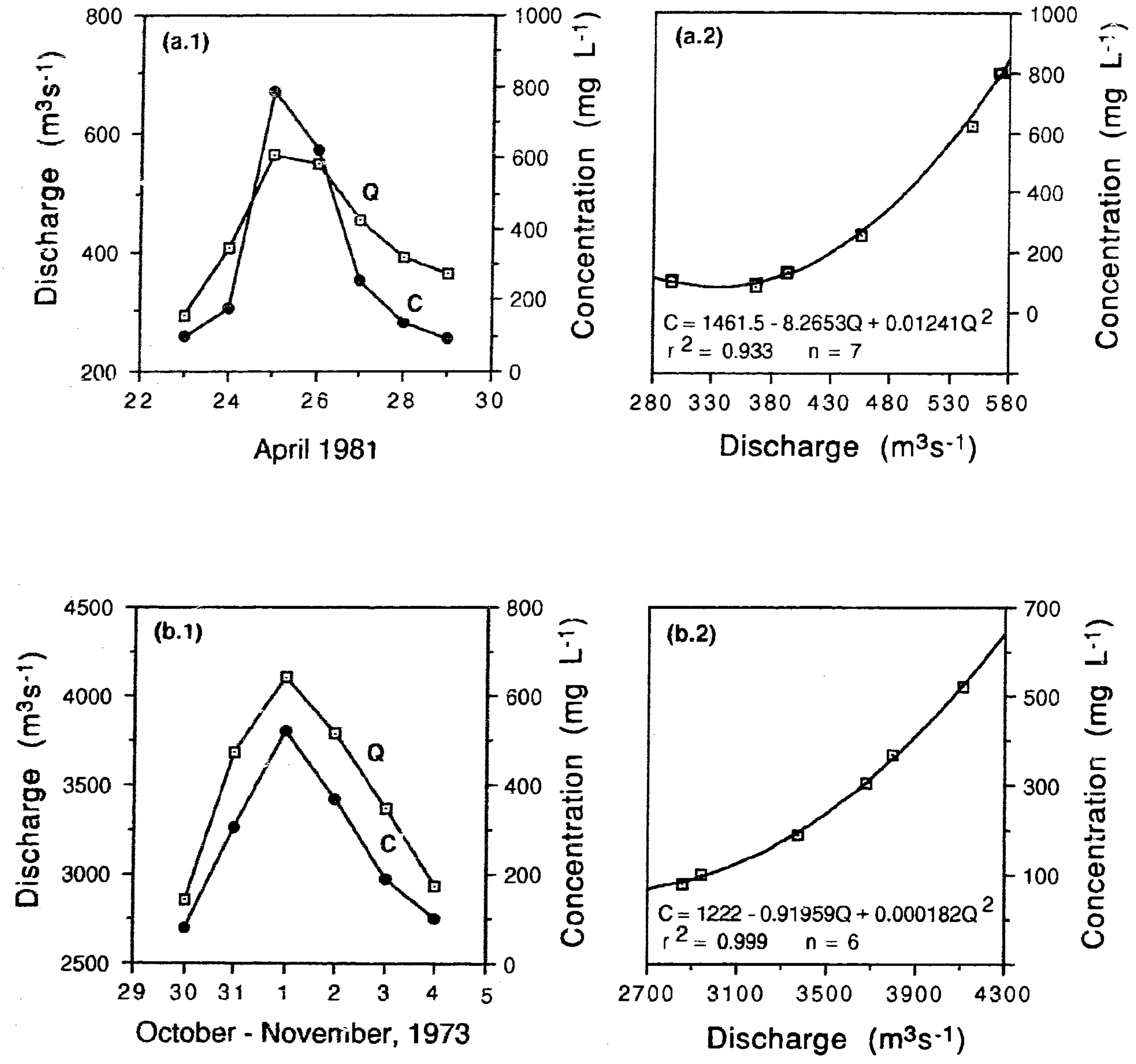


Fig. 5.3. Examples of sediment concentration and discharge graphs for hydrological events with concave sediment rating curves on the Fraser River at (a) Hansard and (b) near Agassiz stations.

Table. 5.3. Summary of qualitative characteristics of temporal graphs for discharge and sediment concentration for storm-period events with concave sediment rating curves in the Fraser River basin.

Event	Station			Peaking first	Skewness	Spread	
No.	No.	River	Period	C or Q	C & Q	C	Q
32.	08KA004	Fraser R. at Hansard	27.03.81 - 07.04.81	Simultaneous	Identical	Narrower	Broader
33.	08KA004	Fraser R. at Hansard	23.04.81 - 29.04.81	Simultaneous	Identical	Narrower	Broader
34.	08MC018	Fraser R. near Marguerite	07.06.77 - 15.06.77	Simultaneous	Identical	Narrower	Broader
35.	08MF005	Fraser R. at Hope	16.01.77 - 28.01.77	Simultaneous	Identical	Narrower	Broader
36.	08MF035	Fraser R.near Agassiz	30.10.73 - 05.11.73	Simultaneous	Identical	Narrower	Broader
37.	08MF035	Fraser R. near Agassiz	03.09.82 - 22.09.82	Simultaneous	Identical	Narrower	Broader
38.	08MF035	Fraser R.near Agassiz	03.01.84 - 10.01.84	Simultaneous	Identical	Narrower	Broader
49.	08MH001	Chilliwack R.at Vedder Crossing	22.09.65 - 30.09.65	Simultaneous	Identical	Narrower	Broader
40.	08MH001	Chilliwack R. at Vedder Crossing	30.11.75 - 07.12.75	Simultaneous	Identical	Narrower	Broader
41.	08MH024	Fraser R. at Mission	15.05.71 - 21.05.71	Simultaneous	Identical	Broader	Narrower
42.	08MH024	Fraser R. at Mission	20.03.72 - 31.03.72	Q	Identical	Narrower	Broader
43.	08MH024	Fraser R. at Mission	06.06.73 - 16.06.73	Simultaneous	Identical	Narrower	Broader
44.	08MH024	Fraser R. at Mission	12.06.87 - 23.06.87	Simultaneous	Identical	Narrower	Broader

Table. 5.4. Regression correlation coefficients for the relationhips between sediment concentration (C) and discharge (Q) for storm-period events with concave single-valued sediment rating curves in the Fraser River basin.

Event no.	Station no.	River	Period	Non - linear curve	r^2	Se^1
32.	08KA004	Fraser R. at Hansard	27.03.81 - 07.04.81	$C = 257.679 - 3.078Q + 0.01Q^2$	0.975	003.779
33.	08KA004	Fraser R. at Hansard	23.04.81 - 29.04.81	$C = 1461.515 - 8.265Q + 0.012Q^2$	0.993	028.772
34.	08MC018	Fraser R. near Marguerite	07.06.77 - 15.06.77	$C = 2159.71Q -1.542Q + 0.0002927Q^2$	0.937	082.597
35.	08MF005	Fraser R. at Hope	16.01.77 - 28.01.77	$C = 317.593 - 0.604Q + 0.0002916Q^2$	0.947	104.803
36.	08MF035	Fraser R. near Agassiz	30.10.73 - 05.11.73	$C = 1222.148 - 0.92Q + 0.0001824Q^2$	0.999	008.319
37.	08MF035	Fraser R. near Agassiz	03.09.82 - 22.09.82	$C = 42.084 - 0.059Q + 0.00002187Q^2$	0.990	013.921
38.	08MF035	Fraser R. near Agassiz	03.01.84 - 10.01.84	$C = - 88.023 - 0.275Q + 0.0002826Q^2$	0.981	088.000
39.	08MH001	Chilliwack R. at Vedder Crossing	22.09.65 - 30.09.65	$C = 28.815 - 3.991Q + 0.177Q^2$	0.988	009.657
40.	08MH001	Chilliwack R. at Vedder Crossing	30.11.75 - 07.12.75	$C = 8.022 - 2.028Q + 0.019Q^2$	0.948	434.363
41.	08MH024	Fraser R. at Mission	15.05.71 - 21.05.71	$C = 5989.131 - 1.732Q + 0.00013Q^2$	0.992	013.937

Table 5.4 continued

Event no.	Station no.	River	Period	Non - linear curve	r^2	Se[1]
42.	08MH024	Fraser R. at Mission	20.03.72 - 31.03.72	$C = 2740.354 - 2.078Q + 0.0002078Q^2$	0.973	039.298
43.	08MH024	Fraser R. at Mission	06.06.73 - 16.06.73	$C = 1284.209 - 0.399Q + 00003476Q^2$	0.979	009.417
44.	08MH024	Fraser R. at Mission	12.06.87 - 23.06.87	$C = 10789.063 - 2.927Q + 0.0002016Q^2$	0.855	046.160

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[1] Se stands for the standard error of estimate (mg L-1).

discharge alone explained between 83 and 99% of the variation in sediment concentration. Results of simple linear regression analysis in Table 5.5 show that rising discharges explained between 52% (r^2 = 0.521) and 100% (r^2 = 1) of the variation in sediment concentration while falling discharges explained between 79% (r^2 = 0.794) and 99% (r^2 = 0.989).

These findings indicate that sediment concentration was more closely related to discharge on falling than on rising stage for concave rating curves. Moreover, higher average slopes (b = 1.811) were observed on the rising than on falling stages (b = 0.944). This suggests that sediment transportation for concave rating curves resemble that for linear curves in which more sediments are transported on the rising than falling stages.

5.3.4 Characteristics of Convex Sediment Rating Curves

The concave rating curves were observed by Williams (1989) to occur when the spread of the C-graph is greater than the Q-graph (Fig. 5.4d, e, f). On the Fraser River the convex form of the rating curve was generally observed when C and Q peaked simultaneously (Table 5.6). But the convex rating curves also occurred when C peaked earlier than Q, as displayed by event number 44 on 10 December 1966 on Silverhope Creek near Hope.

Sediment concentrations in convex events were also found to be strongly related to discharge (r^2: 0.890-0.969) as indicated by the results of non-linear regression analysis shown in Table 5.7. When the data

Table. 5.5. Rising and falling regression correlation coefficients for relationships between sediment concencentration (C) and discharge (Q) for storm-period events with concave single-valued sediment rating curves in the Fraser River basin.

Event	Station			Rising			Falling		
no.	no.	River	Period	Rating curve	r^2	Se	Rating curve	r^2	Se
32.	08KA004	Fraser R. at Hansard	27.03.81 - 07.04.81	C = 0.559Q - 140.352	0.868	05.588	C = 0.754Q - 97.858	0.910	06.218
33.	08KA004	Fraser R. at Hansard	23.04.81 - 29.04.81	$C = 2.631^{a}Q - 756.475$	0.900	168.15	C = 2.933Q - 1015.521	0.967	53.487
34.	08MC018	Fraser R. near Marguerite	07.06.77 - 15.06.77	C = 0.518Q - 1332.958	0.997	22.048	$C = 0.72^{b}Q - 2193.04$	0.879	80.091
35.	08MF005	Fraser R. at Hope	16.01.77 - 28.01.77	C = 0.278Q - 307.115	1	03.213	C = 0.265Q -324.716	0.794	13.480
36.	08MF035	Fraser R. near Agassiz	30.10.73 - 05.11.73	$C = 0.343^{b}Q - 915.306$	0.970	53.800	$C = 0.311^{c}Q - 828.208$	0.963	36.790
37.	08MF035	Fraser R. near Agassiz	03.09.82 - 22.09.82	C = 0.114Q - 386.219	0.996	09.198	C = 0.139Q - 392.11	0.952	29.850
38.	08MF035	Fraser R. near Agassiz	03.01.84 - 10.01.84	C = 0.762Q - 817.541	1	00.000	C = 0.998Q - 1398.105	0.988	53.520
39.	08MH001	Chilliwack R. at Vedder Crossing	22.09.65 - 30.09.65	C = 8.356Q - 149.133	0.999	03.397	C = 4.27Q - 66.543	0.919	05.565
40.	08MH001	Chilliwack R. at Vedder Crossing	30.11.75 - 07.11.75	C = 8.841Q - 709.285	0.999	66.082	C = 17.544Q - 3897.52	0.989	125.297
41.	08MH024	Fraser R. at Mission	15.05.71 - 21.05.71	$C = 0.359^{c}Q - 2411.393$	0.958	32.339	$C = 0.186^{a}Q - 1045.815$	0.939	36.764

Table 5.5 continued

Event	Station			Rising			Falling		
no.	no.	River	Period	Rating curve	r^2	Se	Rating curve	r^2	Se
41.	08MH024	Fraser R. at Mission	15.05.71 - 21.05.71	$C = 0.359^cQ - 2411.393$	0.958	32.339	$C = 0.186^aQ - 1045.815$	0.939	36.764
42.	08MH024	Fraser R. at Mission	20.03.72 - 31.03.72	$C = 0.53Q - 1366.275$	0.965	63.317	$C = 0.491Q - 1230.061$	0.865	79.401
43.	08MH024	Fraser R. at Mission	06.06.73 - 16.06.73	$C = 0.084Q - 378.318$	0.939	18.237	$C = 0.083Q - 379.288$	0.968	09.939
44.	08MH024	Fraser R. at Mission	12.06.87 - 23.06.87	$C = 0.169^bQ - 1047.644$	0.521	95.654	$C = 0.18Q - 1134.95$	0.869	36.213

NOTES:

1. Superscripts indicate levels of significance for coefficients occurring less frequently: (a) - significant at 95 percent level; (b) - 90 percent level; and (c) - 80 percent. Where no superscripts are shown the coefficients are significant at the 99 percent level.
2. Se standards for the standard error of estimate (mg L^{-1}).

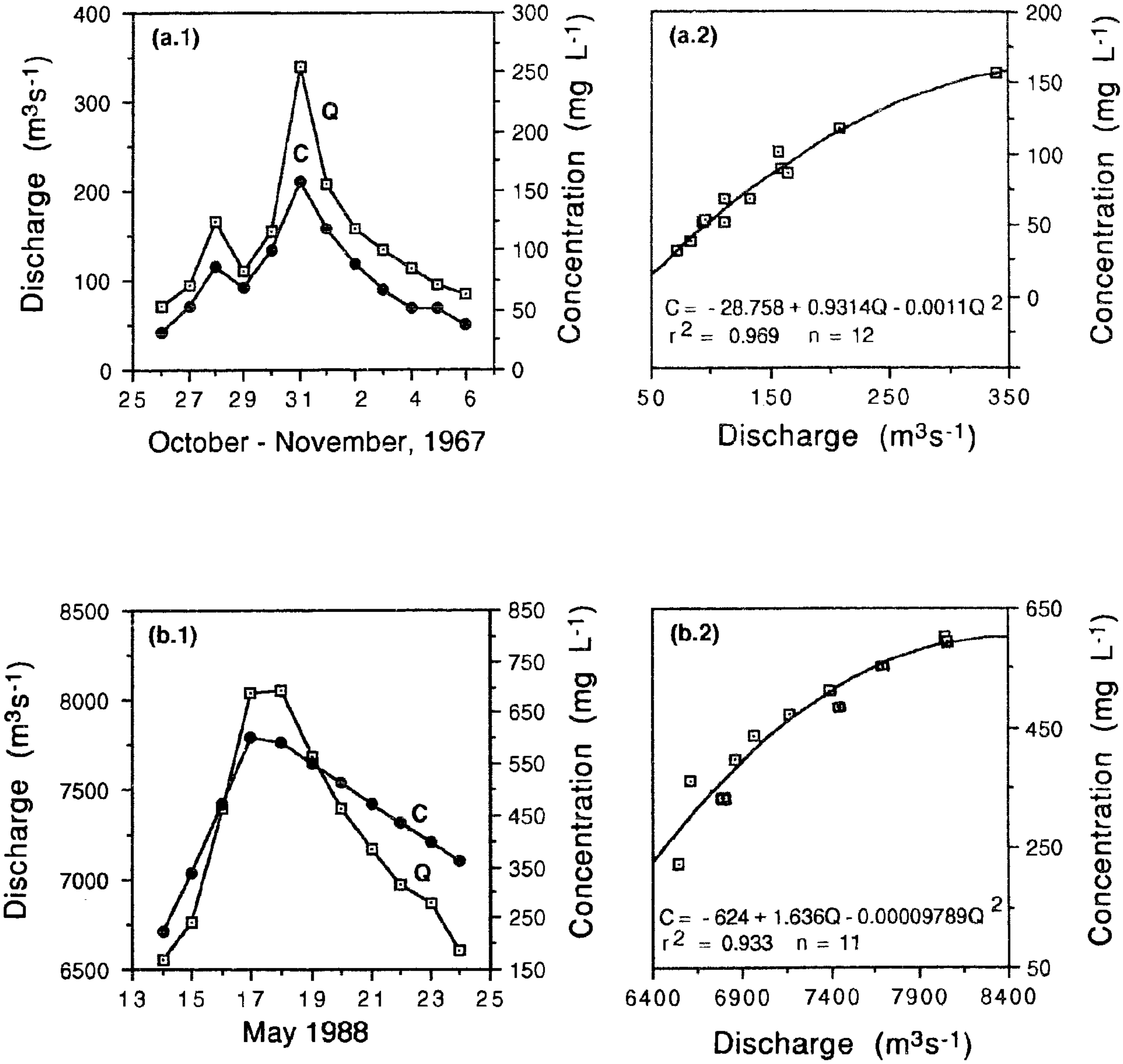

Fig. 5.4. Examples of sediment concentration and discharge graphs for hydrological events with convex sediment rating curves at (a) Vedder Crossing station on the Chilliwack River and (b) Mission station on the Fraser River.

Table. 5.6. Summary of qualitative characteristics of temporal graphs for discharge and sediment concentration for storm-period events with convex sediment rating curves in the Fraser River basin.

Event	Station			Peaking first	Skewness	Spread	
no.	no.	River	Period	C or Q	C & Q	C	Q
45.	08MF009	Silverhope Cr. near Hope	10.12.66 - 28.12.66	C	Identical	Narrower	Broader
46.	08MH001	Chilliwack R.at Vedder Crossing	26.10.67 - 06.11.67	Simultaneous	Identical	Narrower	Broader
47.	08MH001	Chilliwack R. at Vedder Crossing	23.01.68 - 28.01.68	Simultaneous	Identical	Narrower	Broader
48.	08MH001	Chilliwack R. at Vedder Crossing	31.05.68 - 10.06.68	Simultaneous	Identical	Broader	Narrower
49.	08MH024	Fraser R. at Mission	14.05.88 - 24.05.88	Simultaneous	Identical	Narrower	Broader

were divided into the rising and falling stages, simple linear regression analysis showed that rising discharge explained between 58% (r^2 = 0.579) and 100% (r^2 = 1) of the variation in sediment concentration, while falling discharges accounted for between 65% (r^2 = 0.651) and 99% (r^2 = 0.986) of the variation in sediment concentration (Table 5.8).

But since average slopes of the regression lines on the falling stage (b = 0.588) were higher than for the rising stages (b = 0.352), the potential for sediment transport was higher on the falling than rising stages for the convex rating curves. This finding was partly supported by Kuhnle's (1992: 196) and Reid and Frostick's (1984) observations of greater mean bed load transport rates during falling than rising stages. Reid and Frostick (1984) showed that these observations were related to the existence of greater flow strengths for sediment motion at the beginning than at the end of an hydrological event. The physical explanation given for this is that the bed becomes more stable with the passage of time during individual events.

In summary, the strong relationships between concentration and discharge observed for the linear, concave and convex rating curves indicate that these different forms of curves were not controlled by fixed hydrological, geomorphological or sedimentological factors. Rather, as the findings reported herein strongly suggest, sediment concentration for single-valued hydrological events were controlled by a variety of factors; these are analysed in later sections.

Table. 5.7. Regression correlation coefficients for the relationhips between sediment concentration (C) and discharge (Q) for storm-period events with convex single-valued sediment rating curves in the Fraser River basin.

Event no.	Station no.	River	Period	Non - linear curve	r^2	Se[1]
45.	08MF009	Silverhope Cr near Hope	10.12.66 - 28.12.66	$C = 3.307 + 1.043Q - 0.007Q^2$	0.890	3.247
46.	08MH001	Chilliwack R. at Vedder Crossing	26.10.67 - 06.11.67	$C = -28.568 + 0.93Q - 0.001Q^2$	0.969	7.027
47.	08MH001	Chilliwack R. at Vedder Crossing	23.01.68 - 28.01.68	$C = -296.925 + 3.174Q - 0.005Q^2$	0.948	18.337
48.	08MH001	Chilliwack R. at Vedder Crossing	31.05.68 - 10.06.68	$C = -66.812 - 0.91Q - 0.001Q2$	0.968	7.016
49.	08MH024	Fraser R. at Mission	14.05.88 - 24.05.88	$C = -6233 + 1.636Q - 0.00009789Q^2$	0.933	33.319

[1] Se stands for the standard error of estimate (mg L^{-1}).

Table 5.8. Rising and falling regression correlation coefficients for relationships between sediment concencentration (C) and discharge (Q) for storm-period events with convex single-valued sediment rating curves in the Fraser River basin.

Event	Station			Rising			Falling		
no.	no.	River	Period	Rating curve	r^2	Se	Rating curve	r^2	Se
45.	08MF009	Silverhope Cr. near Hope	10.12.66 - 28.12.66	$C = 19.274 + 0.279Q$	0.579	07.096	$C = 16.346 + 0.247Q$	0.651	04.534
46.	08MH001	Chilliwack R. at Vedder Crossing	26.10.67 - 06.11.67	$C = 15.022 + 0.436Q$	0.937	12.288	$C = 0.63Q - 13.403$	0.982	04.457
47.	08MH001	Chilliwack R. at Vedder Crossing	23.01.68 - 28.01.68	$C = 21.444 + 0.444Q$	1.000	00.000	$C = 1.444^{a}Q - 166.253$	0.956	14.602
48.	08MH001	Chilliwack R. at Vedder Crossing	31.05.68 - 10.06.68	$C = 0.377^{c}Q - 16.338$	0.924	26.904	$C = 0.434Q - 14.538$	0.968	03.745
49.	08MH024	Fraser R. at Mission	14.05.88 - 24.05.88	$C = 0.231Q - 1250.958$	0.973	30.973	$C = 0.186Q - 868.947$	0.986	09.541

NOTES: 1. Superscripts indicate levels of significance for coefficients occurring less frequently: (a) - significant at 95 percent level; (b) - 90 percent level; and (c) - 80 percent. Where no superscripts are shown the coefficient are significant at the 99 percent lecel.

2. Se standards for the standard error of estimate (mg L^{-1}).

5.4 Implications of Sediment Concentration and Discharge Hydrograph Characteristics for Single Hydrological Events on Sediment Transport

The investigation of discharge and sediment hydrographs for individual events was useful for the assessment of factors controlling sediment variation in rivers. Features of temporal graphs such as the spreads, timing of discharge and concentration peaks gave clues to the factors controlling different types of rating curves. For instance, the simultaneous peaking of C and Q for linear rating curves could be said to occur under conditions of sediment exhaustion and replenishment. Additionally, events for linear rating curves were found to have occurred throughout the year as flashy, isolated events. On infrequent occasions, they also occurred one after another in quick succession, suggesting that abundant supply of sediments from valley slopes and river channels was one of the controlling factors. This is because, if sediment supply was limited both from the stream-bed and valley slopes, linear sediment rating curves would not have occurred one after another.

In addition, the majority of linear curves occurred during periods of high discharges (May-June) and (October-December) when maximum sediment loads were transported. These two time periods are generally separated by prolonged periods of base flow which implies that, for linear curves to be produced, most sediments originated from the stream-bed and channel banks. Wood (1977) found that in situations where little or no variation in concentration occurred for a given discharge on the rising and falling limbs, the sediment concentration curve was a function of discharge only. He found this to obtain both in conditions of low and high sediment concentrations.

Under conditions of high sediment concentration, linear single-valued curves occur when flood events are not long enough to cause exhaustion of readily transportable materials. It was probably the case for those events which occurred in the May-June period when the snowmelt peak discharge contributed unlimited supply of suspended sediments from valley slopes. When linear curves occurred under conditions of low suspended sediment concentrations, in the October-December period, the rising stages were probably controlled by an exhaustible abundant quantity of fine sediments originating from the channel itself (Arnborg et al. 1967) which were not replenished on falling stages.

The earlier peaking of Q than C observed for the concave rating curves at Mission station on the Fraser River, implies that dilution of flow occurred on the falling stage. This strongly suggests that the concave rating curve occurred under conditions of more rapidly increasing concentration than discharge although discharge could peak earlier than concentration. But in the falling stage sediment concentration decreased at a faster rate, without replenishment, than the fall in discharge because of dilution. This explanation is supported by the narrower spreads observed for the C-graphs than the associated Q-graphs which reflect the physical conditions already alluded to above.

Furthermore, the events which produce concave sediment-rating curves were generally found to be isolated and flashy, a condition necessary for achieving rapid increases in discharge. These events followed prolonged periods of baseflow of up to three months in duration.

Such long time intervals allowed for the accumulation of sediments in river channels. Therefore, when they occurred sediment concentrations increased more rapidly than discharge. Most of the sediments entrained first are those last deposited in the bed during the previous recession flow (Arnborg et al. 1967).

The overwhelming evidence of the nature of sediment transport by single-valued events reported herein strongly indicates that, for the concave rating curves to occur, the sediment most likely originated from the stream-bed but was quickly exhausted. Consequently, the amount of sediment transported on the falling limbs was greatly reduced in order to effect a non-linear curve. From the sedimentological viewpoint, the availability of inexhaustible quantities of readily transportable fine materials from the bed with little or no replenishment in the falling stage was considered as one of the major factors controlling the form of the concave rating curve.

The greater spreads of the C-graphs relative to the Q-graphs observed for the convex rating curves imply that sediment supply to the channels was greater than that of discharge in the duration of these events. This meant that sediment removed from the river systems were continually replenished at rates equal to and greater changes in discharge. The timing of occurrence for events that produced convex rating curves in the months of January, May, October and December months implies that, convex events were also influenced by the high intensity of flooding associated with the annual discharge peaks when abundant sediments originate from valley slopes and the stream-bed. For those events that occurred in the winter months, heavy rainfalls of this season coupled with abundant sediments in the channels probably also controlled the forms of the convex rating curves. For the convex events the earlier peaking of C than Q implies that sediments were sometimes exhausted early in the rising stage and likely were quickly replenished in the falling stage.

5.5 Factors Controlling Variations in Suspended-Sediment Concentration for Different Forms of Sediment Rating Curves

The controls of suspended sediment concentration for single hydrological events relate to their distribution in time and space, and to the hydrological, sedimentological and hydraulic factors discussed below.

5.5.1 Temporal and Spatial Factors

Analysis of temporal graphs of discharge and sediment concentrations alone is not sufficient for the prediction of types of sediment-discharge relations of any given storm event. In a time series of closely or widely spaced storm events there is no way of telling which ones will have linear, concave or convex sediment-discharge relations.

In the Fraser River basin linear sediment rating curves were observed in all months of the year with the exception of April and July. This suggests that linear rating curves were not influenced by initial snowmelt (which generally commences in April) and the recession flows (in July following the annual peak).

As in the case of linear curves, the events for concave rating curves were found to be flashy and isolated and occurred in all months of the year except February, July and December. This suggests that concave events were controlled by changes in discharge associated with snowmelt and intensity of flooding in summer and winter months. In spite of the varied times of occurrence many concave events probably had similar hydrological and sedimentological characteristics.

The convex events, though fewer in number than other single-valued events, were found to occur mainly in the months of January, May, October and December. These months fall into two main groups: October-January, associated with the fall/winter storms, and the May-June period when snowmelt produces the annual peak discharge. This grouping of events for convex rating curves is of particular importance because it is during these periods that a large proportion of the annual load of sediment is transported through the Fraser River system.

The largest number of single-valued events in a given year were observed in 1968 on the Chilliwack River (Fig. 5.5a) probably for two main reasons. Firstly, the Chilliwack River has a bimodal distribution of discharge and sediment concentration caused by spring snowmelt and fall and winter storminess. Secondly, since the Chilliwack River has a small drainage basin with moderate to steep slopes on valley sides, the response of the basin to changes in discharge is almost immediate because storm runoff travels fast and only for short distances to reach the outlet at Vedder Crossing. As a result, the magnitudes of sediment concentration compared to discharge for the Chilliwack River are larger than for the Fraser River stations, and the Chilliwack River basin shows

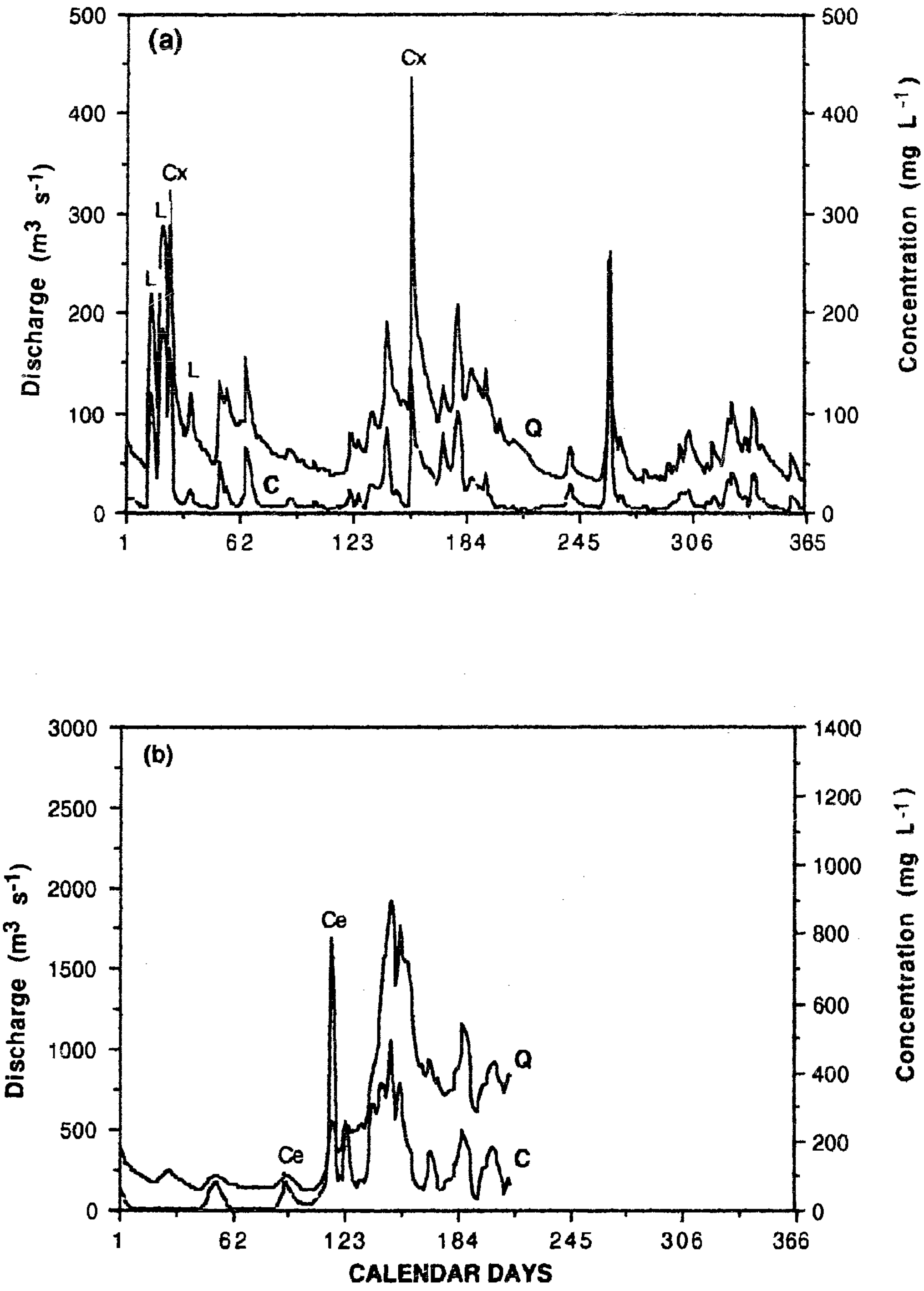

Fig. 5.5. Timing of storm events with (a) linear (L), convex (Cx), on the Chilliwack River at Vedder Crossing in 1968, and (b) concave (Ce) rating curves on the Fraser River at Hansard in 1981. C and Q are sediment concentration and discharge, respectively.

rapid fluctuations in sediment concentration for individual hydrological events.

In Fig. 5.5a it is clear that, whereas closely spaced storm events produced consecutive linear rating curves, convex rating curves occurred subsequently to linear and other events. By contrast, in 1981 (Fig. 5.5b) the concave rating curves at the Hansard station on the Fraser River were produced by consecutive events that apparently coincided with the onset of snowmelt preceded by a long period of baseflow.

Fig. 5.5 supports the contention that, the timing of events offers only partial explanation for the forms of rating curves produced by different storms events even at the same station. This is largely because events occurring in isolation or with others in quick succession do not necessarily produce single-valued sediment-discharge relations. Furthermore, individual storms differ not only in terms of discharge hydrograph characteristics, but also in that amounts of easily transportable sediments available in the channels are site specific and vary from time to time even at the same station. Fig. 5.6 indicates that on the Silverhope Creek near Hope station and on the Fraser River at the Mission station in 1969, more than one group of factors appears to have controlled the occurrence and forms of single-valued sediment-discharge relations shown.

Differences in the bed calibre sediments, gravel at Silverhope and sand at Mission station, could have contributed to the variations in the types of rating curves produced. Other factors that probably influenced the forms of rating curves were the direction of movement of the storm event which meant that it lasted longer at either Mission or Silverhope Creek near Hope.

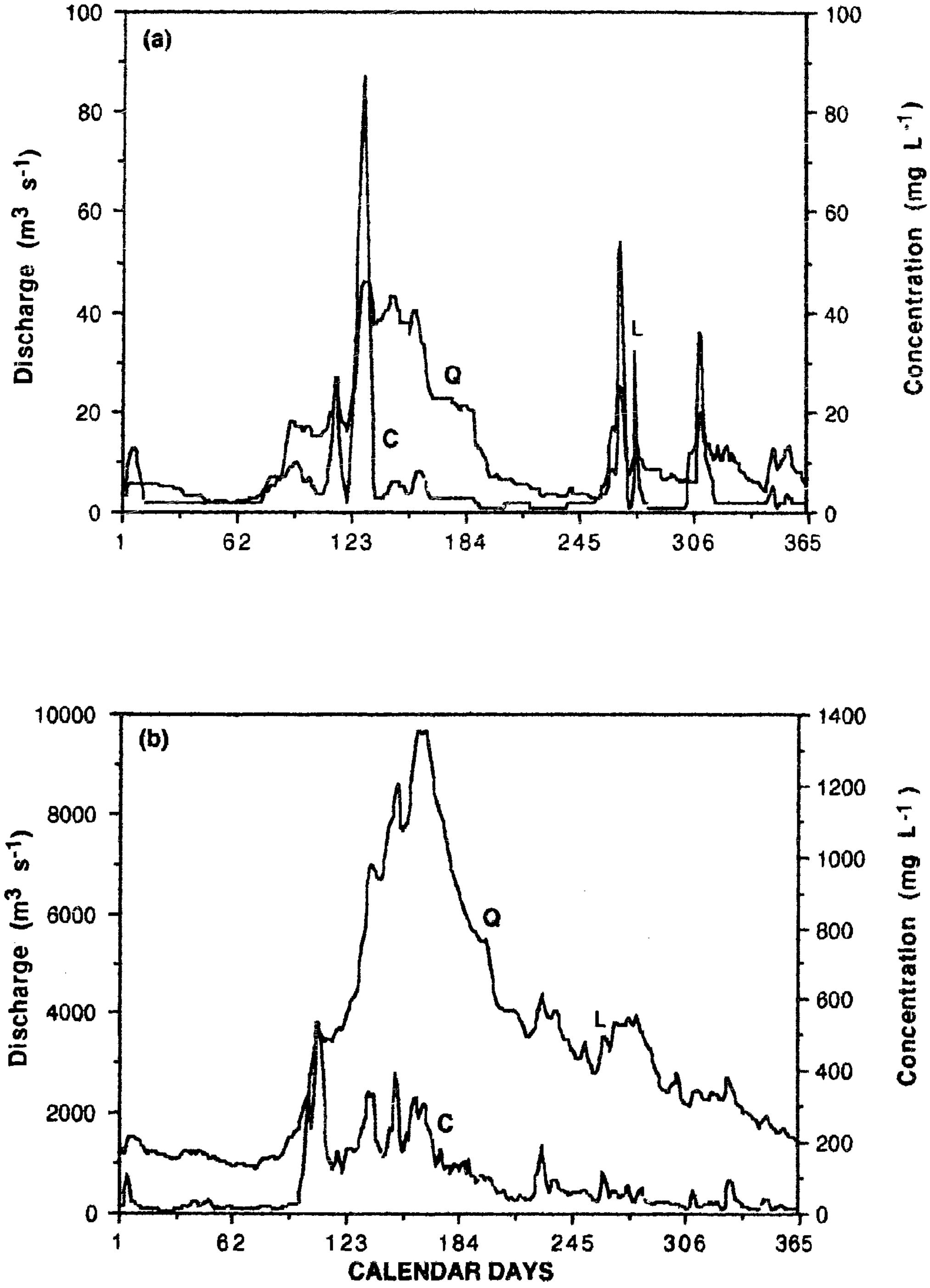

Fig. 5.6. Timing of storm events with linear (L) rating curves (a) on the Silverhope Creek near Hope and (b) on the Fraser River at Mission station in 1969. C and Q are sediment concentration and discharge, respectively.

However, Fig. 5.7 shows that many hydrological events at the Hope and Agassiz stations on the Fraser River in 1969 did not produce different types of rating curves. This indicates that, on a time scale of days, spatial proximity between stations has the effect of producing similar rating curves because factors that control channel processes are indistinguishable within short distances.

Moreover, the event of the peak discharge and that preceding it produced linear rating curves at Agassiz in 1973 while at Mission station the peak event did not effect a single-valued sediment-discharge relation. Unlike the Agassiz station the event preceding peak discharge produced a concave rating curve at Mission station (Fig. 5.8). This variation in rating curves by similar events demonstrates that events were attenuated by spatial effects as they moved downstream along the river.

In addition, events sometimes recruited more sediments as they moved downstream while at other times they deposited some of the sediments. In each case, the sedimentological character of the events concerned were changed. The variations in the rating curves produced by similar events at Agassiz, Mission and Hansard stations suggest that channel processes operating at the these stations were influenced by geography as well as by the distinct character of the channel beds. This observation, to some extent, confirms the differences in the scour and fill processes observed at the Agassiz and Mission stations discussed in Chapter Four.

In summary, the differences in the timing and occurrence of various types of rating curves reported in this section illustrate the difficulty encountered when attempting to pin-point factors accounting for variations in sediment concentrations in rivers. This suggests that it

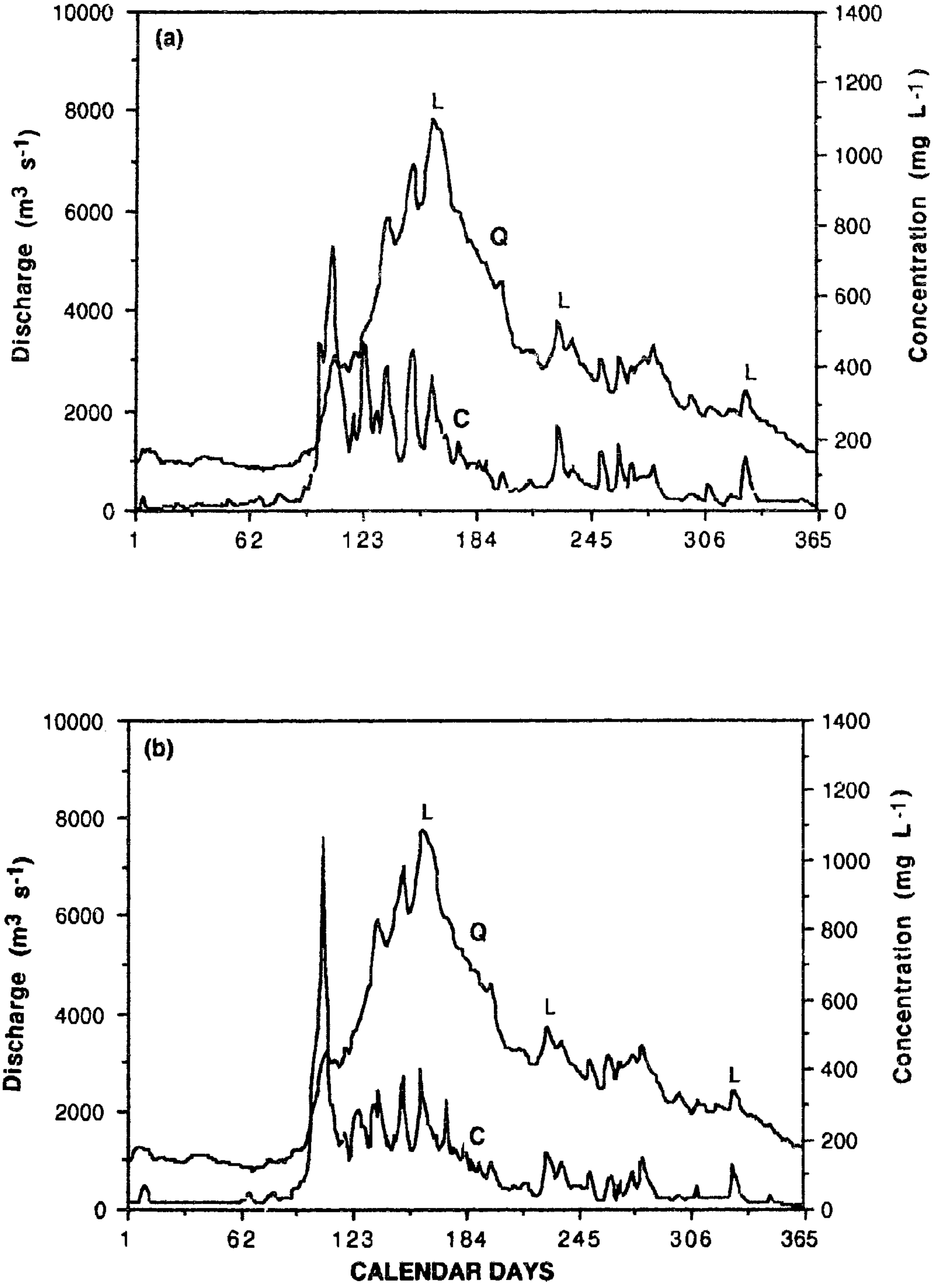

Fig. 5.7. Timing of storm events with linear (L) rating curves on the Fraser River at (a) Hope and (b) near Agassiz station in 1969. C and Q are sediment concentration and discharge, respectively.

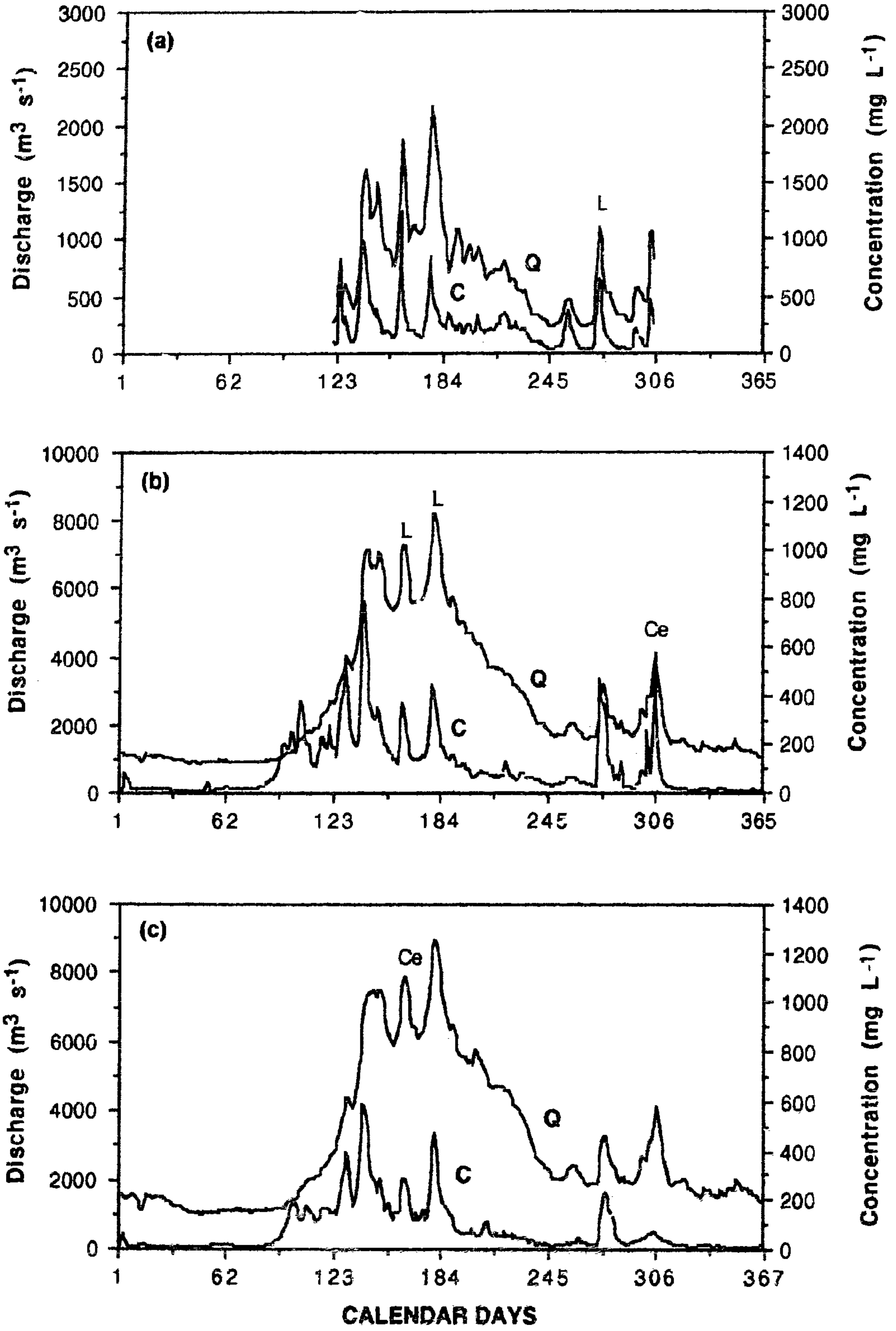

Fig. 5.8. Timing of storm events with linear (L) and concave (Ce) rating curves on the Fraser River at (a) Hansard, (b) near Agassiz and (c) Mission station in 1973. C and Q are sediment concentration and discharge, respectively.

would be fruitless to investigate factors controlling sediment variations for single-valued rating curves by comparing individual events. Instead, it is more useful to consider the events in groups.

5.5.2 Hydrologic Factors

In order to analyse the hydrological factors controlling sediment variation in single-valued hydrological events, the data were divided into the rising and falling stages and arithmetic averages calulated for different discharge factors and concentration. In the rising stage, factors controlling variation in the mean rising-concentration (Cr) included mean rising-discharge (Qr), discharge preceding storm hydrograph rise (Qpr) (a surrogate for antecedent soil moisture conditions) and the index of flood intensity (IFI). In falling stage, factors controlling mean falling-concentration (Cf) were mean falling-discharge (Qf) and the rate of flood recession (IFR). Based on the data in Appendix 3, the relative influences of the aforementioned factors on the variation of sediment concentration for linear and non-linear single-valued rating curves were evaluated. In addition, the non-linear rating curves were further subdivided into concave and convex forms before factors controlling their forms were assessed.

In order to assess factors that control sediment variations for the three types of rating curves, variations in sediment concentrations explained by each variable and standard errors of estimate in the rising and falling stages were compared for different curve forms. The results of the linear regression analyses are presented in Table 5.9(i). For linear

Table 5.9. Summary of results for simple regression analysis of the relationships between mean rising and mean falling sediment concentrations as dependent variables and the independent variables in the rising and falling stages for linear and non-linear: concave and convex single-valued hydrological events in the Fraser River basin.

Variable[1]	n	r^2	Se	P	Dependent variable
I. LINEAR EVENTS					
Q_r	31	0.384	106.952	0.0003	C_r
Q_{pr}	31	0.320	106.921	0.0009	C_r
IFI	31	0.494	92.250	0.0001	C_r
Q_f	31	0.431	88.889	0.0001	C_f
IFR	31	0.596	74.927	0.0001	C_f
II. NON-LINEAR EVENTS					
Q_r	17	0.220	177.570	0.0577	C_r
Q_{pr}	17	0.177	182.345	0.0924	C_r
IFI	17	0.342	163.105	0.0137	C_r
Qf	17	0.391	109.644	0.0073	C_f
IFR	17	0.384	110.200	0.0079	C_f
IIa. CONCAVE EVENTS					
Q_r	13	0.050	202.415	0.4839	C_r
Q_{pr}	13	0.031	204.470	0.5852	C_r
IFI	13	0.517	144.319	0.0084	C_r
Q_f	13	0.126	113.011	0.2585	C_f
IFR	13	0.254	104.375	0.0947	C_f
IIb. CONVEX EVENTS					
Q_r	5	0.963	37.167	0.0030	C_r
Q_{pr}	5	0.965	36.382	0.0028	C_r
IFI	5	0.084	185.329	0.6358	C_r
Q_f	5	0.993	17.259	0.0002	C_f
IFR	5	0.990	21.089	0.0004	C_f

[1] Q_r and Q_f are rising and falling mean discharges (m^3s^{-1}); Q_{pr}, the discharge preceding hydrograph rise (m^3s^{-1}); IFI, the index of flood intensity; IFR, the index of rate of flood recession; Se, the standard error of estimate (mg L^{-1}); and P, the significance level. Dependent and independent variables are defined in section 5.5.2.

rating curves, all independent variables were found to have controlled sediment concentrations in the rising and falling stages at 0.01 level of significance. Based on the coefficient of determination (r^2), mean rising concentrations were found to be controlled more by the index of flood intensity than by mean rising discharge and preceding discharge. In the falling stage, mean falling concentrations were found to be controlled more by the index of flood recession than by the falling mean discharge. Additionally, for linear events, calculated standard errors of estimate indicate that variations in sediment concentration were higher in the rising than in falling the stage.

The results of the simple regression analysis of the non-linear events are also summarized in Table 5.9(II). Note that, the data for the 30 November 1975 event on the Chilliwack River were excluded from the non-linear analysis because the associated concentrations were far above 'normal'. With the exclusion of this event the analysis showed that the independent variables in the rising and falling stages controlled sediment variations at different levels of significance, ranging from 0.01 to 0.10. Rising mean concentrations were found to be controlled more by, in the order of significance, index of flood intensity, mean discharge and finally the preceding discharge. The rate of flood recession was found to control mean falling concentrations as much as mean falling discharge.

Overall, the analysis shows that for non-linear events, sediment concentrations were more related to discharge and hydrograph characteristics in the falling than rising stages. Conversely, for linear events mean discharge and hydrograph characteristics were important, both in rising and falling stages. The discharge preceding hydrograph rises, approximately synonymous with antecedent moisture conditions, was the distinguishing factor between linear and non-linear rating curves because of its greater control on sediment concentrations for the former and not for the latter curve forms. This suggests that, for linear events, other factors remaining constant, high antecedent moisture conditions likely had the effect of generating quick runoff and a rapid increase in sediment concentration in concert with changes in discharge. Apparently, low antecedent moisture conditions produced a delayed increase in sediment concentration, a response not in phase with changes in discharge, which resulted in non-linear sediment rating curves.

Furthermore, non-linear hydrological events were also considered as a separate category comprising concave and convex sediment rating curves. For concave events (Table 5.9(II)a), the factors that significantly controlled sediment variations were the index of flood intensity and the rate of flood recession at 0.01 and 0.10 levels of significance, respectively. The preceding discharge as well as the mean rising and mean falling discharges were found not to have any control on sediment concentrations. In contrast, for convex rating curves (Table 5.9(II)b), mean sediment concentrations were found to be controlled by, in order of significance, mean falling discharge, the index of flood recession, and up to the same extent as the preceding and rising mean discharge, significant at 0.01 level. The index of flood intensity was found not to influence rising mean concentrations significantly.

Therefore, other factors remaining constant, the distinguishing characteristic between concave and convex rating curves is that the concave events were controlled by the index of flood intensity while convex events were not. Also, the results shows that concave sediment rating curves were controlled more by hydrograph characteristics than mean discharge in the rising and falling stages. In contrast, sediment concentrations for convex events were controlled by both mean discharge and hydrograph characteristics in the rising and falling stages with the exception of the index of flood intensity. These observations imply that, in the rising stages, concave rating curves were controlled by the index of flood intensity while convex events were controlled by discharge and antecedent moisture conditions. In the falling stage, convex events were controlled by mean falling discharge while concave events were not.

A stepwise multiple regression approach was used to analyse the complex relationships between sediment concentration and hydrological factors controlling forms of linear and non-linear sediment rating curves. Multiple regression models were developed first by entering various factors in the order of decreasing (r^2) given in Table 5.9. Those factors found not significant at 0.05 level were excluded from the analysis. Since correlation coefficients are not suited for assessing relative influences of different factors that control variations in sediment concentrations, beta coefficients, as suggested by Yevdjevich (1964) were calculated and included in Table 5.10 for comparison purposes. Beta coefficients were also used for determining the order by which different factors were to be entered in the regression models.

The beta coefficients are better than ordinary correlation coefficients because apart from being dimensionless, they measure the effect of a particular independent variable on the variation of the dependent variable (Walling, 1973: 218). The beta values in Table 5.10b

Table 5.10. Results of stepwise multiple regression analysis between hydrological factors and suspended-sediment concentration for linear and non-linear single-valued events in the Fraser River basin.

(a) STEPWISE MULTIPLE REGRESSION EQUATIONS		MULTIPLE CORRELATION COEFFICIENTS		
		n	R^2	P
I. Linear Events				
RISING STAGE:	$C = 49.977 + 0.217IFI + 236Q_r - 0.242Q_{pr}$	31	0.549	0.0001
FALLING STAGE:	$C = 37.605 + 0.869IFR - 0.008Q_f$	31	0.600	0.0001
II Non-Linear Events				
RISING STAGE:	$C = 73.505 + 0.398IFI + 0.023Q_r$	17	0.465	0.0125
FALLING STAGE:	$C = 89.38 + 0.308IFR + 0.017Q_f$	17	0.428	0.0201

(b) BETA COEFFICIENTS ($B = b/(si/sd)$)

	BETA COEFFICIENTS			
	Linear		Non-Linear	
Variable	Rising	Falling	Rising	Falling
Q_r	0.0147		0.4327	
Q_{pr}	-0.0173			
IFI	0.2183		0.6413	
Q_f		0.0005		0.0008
IFR		0.8454		0.2867

NOTES:	C	is the suspended sediment concentration (mg L^{-1});
	Q_r	is rising mean discharge ($m^3 s^{-1}$);
	Q_f	is the falling mean discharge ($m^3 s^{-1}$);
	Q_{pr}	is the discharge preceding hydrograph rise ($m^3 s^{-1}$);
	IFI	is the index of flood intensity;
	IFR	is the index of flood recession;
	B	is the beta coefficient;
	b	is the regression coefficient;
	si	is the standard deviation for the independent variable ($m^3 s^{-1}$);
	sd	is the standard deviation for the dependent variable (mg L^{-1}); and
	P	is the significance level

show that, sediment variation in the rising stages were overwhelmingly controlled by the index of flood intensity followed by mean rising discharge, both for linear and non-linear sediment rating curves. In the falling stage, multiple regression analysis again supports the findings of the simple regression analysis by confirming that hydrological characteristics (defined by the indices of flood intensity and flood recession) control the form of sediment rating curves more than the mean rising and mean falling discharges.

Therefore, the distinguishing feature in the multiple regression models determined in this study is the lack of preceding discharge factor for the non-linear events in the rising stage. Insufficient data for the concave events precluded the analysis of factors that distinguished them from convex events.

In order to predict mean sediment concentrations in the rising and falling stages from various hydrological factors, multiplicative models (uncorrected for underestimation of sediment concentrations) for each of the studied factors are given in Table 5.11. All the factors were significant at 0.01 level. Table 5.11 shows that the different hydrological factors accounted for between 48% and 63% of the variation in sediment concentration in the rising stage and between 55% and 65% in the falling stages. These results suggest that the relationships between sediment concentration and these hydrological factors for individual hydrological events are moderately strong when using multiplicative models for analysis.

Table 5.11. Summary of results of multiplicative regression analysis of the relationships between mean rising and mean falling sediment concentrations and various hydrological factors for linear and non-linear single-valued hydrological events in the Fraser River basin.

Rising Stage			Falling Stage		
Regression equation[1]	n	r^2	Regression equation[1]	n	r^2
I. LINEAR EVENTS					
$Cr = 4.704IFI^{0.688}$	31	0.631	$Cf = 02.969Qf^{0.495}$	31	0.570
$Cr = 3.783Qr^{0.485}$	31	0.543	$Cf = 07.249IFR^{0.582}$	31	0.554
$Cr = 7.204Qpr^{0.409}$	31	0.480			
II. NON-LINEAR EVENTS§					
$Cr = 14.043Qr^{0.365}$	17	0.575	$Cf = 11.287IFR^{0.546}$	17	0.647
$Cr = 20.938Qpr^{0.324}$	17	0.558	$Cf = 09.095Qf^{0.392}$	17	0.623
$Cr = 21.142IFI^{0.430}$	17	0.483			

---

[1] Cr and Cf are rising and falling sediment concentrtation (mg L^{-1}); Qr and Qf are average rising and falling discharges (m^3 s^{-1}); Qpr is the discharge for the day preceding hydrograph rise (m^3 s^{-1}); IFI is the index of flood intensity; IFR is the index of rate of flood recession.

§ The anomalous event of 30 November 1975 on Chilliwack River was excluded from the analysis.

5.5.3 Hydraulic Factors

5.5.3.1 Assumptions

In order to analyse hydraulic factors controlling single-valued rating curves, it was assumed that an increase in sediment concentration resulted from local bed scour (Leopold and Maddock, 1953a: 34) in immediate reaches upstream of gauging sites. Under this assumption increasing velocities were associated with bed scour provided that the discharge and velocity thresholds for bed scour were exceeded. Conversely, decreasing velocities were associated with bed filling.

5.5.3.2 Depth of Flow, Velocity and Stream-bed Elevation

The data for hydraulic factors, namely: flow depth, velocity and stream-bed elevations, found to influence single-valued sediment rating curves are given in Appendix 7. The results of analysis, summarized in Table 5.12, show that there were small differences in the slopes of simple regression lines for relationships between discharge and depth and velocity. Because of too few measured events, the hydraulic factors controlling the variation of sediment concentration were qualitatively assessed. Changes in depth, velocity and bed elevation associated with 8 events with linear, concave and convex rating curves for rising and falling stages are included in Table 5.12.

The timing of events with respect to the occurrence of threshold discharges for bed scour are summarized in Table 5.12 and compared within and between linear, concave and convex rating curves. Threshold

Table 5. 12. Hydraulic changes of depth, mean velocity and stream-bed elevation for measured single-valued linear, concave and convex hydrological events in the Fraser River basin.

Event no.	Station no.	Date	River	Depth		Velocity		Bed elevation path	
				Rising	Falling	Rising	Falling	Rising	Falling
LINEAR EVENTS									
7.	08LA001	27.05.72	Clearwater R.	Shallower (0.002333)[1]	Deeper (0.001771)	Smaller (0.000982)	Greater (0.000363)	Scouring	Filling
8.	08MC018	03.06.79	Fraser R.	Shallower (0.000915)	Deeper (0.000736)	Greater (0.000337)	Smaller (0.000349)	Scouring	Filling at depth
23.	08MF005	23.05.69	Fraser R.	Shallower (0.000301)	Deeper (0.000519)	Greater (0.000204)	Smaller (0.000322)	Scouring	Stable at depth
29.	08MH001	30.05.75	Chilliwack R	Shallower (0.007356)	Deeper (0.005354)	Smaller (0.005604)	Greater (0.003955)	Scouring	Scouring and filling
CONCAVE EVENTS									
39.	08MH001	30.11.75	Chilliwack R.	Shallower (0.004079)	Deeper (0.000756)	Greater (0.008804)	Smaller (0.006794)	Scouring	Filling and scouring
40.	08MH024	15.05.71	Fraser R.	Deeper (0.001050)	Shallower (0.000965)	Greater (0.000037)	Smaller (0.000138)	Scouring	Filling
42.	08MH024	06.06.73	Fraser R.	Shallower (0.000487)	Deeper (0.000354)	Smaller (0.000074)	Greater (0.000060)	Scouring	Filling and stable near surface

Table 5.12 continued

Event no.	Station no.	Date	River	Depth		Velocity		Bed elevation path	
				Rising	Falling	Rising	Falling	Rising	Falling
CONVEX EVENTS									
45.	08MH001	26.10.67	Chilliwack R.	Shallower (0.007775)	Deeper (0.007450)	Smaller (0.009999)	Greater (0.007957)	Filling and scouring	Filling and scouring
47.	08MH001	23.01.68	Chilliwack R.	Shallower (0.006928)	Deeper (0.006258)	Greater (0.003227)	Smaller (0.003282)	Scouring	Filling and scouring

1 The values in parentheses are slopes for simple regression lines of the relationships between discharge and respective hydraulic variables in the rising and falling stages of individual events.

discharge values referred to here are the seasonal values determined in Chapter Four. Discharge thresholds represent the level at which large quantities of gravels were mobilized. Based on this understanding velocities for suspended-sediment transport associated with threshold discharges for individual events, velocity thresholds associated with threshold discharges for individual events were assumed to be lower than those for gravel determined for seasonal scour and fill (Table 5.13).

Linear rating curves occurred when depths were shallower or deeper in rising than falling stages and when the associated velocities were smaller or greater on the rising than those on the falling stage. These processes are partly exemplified by the event of 3 June 1979 on the Fraser River near the Marguerite station (Fig. 5.9a and b). The hydrograph for this event began to rise and terminated when the threshold discharge was greater than 2 000 $m^3 s^{-1}$ (Fig. 5.9c). Consequently, linear rating curves were characterized by bed scour on the rising and falling stages and by constant low or stable low bed elevation in the falling stage associated with high stream velocities that remain unchanged for several days after the discharge peak.

These high velocities that persisted after peak discharge and caused bed elevations to remain stable at depth (e.g. Fig. 5.9a) are what Maddock (1969: 19) hypothesized to be limiting velocities above which a channel would simply erode and enlarge its sections while keeping velocities constant. Stein (1965) called these high velocities "breakaway velocities" which he experimentally observed to occur at the level of dicharge where the bed friction factor is a minimum. According to Maddock's (1969: 19) hypothesis, "breakaway velocities" may be defined as the limiting velocities above which "...a channel will simply erode and

Table. 5.13. Channel hydraulic thresholds for stream-bed scour at sediment stations on the Fraser and Chilliwack Rivers.

No.	Station no.	River	Threshold Levels[1] G. H. (m)	Q_t ($m^3 s^{-1}$)	V_t ($m s^{-1}$)
1.	08KA004	Fraser R. at Hansard	3.250	500	0.700
2.	08MC018	Fraser R. near Marguerite	2.250	2000	2.000
3.	08MF005	Fraser R. at Hope	5.200	1500?	0.850
4.	08MF035	Fraser R. near Agassiz	3.500	3000	1.530
5.	08MH001	Chilliwack R. at Vedder Crossing	2.000	150	2.000
6.	08MH024	Fraser R. at Mission	3.450	6000	1.250

[1] G. H. is the daily gauge height; Q_t the discharge threshold for bed scour and V_t is the mean velocity at the associated discharge threshold. (?) indicates that value is not accurately known due to few measurements at low flows.

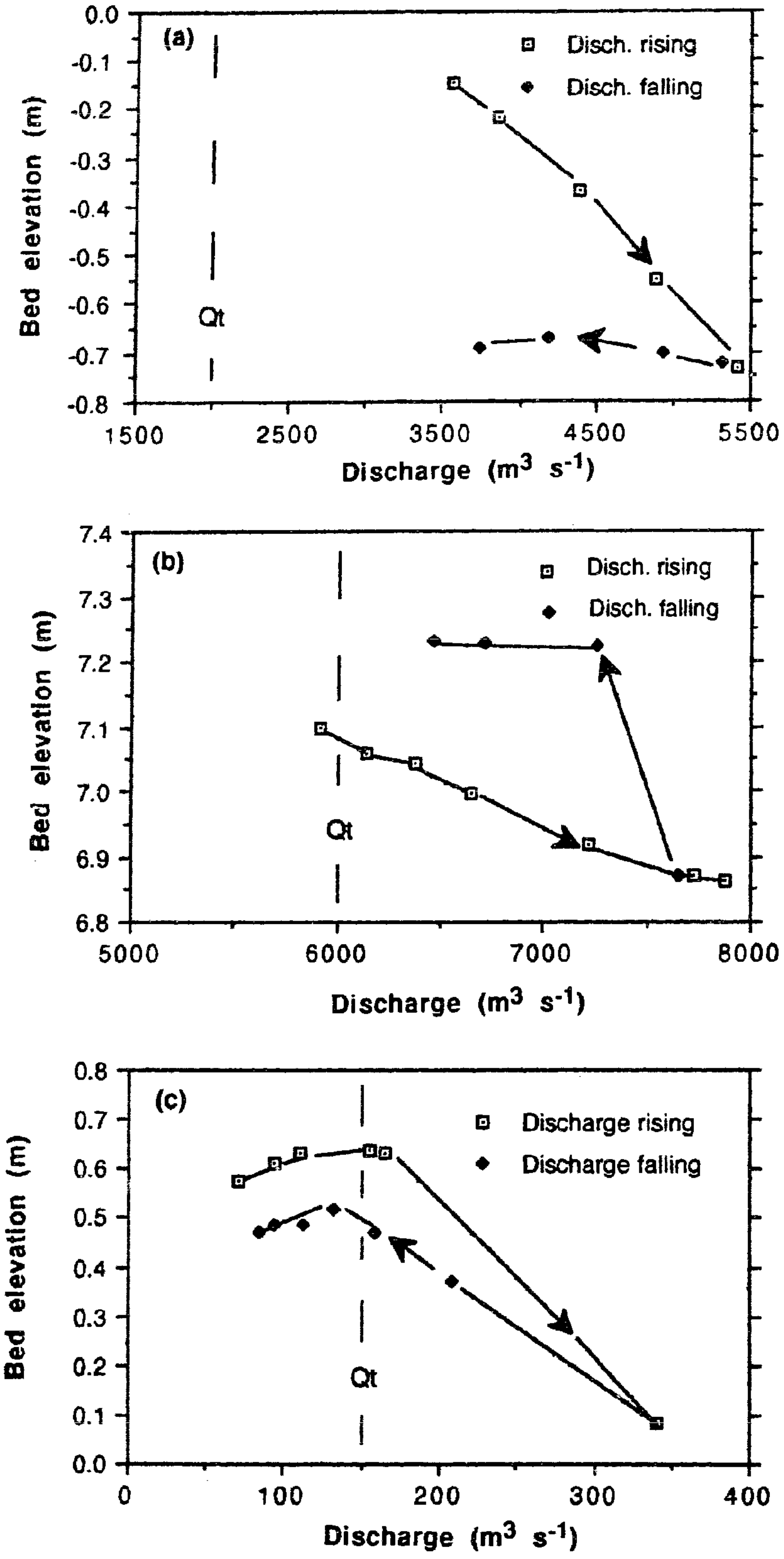

Fig. 5.9. Paths of bed elevation for (a) linear (Marguerite), 3 June 1979, (b) concave (Mission), 6 June 1983, hydrological events on the Fraser River and (c) convex (Vedder Crossing), 26 October 1967, hydrological event on the Chilliwack River.

enlarge its sections...(while)...keeping velocity essentially constant".

At Marguerite station during the 3 June, 1979 event, the scouring of the stream-bed in the rising stage and filling and unchanging bed elevations in the falling stage suggest that, suspended-sediment originated from the channel bed in the rising stage. In the falling stage, sediment most probably supplied from the upstream and banks and none from the bed as no scouring was observed.

In contrast, concave rating curves were observed to occur when depth was shallower on the rising than on falling stage as the event of 6 June 1973 on the Fraser River at Mission shows (Fig. 5.9b). But they also occurred when the same depth was observed on the rising and falling stages (Table 5.11). Unlike the linear rating curves, the velocities for the concave rating curves were greater on the rising than falling stages (Table 5.11). The stream-bed for the concave rating curves was scoured at discharges greater than threshold values on the rising stage and filled for same range of discharge in the falling stage. But re-scouring of the bed occurred when the discharge fell below the threshold value before the termination of the event.

No good example of a measured concave event exhibiting this pattern of bed scour and fill processes was found in this study. But Fig. 5.9b shows that, instead of stabilizing, the bed filled in the rising and was scoured in the falling stage and the event terminated when discharge was above the threshold of bed scour ($Q_t = 6000\ m^3s^{-1}$) at Mission station. This observation is consistent with the observed seasonal scour and fill regime at this station (see Fig. 4.7b). Therefore, for the concave rating curve, it appears that most of the sediments originated from the bed during the scouring phase on the rising limb and during the re-scouring phase in the early part of the falling limb. This likely was followed by sediment exhaustion due to deposition of sediment in the latter part of the falling limb before the event terminated.

Finally, the case of a convex event was exemplified by the event of 26 October 1967 at the Vedder Crossing station on Chilliwack River (Fig. 5.9c). During this event the same depth was observed on the rising and falling stages while the velocity in the rising stage was smaller than that observed on the falling stage. In the rising stage bed elevation adjustments to changes in discharge generally started by filling for discharges less than the scour thresholds and then they scoured for discharges greater than the threshold discharge ($Q_t = 150\ m^3s^{-1}$) value. In the falling stage, the bed was filled and re-scoured for discharges greater and smaller than the threshold value as the event of 26 October 1967 on the Chilliwack River shows (Table 5.11).

The re-scouring on the falling stage for convex events was firstly attributed to the differences in the velocity thresholds for transport of gravel and sand-sized sediments. Secondly, bed re-scouring in the falling stage was the consequence of the winnowing of sand-sized and finer sediments possibly from newly formed dunes. Sediment sources for most of the sediments for the concave rating curves were also assumed to have originated from the channel bed in the latter parts of the rising and falling stages when scouring occurred. The scouring of the bed on the rising as well as in the falling stages implies that the flow was sediment-laden for the entire duration of the events.

In summary, the distinguishing characteristics between different forms of rating curves were, partly, related to the level of discharge at the onset and termination of different events. Events for the linear rating curves mostly began and terminated when discharge was greater than the discharge threshold for bed scour. In such cases, bed scouring occurred in the rising stages and filling in the falling stages.

Conversely, the events for the concave rating curves began when discharge was greater than the threshold discharge but terminated when discharge fell below the scour threshold. For these events the bed was scoured in the rising stage but filling was followed by re-scouring in the latter part of the falling stages. Unlike the events for linear and concave rating curves, the events for convex rating curves began to rise when discharges were below the threshold discharge and terminated in the same range of discharge. Consequently, convex rating curves were influenced by filling as well as scouring in the rising stages and filling followed by re-scouring during falling stages.

The scouring and filling processes described above are supported by the occurrence of precipitation and sub-zero to high temperatures which influenced the occurrence of hydrological events and associated variations in sediment concentrations. These meteorological factors are discussed below.

5.5.4 Meteorological Factors

Precipitation is undoubtedly one of the most important and yet most complex meteorological factors associated with erosion and transport of fluvial sediments (Guy, 1964:6). Precipitation in the form of rainfall and snow expressed as daily total precipitation, in mm, and daily mean temperatures (^{o}C) for the duration of hydrological events comprise the primary driving force for generation of runoff and sediments. The amount of precipitation in all of the Chilliwack River basin was taken as the average of four weather stations located in the basin (Table 3.1). The air temperatures at the Chilliwack station were assumed to be representative of the whole catchment. For the purposes of this discussion, temperatures were conveniently divided into four classes, namely: sub-zero temperatures ($T \leq 0$ °C), low temperatures ($1 \leq T \leq 9$ °C), moderate temperatures ($10 \leq T \leq 19$ °C) and high temperatures ($T \geq 20$ °C). Temperature was categorized in this way for analysis mainly to simplify the assessment of its effects on sediment concentration and discharge. The meteorological conditions in the course of ten hydrological events in Chilliwack River basin are summarized in Table 5.14. In the sections following, meteorological conditions which appear to favour the occurrence of linear, concave and convex sediment rating curves in the Chilliwack River basin are discussed.

5.5.4.1 Linear Sediment Rating Curves

Linear sediment rating curves generally were found to occur when precipitation was received throughout the event under low temperature conditions in the rising stage and under constant low or sub-zero temperatures in the falling stages. This situation was illustrated by the event of 12 January 1968 on Chilliwack River (Fig. 5.10a, b, c). During this event there was high antecedent moisture in the soil because of high preceding precipitation of 50.8 mm recorded at Foley Creek on 9 January, received under low temperature conditions. As a result, the

Table 5.14. Meteorological conditions during single-valued linear, concave, and convex hydrological events in the Chilliwack River basin.

Event no.	Period	Precipitation Received		Air Temperature Range[1]	
		Rising	Falling	Rising	Falling
LINEAR EVENTS					
25.	02.01.68 - 18.01.68	YES	YES	Low	Low
26.	19.01.68 - 23.01.68	YES	YES	Low	Low
27.	01.02.68 - 09.02.68	YES	NO	Low	Low
28.	30.05.70 - 12.06.70	NO	NO	Moderate to high	High to moderate
29.	09.01.72 - 29.01.72	YES	YES	Low	Sub-zero
CONCAVE EVENTS					
39.	22.09.65 - 30.01.68	NO	NO	Moderate	Moderate
40.	30.11.75 - 07.12.75	YES	NO	Low	Sub-zero
CONVEX EVENTS					
46.	26.10.67 - 06.11.67	YES	NO	Moderate	Low
47.	23.01.68 - 28.01.68	NO	YES	Low	Sub-zero
48.	31.05.68 - 10.06.68	YES	NO	Moderate	Moderate

[1] Temperature categories: ($T \leq 0$ °C), sub-zero temperatures; ($1 \leq T \leq 9$ °C), low temperatures; ($10 \leq T \leq 19$ °C), moderate temperatures; and ($T \geq 20$ °C) high temperatures.

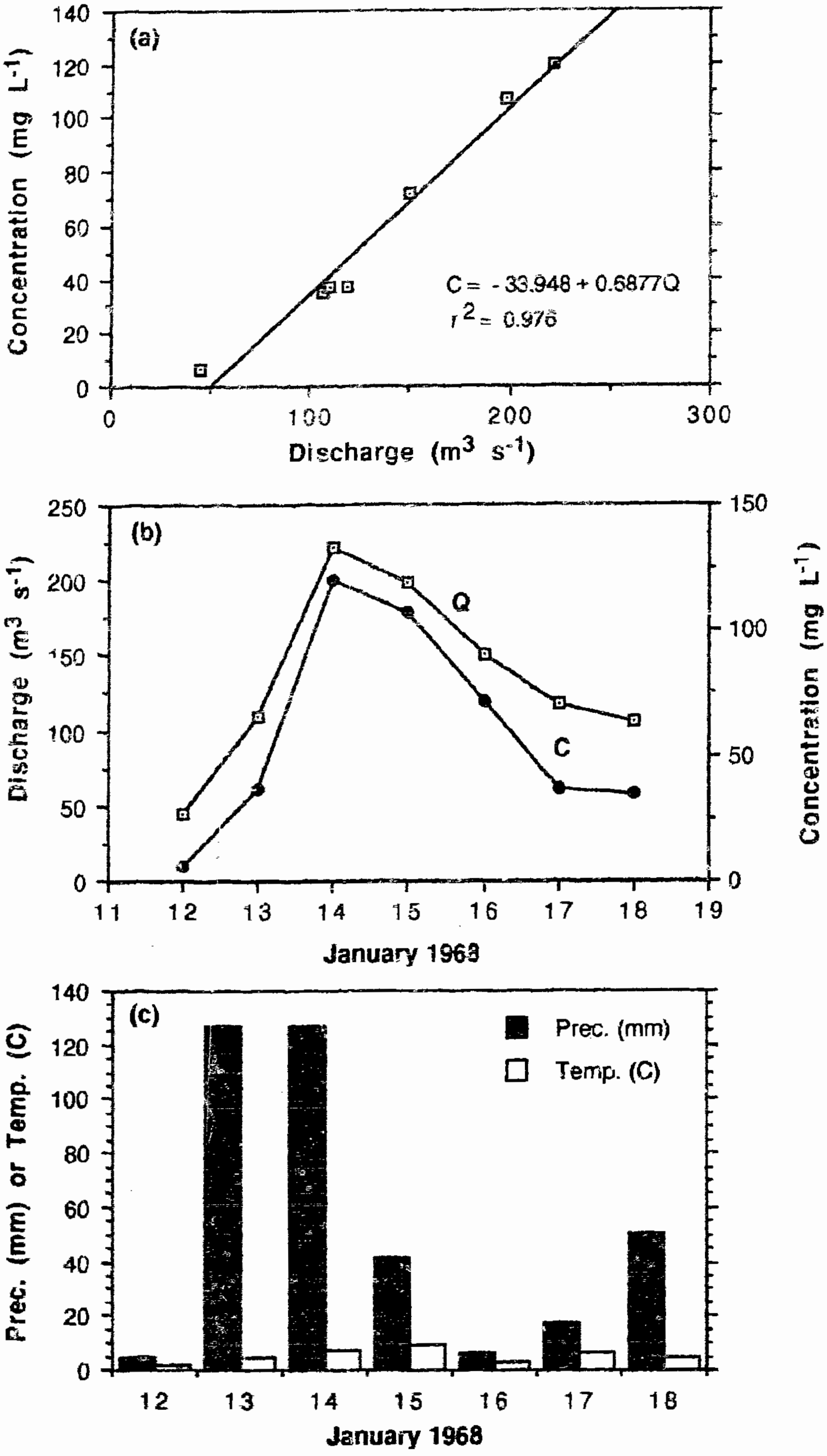

Fig. 5.10. Graphs of (a) linear sediment rating curve, (b) temporal variations in discharge (Q) and concentrations (C) and (c) distributions of daily precipitation and temperature during the event of 12 January 1968 on the Chilliwack River at Vedder Crossing station.

event was characterized by a rapid increase in discharge and concentration in the rising stage. Further continuation of precipitation in the falling stage caused concentrations to decrease at the same rate as that of discharge. These conditions imply that quickflow and/or overland flow composed most of the runoff and that sediment sources originated from areas adjacent to the river channel.

Conversely, when precipitation was received under low temperatures in the rising stage and under sub-zero temperatures in the falling stage, overland flow accounted for the rapid increase in concentration only in the rising stages because it immediately produced runoff. But no runoff from the basin slopes was generated under sub-zero temperatures in the falling stage, implying that sediments most likely originated from the channel itself by the scouring process. This situation was illustrated by the event of 19 January 1972 (Fig. 5.11a, b, c).

There were also two exceptional conditions under which linear rating curves occurred whereby precipitation played a lesser role than temperature in the generation of sediments. The first case was produced when precipitation was received on the rising and none on the falling stage under low temperatures in the rising and falling stages during the event of 1 February 1960 (Fig. 5.12a, b, c). The implication under these conditions is that sediment supplied by quickflow or overland flow from areas near the channel in the rising stage were augmented by sediments stored in the channel and no exhaustion of sediments occurred by the time of discharge peak.

Another exceptional case under which a linear rating curve was produced (not illustrated) occurred when no precipitation was recorded in the rising stage with only minimal amount received in the falling stage.

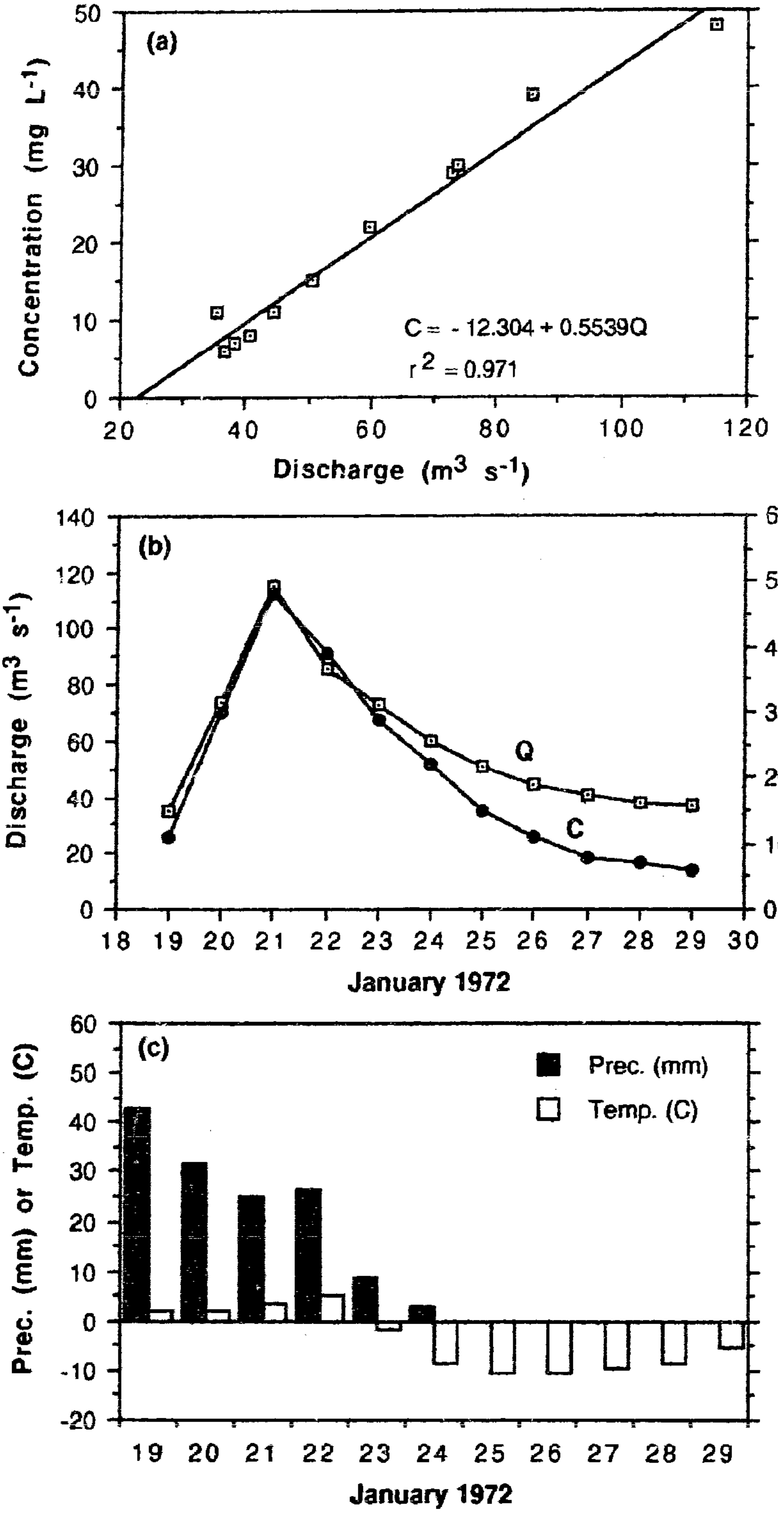

Fig. 5.11. Graphs of (a) linear sediment rating curve, (b) temporal variations in discharge (Q) and concentrations (C) and (c) distributions of daily precipitation and temperature during the event of 19 January 1972 on the Chilliwack River at Vedder Crossing station.

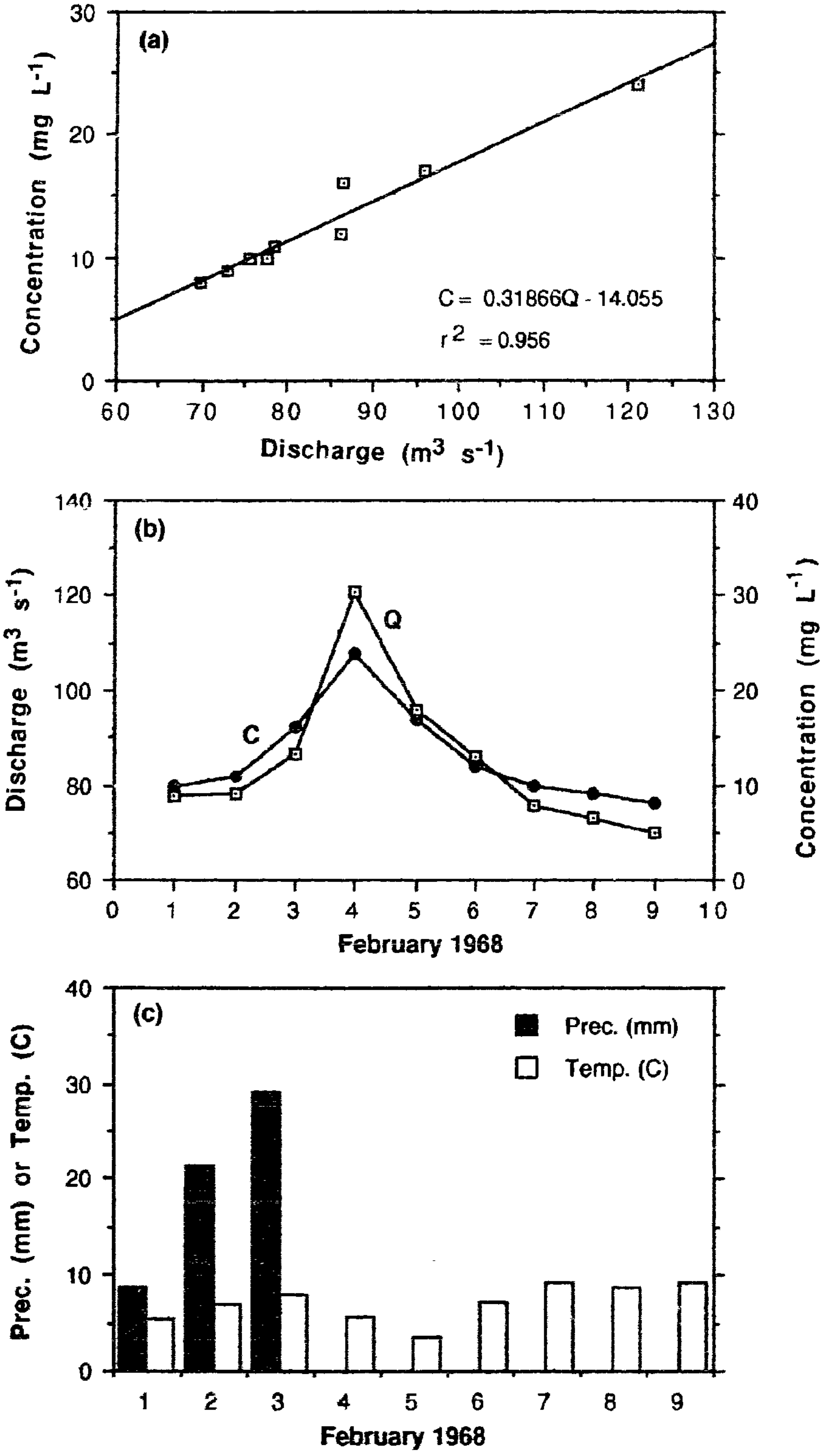

Fig. 5.12. Graphs of (a) linear sediment rating curve, (b) temporal variations in discharge (Q) and concentration (C) and (c) distributions of daily precipitation and temperature during the event of 1 February 1968 on the Chilliwack River at Vedder Crossing station.

Temperatures for the duration of this event were rising from moderate to high ranges in the rising stage and were decreasing from high to moderate ranges in the falling stage. In this event, rapid increases in discharge and concentrations were associated with snowmelt generated by high temperatures in the rising stage. The little precipitation received in the falling stage appears to have been effective in generating sediment as indicated by the associated concentrations which decreased at the same rate as discharge under conditions of moderate temperatures. All the observed meteorological conditions under which linear sediment rating curves occurred have not been reported before.

5.5.4.2 Concave Rating Curves

Meteorological conditions under which concave rating curves occur included cases when precipitation was received in the rising and falling stages under low temperatures conditions, and when no precipitation was received in both rising and falling stages and under increasing and decreasing moderate temperatures in the rising and falling stages. The case of increasing precipitation in the rising stage under low temperature conditions in the rising and falling stages was exemplified by the event of 30 November 1975 on Chilliwack River (Fig. 5.13a, b, c).

During this event, a large proportion of the discharge likely was in surface storage due to high moisture conditions, low infiltration rate of surface water retarded by freezing conditions that existed just below the surface and the presence of snow cover. As temperatures began to

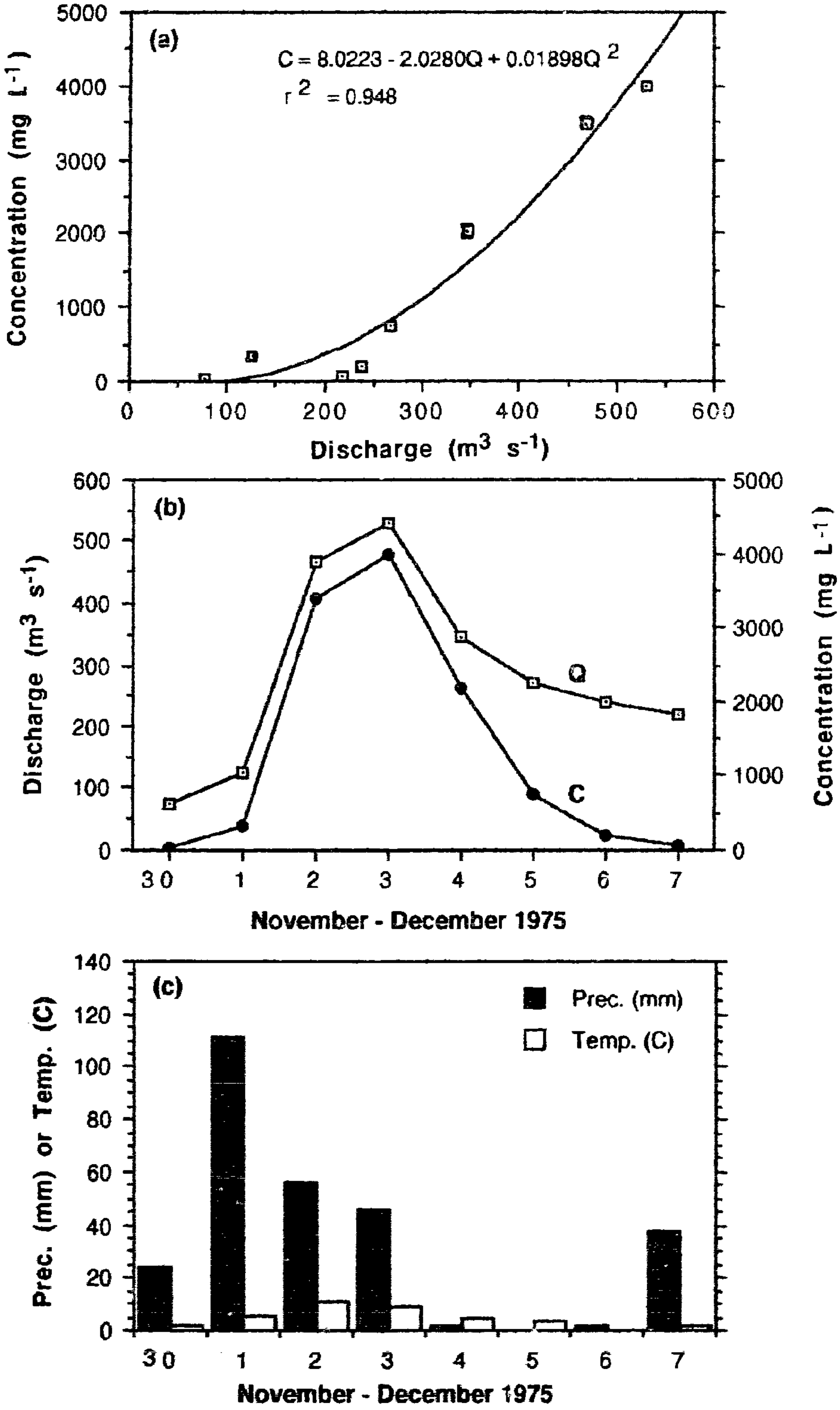

Fig. 5.13. Graphs of (a) concave rating curve, (b) temporal variations in discharge (Q) and concentration (C) and (c) distributions of precipitation and temperature during the event of 30 November 1975 on the Chilliwack River at Vedder Crossing station.

increase, discharge increased rapidly with quickflow or overland flow supplying most of the sediments in the rising stage. In addition, large quantities of sediment likely were also supplied from the channel itself, especially from cut banks, bank collapse and from sites of slope failures in the Liumchen, Tamihi and Sleese Creeks upstream of Vedder Crossing which were documented by Munshaw (1976). In the falling stage, low temperatures likely inhibited sediment transport as indicated by the higher rates of decrease for concentration than for discharge (Fig. 5.13b).

5.5.4.3 Convex Rating Curves

The precipitation regimes for the convex rating curves were similar to those for concave curves when precipitation was received in the rising and falling stages. The distinguishing characteristic between convex and concave types of rating curves is that the former tended to occur under moderate temperature conditions accompanied by the generation of surface runoff while the latter occurred under low temperatures which hampered runoff generation. Under moderate temperature conditions, in the rising stage, precipitation quickly produced runoff and sediments were supplied from surface slopes. In the falling stage, sediment concentrations were high because they likely originated from the channel bed and banks. As a result of this, a convex rating curve was produced by the event of 31 May 1968 on the Chilliwack River (Fig. 5.14a, b, c). The moderate temperatures during this event appear not to have altered the rate of sediment transport in the falling stage, probably due to

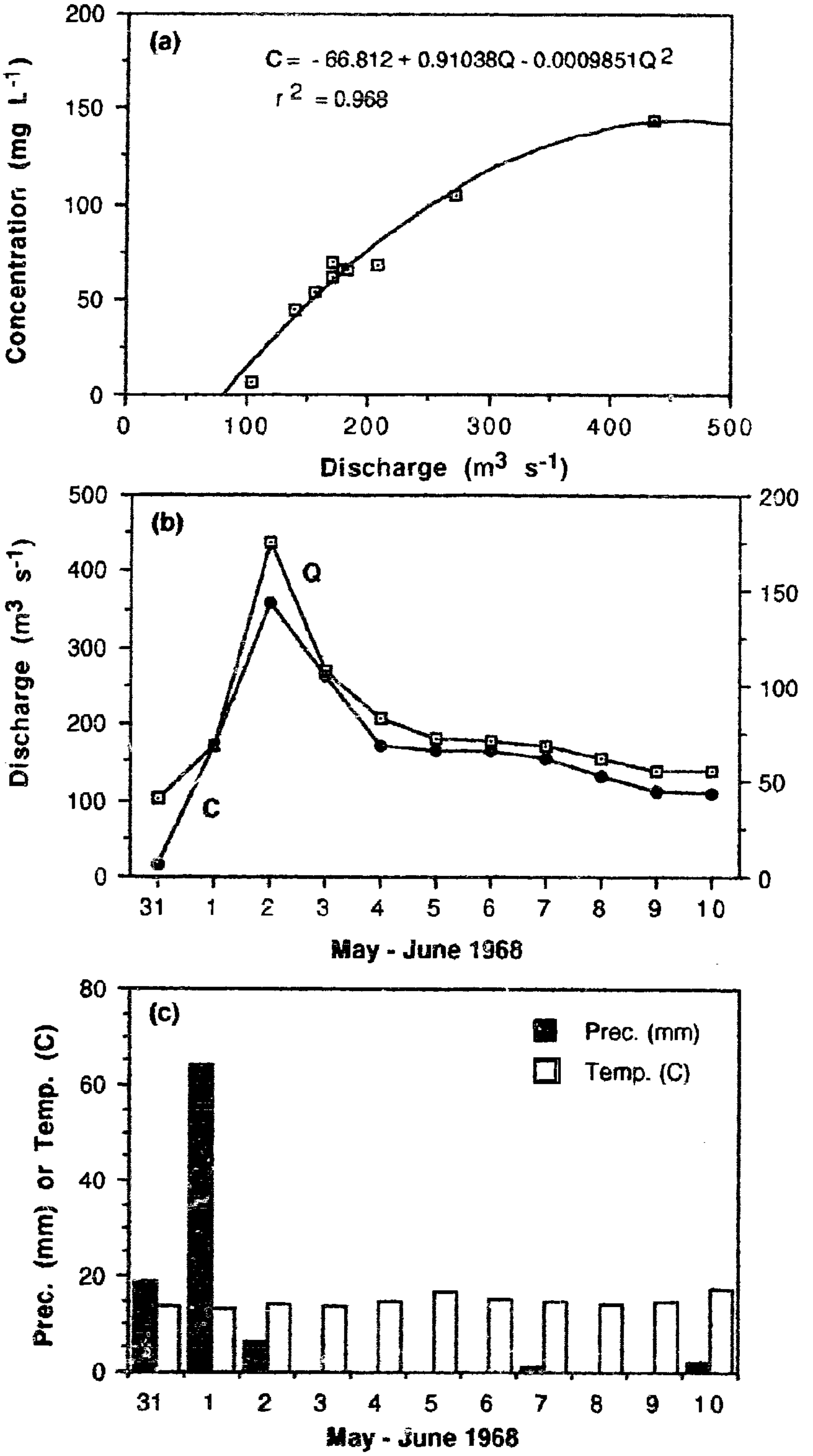

Fig. 5.14. Graphs of (a) convex rating curve, (b) temporal variations in discharge (Q) and concentration (C) and (c) distributions of daily precipitation and temperature during the event of 31 May 1968 on the Chilliwack River at Vedder Crossing station.

snowmelt because concentrations decreased almost at the same rate as that of discharge.

Conversely, low temperatures in the rising stage for concave events did not inhibit runoff and sediment generation from intense storms, but appear to have retarded sediment replenishment in the falling stage such that concentrations decreased at a faster rate than did discharge. The result was the concave sediment rating curve.

5.6 Summary and Conclusions

To summarize and conclude this chapter, types of sediment-discharge relations in Fraser River basin were found to be controlled by the timing of hydrological events in the year, runoff amount and its rate of increase, and sediment availability. No two hydrological events, however similar, produced similar sediment-discharge relationships. The close interplay of spatial and temporal factors in controlling sediment variation for individual hydrological events is the major problem in pin-pointing the different factors accounting for variations in sediment concentrations in rivers. So far, no simple mathematical model is yet available to explain all sediment-discharge relationships for single-valued hydrological events in rivers.

Linear regression analysis of independent hydrological factors in the rising and falling stages, namely, preceding discharge, rising mean discharge, index of flood intensity, falling mean discharge and the rate of flood recession, that control sediment variation for linear and non-linear single hydrological events, revealed several controls. In the rising stage, linear rating curves were found to be controlled more by the index of flood intensity than by the rising mean discharge and antecedent moisture. In the falling stage, linear rating curves were controlled more by the index of flood recession than by the falling mean discharge.

By contrast, non-linear sediment rating curves in the rising stage were found to be controlled more by, in order of significance, the index of flood intensity, rising mean discharge and antecedent moisture. The rate of flood recession was found to control falling mean concentrations as much as the falling mean discharge. Overall, the analysis showed that, for non-linear events, sediment concentration is more related to discharge and hydrograph characteristics in the falling stage. Conversely, for linear events discharge and hydrograph characteristics are important controlling factors both in the rising and falling stages.

The distinguishing characteristics between linear and non-linear rating curves is the influence of preceding discharge or antecedent moisture because of its greater control on sediment concentration for the former and none for the latter curve forms. This implies that, for linear events, other factors remaining constant, high antecedent moisture conditions has the effect of generating quickflow and overland runoff and a rapid increase in sediment concentration in concert with changes in discharge. Therefore, low antecedent moisture conditions produces a delayed increase in sediment concentration, a response not in phase with changes in discharge, which leads to the non-linear relationship between sediment concentration and discharge.

Lastly, the stepwise multiple regression analysis, used to determine the hierarchy of hydrological factors that control sediment variation for linear and non-linear events, revealed that linear events are controlled by antecedent moisture in the rising stage while non-linear events are not.

Hydraulically, linear, concave and convex sediment rating curves were distinguished on the basis of levels of discharge with respect to scouring and filling processes. It was found that, hydrographs for linear events began to rise and terminated when discharge was greater than that for bed scour. Under these conditions, the scouring process in the rising stage operated at rates similar to those for filling. In contrast, concave events began to rise when discharge was greater than the threshold for bed scour and terminated when the discharge fell below the scour threshold, or vise versa. In these cases, scouring occurred in the rising stage and filling in the falling stage when discharge was greater than the scour threshold and the bed was re-scoured once the discharge fell below the threshold of scour before the event terminated. The reverse situation also produced a concave rating curve. The convex events began to rise when the discharge was below the level of bed scour and terminated in the same range of discharge. Therefore, convex rating curves were controlled by filling as well as scouring in the rising stages, and in the falling stages, filling was followed by re-scouring by the termination time.

From the sedimentological point of view, suspended sediments for linear rating curves originated from the channel bed in the rising stage of the events with little or no amount of sediments recruited in the falling stages. For the concave rating curves, the channel bed supplied most of the sediments during scouring in the rising stage as well as during the re-scouring episodes in the latter part of the falling stage. Finally, for the convex rating curves, bed filling occurred before time of peak and most of the suspended sediments originated from the bed in the latter parts of the rising and falling stages when scouring occurred. In some cases, basin slopes contributed sediments in the falling stages of convex events.

The analysis of hydraulic factors demonstrated that the interaction between the stream-bed and streamflow was an important factor in the control of sediment variation for single-hydrological events. During the rising stage of the hydrological events, streamflow occurs within the bed material and the increase in water depth allows the flow to access fine sediment resident in the banks. In the falling stage, overland flow contributions cease and the recession flow curve is controlled in part by effluent flow through the channel boundary.

If the bed is mobile in the rising and falling stages, and sediments are released more rapidly in the rising stage than falling stage, a linear rating curve would be produced. But, if the bed is mobile in rising and immobile in falling stage of an hydrological event, the associated sediment-discharge relation likely will have a concave form. Similarly, If the bed is mobile in the rising and falling stages, the convex rating curve would result since sediments would be released quickly both in the rising and falling stages. It appears to be the case that when the inactive bed becomes mobile, in the rising or falling stages, it could contribute considerable amounts of sediments for transport by the stream. Therefore, the return of stored sediments by the scouring of the bed, in this study, has been found to be one of the major factors controlling the variation of suspended sediment concentration for single hydrological events.

Meteorological factors, namely, precipitation and air temperature, appear to control the forms of single-valued sediment rating curves.

Comparison of changes in bed elevations and the time of precipitation occurrence and temperature conditions in the duration of the events revealed that, bed scour generally was linked to the occurrence of precipitation in the drainage basin. For instance, linear events occurred when it rained under low or sub-zero temperatures in the rising stage and when precipitation was received under similar temperatures conditions in the falling stage. Linear rating curves were also produced when it rained under low to moderate temperature conditions in the rising and falling stages. Under low and sub-zero temperature conditions sediments were only recruited from the stream-bed and none from the slopes due to the frozen ground which inhibited infiltration and runoff generation. But under moderate temperatures runoff generated from precipitation recruited sediments from both the channel and areas adjacent to the river channel.

By contrast, concave events occurred when precipitation was received in the rising and falling stages under low temperature conditions as well as when it rained in the rising and falling stages under moderate temperatures. Under these conditions, concentrations either increased or decreased at rates greater or less than that of discharge in the rising or falling stages, respectively. Lastly, convex rating curves occurred under moderate temperature conditions when precipitation was received in the rising and little or none received in the falling stage. Under these conditions, in the rising stage precipitation quickly produced runoff accompanied by high sediment concentrations from the basin slopes as well as from the stream-bed. In the falling stage, sediment replenishment occurred due to precipitation under moderate temperatures or due to the availability of an inexhaustible amount of sediment in the channel under low temperature conditions.

CHAPTER SIX

CAUSES OF HYSTERESIS IN SUSPENDED-SEDIMENT RATING CURVES

6.1 Hysteresis in Sediment-Discharge Relations

6.1.1 Definition of Hysteresis

Hysteresis exists if, for each discharge on the rising and falling stages, there are more than one statistically dissimilar suspended-sediment concentrations. Not included in this analysis are those events that appeared to be hydrological when in fact they were simply episodes of increasing sediment concentrations related to non-storm events such as snowmelt in which discharges rose without falling back to or near the levels they were at the beginning of the apparent events.

6.1.2 Types of Hysteresis

Two types of hysteresis reported in the literature are clockwise and anticlockwise hysteretic loops. Clockwise hysteresis occurs when the sediment concentration peak leads the discharge peak (see Fig. 6.5b.2; 6.11a) and anticlockwise hysteresis occurs when the discharge peak leads that of sediment concentration (see Fig. 6.2c, event 8; 6.13a). The hydrological events that produced clockwise and anticlockwise forms of hysteresis are referred to here simply as clockwise and anticlockwise hysteretic events, respectively.

6.1.3 Character of Hysteresis in Sediment Concentration to Discharge Relations in the Fraser River basin

In order to assess variations in sediment concentrations within and between hydrological events, eight consecutive events between April and September, 1977, were selected at Marguerite station. These eight events are assumed to be representative of the distribution of the hydrological events in the Fraser River basin for most years. Regression results for the eight individual hydrological events are shown in Table 6.1. Each one of the storm events was divided into rising and falling stages. The discharge peak was included in the rising stage while stationary periods between events were incorporated into the falling stages.

The regression results showed that overall, discharge explained between 15% and 97% of the variation in sediment concentration. Standard errors of estimate, included in Table 6.1, show that the precision of estimating sediment concentration from discharge varied widely among events. Although significant relations between suspended sediment concentration and discharge were obtained, the type of equation was not consistent among events. This was anticipated from responses shown in the discharge hydrographs and sediment graphs (Fig. 6.1) (based on data in Appendix 8). Note especially that even events that had similar peaks (e.g., events 2 and 6), did not produce

Table 6.1. Summary of regression results in the relations of discharge (Q) and sediment concentration (C) for sequential storm events on the Fraser River, near Marguerite, April-September, 1977.

Storm	Calendar	Overall			Rising			Falling		
no.	days	Rating curve	r^2	Se	Rating curve	r^2	Se	Rating curve	r^2	Se
1.	89-112	$C = 205.1 + 0.118^{b}Q$	0.155	178.985	$C = 143.54 + 0.245Q$	0.549	145.001	$C = 0.294Q - 267.600$	0.975	18.918
2.	113-124	$C = 0.214Q - 141.774$	0.608	164.030	$C = 0.273Q - 199.865$	0.988	35.126	$C = 1.107Q - 3244.126$	0.953	50.767
3.	125-142	$C = 0.18Q - 335.788$	0.935	25.224	$C = 0.090^{a}Q - 18.940$	0.574	17.415	$C = 0.185Q - 355.468$	0.944	26.756
4.	143-151	$C = 0.143Q - 248.554$	0.579	18.369	$C = 0.159Q - 274.000$	0.986	04.098	$C = 0.208^{a}Q - 434.164$	0.933	05.141
5.	152-157	$C = 0.151^{a}Q - 285.901$	0.901	10.134	$C = 0.142^{a}Q - 259.605$	0.907	11.877	$C = 0.241Q - 554.000$	1.000	00.000
6.	158-167	$C = 0.566Q - 1585.994$	0.975	104.928	$C = 0.518Q - 1332.958$	0.997	22.048	$C = 0.727Q - 2217.920$	0.896	65.539
7.	168-191	$C = 154Q - 300.832$	0.763	32.167	$C = 0.244Q - 658.542$	0.940	18.518	$C = 0.212Q - 494.118$	0.804	34.176
8.	192-208	$C = 118Q - 237.323$	0.854	22.495	$C = 0.105Q - 207.41$	0.923	14.888	$C = 0.14Q - 286.917$	0.940	18.115

NOTES:

1. Superscripts indicate levels of significance for coefficients occurring less frequently: (a) - significant at 95 percent level; (b) - 90 percent level. Where no superscripts are shown the coefficients are significant at the 99 percent level.
2. Se standards for the standard error of estimate (mg L^{-1}).

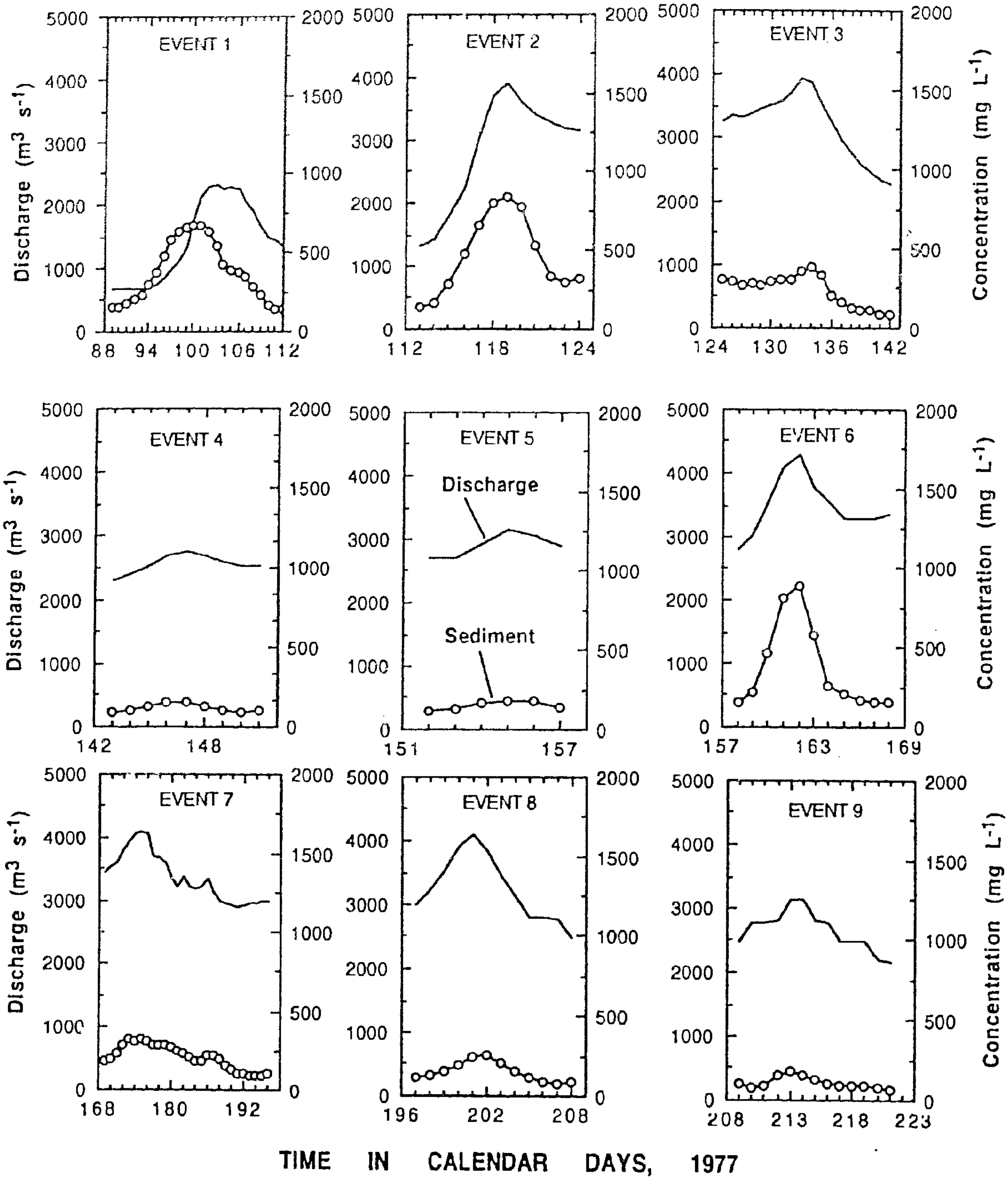

Fig. 6.1. Temporal sediment concentration and discharge graphs for nine hydrological events on the Fraser River at the Marguerite station, April-September, 1977.

similar equations.

Simple regression analysis of the relationship between concentration and discharge in the rising stage shows that the highest coefficient of determination ($r^2 = 0.997$) was associated with event 6 which contained the seasonal discharge peak. A systematic decrease in the explained variance of sediment concentration was also observed in subsequent events after the seasonal discharge peak had passed. Furthermore, slopes for regression lines in the falling stage were generally greater than those in the rising stage. Although this implies that falling discharges have a greater potential for sediment transport than the rising discharges, it is only true for events exhibiting clockwise hysteresis.

By plotting suspended-sediment concentrations sequentially against discharge, different degrees of hysteresis were evident for different events. More pronounced hysteretic loops were associated with events earlier than later in the season (Fig. 6.2). The amount of spread in the hysteretic loops decreased in subsequent events (probably due to exhaustion of sediments). After sediment storage was depleted most of the sediments likely derived from the channel bed and linear sediment rating curves were generally produced (see event 8) (Fig. 6.3). Overall, analysis of hysteresis revealed that, for a given discharge, more suspended sediment was transported on the rising than on falling stages irrespective of whether or not the event was characterized by clockwise or anticlockwise hysteresis. Some of the factors controlling the occurrence of clockwise and anticlockwise hysteresis are discussed in later sections.

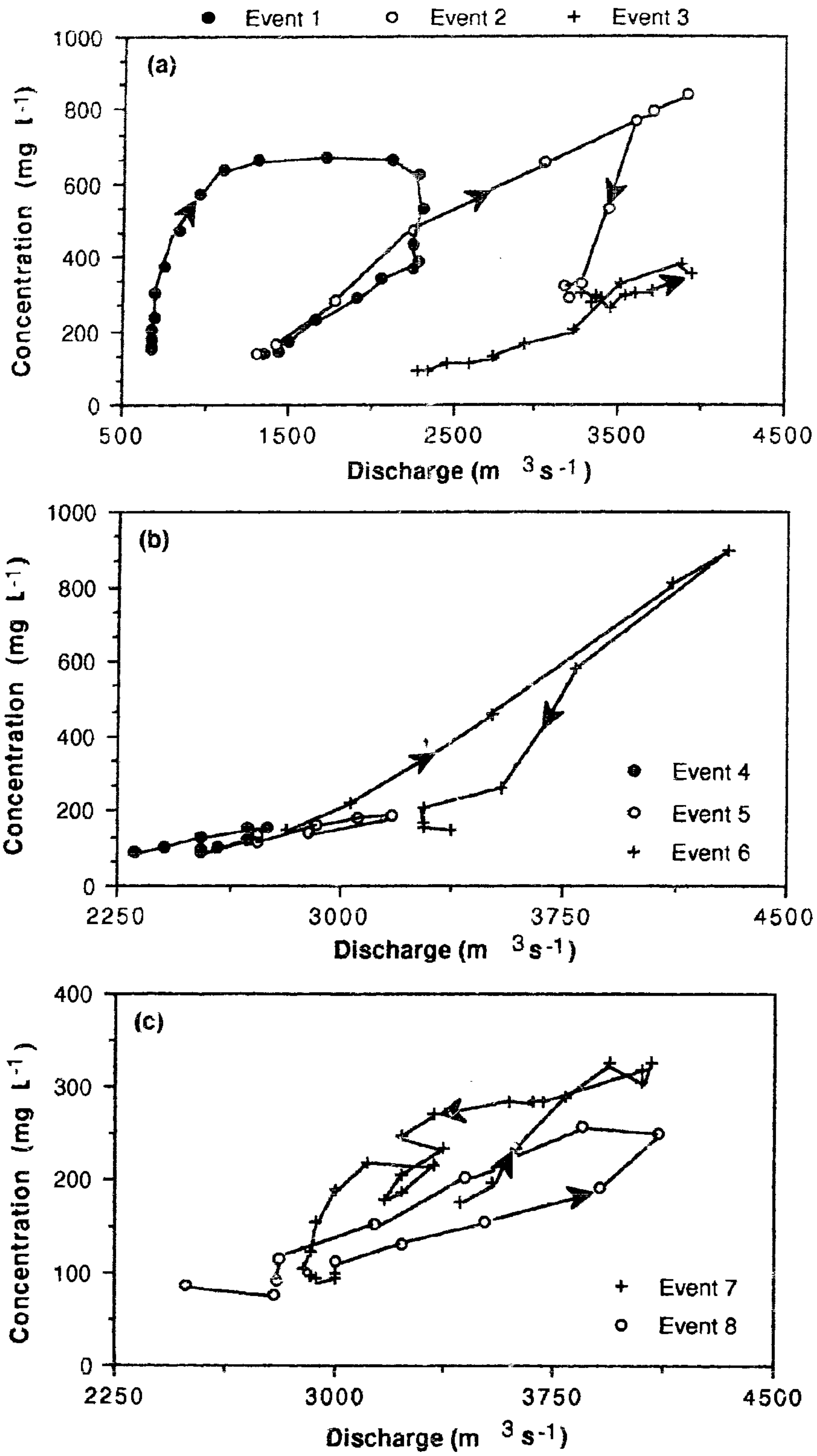

Fig. 6.2. Timing of hysteretic hydrological events on the Fraser River at Marguerite station sequentially plotted, April-September, 1977.

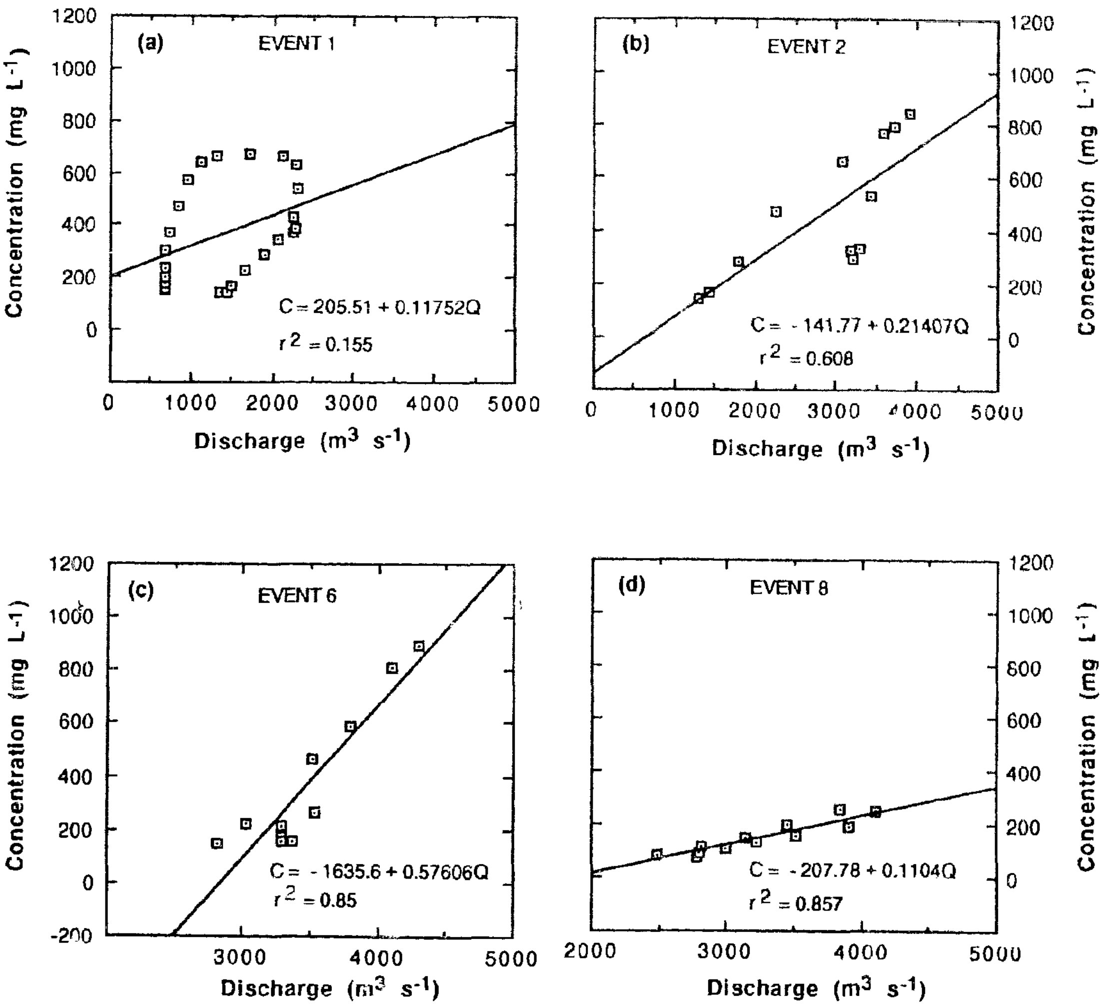

Fig. 6.3. Graphs showing the contraction of the sediment hysteresis loop on the Fraser River for hydrological events in the beginning of spring (a) and (b), and the beginning (c) and end (d) of the summer season at Marguerite station, 1977.

6.1.4 Factors Controlling Hysteresis Sediment Concentration-Discharge Hysteresis

6.1.4.1 Sources of Sediment Supply

For single hydrological events, clockwise hysteresis was observed to occur, at all sediment stations, more commonly in early spring than later events and anticlockwise hysteresis in the later storm than earlier storm events. Generally, clockwise hysteresis appears to be caused by a high influx of sediments from the basin slopes and as well as from areas adjacent to the river channel. But in the anticlockwise case, most sediments likely originated from bank collapse and landslides which are common along Fraser River upstream of Marguerite. For instance, the occurrence of anticlockwise hysteresis in events 3, 7 and 8 (Fig. 6.2) followed major storms during which sediment exhaustion took place. This is why anticlockwise loops were generally of short duration and were not associated with very high sediment concentrations. Their occurrence resembled slug injections of sediments from isolated and localized areas characteristic of bank failures and landslides.

6.1.4.2 Temporal and Spatial Factors

6.1.4.2.1 Time Lag between Sediment Concentration and Discharge Peak

Time lag between suspended sediment and discharge peaks for individual hydrological events partly accounted for hysteresis in sediment-discharge relations. This factor is illustrated below by two events, one in 1976 and the other in 1980. The analysis involved comparing differences in the travel times of suspended sediment and flood peaks at different stations along the main channel of Fraser River.

Hydrological information for the 30 March 1976 event indicated that it was not registered at the Hansard station and, therefore, originated somewhere between Quesnel and Marguerite station. The sediment concentration peak arrived at Marguerite station on 9 April, five days ahead of the flood peak registered on 14 April 1976 (Fig. 6.4a). The increase in sediment concentration during this event at Marguerite station was also found to have been unrelated to discharge. Note that even after peaking, sediment concentrations continued to fall while discharge was steadily rising. Evidently, during this event at Marguerite station, variations in sediment concentration were mainly supply dependent and independent of flow conditions.

At the Hope (Fig. 6.4b) and Agassiz (Fig. 6.4c) stations, the sediment concentration peak occurred on 14 April while discharge peaked three days later. Whereas the discharge peaked at Hope, Agassiz and Mission on 17 April, the concentration peak stalled for three days between Agassiz and Mission so that the two peaks occurred simultaneously at Mission on 17 April (Fig. 6.4d). Between Hope and Agassiz stations the river planform changes from a straight to braided pattern. Undoubtedly, this change in channel planform (and sediment storage capacity) partly account for this phenomenon. Deposition of much of the suspended-sediment on gravel, in the past likely contributed to the formation of gravel bars and islands which characterize the reach. Before the 30 March event terminated, the deposited sediment appear to have beenremobilized en masse by the flood which arrived at the

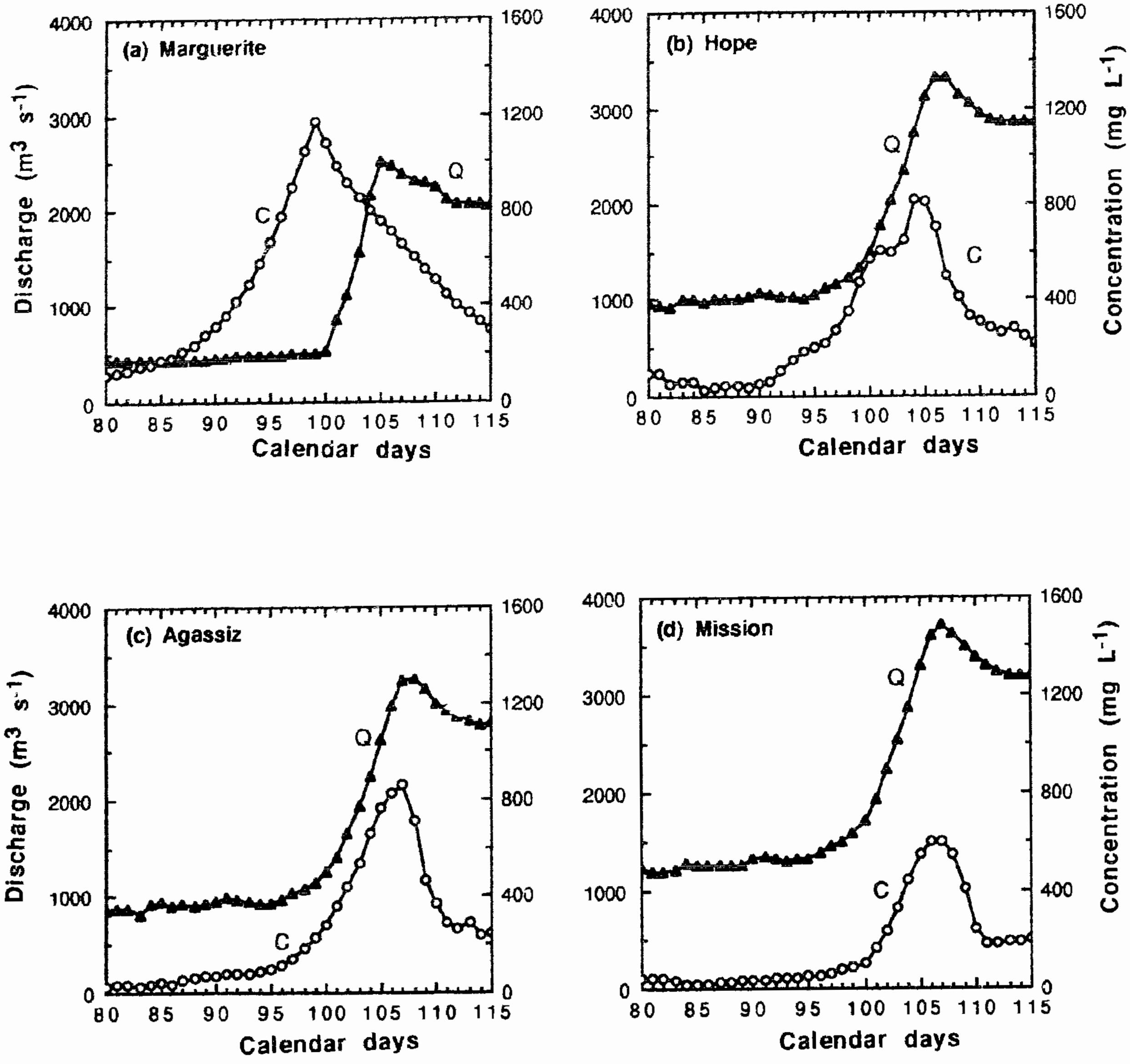

Fig. 6.4. Discharge and suspended sediment concentration graphs for the Fraser River during the 30 March - 23 April 1976 hydrological event (a) near Marguerite, (b) at Hope, (c) near Agassiz and (d) at Mission stations.

Agassiz station three days later than the sediment peak.

Therefore, differences in the travel times of concentration and discharge peaks between stations partly accounts for the generally poor relationships between concentration and discharge at different stations. Table 6.2 indicates that discharge accounted only for a negligible amount of the variation in suspended-sediment concentration during the 30 March 1976 event at Marguerite station. However, when the data were divided into the rising and falling stages, regression analysis revealed that falling sediment concentration were more related to falling discharge than were rising concentrations to rising discharges. This implies that, at the onset of spring snowmelt, easily transportable fines were quickly entrained by the flow even when there was little change in discharge.

The decreasing length of time lag between sediment and discharge peaks in the downstream direction led to an improvement in the simple predictive capacity of the sediment-discharge relationships. This was indicated by the increase in the overall r^2 from 0.031 near Marguerite to 0.74 at Mission where sediment and discharge peaks occurred simultaneously (Table 6.2). For the rising stage, the variance in sediment concentration explained by the discharge alone increased from 14% near Marguerite to 99% at Mission. However, an opposite situation was observed for the falling stage in which the variance of sediment concentration explained by discharge decreased from 95% near Marguerite to 87% at Mission. The dilution of the flow by the flood flow and contributions from tributaries presumably accounted for this change. The small change in the explained variance between Marguerite and Mission stations for the falling stage was probably due to the interplay of

Table 6.2. Results of simple regression analysis in the relations of discharge (Q) and sediment concentration (C) for the hydrological event of 30 March - 23 April 1976 on the Fraser River at Marguerite, British Columbia.

Station	Overall			Rising			Falling		
	Rating curve	r^2	Se	Rating curve	r^2	Se	Rating curve	r^2	Se
Marguerite	$C = 448.369 + 0.066^{b}Q$	0.031	308.554	$C = 359.73 + 0.251Q$	0.149	334.046	$C = 0.913Q - 1519.537$	0.951	33.658
Hope	$C = 0.169Q - 19.207$	0.423	183.003	$C = 0.35Q - 218.824$	0.806	121.299	$C = 536Q - 1276.85$	0.949	21.478
Agassiz	$C = 0.214Q - 99.83$	0.617	157.079	$C = 0.354Q - 234$	0.945	065.767	$C = 0.614Q - 1472.697$	0.945	21.071
Mission	$C = 0.164Q - 174.678$	0.74	094.344	$C = 0.242Q - 279.171$	0.990	018.882	$C = 0.784Q - 2346.154$	0.873	52.237

NOTES: 1. Superscript (b) indicate 95 percent level of significance for slope coefficient. Where no superscripts are shown the coefficients are significant at the 99 percent level.

2. Se standards for the standard error of estimate (mg L^{-1}).

factors other than discharge.

The temporary stalling of the sediment peak between Hope and Agassiz due to the change in channel pattern discussed above, partly explains the similarities in the coefficients of determination in the rising and falling stages at Agassiz ($r^2 = 0.945$), and between Hope ($r^2 = 0.949$) and Agassiz ($r^2 = 0.945$) stations in the falling stage. The change in channel pattern apparently had the effect of slowing down the downstream movement of the wave of high sediment-concentration, thereby allowing for an equivalent amount of sediment to be transported in the rising and falling stages at the Agassiz station. Table 6.3 shows that most of the sediment load transported by the 30 March 1976 event originated from the reach between Hansard and Marguerite and only a negligible amount was supplied from the reach upstream of Hansard. A systematic decrease in sediment load was observed in the downstream direction between Marguerite and Hope station due to in-channel storage. The negative net sediment transport downstream of Hope indicates that more sediment was being stored than was being transported through the system, further supporting the results of the bed elevation analysis discussed in Chapter Four.

Another event in which lag time between concentration and discharge peaks influenced sediment variations was that of 15 December 1980 recorded at Hansard and Marguerite stations on the Fraser River. Hydrological information indicated that this event was restricted only to the river reach above Marguerite. This event was initiated by a two-day precipitation received on 15th-16th December. The precipitation in these two days decreased in the downstream direction, being highest at McBride (61.5 mm) which is located upstream

Table 6.3. Net storage of suspended-sediment load on the main channel of Fraser River during the hydrological event of 30 March - 23 April, 1976.

No.	Station	Period	Event sediment load (tonnes)	Sediment change (tonnes)	Sediment change (%)
1.	Hansard	30.03.76 - 23.04.76	3695		
				1489444	+403097.0
2.	Marguerite	30.03.76 - 23.04.76	1493139		
				519581	+34.8
3.	Hope	30.03.76 - 23.04.76	2012720		
				150336	-7.5
4.	Agassiz	30.03.76 - 23.04.76	1862384		
				327892	-17.6
5.	Mission	30.03.76 - 23.04.76	1534492		

of Hansard, and lowest at Kersely (1.2 mm), the nearest weather station to the Marguerite sediment station. Other weather stations affected by this event included Dome Creek, Prince George, Hixon and Quesnel with 32.4 mm, 17.9 mm, 7.0 mm, and 2.6 mm, respectively; temperatures at these stations in the two days were low (2.5 °C-7.8 °C). Although some precipitation was received at a number of these stations, after 16th December, it did not generate any runoff due to sub-zero temperatures that obtained in the area. For instance, temperatures ranged from -8.3 °C to -18.0 °C at Dome Creek; -5.2 °C to -19.0 °C at Prince George; -6 °C to -17.3 °C at Hixon; -4.3 °C to -16.4 °C at Quesnel; and -5 °C to -17.3 °C at Kersely. Under these meteorological conditions, no sediments from the basin slopes entered the river implying that most of the sediment were recruited from the river bed and banks.

At Hansard, because the discharge and concentration peaks occurred simultaneously, there was little variation in concentrations in the rising and falling stages (Fig. 6.5a.1, a.2). In contrast, at Marguerite station, where concentration peaked earlier than discharge, greater variations in concentrations occurred on the rising and falling stages (Fig. 6.5b.1, b.2). Concentrations appear to have increased at a rate faster than that of discharge in the rising stage, resulting in a pronounced hysteretic loop in the sediment-discharge line plot. The other cause of variation in sediment concentration at the two stations was that, the core of maximum concentration traveled faster than the flood wave because they peaked on the same day at Hansard and Marguerite stations while a day lapsed before flood peak reached the Marguerite station.

The 15 December 1980 event also indicated that there was no temporal and spatial variation in sediment concentration partly because

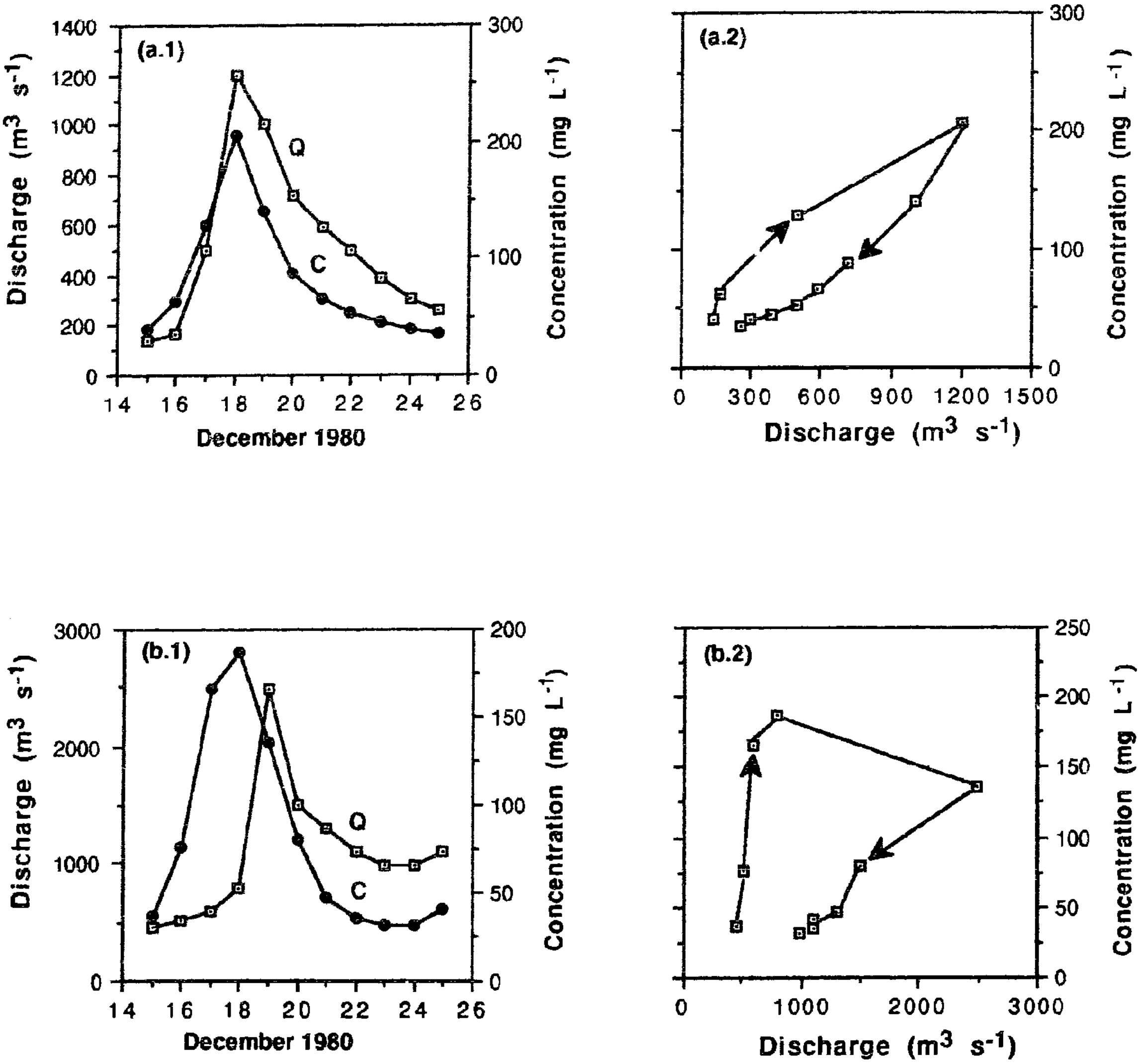

Fig. 6.5. Temporal sediment concentration and discharge graphs (a.1, b.1) and associated sediment discharge hysteretic loops (a.2, b.2) for the 15 December 1980 hydrological event at (a) Hansard and (b) Marguerite stations on the Fraser River.

most of the sediments were supplied from the upstream reaches with little or no additions from the slopes. Conversely, there was temporal and spatial variation in the streamflow between Hansard and Marguerite stations which caused differences in the degrees of hysteresis at these stations.

In summary, it appears that the peaking of sediment concentration earlier than discharge at Marguerite and Hope stations for the 30 March 1976 event were controlled by differences in travel distances and by differences in time of travel for the two peaks. At the beginning of this hydrological event, suspended-sediment were quickly entrained and traveled faster with streamflow than than the associated runoff which was still concentrating to form a flood wave. Since the flood wave travels faster than streamflow, the flood wave was able to catch up with the concentration peak by the time it reached the Agassiz station. The discharge and concentration remained coincident up to the Mission station. However, the movement of suspended-sediment seems to be complicated by the deposition and re-mobilization of the sediment, especially in the Agassiz-Mission reach.

The 25 December 1980 event in the upper reaches of the Fraser River revealed that sediment variation could be caused by the temporal and spatial variation in discharge alone with little or no variation in concentration between stations and also by the time lag between discharge and concentration peaks.

6.1.4.2.2 Direction of Storm Movement

Direction of storm movement within a drainage basin was found to control runoff and sediment generation which, in turn, accounted for some variations in sediment concentrations for individual events. This situation was illustrated by the event of 23 December 1980 at a number of stations in the Lower Fraser basin. Stations investigated for this event included Vedder Crossing station on the Chilliwack River, Mission, Agassiz and Hope stations on the Fraser River and the Harrison Hot Springs station on the Harrison River. Of these stations, only Mission and Agassiz had both sediment and discharge records. Since the time scale of days for precipitation measurements was not appropriate for assessing the direction of storm movement discharge measurements were used as a surrogate for precipitation.

Based on the times of rise and discharge peaks the rain storm that effected the 23 December 1980 event was assumed to have been moving initially in the north-westerly direction as indicated by the discharge records at Harrison Hot Springs (Fig. 6.6a) Mission (Fig. 6.6b) and Vedder Crossing station (Fig. 6.6a). Thereafter, this same storm or in combination with another appears to have started moving in the up-basin direction as evidenced by the one day time lag between the early discharge peak at Mission registered on 26 December and the later simultaneous peaks at Agassiz and Hope stations. The up-basin movement of one or two storms between Mission and Hope was corroborated by the higher sediment concentrations recorded at Mission than at the Agassiz station located upstream of Mission (Fig. 6.6c). These sediment records not only confirmed that transportation of

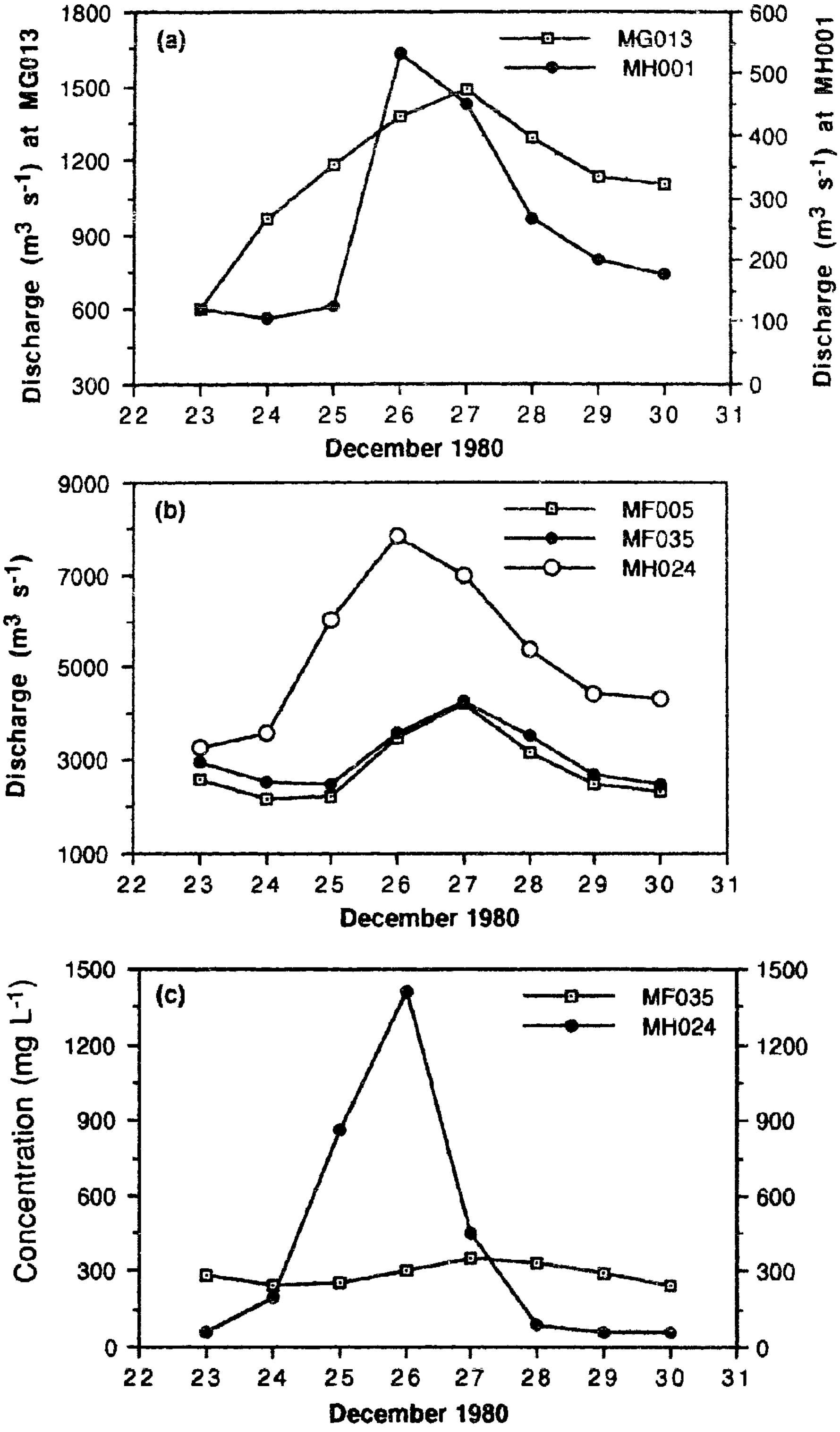

Fig. 6.6. Temporal variations in discharge at (a) Harrison Hot Springs (MG013) on the Harrison River and at Vedder Crossing (MH001) on the Chilliwack River, and (b) at Hope (MF005), Agassiz (MF035) and Mission (MH024) stations on the Fraser River; and in sediment concentration (c) at the Agassiz and Mission stations during the 23 December 1980 event.

sediment was confined to the reaches downstream of Agassiz, but also complicated the determination of the sources of sediment observed at the Mission station.

The discharge peak associated with the 23 December 1980 event at Mission was the only annual peak that was unrelated to the freshet occurring in the spring months. Geomorphological and hydrological factors alone could not sufficiently explain sediment variations associated with this event on the Fraser, Harrison and Chilliwack Rivers. But a fuller understanding of the discharge and sediment generation processes was gained when the influences of some meteorological factors were considered. This led to the realization that it was the high intensity rain storm received around Agassiz and Mission stations (Fig. 6.7a) combined with runoff contributions from Chilliwack and Harrison tributaries that generated the major flood of 1980 recorded at Mission. This event was accompanied by intense suspended-sediment transport in the lower parts of the Fraser River (Fig. 6.6c).

Note that other stations in the vicinity of Mission also received an equivalent amount of precipitation but not enough runoff was generated to cause a flood. A partial explanation for this appears to lie in the air temperature regimes that obtained in different areas of the lower basin. The area around Hope experienced the lowest temperatures including sub-zero temperatures at the beginning of the 23 December event (Fig. 6.7b). Under these conditions most of the precipitation was received as snow which was not quickly translated into runoff. In contrast, at the beginning of the event, the area around Mission experienced the highest temperatures, with a maximum of 14 °C reached on 26 December when the highest rainfall of 86 mm was received (Fig. 6.7a). These conditions

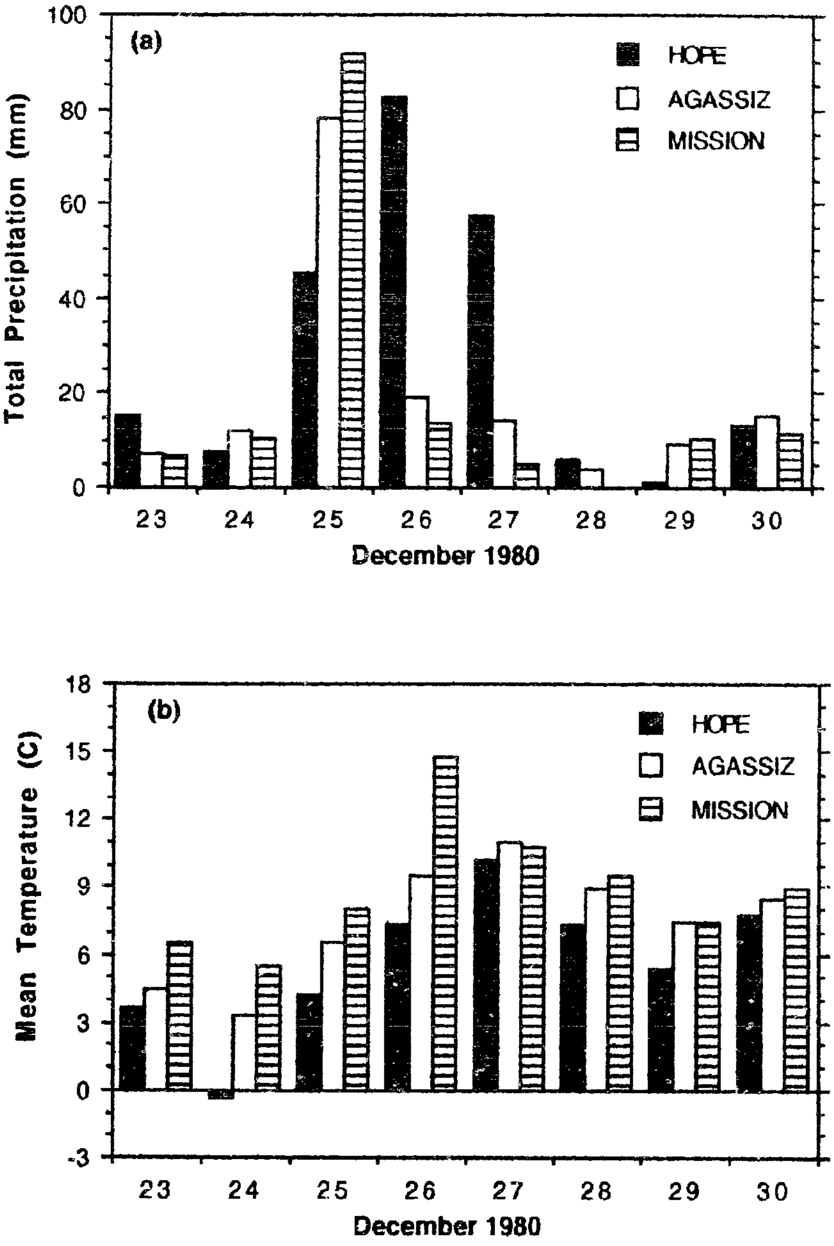

Fig. 6.7. Variations of daily total precipitation (a) and daily mean temperatures (b) during the 23 December 1980 hydrological event at Hope, Agassiz and Mission.

highly favoured rapid generation of runoff and massive transport of sediment from the stream bed and banks as the record showed.

The 23 December 1980 event revealed that more than one group of factors were required to account for the variations in suspended-sediment. Lack of meteorological data for most of the stations on the main channel of the Fraser River precluded the consideration of meteorological factors in the analysis of factors controlling sediment variation for other single hydrological events. The next section deals with factors controlling the occurrence of different types of hysteresis in the sediment concentration-discharge relations.

6.1.5. Factors Controlling Clockwise and Anticlockwise Hysteresis

6.1.5.1 Hydrological Factors

Based on data given in Appendix 4, stepwise multiple regression analysis of sediment concentration as the dependent variable and three independent variables, showed that rising stages of clockwise sediment-discharge hysteresis for 88 events were controlled by, in order of importance, the index of flood intensity, preceding discharge and the measured discharge, while 34 anticlockwise events were controlled by the rate of flood rise, measured discharge and the preceding discharge (Table 6.4). In the falling stage both clockwise and anticlockwise events were controlled by, in the order of decreasing importance, the rate of flood recession and measured discharge.

Table 6.4. Results of stepwise multiple regresion analysis between hydrological factors and suspended-sediment concentration for hysteretic events in the Fraser River basin.

(a) STEPWISE MULTIPLE REGRESSION EQUATIONS		MULTIPLE CORRELATION COEFFICIENTS		
I. Clockwise Hysteretic Events		n	R^2	P
RISING STAGE:	$Cr = 249.907 + 0.266IFI - 0.004Qpr + 0.12Qr$	88	0.184	0.0022
FALLING STAGE:	$Cf = 146.049 + 0.203IFR + 0.012Qf$	88	0.466	0.0001
II. Anticlockwise Hysteretic Events				
RISING STAGE:	$Cr = 42.303 + 0.653IFI + 0.018Qr - 0.012Qpr$	34	0.630	0.0001
FALLING STAGE:	$Cf = 67.082 + 0.739IFR + 0.02Qf$	34	0.998	0.0001

(b) BETA COEFFICIENTS ($B = b/(si/sd)$)

	BETA COEFFICIENTS			
	Clockwise		Anticlockwise	
Variable	Rising	Falling	Rising	Falling
Qr	0.1891		0.4330	
Qpr	-0.0482		-0.2620	
IFI	0.2779		0.6412	
Qf		0.3949		0.4462
IFR		0.2013		0.2995

NOTES:		
	Cr/Cf	are suspended-sediment concentrations (mg L^{-1}) in risng and falling stages;
	Qr	is rising mean discharge (m^3s^{-1});
	Qf	is the falling mean discharge (m^3s^{-1});
	Qpr	is the discharge preceding hydrograph rise (m^3s^{-1});
	IFI	is the index of flood intensity;
	IFR	is the index of flood recession;
	B	is the beta coefficient;
	b	is the regression coefficient;
	si	is the standard deviation for the independent variable (m^3 s^{-1});
	sd	is the standard deviation for the dependent variable (mg L^{-1}); and
	P	is the significance level.

These observations suggest that sources of sediment supply in the rising stage for clockwise hysteresis were areas adjacent to the river channel, while for anticlockwise cases most of the sediment originated from basin slopes. This was indicated by the fact that preceding discharge was more important in the clockwise than anticlockwise events. Runoff generated by quickflow and/or overland flow probably comprised a higher proportion of the discharge for clockwise than anticlockwise events.

For the prediction of mean sediment concentrations in the rising and falling stages from various hydrological factors, multiplicative models for each of the studied factors significant at 0.01 level are given in Table 6.5. Table 6.5 shows that the studied hydrological factors accounted for between 35% and 56% of the variation in sediment concentration in the rising stage and between 32% and 70% in the falling stages. These results suggest that the relationships between sediment concentration and the studied hydrological factors are generally stronger for anticlockwise than clockwise hydrological events. The explanation for this observation is not known.

6.1.5.2 Hydraulic Factors

The hydraulic data for some hysteretic events analysed in this study are given in Appendix 9. Because of the lack of measured data only qualitative assessments were made of the hydraulic controls on sediment concentrations during hysteretic events. Changes in depth, velocity and bed elevations associated with 13 clockwise hysteretic

Table 6.5. Summary of results of multiplicative regression analysis of the relationships between mean rising and mean falling sediment concentrations and various hydrological factors for hysteretic events in the Fraser River basin.

Rising Stage			Falling Stage		
Regression equation[1]	n	r^2	Regression equation[1]	n	r^2
I. CLOCKWISE EVENTS					
$Cr = 18.489Qpr^{0.374}$	89	0.414	$Cf = 05.273Qf^{0.462}$	89	0.446
$Cr = 11.915Qr^{0.411}$	89	0.366	$Cf = 16.874IFR^{0.493}$	89	0.322
$Cr = 14.613IFI^{0.567}$	89	0.357			
II. ANTICLOCKWISE EVENTS					
$Cr = 08.483IFI^{0.571}$	34	0.562	$Cf = 10.919IFR^{0.568}$	34	0.698
$Cr = 04.498Qr^{0.444}$	34	0.531	$Cf = 05.820Qf^{0.427}$	34	0.614
$Cr = 06.357Qpr^{0.409}$	34	0.519			

---

[1] Cr and Cf are rising and falling sediment concentrtation (mg L^{-1}); Qr and Qf are average rising and falling discharges (m^3 s^{-1}); Qpr is the discharge for the day preceding hydrograph rise (m^3 s^{-1}); IFI is the index of flood intensity; IFR is the index of rate of flood recession.

events were also compiled. Table 6.6 shows that changes in these hydraulic variables for hysteretic events were essentially similar to those for the single-valued events discussed in Chapter Five (Table 5.12). In all events, increase in sediment concentration likely was a result of the flow accessing sediment in the stream-bed by the scouring process whenever the discharge threshold for bed scour was exceeded in the rising stage. Decreases in sediment concentrations were linked to the filling of the bed in the falling stage above the discharge threshold. On many occasions, scouring of the bed also occurred in the falling stage even when the discharge fell below the scour threshold level as was discussed in Chapter Five.

The effect of 'breakaway velocities' on sediment variation observed on some single-valued evensts also apparently influenced variations in sediment concentrations of several hysteretic events. But the occurrence of 'breakaway' velocities was genearally more common for hysteretic than single-valued events. In addition, whereas 'breakaway' velocities in the single-valued events tended to cause linear sediment-discharge relations, they generally effected clockwise hysteresis in the hysteretic events. This was largely because the occurrence of high velocities near peak discharge when supply of fine sediment from the bed was exhausted also inhibited deposition. Hysteresis in relations of sediment concentration and discharge were also common among double peaked hydrological events. This was attributed largely to the fact that changes in discharge for the second peak had little or no influence on the variation in sediment concentration.

For instance, the event of 28 April 1976 at the Marguerite station on Fraser River showed that the increase in concentrations were

Table 6.6. Changes in depth, mean velocity and stream-bed elevation for measured hysteretic events in the Fraser River basin.

Event no[3].	Station no.	Date	River	Depth		Velocity		Bed elevation path	
				Rising	Falling	Rising	Falling	Rising	Falling
77.	08LA001	07.06.72	Clearwater R.	Deeper (0.001772)+	Shallower (0.002167)	Greater[1] (0.000363)	Smaller (0.000741)	Scouring	Filling
78.	08MC018	05.06.72	Fraser R.	Shallower (0.000627)	Deeper (0.000434)	Same[2] (0.000299)	Same (0.000311)	Scouring	Filling and stable at depth
79.	08MC018	25.04.76	Fraser R.	Deeper (0.000884)	Shallower (0.000484)	Greater[1] (0.000249)	Smaller (0.000360)	Scouring	Filling
92.	08MF005	04.06.69	Fraser R	Same (0.000005)	Same (0.000005)	Smaller[1] (0.000322)	Greater (0.00025)	Scouring	Filling
97.	08M005	05.06.78	Fraser R.	Shallower (0.000771)	Deeper (0.000691)	Smaller[2] (0.000016)	Greater (0.000018)	Scouring	Filling
115.	08MF035	15.05.85	Fraser R.	Shallower (0.0000338)	Deeper (0.000204)	Greater[1] (0.000126)	Smaller (0.000149)	Filling snd scouring	Scouring
122	08MH001	11.06.74	Chilliwack R.	Shallower (0.005142)	Deeper (0.000457)	Smaller[1] (0.003486)	Greater (0.001587)	Scouring	Scouring
123.	08MH024	05.06.69	Fraser R.	Shallower (0.000307)	Deeper (0.000250)	Greater[1] (0.000049)	Smaller (0.000106)	Scouring	Filling
126.	08MH024	13.05.72	Fraser R.	Deeper (0.000063)	Shallower (0.000083)	Same[3] (0.000092)	Same (0.000092)	Scouring	Stable at depth
128.	08MH024	06.05.74	Fraser R.	Shallower (0.001200)	Deeper (0.001027)	Greater[1] (0.000129)	Smaller (0.000161)	Scouring	Filling

Table 6.5 continued

Event no^3.	Station no.	Date	River	Depth		Velocity		Bed elevation path	
				Rising	Falling	Rising	Falling	Rising	Falling
128.	08MH024	12.06.74	Fraser R.	Deeper & shallower (0.000377)	Shallower & deeper (0.000176)	Smaller^1 (0.000074)	Greater (0.000041)	Scouring & filling	Scouring and filling
133.	08MH024	17.06.80	Fraser R.	Deeper (0.000417)	Shallower (0.000599)	Smaller^1 (0.000350)	Greater (0.000192)	Scouring	Stable at depth
135.	08MH024	11.06.82	Fraser R.	Deeper (0.000314)	Shallower (0.000637)	Greater^1 (0.000106)	Smaller (0.000208)	Scouring & filling	Filling and scouring
138.	08MH024	28.05.86	Fraser R.	Deeper (0.000395)	Shallower (0.000356)	Smaller & greater^2 (0.000097)	Smaller & greater (0.000088)	Filling & scouring	Scouring, filling & scouring

+ The values in parentheses are slopes for simlpe regression lines of the relationships between discharge and respective hydraulic variables in the rising and falling stages of individual events.

1 Crossing-over of average velocities occurred at higher than lower discharges; 2 - at discharges near time of rise and termination of individual hydrological events.

3 Numbers of events correspond to the numbers of events listed in Appendix 4.

associated with the first discharge peak (Fig. 6.8a). Sediment concentrations continued to decrease after the first peak even during the rising stage of the second peak which caused large variations in concentrations between rising and falling stages (Fig. 6.8b). The changes in depth, and mean velocities were more related to second than the first peak (Fig. 6.8c, d). However, channel bed adjustment, indicated by bed elevations, was not influenced by the two discharge peaks (Fig. 6.8e). Scouring of the bed continued in the entire duration of the event for as long as the discharge was above bankfull ($Q = 4200\ m^3\ s^{-1}$) which was far above the threshold for bed scour ($Q_t = 2000\ m^3\ s^{-1}$) (Fig. 6.8c). Scouring of the bed in the falling stage was possible because of the existence of 'breakaway velocitites' at high flows.

The role of 'breakaway velocities' in controlling sediment variation for hysteretic events is illustrated by the event of 12 June 1974 at Mission station. During this event it was observed that, while changes in depth were approximately in phase with changes in discharge, the changes in velocities were not (Fig. 6.9a.1, a.2; Fig. 6.9b.1, b.2). This was because peak velocities persisted for six days after the flood peak. For this event, it appears that changes in bed elevation were largely controlled by the changes in velocity. At Mission station the path of seasonal scour and fill regime generally has an anticlockwise form at high flows. But during this event, after the peak the stream-bed was scoured for six days instead of being filled (Fig. 6.9c.2). The effect of these hydraulic changes during the 12 June 1974 event was a shift in the sediment rating curves for the rising and falling stages (gig. 6.9c.1). Without this knowledge that the variations in sediment concentration is related to hydraulic changes, one could have mistaken the sediment-discharge relation (Fig. 6.9c.1) with

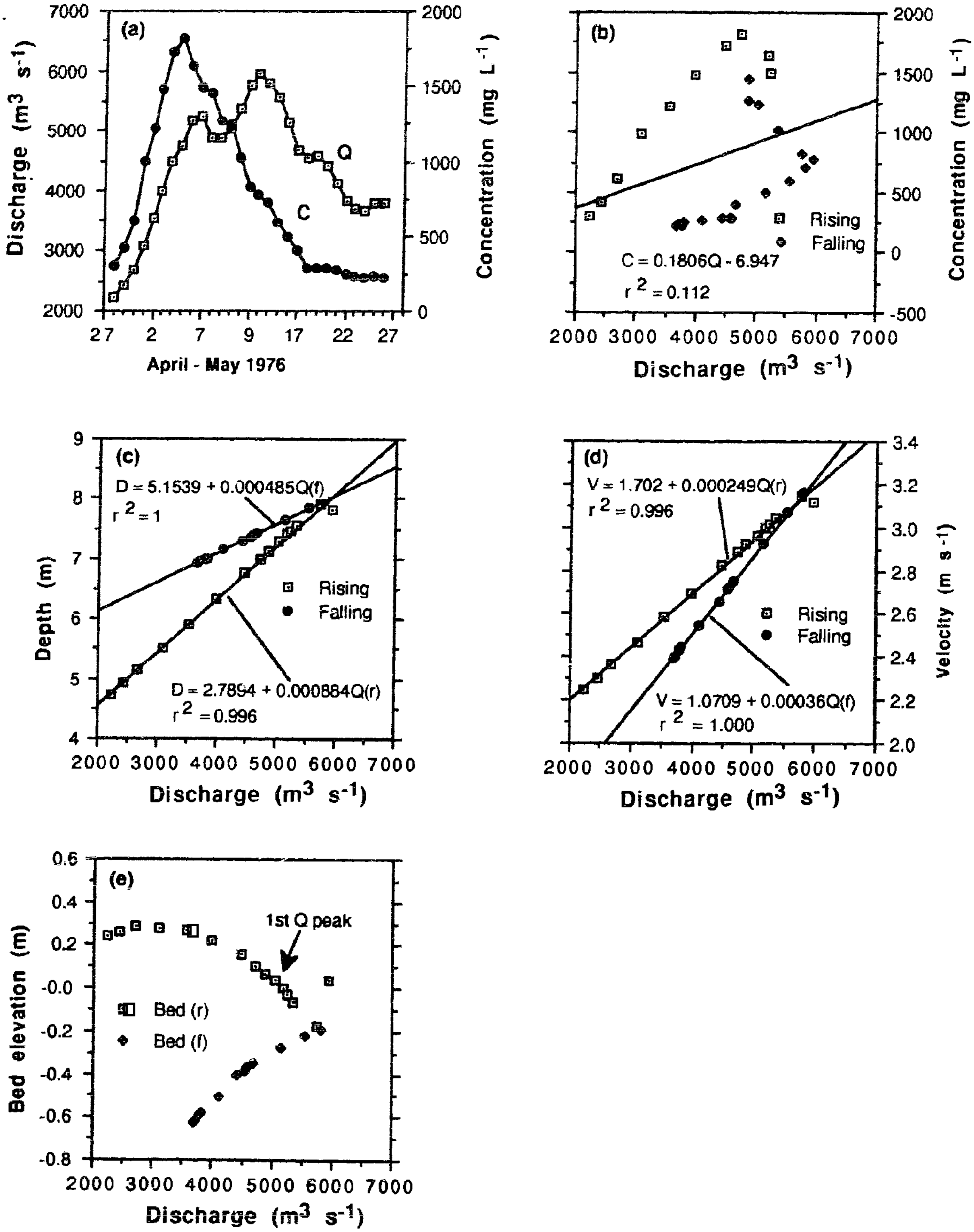

Fig. 6.8. Temporal sediment concentration and discharge graphs (a) relationship of discharge and concentration (b) and discharge and depth (c) and velocity (d); and the bed elevation (e) in the rising (r) and falling (f) stages of the 28 April, 1976 event on the Fraser River near Marguerite station.

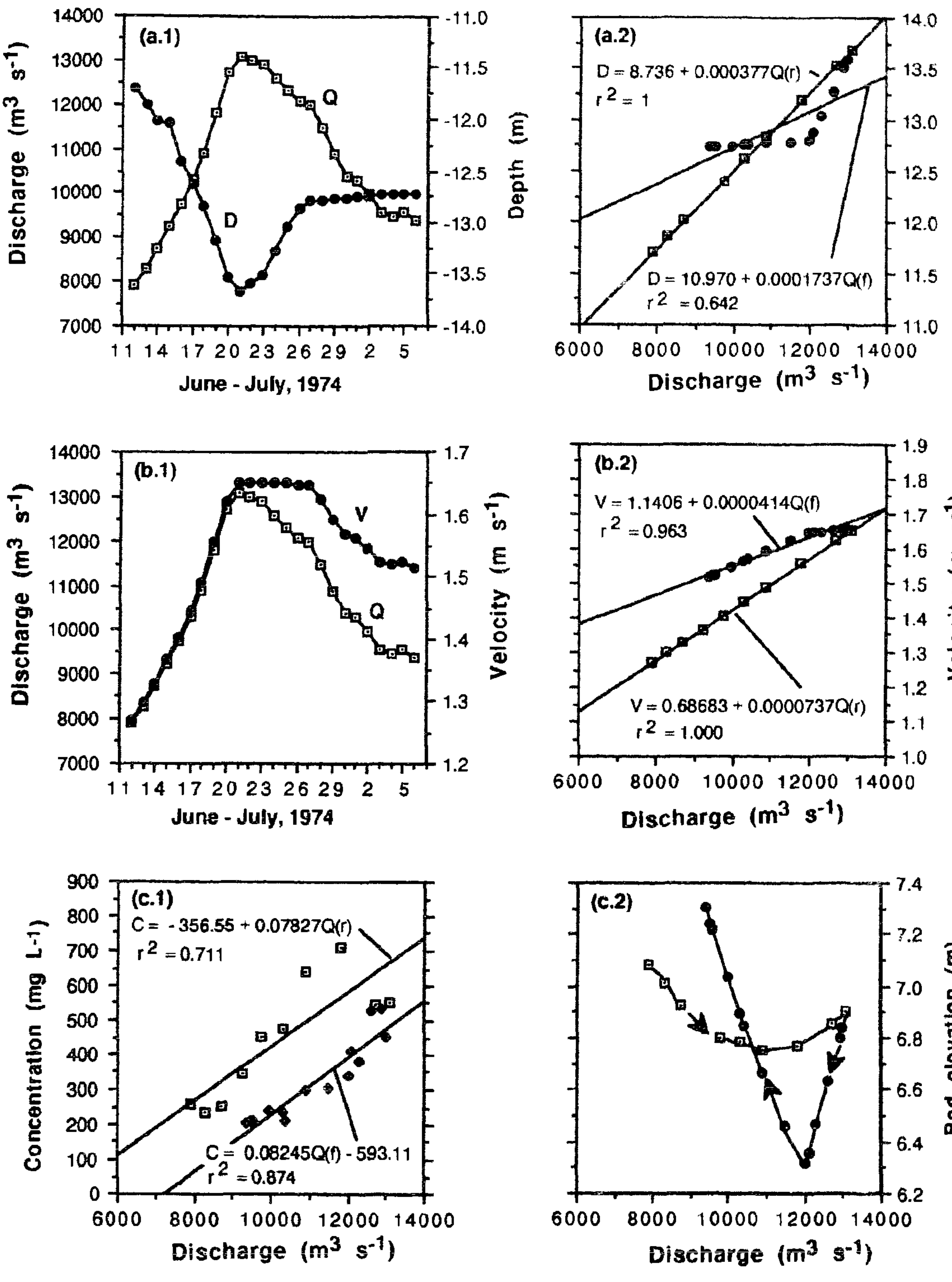

Fig. 6.9. Temporal graphs of discharge and depth (a.1) and velocity (b.1) and relationships of discharge and depth (a.2), velocity (b.2) and sediment concentration (c.1); and the path of bed scour (c.2) in the rising (r) and falling (f) stages of the 12 June 1974 event on the Fraser River at the Mission station.

changes caused perhaps by changes in hydrological regimes similar to those for which (Church et al. 1985) proposed the use of a shifting rating curve to characterize sediment variation in two different periods.

Additionally, for a majority of measured hysteretic events, it was observed that larger variations in sediment concentrations occurred when there was a cross-over of average velocities in the rising and falling stages. Cross-over of average velocities occurs when for any given discharge velocities in the rising stage are either lower or higher than those in the falling stage and vice versa. For instance the cross-over of avarage velocities from high to low in Fig. 6.8d occurred at high discharges. Generally, variations in concentrations were greater if the cross-over of the rising and falling velocities occurred at high discharges than if it occurred at low discharges. The implication of this is that rapid changes in velocity from low to high at high flows results in greater changes to the channel shape and likely has the potential to cause massive scouring of the bed. Conversely, a rapid change from high to low velocities at high flows implies massive deposition of sediments as was the case in the event of 12 June 1974 at Mission (Fig. 6.9b.2). Undoubtedly, observations such as these greatly enhance the understanding of sediment transport dynamics in rivers. In the section following the influence of meteorological factors on sediment variation is discussed.

6.1.5.3 Meteorological Factors

The investigation of the role meteorological factors have in producing different types of hysteresis required data from a relatively small scale basin. Consequently, the Chilliwack River basin was selected; it also has a relatively good distribution of weather stations. However, Chilliwack River basin, because of its location in the Coast Mountains Region which receives more precipitation than the Interior Plateau and Rocky Mountains regions, is not representative of the larger Fraser River basin, but of basins in humid temperate regions. Daily total precipitation and daily mean temperature data used for this analysis were for stations located near the main channel between Chilliwack Lake and Vedder Crossing (Fig. 2.2). The basin above Chilliwack Lake has little or no control on channel processes in the river below it. Consequently, all discussions of sediment and discharge variations in the Chilliwack River focus on the reach downstream of the lake.

6.1.5.3.1 Clockwise Hysteresis

In the Chilliwack River basin, the meteorological conditions under which hysteresis in the sediment and discharge relations occurred are summarized in Table 6.7. Clockwise hysteresis generally occurred when precipitation was received in the rising stage with or without any received in the falling stage. Two temperature regimes characterized these two precipitation regimes. Firstly, in the case when precipitation was received in the rising and falling stages, the associated temperatures

Table 6.7. Meteorological conditions during clockwise and anticlockwise hysteretic hydrological events in the Chilliwack River basin.

Event no.	Period	Precipitation Received Rising	Precipitation Received Falling	Air Temperature Range[1] Rising	Air Temperature Range[1] Falling
CLOCKWISE EVENTS					
118.	03.01.69-17.01.69	YES	YES	Sub-zero	Sub-zero
119.	29.03.69 - 09.04.69	YES	YES	Moderate to low	Low to moderate
120.	25.04.69 - 06.05.69	YES	NO	Moderate	Moderate to high
121.	26.05.72 - 03.06.72	NO	NO	Moderate to high	Moderate
ANTICLOCKWISE EVENTS					
157.	08.06.69 - 18.06.69	YES	NO	High to moderate	High
158.	19.01.70 - 02.02.70	YES	YES	Sub-zero to Low	Low
159.	29.01.71 - 09.02.71	YES	YES	Low	Low
160.	10.05.71 - 18.05.71	YES	YES	Low to moderate	Low
161	24.05.71 - 31.05.71	YES	YES	Moderate	Moderate
162.	05.06.72 - 15.06.72	NO	YES	High to low	Moderate
163.	11.07.72 - 23.07.72	YES	NO	Moderate	High to moderate
164.	23.12.72 - 31.12.72	YES	YES	Low	Low to sub-zero

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1 Temperature categories: ($T \leq 0$ ^{o}C), sub-zero temperatures; ($1 \leq T \leq 9$ ^{o}C), low temperatures; ($10 \leq T \leq 19$ ^{o}C), moderate temperatures; and ($T \geq 20$ ^{o}C) high temperatures.

were in the sub-zero range in the rising stage and in the low to sub-zero range in the falling stage, as exemplified by the event of 3 January 1969 on the Chilliwack River (Fig. 6.10).

Under these conditions, sediment generation in the rising stage was likely caused by runoff coming from the basin slopes and by the scouring of the stream-bed due to minor influence of direct channel precipitation. As a result, sediment concentration and discharge apparently increased at similar rates (Fig. 6.10b). However, in the falling stage due to the sub-zero temperatures that prevailed (Fig. 6.10c) sediment concentration and discharge appear not to have decreased at similar rates, thus causing clockwise hysteresis in the sediment-discharge relationship.

Secondly, the event of 29 March 1969 illustrated the situation when precipitation was received in the rising and falling stages. Clockwise hysteresis occurred under conditions of decreasing temperatures (from moderate to low) in the rising stage and under increasing temperatures (from low to high) in the falling stage (Fig. 6.11). During this event more sediment were transported in the rising than falling stage due to intense precipitation combined with snowmelt caused by moderate temperatures (Fig. 3.11a, c) in the rising stage. In the falling stage, in spite of precipitation received, no sediment replenishment occurred so discharge decreased at a rate slower than that of concentration (Fig. 6.11c) causing clockwise hysteresis in the sediment-discharge relation.

For clockwise hysteresis, when precipitation occurred in the rising stage and none in the falling stage, temperatures during the event of 25 May 1969 were moderate in the rising stage and increased (from

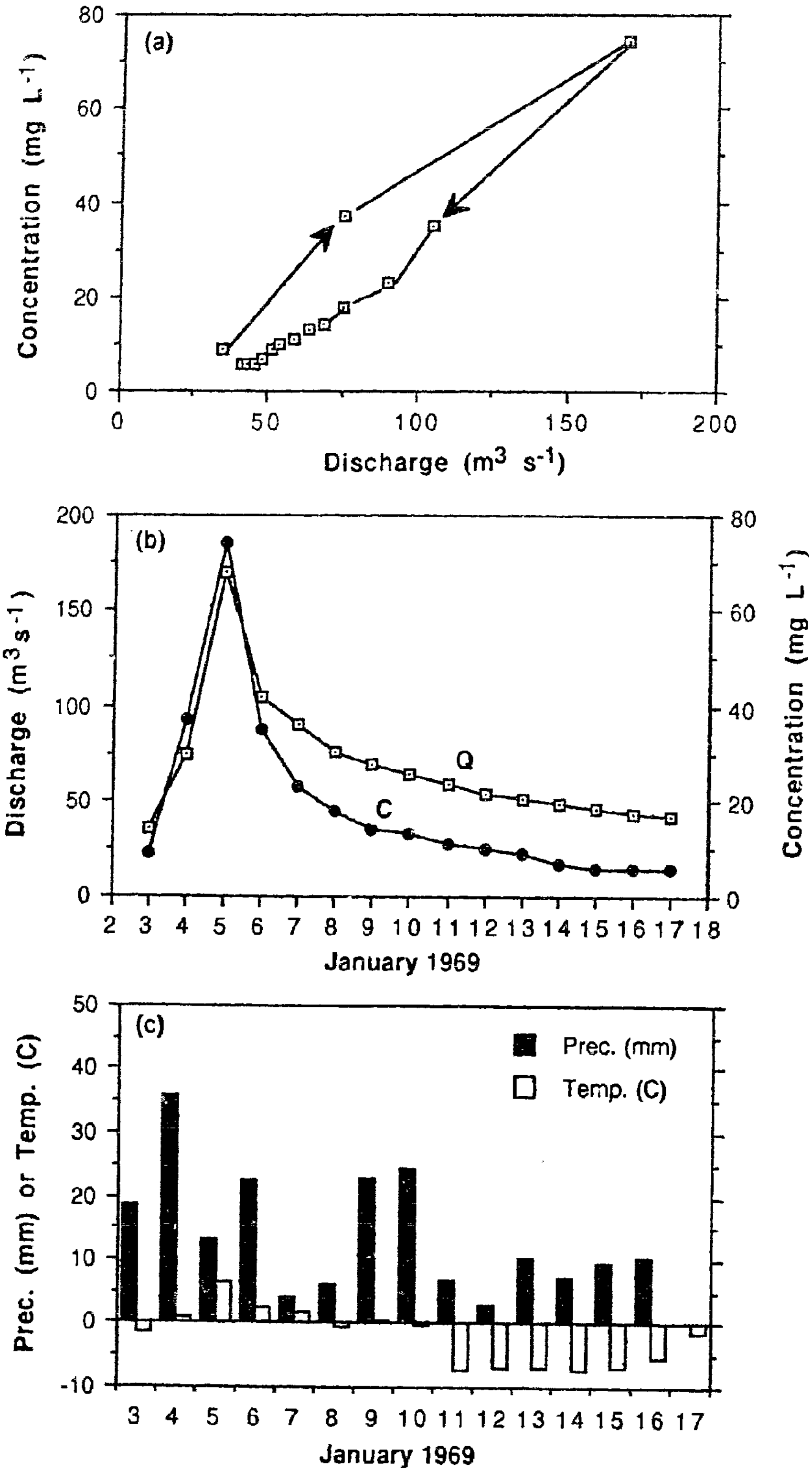

Fig. 6.10. Graphs of (a) clockwise hysteresis, (b) temporal variations in discharge (Q) and concentration (C) and (c) distributions of daily precipitation and temperature during the event of 3 January 1969 on the Chilliwack River at the Vedder Crossing station.

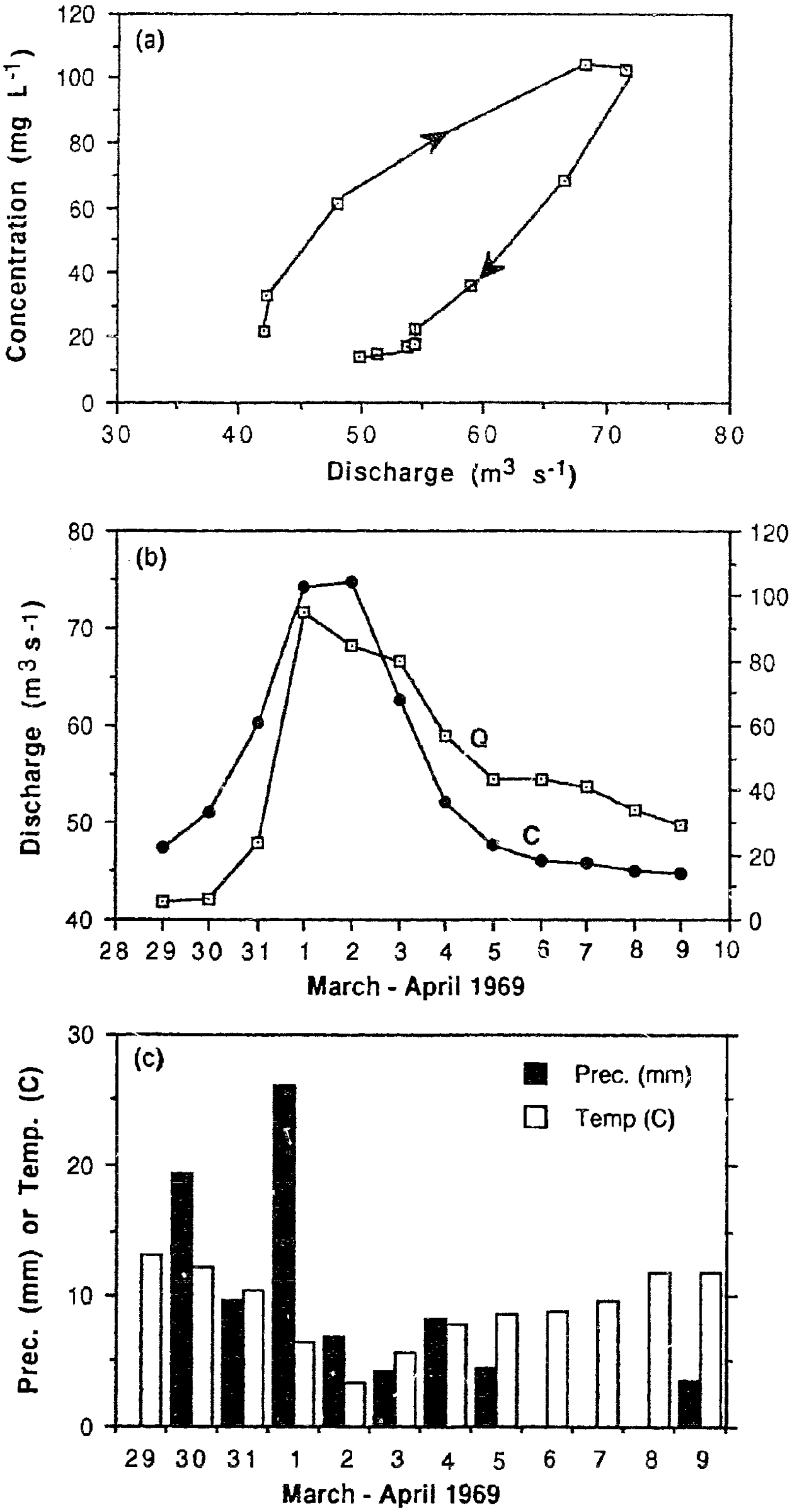

Fig. 6.11. Graphs of (a) clockwise hysteresis, (b) temporal variations in discharge (Q) and concentration (C) and (c) distributions of daily precipitation and temperature during the event of 29 March 1969 on the Chilliwack River at the Vedder Crossing station.

moderate to high) in the falling stage (Fig. 6.12a, b, c). Under these conditions, increases in discharge and concentrations resulted from snowmelt and precipitation in the rising stage with exhaustion of readily transportable sediment occurring by the time of peak discharge. In the falling stage, no sediment replenishment occurred which caused concentrations to decrease at a rate faster than the decline in discharge (Fig. 6.12b).

The May-June 1969 event shows that rainfall intensity and duration, if important at all, had little influence on the variation in sediment concentration probably accounted for by differences in runoff travel distances between locations of precipitation and the measuring site at Vedder Crossing. This observation is partly supported by the peak discharge which remained unchanged for five days following termination of precipitation. The discharge data suggests other sources of runoff such as snowmelt indicated by increasing temperatures in the falling stage. Since no detailed data of snowmelt in the basin are available one can only speculate that, in this case, variation in sediment concentration depended more on its supply and exhaustion from the river system than on the amount of precipitation and level of temperature.

In an exceptional case (26 May, 1972), hysteresis also occurred when no precipitation was received during the event. In this case, moderate temperatures increased to high in the rising stage, while moderate temperatures prevailed in the falling stage. Based on the knowledge of runoff generation processes in temperate environments, the occurrence of hysteresis during the 26 May event was attributed to the small size of the Chilliwack River basin. Under high temperatures, snowmelt generated runoff likely recruited sediments which was

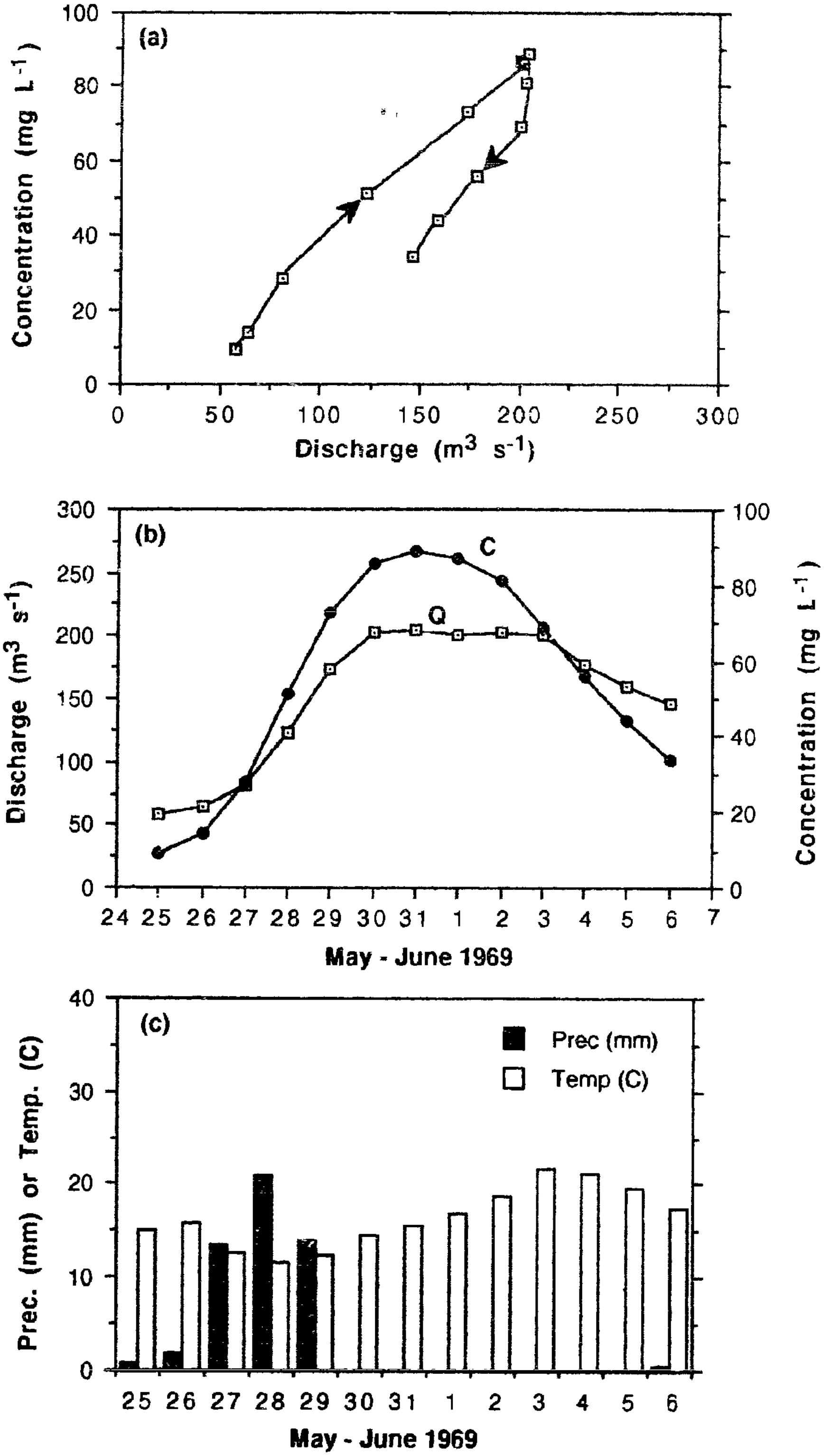

Fig. 6.12. Graphs of (a) clockwise hysteresis, (b) temporal variations in discharge (Q) and concentration (C) and (c) distributions of daily precipitation and temperature during the event of 25 May 1969 on the Chilliwack River at the Vedder Crossing station.

presumably depleted by the time of discharge peak. Consequently, in the falling stage the flow receded to pre-snowmelt levels with sediment concentrations decreasing at a rate faster than that of discharge.

The cases described above cover most of the scenarios of precipitation and temperature conditions for the occurrence of clockwise hysteresis in a humid temperate environment. In the section following the meteorological conditions favouring the occurrence of anticlockwise hysteresis are discussed.

6.1.5.3.2 Anticlockwise Hysteresis

In the Chilliwack River basin, anticlockwise hysteresis was observed to generally occur when precipitation was received in the rising and falling stages of individual hydrological events (Table 6.6). The attendant temperatures during the events were either in the moderate range or increasing from sub-zero to low temperatures in the rising stage. In the falling stage, temperatures were either in the low range or were decreasing from moderate to sub-zero ranges. The cases in which precipitation was received in the rising and falling stages with temperatures in the sub-zero to low ranges were exemplified by the event of 19 January 1970 (Fig. 6.13a, b, c). During this event, the rises in discharge and concentrations likely were caused by precipitation and snowmelt which supplied sediment from the channel boundary in the rising stage. Higher sediment concentrations in the falling stage likely were due to the arrival of sediments from the basin slopes under continued precipitation and low temperatures. The above explanation is

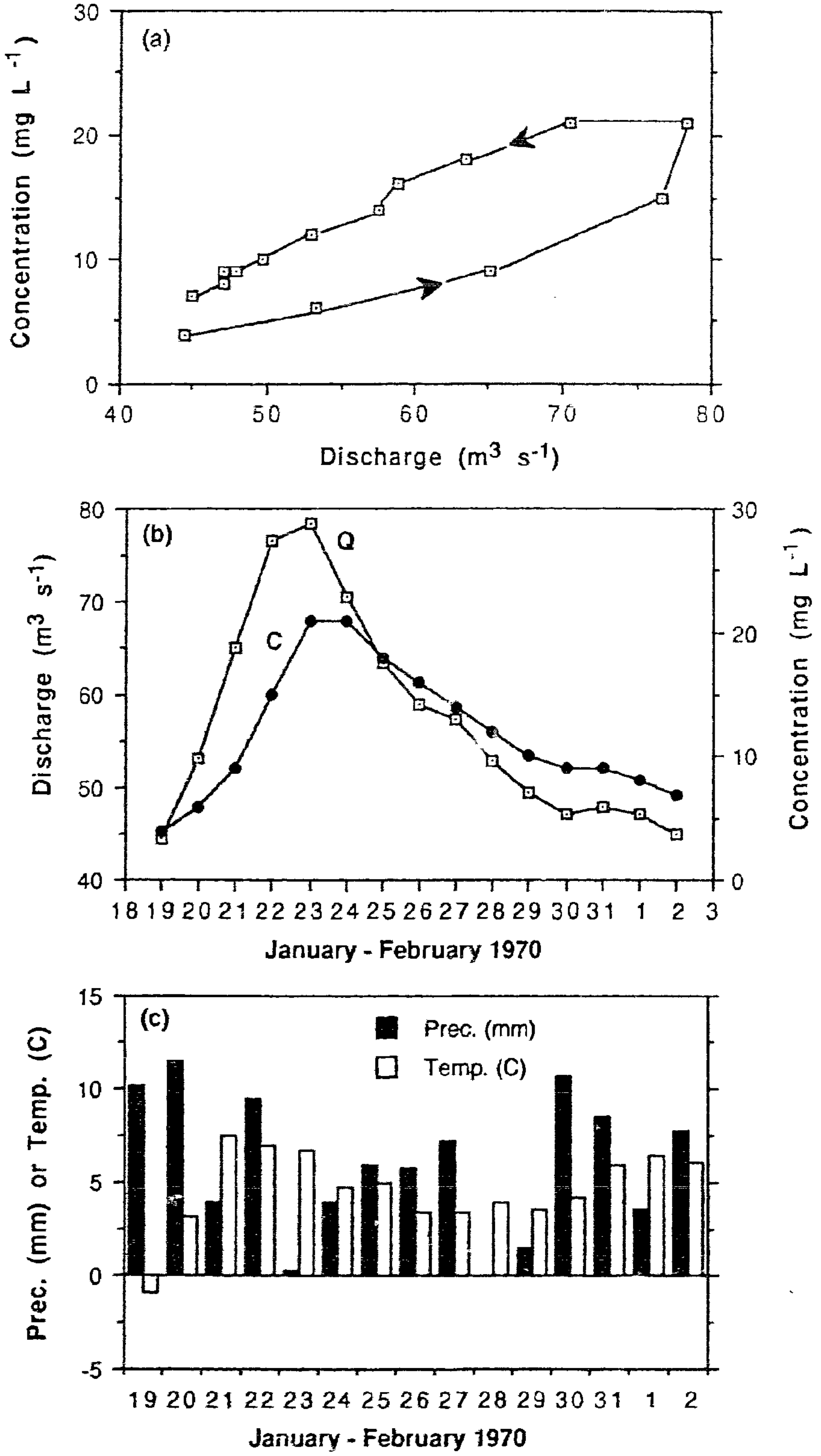

Fig. 6.13. Graphs of (a) anticlockwise hysteresis, (b) temporal variations in discharge (Q) and concentration (C) and (c) distributions of daily precipitation and temperature during the event of 19 January 1970 on the Chilliwack River at the Vedder Crossing station.

also valid for cases in which precipitation was received in the rising and falling stages with temperatures decreasing from high to low.

On fewer occasions, anticlockwise hysteresis was also found to occur when precipitation was received in the rising stage and none in the falling stage and vise versa. The temperatures in these situations were in the moderate to high range. The event of 11 July 1972 (Fig. 6.14a, b, c) showed the situations in which precipitation fell only in the rising stage of the event under moderate to high temperatures. In this case, discharge and concentration apparently increased at similar rates in the rising stage. But in the falling stage concentrations apparently decreased at a rate faster than the decline in discharge because no sediment were recruited from basin slopes.

In contrast, the event of 5 June 1972 (Fig. 6.15a, b, c) illustrates a situation in which precipitation was received only in the falling stage. Consequently, in the rising stage runoff generated by snowmelt increased at a rate slower than that of concentration (Fig. 6.15b). But in the falling stage both discharge and concentration decreased at similar rates. Therefore, the scouring of the bed associated with the precipitation received in the falling stage caused the anticlockwise hysteresis in the sediment-discharge relationship of this particular hydrological event.

These last two events showed that anticlockwise hysteresis in the sediment-discharge relationship can also occur when the sediment concentration increases at rates faster than that of discharge in the rising or falling stage. This finding has not been reported before.

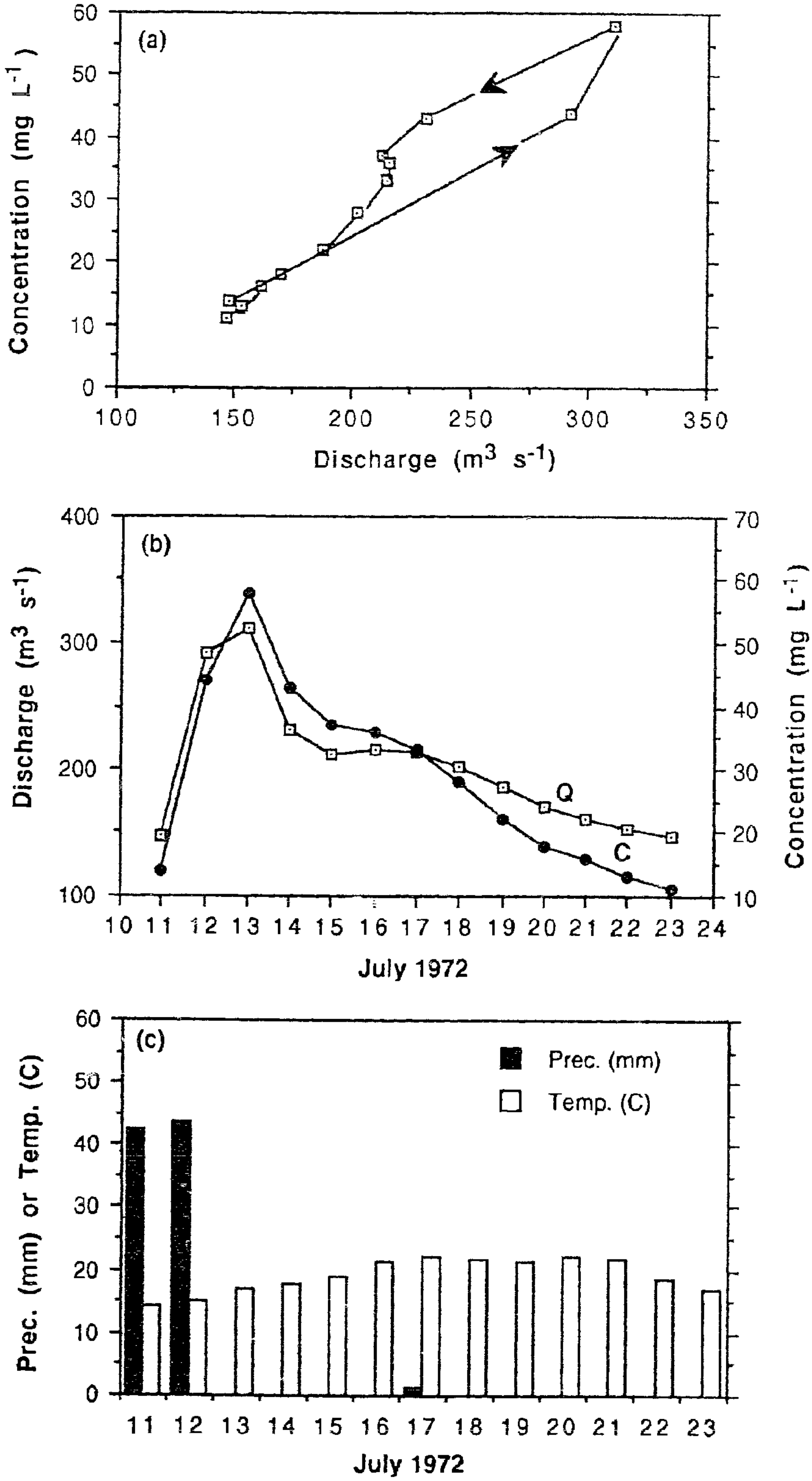

Fig. 6.14. Graphs of (a) anticlockwise hysteresis, (b) temporal variations in discharge (Q) and concentration (C) and (c) distributions of daily precipitation and temperature during the event of 11 July 1972 on the Chilliwack River at the Vedder Crossing station.

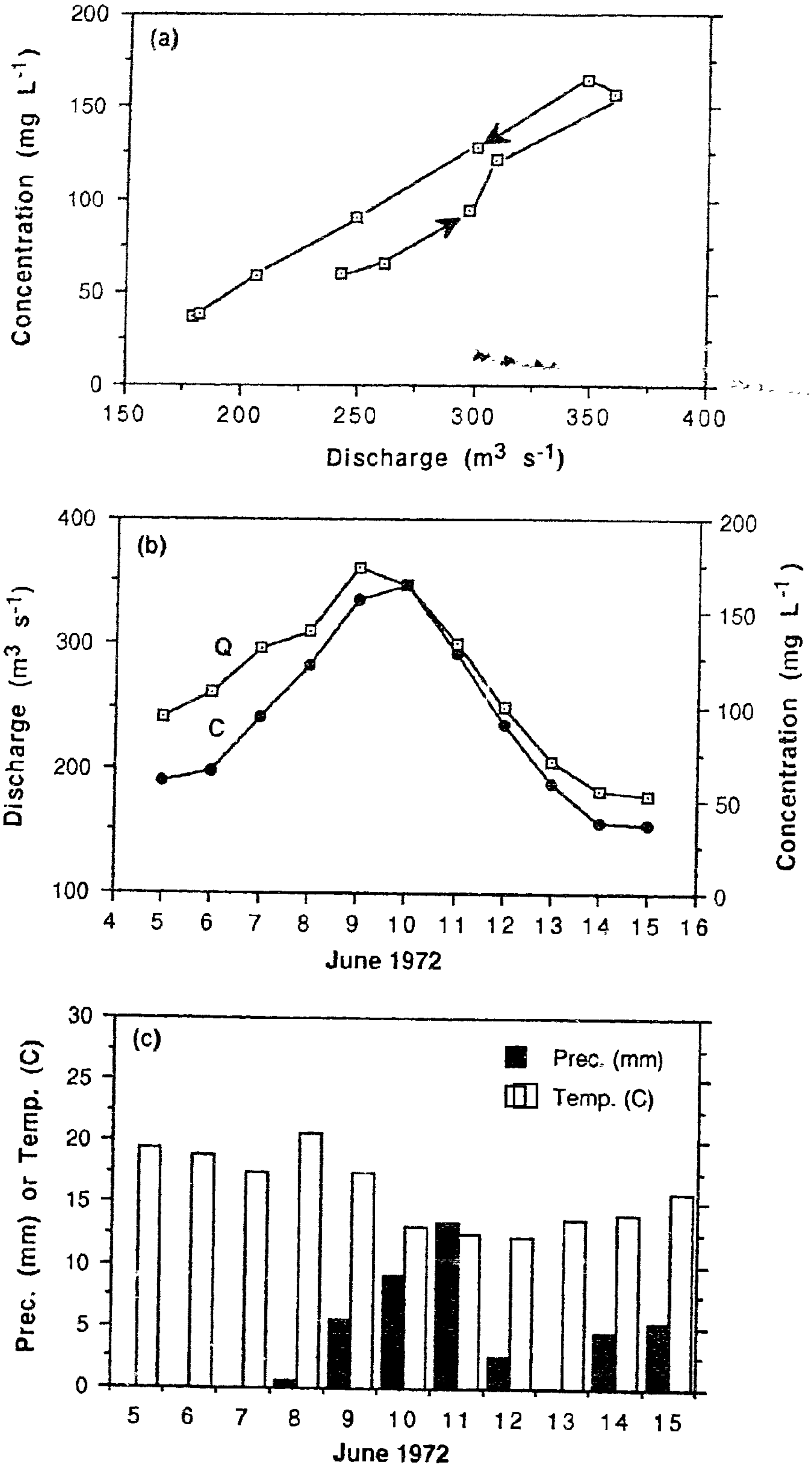

Fig. 6.15. Graphs of (a) anticlockwise hysteresis, (b) temporal variations in discharge (Q) and concentration (C) and (c) distributions of daily precipitation and temperature during the event of 5 June 1972 on the Chilliwack River at the Vedder Crossing station.

6.1.6 Summary and Conclusions

Hysteresis in the relations of sediment concentration and discharge for single hydrological events was found to be controlled by a variety of factors. These factors included, time lags between concentration and discharge peaks; differences in the rates of downstream movement of flood waves and the core of maximum concentration; differences in spatial distances between sediment measuring stations. These findings support Heidal (1956) and Marcus' (1989) observations who concluded that a flood wave moves downstream more rapidly than the streamflow in which sediment are entrained. The relative positions of the flood wave and core of maximum suspended-sediment concentration vary leading to spatial and temporal variations in sediment discharge. Variations in sediment concentration in the rising and falling stages sufficiently accounted for the existence of hysteresis in relations of sediment concentration and discharge. Higher sediment concentrations on the rising than falling stages were previously attributed to the release of sediments from bed gravels which were inhibited by the formation of a new armour layer after the passage of a hydrograph peak (Paustian and Beschta, 1979).

Richards (1982), by contrast, attributed hysteresis in single storms to sediment supply changes between the rising and falling floods stages. In small catchments, in particular, he says that wash load inputs continue to rise as rain and runoff occur during the flood but cease when hillslope runoff ends after the peak. He says that this is amplified by exhaustion of supply if suspended-sediment is predominantly derived from stream banks or the surrounding channel areas, because the increase in the active channel width introduces new sources of sediment which are exhausted by the time the flood recedes.

Similarly, Loughran (1974) attributed the rapid increase of suspended sediment concentration at the beginning of the stream-rise to the initial impact of storm rainfall which tended to flush sediment through the system of a small catchments. Later during the storm, he observed that while the supply of water to the system was still increasing, there was less sediment available for transport.

The present study also confirms Loughran (1976) and Klein's (1984) finding that, during storm events, the index of flood intensity and rate of hydrograph rise are the most important factors controlling sediment transport. Klein (1984) observed that, in small basins when sediment originates from the slopes, the flood wave and sediment wave can be out of phase. In big basins, if the dominant process is channel erosion, flood and sediment waves are in phase. These observation support the contention that, in small basins suspended-sediment is related to rainfall erosivity, whereas in large basins suspended-sediment is related to runoff (McGuinness et al. (1971).

In conclusion, the investigation of factors controlling the existence of clockwise and anticlockwise hysteresis supported Klein's (1984) conclusion that, clockwise hysteresis occurs when sediment are derived from the bed and banks of the channel. By contrast, anticlockwise hysteresis was found to occur when upper basin slopes supply most of the sediment. Quantitative analysis of hydrologic factors controlling clockwise and anticlockwise hysteresis revealed results which have not been reported before. It was found that, for clockwise hysteresis, antecedent moisture conditions exerted greater control on sediment variation than measured discharge. For anticlockwise hysteresis, measured discharge exerted greater control on sediment variation than did antecedent moisture conditions. In the falling stage, there was no difference in the factors that controlled variations in sediment concentration between clockwise and anticlockwise hysteretic events.

Hydraulically, for a majority of measured hysteretic events, it was observed that larger variations in sediment concentrations occurred when there was a cross-over of average velocities in the rising and falling stages. Variations in concentrations for hydraulic events were found to be greater if the velocity cross-over occurred at higher than at lower discharges. This was because rapid changes in velocity from low to high at high flows results in greater changes to the channel shape than changes from high to low velocities at higher flows. Therefore, the crossing-over of velocities at higher flows has the potential of causing massive scouring of the stream-bed.

No clear-cut distinction was observed between the meteorological factors in causing clockwise and anticlockwise hysteresis for hydrological events that occurred in summer or winter months. It was found that clockwise hysteresis resulted in the sediment-discharge relations when precipitation was received in the rising stage with or without precipitation in the falling stage. By contrast, anticlockwise hysteresis generally resulted when precipitation was received in the basin both in the rising and falling stages of hydrological events.

The influence of air temperature in causing clockwise or anticlockwise hysteresis was also found not to be clear-cut for a majority of events studied. However, for those events that occurred in winter months clear influences of temperature on clockwise and anticlockwise hysteresis may be distinguished. In the Chilliwack River basin, it was found that clockwise hysteresis occurred when precipitation was received in the rising stage and with or without precipitation received under sub-zero temperatures in the falling stage. Under these conditions, sediments were recruited from the basin slopes and from areas adjacent to the river channel as well as from the channel bed. In the falling stage, no sediments were recruited from basin slopes and only a limited amount of sediments were transported from the channel bed due to the existence of sub-zero temperatures. Consequently, clockwise hysteresis was produced in sediment-discharge relations.

Conversely, anticlockwise hysteresis occurred when precipitation was received under sub-zero temperatures in the rising stage and under low to moderate temperatures in the falling stage. Under these conditions, sediment transport from the basin and channel bed was inhibited in the rising stage by the sub-zero temperatures. But in the falling stage, an abundant amount of sediment were recruited from the basin slopes and the channel bed thereby causing anticlockwise hysteresis. These observations probably apply to other basins in the humid temperate regions. To some extent, these observations also shed light on the influence of runoff processes during snowmelt on sediment transport in cold-temperate regions (Dunne, 1982).

CHAPTER SEVEN

MAGNITUDE AND FREQUENCY CHARACTERISTICS OF EFFECTIVE DISCHARGE FOR SUSPENDED-SEDIMENT TRANSPORT

7.1 Effective Discharge for Suspended-Sediment Transport

7.1.1 Determination of Effective Discharge

In order to evaluate the validity of the effective discharge concept in sediment transport and to establish its statistical properties, sediment data for eight stations in the Fraser River basin were analyzed. Using daily discharge and sediment concentration data in the period of sediment record (too large to be appended), effective discharge was determined in three stages. Firstly, the discharge range was divided into approximately 20 non-overlapping classes of equal widths at each station, determined the duration (relative frequency) of flows in each class, calculated daily suspended-sediment load and multiplied it by duration. Secondly, sediment-discharge graphs were constructed for the identification of the most effective discharge class (Fig. 7.1a, c through 7.4a). Thirdly, The effective discharge was determined as the class mark (mid-point) of the discharge class transporting the greatest portion of the suspended-sediment load.

Evidently, this procedure is subjective, thus arbitrary when selecting number of classes to be used in the analysis. This is partly because in order to determine the number of classes objectively one has

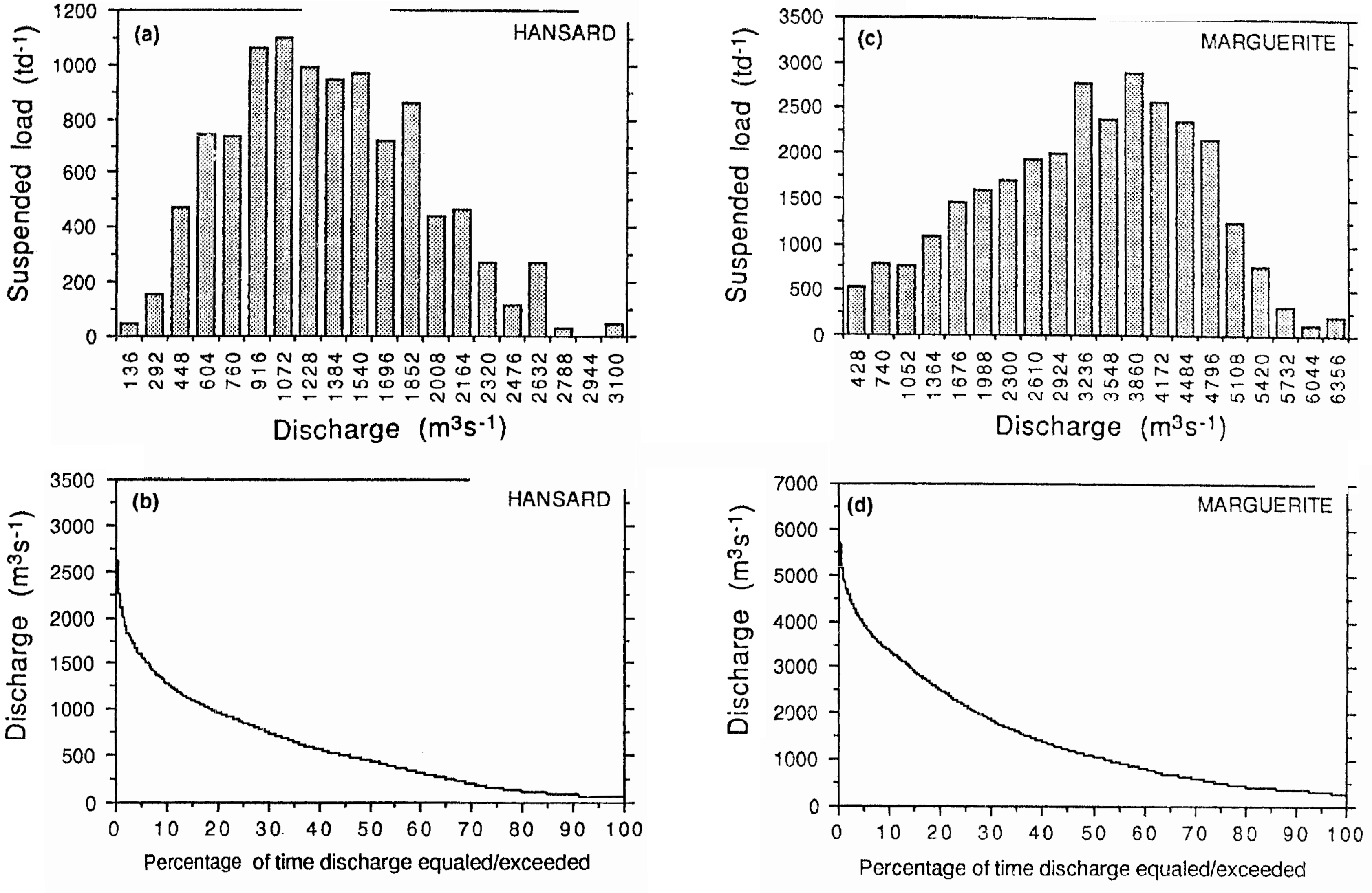

Fig. 7.1. Forms of sediment-discharge regimes and discharge duration curves for the Fraser River at (a,b) Hansard (1972-1986) and (c, d) Marguerite (1971-86) stations. Discharge values are the mid-points of various classes.

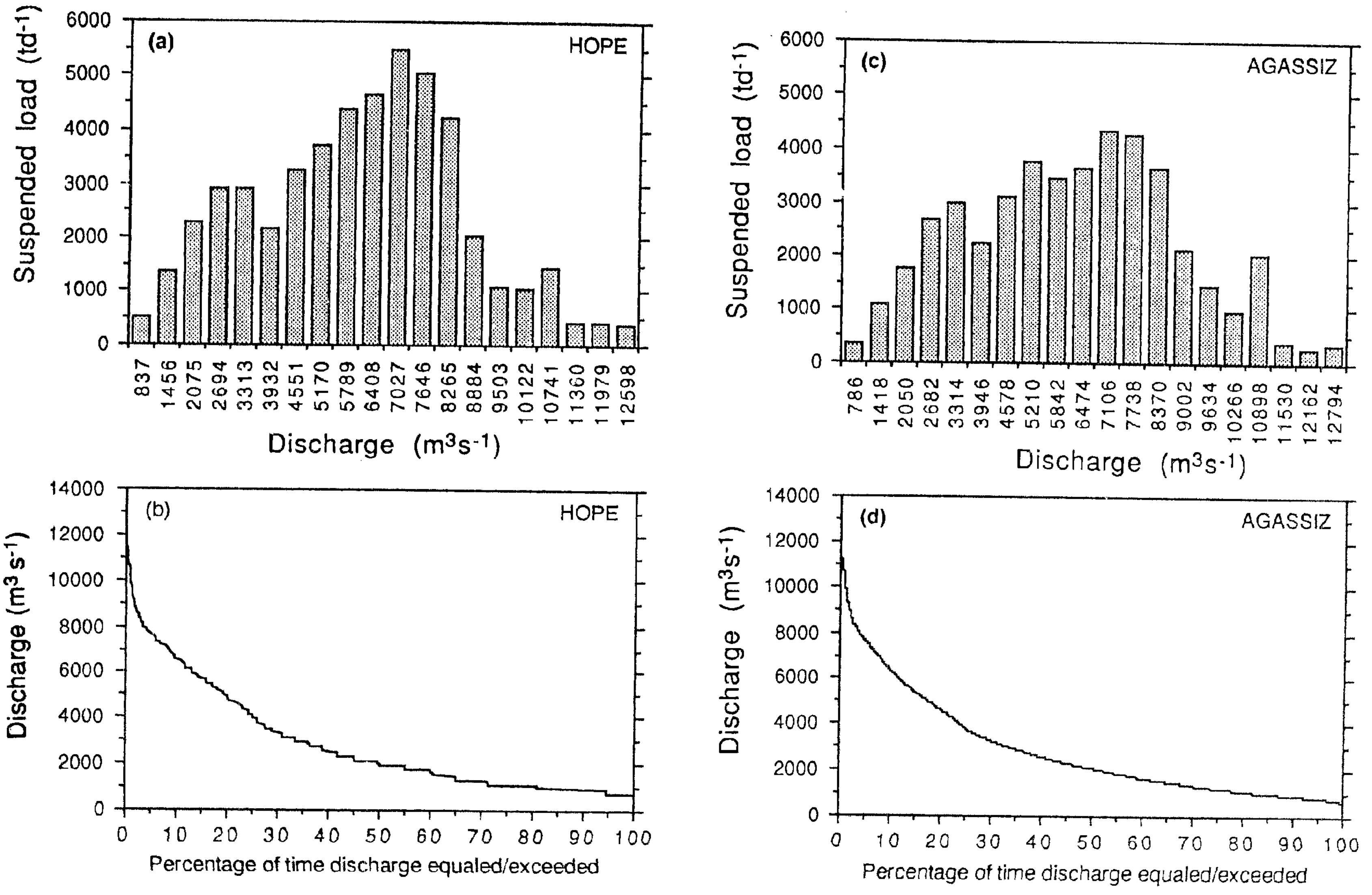

Fig. 7.2. Forms of sediment-discharge regimes and discharge duration curves for the Fraser River at (a, b) Hope (1965-79) and (c, d) Agassiz (1966-86) stations. Discharge values are the mid-points of various classes.

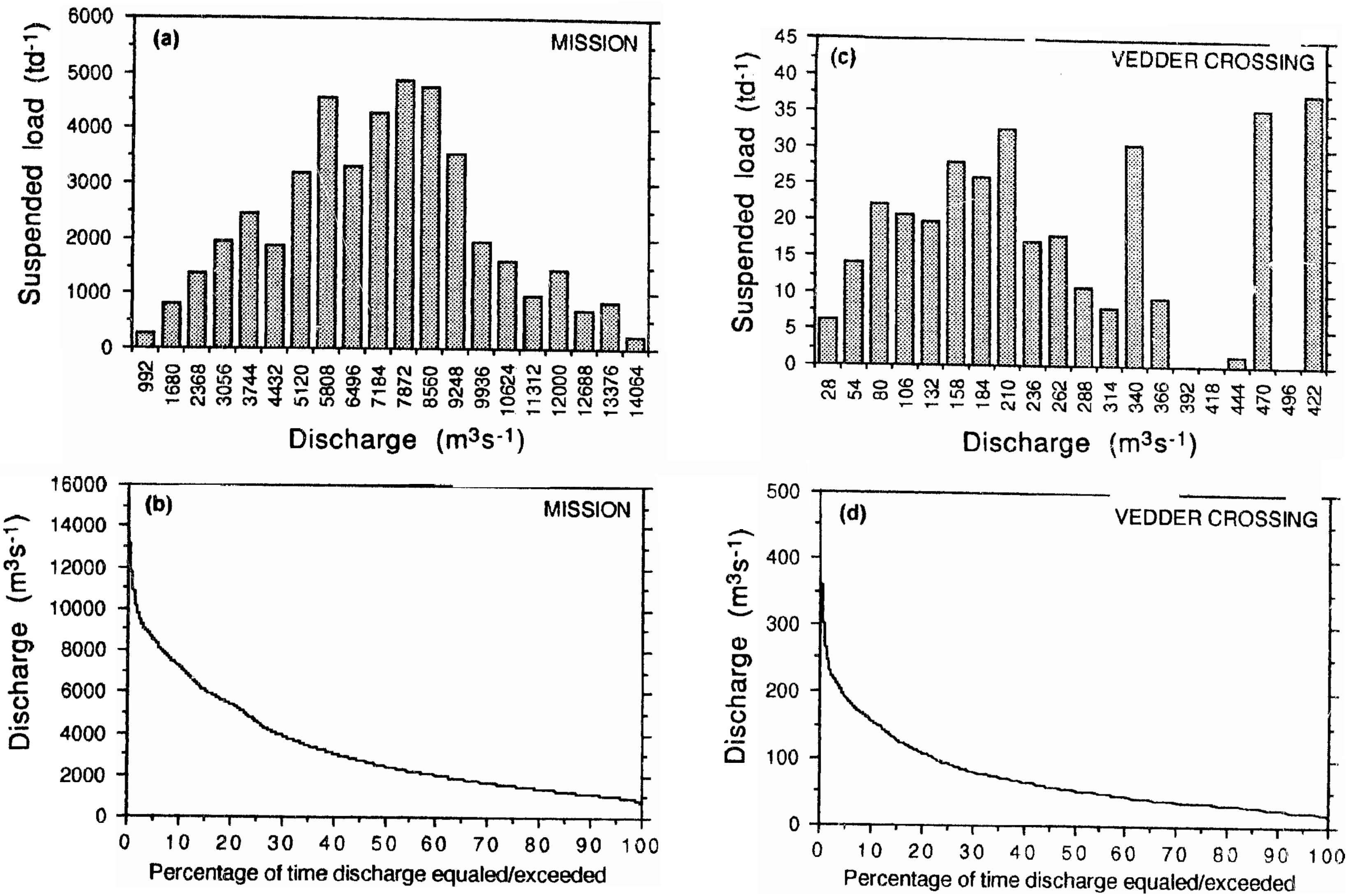

Fig. 7.3. Forms of sediment-discharge regimes and discharge duration curves at (a, b) Mission (1966-88) on the Fraser River and (c, d) Vedder Crossing (1965-75) on the Chilliwack River. Discharge values are the mid-points of various classes.

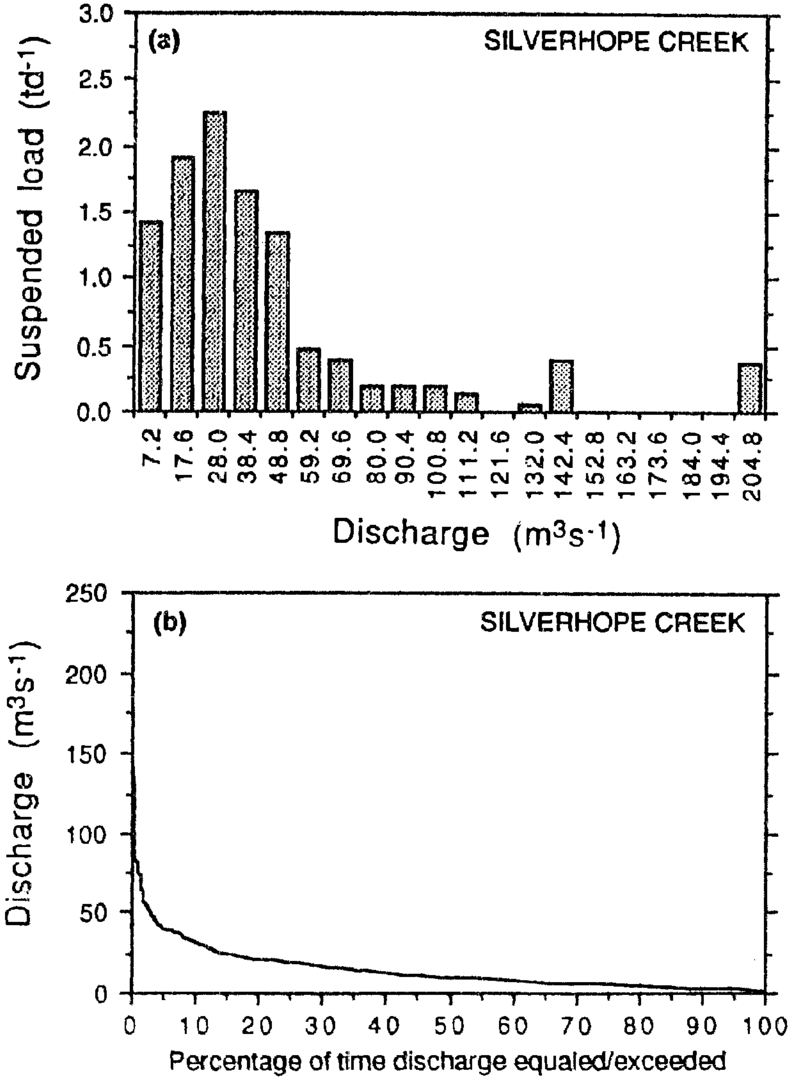

Fig. 7.4. Forms of sediment-discharge regimes and discharge duration curves on the Silverhope Creek near Hope (a, b) (1965-70). Discharge values are the mid-points of various classes.

to divide the range by a pre-determined class-interval size (Hays, 1988: 75-80; Johnson, 1984: 33-40). Consequently, in the literature there is no general accord on the correct method of determining the effective discharge for suspended-sediment transport.

A method for determining the effective discharge was provided by Wolman and Miller (1960: 54) when they stated that: "...the product of frequency and rate, a measure of the work performed by events having different frequencies and magnitudes will attain a maximum (at the effective discharge). The frequency at which this maximum occurs provides a measure of the level at which the largest portion of the work is accomplished."

Previous investigators also have determined the effective discharge by dividing the discharge range, at each station, into equal increment classes and finding the duration of flows in each class. Obviously, this procedure is not objective as the selection of the number of classes is a matter of judgement. This subjectivity is clearly illustrated by the use in the literature of imprecise definition of class size such as "equal intervals of stream discharge" (Benson and Thomas, 1966: 77); "small classes" (Pickup and Warner, 1976: 52) and "increments of discharge range" (Ashmore and Day, 1988: 865). For those studies that specified number of classes, each differs, one from the other. For instance, "approximately 20 equal increments" were used by Andrews (1980: 320) while Webb and Walling (1982: 19) used "23 equal discharge classes." The use of various number of classes between different investigators makes comparison of results difficult and may partly explain the wide range of frequencies of effective discharges reported on rivers.

7.1.2 Duration of Effective Discharge

The durations of the upper and lower limits of the effective discharge classes reported here were simply read from discharge duration curves based on daily discharge measurements in the period of sediment record. The discharge duration curves were constructed as the plot of discharge arranged in descending order, as ordinate, and percentage of time each discharge was equaled or exceeded, as the abscissa (Figs. 7.1b, d through 7.4b),. The determined durations of effective discharge classes in the Fraser River basin were found to range from 0.02 to 19.6% (Table 7.1). The calculated durations of individual effective discharges were found to range from 0.03% to 11.95% with an average of 8.82 per cent. These findings agree with observations of previous studies. For instance, Andrews (1980) observed that the effective discharge for total sediment load in the Yampa River basin of Colorado and Wyoming, were equaled or exceeded on average of 0.4% to 3.0% of the time.

In Britain, Webb and Walling (1982) found that in the River Creedy, 50% of the total suspended load was transported in 0.8% of the time. In the Cumberland streams, New South Wales, Pickup and Warner (1976) found effective discharge for bed load sediment transport to be equaled or exceeded on average of 3 to 5 times a year. In Canada, Ashmore and Day (1988) found that, for the Saskatchewan River basin, the durations of the effective discharge for suspended sediment load are less than 0.1% in some cases and over 15% in others, with the majority of stations having values between 1 and 10 percent. Thus, while the hypothesis that effective discharge for suspended sediment transport in many cases

Table 7.1. Magnitude and frequency characteristics of effective and bankfull discharges in the Fraser River basin, British Columbia.

Station no.	River	Drainage Area (km^2)	Bankfull Discharge ($m^3 s^{-1}$)	Bankfull Discharge % Freq	Effective Discharge[1] ($m^3 s^{-1}$)	(Class Duration, %) Lower	(Class Duration, %) Q_{eff}	(Class Duration, %) Upper
08KA004	Fraser R. at Hansard	18000	1950	1.68	1072	13.12	(16.040)	18.95
08MC018	Fraser R. near Marguerite	114000	4200	3.33	3236	4.43	(05.540)	6.64
08MF005	Fraser R. at Hope	212000	8000	3.45	7027	6.41	(08.080)	9.74
08MF009	Silverhope Cr. near Hope	350			28	9.50	(14.550)	19.60
08MF035	Fraser R. near Agassiz	218000	8000?	3.73	7106	5.76	(07.010)	8.25
08MG013	Harrison R. near Harrison Hot Springs	7870			865	8.61	(08.830)	9.05
08MH001	Chilliwack R. at V. Crossing	1230	275	0.94	522	0.02	(00.025)	0.03
08MH024	Fraser R. at Mission	228000	8000?	6.43	7872	6.43	(06.980)	8.55

[1] Values in parentheses are durations for individual effective discharges. (?) indicates that the value is not accurately known due to short discharge record, value given is for Hope station.

is the event of moderate magnitude as proposed by Wolman and Miller (1960) and confirmed by Pickup and Warner (1976) and Andrews (1980), it was not supported by Ashmore and Day (1988) for Saskatchewan River basin. Results of the present study given in Table 7.1 support the Wolman and Miller (1960) position.

Ashmore and Day (1988) found that, similar quantities of sediment were transported by flows of quite different magnitude and frequency in several streams of the Saskatchewan River basin. Consequently, they concluded that the concept of effective discharge for suspended sediment transport was inapplicable to Saskatchewan rivers.

Ashmore and Day's (1988) conclusion appears to be based on the imprecise definition of effective discharge given by Wolman and Miller (1960) which needs to be pointed out. If this is the case, I would argue that the problem of definition is not as serious as the problem of lack of a standard procedure for determining effective discharge. To illustrate the this point, in this study an evaluation of how effective discharge varies with number of class sizes at Marguerite and Hope stations on Fraser River was conducted. The results given in Table 7.2 show that different numbers of discharge classes produce significant variation in effective discharge even at the same station. For the nine selected discharge classes (5 to 30 number of classes) at Marguerite station, the effective discharge was found to range from 3236 $m^3 s^{-1}$ to 4900 $m^3 s^{-1}$. At Hope station effective discharge for the same number of classes was found to range from 6715 $m^3 s^{-1}$ to 7705 $m^3 s^{-1}$. Although these effective discharges are somewhat stable at each station, the question of which is the correct effective discharge remains unanswered.

It is therefore clear that, for every class size used in determining

Table 7.2. Results of an evaluation of the effect of using various discharge classes on the magnitude of effective discharge at Marguerite and Hope stations on the Fraser River, British Columbia.

River and Station	Area (km^2)	Period	No. of Classes	Effective Discharge (m^3s^{-1})
Fraser R. at Marguerite	114000	1971-1986	n	4900
			5	3392
			10	3704
			12	3652
			15	3808
			17	3759
			20	3236
			22	3822
			25	3897
			30	3912
Fraser R. at Hope	212000	1965-1979	n	6900
			5	6715
			10	7336
			12	7235
			15	6715
			17	6715
			20	7027
			22	7002
			25	7705
			30	6929

n = all discharge measurements.

effective discharge a different effective discharge is obtained. Thus, there is no number of class size at which the effective discharge remains unchanged. This finding raises another question: What is the correct number of discharge classes required for one to objectively determine the effective discharge? So far, there is no correct number of discharge classes; any number of classes can be used depending on the investigators' preference. Therefore, the problem of the applicability of the concept of the effective discharge in my view is in the procedure for determining the effective discharge and not in its definition. The debate about the applicability of the effective discharge will likely continue until a procedure for its estimation becomes established.

Note that when the discharge data are not divided into classes (i.e. dealing with individual flow events; n number of classes) (Table 7.2) the effective discharge (6900 m^3 s^{-1} at Hope) fall within the ranges of those for the nine selected discharge classes. This suggests that, it is perhaps not necessary to classify the discharge range in order to accurately determine the effective discharge. Therefore, it is suggested that until a standardized procedure for determining effective discharge is introduced, determination of effective discharge be based on the rate of sediment transport, magnitudes and durations of individual flow events.

The problem of the method of determining effective discharge is apparently not uncommon in fluvial geomorphology as it also relates to the concept of bankfull discharge which also previously has been determined in a number of ways. For instance, the determination of bankfull discharge has depended variously on elevations of sedimentary surfaces (Woodyer, 1968), elevations of boundary features (Sigafoos, 1964; Nunally, 1967), or on channel hydraulic geometry relations

(Wolman, 1955; Harvey, 1969; Pickup and Warner, 1976). The 1.58-year flood previously also has been taken as the statistical definition of bankfull discharge (Dury et al. 1963). These various geomorphological and computational considerations lead to a variety of bankfull discharge estimates. Therefore, a standardized method of determining bankful discharge is also required.

Another point of disagreement on the applicability of the concept of effective discharge which is related to its definition is the form of the sediment-discharge regime; this matter is discussed in the section following.

7.2 Character of Suspended-Sediment Transport

7.2.1 Sediment-Discharge Regimes

Ashmore and Day's (1988) rejection of the concept of effective discharge is, based on their observation that, in many cases of the Saskatchewan streams, the effective discharge histograms (regimes) were not the simple unimodal distributions envisaged by Woman and Miller (1960) but rather had complex forms sometimes having peaks of similar magnitude at two or more discharges with quite different durations.

Sediment-discharge regimes showing the most effective discharge for suspended sediment load in the Fraser River basin vary from station to station (Figs. 7.1a, c through 7.4a). The sediment-discharge regimes do not portray the unimodal form expected from the Wolman and Miller's (1960) hypothesis. The eight sediment-discharge regimes in the Fraser River basin have been classified into four characteristic forms first described by Ashmore and Day (1988).

The first type is the unimodal histogram having a well defined single mode and a relatively frequent effective discharge. This is the type of distribution predicted by the Woman and Miller's (1960) hypothesis. Only two stations, Fraser River at Hansard and at Hope, fall in this category (Fig. 7.1a; 7.2a). The duration of the most effective discharge of this unimodal form ranges from 6.41% to 18.95 % (Table 7.1). The second form is characterized by a clearly recognizable effective discharge but has a very erratic form due to discharges of widely differing durations transporting similar sediment loads. Three stations on the Fraser River namely: Marguerite, (Fig. 7.1c), Agassiz (Fig. 7.2c) and Mission (Fig. 7.3a) exhibit this form with durations of most effective discharges classes ranging from 4.43% to 8.55% (Table 7.1; Figs. 7.1d, 7.2d and 7.3b). The other distinguishing characteristic of this sediment-discharge regime is that, for the Agassiz station there is one significant secondary peak at the lower end of the discharge range. This form of sediment distribution suggests that there is little variation in the magnitudes of effective discharge and other moderate flows at stations with this characteristic form.

The third form of sediment-discharge regime is one in which the extreme upper level events are the effective discharges. Only one station falls in this category, Chilliwack River at Vedder Crossing (Fig. 7.3c). The duration of the effective discharge class at Vedder Crossing ranges from 0.02% to 0.03% (Table 7.1; Fig. 7.3d). This category, undoubtedly, reflects the importance of upper extreme flows in sediment transport, especially in small alpine basins such as that drained by the Chilliwack

River. The final sediment-discharge form is one in which the extreme lower level flows are the effective discharge. Two stations fall in this category namely: Silverhope Creek near Hope (Fig. 7.4a) and the Harrison River at Harrison Hot Springs (not illustrated). The duration of the effective discharge in this category ranges from 8.61% to 19.6% (Table 7.1; Figs. 7.4b). This form is characteristic of small rivers which are dominated by low flows, although the flow of the Harrison River at Harrison Hot Springs also is controlled on the upstream by Harrison Lake.

An alternative way, of looking at discharge effectiveness in transporting suspended sediment load is by constructing sediment load and discharge duration curves, subjects of discussion in the next section.

7.2.2 Duration of Suspended-Sediment Loads

The analysis of durations of suspended-sediment loads were based on plots of cumulative percentages of daily suspended-sediment loads transported in a given percentage of time, and the cumulative percentages of suspended-sediment loads transported by cumulative percentages of total discharges. Sediment and discharge duration curves were constructed for the nine sediment stations in Fraser River basin based on daily values. This was done by arranging daily suspended sediment loads in the order of decreasing magnitude and the percentages of total sediment load and total time calculated and graphed (Fig. 7.5a, c through 7.6a.1, b.1 to 7.7a.2, b.2). From these two types of curves were obtained times in percentages when 50% of the sediment

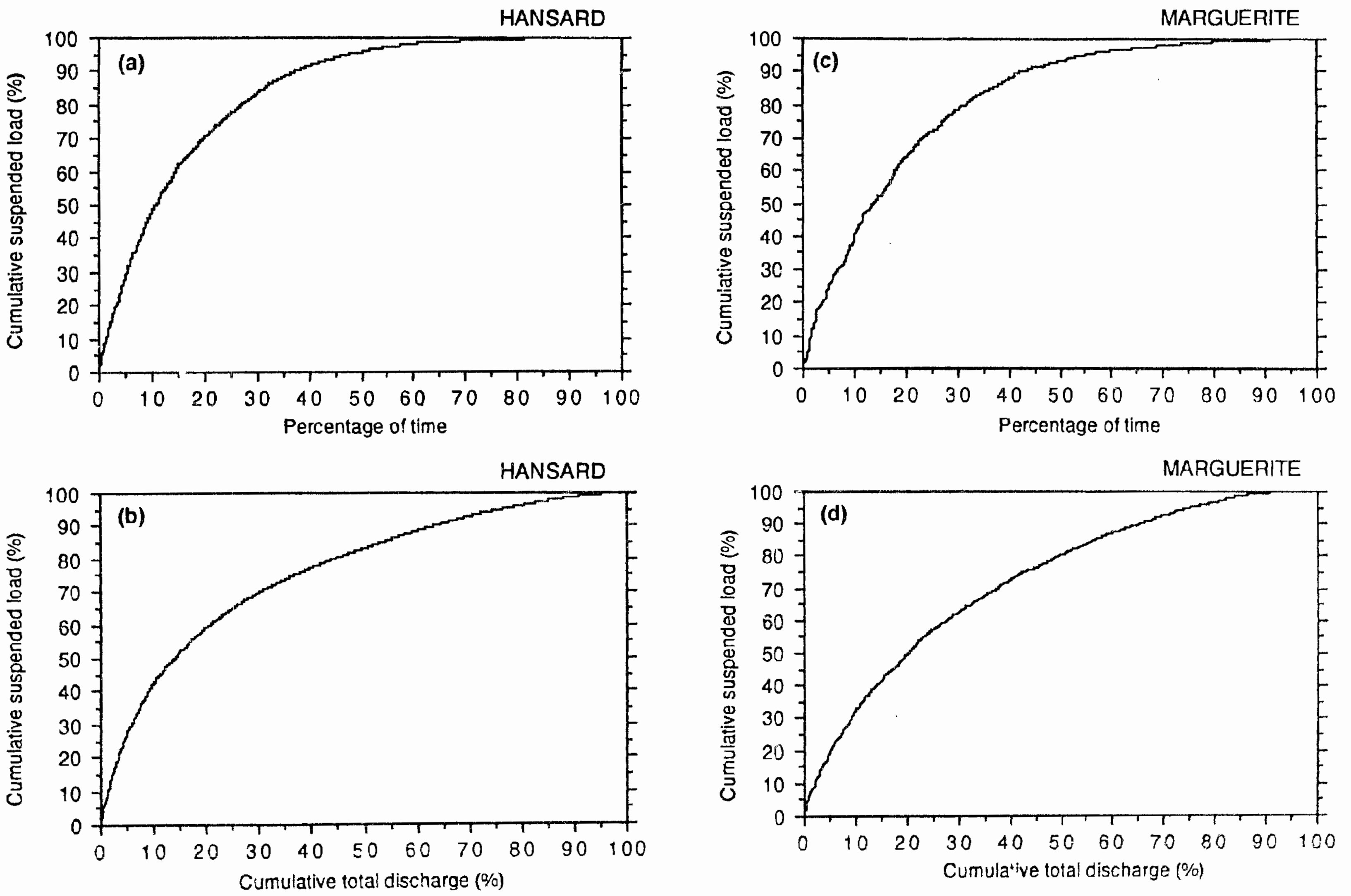

Fig. 7.5. Cumulative suspended sediment load duration curve plotted with respect to time (a, c) and cumulative percentage of total discharge (b, d) for the Fraser River at Hansard (1972-86) and Marguerite (1971-86) stations.

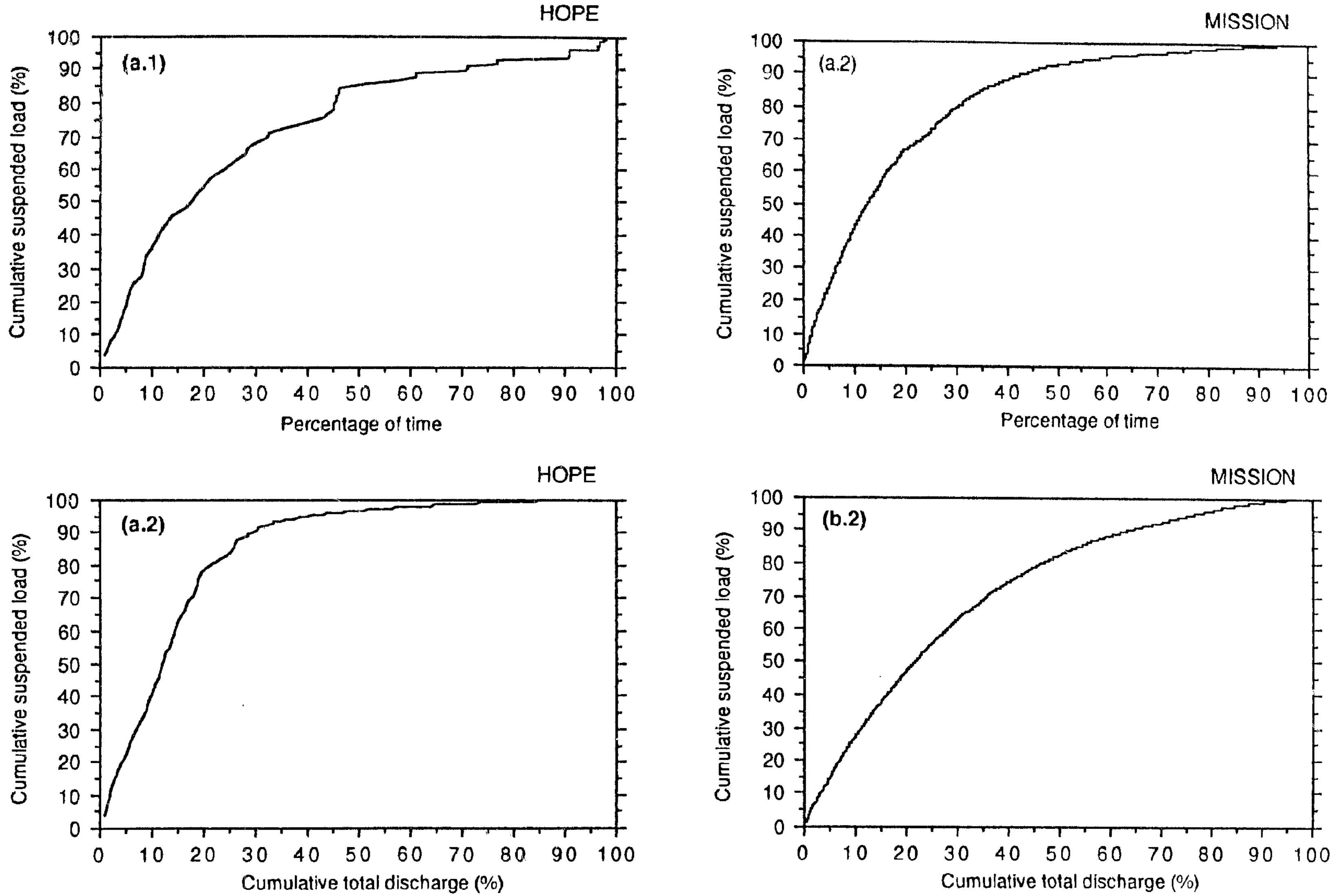

Fig. 7.6. Cumulative suspended sediment load duration curve plotted with respect to time (a.1, b.1) and cumulative percentage of total discharge (a.2, b.2) for the Fraser River at Hope (1965-79) and Mission (1966-88) stations.

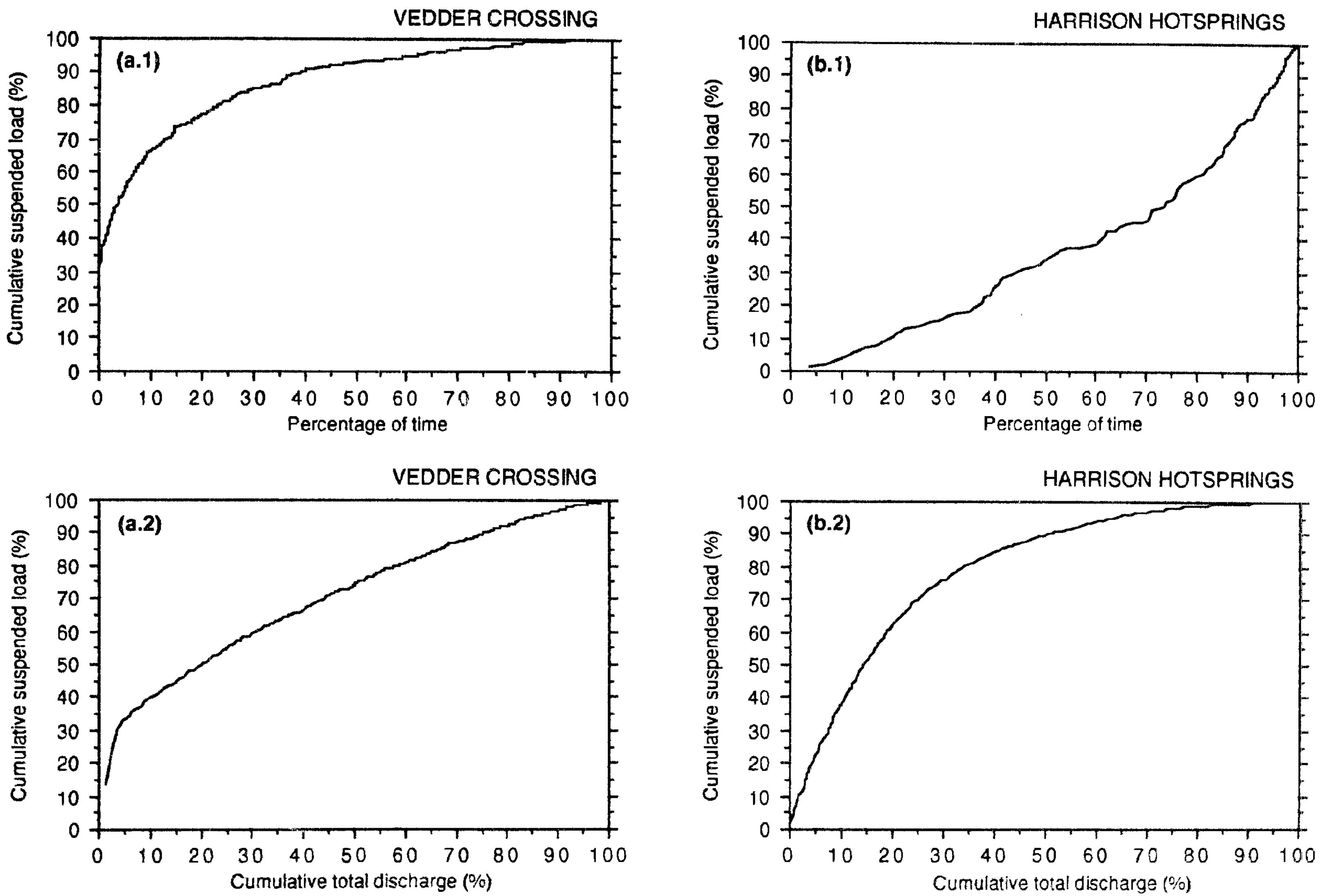

Fig. 7.7. Cumulative suspended sediment load duration curve plotted with respect to time (a.1, b.1) and cumulative percentage of total discharge (a.2, b.2) for the Chilliwack River at Vedder Crossing (1966-75) and on the Harrison River at Harrison Hotsprings (1966-70) stations.

loads were moved as well as the percentages of the total discharges which transport 50% of suspended sediment loads.

Table 7.3 shows that 50% of sediment loads in the Fraser River is moved in 3% to 73% of the time with an average of 21.9%. If lake-influenced Harrison River, on which 50% of suspended sediment load is moved in 73% of the time is excluded, the sediment loads are found to be moved in 3% to 22% of time with an average of 13.4%. This generally indicates the effectiveness of suspended sediment transport during high flows.

The graphs showing cumulative percentage of suspended sediment loads and the associated cumulative percentage of total discharges (Fig. 7.5 through Fig. 7.7) clearly portray the relationship between suspended sediment load and discharge in the Fraser River. Table 7.3 shows that 50% of suspended sediment load is moved by 12% to 22% of the total discharge. Since half of total suspended sediment load is moved by less than 22% of the total discharge, these results confirm further that the relationship between suspended-sediment load and discharge in the Fraser River basin is a very weak one - or a steep one.

7.3 Relationships among Effective Discharge, Threshold Discharge for Stream-bed Scour, Bankfull Discharge and Basin Area

The link between effective discharge and bankfull discharge is difficult to establish in terms of recurrence interval. This is largely because the magnitude frequency analysis approach is inapplicable to

Table 7.3. Cumulative suspended-sediment load transported in given percentage of time and by percentage of total discharge in the Fraser River basin, British Columbia.

Station no.	River	Area (km^2)	50% of total cumulative suspended sediment load is moved in given % of time	50% of total cumulative suspended sediment load is moved by given % of total discharge
08KA004	Fraser R. at Hansard	18000	11.0	15
08MC018	Fraser R. near Marguerite	114000	14.5	21
08MF005	Fraser R. at Hope	212000	17.0	12
08MF009	Silverhope Cr. near Hope	350	22.0	21
08MF035	Fraser R. near Agassiz	218000	16.0	22
08MG013	Harrison R. near Harrison Hot Springs	7870	73.0	14
08MH001	Chilliwack R. at Vedder Crossing	1230	3.0	20
08MH024	Fraser R. at Mission	228000	13.0	22

most effective discharges which are smaller than annual floods at each station. Consequently, a realistic comparison of the effective discharge to bankfull discharge would be the ratio of the two discharges. For the studied stations in Fraser River basin, the ratio of the effective discharge to bankfull discharge (Q_{eff}/Q_{bf}) was found to range from 0.476 at Marguerite on Fraser River to 1.898, at Vedder Crossing on the Chilliwack River (Table 7.4). For stations on the main channel of the Fraser River the Q_{eff}/Q_{bf} ratio has a small range: 0.550 to 0.984. This shows that the relationship between effective discharge and bankfull discharge is stable on large rivers.

By comparison, the ratios of threshold discharge to bankfull discharge (Q_t/Q_{bf}) for eleven studied stations was found to range from 0.086 at Red Pass to 0.777 at Marguerite station. On average the threshold discharge is about 0.349 times smaller than the bankfull discharge while the effective discharge, excluding the Chilliwack River, is 0.755 times. Figs. 7.8a and b show that effective discharge is more related to bankfull discharge than threshold discharge for bed scour. This may be due to the fact that, the determination of threshold discharge on a number of stations was not clear cut, while a specific procedure for obtaining the effective discharge was used.

7.3.1 Estimation of Effective Discharge

Equations in Figs. 7.8b and c, based on data in Table 7.1, were used to estimate effective discharge for stations with no sediment record using bankfull discharge and area of drainage basin as independent

Table. 7.4. Comparative data for effective dscharge, threshold discharge and bankfull discharge as determined in this study.

No.	Station No.	River	Q_{eff} (m^3s^{-1})	$Q_{eff}/Q_{1.58}$[1]	$Q_t/Q_{1.58}$[1]
1.	08KA007	Fraser R. at Red Pass			0.086
2.	08KA005	Fraser R. at McBride			0.122
3.	08KA004	Fraser R. at Hansard	1072	0.550	0.308
4.	08KB001	Fraser R. at Shelley			0.229
5.	08MC018	Fraser R. near Marguerite	3236	0.476	0.777
6.	08MD013	Fraser R. near Big Bar Creek			0.236
7.	08MF040	Fraser R. at Texas Creek			0.222
8.	08MF005	Fraser R. at Hope	7027	0.878	0.188
9.	08MF009	Silverhope Cr. near Hope	28		
10.	08MF035	Fraser R. near Agassiz	7106	0.888	0.375
11.	08MG013	Harrison R. near Harrison Hot Springs	865		
12.	08MH001	Chilliwack R. at Vedder Crossing	522	1.898	0.545
13.	08MH024	Fraser R. at Mission	7872	0.984	0.750

[1] Data for discharge threshold for bed scour (Q_t) and bankfull discharge ($Q_{1.58}$) are given in Table 4.2.

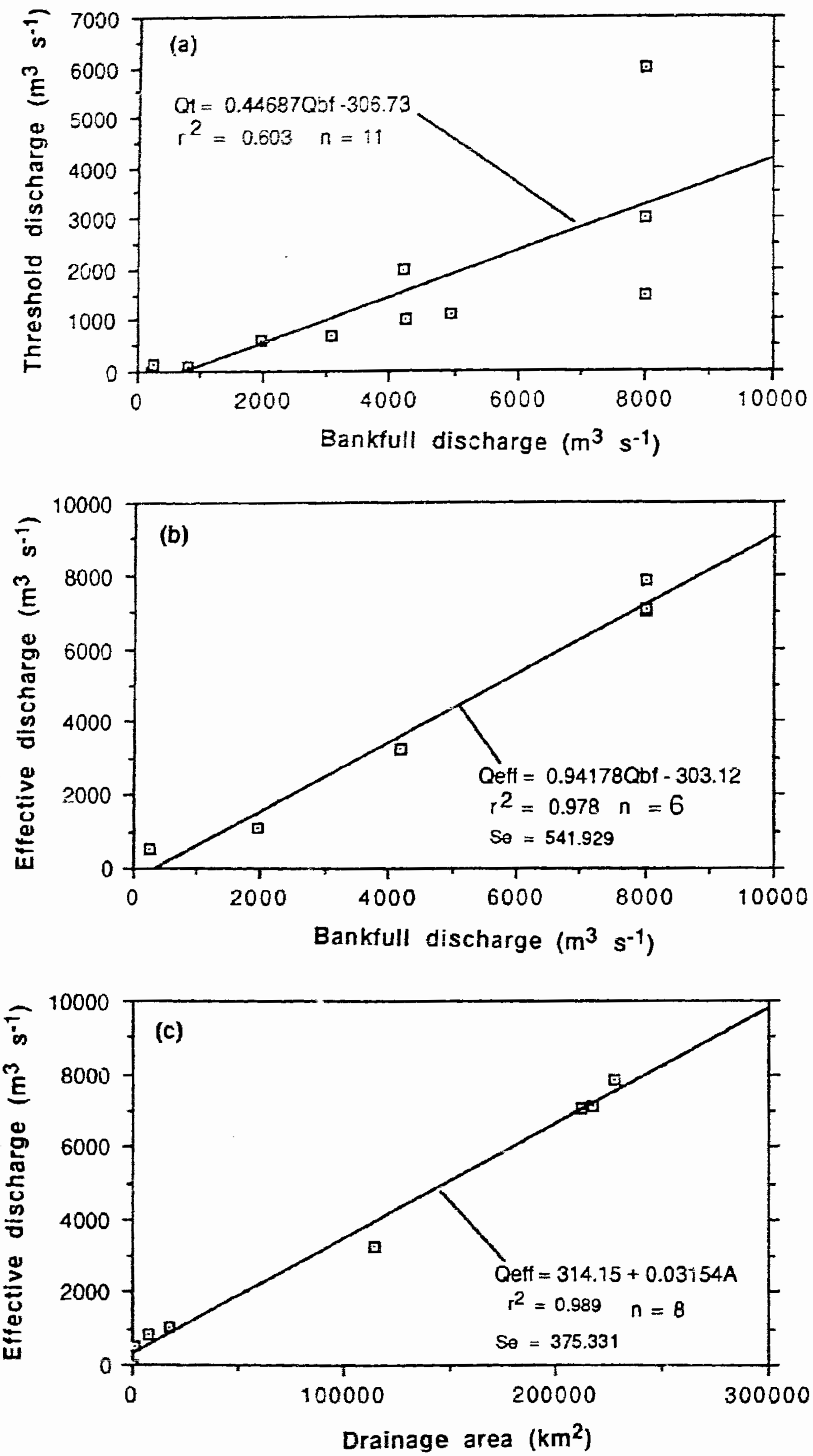

Fig. 7.8. Relationships between threshold discharge and bankfull discharge (a), effective discharge and bankfull discharge (b), and effective discharge and drainage area (c), for studied sediment and discharge stations in the Fraser River basin.

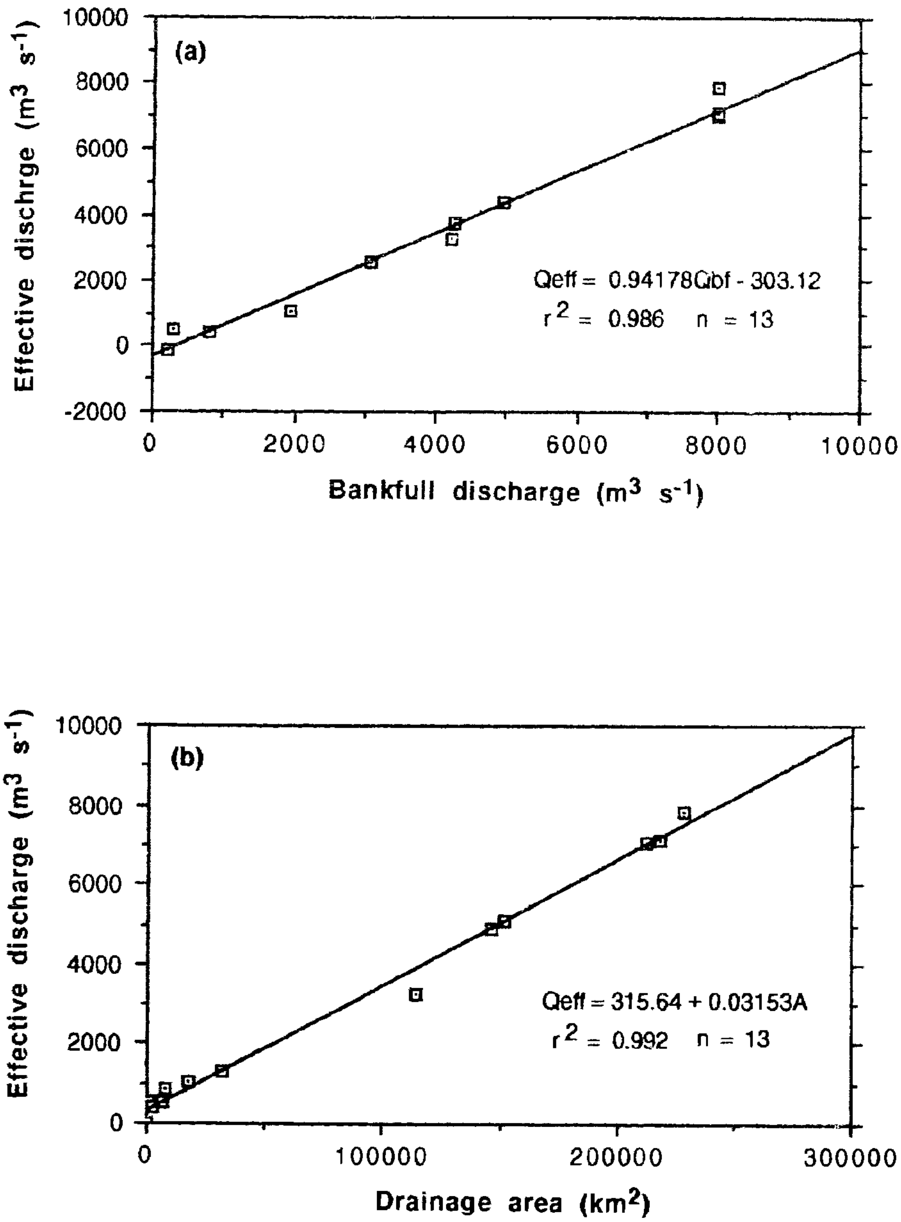

Fig. 7.9. Estimation of effective discharge from bankull discharge (a) and drainage area (b) in the Fraser River basin.

variables (Fig. 7.9). The estimated data for effective discharge are included in Table 7.5. Equations of the relationships between 'measured' and estimated values of effective discharge (excluding Clearwater station) and bankull discharge (Fig. 7.9a) and between effective discharge and drainage area (Fig. 7.9b), based on data in Table 7.5, may be used to predict the effective discharge in the Fraser River basin. The close relationships that exists between bankfull discharge and effective discharge ($r^2 = 0.986$) and between effective discharge and drainage area ($r^2 = 0.992$) indicate that effective discharge can be estimated quite accurately from the two independent variables. However, note that the variations in the standard errors of estimate given are quite large. But considering the size of the Fraser River and the large variations in discharge at various stations the standard errors of estimate are probably within acceptable limits. Thus, estimated values of the effective discharge would probably not differ significantly from true values.

Therefore effective discharge for suspended sediment load in the Fraser River basin may be estimated by two equations:

$$Q_{eff} = 0.942Qbf - 303 \qquad (8)$$

$$Q_{eff} = 315.64 + 0.032A \qquad (9)$$

At this stage, data for threshold discharge for stream-bed scour are not enough to permit its prediction in the Fraser River.

Table 7.5. Effective discharge data for the Fraser River basin.

			Q_{eff} for Fraser River basin	
No.	Station No.	River	A (m^3s^{-1})	B (m^3s^{-1})
1.	08KA007	Fraser R. at Red Pass	337.768[¥]	-84.627[§]
2.	08KA005	Fraser R. at McBride	531.461[¥]	467.256[§]
3.	08KA004	Fraser R. at Hansard	1072.000	1072.000
4.	08KB001	Fraser R. at Shelley	1336.046[¥]	2578.727[§]
5.	08MC018	Fraser R. near Marguerite	3236.009	3236.000
6.	08MD013	Fraser R. near Big Bar Creek	4918.000[¥]	3690.000[§]
7.	08MF040	Fraser R. at Texas Creek	5105.000[¥]	4368.109[§]
8.	08MF005	Fraser R. at Hope	7027.000	7027.000
9.	08MF009	Silverhope Cr. near Hope	28.000	28.000
10.	08MF035	Fraser R. near Agassiz	7106.000	7106.000
11.	08MG013	Harrison R. near Harrison Hot Springs	865.000	865.000
12.	08MH001	Chilliwack R. at Vedder Crossing	522.000	522.000
13.	08MH024	Fraser R. at Mission	7872.000	7872.000

[¥] Effective discharge estimated by bankfull equation given in Fig. 7.8b.

[§] Effective discharge estimated by drainage area equation given in Fig. 7.8c.

7.4 Summary and Conclusions

This study found that the concept of effective discharge generally applies to rivers in the Fraser River basin. The frequency characteristics of the effective discharge in the Fraser River basin range from 0.03% to 16.04% with a majority of cases falling in the range between 5.5% and 9.7%. These findings confirm the view of Wolman and Miller (1960) who argue that effective discharges are events of moderate frequency. But the sediment-discharge regimes based on 20 discharge classes were found to vary widely among stations.

Duration curves of suspended sediment load and discharge for Fraser rivers have revealed that 50% of total sediments are transported in 3% to 22% of the time with an average of 13.4%. Larger flow events generally transport most of the suspended load in the Fraser River basin. Specifically, 50% of suspended sediment loads are moved by 12% to 22% of the total discharge with an average of 17.9%. However, these conclusions require further testing.

The problem of the applicability of the effective discharge in fluvial geomorphology (and perhaps the definition of effective discharge) raised by Ashmore and Day (1988), remains unresolved. In this study, the concept of effective discharge was found to be applicable to the Fraser River. This study found the problem of the lack of an objective method of determining effective discharge to be more important than that of its definition. Therefore, in this section of study, it is concluded that, before testing the applicability of the concept of effective discharge in different areas, an objective criterion and method for determining effective discharge are required. It is further suggested that, the determination of effective discharge be based on the rate of sediment transport, magnitude and the frequency of occurrence of individual flow events without dividing them into various classes. This is necessary so that there should be no dispute about how each researcher determines the effective discharge.

Unfortunately, the question of determining effective discharge also applies to bankfull discharge. Bankfull discharge has previously been determined in a variety of ways and there is no general accord on the correct method for its determination. An objective definition and criterion for determining bankfull discharge are long overdue from fluvial geomorphologists as well as from practicing river engineers.

Finally, the effective discharge may be predicted in Fraser River basin at a number of ungauged stations from the knowledge of bankfull discharge or area of the drainage basin using equations provided by this study.

CHAPTER EIGHT

SUMMARY AND CONCLUSIONS

8.1 Summary

8.1.1 Seasonal Channel Scour and Fill Regimes

The research question relating to the nature of the relationship among discharge, suspended-sediment concentration, and channel scour and fill for seasonal and individual events was answered in two parts.

Firstly, with respect to discharge and seasonal stream-bed scour and fill, this study has demonstrated that, seasonal channel scour and fill regimes in the Fraser River basin show rapid lowering of the bed caused largely by the spring snowmelt and progressive adjustment of stream-bed and sediment transport. The spring snowmelt which drives the scour cycle leaves river beds at lower elevations than those preceding it. Although the scour cycle is more complete at some stations than at others, generally the succession of scour and fill sequences is almost the same from year to year.

Secondly, this study identifies a close relationship between the scouring and filling of the bed and suspended sediment concentration which greatly increase when the discharge for bed scour and bankfull discharges are exceeded. This observation suggests that seasonal suspended-sediment transport probably is controlled by the destruction of the channel bed armour, especially when discharge thresholds for bed scour and the bankfull discharge are exceeded. This is largely because discharges greater than the discharge threshold and bankfull discharge liberate large quantities of fine sediments trapped in the bed forms and on high elevation bars as they are accessed by the flow.

8.1.2 Factors Controlling Sediment Variations in Single-Valued Events

The answer to the research question relating to factors controlling the form of single-valued sediment rating curves has four parts, each dealing with a different group of factors.

8.1.2.1 Hydrological Factors

In the rising stage, linear and non-linear single-valued sediment rating curves were found to have been controlled more by the index of flood intensity than by the mean rising discharge and antecedent moisture conditions (approximated by the discharge on the day preceding the beginning of the event). But in the falling stage, the index of flood recession controls suspended-sediment concentration variation more or less than the mean falling discharge. Overall, for non-linear events sediment concentration was found to be more related to discharge and hydrograph characteristics in falling stages while for linear events discharge and hydrograph characteristics control sediment concentration to the same extent.

8.1.2.2 Hydraulic Factors

Channel hydraulic factors controlling sediment variation in single-valued sediment rating curves are: velocity, depth and bed elevation. The most important finding of this study is the timing of different hydrological events with respect to the level of the discharge for stream-bed scour which is closely related to the sediment supply. Therefore, hydraulic factors controlling linear, concave and convex sediment rating curves may be distinguished on the basis of the level of discharge with respect to scouring and filling processes.

Hydrographs for linear events were found to rise and terminate when discharge is greater than the threshold discharge for bed scour. Under these conditions the scouring process in the rising stage operates at rates similar to those for filling. Consequently, suspended-sediment for linear rating curves most likely originate from the channel bed in the rising stage with little or no amount of sediment recruited in the falling stages.

In contrast, concave events begin to rise when discharge is greater than the threshold for bed scour and terminate when the discharge falls below the scour threshold. In these cases, scouring occurs in the rising stage and filling in the falling stage when discharge is greater than the scour threshold. For the concave events, the channel bed supplies most of the sediments during scouring in the rising stage as well as during the re-scouring episodes in the latter part of the falling stage.

Conversely, convex events begin to rise when the discharge is below the level of bed scour and terminate in the same range of discharge. Therefore, convex rating curves are controlled by filling as well as scouring in the rising stages and by filling and re-scouring of the bed in falling stages. For convex events, bed filling occurs in the early part of the rising stage followed by scouring before time of peak. It is probable that most of the suspended-sediments originate from the bed in the latter parts of the rising and falling stages when scouring occurs.

8.1.2.3 Meteorological Factors

Comparison of changes in bed elevations and timing of precipitation and temperature conditions during individual events in a small drainage basin of Chilliwack River revealed that, bed scour generally was linked to the occurrence of storm runoff due to precipitation, or to snowmelt.

Linear events were observed to occur when it rained or snowed under low or sub-zero temperatures in the rising stage and when precipitation was received under similar temperatures conditions in the falling stage. But linear rating curves were also produced when it rained under low to moderate temperature conditions in the rising and falling stages. Under low and sub-zero temperature conditions sediments are recruited only from the stream-bed and none from the slopes due to the frozen ground which inhibits infiltration and surface runoff. But under moderate temperatures runoff generated from precipitation recruits sediments both from the channel and areas adjacent to it. Therefore, a continuous supply of sediments in the entire duration of the linear events likely control linear sediment rating curves.

By contrast, concave events occur when precipitation is received in the rising and falling stages under low temperature conditions as well as when it rains in the rising and falling stages under moderate temperatures.

Under these conditions, concentrations either increase or decrease at rates greater or less than that of discharge in the rising or falling stages. In such cases, most sediments are recruited either in the rising or falling stages which promotes the production of concave sediment rating curves. Therefore, differences in rates of sediment supply during rising and falling stages likely controls the forms of concave sediment rating curves.

Lastly, convex rating curves occur under moderate or low temperature conditions when precipitation is received either in the rising stages with little or none received in the falling stage or when precipitation is received both in the rising and falling stages. Therefore, for convex events precipitation received in the rising stage likely produces quickflow and/or overland flow accompanied by high sediment concentrations from both the basin slopes and stream-bed. In the falling stage, sediment replenishment likely occurs due to availability of an inexhaustible amount of sediments in the channel under low or moderate temperature conditions.

Sources of sediment supply, physical characteristics of the basins in the vicinity of sediment stations apparently contributed to the existence of single-valued sediment rating curves. For instance, the highest number of single-valued events (20%) were observed at Vedder Crossing on the Chilliwack River. This is not only because of frequent occurrence of mudslides on steep slopes and high precipitation received in the river basin, but also the existence of two discharge peaks associated with spring snowmelt and fall storminess.

Agassiz and Mission stations, where respectively 18% and 12% of single-valued events were observed, generally carry sand. The Hansard station, with 16% of the events, is located downstream of the Robson

Reach where most of the sediment supply comes from glaciers and alluvial fans in the Rocky Mountains. However, the availability of large quantities of unconsolidated sediments in the Marguerite station reach seems not to have contributed to the existence of single-valued events at the station as only 4% were observed. This is largely because of the high contributions of snowmelt to the spring floods which cause moderate to pronounced hysteresis in the sediment-discharge relations.

8.1.3 Factors Controlling Hysteresis in Relations of Discharge and Suspended-Sediment Concentration

The question relating to factors controlling the occurrence of hysteresis in single hydrological events was answered in three parts dealing with different factors. The findings of this study in this section are preceded by a theoretical background in order to put the discussion in the proper perspective.

Hysteresis in the sediment concentration versus discharge relations for single hydrological events has previously been attributed to a variety of factors which include, time lags between concentration and discharge peaks, differences in the rates of downstream movement of flood waves and the core of maximum concentration, differences in spatial distances between source areas and sediment measuring stations (Heidal, 1956; Wood, 1977; Bogen, 1980; Marcus, 1989); index of flood intensity and rate of hydrograph rise (Gregory and Walling, 1973) and by the rainfall intensity (Klein, 1984). Observations on the Fraser River in this study support Heidal (1956) and Marcus' (1989) conclusion that, a flood wave moves downstream more rapidly than the streamflow in which sediment is entrained. The relative positions of the flood wave and core of maximum suspended concentration vary which leads to spatial and temporal variations in sediment discharge. Paustian and Beschta (1979) attributed higher sediment concentrations on the rising than falling hydrograph limbs to the release of sediments from bed gravels after a hydrograph peak which inhibits the formation of a new armour layer.

Among hydrological factors controlling the occurrence of hysteresis, in this study it was found that, in the rising stage, antecedent moisture exerts greater control on suspended-sediment variation than mean rising-discharge for clockwise hysteretic events. But for anticlockwise hysteretic events, mean rising-discharge was found to exert greater control on suspended-sediment variation than antecedent moisture. In the falling stage, no difference was found between hydrological factors which control variations in sediment concentration for clockwise and anticlockwise hysteretic events.

Among hydraulic factors it was found that, for a majority of hysteretic events variations in sediment concentrations occur when there is a cross-over of average velocities in the rising and falling stages. Variations in concentrations are greater if the velocity cross-over occurs at higher than at lower discharges. This is because rapid changes in velocity from low to high at high flows results in greater changes to the channel shape than changes from high to low velocity at higher flows. Therefore, the crossing-over of velocities potentially liberates more fine sediments from the stream-bed for transport than when it occurs at lower discharges.

Lastly, no clear-cut distinction was observed between meteorological factors (namely, precipitation and air temperature) in causing clockwise and anticlockwise hysteresis for hydrological events that occur in summer and winter months. However, it was found that clockwise hysteresis resulted in sediment-discharge relations when precipitation was received in the rising stage with little or no precipitation received in the falling stage. This indicates that sediment supply from storm runoff likely is restricted to the rising stage. By contrast, anticlockwise hysteresis was found to generally result when precipitation is received in the basin both in the rising and falling stages of hydrological events. But sediment supply is higher in the falling than in the rising stages.

The influence of air temperature in causing clockwise or anticlockwise hysteresis was also found not to be clear-cut for a majority of events studied. However, for those events that occurred in winter months clear influences of temperature on clockwise and anticlockwise hysteresis can be distinguished. In the Chilliwack River basin, it was found that clockwise hysteresis occurs when precipitation is received in the rising stage with little or no precipitation received in falling stage under sub-zero temperatures. Under these conditions, sediments are recruited from the basin slopes, areas adjacent to the river channel and from the channel bed. In the falling stage, no sediment is recruited from basin slopes and only a limited amount of sediment is transported from the stream-bed due to the existence of sub-zero temperatures which inhibit runoff and sediment generation. These conditions favour the production of clockwise hysteresis in the sediment-discharge relations.

Conversely, in the Chilliwack River basin anticlockwise hysteresis also was observed to occur when precipitation is received under sub-zero temperatures in the rising stage and under low to moderate temperatures in the falling stage. These observations strongly suggest that, sediment transport from the basin and channel bed is inhibited in the rising stage by the sub-zero temperatures. But in the falling stage, an abundant amount of sediments are recruited from the basin slopes and the channel bed thereby causing anticlockwise hysteresis. These meteorological controls on sediment concentration are only true for the Chilliwack River. But similar processes probably obtain in other small drainage basins in humid temperate regions.

This is study has largely combined functional (regression) analysis and cause-and-effect analysis in the explanation of the existence of various types of single-valued and hysteretic relationships between suspended-sediment concentration and discharge. These methods are among other approaches such morphometric and systems analysis employed in geomorphology. Each one of these approaches has limitations and drawbacks; and are only appropriate in certain circumstances. The functional and cause-and-effect analysis used in this study have added to the knowledge of the character and factors controlling suspended-sediment concentration in the Fraser River basin.

8.1.4 Prediction of Forms of Suspended-Sediment Rating Curves

The potential mix and interrelations of factors controlling sediment variations which Williams (1989: 105) concluded as presenting a formidable challenge to predicting the type and magnitude of C-Q relations for a particular site and occasion are considered here by way of conclusion. Findings of this study allow for the prediction of expected forms of sediment-discharge relations for single hydrological events under different geomorphic, hydrologic, hydraulic and meteorological conditions. Since deriving general models to explain sediment transport in rivers is complicated by the large number of variables involved, concepts of geomorphic threshold and complex response (Schumm, 1973) are utilized. Schumm (1977) has provided a predictive cascading system to enhance the understanding of the fluvial system.

Insights gained from analyses of factors controlling suspended-sediment concentration in the Fraser River, in a time scale of days to years, lead to the modification of Schumm's (1977: 323) types of landform response to and Sichingabula's (1986: 118) model of river channel response to external and internal influences into an idealized model of interrelations of factors controlling suspended-sediment transport for single hydrological events (Fig. 8.1). Fig. 8.1 shows the various controlling factors that influence sediment-discharge relations of single hydrological events.

In a fluvial system, the character of hydrological events reflect channel responses to both external and internal influences which lead to the exceedance of extrinsic and intrinsic thresholds. In a time scale of years external influences may be in the form of hydrologic and meteorological events as well as changes in temperature regimes. In the short-term, internal influences may be in the form of changes in sediment load and in hydraulic variables. In rivers external and internal influences lead to the exceedance of geomorphic and meteorologic thresholds which bring about a series of minor channel adjustments such as sediment movement and stream-bed scour and fill. In turn, these adjustments lead to the complex response as rivers search a new equilibrium state between

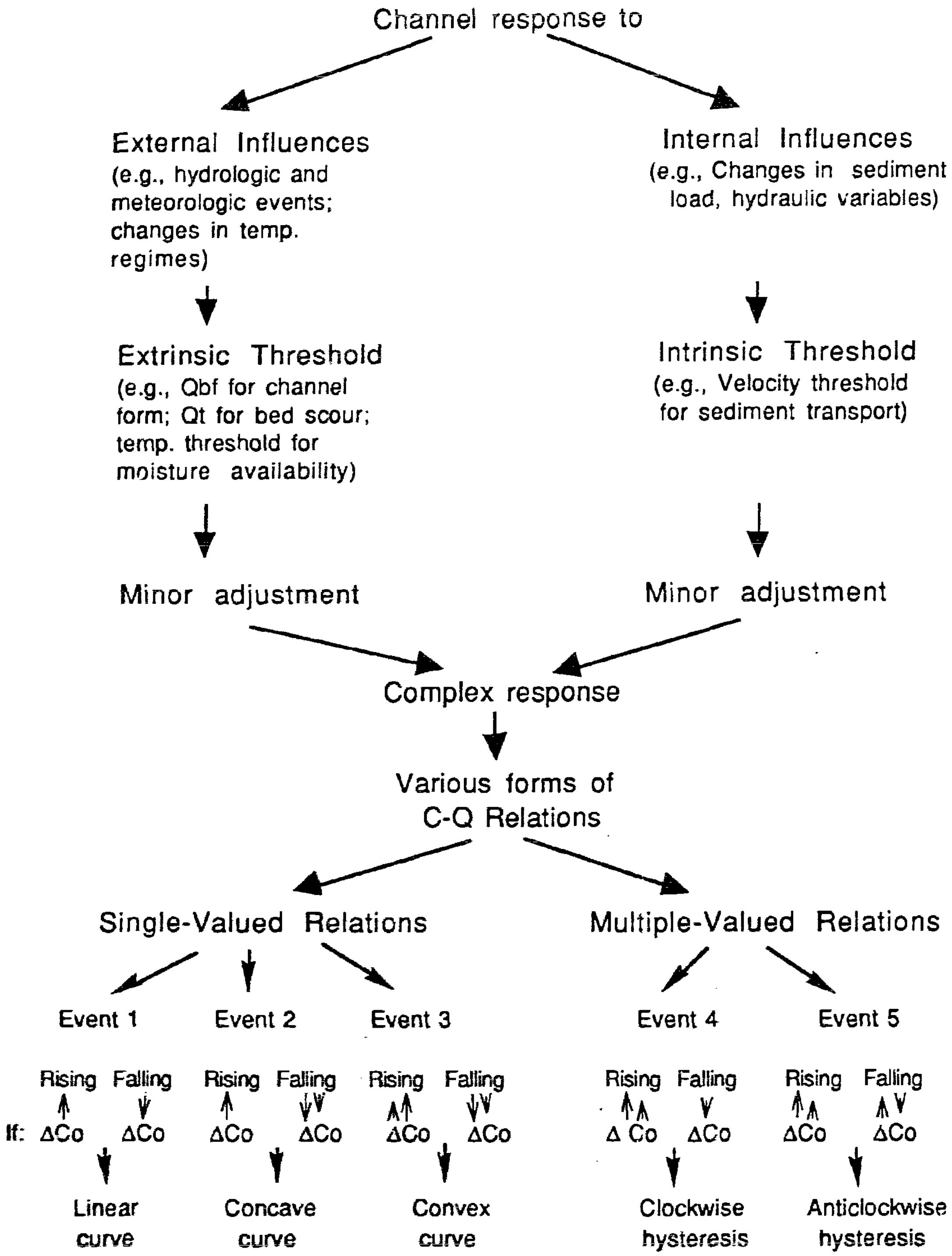

Fig. 8.1. An idealized model of interrelations of factors controlling suspended-sediment concentration for single hydrological events. Where C, and Co are sediment concentration; Q, Qbf, Qt, temp. are daily discharge, bankfull discharge, discharge threshold for stream-bed scour and temperature, respectively. The model is an extension of Schumm's (1977: 323) and Sichingabula's (1986: 113) models of landform and channel responses to external and internal influences. Size of arrows above ΔCo indicate relative magnitudes of change.

morphologic and cascading components of the process-response system.

The search of a new equilibrium is manifested in the complicated and various forms of sediment-discharge (C-Q) relations for single hydrological events. The two forms of sediment-discharge relations distinguished in this study are the single-valued and multi-valued (hysteretic) sediment rating curves. The evidence presented herein allows for prediction of the occurrence of a particular type of sediment-discharge relation in the Fraser River basin. Although the model presented is mainly applicable to the Fraser River basin it can also be extended to other rivers influenced by factors similar to those that obtain on the Fraser River.

For instance, for single-valued sediment-discharge relations Fig. 8.1 shows that if:

1. in event 1, the rate of increase in sediment concentration in the rising stage is similar to that of decreasing concentration in the falling stage, a linear rating curve would be produced;

2. in event 2, sediment concentration increases in the rising stage and decreases at two different rates in the falling stage, a concave rating curve would be produced;

3. in event 3, sediment concentration increases at two different rates in the rising stage and also decreases at two different rates in the falling stage, a convex rating curve would be produced.

For multi-valued sediment-discharge relations, if:

4. in event 4, sediment concentration in the rising stage increases at two rates and also decreases at two different rates in the falling stage, a clockwise hysteresis would be produced, and lastly;

5. in event 5, sediment concentration increases at two different rates in the rising stage increases and decreases in the falling stage, an anticlockwise hysteresis would be produced.

Note that the initial increase in sediment concentration for each event could be caused by external factors such as hydrologic events due to precipitation or snowmelt and the arrival of sediment-laden runoff from basin slopes. But differences in rates of increase and decrease in sediment concentration either in the rising or falling stages could be caused by internal factors. Such factors include changes in sediment load, the exceedance of velocity threshold for sediment movement, the discharge threshold for stream-bed scour, and due to direct precipitation which is deficient in suspended-sediment. In winter the generation of runoff largely depends on temperature ranges below and above the freezing point. More runoff and sediment are generated under higher than lower temperatures.

8.1.5 Frequency Characteristics of Sediment Loads

With respect to the question relating to frequency statistics of effective discharge it was found that the duration of the effective discharge for Fraser River varied widely (0.03% to 16%) as observed in previous studies. These findings confirm the hypothesis of Wolman and Miller (1960) stating that effective discharges are events of moderate frequency. The problem of the applicability and definition of effective discharge raised by Ashmore and Day (1988), in this study has been found to be less important than the problem of a lack of an objective method for determining the effective discharge. An objective criterion and method for determining effective discharge is presently lacking in fluvial geomorphology.

Lastly, using an alternative way of looking at discharge effectiveness in transporting suspended sediment load, this study found that, in Fraser River basin 50% of total sediments are transported in 13.8% of the time. Additionally, 50% of suspended sediment loads are moved by 12% to 22% of total discharge. This indicates that larger flow events transport most of the suspended-sediment load.

8.1.6 Relationships among Effective Discharge, Threshold Discharge and Bankfull Discharge

The question of the relationships among effective, threshold and bankfull discharges was answered by assessing their relative magnitudes. This study has found that in the Fraser River, the effective and threshold discharges generally are smaller than the bankfull discharge at each station. On the main channel of the Fraser River the ratio of effective discharge to bankfull discharge ranges from 0.550 to 0.984. This shows that the relationship between effective discharge and bankfull discharge is fairly stable on large rivers.

By comparison, the ratios of threshold discharge to bankfull discharge for the studied stations was found to range from 0.086 to 0.777. On average, results of this study show that the threshold discharge and effective discharge in the Fraser River are 0.349 and 0.755 times smaller than bankfull discharge, respectively.

Finally, the effective and threshold discharges in Fraser River may be predicted from the knowledge of either bankfull discharge or drainage area of the basin for which applicable equations have been provided.

8.2 Conclusions

It is concluded that spring snowmelt which drives the scour cycle leaves river beds at lower elevations than those preceding it and that, generally the succession of scour and fill sequence is almost the same from year to year. A close relationship between the scouring and filling of the bed and sediment concentration has been identified, especially when the discharge for bed scour and bankfull discharges are exceeded. This observation indicates discharges greater than the discharge threshold for bed scour and bankfull discharge liberate large quantities of fine sediments trapped in the bed forms and on high elevation bars.

Another conclusion of this study is that, linear and non-linear sediment rating curves can be distinguished by the greater influence of preceding discharge or antecedent moisture on the linear curve forms. This implies that, for linear events, other factors remaining constant, high antecedent moisture conditions have the effect of generating quick runoff and rapid increases in sediment concentration in concert with changes in discharge. Conversely, low antecedent moisture conditions likely produce delayed increases in sediment concentration not in phase with changes in discharge. Consequently, a non-linear relationship between sediment concentration and discharge is produced.

The analysis of hydraulic factors demonstrated that the interaction between the stream-bed and streamflow is an important factor in the control of suspended-sediment variation for single hydrological events. If the bed is mobile in the rising and falling stages and no replenishment of sediment occurs in the falling stage, a linear rating curve is produced. But, if the bed is mobile in rising and immobile in falling stage of an hydrological event, or vise versa, the associated sediment-discharge relation likely will have a concave form.

Similarly, if the bed is mobile in the rising and falling stages and sediment replenishment occurs in the falling stage, a convex rating curve would result since sediments would be released and supplied more quickly in the falling than rising stages. It appears to be the case that, when the inactive bed becomes mobile, in the rising or/and falling stages, it contributes considerable amounts of sediments for transport by the stream. Therefore, the return of stored sediments by the scouring of the bed has been found to be one of the major factors controlling the variation of suspended-sediment concentration for single-valued hydrological events.

Clockwise hysteretic events in the rising stage were found to be controlled more by high antecedent moisture condition than the mean rising-discharge. Conversely, anticlockwise hysteretic events have been found to be controlled more by mean rising-discharge than antecedent moisture in the rising stage. No difference was found between hydrological factors controlling variations in sediment concentration for clockwise and anticlockwise hysteretic events.

Hydraulically, for a majority of hysteretic events variations in sediment concentrations occur when there is a cross-over of average velocities in the rising and falling stages. Variations in concentrations are greater if the velocity cross-over occurs at higher than at lower discharges. This is because rapid changes in velocity from low to high at high flows liberates more fine sediments from the stream-bed for transport than when the cross-over occurs at lower discharges.

Lastly, in a small temperate stream such as the Chilliwack River precipitation and air temperature influence single-valued sediment rating curves as well as clockwise and anticlockwise hysteretic events that occur in winter months. It is difficult to isolate the true nature of meteorological factors that control variations in suspended-sediment concentration for single hydrological factors. This is because these and other factors operate at the same. Their isolation here is a matter of convenience. But it is safe to say that the occurrence of precipitation in the rising and/or falling stage conditions runoff and sediment generation from basin slopes as well as from the stream-bed.

Similarly, air temperature in sub-zero to moderate ranges controls the rates of runoff generation and sediment supply to river channels in winter months. Sub-zero and near zero low temperatures inhibit sediment recruitment from basin slopes and from the stream-bed due to the existence of an impervious surface layer of ice cover and the lack of runoff from basin slopes. Higher temperatures up to moderate ranges promote runoff and sediment generation. It is the varying combination of precipitation occurrence under different temperature conditions which ultimately determines the forms of single-valued sediment rating curves effected and the type of hysteresis observed in the sediment-discharge relationships. It is concluded that multivariate analysis involving major factors controlling variations in suspended-sediment concentration can greatly increase the prediction of sediment loads in the Fraser River.

The frequency characteristics of the effective discharge for the Fraser River were found to be in the range of values as those observed by previous studies. The findings of this study also confirm the hypothesis of Wolman and Miller (1960) stating that effective discharges are events of moderate frequency. The problem of the lack of an objective method for determining the effective discharge remains unresolved. As a first step to its solution, it is concluded that the determination effective discharge be based on the rate of sediment transport, magnitude and the frequency of occurrence of individual flow events without dividing them into various classes. This should provide an objective criterion and method for determining effective discharge which is presently lacking in fluvial geomorphology.

Based on the methods used in this study, the effective discharge and threshold discharge for stream-bed scour in Fraser River were found to be 0.349 and 0.755 times bankfull discharge, respectively. The effective and threshold discharges may be predicted with good results from either bankfull discharge or the drainage area for which applicable equations have been provided in this study.

Overall, better knowledge of the character and factors controlling suspended-sediment concentration and discharge effectiveness, in the Fraser River basin will require more detailed analysis than has been conducted in this study. But the processes of seasonal scour and fill regimes and hysteretic phenomenon demonstrated in this study indicate that sediment transport in the Fraser River basin involves some kind of 'memory' (Bogen, 1980: 52) of past history of fluvial processes. The memory effect indicates the relative importance of in-channel sediment storage at both seasonal and storm-period times scales. The knowledge of relative amounts of sediment in storage between and within seasons is critical to better management and planning of water systems for navigation and purifcation of industrial and municipal water supplies.

Further investigations of seasonal and storm-period factors associated with scour and fill processes for single hydrological events may provide insights into the mechanisms operating. This also would allow for valuable information about the underlying physical processes to be discerned.

Future research on suspended-sediment transport should be directed at ascertaining whether or not findings reported herein for the Fraser River are typical of other rivers in temperate regions. Research into possible applications of the knowledge of threshold discharge for stream-bed scour and of factors controlling sediment variation in rivers should be worthwhile to river engineering and to the solution of many human problems caused by suspended-sediment transport in rivers.

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APPENDIX 1

Discharge (Q) and sediment concentration (C) data in the rising (r) and falling (f) stages of some single-valued hydrological events in the Fraser River basin.

Event No.	Station & Date	Q (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(f) (m^3/s)	C(f) (mg/L)
1	08KA004						
	1973: Sep. 27	337.0	87	337.0	87		
	28	586.0	256	586.0	256		
	29	790.0	381	790.0	381		
	30	1100.0	656	1100.0	656		
	Oct. 01	980.0	577			980.0	577
	02	745.0	381			745.0	381
	03	597.0	223			597.0	223
	04	538.0	160			538.0	160
	05	535.0	133			535.0	133
	06	530.0	128			530.0	128
	07	487.0	106			487.0	106
	08	425.0	75			425.0	75
	09	374.0	65			374.0	65
	10	340.0	53			340.0	53
	11	328.0	47			328.0	47
	12	328.0	44			328.0	44
2	08KA004						
	1974: Jun. 02	855.0	106	855.0	106		
	03	1120.0	204	1120.0	204		
	04	1230.0	276	1230.0	276		
	05	1130.0	227			1130.0	227
	06	1030.0	182			1030.0	182
	07	1020.0	147			1020.0	147
	08	977.0	123			977.0	123
	09	949.0	111			949.0	111
3	08KA004						
	1980: Sept. 29	446.0	60	446.0	60		
	30	482.0	85	482.0	85		
	Oct. 01	738.0	241	738.0	241		
	02	782.0	271	782.0	271		
	03	672.0	212			672.0	212
	04	583.0	163			583.0	163

Event No.	Station & Date	Q (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(f) (m^3/s)	C(f) (mg/L)
	05	537.0	126			537.0	126
	06	509.0	98			509.0	98
	07	493.0	82			493.0	82
	08	492.0	74			492.0	74
	09	491.0	68			491.0	68
	10	486.0	61			486.0	61
	11	446.0	47			446.0	47
4	08KA004						
	1983: May 29	822.0	117	822.0	117		
	30	1080.0	242	1080.0	242		
	31	1330.0	469	1330.0	469		
	Jun. 01	1430.0	515	1430.0	515		
	02	1380.0	493			1380.0	493
	03	1250.0	346			1250.0	346
	04	1100.0	256			1100.0	256
	05	980.0	194			980.0	194
	06	915.0	135			915.0	135
7	1972: May 26	824.0	31	824.0	31		
	27	824.0	33	824.0	33		
	28	881.0	40	881.0	40		
	29	981.0	50	981.0	50		
	30	1120.0	60	1120.0	60		
	31	1250.0	76	1250.0	76		
	32	1300.0	82	1300.0	82		
	33	1250.0	67			1250.0	67
	34	1180.0	59			1180.0	59
	35	1120.0	57			1120.0	57
	36	1080.0	54			1080.0	54
	37	1070.0	52			1070.0	52
8	08MC018						
	1979: Jun. 03	3560.0	299	3560.0	299		
	04	3850.0	341	3850.0	341		
	05	4390.0	531	4390.0	531		
	06	4890.0	706	4890.0	706		
	07	5410.0	970	5410.0	970		
	08	5320.0	789			5320.0	789

Event No.	Station & Date	Q(r) (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)
	09	4940.0	636			4940.0	636
	10	4190.0	448			4190.0	448
	11	3740.0	415			3740.0	415
9	08MF005						
	1967: 09	1280.0	28	1280.0	28		
	10	1570.0	181	1570.0	181		
	11	1510.0	160			1510.0	160
	12	1380.0	100			1380.0	100
	13	1290.0	65			1290.0	65
	14	1200.0	40			1200.0	40
	15	1180.0	21			1180.0	21
10	08MF005						
	1969: May 25	6030.0	202	6030.0	202		
	26	6170.0	272	6170.0	272		
	27	6460.0	359	6460.0	359		
	28	6770.0	428	6770.0	428		
	29	6940.0	450	6940.0	450		
	30	6770.0	395			6770.0	395
	Jun 01	6310.0	300			6310.0	300
	02	6060.0	215			6060.0	215
11	08MF005						
	1969: Aug. 12	3090.0	87	3090.0	87		
	13	3310.0	119	3310.0	119		
	14	3570.0	181	3570.0	181		
	15	3770.0	241	3770.0	241		
	16	3710.0	233			3710.0	233
	17	3540.0	186			3540.0	186
	18	3370.0	145			3370.0	145
	19	3260.0	118			3260.0	118
	20	3230.0	104			3230.0	104

Event No.	Station & Date	Q (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(f) (m^3/s)	C(f) (mg/L)
12	08MF005						
	1969: Nov. 21	1890.0	33	1890.0	33		
	22	1990.0	53	1990.0	53		
	23	2300.0	125	2300.0	125		
	24	2410.0	154	2410.0	154		
	25	2300.0	121			2300.0	121
	26	2200.0	90			2200.0	90
	27	2080.0	76			2080.0	76
	28	1990.0	62			1990.0	62
	29	1940.0	49			1940.0	49
	30	1840.0	36			1840.0	36
13	08MF005						
	1977: Oct. 31	1460.0	21	1460.0	21		
	Nov. 01	1660.0	122	1660.0	122		
	02	1820.0	168	1820.0	168		
	03	1600.0	91			1600.0	91
	04	1520.0	47			1520.0	47
	05	1460.0	40			1460.0	40
	06	1420.0	32			1420.0	32
	07	1400.0	23			1400.0	23
14	08MF009						
	1968: Dec. 01	8.9	4	8.9	4		
	02	10.1	5	10.1	5		
	03	55.2	16	55.2	16		
	04	47.9	16			47.9	16
	05	40.8	13			40.8	13
	06	26.3	10			26.3	10
	07	14.5	7			14.5	7
	08	11.4	5			11.4	5
	09	10.1	3			10.1	3
	10	10.1	4			10.1	4
	11	8.9	4			8.9	4

Event No.	Station & Date	Q (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(f) (m^3/s)	C(f) (mg/L)
15	08MF009						
	1969: Sep. 30	9.7	2	273.0	10		
	Oct. 01	10.9	7	274.0	11		
	02	21.1	32	275.0	21		
	03	13.5	13	276.0		13.5	13
	04	10.9	5	277.0		10.9	5
	05	10.3	4	278.0		10.3	4
	06	9.1	2	279.0		9.1	2
	07	9.1	2	280.0		9.1	2
16	08MF009						
	1969: Jun 01	26.1	27	26.1	27		
	02	41.9	65	41.9	65		
	03	48.7	89	48.7	89		
	04	40.8	76			40.8	76
	05	37.7	65			37.7	65
	06	34.5	59			34.5	59
	07	33.4	51			33.4	51
	08	30.3	45			30.3	45
	09	28.3	36			28.3	36
	10	25.1	22			25.1	22
17	08MF035						
	1968: Jan. 23	1990.0	136	1990.0	136		
	24	2480.0	190	2480.0	190		
	25	2430.0	194	2430.0	194		
	26	2570.0	201	2570.0	201		
	27	2940.0	241	2940.0	241		
	28	3200.0	313	3200.0	313		
	29	3200.0	320			3200.0	320
	30	2860.0	242			2860.0	242
	31	2500.0	170			2500.0	170
	Feb. 01	2180.0	124			2180.0	124
	02	2060.0	109			2060.0	109

Event No.	Station & Date	Q (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(f) (m^3/s)	C(f) (mg/L)
18	08MF035						
	1969: Aug.10	3000.0	41	3000.0	41		
	11	3090.0	41	3090.0	41		
	12	3140.0	50	3140.0	50		
	13	3280.0	81	3280.0	81		
	14	3540.0	127	3540.0	127		
	15	3710.0	161	3710.0	161		
	16	3740.0	166	3740.0	166		
	17	3600.0	144			3600.0	144
	18	3450.0	127			3450.0	127
	19	3340.0	104			3340.0	104
	20	3280.0	86			3280.0	86
	21	3280.0	98			3280.0	98
19	08MF035						
	1973: Jun. 08	5640.0	125	5640.0	125		
	09	6170.0	204	6170.0	204		
	10	6970.0	297	6970.0	297		
	11	7420.0	371	7420.0	371		
	12	7250.0	329			7250.0	329
	13	6770.0	252			6770.0	252
	14	6230.0	201			6230.0	201
	15	5720.0	165			5720.0	165
	16	5550.0	146			5550.0	146
20	08MF035						
	1973: Jun 24	6030.0	149	6030.0	149		
	25	6310.0	172	6310.0	172		
	26	6970.0	265	6970.0	265		
	27	7700.0	408	7700.0	408		
	28	8210.0	447	8210.0	447		
	29	8240.0	413	8240.0	413		
	30	7840.0	343			7840.0	343
	Jun. 01	7360.0	292			7360.0	292
	02	6970.0	235			6970.0	235
	03	6480.0	196			6480.0	196
	04	6060.0	197			6060.0	197

Event No.	Station & Date	Q (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(f) (m^3/s)	C(f) (mg/L)
21	08MF035						
	1986: Feb. 22	715.0	6	715.0	6		
	23	726.0	7	726.0	7		
	24	1390.0	107	1390.0	107		
	25	2290.0	359	2290.0	359		
	26	1860.0	249			1860.0	249
	27	1420.0	171			1420.0	171
	28	1240.0	116			1240.0	116
	Mar. 01	1210.0	79			1210.0	79
	02	1120.0	61			1120.0	61
	03	1100.0	52			1100.0	52
	04	1110.0	49			1110.0	49
	05	1110.0	50			1110.0	50
22	08MF035						
	1986: Jan. 16	874.0	7	874.0	7		
	17	914.0	6	914.0	6		
	18	1320.0	92	1320.0	92		
	19	1790.0	331	1790.0	331		
	20	1250.0	143			1250.0	143
	21	1090.0	39			1090.0	39
	22	1030.0	20			1030.0	20
	23	1010.0	14			1010.0	14
	24	969.0	12			969.0	12
23	08MG013						
	1970: Mar. 12	107.0	5	107.0	5		
	13	112.0	6	112.0	6		
	14	118.0	9	118.0	9		
	15	124.0	12	124.0	12		
	16	129.0	16	129.0	16		
	17	136.0	19	136.0	19		
	18	136.0	20			136.0	20
	19	136.0	20			136.0	20
	20	133.0	20			133.0	20
	21	131.0	18			131.0	18
	22	129.0	17			129.0	17
	23	125.0	15			125.0	15

Event No.	Station & Date	Q (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(f) (m^3/s)	C(f) (mg/L)
24	08MG013						
	1970: Jun. 01	549.0	3	549.0	3		
	02	572.0	3	572.0	3		
	03	629.0	6	629.0	6		
	04	702.0	11	702.0	11		
	05	773.0	16	773.0	16		
	06	867.0	21	867.0	21		
	07	813.0	14			813.0	14
	08	651.0	5			651.0	5
	09	606.0	4			606.0	4

APPENDIX 2

Discharge (Q) and sediment concentration (C) data in the rising (r) and falling (f) stages of some hysteretic events in the Fraser River basin.

Event No.	Station	Date	Q (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)
CIOCKWISE EVENTS								
50	08KA004: 1972							
		May 09	510.0	140	963.0	535		
		10	603.0	251	1330.0	933		
		11	697.0	333	1630.0	902		
		12	801.0	446			801.0	446
		13	963.0	535			963.0	535
		14	1330.0	933			1330.0	933
		15	1630.0	902			1630.0	902
		16	1460.0	534			1460.0	534
		17	1230.0	524			1230.0	524
		18	1130.0	310			1130.0	310
		19	1040.0	325			1040.0	325
51	08KA004: 1972							
		May 21	1160.0	362	1160.0	362		
		22	1540.0	571	1540.0	571		
		23	1880.0	693	1880.0	693		
		24	1830.0	610			1830.0	610
		25	1540.0	392			1540.0	392
		26	1340.0	425			1340.0	425
		27	1250.0	410			1250.0	410
52	08KA004: 1972							
		May 29	1610.0	357	1610.0	357		
		30	2000.0	594	2000.0	594		
		31	2400.0	920	2400.0	920		
		01	2630.0	889	2630.0	889		
		02	2650.0	717	2650.0	717		
		03	2390.0	634			2390.0	634
		04	2020.0	495			2020.0	495
		05	1810.0	530			1810.0	530

Event No.	Station	Date	Q (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)
53	08KA004: 1972							
		Jun 08	2060.0	274	2060.0	274		
		9	2180.0	347	2180.0	347		
		10	2370.0	426	2370.0	426		
		11	2550.0	449	2550.0	449		
		12	2760.0	407	2760.0	407		
		13	3030.0	404	3030.0	404		
		14	3170.0	329	3170.0	329		
		15	3030.0	261			3030.0	261
		16	2700.0	285			2700.0	285
		17	2390.0	328			2390.0	328
		18	2180.0	320			2180.0	320
54	08KA004: 1973							
		May 14	459.0	138	459.0	138		
		15	660.0	342	660.0	342		
		16	968.0	810	968.0	810		
		17	1300.0	910	1300.0	910		
		18	1540.0	981	1540.0	981		
		19	1620.0	848	1620.0	848		
		20	1500.0	673			1500.0	673
		21	1330.0	511			1330.0	511
		22	1190.0	462			1190.0	462
55	08KA004: 1973							
		June 05	767.0	147	767.0	147		
		06	912.0	181	912.0	181		
		07	1340.0	546	1340.0	546		
		08	1830.0	1250	1830.0	1250		
		09	1870.0	682	1870.0	682		
		10	1590.0	440			1590.0	440
		11	1300.0	293			1300.0	293
		12	1080.0	257			1080.0	257
		13	980.0	200			980.0	200

Event No.	Station	Date	Q (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)
59	08KA004:	1976						
		Aug. 16	855.0	92	855.0	92		
		17	909.0	440	909.0	440		
		18	1360.0	1650	1360.0	1650		
		19	1370.0	556	1370.0	556		
		20	1170.0	181			1170.0	181
		21	1230.0	123			1230.0	123
		22	1210.0	144			1210.0	144
		23	1040.0	91			1040.0	91
		24	912.0	74			912.0	74
		25	821.0	72			821.0	72
60	08KA004:	1977						
		Jun 04	113.0	24	113.0	24		
		05	122.0	31	122.0	31		
		06	142.0	54	142.0	54		
		07	207.0	127	207.0	127		
		08	311.0	232	311.0	232		
		09	623.0	317	623.0	317		
		10	566.0	327			566.0	327
		11	515.0	296			515.0	296
		12	479.0	248			479.0	248
		13	436.0	186			436.0	186
		14	371.0	133			371.0	133
		15	331.0	109			331.0	109
		16	314.0	91			314.0	91
		17	292.0	73			292.0	73
		18	270.0	55			270.0	55
		19	249.0	39			249.0	39
		20	233.0	28			233.0	28
		21	226.0	19			226.0	19
	ANTICLOCKWISE	EVENTS						
139	08KA004:	1976						
		Aug. 06	1180.0	163	1180.0	163		
		07	1220.0	178	1220.0	178		
		08	1290.0	621	1290.0	621		
		09	1270.0	1020			1270.0	1020
		10	1220.0	423			1220.0	423
		11	1110.0	142			1110.0	142

Event No.	Station	Date	Q (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)
56	08KA004:	1973						
		Jun 21	1110.0	160	1110.0	160		
		22	1200.0	193	1200.0	193		
		23	1440.0	293	1440.0	293		
		24	1780.0	524	1780.0	524		
		25	2110.0	851	2110.0	851		
		26	2180.0	695	2180.0	695		
		27	2040.0	503			2040.0	503
		28	1830.0	417			1830.0	417
		29	1670.0	375			1670.0	375
		30	1520.0	307			1520.0	307
		1	1340.0	277			1340.0	277
		2	1160.0	252			1160.0	252
57	08 KA004:	1974						
		May 24	782.0	128	782.0	128		
		25	881.0	181	881.0	181		
		26	988.0	248	988.0	248		
		27	1170.0	318	1170.0	318		
		28	1170.0	333			1170.0	333
		29	1030.0	230			1030.0	230
		30	900.0	146			900.0	146
		31	818.0	100			818.0	100
		Jun 01	779.0	85			779.0	85
58	08KA004:	1976						
		May 09	1030.0	224	1030.0	224		
		10	1220.0	313	1220.0	313		
		11	1420.0	399	1420.0	399		
		12	1670.0	518	1670.0	518		
		13	1560.0	192			1560.0	192
		14	1440.0	214			1440.0	214
		15	1290.0	289			1290.0	289
		16	1100.0	212			1100.0	212
		17	1030.0	176			1030.0	176

Event No.	Station	Date	Q (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)
140	08KA004:	1984						
		06	434.0	85	526.0	145		
		07	526.0	145	752.0	302		
		08	752.0	302	796.0	530		
		09	796.0	530			796.0	530
		10	667.0	355			667.0	355
		11	557.0	238			557.0	238
		12	498.0	108			498.0	108
		13	407.0	83			407.0	83
142	08MC018:	1976						
		Jul 01	4020.0	373	4020.0	373		
		02	4420.0	383	4420.0	383		
		03	4670.0	406	4670.0	406		
		04	5240.0	482	5240.0	482		
		05	4980.0	520			4980.0	520
		06	4760.0	492			4760.0	492
		07	4730.0	457			4730.0	457
		08	4670.0	425			4670.0	425
		09	4640.0	388			4640.0	388
		10	4670.0	352			4670.0	352
		11	4670.0	317			4670.0	317
		12	4560.0	278			4560.0	278
		13	4300.0	238			4300.0	238
		14	4110.0	202			4110.0	202
		15	3960.0	173			3960.0	173
146	08MF005:	1970						
		02	5150.0	195	5150.0	195		
		03	5490.0	203	5490.0	203		
		04	5830.0	221	5830.0	221		
		05	6480.0	375	6480.0	375		
		06	7480.0	644	7480.0	644		
		07	8300.0	826	8300.0	826		
		08	8670.0	836	8670.0	836		
		09	8580.0	678			8580.0	678
		10	8180.0	507			8180.0	507
		11	7960.0	441			7960.0	441
		12	7590.0	399			7590.0	399

Event No.	Station	Date	Q (m^3/s)	C (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)	Q(r) (m^3/s)	C(r) (mg/L)
		13	7280.0	348			7280.0	348
		14	6880.0	311			6880.0	311
		15	6370.0	273			6370.0	273
		16	5830.0	235			5830.0	235
		17	5690.0	206			5690.0	206
149	08MF009:	1968						
		Sep.13	3.2	4	3.2	4		
		14	3.2	6	3.2	6		
		15	6.7	34	6.7	34		
		16	6.2	71			6.2	71
		17	5.8	59			5.8	59
		18	4.5	37			4.5	37
		19	4.5	20			4.5	20
		20	3.8	8			3.8	8
		21	3.2	4			3.2	4
155	08MF035:	1979						
		Jun 05	6250.0	255	6250.0	255		
		06	6920.0	201	6920.0	201		
		07	7480.0	196	7480.0	196		
		08	8010.0	230	8010.0	230		
		09	8430.0	330	8430.0	330		
		10	8080.0	329			8080.0	329
		11	7150.0	306			7150.0	306
		12	6490.0	277			6490.0	277
		13	6180.0	241			6180.0	241

APPENDIX 3

Data for hydrological factors controlling rising mean sediment concentration (Cr): discharge for day preceding event (Qpr), mean rising discharge (Qr), and index for flood intensity (IFI), and for falling mean sediment concentration (Cf): mean falling discharge (Qf) and index of flood recession (IFR) for single-valued hydrological events in the Fraser River basin.

Event No.	Station	Period	Qpr (m^3/s)	Qr (m^3/s)	Cr (mg/L)	Qf (m^3/s)	Cf (mg/L)	IFI	IFR
	LINEAR								
1	08KA004	27.09.73-12.1073	262.000	703.000	345.000	517.000	166.000	209.500	64.333
2	08KA004	02.06.74-09.06.74	779.000	1063.330	195.333	1021.200	158.000	150.333	56.200
3	08KA004	29.09.80-11.10.80	464.000	612.000	164.000	523.000	103.000	79.750	37.444
4	08KA004	29.05.83-06.06.83	785.000	1166.000	336.000	1125.000	285.000	161.250	103.000
5	08KA004	09.06.83-14.06.83	1050.000	1103.333	181.000	1003.667	131.667	50.000	97.667
6	08KA004	17.06.83-24.06.83	848.000	1087.600	123.600	974.000	95.000	88.400	129.667
7	08LA001	26.05.72-12.10.72	852.000	1026.000	53.000	1140.000	58.000	64.000	46.000
8	08MC018	03.06.79-11.06.79	3490.000	4420.000	569.000	4548.000	572.000	384.000	417.500
9	08MF005	09.12.67-15.12.67	1330.000	1425.000	105.000	1312.000	77.000	120.000	78.000
10	08MF005	25.05.69-01.06.69	5830.000	6470.000	342.000	6380.000	303.000	222.000	293.333
11	08MF005	12.08.69-20.08.69	3030.000	3435.000	157.000	3422.000	157.000	185.000	108.000
12	08MF005	21.11.69-01.12.69	1950.000	2148.000	91.000	2058.000	72.000	115.000	95.000
13	08MF005	31.10.77-06.11.77	1480.000	1647.000	104.000	1480.000	47.000	113.333	84.000
14	08MF009	01.12.68-11.12.68	9.490	24.730	8.000	21.250	8.000	15.237	5.789
15	08MF009	30.09.69-07.10.69	7.390	13.887	14.000	10.560	5.000	4.537	2.388
16	08MF009	01.06.70-10.06.70	25.500	38.900	60.000	32.870	51.000	7.733	3.371
17	08MF035	18.01.68-02.02.68	1540.000	2318.000	175.000	2119.000	130.000	150.909	183.750
18	08MFO35	10.08.69-21.08.69	2940.000	3357.000	95.000	3390.000	112.000	114.286	92.000
19	08MF035	08.06.73-16.06.73	5520.000	6550.000	249.000	6304.000	219.000	475.000	374.000
20	08MF035	24.06.73-04.07.73	6000.000	7243.000	309.000	6942.000	253.000	373.333	436.000
21	08MF035	16.01.86-24.01.86	876.000	1225.000	109.000	1070.000	46.000	228.500	164.200
22	08MF035	22.03.86-05.03.86	722.000	1280.000	120.000	1271.000	103.000	392.000	147.500

Event No.	Station	Period	Qpr (m^3/s)	Qr (m^3/s)	Cr (mg/L)	Qf (m^3/s)	Cf (mg/L)	IFI	IFR
23	08MG013	01.01.70-09.01.70	549.000	682.000	10.000	690.000	8.000	53.000	87.000
24	08MG013	12.03.70-12.03.70	108.000	121.000	11.000	132.000	18.000	4.667	1.833
25	08MH001	12.01.68-18.01.68	45.000	125.170	54.000	143.000	63.000	59.000	29.000
26	08MH001	19.01.68-23.01.68	118.000	220.000	127.000	216.000	144.000	57.000	39.667
27	08MH001	01.02.68-09.02.68	86.700	90.850	15.000	80.140	11.000	8.575	10.220
28	08MH001	30.05.70-12.06.70	87.200	148.200	51.000	147.000	57.000	20.967	15.613
29	08MH001	19.01.72-29.01.72	26.500	74.700	30.000	53.550	17.000	29.500	9.812
30	08MH001	30.05.75-11.06.75	119.000	216.000	122.000	175.000	86.000	21.000	21.333
31	08MH024	09.08.69-20.08.69	3540.000	3873.000	94.000	4075.000	114.000	106.250	120.000
	CONCAVE								
32	08KA004	27.03.81-07.04.81	157.000	192.000	44.000	197.000	50.000	14.400	9.857
33	08KA004	23.04.81-29.04.81	246.000	422.000	354.000	422.000	354.000	106.333	49.750
34	08MC018	07.06.77-15.06.77	2890.000	3550.000	507.000	3473.000	308.000	282.000	255.000
35	08MF005	16.01.77-28.01.77	1100.000	1447.000	95.000	1346.000	32.000	270.000	69.000
36	08MF035	30.10.73-05.11.73	2860.000	3550.000	302.000	3367.000	220.000	416.667	390.000
37	08MF035	03.09.82-22.09.82	3270.000	4029.000	180.000	4093.000	177.000	264.545	336.667
38	08MFO35	03.01.84-10.01.84	1000.000	2010.000	715.000	1720.000	318.000	935.000	246.667
39	08MH001	22.09.65-30.09.65	20.100	28.050	85.000	25.000	40.000	7.225	5.500
*40	08MH001	30.11.75-07.12.75	79.600	3000.000	1940.000	268.000	800.000	112.600	78.000
41	08MH024	15.05.71-21.05.71	7760.000	8033.000	472.000	7390.000	331.000	180.000	412.500
42	08MH024	20.03.72-31.03.72	2770.000	3018.000	232.000	2024.000	254.000	242.500	142.500
43	08MH024	06.06.73-16.06.73	5920.000	6843.000	199.000	7018.000	203.000	278.571	352.500
44	08MH024	12.06.87-23.06.87	6930.000	7786.000	243.000	7530.000	218.000	314.000	220.000

Event No.	Station	Period	Qpr (m^3/s)	Qr (m^3/s)	Cr (mg/L)	Qf (m^3/s)	Cf (mg/L)	IFI	IFR
	CONVEX								
45	08MF009	10.12.66-28.12.66	12.900	43.200	31.000	31.800	24.000	9.789	8.490
46	08MH001	26.10.67-06.11.67	83.800	156.000	83.000	132.000	70.000	42.700	42.750
47	08MH001	23.01.68-28.01.68	203.000	247.000	131.000	155.000	57.000	60.000	51.500
48	08MH001	31.05.68-10.06.68	112.000	236.667	73.000	180.125	63.625	679.667	37.250
49	08MH024	14.05.88-24.05.88	6060.000	7358.000	446.000	7115.000	455.000	398.000	240.000

* Anomalous event not included in the analysis.

APPENDIX 4

Data for hydrological factors controlling rising mean sediment concentration in (Cr): discharge for day preceding event (Qpr), mean rising discharge (Qr), and index for flood intensity (IFI), and for falling mean sediment concentration (Cf): mean falling discharge (Qf) and index of flood recession (IFR) for clockwise and anticlockwise hysteretic hydrological events in the Fraser River basin.

Event No.	Station	Period	Qpr (m^3/s)	Qr (m^3/s)	Cr (mg/L)	Qf (m^3/s)	Cf (mg/L)	IFI	IFR
CLOCKWISE EVENTS									
50	08KA004	09.05.72-19.05.72	476.000	933.429	505.714	1215.000	423.250	164.857	147.500
51	08KA004	21.05.72-27.05.72	1010.000	1526.667	542.000	1490.000	459.250	290.000	157.500
52	08KA004	29.05.72-05.06.72	1350.000	2258.000	695.400	2073.333	553.000	260.000	280.000
53	08KA004	08.06.72-18.06.72	2000.000	2588.571	376.571	2575.000	298.500	167.143	247.500
54	08KA004	14.05.73-22.05.73	391.000	109.670	671.500	1340.000	548.667	204.833	143.333
55	08KA004	05.06.73-13.06.73	762.000	1343.800	561.200	1237.500	297.500	221.600	222.500
56	08KA004	21.06.73-02.07.73	1070.000	1636.667	452.667	1593.333	355.167	185.000	170.000
57	08KA004	24.05.74-01.06.74	643.000	955.250	218.750	939.400	178.800	131.750	78.200
58	08KA004	09.05.76-17.05.76	932.000	1335.000	363.500	1280.000	216.600	184.500	128.000
59	08KA004	16.08.76-25.08.76	917.000	1123.500	684.500	1063.833	114.167	113.250	91.500
60	08KA004	05.04.77-21.04.77	110.000	253.000	130.833	356.833	133.667	85.500	29.417
61	08KA004	06.06.77-13.06.77	824.000	1282.750	415.000	1352.500	267.750	251.500	192.500
62	08KA004	24.05.79-01.06.79	793.000	1255.167	363.167	1086.667	218.000	161.167	256.667
63	08KA004	03.06.79-10.06.79	990.000	1830.000	357.667	1543.333	225.667	233.333	373.333
64	08KA004	27.06.79-04.07.79	1270.000	1583.333	205.333	1370.000	190.500	108.333	360.000
65	08KA004	13.02.80-23.02.80	190.000	418.667	192.667	499.800	191.400	70.833	40.000
66	08KA004	15.04.80-23.04.80	283.000	500.500	259.500	499.800	191.400	83.000	40.000
67	08KA004	25.04.80-06.05.80	427.000	740.833	305.500	1070.800	316.800	132.167	46.000
68	08KA004	15.12.80-25.12.80	132.000	501.750	109.250	537.143	66.571	267.000	134.286
69	08KA004	30.05.82-09.06.82	1050.000	1504.286	406.857	1435.000	243.250	115.714	180.000
70	08KA004	11.06.82-18.06.82	1160.000	1748.000	370.200	2030.000	305.000	190.000	53.333
71	08KA004	19.06.82-25.06.82	1950.000	2062.500	281.500	2020.000	224.667	55.000	96.667
72	08KA004	30.07.82-09.08.82	955.000	1203.000	332.167	1099.400	199.400	95.833	128.400
73	08KA004	04.09.82-20.09.82	531.000	968.429	419.857	891.600	183.300	192.714	136.600
74	08KA004	08.06.84-21.06.84	815.000	1341.875	331.250	1359.833	288.000	114.375	130.167

Event No.	Station	Period	Qpr (m^3/s)	Qr (m^3/s)	Cr (mg/L)	Qf (m^3/s)	Cf (mg/L)	IFI	IFR
75	08KA004	05.07.84-11.07.84	1370.000	1646.667	256.000	1447.500	150.750	170.000	147.500
76	08KA004	02.05.85-13.05.85	242.000	428.750	198.250	479.750	123.500	86.500	18.875
77	08LA001	07.06.72-16.06.72	52.000	1263.333	77.667	1157.500	54.500	234.667	100.000
78	08MC018	05.06.72-22.06.72	5490.000	5435.333	398.083	5323.333	358.000	85.000	340.000
79	08MC018	28.04.76-26.05.76	2150.000	4338.125	1141.313	4433.846	344.769	237.500	166.154
80	08MC018	20.05.78-30.05.78	1970.000	2240.000	327.400	2281.667	215.500	130.000	71.667
81	08MC018	04.06.78-18.06.78	2000.000	2830.000	563.000	2697.000	235.700	256.000	97.000
82	08MCO18	24.06.80-03.07.80	2470.000	2605.000	215.833	2627.500	120.000	98.333	180.000
83	08MC018	13.12.80-23.12.80	425.000	817.000	93.286	1222.750	48.250	295.000	374.750
84	08MC018	31.05.82-11.06.82	3620.000	4105.000	387.333	4003.333	252.167	180.000	205.000
85	08MC018	04.04.83-16.04.83	632.000	847.667	369.833	874.143	159.714	91.333	67.714
86	08MC018	30.05.83-07.06.83	2100.000	2648.000	586.200	2540.000	250.000	178.000	177.500
87	08MC018	17.06.83-29.06.83	2250.000	2638.333	252.000	2558.571	183.571	161.667	137.143
88	08MC018	02.06.85-08.06.85	4220.000	4354.000	450.000	4350.000	384.500	54.000	120.000
89	08MF005	29.10.67-10.11.67	2120.000	2233.333	254.667	2264.444	229.667	236.667	108.889
90	08MF005	11.05.69-19.05.69	4420.000	5250.000	301.400	5590.000	279.750	288.000	135.000
91	08MF005	22.05.69-01.06.69	5380.000	6160.000	268.500	6380.000	303.333	195.000	293.333
92	08MF005	04.06.69-18.06.69	6140.000	7062.857	265.429	7033.636	207.909	240.000	162.727
93	08MF005	12.06.74-12.07.74	6800.000	8809.000	350.000	8881.429	214.571	400.000	177.143
94	08MF005	12.05.75-27.05.75	3450.000	4848.000	550.000	4772.727	197.364	432.000	134.545
95	08MF005	06.04.77-22.04.77	1020.000	1981.111	393.667	2556.250	227.250	216.667	111.250
96	08MF005	23.04.77-05.05.77	4640.000	3358.750	470.625	4858.000	425.600	63.750	614.000
97	08MF005	02.06.78-17.06.78	4620.000	5823.750	261.625	6163.750	185.750	293.750	163.750
98	08MF009	19.10.66-04.11.66	3.820	32.600	11.000	27.092	7.167	13.056	4.750
99	08MF009	09.12.66-30.12.66	12.100	40.190	28.800	28.177	20.923	8.890	6.531
100	08MF035	20.02.68-28.02.68	1360.000	1616.000	29.800	1602.500	26.250	116.000	97.500
101	08MF035	29.02.68-22.03.68	1550.000	2035.385	122.769	2015.000	89.100	72.308	68.000
102	08MF035	15.05.70-24.05.70	3140.000	4180.000	465.000	4727.500	328.250	368.333	225.000

Event No.	Station	Period	Qpr (m^3/s)	Qr (m^3/s)	Cr (mg/L)	Qf (m^3/s)	Cf (mg/L)	IFI	IFR
103	08MF035	03.06.70-17.06.70	5380.000	7136.667	519.333	7197.778	405.111	556.667	326.667
104	08MF035	21.03.72-31.03.72	1870.000	2726.667	259.667	2487.500	209.000	613.333	182.500
105	08MF035	25.06.73-03.07.73	2750.000	7486.000	341.000	7162.500	266.500	1098.000	440.000
106	08MF035	16.05.73-03.07.73	4020.000	5906.667	534.333	6790.000	380.500	523.333	102.000
107	08MF035	11.06.74-12.07.74	6970.000	9009.091	457.182	9190.476	277.095	393.636	197.143
108	08MF035	04.05.75-26.05.75	2170.000	3476.923	470.615	4848.000	267.300	264.615	145.000
109	08MF035	21.04.79-17.05.79	1190.000	2760.556	633.389	4270.000	452.444	208.889	113.333
110	08MF035	17.06.80-25.06.80	4770.000	5310.000	272.167	5136.667	287.667	210.000	413.333
111	08MF035	12.06.84-19.06.84	5760.000	7436.667	542.000	7308.571	347.286	415.000	270.000
112	08MF035	25.06.84-07.07.84	6360.000	7530.000	290.556	7732.500	253.500	220.000	317.500
113	08MF035	06.04.85-26.04.85	1080.000	2022.143	365.714	2747.143	234.429	150.000	117.143
114	08MF035	03.05.85-15.05.85	2190.000	2915.000	229.500	3550.000	192.000	245.000	25.714
115	08MF035	15.05.85-15.06.85	3510.000	6742.857	511.786	8760.000	263.778	485.000	190.000
116	08MG013	12.12.66-31.12.66	368.000	753.625	16.750	689.500	13.667	82.750	50.667
117	08MG013	01.06.70-08.06.70	549.000	708.600	11.400	690.000	7.667	63.600	87.000
118	08MH001	03.01.69-17.01.69	34.800	93.267	40.000	62.075	13.167	45.067	10.725
119	08MH001	29.03.69-09.04.69	39.400	50.900	54.750	57.162	36.875	8.050	2.725
120	08MH024	25.04.69-06.05.69	58.000	129.257	50.000	181.167	61.833	20.857	9.667
121	08MH001	26.05.72-03.06.72	163.000	251.600	174.600	260.750	129.500	37.000	28.500
122	08MH001	11.06.74-23.06.74	195.000	317.333	250.000	309.250	155.750	18.556	21.750
123	08MH024	02.06.69-24.06.69	7760.000	8487.500	247.875	8877.333	225.467	230.000	122.667
124	08MH024	15.05.70-24.06.70	3340.000	4231.667	331.667	5052.500	311.250	391.667	197.500
125	08MH024	01.06.70-17.06.70	5830.000	7568.889	370.667	8130.000	360.375	415.556	340.000
126	08MH024	13.05.72-20.05.72	5210.000	13760.000	465.400	13366.667	421.000	754.000	133.000
127	08MH024	24.06.73-07.07.73	6630.000	7840.000	279.000	7476.250	218.375	391.667	326.250
128	08MH024	06.05.74-15.05.74	6260.000	7008.333	437.667	6902.500	332.750	211.667	297.500
129	08MH024	13.06.74-14.07.74	7900.000	10532.222	468.333	10370.455	283.091	577.778	216.818
130	08MH024	01.02.75-08.02.75	2130.000	2565.000	175.000	2230.000	51.750	225.000	270.000

Event No.	Station	Period	Qpr (m^3/s)	Qr (m^3/s)	Cr (mg/L)	Qf (m^3/s)	Cf (mg/L)	IFI	IFR
131	08MH024	09.04.77-23.04.77	1670.000	2628.571	302.000	2835.000	158.500	227.143	107.500
132	08MH024	05.06.78-20.06.78	5380.000	6960.000	375.500	6637.000	310.400	391.667	167.000
133	08MH024	17.06.80-27 06.80	5570.000	6110.000	361.833	5926.000	176.200	181.667	218.000
134	08MH024	25.12.80-07.01.81	3800.000	5185.000	630.750	4392.727	97.091	1012.500	472.000
135	08MH024	11.06.82-05.07.82	8380.000	9726.364	367.455	10658.750	320.875	247.273	251.250
136	08MH024	07.09.82-20.09.82	4000.000	5053.750	253.000	4848.333	144.500	296.250	401.667
137	08MH024	14.04.85-26.04.85	2590.000	3270.000	338.167	3162.857	198.000	163.333	112.857
138	08MH024	24.05.86-25.07.86	4640.000	8530.000	621.500	7883.137	206.608	646.667	137.059
ANTICLOCKWISE EVENTS									
139	08KA004	06.08.76-11.08.76	1180.000	1230.000	320.667	1200.000	528.333	36.667	60.000
140	08KA004	06.08.84-13.08.84	444.000	627.000	265.500	532.250	196.000	88.000	97.250
141	08KA004	20.09.85-27.09.85	440.000	547.333	148.667	481.800	101.000	74.000	46.000
142	08MC018	01.07.76-15.07.76	3990.000	4587.500	411.000	4550.000	349.273	312.500	116.364
143	08MC018	24.12.80-06.01.81	991.000	1222.750	50.000	1182.000	50.700	127.250	49.000
144	08MC018	27.08.84-03.08.84	1290.000	1550.000	108.500	1537.500	129.000	127.500	102.500
145	08MC018	08.09.84-18.09.84	1440.000	2185.000	187.250	1700.000	134.000	287.500	192.857
146	08MF005	02.06.70-17.06.70	5040.000	5771.429	471.429	7151.111	377.556	518.571	331.111
147	08MF005	15.06.71-21.06.71	7960.000	7816.667	207.333	7687.500	289.500	83.333	232.500
148	08MF009	26.10.67-07.11.67	17.000	77.967	17.667	58.843	19.571	31.833	27.414
149	08MF009	13.09.68-21.09.68	3.170	4.340	14.667	4.662	33.167	1.170	0.585
150	08MF009	30.05.70-10.06.70	24.000	33.460	44.600	32.871	50.571	4.940	3.371
151	08MF009	15.11.70-23.11.70	5.890	10.263	15.330	8.807	15.833	2.603	1.302
152	08MF035	17.06.67-28.06.67	10000.000	10666.667	281.500	10800.000	318.000	200.000	166.667
153	08MF035	27.05.79-04.06.79	4770.000	6330.000	559.200	6047.500	591.000	436.000	267.500
154	08MF035	24.05.79-31.05.79	4260.000	5191.667	361.667	5865.000	454.500	351.667	245.000

Event No.	Station	Period	Qpr (m^3/s)	Qr (m^3/s)	Cr (mg/L)	Qf (m^3/s)	Cf (mg/L)	IFI	IFR
155	08MF035	05.06.79-13.06.79	6920.000	7418.000	242.400	6975.000	288.250	302.000	562.500
156	08MG013	13.06.70-03.07.70	827.000	918.417	13.333	940.889	17.333	5.500	3.846
157	08MG013	20.10.70-07.11.70	120.000	138.500	6.500	124.693	7.385	5.500	3.846
158	08MH001	08.06.69-18.06.69	146.000	203.143	64.429	186.250	73.000	17.857	29.250
159	08MH001	19.01.70-02.02.70	36.800	63.580	11.000	53.980	12.400	8.320	5.340
160	08MH001	29.01.71-09.02.71	80.100	234.330	135.667	125.244	94.778	92.300	31.678
161	08MH001	10.05.71-18.05.71	173.000	200.000	74.000	149.000	47.000	19.000	27.400
162	08MH001	24.05.71-31.05.71	126.000	178.833	37.667	171.500	46.500	13.333	24.000
163	08MH001	05.06.72-15.06.72	243.000	293.800	99.600	244.000	86.000	23.400	30.167
164	08MH001	11.07.72-23.07.72	156.000	250.333	38.667	189.200	25.700	51.667	16.400
165	08MH001	23.12.72-31.12.72	169.000	159.500	62.000	110.860	62.800	13.250	28.140
166	08MH024	17.06.67-03.07.67	11300.000	12316.667	271.833	12381.818	352.364	366.667	209.091
167	08MH024	29.09.73-13.10.73	1890.000	2632.000	108.200	2481.000	115.600	278.000	126.000
168	08MH024	05.07.75-19.07.75	7140.000	8393.750	117.625	8107.143	136.143	251.250	271.429
169	08MH024	21.05.78-30.05.78	4730.000	5455.000	268.833	5407.500	262.750	178.333	175.000
170	08MH024	07.04.83-16.04.83	1950.000	2110.000	68.200	2128.000	123.400	88.000	78.000
171	08MH024	12.06.87-23.06.87	6930.000	7905.000	291.167	7530.000	218.333	261.667	256.667
172	08MH024	30.10.87-11.11.87	1120.000	1434.000	9.200	1660.000	79.125	204.000	87.500

APPENDIX 5A

Channel hydraulic data: discharge (Q), stream-bed elevation (Be) and moving averaged stream-bed elevations (5 points) on rising and falling (f) stages of single hydrological events on the Fraser River at Red Pass station (1960-1981).

No.	Date	Discharge ($m^3 s^{-1}$)	Be (m)	Be (r) (m)	Be (f) (m)	Be (r) Moving av. (5)	Be (f) Moving av. (5)
1	25.02.60	5.235	-0.054		-0.054		-0.088
2	02.06.60	59.713	-1.399	-1.399		-1.220	
3	21.07.60	182.818	-3.592		-3.592		-3.638
4	04.08.60	115.747	-2.517		-2.517		-2.667
5	09.11.60	22.838	-0.536		-0.536		-0.880
6	08.02.61	7.188	-0.139		-0.139		-0.176
7	11.04.61	6.085	0.096	0.096		0.086	
8	28.06.61	108.672	-2.560		-2.560		-2.530
9	21.11.61	12.509	-0.204		-0.204		-0.280
10	15.03.62	4.698	0.311		0.311		
11	17.07.62	128.482	-2.835	-2.835		-2.818	
12	19.09.62	32.828	-0.947		-0.947		-1.177
13	22.01.63	7.499	-0.341		-0.341		-0.299
14	18.04.63	8.547	-0.281	-0.281		-0.584	
15	06.06.63	146.311	-3.044	-3.044		-3.194	
16	14.01.64	7.839	-0.274		-0.274		-0.223
17	22.04.64	6.566	0.355	0.355		0.092	
18	18.06.64	241.116	-3.604		-3.604		
19	19.08.64	74.146	-1.731		-1.731		-2.114
20	18.11.64	19.244	-0.442		-0.442		-0.397
21	26.01.65	6.764	0.343		0.343		-0.271
22	16.06.65	159.329	-3.228		-3.228		-3.535
23	17.08.65	80.938	-1.866		-1.866		-2.200
24	23.02.66	5.207	-0.172		-0.172		-0.130
25	10.05.66	77.259	-1.787	-1.787		-1.686	
26	21.06.66	159.329	-3.109	-3.109			
27	04.10.66	42.903	-1.138		-1.138		-1.648
28	24.01.67	8.547	-0.641	-0.641		-0.376	
29	28.02.67	6.735	-0.361	-0.361		-0.145	
30	12.10.67	51.789	-1.387		-1.387		-1.806
31	18.01.68	8.575	-0.141	-0.141		-0.850	
32	21.03.68	7.103	-0.456	-0.456		-0.420	
33	21.01.69	6.934	-0.578		-0.578		-0.184
34	06.03.69	5.292	-0.499		-0.499		-0.092
35	27.05.69	153.103	-3.091		-3.091		-3.276
36	07.08.69	153.386	-3.856		-3.856		-3.355
37	03.02.70	6.283	-0.940		-0.940		-0.654
38	17.09.70	18.282	-0.347		-0.347		-0.289

39	11.12.70	7.047	-0.361	-0.361		-0.293	
45	20.03.73	4.924	0.733	0.733			
46	10.07.73	107.823	-2.688		-2.688		-2.272
47	23.01.75	6.367	-0.780		-0.780		-0.304
48	18.03.75	4.556	-0.394	-0.394			
49	07.07.75	221.589	-4.371	-4.371			
50	25.08.75	82.636	-2.494	-2.494		-2.225	
51	22.09.75	37.922	-1.800		-1.800		-1.560
52	27.10.75	21.678	-0.674		-0.674		-0.584
53	02.03.77	5.320	0.218		0.218		-0.044
54	31.08.77	69.618	-2.285		-2.285		-2.004
55	12.10.77	19.668	-0.319		-0.319		-0.464
56	04.10.78	6.113	-1.405		-1.405		-0.425
57	28.02.78	4.896	0.011		0.011		0.065
58	07.04.78	5.349	0.046		0.046		-0.015
59	14.06.78	138.387	-3.198		-3.198		-2.973
60	26.07.78	110.087	-2.610	-2.610		-2.554	
61	26.10.78	36.790	-1.926		-1.926		-1.269
62	20.12.78	10.754	-0.132		-0.132		-0.224
63	07.02.79	6.028	0.070		0.070		-0.196
64	04.04.79	5.037	0.065		0.065		0.032
65	05.07.79	124.237	-2.553		-2.553		-2.858
66	29.08.79	72.165	-2.157		-2.157		-2.023
67	24.10.79	7.584	-0.166		-0.166		-0.210
68	16.01.80	6.169	0.061		0.061		-0.594
69	09.04.80	4.132	0.112		0.112		
70	21.05.80	118.294	-3.017		-3.017		-2.769
71	24.06.80	144.047	-3.005		-3.005		-3.141
72	28.08.80	50.940	-1.989		-1.989		-1.720
73	08.10.80	69.618	-2.230		-2.230		-2.038
74	04.03.81	6.452	-0.204		-0.204		-0.432
75	01.04.81	6.085	0.092		0.092		-0.227
76	04.06.81	185.648	-3.908		-3.908		
77	01.09.81	71.033	-2.130		-2.130		-2.107

APPENDIX 5B

Channel hydraulic data: discharge (Q), stream-bed elevation (Be) and moving averaged stream-bed elevations (5 points) on rising and falling (f) stages of single hydrological events on the Fraser River at McBride station (1969-1985.

No.	Date	Discharge ($m^3 s^{-1}$)	Be (m)	Be (r) (m)	Be (f) (m)	Be (r) Moving av. (5)	Be (f) Moving av. (5)
1	14.04.69	73.580	-1.916	-1.916		-1.807	
2	26.05.69	560.340	-2.861	-2.861		-2.662	
3	18.07.69	258.096	-2.433	-2.433		-2.409	
4	09.07.69	461.290	-2.531	-2.531		-2.610	
5	25.09.69	198.383	-2.405		-2.405		-2.248
6	31.03.70	41.035	-1.591	-1.591		-1.576	
7	23.04.70	48.959	-1.735	-1.735		-1.654	
8	26.05.70	370.730	-2.710	-2.710		-2.562	
9	03.06.70	721.650	-3.216	-3.216		-2.620	
10	08.06.70	812.210	-3.076		-3.076		
11	27.04.71	120.841	-1.893	-1.893		-1.907	
12	28.05.71	500.910	-2.759	-2.759		-2.640	
13	25.04.72	54.902	-1.677	-1.677		-1.719	
14	01.06.72	1078.230	-2.757	-2.757			
15	06.09.72	276.491	-2.700	-2.700		-2.494	
16	16.04.73	46.129	-1.643		-1.643		-1.756
17	14.05.73	136.972	-1.688	-1.688		-2.000	
18	13.06.73	382.050	-2.536	-2.536		-2.574	
19	27.06.73	823.530	-2.552	-2.552		-2.681	
20	18.10.73	101.031	-1.844	-1.844		-1.852	
21	19.06.74	945.220	-2.686	-2.686			
22	17.09.74	217.344	-2.287	-2.287		-2.317	
23	08.07.75	925.410	-2.373	-2.373		-2.717	
24	26.08.75	254.983	-2.292	-2.292		-2.419	
25	23.09.75	156.782	-2.188	-2.188		-2.088	
26	28.10.75	88.862	-1.823		-1.823		-1.719
27	13.04.76	96.220	-1.919	-1.919		-1.850	
28	05.07.76	616.940	-2.733	-2.733		-2.578	
29	22.01.77	783.910	-2.560		-2.560		
30	11.10.77	89.994	-1.776		-1.776		-1.750
31	04.04.78	42.450	-1.712		-1.712		
32	12.06.78	444.310	-2.594		-2.594		-2.563
33	25.07.78	509.400	-2.515	-2.515		-2.705	
34	12.09.78	302.810	-2.629		-2.629		-2.618
35	03.04.79	28.300	-2.402	-2.402			
36	04.07.79	418.840	-2.420		-2.420		-2.512
37	27.08.79	339.600	-2.744		-2.744		-2.555
38	23.10.79	82.636	-1.800		-1.800		-1.751
39	08.04.80	41.318	-1.804		-1.804		

40	22.05.80	328.280	-2.708		-2.708		-2.604
41	25.06.80	469.780	-2.701		-2.701		-2.583
42	29.08.80	189.610	-2.385	-2.385		-2.168	
43	30.03.81	46.978	-1.588	-1.588		-1.569	
44	03.06.81	619.770	-2.638		-2.638		-2.714
45	31.08.81	256.964	-2.746		-2.746		-2.637
46	09.06.82	357.000	-2.605		-2.605		-2.581
47	13.07.82	580.000	-2.337	-2.337		-2.635	
48	31.08.82	274.000	-2.672		-2.672		-2.623
49	28.02.83	33.200	-1.713	-1.713			
50	30.05.83	541.000	-2.862	-2.862		-2.667	
51	27.07.83	413.000	-2.462		-2.462		-2.493
52	13.10.83	92.100	-1.554		-1.554		-1.871
53	02.04.84	38.600	-1.253	-1.253		-1.710	
54	01.06.84	238.000	-2.735		-2.735		-2.471
55	20.06.84	401.000	-2.386		-2.386		-2.523
56	26.06.84	688.000	-2.580	-2.580		-2.692	
57	27.07.84	680.000	-2.380	-2.380		-2.649	
58	23.04.85	60.400	-1.678	-1.678		-1.785	
59	11.06.85	323.000	-2.334	-2.334	-2.334	-2.543	
60	09.09.85	136.000	-1.798		-1.798		-2.617
							-2.054

APPENDIX 5C

Channel hydraulic data: discharge (Q), stream-bed elevation (Be) and moving averaged stream-bed elevations (11 points) on rising and falling (f) stages of single hydrological events on the Fraser River at Hansard station (1972-1985).

No	Date	Discharge ($m^3 s^{-1}$)	Be (m)	Be (r) (m)	Be (f) (m)	Be (r) Moving av. (11)	Be (f) Moving av. (11)
1	02.03.72	55.751	-1.712	-0.406			
2	10.05.72	554.680	-0.406	-0.470		-0.365	
3	24.05.72	1884.780	-0.470	-1.071		-0.752	
4	03.06.72	2456.440	-1.071		-0.383	-0.858	
5	07.06.72	2029.110	-0.383	-1.099		-0.671	
6	12.06.72	2742.270	-1.099	-1.115			
7	15.06.72	3028.100	-1.115		-0.323		
8	22.06.72	1570.650	-0.323		-0.574		
9	19.07.72	970.690	-0.574		-0.090		-0.564
10	21.09.72	249.323	-0.090	-0.363			-0.272
11	08.03.73	86.315	-1.649	-0.649		-0.731	
12	08.05.73	628.260	-0.363		-0.498	-0.518	
13	25.05.73	1307.460	-0.649	-0.622		-0.749	
14	15.06.73	1134.830	-0.498		-0.401	-0.670	
15	27.06.73	2128.160	-0.622		-0.265	-0.797	
16	25.07.73	786.740	-0.401		-0.908		-0.513
17	25.09.73	268.001	-0.265	-0.390			-0.281
18	19.12.73	131.029	-0.908	-0.871			-0.592
19	09.05.74	1021.630	-0.390		-0.597	-0.586	
20	19.06.74	1765.920	-0.871		-0.293	-0.812	
21	03.07.74	1290.480	-0.597	-0.225			
22	26.07.74	464.120	-0.293	-0.373			-0.398
23	30.08.74	619.770	-0.225	-0.566			-0.412
24	18.10.74	642.410	-0.373	-0.577			-0.423
25	21.05.75	1106.530	-0.566		-0.345	-0.583	
26	13.06.75	1508.390	-0.577		-0.142	-0.784	
27	11.07.75	512.230	-0.345		-0.592		-0.363
28	05.09.75	243.946	-0.142	-0.788			-0.524
29	03.10.75	101.314	-0.592	-0.600			-0.533
30	08.01.76	81.787	-0.788		-0.490	-0.833	
31	10.03.76	1024.460	-0.600	-0.687		-0.601	
32	07.05.76	891.450	-0.490		-0.543	-0.540	
33	25.05.76	1542.350	-0.687		-0.513	-0.826	
34	23.06.76	1163.130	-0.543		-0.401		-0.537
35	15.07.76	1001.820	-0.513		-0.889		-0.587
36	08.09.76	365.070	-0.401	-0.699			-0.352
37	18.10.76	149.424	-0.889	-0.809			-0.610
38	19.01.77	102.446	-0.699		-0.273	-0.700	

39	18.03.77	1904.590	-0.809		-0.413	-0.631	
40	10.06.77	260.926	-0.273	-0.524			-0.318
41	21.10.77	66.788	-0.413		-0.458		
42	25.11.77	127.633	-0.524		-0.572		-0.682
43	07.12.78	79.806	-0.458	-0.062		-0.796	
44	20.01.78	70.184	-0.572	-0.301		-0.808	
45	10.03.78	173.479	-0.062	-0.768		-0.624	
46	18.04.78	367.900	-0.301		-0.592	-0.432	
47	12.05.78	1443.300	-0.768		-0.534	-0.669	
48	06.06.78	766.930	-0.592	-0.510			-0.443
49	20.07.78	82.070	-0.534	-0.622			-0.714
50	23.01.79	58.600	-0.510		-0.524		
51	21.03.80	1120.000	-0.622		-0.497	-0.644	
52	18.06.80	561.000	-0.524	-0.589			-0.352
53	21.08.80	121.000	-0.497	-0.816			-0.611
54	12.12.80	248.000	-0.589	-0.632			-0.396
55	09.01.81	1010.000	-0.816	-0.691		-0.587	
56	20.05.81	1040.000	-0.632	-0.641		-0.562	
57	08.07.81	70.000	-1.434	-0.905			
58	25.03.82	573.000	-0.691		-0.707	-0.480	
59	11.05.82	677.000	-0.641		-0.427	-0.600	
60	14.05.82	1190.000	-0.905	-0.626		-0.687	
61	08.06.82	986.000	-0.707		-0.375		-0.592
62	12.07.82	431.000	-0.427	-0.762			-0.368
63	18.05.83	947.000	-0.626	-0.663			-0.580
64	13.06.83	357.000	-0.375	-1.225			-0.348
65	15.05.84	1210.000	-0.762		-0.515	-0.695	
66	11.06.84	1340.000	-0.663			-0.684	
67	25.06.84	1750.000	-1.225			-0.766	
68	06.06.85	81.000	-0.515				-0.698

APPENDIX 5D

Channel hydraulic data: discharge (Q), stream-bed elevation (Be) and moving averaged stream-bed elevations (11 points) on rising and falling (f) stages of single hydrological events on the Fraser River at Shelley station (1960-1986).

No.	Date	Discharge ($m^3 s^{-1}$)	Be (m)	Be (r) (m)	Be (f) (m)	Be (r) Moving av. (11)	Be (f) Moving av. (11)
1	22.04.60	718.820	0.138	0.138		0.075	
2	20.05.60	1652.720	-0.188	-0.188		-0.214	
3	03.06.60	1443.300	-0.052	-0.052		-0.180	
4	27.06.60	2914.900	-0.446	-0.446		-0.385	
5	20.07.60	2210.230	-0.365		-0.365		-0.349
6	23.08.60	1177.280	0.050		0.050		-0.094
7	04.10.60	622.600	0.268	0.268		0.121	
8	10.04.61	619.770	0.327		0.327		0.046
9	11.05.61	1092.380	0.070	0.070		-0.051	
10	28.05.61	2719.630	-0.375		-0.375		
11	13.06.61	1958.360	-0.259		-0.259		-0.279
12	13.07.61	939.560	0.095		0.095		-0.029
13	25.09.61	588.640	0.284	0.284			
14	26.09.61	744.290	0.300	0.300		0.056	
15	20.02.62	299.980	-0.634		-0.634		
16	03.05.62	1075.400	0.041		0.041		-0.080
17	07.07.62	1499.900	-0.153		-0.153		-0.183
18	29.06.62	3197.900	-0.446		-0.446		
19	22.08.62	2210.230	-0.323	-0.323		-0.284	
20	27.08.62	1610.270	-0.280		-0.280		-0.220
21	15.10.62	566.000	0.223	0.223			
22	14.01.63	254.417	0.285		0.285		
23	14.02.63	319.790	-1.359		-1.359		-0.150
24	13.03.63	283.000	-0.913		-0.913		
25	24.04.63	982.010	-0.006		-0.006		-0.051
26	11.06.63	1763.090	-0.405	-0.405		-0.247	
27	30.07.63	1304.630	-0.181	-0.181		-0.103	
28	10.10.63	625.430	0.173		0.173		0.149
29	11.06.64	4063.880	-0.687	-0.687			
30	09.03.64	625.430	0.158		0.158		0.178
31	22.01.65	272.529	-1.518	-1.518			
32	04.03.65	251.021	-0.772		-0.772		
33	10.06.65	2391.350	-0.390		-0.390		
34	28.09.65	432.990	0.309		0.309		-0.065
35	06.06.66	2430.970	-0.493	-0.493		-0.371	
36	20.09.66	622.600	-0.026	-0.026		0.130	
37	31.10.66	816.172	0.058		0.058		0.064
38	05.06.67	3792.200	-0.653		-0.653		
39	26.06.67	3056.400	-0.598		-0.598		

40	26.07.67	1369.720	-0.083		-0.083		-0.177
41	16.10.67	778.250	0.101		0.101		0.096
42	01.04.68	452.800	0.127	0.127			
43	31.05.68	2306.450	-0.320	-0.320		-0.337	
44	30.09.68	789.570	0.158	0.158		0.045	
45	15.09.69	1431.980	-0.103	-0.103		-0.147	
46	17.07.70	1015.970	-0.082	-0.082		-0.001	
47	29.04.71	1853.650	-0.185		-0.185		-0.260
48	01.06.72	4188.400	-0.425	-0.425			
49	13.06.72	4782.700	-0.342	-0.342			
50	17.10.72	486.760	0.385		0.385		-0.004
51	26.06.73	3282.800	-0.205	-0.205			
52	13.06.74	2048.920	-0.217		-0.217		-0.271
53	18.06.74	3282.800	-0.308	-0.308			
54	24.09.74	455.630	0.289		0.289		-0.075
55	17.01.75	2179.100	-0.075		-0.075		-0.304
56	19.09.75	636.750	-0.071	-0.071		0.091	
57	06.10.76	585.810	0.091	0.091			
58	06.09.77	857.490	0.038	0.038		0.038	
59	27.06.78	1284.820	-0.169		-0.169		-0.120
60	17.10.78	551.850	0.189		0.189		-0.017
61	18.08.80	1000.000	-0.114	-0.114		0.009	
62	03.07.81	1330.000	-0.690		-0.690		-0.149
63	08.10.81	286.000	0.247		0.247		
64	21.07.82	1980.000	-0.279	-0.279		-0.272	
65	23.08.84	734.000	-0.128		-0.128		0.127
66	26.08.86	607.000	-0.066	-0.066		-0.023	

APPENDIX 5E.1

Channel hydraulic data: discharge (Q), stream-bed elevation (Be) and moving averaged stream-bed elevations (11 points) on rising and falling (f) stages of single hydrological events on the Fraser River at Marguerite station (1971-1986).

No	Date	Discharge ($m^3 s^{-1}$)	Be (m)	Be (r) (m)	Be (f) (m)	Be (r) Moving av. (11)	Be (f) Moving av. (11)
1	11.05.71	3226	-2.867	-2.867		-2.581	
2	07.06.71	3792	-3.570	-3.570		-2.782	
3	28.06.71	2887	-3.258	-3.258		-2.440	
4	14.09.71	1593	-2.717	-2.717		-2.498	
5	09.11.71	739	-2.800	-2.800			
6	08.05.72	2793	-2.416	-2.416		-2.522	
7	25.05.72	4839	-2.958	-2.958			
8	05.06.72	4952	-2.662		-2.662		
9	13.06.72	6084	-2.719	-2.719			
10	21.06.72	4698	-2.876		-2.876		
11	09.08.72	2425	-3.287	-3.287		-2.537	
12	05.10.72	1460	-3.133		-3.133		-2.708
13	28.11.72	685	-2.683		-2.683		
14	27.04.73	1525	-2.708	-2.708		-2.514	
15	30.05.73	3141	-3.099		-3.099		-2.831
16	11.06.73	4217	-2.983		-2.983		
17	25.06.73	4104	-3.167	-3.167		-2.874	
18	17.07.73	2445	-3.206	-3.206		-2.543	
19	22.08.73	1259	-2.733		-2.733		-2.597
20	11.10.73	1027	-2.502		-2.502		-2.483
21	24.04.74	2315	-2.476	-2.476		-2.506	
22	15.05.74	3396	-3.456		-3.456		-2.930
23	18.06.74	4811	-3.069	-3.069			
24	04.07.74	4160	-3.242	-3.242		-2.904	
25	16.08.74	1755	-3.426		-3.426		-2.646
26	09.10.74	889	-2.514	-2.514		-2.542	
27	08.05.75	1944	-2.144	-2.144		-2.452	
28	12.06.75	2558	-2.019	-2.019		-2.572	
29	26.06.75	3283	-2.229	-2.229		-2.681	
30	17.07.75	3113	-2.428		-2.428		-2.810
31	07.08.75	1823	-2.274		-2.274		-2.657
32	06.10.75	891	-1.836	-1.836		-2.532	
33	28.04.76	2332	-1.945	-1.945		-2.513	
34	14.05.76	5773	-2.488		-2.488		
35	26.05.76	3707	-2.837	-2.837		-2.813	
36	15.06.76	4302	-2.534	-2.534		-2.925	
37	10.08.76	4047	-2.583		-2.583		-2.952
38	05.10.76	1489	-2.423		-2.423		-2.673

39	07.04.77	942	-2.604	-2.604		-2.527	
40	05.05.77	3396	-2.300	-2.300		-2.749	
41	15.06.77	3170	-2.572		-2.572		-2.900
42	23.06.77	3905	-2.472	-2.472		-2.834	
43	11.08.77	2241	-2.942	-2.942		-2.566	
44	22.09.77	1036	-2.634	-2.634		-2.519	
45	27.04.78	1605	-2.202	-2.202		-2.429	
46	18.05.78	1876	-2.069	-2.069		-2.425	
47	08.06.78	3198	-2.017	-2.017		-2.526	
48	29.06.78	2142	-2.223		-2.223		-2.654
49	11.10.78	1016	-2.041		-2.041		-2.551
50	30.04.79	2680	-2.046	-2.046		-2.614	
51	17.05.79	2858	-2.661		-2.661		-2.762
52	07.06.79	5717	-2.821	-2.821			
53	21.06.79	3566	-2.963	-2.963		-2.748	
54	09.04.80	484	-2.626	-2.626			
55	04.06.80	2004	-2.224	-2.224		-2.364	
56	25.06.80	2414	-2.513	-2.513		-2.475	
57	13.08.80	1129	-2.392	-2.392		-2.520	
58	18.09.80	1092	-2.273		-2.273		-2.511
59	08.04.81	801	-2.182		-2.182		
60	01.05.81	1704	-2.224		-2.224		-2.642
61	27.05.81	4302	-2.729	-2.729		-2.914	
62	18.06.81	2714	-2.900	-2.900		-2.618	
63	15.07.81	1913	-2.675	-2.675		-2.461	
64	25.08.81	1381	-2.502		-2.502		-2.543
65	22.10.81	594	-2.704		-2.704		
66	04.05.82	1989	-2.460	-2.460		-2.382	
67	19.05.82	4528	-2.632	-2.632			
68	14.06.82	4386	-3.127	-3.127		-2.857	
69	23.09.82	1395	-2.592		-2.592		-2.669
70	09.11.82	804	-2.681		-2.681		
71	02.03.83	457	-2.665	-2.665			
72	25.04.83	1480	-2.547	-2.547		-2.479	
73	18.05.83	1490	-2.577	-2.577		-2.556	
74	31.05.83	2610	-2.222	-2.222		-2.530	
75	05.07.83	2190	-2.547		-2.547		-2.686
76	24.08.83	1260	-2.562		-2.562		-2.574
77	15.11.83	908	-2.561		-2.561		-2.569

78	25.05.84	1840	-2.348		-2.348		-2.593
79	11.06.84	3250	-2.563	-2.563		-2.720	
80	19.06.84	3560	-2.800		-2.800		-2.881
81	18.07.84	2770	-3.032		-3.032		-2.688
82	16.08.84	1790	-2.934		-2.934		-2.686
83	09.11.84	808	-2.540	-2.540			
84	11.04.85	863	-2.367	-2.367			
85	23.05.85	4460	-2.671	-2.671		-2.879	
86	11.06.85	3440	-3.741		-3.741		-2.896
87	16.08.85	1440	-2.986		-2.986		-2.708
88	19.09.86	657	-3.341		-3.341		
89	02.04.86	1090	-2.986	-2.986		-2.535	
90	09.05.86	2010	-2.349	-2.349		-2.462	
91	02.06.86	5790	-3.213		-3.213		

APPENDIX 5E.2

Data for discharge (Q), sediment concentration (C) and moving averaged sediment concentration (11 points) on rising (r) and falling (f) stages of single hydrological events on the Fraser River at Marguerite station (1971-1986).

No	Date	Discharge ($m^3 s^{-1}$)	C ($mg L^{-1}$)	C (r) ($mg L^{-1}$)	C(f) ($mg L^{-1}$)	C(r) Moving av. (11)	C(f) Moving av. (11)
1	11.05.71	3226	390	390		394.364	
2	07.06.71	3792	339	339		339.545	
3	28.06.71	2887	386	386		418.545	
4	14.09.71	1593	116	116		216.455	
5	09.11.71	739	21	21			
6	08.05.72	2793	363	363		398.636	
7	25.05.72	4839	551	551			
8	05.06.72	4952	402		402		
9	13.06.72	6084	594	594			
10	21.06.72	4698	329		329		
11	09.08.72	2425	87	87		305.727	
12	05.10.72	1460	126		126		73.364
13	28.11.72	685	29		29		
14	27.04.73	1525	453	453		173.455	
15	30.05.73	3141	200		200		185.909
16	11.06.73	4217	407		407		
17	25.06.73	4104	393	393		329.273	
18	17.07.73	2445	85	85		317.000	
19	22.08.73	1259	46		46		49.909
20	11.10.73	1027	83		83		46.636
21	24.04.74	2315	657	657		233.000	
22	15.05.74	3396	208		208		233.455
23	18.06.74	4811	774	774			
24	04.07.74	4160	267	267		398.000	
25	16.08.74	1755	75		75		89.727
26	09.10.74	889	80	80		208.545	
27	08.05.75	1944	303	303		268.455	
28	12.06.75	2558	139	139		344.000	
29	26.06.75	3283	187	187		345.091	
30	17.07.75	3113	188		188		172.818
31	07.08.75	1823	69		69		112.273
32	06.10.75	891	20	20		224.273	
33	28.04.76	2332	303	303		251.455	
34	14.05.76	5773	714		714		
35	26.05.76	3707	217	217		350.818	
36	15.06.76	4302	266	266		484.000	
37	10.08.76	4047	256		256		356.000
38	05.10.76	1489	57		57		79.364

39	07.04.77	942	575	575		194.455	
40	05.05.77	3396	304	304		347.818	
41	15.06.77	3170	172		172		212.273
42	23.06.77	3905	306	306		326.636	
43	11.08.77	2241	89	89		225.727	
44	22.09.77	1036	30	30		233.727	
45	27.04.78	1605	275	275		214.545	
46	18.05.78	1876	172	172		233.545	
47	08.06.78	3198	684	684		420.636	
48	29.06.78	2142	117		117		130.909
49	11.10.78	1016	25		25		45.727
50	30.04.79	2680	1050	1050		354.364	
51	17.05.79	2858	217		217		154.182
52	07.06.79	5717	970	970			
53	21.06.79	3566	162	162		337.000	
54	09.04.80	484	404	404			
55	04.06.80	2004	87	87		250.727	
56	25.06.80	2414	71	71		301.182	
57	13.08.80	1129	30	30		186.273	
58	18.09.80	1092	34		34		48.455
59	08.04.81	801	110		110		
60	01.05.81	1704	175		175		85.545
61	27.05.81	4302	836	836		453.636	
62	18.06.81	2714	137	137		389.545	
63	15.07.81	1913	59	59		215.636	
64	25.08.81	1381	50		50		67.727
65	22.10.81	594	10		10		
66	04.05.82	1989	503	503		254.818	
67	19.05.82	4528	1060	1060			
68	14.06.82	4386	316	316		541.364	
69	23.09.82	1395	51		51		72.273
70	09.11.82	804	19		19		
71	02.03.83	457	113	113			
72	25.04.83	1480	286	286		194.636	
73	18.05.83	1490	76	76		198.182	
74	31.05.83	2610	506	506		346.455	
75	05.07.83	2190	96		96		130.636
76	24.08.83	1260	49		49		53.364
77	15.11.83	908	17		17		42.091

78	25.05.84	1840	112		112		117.909
79	11.06.84	3250	458	458		329.727	
80	19.06.84	3560	274		274		303.273
81	18.07.84	2770	131		131		142.727
82	16.08.84	1790	60		60		97.000
83	09.11.84	808	34	34			
84	11.04.85	863	879	879			
85	23.05.85	4460	216	216		567.545	
86	11.06.85	3440	186		186		258.091
87	16.08.85	1440	49		49		70.182
88	19.09.86	657	41		41		
89	02.04.86	1090	108	108		241.182	
90	09.05.86	2010	239	239		233.636	
91	02.06.86	5790	768		768		

APPENDIX 5F

Channel hydraulic data: discharge (Q), stream-bed elevation (Be) and moving averaged stream-bed elevations (3 points) on rising and falling (f) stages of single hydrological events on the Fraser River at Big Bar Creek station (1960-1972).

No.	Date	Discharge ($m^3 s^{-1}$)	Be (m)	Be (r) (m)	Be (f) (m)	Be (r) Moving av. (3)	Be (f) Moving av. (3)
1	27.04.60	1581.970	1.391		1.391	1.295	
2	13.07.60	3763.900	0.444		0.444	0.388	
3	13.09.60	1737.620	1.098		1.098	1.158	
4	04.11.60	1601.780	1.209		1.209	1.207	
5	26.04.61	1265.010	1.358	1.358			1.194
6	12.09.61	1698.000	1.152		1.152	1.090	
7	10.05.63	2306.450	1.136		1.136	0.909	
8	22.06.63	4471.400	0.351	0.351			0.173
9	30.10.63	1163.130	1.459		1.459	1.557	
10	06.05.64	1700.830	1.172	1.172			1.090
11	09.09.64	1695.170	1.021		1.021	1.127	
12	04.11.64	1944.210	0.888		0.888	1.082	
13	04.05.65	3424.300	0.191		0.191	0.413	
14	21.07.65	3220.540	0.443		0.443	0.525	
15	09.06.66	4216.700	0.116		0.116	0.114	
16	04.11.66	1423.490	1.491		1.491	1.427	
17	05.05.67	2501.720	0.445	0.445			0.240
18	02.06.67	4697.800	-0.077	-0.077			
19	29.07.67	2787.550	0.941		0.941	0.695	
20	26.10.67	1103.700	1.722		1.722	1.562	
21	09.04.68	973.520	1.584	1.584			1.371
22	23.05.68	5405.300	0.244	0.244			
23	29.10.68	1482.920	1.285		1.285	1.336	
24	21.11.68	950.880	1.634		1.634	1.699	
25	14.04.69	2164.950	1.046	1.046			0.614
26	16.10.69	1451.790	1.331		1.331	1.369	
27	28.07.70	1836.670	1.223		1.223	1.070	
28	14.10.70	1086.720	1.506		1.506	1.621	
29	18.03.71	379.220	1.956		1.956		
30	05.08.71	2507.380	0.702		0.702	0.926	
31	23.11.71	1706.490	1.052	1.052			0.848
32	19.06.72	6282.600	-0.217		-0.217		
33	19.07.72	3650.700	0.604		0.604	0.413	

APPENDIX 5G

Channel hydraulic data: discharge (Q), stream-bed elevation (Be) and moving averaged stream-bed elevations (11 points) on rising and falling (f) stages of single hydrological events on the Fraser River at Texas Creek station (1960-1986).

No.	Date	Discharge ($m^3 s^{-1}$)	Be (Gh-d)[1] (m)	Be (r) (m)	Be (f) (m)	Be (r) Moving av. (11)	Be (f) Moving av. (11)
1	18.02.60	650.900	1.279		1.279		1.340
2	28.04.60	1389.530	1.489	1.489		1.243	
3	25.05.60	3288.460	0.653		0.653		0.957
4	17.06.60	4556.300	0.869	0.869		0.721	
5	28.06.60	5575.100	0.878	0.878			
6	13.07.60	4188.400	0.874		0.874		
7	24.08.60	2453.610	0.866		0.866		1.104
8	12.10.60	1683.850	1.158		1.158		1.196
9	22.11.60	1109.360	1.318		1.318		1.294
10	02.02.61	512.230	1.420		1.420		
11	12.04.61	1310.290	1.245		1.245		1.285
12	25.05.61	4726.100	0.815	0.815		0.717	
13	02.06.61	4499.700	0.675		0.675		
14	13.06.61	4358.200	0.813		0.813		
15	28.06.61	3158.280	0.918		0.918		0.978
16	12.09.61	2173.440	1.208		1.208		1.176
17	14.02.62	1100.870	1.348		1.348		1.312
18	13.04.62	1228.220	1.210	1.210		1.255	
19	18.06.62	3831.820	0.880	0.880		0.911	
20	27.06.62	4245.000	0.860	0.860		0.859	
21	26.09.62	1482.920	1.262		1.262		1.252
22	29.11.62	1315.950	1.258		1.258		1.272
23	12.02.63	990.500	1.265	1.265		1.251	
24	20.04.63	2521.530	1.021		1.021		1.065
25	19.06.63	4414.800	0.895	0.895		0.801	
26	04.07.63	3226.200	0.641	0.641		0.983	
27	09.09.63	2102.690	1.110	1.110		1.118	
28	20.11.63	888.620	1.302		1.302		1.325
29	05.02.64	642.410	1.317		1.317		1.347
30	18.03.64	566.000	1.319		1.319		
31	27.05.64	3650.700	0.994		0.994		0.894
32	12.06.64	7301.400	0.656	0.656			
33	24.09.64	2012.130	1.090	1.090		1.148	
34	12.12.64	916.920	1.158	1.158		1.276	
35	10.02.65	696.180	1.287		1.287		1.333
36	06.05.65	3311.100	0.775		0.775		0.932
37	03.06.65	5207.200	0.192	0.192		0.532	
38	28.07.65	2648.880	0.869		0.869		0.983

39	02.10.65	1083.890	1.104	1.104		1.268	
40	08.12.65	865.980	1.242	1.242			
41	03.02.66	611.280	1.256	1.256			
42	15.03.66	594.300	1.347		1.347		1.364
43	19.04.66	1423.490	0.796			0.721	
44	07.06.66	4423.290	0.774	0.774		0.610	
45	13.06.66	4949.670	0.541	0.541			1.234
46	22.09.66	1607.440	1.325		1.325		1.194
47	03.11.66	1613.100	1.291		1.291		
48	26.01.67	526.380	1.356		1.356	1.301	
49	14.04.67	905.600	1.383	1.383			
50	16.06.67	5405.300	0.516		0.516		0.977
51	26.07.67	3028.100	1.045		1.045		1.087
52	19.08.69	2510.210	1.301		1.301		1.333
53	24.02.70	667.880	1.369		1.369	0.933	
54	26.05.70	3282.800	0.921	0.921		1.089	
55	21.07.70	2264.000	1.180	1.180			
56	13.01.71	532.040	1.391	1.391			
57	30.03.71	472.610	1.379		1.379		0.840
58	02.06.71	3763.900	1.182		1.182		1.322
59	03.11.71	1049.930	1.348		1.348	1.251	
60	20.04.72	1307.460	1.175	1.175		1.220	
61	27.04.72	1613.100	1.343	1.343		0.672	
62	30.05.72	4726.100	0.545	0.545			
63	15.06.72	7216.500	0.037	0.037			
64	18.07.72	4160.100	0.788		0.788	1.178	
65	27.04.73	1638.570	1.389	1.389			0.989
66	05.06.73	3084.700	1.107		1.107	0.521	
67	28.06.73	5263.800	0.640	0.640			1.165
68	10.08.73	2190.420	1.126		1.126		
69	09.01.74	449.970	1.473		1.473		
70	20.06.74	5971.300	0.389	0.389			
71	18.02.75	486.760	1.444	1.444			1.298
72	18.09.75	1298.970	1.279		1.279		
73	23.06.76	6169.400	0.174	0.174			1.333
74	05.04.77	693.350	1.461		1.461		0.927
75	10.06.78	3452.600	1.052		1.052	1.282	
76	24.10.80	1160.000	1.251	1.251			1.297
77	17.11.81	1190.000	1.304		1.304	1.260	
78	19.04.83	1000.000	1.331	1.331			1.015
79	06.07.83	2620.000	1.140		1.140		1.129
80	05.06.84	2300.000	1.120		1.120		
81	07.01.86	462.000	1.485	1.485		1.035	
82	22.05.86	2540.000	1.076	1.076			1.329
83	24.09.86	858.000	1.283		1.283		

APPENDIX 5H.1

Channel hydraulic data: discharge (Q), stream-bed elevation (Be) and moving averaged stream-bed elevations (11 points) on rising and falling (f) stages of single hydrological events on the Fraser River at Hope station (1965-1979).

No.	Date	Q (m^3/s)	Be (m)	Be(r) (m)	Be(f) (m)	Be(r) Moving av. (11) (m)	Be(f) Moving (11) (m)
1	02.06.65	8320.200	2.217	2.217			
2	17.06.65	8065.500	2.094	2.094		2.415	
3	05.10.65	2031.940	2.923		2.923		3.239
4	10.02.66	967.860	3.218		3.218		3.584
5	20.04.66	2337.580	3.121	3.121		3.152	
6	09.06.66	7788.160	2.569	2.569		2.482	
7	24.08.66	3254.500	2.865		2.865		2.837
8	19.10.66	2181.930	3.209		3.209		3.119
9	10.02.67	1211.240	3.318		3.318		3.635
10	25.04.67	1692.340	3.374	3.374		3.488	
11	09.05.67	4281.790	2.634	2.634		2.804	
12	25.05.67	8226.810	2.290	2.290			
13	06.06.67	10635.140	2.287	2.287			
14	12.07.67	7103.300	2.682		2.682		
15	08.09.67	2745.100	3.049		3.049		2.983
16	19.10.67	2184.760	3.197		3.197		3.101
17	14.02.68	1364.060	3.420		3.420		3.550
18	28.03.68	2012.130	3.481		3.481		3.290
19	18.04.68	1748.940	3.359	3.359		3.388	
20	06.05.68	2781.890	2.870	2.870		3.060	
21	16.05.68	4734.590	2.857	2.857		2.759	
22	17.06.68	8156.060	2.739	2.739		2.331	
23	26.06.68	758.440	2.660	2.660			
24	24.07.68	5688.300	2.634		2.634		
25	08.08.68	4612.900	2.840		2.840		2.827
26	20.08.68	3220.540	2.914		2.914		2.876
27	17.10.68	2184.760	2.721		2.721		3.122
28	19.11.68	1997.980	2.751		2.751		3.307
29	24.01.69	973.520	3.177		3.177		3.6
30	19.02.69	939.560	3.176		3.176		3.624
31	27.02.69	897.110	3.632		3.632		3.621
32	06.03.69	851.830	3.546		3.546		3.854
33	18.04.69	3311.100	2.676	2.676		2.967	
34	14.05.69	7558.930	2.852	2.852		2.481	
35	30.05.69	6735.400	2.659	2.659		2.554	
36	09.06.69	8150.400	2.628	2.628		2.354	
37	26.06.69	5631.700	2.627	2.627		2.701	
38	17.07.69	4443.100	2.618		2.618		2.806

No.	Date	Q (m^3/s)	Be (m)	Be(r) (m)	Be(f) (m)	Be(r) Moving av. (11) (m)	Be(f) Moving (11) (m)
39	19.08.69	3197.900	2.300		2.300		2.918
40	18 09.69	3169.600	2.839		2.839		2.940
41	17.10.69	2326.260	3.098		3.098		3.083
42	16.12.69	1499.900	3.405		3.405		3.495
43	30.12.69	1197.090	3.284		3.284		3.69
44	19.03.70	950.880	3.573		3.573		3.614
45	22.04.70	1497.070	3.378	3.378		3.475	
46	20.05.70	5688.300	2.675	2.675		2.677	
47	18.06.70	6339.200	2.714	2.714		2.644	
48	03.07.70	5546.800	3.524		3.524		2.740
49	13.07.70	4131.800	2.724		2.724		2.802
50	27.07.70	2999.800	3.108		3.108		2.953
51	25.08.70	2077.220	3.307		3.307		3.120
52	23.09.70	1700.830	3.416		3.416		3.379
53	29.09.70	1304.630	3.691		3.691		3.584
54	01.12.70	614.110	3.972		3.972		
55	05.02.71	1078.230	3.739		3.739		3.643
56	25.03.71	806.550	3.871		3.871		3.851
57	14.04.71	1081.060	3.730	3.730		3.304	
58	28.04.71	416.010	2.950	2.950			
59	17.05.71	755.610	2.512	2.512			
60	12.06.71	911.260	2.907	2.907			
61	26.07.71	563.170	2.940		2.940		
62	18.08.71	3424.300	2.883		2.883		2.736
63	30.09.71	2142.310	3.081		3.081		3.104
64	36.11.71	2031.940	3.151		3.151		3.220
65	13.02.73	795.230	4.284		4.284		
66	27.03.73	820.700	4.307		4.307		3.872
67	09.04.73	1117.850	4.197	4.197		3.345	
68	08.05.73	3506.370	3.326	3.326		2.863	
69	13.06.73	6769.360	2.802	2.802		2.553	
70	20.08.73	2716.800	3.187		3.187		2.966
71	26.09.73	1499.900	3.647		3.647		3.449
72	04.12.73	1132.000	3.907		3.907		3.698
73	26.02.74	877.300	4.000		4.000		3.807
74	27.03.74	1004.650	4.024		4.024		3.626
75	16.04.74	2023.450	3.400	3.400		3.293	
76	03.05.74	6112.800	2.408	2.408		2.682	
77	29.05.74	7159.900	2.463	2.463		2.567	
78	18.06.74	9678.600	2.179	2.179			
79	10.07.74	7499.500	2.359		2.359		
80	20.08.74	3424.300	3.033		3.033		2.758
81	24.09.74	1986.660	3.617		3.617		3.322
82	10.12.74	1001.820	3.902		3.902		3.604
83	05.03.75	789.570	4.149		4.149		
84	17.04.75	1061.250	3.960	3.960			

No.	Date	Q (m^3/s)	Be (m)	Be(r) (m)	Be(f) (m)	Be(r) Moving av. (11) (m)	Be(f) Moving (11) (m)
85	02.05.75	2099.860	3.486	3.486		3.214	
86	16.05.75	5722.260	2.887	2.887		2.633	
87	09.06.75	7358.000	2.581	2.581		2.532	
88	18.06.75	7952.300	2.510	2.510		2.467	
89	11.07.75	7754.200	2.502		2.502		
90	31.07.75	4726.100	2.876		2.876		2.767
91	04.09.75	3056.400	3.084		3.084		2.947
92	29.10.75	2037.600	3.277		3.277		3.158
93	27.01.76	1381.040	3.481		3.481		3.577
94	09.03.76	945.220	3.774		3.774		3.571
95	06.05.76	6735.400	2.548	2.548		2.557	
96	27.05.76	7184.521	1.961	1.961		2.549	
97	25.06.76	8546.600	1.762	1.762			
98	30.07.76	6480.700	2.434		2.434		
99	02.09.76	5575.100	2.599		2.599		2.764
100	05.11.76	2099.860	3.225		3.225		3.152
101	26.01.77	1279.160	3.994		3.994		3.587
102	18.03.77	1109.360	3.677		3.677		3.717
103	19.04.77	2496.060	3.043	3.043		3.104	
104	02.05.77	5094.000	2.265	2.265		2.749	
105	17.05.77	5009.100	2.331	2.331		2.727	
106	06.06.78	6056.200	2.588	2.588		2.671	
107	15.06.78	6022.240	2.814	2.814		2.678	
108	27.07.78	3707.300	2.840		2.840		2.749
109	06.10.78	2487.570	2.957		2.957		3.070
110	19.12.78	1001.820	3.717		3.717		3.671
111	29.01.79	752.780	4.094		4.094		
112	06.03.79	1013.140	3.672		3.672		3.603
113	23.04.79	1211.240	3.315	3.315		3.433	
114	08.05.79	5575.100	2.835	2.835		2.685	
115	22.05.79	4839.300	2.889	2.889		2.726	
116	28.05.79	6509.000	2.551	2.551		2.557	
117	30.05.79	7584.400	2.543	2.543		2.488	
118	07.06.79	8037.200	2.366	2.366		2.49	
119	14.06.79	5999.600	2.619	2.619		2.694	
120	20.06.79	5801.500	2.914	2.914		2.668	
121	10.07.79	5320.400	2.964		2.964		2.763
122	24.07.79	4669.500	2.986		2.986		2.804
123	26.07.79	4471.400	2.240		2.240		2.866
124	21.08.79	2549.830	3.081		3.081		3.048
125	19.09.79	1748.940	3.399		3.399		3.335
126	22.10.79	1318.780	3.629		3.629		3.54
127	20.11.79	877.300	3.562		3.562		3.722
128	20.12.79	1231.050	3.650		3.650		3.617

APPENDIX 5H.2

Data for discharge (Q), sediment concentration (C) and moving averaged sediment concentrations (11 points) on rising (r) and falling (f) stages of single hydrological events on the Fraser River at Hope station (1965-1979).

No.	Date	Q (m^3/s)	C (mg/L)	C(r) (mg/L)	C(f) (mg/L)	C(r) Moving av. (11) (mg/L)	C(f) Moving av. (11) (mg/L)
1	02.06.65	8320.200	745	745			
2	17.06.65	8065.500	315	315		447.545	
3	05.10.65	2031.940	90		90		69.818
4	10.02.66	967.860	9		9		24.091
5	20.04.66	2337.580	115	115		310.727	
6	09.06.66	7788.160	285	285		385.000	
7	24.08.66	3254.500	85		85		93.545
8	19.10.66	2181.930	40		40		60.545
9	10.02.67	1211.240	5		5		28.182
10	25.04.67	1692.340	310	310		197.000	
11	09.05.67	4281.790	610	610		395.182	
12	25.05.67	8226.810	635	635			
13	06.06.67	10635.140	585	585			
14	12.07.67	7103.300	170		170		
15	08.09.67	2745.100	115		115		82.545
16	19.10.67	2184.760	73		73		52.636
17	14.02.68	1364.060	8		8		28.455
18	25.03.68	2012.130	162		162		68.364
19	18.04.68	1748.940	120	120		212.364	
20	06.05.68	2781.890	270	270		334.545	
21	16.05.68	4734.590	442	442		397.182	
22	17.06.68	8156.060	274	274		430.364	
23	26.06.68	758.440	165	165			
24	24.07.68	5688.300	177		177		
25	08.08.68	4612.900	118		118		114.091
26	20.08.68	3220.540	96		96		94.909
27	17.10.68	2184.760	34		34		44.727
28	19.11.68	1997.980	32		32		67.364
29	24.01.69	973.520	22		22		26.000
30	19.02.69	939.560	31		31		23.818
31	27.02.69	897.110	17		17		20.545
32	06.03.69	851.830	27		27		17.364
33	18.04.69	3311.100	518	518		342.364	
34	14.05.69	7558.930	389	389		451.364	
35	30.05.69	6735.400	395	395		456.455	
36	09.06.69	8150.400	350	350		453.455	
37	26.06.69	5631.700	137	137		376.818	
38	17.07.69	4443.100	100		100		104.545

No.	Date	Q (m^3/s)	C (mg/L)	C(r) (mg/L)	C(f) (mg/L)	C(r) Moving av. (11) (mg/L)	C(f) Moving av. (11) (mg/L)
39	19.08.69	3197.900	145		145		91.545
40	18.09.69	3169.600	142		142		90.818
41	17.10.69	2326.260	33		33		55.818
42	16.12.69	1499.900	26		26		23.545
43	30.12.69	1197.090	13		13		31.273
44	19.03.70	950.880	25		25		22.364
45	22.04.70	1497.070	64	64		206.455	
46	20.05.70	5688.300	897	897		362.182	
47	18.06.70	6339.200	207	207		445.182	
48	03.07.70	5546.800	164		164		141.364
49	13.07.70	4131.800	107		107		100.364
50	27.07.70	2999.800	82		82		83.636
51	25.08.70	2077.220	47		47		74.455
52	23.09.70	1700.830	35		35		42.727
53	29.09.70	1304.630	25		25		24.727
54	01.12.70	614.110	12		12		
55	05.02.71	1078.230	29		29		33.000
56	25.03.71	806.550	16		16		24.455
57	14.04.71	1081.060	119	119		305.727	
58	28.04.71	416.010	1050	1050			
59	17.05.71	755.610	670	670			
60	12.06.71	911.260	317	317			
61	26.07.71	563.170	114		114		
62	18.08.71	3424.300	80		80		103.182
63	30.09.71	2142.310	32		32		63.818
64	36.11.71	2031.940	244		244		70.273
65	13.02.73	795.230	5		5		
66	27.03.73	820.700	36		36		16.909
67	09.04.73	1117.850	285	285		247.091	
68	08.05.73	3506.370	520	520		350.000	
69	13.06.73	6769.360	304	304		528.273	
70	20.08.73	2716.800	70		70		76.909
71	26.09.73	1499.900	16		16		36.818
72	04.12.73	1132.000	9		9		30.000
73	26.02.74	877.300	18		18		19.182
74	27.03.74	1004.650	42		42		25.273
75	16.04.74	2023.450	405	405		248.636	
76	03.05.74	6112.800	954	954		444.636	
77	29.05.74	7159.900	465	465		467.455	
78	18.06.74	9678.600	454	454			
79	10.07.74	7499.500	156		156		
80	20.08.74	3424.300	76		76		97.364
81	24.09.74	1986.660	33		33		65.000

No.	Date	Q (m^3/s)	C (mg/L)	C(r) (mg/L)	C(f) (mg/L)	C(r) Moving av. (11) (mg/L)	C(f) Moving av. (11) (mg/L)
82	10.12.74	1001.820	52		52		27.636
83	05.03.75	789.570	11		11		
84	17.04.75	1061.250	101	101			
85	02.05.75	2099.860	273	273		270.000	
86	16.05.75	5722.260	286	286		431.273	
87	09.06.75	7358.000	292	292		458.636	
88	18.06.75	7952.300	200		200	400.455	
89	11.07.75	7754.200	123		123		
90	31.07.75	4726.100	54		54		130.545
91	04.09.75	3056.400	28		28		87.545
92	29.10.75	2037.600	21		21		70.818
93	27.01.76	1381.040	17		17		31.000
94	09.03.76	945.220	1050	1050			21.000
95	06.05.76	6735.400	232	232		477.545	
96	27.05.76	7184.521	291	291		475.182	
97	25.06.76	8546.600	146		146		
98	30.07.76	6480.700	102		102		
99	02.09.76	5575.100	37		37		148.273
100	05.11.76	2099.860	16		16		74.545
101	26.01.77	1279.160	35		35		26.455
102	18.03.77	1109.360	213	213			32.455
103	19.04.77	2496.060	489	489		345.091	
104	02.05.77	5094.000	206	206		444.455	
105	17.05.77	5009.100	281	281		476.545	
106	06.06.78	6056.200	157	157		498.545	
107	15.06.78	6022.240	62		62	415.545	
108	27.07.78	3707.300	44		44		102.364
109	06.10.78	2487.570	5		5		57.364
110	19.12.78	1001.820	5		5		25.636
111	29.01.79	752.780	37		37		
112	06.03.79	1013.140	162	162			23.455
113	23.04.79	1211.240	770	770		211.000	
114	08.05.79	5575.100	194	194		418.000	
115	22.05.79	4839.300	690	690		459.364	
116	28.05.79	6509.000	839	839		451.273	
117	30.05.79	7584.400	508	508		387.727	
118	07.06.79	8037.200	538	538		447.091	
119	14.06.79	5999.600	229	229		449.636	
120	20.06.79	5801.500	165	165		431.364	
121	10.07.79	5320.400	142		142		136.273
122	24.07.79	4669.500	133		133		122.909
123	26.07.79	4471.400	124		124		111.727
124	21.08.79	2549.830	54		54		67.364
125	19.09.79	1748.940	28		28		63.182
126	22.10.79	1318.780	19		19		27.091
127	20.11.79	877.300	8		8		19.000
128	20.12.79	1231.050	114		114		26.727

APPENDIX 5I.1

Channel hydraulic data: discharge (Q), stream-bed elevation (Be) and moving averaged stream-bed elevations (11 points) on rising (r) and falling (f) stages of single hydrological events on the Fraser River at Agassiz station (1968-1986).

No.	Date	Q (m^3/s)	Be (m)	Be(r) (m)	Be(f) (m)	Be(r) Moving av. (11) (m)	Be(f) Moving av. (11) (m)
1	14.03.68	2239.000	-0.609		-0.609		-0.415
2	09.04.68	1749.000	-0.865	-0.865		-0.564	
3	24.04.68	1769.000	-0.571	-0.571		-0.508	
4	09.05.68	3481.000	-0.527	-0.527		-0.347	
5	20.05.68	5915.000	-0.589	-0.589		-0.487	
6	24.05.68	7896.000	-0.545	-0.545		-0.454	
7	13.06.68	8122.000	-0.447	-0.447		-0.454	
8	26.06.68	7415.000	-0.512	-0.512		-0.527	
9	09.07.68	8405.000	-0.459	-0.459		-0.466	
10	16.07.68	8405.000	-0.495	-0.495		-0.468	
11	19.07.68	6735.000	-0.395		-0.395		-0.549
12	22.07.68	5802.000	-0.379		-0.379		-0.425
13	25.07.68	5575.000	-0.366		-0.366		-0.443
14	30.07.68	5292.000	-0.497		-0.497		-0.557
15	07.08.68	3877.000	-0.507		-0.507		-0.535
16	21.08.68	3226.000	-0.558		-0.558		-0.497
17	13.09.68	2915.000	-0.441		-0.441		-0.536
18	07.10.68	2601.000	-0.463		-0.463		-0.411
19	08.11.68	2541.000	-0.457		-0.457		-0.379
20	20.11.68	2094.000	-0.484		-0.484		-0.437
21	04.12.68	2035.000	-0.452		-0.452		-0.441
22	17.03.69	900.000	-0.467	-0.467		-0.521	
23	26.03.69	829.000	-0.400		-0.400		
24	08.05.69	4273.000	-0.528	-0.528		-0.396	
25	12.05.69	5094.000	-0.486	-0.486		-0.455	
26	16.05.69	5745.000	-0.392		-0.392		-0.461
27	29.05.69	7160.000	-0.441	-0.441		-0.505	
28	26.05.69	6311.000	-0.457	-0.457		-0.414	
29	10.06.69	7924.000	-0.581		-0.581		-0.573
30	24.06.69	5858.000	-0.415		-0.415		-0.457
31	08.07.69	4981.000	-0.450		-0.450		-0.476
32	23.07.69	3424.000	-0.399		-0.399		-0.476
33	07.08.69	2830.000	-0.431	-0.431		-0.385	
34	20.08.69	3283.000	-0.286		-0.286		-0.547
35	09.09.69	3113.000	-0.473		-0.473		-0.548
36	19.09.69	3198.000	-0.462	-0.462		-0.263	
37	02.10.69	3311.000	-0.392		-0.392		-0.529
38	23.10.69	2222.000	-0.396	-0.396		-0.448	

No.	Date	Q (m^3/s)	Be (m)	Be(r) (m)	Be(f) (m)	Be(r) Moving av. (11) (m)	Be(f) Moving av. (11) (m)
39	06.11.69	2173.000	-0.364		-0.364		-0.460
40	19.11.69	2128.000	-0.449		-0.449		-0.444
41	27.11.69	2332.000	-0.365		-0.365		-0.417
42	09.12.69	1840.000	-0.344		-0.344		-0.468
43	17.12.69	1602.000	-0.368		-0.368		-0.473
44	29.12.69	1344.000	-0.386	-0.386		-0.511	
45	28.01.70	1191.000	0.007		0.007		-0.327
46	05.02.70	1132.000	-0.405		-0.405		-0.322
47	09.02.70	1098.000	-0.485		-0.485		
48	13.02.70	1180.000	-0.450	-0.450		-0.595	
49	18.02.70	1121.000	-0.334		-0.334		-0.335
50	03.03.70	1013.000	-0.363		-0.363		
51	16.04.70	1443.000	-0.383	-0.383		-0.446	
52	26.04.70	1825.000	-0.353	-0.353		-0.466	
53	08.05.70	2972.000	-0.342	-0.342		-0.310	
54	19.05.70	5066.000	-0.428	-0.428		-0.416	
55	02.06.70	5434.000	-0.545	-0.545		-0.454	
56	11.06.70	8066.000	-0.489		-0.489		-0.546
57	17.06.70	5830.000	-0.483		-0.483		-0.440
58	02.07.70	5603.000	-0.489		-0.489		-0.428
59	14.07.70	3990.000	-0.516		-0.516		-0.539
60	23.07.70	3509.000	-0.535		-0.535		-0.558
61	12.08.70	2915.000	-1.005		-1.005		-0.492
62	24.08.70	2142.000	-0.332		-0.332		-0.434
63	22.09.70	1817.000	-0.467	-0.467		-0.486	
64	28.10.70	1395.000	-0.445		-0.445		-0.473
65	18.11.70	1240.000	-0.394		-0.394		-0.352
66	04.02.71	1172.000	-0.338		-0.338		-0.314
67	23.02.71	1084.000	-0.355	-0.355		-0.597	
68	19.04.71	1347.000	-0.416	-0.416		-0.485	
69	29.04.71	4104.000	-0.499	-0.499		-0.353	
70	13.05.71	6707.000	-0.513	-0.513		-0.479	
71	18.05.71	7301.000	-0.499	-0.499		-0.485	
72	02.06.71	7415.000	-0.359	-0.359		-0.502	
73	10.06.71	8632.000	-0.593	-0.593		-0.492	
74	08.07.71	5264.000	-0.324	-0.324		-0.386	
75	27.07.71	5490.000	-0.363		-0.363		-0.544
76	12.08.71	3962.000	-0.358		-0.358		-0.541
77	01.11.71	1698.000	-0.267		-0.267		-0.508
78	22.03.72	2632.000	-0.347	-0.347		-0.462	
79	11.04.72	2507.000	-0.335	-0.335		-0.395	
80	03.05.72	3368.000	-0.324	-0.324		-0.331	
81	12.05.72	4896.000	-0.433	-0.433		-0.383	
82	18.05.72	8490.000	-0.441	-0.441		-0.497	
83	30.05.72	9792.000	-0.623	-0.623			
84	16.06.72	13329.000	-1.036	-1.036			

No.	Date	Q (m^3/s)	Be (m)	Be(r) (m)	Be(f) (m)	Be(r) Moving av. (11) (m)	Be(f) Moving av. (11) (m)
85	29.06.72	9198.000	-0.938		-0.938		-0.532
86	19.07.72	7132.000	-0.928		-0.928		-0.609
87	24.08.72	3283.000	-0.928		-0.928		-0.563
88	02.10.72	1800.000	-0.874	-0.874		-0.509	
89	23.11.72	1203.000	-0.859		-0.859		-0.391
90	20.02.73	951.000	-0.816		-0.816		
91	06.04.73	1217.000	-0.908	-0.908		-0.486	
92	19.04.73	1769.000	-0.865	-0.865		-0.549	
93	09.05.73	3792.000	-0.750	-0.750		-0.324	
94	24.05.73	6764.000	-0.848		-0.848		-0.590
95	05.06.73	5264.000	-0.979		-0.979		-0.533
96	20.06.73	5688.000	-0.963	-0.963		-0.442	
97	29.06.73	8235.000	-0.932	-0.932		-0.483	
98	19.07.73	4726.000	-0.857		-0.857		-0.468
99	21.08.73	2708.000	-0.906		-0.906		-0.434
100	27.09.73	1559.000	-0.797	-0.797		-0.469	
101	05.12.73	1259.000	-0.788		-0.788		-0.439
102	27.02.74	962.000	-0.783	-0.783		-0.511	
103	28.03.74	1121.000	-0.759	-0.759		-0.575	
104	17.04.74	2309.000	-0.845	-0.845		-0.425	
105	30.04.74	4839.000	-0.798	-0.798		-0.438	
106	16.05.74	5632.000	-0.867		-0.867		-0.487
107	30.05.74	7188.000	-0.865	-0.865		-0.508	
108	19.06.74	10584.000	-0.869	-0.869			
109	11.07.74	7160.000	-0.876		-0.876		-0.650
110	22.08.74	3396.000	-0.701		-0.701		-0.478
111	25.09.74	1924.000	-0.716		-0.716		-0.464
112	25.02.75	659.000	-0.659	-0.659			
113	08.03.75	852.000	-0.668		-0.668		
114	07.05.75	2493.000	-0.656	-0.656		-0.404	
115	16.05.75	5830.000	-0.731	-0.731		-0.509	
116	05.06.75	6650.000	-0.780	-0.780		-0.424	
117	08.06.75	7782.000	-0.685	-0.685		-0.445	
118	03.07.75	6452.000	-0.789		-0.789		-0.592
119	14.07.75	7075.000	-0.744		-0.744		-0.568
120	07.08.75	3764.000	-0.728		-0.728		-0.573
121	19.11.75	2420.000	-0.641	-0.641		-0.422	
122	18.09.75	1998.000	-0.736		-0.736		-0.417
123	23.03.76	965.000	-0.715	-0.715		-0.511	
124	28.04.76	3141.000	-0.753	-0.753		-0.296	
125	07.05.76	6962.000	-0.731	-0.731		-0.492	
126	21.05.76	7330.000	-0.719		-0.719		-0.659
127	08.06.76	5745.000	-0.699		-0.699		-0.435
128	23.06.76	9367.000	-0.739	-0.739		-0.475	
129	21.07.76	7471.000	-0.805	-0.805		-0.444	
130	26.08.76	6339.000	-0.825		-0.825		-0.564

No.	Date	Q (m^3/s)	Be (m)	Be(r) (m)	Be(f) (m)	Be(r) Moving av. (11) (m)	Be(f) Moving av. (11) (m)
131	08.10.76	2595.000	-0.669		-0.669		-0.399
132	03.12.76	1460.000	-0.682		-0.682		-0.498
133	15.02.77	1254.000	-0.763		-0.763		-0.400
134	06.04.77	1075.000	-0.802	-0.802		-0.587	
135	20.04.77	2323.000	-0.628		-0.628		-0.425
136	03.05.77	4726.000	-0.718		-0.718		-0.436
137	18.05.77	4613.000	-0.716		-0.716		-0.424
138	15.06.77	5575.000	-0.656		-0.656		-0.425
139	27.06.77	6254.000	-0.618		-0.618		-0.549
140	21.07.77	5886.000	-0.682	-0.682		-0.496	
141	16.08.77	3453.000	-0.708		-0.708		-0.498
142	16.09.77	2148.000	-0.661		-0.661		-0.469
143	30.11.77	1155.000	-0.643		-0.643		-0.344
144	31.03.78	1463.000	-0.635	-0.635		-0.442	
145	09.05.78	3339.000	-0.827		-0.827		-0.522
146	07.06.78	6116.000	-0.683	-0.683		-0.484	
147	14.06.78	5886.000	-0.629		-0.629		-0.481
148	29.06.78	5199.000	-0.677		-0.677		-0.487
149	13.07.78	4641.000	-0.679		-0.679		-0.437
150	03.08.78	3311.000	-0.541		-0.541		-0.535
151	12.10.78	2066.000	-0.594		-0.594		-0.455
152	26.10.78	1800.000	-0.643	-0.643		-0.488	
153	05.03.79	855.000	-0.628	-0.628			
154	13.03.79	931.000	-0.631	-0.631		-0.493	
155	23.04.79	1271.000	-0.572	-0.572		-0.470	
156	08.05.79	5094.000	-0.642	-0.642		-0.453	
157	22.05.79	4471.000	-0.626	-0.626		-0.409	
158	28.05.79	5971.000	-0.705	-0.705		-0.483	
159	31.05.79	6707.000	-0.505	-0.505		-0.483	
160	05.06.79	6339.000	-0.501	-0.501		-0.455	
161	15.06.79	6226.000	-0.402	-0.402		-0.412	
162	27.06.79	5434.000	-0.425	-0.425		-0.427	
163	10.07.79	4896.000	-0.346	-0.346		-0.420	
164	25.07.79	4245.000	-0.470		-0.470		-0.495
165	23.08.79	2499.000	-0.358	-0.358		-0.411	
166	20.09.79	1738.000	-0.468		-0.468		-0.473
167	23.10.79	1330.000	-0.387		-0.387		-0.430
168	21.11.79	883.000	-0.390	-0.390			
169	14.12.79	1183.000	-0.396	-0.396		-0.516	
170	18.02.80	604.000	-0.360	-0.360			
172	25.03.80	722.000	-0.389	-0.389			
173	05.03.80	795.000	-0.504		-0.504		
174	21.04.80	2931.000	-0.412		-0.412		-0.518
175	12.05.80	5493.000	-0.350	-0.350		-0.458	
176	29.05.80	4078.000	-0.267		-0.267		-0.528

No.	Date	Q (m^3/s)	Be (m)	Be(r) (m)	Be(f) (m)	Be(r) Moving av. (11) (m)	Be(f) Moving av. (11) (m)
177	05.06.80	4587.000	-0.301		-0.301		-0.423
178	16.06.80	4786.000	-0.329	-0.329		-0.439	
179	03.07.80	4757.000	-0.140	-0.140		-0.449	
180	02.09.80	2244.000	-0.154		-0.154		-0.435
181	01.10.80	2533.000	-0.203		-0.203		-0.382
182	05.11.80	1693.000	-0.242	-0.242		-0.593	
183	22.01.81	1563.000	-0.481	-0.481		-0.485	
184	06.03.81	1345.000	-0.185		-0.185		-0.417
185	02.04.81	1662.000	-0.170	-0.170		-0.506	
186	07.05.81	3376.000	-0.208	-0.208		-0.359	
187	27.05.81	7529.000	-0.313		-0.313		-0.649
188	11.06.81	6386.000	-0.274	-0.274		-0.416	
189	16.06.81	5440.000	-0.230		-0.230		-0.576
190	13.07.81	4333.000	-0.228		-0.228		-0.492
191	20.08.81	3344.000	-0.259		-0.259		-0.454
192	02.02.82	993.000	-0.235		-0.235		
193	16.03.82	902.000	-0.161		-0.161		
194	19.04.82	949.000	-0.194	-0.194		-0.527	
195	04.05.82	2966.000	-0.157	-0.157		-0.369	
196	21.05.82	7474.000	-0.270	-0.270		-0.406	
197	08.06.82	8723.000	-0.321	-0.321		-0.486	
198	19.06.82	10162.000	-0.389	-0.389			
199	06.07.82	8022.000	-0.273	-0.273		-0.487	
200	16.07.82	6151.000	-0.413		-0.413		-0.526
201	09.08.82	5414.000	-0.311		-0.311		-0.583
202	15.09.82	5099.000	-0.223		-0.223		-0.450
203	20.04.83	1904.000	-0.262	-0.262		-0.474	
204	27.04.83	3120.000	-0.220	-0.220		-0.307	
205	31.05.83	6267.000	-0.253	-0.253		-0.421	
206	06.06.83	6779.000	-0.271	-0.271		-0.470	
207	21.06.83	5799.000	-0.266	-0.266		-0.486	
208	12.07.83	5357.000	-0.224	-0.224		-0.442	
209	05.01.84	2296.000	-0.013	-0.013		-0.399	
210	16.04.84	1800.000	-0.058	-0.058		-0.488	
211	18.05.84	3180.000	0.004	0.004		-0.312	
212	12.06.84	5970.000	-0.048	-0.048		-0.525	
213	20.06.84	7650.000	-0.022		-0.022		-0.595
214	03.07.84	7920.000	0.010	0.010		-0.452	
215	09.07.84	7450.000	-0.082	-0.082		-0.459	
216	23.07.84	5500.000	0.080		0.080		-0.475
217	28.11.84	1390.000	0.086	0.086		-0.460	
218	04.12.84	1130.000	0.172		0.172		-0.331
219	22.01.85	890.000	0.149		0.149		
220	20.02.85	737.000	0.125		0.125		
221	19.04.85	3360.000	-0.012	-0.012		-0.317	
222	01.05.85	2220.000	0.048		0.048		-0.424

No.	Date	Q (m^3/s)	Be (m)	Be(r) (m)	Be(f) (m)	Be(r) Moving av. (11) (m)	Be(f) Moving av. (11) (m)
223	21.05.85	6400.000	0.063	0.063		-0.420	
224	28.05.85	9730.000	0.031	0.031		-0.524	
225	10.06.85	8360.000	-0.152		-0.152		-0.524
226	19.06.85	6830.000	-0.090		-0.090		-0.535
227	17.07.85	4500.000	-0.035		-0.035		-0.432
228	31.07.85	3210.000	0.124		0.124		-0.479
229	16.01.86	885.000	-0.070	-0.070		-0.481	
230	18.04.86	1940.000	0.073		0.073		-0.385
231	21.05.86	3610.000	0.111	0.111		-0.353	
232	28.05.86	5540.000	-0.038	-0.038		-0.467	
233	03.06.86	10900.000	-0.328	-0.328			
234	19.06.86	8260.000	-0.451	-0.451		-0.450	
235	28.07.86	4520.000	-0.065	-0.065		-0.400	
236	16.10.86	1610.000	-0.451		-0.451		-0.483

APPENDIX 5I.2

Data for discharge (Q), sediment concentartion (C) and moving averaged sediment concentrations (11 points) on rising (r) and falling (f) stages of single hydrological events on the Fraser River at Agassiz station (1968-1986).

No.	Date	Q (m^3/s)	C (mg/L)	C(r) (mg/L)	C(f) (mg/L)	C(r) Moving av. (11) (mg/L)	C(f) Moving av. (11) (mg/L)
1	14.03.68	2239.000	125		125		166.636
2	09.04.68	1749.000	52	52		69.273	
3	24.04.68	1769.000	54	54		68.636	
4	09.05.68	3481.000	401	401		342.182	
5	20.05.68	5915.000	503	503		340.909	
6	24.05.68	7896.000	821	821		377.909	
7	13.06.68	8122.000	263	263		438.545	
8	26.06.68	7415.000	180	180		473.727	
9	09.07.68	8405.000	257	257		385.364	
10	16.07.68	8405.000	240	240		357.727	
11	19.07.68	6735.000	213		213		192.000
12	22.07.68	5802.000	206		206		218.818
13	25.07.68	5575.000	193		193		174.273
14	30.07.68	5292.000	95		95		145.727
15	07.08.68	3877.000	112		112		87.909
16	21.08.68	3226.000	81		81		85.455
17	13.09.68	2915.000	106		106		77.091
18	07.10.68	2601.000	41		41		79.818
19	08.11.68	2541.000	39		39		178.182
20	20.11.68	2094.000	30		30		43.455
21	04.12.68	2035.000	67		67		38.000
22	17.03.69	900.000	39	39		65.545	
23	26.03.69	829.000	32		32		
24	08.05.69	4273.000	236	236		331.364	
25	12.05.69	5094.000	257	257		345.182	
26	16.05.69	5745.000	337		337		218.727
27	29.05.69	7160.000	381	381		412.636	
28	26.05.69	6311.000	209	209		308.182	
29	10.06.69	7924.000	297		297		
30	24.06.69	5858.000	160		160		207.818
31	08.07.69	4981.000	107		107		168.000
32	23.07.69	3424.000	59		59		78.545
33	07.08.69	2830.000	52	52		221.455	
34	20.08.69	3283.000	86		86		72.455
35	09.09.69	3113.000	84		84		78.909
36	19.09.69	3198.000	94	94		286.727	
37	02.10.69	3311.000	29		29		74.455
38	23.10.69	2222.000	30	30		221.455	

No.	Date	Q (m^3/s)	C (mg/L)	C(r) (mg/L)	C(f) (mg/L)	C(r) Moving av. (11) (mg/L)	C(f) Moving av. (11) (mg/L)
39	06.11.69	2173.000	33		33		162.909
40	19.11.69	2128.000	33		33		52.091
41	27.11.69	2332.000	62		62		170.727
42	09.12.69	1840.000	22		22		32.091
43	17.12.69	1602.000	21		21		21.364
44	29.12.69	1344.000	11	11		102.000	
45	28.01.70	1191.000	17		17		17.727
46	05.02.70	1132.000	14		14		17.727
47	09.02.70	1098.000	14		14		19.182
48	13.02.70	1180.000	15	15		103.818	
49	18.02.70	1121.000	13		13		19.636
50	03.03.70	1013.000	16		16		20.727
51	16.04.70	1443.000	89	89		101.000	
52	26.04.70	1825.000	154	154		193.818	
53	08.05.70	2972.000	208	208		241.455	
54	19.05.70	5066.000	301	301		331.364	
55	02.06.70	5434.000	170	170		297.273	
56	11.06.70	8066.000	394		394		
57	17.06.70	5830.000	247		247		212.727
58	02.07.70	5603.000	160		160		192.364
59	14.07.70	3990.000	103		103		95.455
60	23.07.70	3509.000	101		101		84.273
61	12.08.70	2915.000	181		181		72.455
62	24.08.70	2142.000	55		55		50.727
63	22.09.70	1817.000	25	25		206.545	
64	28.10.70	1395.000	14		14		18.182
65	18.11.70	1240.000	15		15		16.727
66	04.02.71	1172.000	20		20		16.636
67	23.02.71	1084.000	16	16		96.000	
68	19.04.71	1347.000	268	268		100.364	
69	29.04.71	4104.000	856	856		291.000	
70	13.05.71	6707.000	371	371		392.455	
71	18.05.71	7301.000	495	495		449.818	
72	02.06.71	7415.000	189	189		419.455	
73	10.06.71	8632.000	301	301		423.273	
74	08.07.71	5264.000	139	139		305.455	
75	27.07.71	5490.000	108		108		156.455
76	12.08.71	3962.000	94		94		90.000
77	01.11.71	1698.000	16		16		26.545
78	22.03.72	2632.000	304	304		241.727	
79	11.04.72	2507.000	183	183		325.364	
80	03.05.72	3368.000	368	368		348.000	
81	12.05.72	4896.000	467	467		324.909	
82	18.05.72	8490.000	827	827		409.909	
83	30.05.72	9792.000	487	487			
84	16.06.72	13329.000	633	633			

No.	Date	Q (m^3/s)	C (mg/L)	C(r) (mg/L)	C(f) (mg/L)	C(r) Moving av. (11) (mg/L)	C(f) Moving av. (11) (mg/L)
85	29.06.72	9198.000	250		250		
86	19.07.72	7132.000	144		144		247.273
87	24.08.72	3283.000	84		84		74.455
88	02.10.72	1600.000	27	27		63.727	
89	23.11.72	1203.000	18		18		18.000
90	20.02.73	951.000	42		42		20.727
91	06.04.73	1217.000	184	184		93.091	
92	19.04.73	1769.000	182	182		57.182	
93	09.05.73	3792.000	539	539		328.273	
94	24.05.73	6764.000	354		354		186.455
95	05.06.73	5264.000	159		159		162.818
96	20.06.73	5688.000	140	140		271.727	
97	29.06.73	8235.000	413	413		388.909	
98	19.07.73	4726.000	95		95		163.273
99	21.08.73	2708.000	65		65		70.727
100	27.09.73	1559.000	28	28		87.455	
101	05.12.73	1259.000	8		8		15.909
102	27.02.74	962.000	198	198		56.636	
103	28.03.74	1121.000	44	44		85.091	
104	17.04.74	2309.000	485	485		255.909	
105	30.04.74	4839.000	812	812		336.273	
106	16.05.74	5632.000	264		264		194.000
107	30.05.74	7188.000	341	341		406.545	
108	19.06.74	10584.000	638	638			
109	11.07.74	7160.000	154		154		273.455
110	22.08.74	3396.000	84		84		77.818
111	25.09.74	1924.000	30		30		33.132
112	25.02.75	659.000	23	23			
113	08.03.75	852.000	37		37		
114	07.05.75	2493.000	328	328		291.000	
115	16.05.75	5830.000	530	530		328.091	
116	05.06.75	6650.000	337	337		385.818	
117	08.06.75	7782.000	320	320		368.909	
118	03.07.75	6452.000	106		106		192.545
119	14.07.75	7075.000	139		139		233.727
120	07.08.75	3764.000	82		82		86.818
121	19.11.75	2420.000	42	42		258.364	
122	18.09.75	1998.000	33		33		36.273
123	23.03.76	965.000	29	29		65.364	
124	28.04.76	3141.000	240	240		269.455	
125	07.05.76	6962.000	1160	1160		410.727	
126	21.05.76	7330.000	263		263		276.727
127	08.06.76	5745.000	140		140		213.636
128	23.06.76	9367.000	378	378		479.727	
129	21.07.76	7471.000	270	270		383.455	
130	26.08.76	6339.000	148		148		201.909

No.	Date	Q (m^3/s)	C (mg/L)	C(r) (mg/L)	C(f) (mg/L)	Moving av. (11) (mg/L)	C(f) Moving av. (11) (mg/L)
177	05.06.80	4587.000	119		119		133.727
178	16.06.80	4786.000	86	86		390.727	
179	03.07.80	4757.000	123	123		347.000	
180	02.09.80	2244.000	43		43		167.182
181	01.10.80	2533.000	33		33		179.909
182	05.11.80	1693.000	22	22		70.000	
183	22.01.81	1563.000	26	26		91.364	
184	06.03.81	1345.000	16		16		17.000
185	02.04.81	1662.000	106	106		69.364	
186	07.05.81	3376.000	179	179		346.909	
187	27.05.81	7529.000	559		559		267.273
188	11.06.81	6386.000	199	199		305.364	
189	16.06.81	5440.000	142		142		161.455
190	13.07.81	4333.000	72		72		134.091
191	20.08.81	3344.000	60		60		75.273
192	02.02.82	993.000	6		6		20.545
193	16.03.82	902.000	12		12		19.727
194	19.04.82	949.000	62	62		67.545	
195	04.05.82	2966.000	513	513		226.182	
196	21.05.82	7474.000	847	847		376.364	
197	08.06.82	8723.000	420	420		443.727	
198	19.06.82	10162.000	410	410			
199	06.07.82	8022.000	217	217		387.909	
200	16.07.82	6151.000	160		160		222.636
201	09.08.82	5414.000	159		159		156.636
202	15.09.82	5099.000	319		319		170.091
203	20.04.83	1904.000	48	48		218.727	
204	27.04.83	3120.000	248	248		269.818	
205	31.05.83	6267.000	268	268		320.182	
206	06.06.83	6779.000	224	224		412.455	
207	21.06.83	5799.000	137	137		303.455	
208	12.07.83	5357.000	160	160		306.455	
209	05.01.84	2296.000	1160	1160		235.636	
210	05.01.84	2296.000	1160		1160		167.273
210	16.04.84	1800.000	81	81		167.182	
211	18.05.84	3180.000	262	262		278.273	
212	12.06.84	5970.000	400	400		325.818	
213	20.06.84	7650.000	315		315		296.273
214	03.07.84	7920.000	331	331		383.364	
215	09.07.84	7450.000	207	207		398.364	
216	23.07.84	5500.000	104		104		158.091
217	28.11.84	1390.000	20	20		108.636	
218	04.12.84	1130.000	28		28		20.182
219	22.01.85	890.000	12		12		19.455
220	20.02.85	737.000	17		17		
221	19.04.85	3360.000	496	496		289.091	
222	01.05.85	2220.000	80		80		166.364

No.	Date	Q (m^3/s)	C (mg/L)	C(r) (mg/L)	C(f) (mg/L)	C(r) Moving av. (11) (mg/L)	C(f) Moving av. (11) (mg/L)
131	08.10.76	2595.000	56		56		177.636
132	03.12.76	1460.000	18		18		18.818
133	15.02.77	1254.000	2		2		17.091
134	06.04.77	1075.000	72	72		81.455	
135	20.04.77	2323.000	174		174		167.818
136	03.05.77	4726.000	381		381		161.182
137	18.05.77	4613.000	177		177		153.364
138	15.06.77	5575.000	215		215		184.364
139	27.06.77	6254.000	194		194		208.000
140	21.07.77	5886.000	232	232		333.909	
141	16.08.77	3453.000	65		65		85.273
142	16.09.77	2148.000	35		35		153.182
143	30.11.77	1155.000	34		34		17.364
144	31.03.78	1463.000	158	158		89.000	
145	09.05.78	3339.000	101		101		75.182
146	07.06.78	6116.000	422	422		341.909	
147	14.06.78	5886.000	324		324		203.182
148	29.06.78	5199.000	122		122		163.818
149	13.07.78	4641.000	115		115		158.455
150	03.08.78	3311.000	77		77		72.727
151	12.10.78	2066.000	24		24		38.182
152	26.10.78	1800.000	26	26		70.636	
153	05.03.79	855.000	135	135			
154	13.03.79	931.000	131	131		64.909	
155	23.04.79	1271.000	199	199		100.909	
156	08.05.79	5094.000	1020	1020		335.636	
157	22.05.79	4471.000	188	188		326.818	
158	28.05.79	5971.000	509	509		336.273	
159	31.05.79	6707.000	654	654		418.455	
160	05.06.79	6339.000	255	255		331.273	
161	15.06.79	6226.000	234	234		310.636	
162	27.06.79	5434.000	151	151		276.455	
163	10.07.79	4896.000	129	129		327.455	
164	25.07.79	4245.000	129		129		106.909
165	23.08.79	2499.000	56	56		305.545	
166	20.09.79	1738.000	31		31		31.182
167	23.10.79	1330.000	26		26		17.091
168	21.11.79	883.000	10	10			
169	14.12.79	1183.000	106	106		87.636	
170	07.02.80	674.000	10		10		
171	18.02.80	604.000	9	9			
172	25.03.80	722.000	15	15			
173	05.03.80	795.000	16		16		
174	21.04.80	2931.000	37		37		81.364
175	12.05.80	5493.000	191	191		225.636	
176	29.05.80	4078.000	66		66		105.636

No.	Date	Q (m^3/s)	C (mg/L)	C(r) (mg/L)	C(f) (mg/L)	C(r) Moving av. (11) (mg/L)	C(f) Moving av. (11) (mg/L)
223	21.05.85	6400.000	186	186		372.455	
224	28.05.85	9730.000	635	635		515.455	
225	10.06.85	8360.000	249		249		
226	19.06.85	6830.000	176		176		222.727
227	17.07.85	4500.000	107		107		132.545
228	31.07.85	3210.000	74		74		82.182
229	16.01.86	885.000	7	7		59.818	
230	18.04.86	1940.000	58		58		34.273
231	21.05.86	3610.000	145	145		325.636	
232	28.05.86	5540.000	375	375		248.000	
233	03.06.86	10900.000	684	684			
234	19.06.86	8260.000	288	288		398.000	
235	28.07.86	4520.000	80	80		332.818	
236	16.10.86	1610.000	33		33		25.909

APPENDIX 5J.1

Channel hydraulic data: discharge (Q), stream-bed elevation (Be) and moving averaged stream-bed elevations (11 points) on rising (r) and falling (f) stages of single hydrological events on the Chilliwack River at Vedder Crossing station (1965-1975).

No.	Date	Discharge ($m^3 s^{-1}$)	Be (m)	Be (r) (m)	Be (f) (m)	Be (r) Moving av. (11)	Be (f) Moving av. (11)
1	07.06.65	151.971	0.580	0.580		0.434	
2	03.08.65	55.751	0.474		0.474		0.215
3	01.09.65	26.149	0.465		0.465		0.214
4	15.11.65	85.466	0.834	0.834		0.444	
5	24.01.66	32.262	0.332		0.332		0.187
6	14.03.66	41.884	0.521	0.521		0.230	
7	05.05.66	118.577	0.552	0.552		0.342	
8	11.05.66	137.538	0.562		0.562		0.401
9	23.06.66	119.143	0.424		0.424		0.387
10	19.08.66	40.752	0.242		0.242		0.139
11	09.09.66	29.715	0.125		0.125		0.188
12	14.09.66	26.574	0.214		0.214		0.227
13	19.10.66	40.752	0.282	0.282		0.217	
14	18.11.66	46.129	0.330		0.330		0.193
15	15.12.66	148.575	0.536	0.536		0.465	
16	20.01.67	86.598	0.648	0.648		0.418	
17	15.02.67	55.185	0.510	0.510		0.228	
18	15.03.67	31.130	0.335	0.335		0.268	
19	27.04.67	29.998	0.377	0.377		0.247	
20	25.05.67	129.048	0.486	0.486		0.500	
21	31.05.67	126.501	0.600		0.600		0.404
22	07.06.67	214.514	0.666		0.666		0.385
23	19.06.67	247.625	0.662	0.662		0.456	
24	28.06.67	196.402	0.362		0.362		0.388
25	11.07.67	103.295	0.520		0.520		0.349
26	11.08.67	59.713	0.451		0.451		0.332
27	11.10.67	170.309	0.596		0.596		0.426
28	31.10.67	485.911	0.462		0.462		
29	02.11.67	166.970	0.459		0.459		0.415
30	28.11.67	48.393	0.433		0.433		0.281
31	16.01.68	141.415	0.499		0.499		0.447
32	24.01.68	314.130	0.174		0.174		0.161
33	14.02.68	55.468	0.275		0.275		0.154
34	26.03.68	50.940	0.327	0.327		0.188	
35	09.05.68	64.807	0.365	0.365		0.229	
36	24.06.68	116.426	0.318	0.318		0.287	
37	24.07.68	75.080	0.294		0.294		0.440
38	10.09.68	32.149	0.225	0.225		0.258	

39	13.11.68	65.373	0.294		0.294		0.302
40	23.01.69	32.828	0.209		0.209		0.179
41	04.02.69	25.328	0.152	0.152		0.230	
42	16.05.69	156.499	0.218		0.218		0.506
43	04.06.69	209.703	0.114	0.114		0.251	
44	16.07.69	56.317	0.171		0.171		0.328
45	19.09.69	56.883	-0.219	-0.219		0.229	
46	25.09.69	118.860	0.244		0.244		0.371
47	05.11.69	95.654	0.160	0.160		0.127	
48	07.11.69	66.505	0.190		0.190		0.274
49	17.12.69	54.619	0.148		0.148		0.162
50	09.01.70	39.054	0.078	0.078		0.247	
51	03.03.70	39.054	-0.016		-0.016		0.066
52	04.06.70	198.666	0.216	0.216		0.231	
53	11.06.70	99.616	0.332		0.332		0.372
54	03.09.70	25.300	0.147	0.147		0.205	
55	15.09.70	20.206	0.225		0.225		
56	28.10.70	25.215	0.143		0.143		0.218
57	13.11.70	44.148	0.102	0.102		0.246	
58	17.11.70	60.138	0.269		0.269		0.275
59	07.12.70	80.655	0.324	0.324		0.409	
60	19.01.71	118.860	0.343	0.343		0.447	
61	05.02.71	103.578	0.447		0.447		0.394
62	09.06.71	140.651	0.362		0.362		0.516
63	06.07.71	102.163	0.333		0.333		0.367
64	21.07.71	190.883	0.276		0.276		0.447
65	15.09.71	35.941	0.145		0.145		0.143
66	25.10.71	44.714	0.166	0.166		0.254	
67	16.01.72	86.881	0.057	0.057		0.379	
68	11.04.72	73.580	0.315		0.315		0.290
69	19.04.72	50.091	0.254		0.254		0.173
70	30.05.72	348.090	0.106	0.106		0.375	
71	12.06.72	245.361	0.299		0.299		0.323
72	05.07.72	213.099	0.256	0.256		0.345	
73	31.08.72	55.185	-0.298		-0.298		0.171
74	17.10.72	26.715	0.188		0.188		0.265
75	22.11.72	21.140	0.141	0.141			
76	20.12.72	113.766	0.012	0.012		0.250	
77	16.01.73	86.881	0.057		0.057		0.375
78	29.01.73	39.620	-0.293		-0.293		0.103
79	29.03.73	21.140	0.210		0.210		
80	22.05.73	101.031	0.201		0.201		0.289
81	20.06.73	82.636	0.358	0.358		0.466	
82	06.09.73	20.942	0.206	0.206			
83	23.10.73	37.922	0.250		0.250		0.043
84	11.12.73	76.127	0.348		0.348		0.391

85	18.01.74	159.895	0.466		0.466		0.525
86	25.02.74	33.394	0.250	0.250		0.198	
87	01.04.74	70.750	0.304		0.304		0.279
88	08.05.74	163.574	0.377	0.377		0.380	
89	12.06.74	234.890	0.478	0.478		0.386	
90	19.06.74	359.410	0.477	0.477			
91	23.06.74	278.755	-0.035		-0.035		0.245
92	06.08.74	128.765	0.211		0.211		0.373
93	11.10.74	24.564	0.059		0.059		0.220
94	20.11.74	48.110	0.156	0.156		0.252	
95	20.12.74	72.165	0.164	0.164		0.198	
96	23.01.75	98.767	0.210	0.210		0.179	
97	17.03.75	33.677	0.126		0.126		0.162
98	30.04.75	34.243	0.104	0.104		0.188	
99	28.05.75	94.522	0.195	0.195		0.254	
100	04.06.75	175.460	0.335		0.335		0.406
101	05.06.75	264.605	0.419	0.419		0.426	
102	09.06.75	138.104	0.270		0.270		0.381
103	15.07.75	125.935	0.220		0.220		0.340
104	11.09.75	32.262	0.081		0.081		0.175
105	04.11.75	170.083	0.191	0.191		0.296	
106	03.12.75	532.040	0.406	0.406			
107	04.12.75	489.307	-0.118		-0.118		
108	05.12.75	263.473	0.323		0.323		0.286
109	09.12.75	319.790	0.464	0.464		0.426	
110	12.12.75	142.066	0.887		0.887		0.486
111	17.12.75	76.976	0.939		0.939		0.394

APPENDIX 5J.2

Data for discharge (Q), sediment concentartion (C) and moving averaged sediment concentrations (11 points) on rising (r) and falling (f) stages of single hydrological events on the Chilliwack River at Vedder Crossing station (1965-(1975).

No	Date	Discharge ($m^3 s^{-1}$)	C ($mg L^{-1}$)	C (r) ($mg L^{-1}$)	C(f) ($mg L^{-1}$)	C(r) Moving av. (11)	C(f) Moving av. (11)
1	07.06.65	151.971	15	15		54.273	
2	03.08.65	55.751	4		4		10.636
3	01.09.65	26.149	5		5		
4	15.11.65	85.466	36	36		35.818	
5	24.01.66	32.262	30		30		10.000
6	14.03.66	41.884	15	15		15.273	
7	05.05.66	118.577	4	4		39.182	
8	11.05.66	137.538	4		4		32.091
9	23.06.66	119.143	4		4		28.545
10	19.08.66	40.752	5		5		9.909
11	09.09.66	29.715	4		4		8.545
12	14.09.66	26.574	4		4		5.455
13	19.10.66	40.752	17	17		14.636	
14	18.11.66	46.129	23		23		6.909
15	15.12.66	148.575	85	85		52.636	
16	20.01.67	86.598	100	100		40.545	
17	15.02.67	55.185	12	12		22.727	
18	15.03.67	31.130	5	5		6.909	
19	27.04.67	29.998	4	4			
20	25.05.67	129.048	21	21		52.909	
21	31.05.67	126.501	18		18		35.909
22	07.06.67	214.514	105		105		
23	19.06.67	247.625	125	125		156.273	
24	28.06.67	196.402	130		130		
25	11.07.67	103.295	34		34		27.364
26	11.08.67	59.713	6	6		23.727	
27	11.10.67	170.309	108	108		76.000	
28	31.10.67	485.911	157	157			
29	02.11.67	166.970	89		89		77.009
30	28.11.67	48.393	5		5		7.727
31	16.01.68	141.415	72		72		53.636
32	24.01.68	314.130	165	165			
33	14.02.68	55.468	5	5		21.727	
34	26.03.68	50.940	8	8		22.455	
35	09.05.68	64.807	67	67		26.909	
36	24.06.68	116.426	50	50		37.636	
37	24.07.68	75.080	20		20		18.000
38	10.09.68	32.149	6	6		7.818	

39	13.11.68	65.373	16		16		12.727
40	23.01.69	32.828	4		4		10.091
41	04.02.69	25.328	5	5			
42	16.05.69	156.499	44		44		66.273
43	04.06.69	209.703	76	76		97.727	
44	16.07.69	56.317	9		9		11.273
45	19.09.69	56.883	30	30		22.455	
46	25.09.69	118.860	70		70		25.909
47	05.11.69	95.654	47	47		39.727	
48	07.11.69	66.505	26		26		14.091
49	17.12.69	54.619	5		5		8.091
50	09.01.70	39.054	3	3		14.273	
51	03.03.70	39.054	3		3		10.000
52	04.06.70	198.666	92	92		90.455	
53	11.06.70	99.616	34		34		29.455
54	03.09.70	25.300	6	6			
55	15.09.70	20.206	1		1		
56	28.10.70	25.215	0		0		
57	13.11.70	44.148	0	0		15.182	
58	17.11.70	60.138	8		8		12.636
59	07.12.70	80.655	4	4		26.091	
60	19.01.71	118.860	28	28		47.364	
61	05.02.71	103.578	77		77		26.182
62	09.06.71	140.651	30		30		43.727
63	06.07.71	102.163	5		5		26.727
64	21.07.71	190.883	34		34		
65	15.09.71	35.941	0		0		11.727
66	25.10.71	44.714	22	22		17.000	
67	16.01.72	86.881	1	1		39.000	
68	11.04.72	73.580	30		30		17.364
69	19.04.72	50.091	10		10		6.909
70	30.05.72	348.090	314	314			
71	12.06.72	245.361	90		90		
72	05.07.72	213.099	40	40		112.273	
73	31.08.72	55.185	1		1		10.182
74	17.10.72	26.715	6		6		8.727
75	22.11.72	21.140	5	5			
76	20.12.72	113.766	58	58		45.364	
77	16.01.73	86.881	7		7		24.000
78	29.01.73	39.620	3		3		10.182
79	29.03.73	21.140	2		2		
80	22.05.73	101.031	16		16		27.091
81	20.06.73	82.636	8	8		29.909	
82	06.09.73	20.942	5	5			
83	23.10.73	37.922	17		17		11.818
84	11.12.73	76.127	11		11		17.727

85	18.01.74	159.895	113		113		75.455
86	25.02.74	33.394	10	10		7.364	
87	01.04.74	70.750	10		10		14.636
88	08.05.74	163.574	18	18		53.364	
89	12.06.74	234.890	156	156		139.182	
90	19.06.74	359.410	288	288			
91	23.06.74	278.755	156		156		
92	06.08.74	128.765	7		7		35.091
93	11.10.74	24.564	1		1		
94	20.11.74	48.110	65	65		16.636	
95	20.12.74	72.165	20	20		26.273	
96	23.01.75	98.767	95	95		40.909	
97	17.03.75	33.677	37		37		10.182
98	30.04.75	34.243	10	10		8.818	
99	28.05.75	94.522	10	10		37.545	
100	04.06.75	175.460	125		125		89.364
101	05.06.75	264.605	180	180		160.727	
102	09.06.75	138.104	63		63		36.000
103	15.07.75	125.935	16		16		29.818
104	11.09.75	32.262	3		3		10.273
105	04.11.75	170.083	100	100		67.182	
106	03.12.75	532.040	4000				
107	04.12.75	489.307	2200				55.091
108	05.12.75	263.473	750				19.364
109	09.12.75	319.790	175	175			
110	12.12.75	142.066	25		25		
111	17.12.75	76.976	20		20		

APPENDIX 5K.1

Channel hydraulic data: discharge (Q), stream-bed elevation (Be) and moving averaged stream-bed elevations (11 points) on rising (r) and falling (f) stages of single hydrological events on the Fraser River at Mission station (1969-1988).

No	Date	Discharge ($m^3 s^{-1}$)	Be (m)	Be (r) (m)	Be (f) (m)	Be Moving av. (11)	Be Moving av. (11)
1	25.02.69	1148.980	7.160		7.160		
2	03.03.69	982.010	7.161		7.161		
3	12.03.69	1248.030	7.220		7.220		7.343
4	19.03.69	931.070	7.074	7.074			
5	25.03.69	1185.770	7.092		7.092		7.259
6	09.04.69	2235.700	7.018	7.018		7.322	
7	15.04.69	3056.400	6.850	6.850		7.196	
8	23.04.69	3452.600	7.134		7.134		7.118
9	30.04.69	3820.500	7.091	7.091		7.194	
10	09.05.69	5009.100	6.925	6.925		7.100	
11	15.05.69	6905.200	6.787	6.787		7.015	
12	23.05.69	6876.900	6.980	6.980		6.986	
13	31.05.69	7980.600	7.127	7.127		7.049	
14	05.06.69	7980.600	6.926	6.926		7.066	
15	11.06.69	9112.600	6.607		6.607		7.095
16	20.06.69	7810.800	6.989		6.989		7.122
17	27.06.69	6650.500	6.946		6.946		7.159
18	10.07.69	5433.600	7.069		7.069		7.141
19	21.07.69	4273.300	7.074		7.074		7.245
20	01.08.69	3763.900	6.905		6.905		7.165
21	13.08.69	3707.300	7.215	7.215		7.132	
22	18.08.69	3792.200	6.647		6.647		7.159
23	27.08.69	3622.400	7.159		7.159		7.119
24	02.09.69	2999.800	7.164		7.164		7.112
25	12.09.69	2858.300	7.068		7.068		7.162
26	16.09.69	3339.400	6.915	6.915		7.130	
27	17.09.69	3282.800	6.967	6.967		7.101	
28	23.09.69	3735.600	6.775	6.775		7.136	
29	15.10.69	2436.630	7.203		7.203		7.204
30	21.10.69	2289.470	7.101		7.101		7.246
31	09.01.70	950.880	7.147	7.147			
32	23.01.70	1389.530	7.144	7.144			
33	25.02.70	1154.640	7.146		7.146		7.244
34	26.03.70	1533.860	7.145		7.145		7.357
35	07.05.70	3028.100	7.231	7.231		7.209	
36	11.05.70	3169.600	7.068		7.068		7.102
37	21.05.70	5546.800	6.998		6.998		7.117
38	26.05.70	5829.800	6.889	6.889		7.121	

39	03.06.70	6282.600	6.874	6.874		6.981	
40	09.06.70	9452.200	6.437	6.437		6.926	
41	12.06.70	8688.100	6.684		6.684		7.096
42	22.06.70	7527.800	6.880	6.880		7.039	
43	29.06.70	7075.000	6.993		6.993		7.166
44	09.07.70	5292.100	6.937	6.937		7.119	
45	22.07.70	3877.100	7.141		7.141		7.195
46	29.07.70	3622.400	6.787		6.787		7.117
47	06.08.70	2943.200	7.154	7.154		7.218	
48	14.08.70	3169.600	7.237		7.237		7.084
49	24.09.70	1930.060	7.248	7.248		7.327	
50	21.10.70	1202.750	7.320		7.320		7.279
51	16.12.70	1491.410	7.237	7.237			
52	24.03.71	1528.200	7.211	7.211		7.289	
53	30.04.71	4556.300	7.065	7.065		7.179	
54	12.05.71	7329.700	6.784	6.784		7.072	
55	19.05.71	7641.000	7.029		7.029		7.149
56	26.05.71	7669.300	6.988	6.988		7.049	
57	14.06.71	9395.600	6.781		6.781		7.170
58	25.06.71	8829.600	6.902	6.902		6.944	
59	09.07.71	5858.100	7.192	7.192		7.101	
60	19.07.71	7103.300	7.112		7.112		7.140
61	05.08.71	5829.800	7.287		7.287		7.061
62	26.08.71	3650.700	7.408		7.408		7.120
63	20.10.71	2238.530	7.300		7.300		7.244
64	15.12.71	1242.370	7.229		7.229		7.308
65	23.03.72	4584.600	7.164	7.164		7.165	
66	04.05.72	3622.400	7.177	7.177		7.142	
67	10.05.72	4924.200	7.083	7.083		7.133	
68	18.05.72	8857.900	7.005	7.005		6.947	
69	29.05.72	10131.400	7.238	7.238			
70	07.06.72	12084.100	7.283		7.283		
71	17.06.72	13640.600	6.925	6.925			
72	23.06.72	10782.300	7.026		7.026		
73	30.06.72	10188.000	7.453		7.453		7.028
74	06.07.72	9735.200	7.526		7.526		7.082
75	20.07.72	8235.300	7.207		7.207		7.112
76	31.07.72	6254.300	7.114		7.114		7.124
77	18.08.72	4443.100	7.600		7.600		7.294
78	30.08.72	3650.700	7.378		7.378		7.150
79	02.10.72	2102.690	7.581		7.581		7.337
80	22.11.72	1095.210	7.043		7.043		
81	17.05.73	5320.400	7.156	7.156		7.114	
82	26.05.73	7556.100	7.150	7.150		6.984	
83	06.06.73	5801.500	7.109	7.109		7.106	

84	14.06.73	7273.100	7.170		7.170		7.139
85	21.06.73	6226.000	7.213	7.213		7.083	
86	30.06.73	9027.700	6.978		6.978		7.067
87	20.07.73	5631.700	7.262	7.262		7.055	
88	07.05.74	6763.700	6.836	6.836		6.950	
89	14.05.74	6763.700	7.165		7.165		7.179
90	06.06.74	8093.800	7.050	7.050		7.034	
91	13.06.74	8291.900	7.061	7.061		7.037	
92	21.06.74	12593.500	6.859	6.859			
93	27.06.74	11716.200	6.313		6.313		
94	05.07.74	9622.000	7.185		7.185		7.112
95	18.07.74	8207.000	7.198	7.198		7.036	
96	30.07.74	7584.400	7.218		7.218		7.131
97	06.08.74	6735.400	7.019		7.019		7.174
98	21.02.75	1010.310	7.631	7.631			
99	04.04.75	1047.100	7.355		7.355		
100	16.04.75	1613.100	7.776	7.776		7.305	
101	06.05.75	2784.720	7.567	7.567		7.238	
102	17.05.75	6197.700	6.589		6.589		7.078
103	27.05.75	4754.400	7.385		7.385		7.275
104	04.06.75	7244.800	7.223	7.223		7.068	
105	17.06.75	8461.700	7.395	7.395		7.019	
106	04.07.75	7131.600	7.527		7.527		7.142
107	15.07.75	8263.600	7.217		7.217		7.090
108	29.07.75	5065.700	7.452		7.452		7.157
109	08.08.75	4216.700	7.397		7.397		7.205
110	29.08.75	4216.700	7.582		7.582		7.205
111	14.05.76	9423.900	6.980	6.980		6.909	
112	27.05.76	7612.700	7.054	7.054		7.004	
113	04.05.76	6537.300	7.164		7.164		7.115
114	17.06.76	8008.900	7.108	7.108		7.043	
115	24.06.76	10329.500	6.727		6.727		
116	07.07.76	10018.200	6.834	6.834			
117	16.06.76	8829.600	7.360		7.360		7.077
118	28.07.76	7471.200	7.440		7.440		7.150
119	19.08.76	6678.800	7.337		7.337		7.191
120	09.06.77	5971.300	7.274	7.274		7.119	
121	16.06.77	6395.800	7.169		7.169		7.093
122	29.06.77	6650.500	7.451		7.451		7.159
123	22.07.77	6254.300	7.351	7.351		7.052	
124	07.06.78	7075.000	7.261	7.261		7.079	
125	12.06.78	7527.800	6.982		6.982		7.164
126	13.06.78	7301.400	7.168		7.168		7.179
127	28.06.78	6197.700	7.086		7.086		7.049
128	11.05.79	5716.600	7.097	7.097		7.067	

129	06.06.79	7612.700	7.211	7.211		7.013	
130	19.06.79	6537.300	7.321		7.321		7.122
131	26.06.79	5971.300	7.321	7.321		7.094	
132	29.02.80	2421.000	7.254	7.254		7.289	
133	28.04.80	3922.000	7.307	7.307		7.190	
134	07.05.80	6170.000	7.079	7.079		7.093	
135	22.05.80	6516.000	7.069		7.069		7.132
136	28.05.80	4927.000	7.107		7.107		7.167
137	09.06.80	5448.000	7.077	7.077		7.078	
138	18.06.80	5890.000	7.021	7.021		7.112	
139	23.06.80	7136.000	6.877		6.877		7.151
140	27.06.80	5734.000	6.950		6.950		7.060
141	08.07.80	4616.000	7.275	7.275		7.151	
142	10.06.80	4927.000	7.059	7.059		7.112	
143	23.07.80	4916.000	7.213		7.213		7.221
144	25.07.80	3370.000	7.421		7.421		7.133
145	02.10.80	3087.000	7.201	7.201		7.189	
146	03.11.80	2056.000	7.181	7.181		7.321	
147	25.05.81	7509.000	6.765	6.765		7.063	
148	30.05.81	8620.000	6.740	6.740		7.024	
149	12.06.81	7310.000	6.966		6.966		7.189
150	09.07.81	5867.000	6.908		6.908		7.075
151	03.05.82	3210.000	7.260	7.260		7.173	
152	17.05.82	5830.000	6.825	6.825		7.122	
153	20.05.82	6730.000	6.677	6.677		6.968	
154	03.06.82	7540.000	7.096	7.096		7.016	
155	08.06.82	9610.000	6.917		6.917		7.112
156	19.06.82	6490.000	6.600	6.600		6.979	
157	13.09.82	6270.000	6.830	6.830		7.012	
158	05.12.82	1170.000	7.436		7.436		7.210
159	30.05.83	6950.000	7.144	7.144		7.081	
160	07.06.83	7590.000	7.103		7.103		7.154
161	22.06.83	6930.000	7.099	7.099		7.071	
162	04.07.83	5800.000	7.269	7.269		7.076	
163	15.07.83	7430.000	7.024	7.024		7.064	
164	17.08.83	4280.000	7.552		7.552		7.297
165	15.02.84	2117.000	7.360		7.360		7.311
166	15.05.84	3530.000	7.367	7.367		7.129	
167	11.06.84	6420.000	7.310	7.310		7.002	
168	13.06.84	7050.000	7.227	7.227		7.098	
169	19.06.84	8703.000	6.891	6.891		6.963	
170	22.06.84	7626.000	6.999	6.999		7.028	

171	04.07.84	9220.000	7.584		7.584		7.100
172	16.07.84	7145.000	7.225		7.225		7.148
173	25.07.84	5952.000	7.204		7.204		7.040
174	20.08.84	385.000	7.524		7.524		
175	07.05.85	4183.000	7.501	7.501		7.200	
176	23.05.85	7535.000	7.074		7.074		7.143
177	13.06.85	8310.000	7.392		7.392		7.045
178	16.07.85	4626.000	6.701		6.701		7.270
179	08.10.85	1750.000	7.700		7.700		7.327
180	26.03.86	2570.000	7.391	7.391		7.237	
181	24.04.86	3760.000	7.220	7.220		7.218	
182	22.05.86	4360.000	7.225	7.225		7.185	
183	29.05.86	7150.000	7.242	7.242		7.040	
184	30.05.86	8940.000	6.938	6.938		6.958	
185	04.06.86	12100.000	7.178	7.178			
186	05.06.86	11200.000	6.653		6.653		
187	10.06.86	10100.000	7.444		7.444		7.055
188	16.06.86	8920.000	7.035		7.035		7.069
189	25.06.86	7570.000	7.430		7.430		7.127
190	31.07.86	4800.000	7.347		7.347		7.228
191	15.10.86	2140.000	7.545		7.545		7.297
192	17.03.87	2740.000	7.040		7.040		7.157
193	06.05.87	6199.000	7.040	7.040		7.137	
194	12.05.87	7723.000	6.876	6.876		7.044	
195	26.05.87	5000.000	7.011		7.011		7.138
196	16.06.87	7880.000	7.000	7.000	0.000	7.049	
197	22.07.87	4049.000	7.274	7.274		7.235	
198	20.08.87	2906.000	6.640		6.640		7.125
199	22.02.88	2280.000	7.509	7.509		7.322	
200	19.04.88	3765.000	6.995	6.995		7.205	
201	13.06.88	6900.000	7.308	7.308		7.021	
202	22.07.88	4049.000	7.274		7.274		7.269
203	08.08.88	3754.000	7.471	7.471		7.164	

APPENDIX 5K.2

Data for discharge (Q), sediment concentartion (C) and moving averaged sediment concentrations (11 points) on rising (r) and falling (f) stages of single hydrological events on the Fraser River at Mission station (1968-1986).

No.	Date	Discharge ($m^3 s^{-1}$)	C mg L^{-1})	C (r)	C (f)	C(r) Moving av. (11)	C(f) Moving av. (11)
1	25.02.69	1148.980	13		13		
2	03.03.69	982.010	14		14		
3	12.03.69	1248.030	12		12		17.545
4	19.03.69	931.070	22	22			
5	25.03.69	1185.770	16		16		15.273
6	09.04.69	2235.700	91	91		49.818	
7	15.04.69	3056.400	324	324		134.909	
8	23.04.69	3452.600	158		158		71.455
9	30.04.69	3820.500	124	124		187.182	
10	09.05.69	5009.100	188	188		275.455	
11	15.05.69	6905.200	340	340		309.727	
12	23.05.69	6876.900	160	160		283.182	
13	31.05.69	7980.600	254	254		265.909	
14	05.06.69	7980.600	208	208		267.182	
15	11.06.69	9112.600	269		269		269.909
16	20.06.69	7810.800	134		134		203.364
17	27.06.69	6650.500	131		131		170.909
18	10.07.69	5433.600	87		87		119.455
19	21.07.69	4273.300	99		99		74.000
20	01.08.69	3763.900	43		43		65.000
21	13.08.69	3707.300	105	105		153.000	
22	18.08.69	3792.200	135		135		64.545
23	27.08.69	3622.400	67		67		79.000
24	02.09.69	2999.800	57		57		65.455
25	12.09.69	2858.300	49		49		52.273
26	16.09.69	3339.400	52	52		154.364	
27	17.09.69	3282.800	47	47		131.364	
28	23.09.69	3735.600	59	59		118.000	
29	15.10.69	2436.630	56		56		38.909
30	21.10.69	2289.470	33		33		35.636
31	09.01.70	950.880	10	10			
32	23.01.70	1359.530	16	16			
33	25.02.70	1154.640	9		9		16.909
34	26.03.70	1533.860	32		32		19.909
35	07.05.70	3028.100	158	158		128.636	
36	11.05.70	3169.600	136		136		68.636
37	21.05.70	5546.800	471		471		137.909
38	26.05.70	5829.800	277	277		202.273	

39	03.06.70	6282.600	188	188		284.182	
40	09.06.70	9452.200	532	532		499.636	
41	12.06.70	8588.100	446		446		245.455
42	22.06.70	7527.800	209	209		294.636	
43	29.06.70	7075.000	170		170		178.727
44	09.07.70	5292.100	116	116		232.000	
45	22.07.70	3877.100	56		56		66.455
46	29.07.70	3622.400	59		59		71.909
47	06.08.70	2943.200	40	40		132.182	
48	14.08.70	3169.600	57		57		68.545
49	24.09.70	1930.060	23	23		33.545	
50	21.10.70	1202.750	13		13		15.455
51	16.12.70	1491.410	8	8			
52	24.03.71	1528.200	13	13		22.818	
53	30.04.71	4556.300	552	552		233.545	
54	12.05.71	7329.700	397	397		323.818	
55	19.05.71	7641.000	353		353		227.727
56	26.05.71	7669.300	240	240		280.182	
57	14.06.71	9395.600	239		239		265.000
58	25.06.71	8829.600	137	137		415.364	
59	09.07.71	5858.100	106	106		217.182	
60	19.07.71	7103.300	106		106		183.545
61	05.08.71	5829.800	77		77		163.182
62	26.08.71	3650.700	60		60		71.818
63	20.10.71	2238.530	35		35		33.364
64	15.12.71	1242.370	7		7		15.364
65	23.03.72	4584.600	642	642		232.818	
66	04.05.72	3622.400	116	116		139.545	
67	10.05.72	4924.200	279	279		254.182	
68	18.05.72	8857.900	773	773		435.455	
69	29.05.72	10131.400	358	358			
70	07.06.72	12084.100	451		451		
71	17.06.72	13640.600	566	566			
72	23.06.72	10782.300	287		287		
73	30.06.72	10188.000	268		268		336.000
74	06.07.72	9735.200	243		243		299.909
75	20.07.72	8235.300	167		167		217.909
76	31.07.72	6254.300	114		114		168.273
77	18.08.72	4443.100	88		88		73.818
78	30.08.72	3650.700	57		57		78.909
79	02.10.72	2102.690	22		22		26.091
80	22.11.72	1095.210	20		20		
81	17.05.73	5320.400	351	351		186.636	
82	26.05.73	7556.100	278	278		297.364	
83	06.06.73	5801.500	143	143		222.273	

129	06.06.79	7612.700	284	284		306.455	
130	19.06.79	6537.300	164		164		186.364
131	26.06.79	5971.300	131	131		234.545	
132	29.02.80	2421.000	46	46		91.727	
133	28.04.80	3922.000	179	179		235.000	
134	07.05.80	6170.000	242	242		226.455	
135	22.05.80	6516.000	173		173		184.000
136	28.05.80	4927.000	88		88		119.091
137	09.06.80	5448.000	112	112		205.636	
138	18.06.80	5890.000	154	154		179.545	
139	23.06.80	7136.000	109		109		160.818
140	27.06.80	5734.000	68	68		248.455	
141	08.07.80	4616.000	101	101		238.364	
142	10.06.80	4927.000	88		88		114.091
143	23.07.80	4916.000	52		52		71.818
144	25.07.80	3370.000	31	31		141.273	
145	02.10.80	3087.000	22	22		47.636	
146	03.11.80	2056.000	542	542		307.182	
147	25.05.81	7509.000	561	561		391.091	
148	30.05.81	8620.000	184		184		189.000
149	12.06.81	7310.000	107		107		181.000
150	09.07.81	5867.000	434	434		141.364	
151	03.05.82	3210.000	386	386		214.091	
152	17.05.82	5830.000	569	569		296.182	
153	20.05.82	6730.000	274	274		273.909	
154	03.06.82	7540.000	381		381		281.182
155	08.06.82	9610.000	141	141		298.636	
156	19.06.82	6490.000	597	597		281.545	
157	13.09.82	6270.000	5		5		14.636
158	05.12.82	1170.000	268	268		301.364	
159	30.05.83	6950.000	195		195		196.545
160	07.06.83	7590.000	100	100		317.000	
161	22.06.83	6930.000	74	74		212.727	
162	04.07.83	5800.000	125	125		318.727	
163	15.07.83	7430.000	54		54		78.091
164	17.08.83	4280.000	19		19		27.182
165	15.02.84	2117.000	79	79		157.727	
166	15.05.84	3530.000	357	357		278.091	
167	11.06.84	6420.000	411	411		275.818	
168	13.06.84	7050.000	346	346		420.273	
169	19.06.84	8703.000	231	231		276.091	
170	22.06.84	7626.000	124		124		281.182

84	14.06.73	7273.100	214		214		204.364
85	21.06.73	6226.000	127	127		227.000	
86	30.06.73	9027.700	393		393		261.000
87	20.07.73	5631.700	80	80		215.364	
88	07.05.74	6763.700	406	406		300.091	
89	14.05.74	6763.700	287		287		160.545
90	06.06.74	8093.800	324	324		283.000	
91	13.06.74	8291.900	233	233		309.182	
92	21.06.74	12593.500	552	552			
93	27.06.74	11716.200	339		339		
94	05.07.74	9622.000	205		205		281.000
95	18.07.74	8207.000	137	137		267.182	
96	30.07.74	7584.400	120		120		195.182
97	06.08.74	6735.400	95		95		153.818
98	21.02.75	1010.310	14	14			
99	04.04.75	1047.100	20		20		
100	16.04.75	1613.100	22	22		25.000	
101	06.05.75	2784.720	169	169		129.909	
102	17.05.75	6197.700	340		340		166.273
103	27.05.75	4754.400	100		100		75.636
104	04.06.75	7244.800	221	221		307.636	
105	17.06.75	8461.700	217	217		349.091	
106	04.07.75	7131.600	113		113		172.273
107	15.07.75	8263.600	145		145		238.364
108	29.07.75	5065.700	81		81		120.545
109	08.08.75	4216.700	58		58		68.545
110	29.08.75	4216.700	36		36		72.182
111	14.05.76	9423.900	716	716		499.182	
112	27.05.76	7612.700	212	212		289.545	
113	04.05.76	6537.300	140		140		184.636
114	17.06.76	8008.900	211	211		295.091	
115	24.06.76	10329.500	359		359		
116	07.07.76	10018.200	270	270			
117	16.06.76	8829.600	181		181		235.091
118	28.07.76	7471.200	103		103		197.091
119	19.08.76	6678.800	130		130		157.818
120	09.06.77	5971.300	221	221		193.273	
121	16.06.77	6395.800	249		249		181.909
122	29.06.77	6650.500	227		227		170.182
123	22.07.77	6254.300	225	225		264.727	
124	07.06.78	7075.000	369	369		310.545	
125	12.06.78	7527.800	449		449		218.909
126	13.06.78	7301.400	364		364		193.545
127	28.06.78	6197.700	268		268		194.182
128	11.05.79	5716.600	541	541		215.818	

171	04.07.84	9220.000	129		129		201.273
172	16.07.84	7145.000	88		88		189.364
173	25.07.84	5952.000	57		57		
174	20.08.84	385.000	254	254		251.636	
175	07.05.85	4183.000	129		129		219.364
176	23.05.85	7535.000	199		199		251.909
177	13.06.85	8310.000	80		80		73.545
178	16.07.85	4626.000	21		21		22.455
179	08.10.85	1750.000	104	104		92.545	
180	26.03.86	2570.000	293	293		136.818	
181	24.04.86	3760.000	133	133		234.182	
182	22.05.86	4360.000	468	468		313.636	
183	29.05.86	7150.000	647	647		468.727	
184	30.05.86	8940.000	599	599			
185	04.06.86	12100.000	601		601		
186	05.06.86	11200.000	323		323		306.273
187	10.06.86	10100.000	289		289		257.545
188	16.06.86	8920.000	168		168		215.091
189	25.06.86	7570.000	65		65		80.273
190	31.07.86	4800.000	37		37		31.000
191	15.10.86	2140.000	25		25		49.273
192	17.03.87	2740.000	114	114		223.818	
193	06.05.87	6199.000	479	479		274.455	
194	12.05.87	7723.000	53		53		118.091
195	26.05.87	5000.000	311	311		278.636	
196	16.06.87	7880.000	311	311		271.818	
197	22.07.87	4049.000	49	49		231.636	
198	20.08.87	2906.000	38		38		63.273
199	22.02.88	2280.000	10	10		63.455	
200	19.04.88	3765.000	195	195		144.182	
201	13.06.88	6900.000	175	175		299.636	
202	22.07.88	4049.000	45		45		70.364
203	08.08.88	3754.000	7	7		7.164	

APPENDIX 6

Monthly mean discharge (Q) and monthly mean sediment concentration (C) data for 1977, 1978 and 1979 at the Marguerite and Hope stations on the Fraser River.

Month	1977 C (mg/L)	1977 Q (m^3/s)	1978 C (mg/L)	1978 Q (m^3/s)	1979 C (mg/L)	1979 Q (m^3/s)
08MC018						
JAN	25	648	8	414	5	380
FEB	132	654	30	422	8	361
MAR	138	682	254	430	29	380
APR	426	1797	281	1100	350	779
MAY	221	3028	253	2010	524	3320
JUN	285	3453	231	2480	299	3830
JUL	147	3085	113	1980	129	2890
AUG	87	2117	69	1410	59	1360
SEP	41	1381	47	1240	32	819
OCT	27	1010	41	1100	27	668
NOV	25	702	41	873	16	349
DEC	4	456	9	512	15	289
08MF005						
JAN	34	1240	9	881	5	801
FEB	39	1231	48	791	27	721
MAR	44	1229	67	952	35	957
APR	337	2346	201	960	179	1290
MAY	224	4698	251	3950	457	4910
JUN	214	5660	165	5730	296	6360
JUL	131	4839	73	4540	139	4860
AUG	85	3622	80	2970	79	2610
SEP	34	2335	49	2600	95	1830
OCT	28	1653	33	2090	22	1420
NOV	32	1259	30	1590	16	918
DEC	14	1033	8	1010	40	852

APPENDIX 7

Measured and interpolated daily channel hydraulic data: discharge (Q), flow depth (D), flow velocity (V), gauge height (G.H.), stream-bed elevation (Be) and sediment concentration (C) on the rising (r) and falling (f) stages of some single-valued hydrological events in the Fraser River basin.

Event no.	Station	Date	Q (m^3/s)	C(r) (mg/L)	C(f) (mg/L)	D(r) (m)	D(f) (m)	V(r) (m/s)	V(f) (m/s)	G.H. (m)	Be(r) (m)	Be(f) (m)
LINEAR EVENTS												
7.	08LA001: 1972											
		*26	824.0									
		May 27	824.0	33		3.688		2.637		2.280	-1.408	
		28	881.0	40		3.821		2.693		2.326	-1.495	
		29	980.0	50		4.052		2.790		2.423	-1.629	
		30	1120.0	60		4.379		2.937		2.557	-1.822	
		31	1250.0	76		4.682		3.054		2.682	-2.000	
		June 01	1300.0	82		4.798		3.103		2.740	-2.058	
		*02	1250.0		67		4.682		3.054	2.704		-1.978
		03	1180.0		59		4.558		3.029	2.627		-1.931
		04	1120.0		57		4.452		3.007	2.573		-1.879
		05	1080.0		54		4.381		2.992	2.539		-1.842
		06	1070.0		52		4.363		2.989	2.536		-1.827
		*13	1360.0			4.877			3.094			

Event no.	Station	Date	Q (m^3/s)	C(r) (mg/L)	C(f) (mg/L)	D(r) (m)	D(f) (m)	V(r) (m/s)	V(f) (m/s)	G.H. (m)	Be(r) (m)	Be(f) (m)
8.	08MC018: 1979											
		*May 17	2810.0			5.791		2.323				
		Jun 03	3560.0	299		6.477		2.576		6.035	-0.442	
		04	3850.0	341		6.743		2.674		6.279	-0.464	
		05	4390.0	531		7.237		2.856		6.706	-0.531	
		06	4890.0	706		7.694		3.025		7.062	-0.632	
		*07	5410.0	970		8.170		3.200		7.437	-0.733	
		08	5320.0		789		8.104		3.168	7.376		-0.728
		09	4940.0		636		7.824		3.034	7.102		-0.722
		10	4190.0		448		7.272		2.768	6.553		-0.719
		11	3740.0		415		6.941		2.616	6.187		-0.754
		12	3740.0		302		6.941		2.616	6.187		-0.754
		*21	3420.0				6.706		2.496			
23.	08MF005: 1969											
		*May 14	5860.0			9.816		2.338				
		May 23	5610.0	137		9.741		2.287		6.876	2.865	
		24	5830.0	161		9.807		2.332		7.001	2.806	
		25	6030.0	202		9.867		2.375		7.093	2.774	
		26	6170.0	272		9.909		2.401		7.175	2.734	
		27	6460.0	359		9.997		2.461		7.315	2.682	
		28	6770.0	428		10.090		2.524		7.471	2.619	

Event no.	Station	Date	Q (m^3/s)	C(r) (mg/L)	C(f) (mg/L)	D(r) (m)	D(f) (m)	V(r) (m/s)	V(f) (m/s)	G.H. (m)	Be(r) (m)	Be(f) (m)
		29	6940.0	450		10.141		2.559		7.547	2.594	
		*30	6770.0		395		10.090		2.524	7.435		2.625
		31	6310.0		300		9.851		2.375	7.242		2.609
		Jun 01	6060.0		215		9.721		2.295	7.114		2.607
		*09	7820.0			10.635			2.862			
29.	08MH001:	1975										
		May 30	154.0	55		1.372		1.829		1.875	0.503	
		31	188.0	67		1.622		2.020		2.085	0.463	
		Jun 01	222.0	138		1.872		2.210		2.283	0.411	
		02	265.0	170		2.189		2.451		2.518	0.329	
		03	214.0	120		1.813		2.165		2.240	0.427	
		*04	205.0	125		1.747		2.115		2.182	0.435	
		*05	266.0	180		2.196		2.457		2.521	0.325	
		06	211.0		140		1.901		2.240	2.219		0.318
		07	205.0		115		1.869		2.216	1.981		0.112
		08	171.0		90		1.687		2.081	1.835		0.148
		09	175.0		65		1.708		2.097	1.801		0.093
		10	148.0		63		1.564		1.991	1.884		0.320
		*11	138.0		45		1.510		1.951	1.929		0.419

Event no.	Station	Date	Q (m^3/s)	C(r) (mg/L)	C(f) (mg/L)	D(r) (m)	D(f) (m)	V(r) (m/s)	V(f) (m/s)	G.H. (m)	Be(r) (m)	Be(f) (m)
CONCAVE EVENTS												
39.	08MH001: 1975											
		Nov 30	75.0	21		1.334		0.061		1.265	-0.069	
		Dec 01	126.0	340		1.542		1.016		1.643	0.101	
		02	467.0	3400		2.933		3.760		3.414	0.481	
		*03	530.0	4000		3.190		4.267		3.578	0.388	
		*04	345.0		2200		3.334		2.975	3.054		-0.280
		*05	269.0		750		3.277		2.464	2.408		-0.869
		06	239.0		200		3.254		2.257	2.387		-0.867
		07	218.0		50		3.238		2.111	2.216		-1.022
40.	08MH024: 1971											
		*May 12										
		15	7700.0	361		11.590		1.255		4.499	-7.091	
		16	8100.0	470		12.010		1.270		4.740	-7.270	
		17	8300.0	585		12.220		1.277		4.862	-7.358	
		18	8100.0		491		12.010		1.270	4.730		-7.280
		*19	7670.0		353		11.558		1.256	4.471		-7.087
		20	7140.0		262		11.091		1.117	4.148		-6.943
		21	6650.0		216		10.594		1.093	3.865		-6.729
		*26	7600.0			11.487			1.268			

Event no.	Station	Date	Q (m^3/s)	C(r) (mg/L)	C(f) (mg/L)	D(r) (m)	D(f) (m)	V(r) (m/s)	V(f) (m/s)	G.H. (m)	Be(r) (m)	Be(f) (m)
42.	08MH024:	1973										
		*Jun 06	5920.0	143		10.526		1.052		3.426	-7.100	
		07	6140.0	146		10.633		1.068		3.575	-7.058	
		08	6370.0	145		10.745		1.085		3.703	-7.042	
		09	6650.0	158		10.881		1.106		3.886	-6.995	
		10	7220.0	220		11.156		1.148		4.240	-6.916	
		11	7730.0	288		11.406		1.186		4.535	-6.871	
		12	7870.0	290		11.478		1.197		4.615	-6.863	
		13	7650.0		258		11.367		1.180	4.496		-6.871
		*14	7250.0		214		11.474		1.196	4.252		-7.222
		15	6710.0		187		11.143		1.141	3.917		-7.226
		16	6460.0		151		10.990		1.115	3.758		-7.232
		*21	6230.0			10.849			1.092			
CONVEX EVENTS												
45.	08MH001:	1967										
		*Oct 11	180.0			1.769		2.469				
		26	71.4	32		0.922		1.377		1.500	0.578	
		27	94.6	53		1.108		1.617		1.719	0.611	
		28	165.0	87		1.652		2.319		2.286	0.634	
		29	111.0	69		1.233		1.800		1.865	0.632	
		30	156.0	101		1.582		2.229		2.219	0.637	
		*31	340.0	157		3.013		4.072		3.097	0.084	

Event no.	Station	Date	Q (m^3/s)	C(r) (mg/L)	C(f) (mg/L)	D(r) (m)	D(f) (m)	V(r) (m/s)	V(f) (m/s)	G.H. (m)	Be(r) (m)	Be(f) (m)
		Nov 01	208.0		118		2.004		3.018	2.377		0.373
		*02	159.0		89		1.629		2.627	2.097		0.468
		03	133.0		68		1.430		2.420	1.929		0.499
		04	112.0		52		1.270		2.252	1.780		0.510
		05	93.7		52		1.132		2.108	1.652		0.520
		06	83.5		38		1.094		2.028	1.567		0.473

* Measurement day.

APPENDIX 8

Daily discharge (Q) and daily sediment concentration (C) data for 9 hydrological events at Marguerite station on the Fraser River between April and September, 1977.

Calendar days	Q (m^3/s)	C (mg/L)
EVENT 1		
89	680	154
90	680	158
91	680	176
92	680	202
93	691	238
94	691	300
95	745	374
96	835	472
97	960	575
98	1110	635
99	1310	662
100	1720	671
101	2130	667
102	2280	627
103	2310	536
104	2250	432
105	2280	387
106	2250	371
107	2060	342
108	1910	289
109	1660	227
110	1500	172
111	1450	147
112	1360	140
EVENT 2		
113	1310	140
114	1430	162
115	1780	283
116	2250	475
117	3060	658
118	3710	797
119	3910	843
120	3600	770
121	3430	531
122	3280	332
123	3200	291
124	3170	323
EVENT 3		
125	3280	304
126	3370	298
127	3340	274
128	3400	288
129	3450	266
130	3540	293
131	3600	303
132	3710	306
133	3940	354
134	3880	380
135	3510	327
136	3230	202
137	2940	166
138	2750	132
139	2590	114
140	2470	113
141	2340	95
142	2280	89
EVENT 4		
143	2310	94
144	2410	103
145	2530	131
146	2690	154
147	2750	160
148	2690	127
149	2590	102
150	2530	89
151	2530	98
EVENT 5		
152	2720	115
153	2720	134
154	2920	164
155	3170	187
156	3060	184
157	2890	143

Calendar days	Q (m^3/s)	C (mg/L)	Calendar days	Q (m^3/s)	C (mg/L)
EVENT 6			EVENT 8		
158	2820	149	197	3000	112
159	3030	222	198	3230	132
160	3510	460	199	3510	155
161	4110	809	200	3910	191
162	4300	893	201	4110	249
163	3790	584	202	3850	257
164	3540	263	203	3450	202
165	3280	212	204	3140	152
166	3280	172	205	2810	117
167	3280	160	206	2800	92
168	3370	153	207	2790	77
			208	2490	86
EVENT 7					
			EVENT 9		
169	3430	176			
170	3540	197	209	2490	107
171	3620	234	210	2790	79
172	3790	290	211	2790	92
173	3940	326	212	2810	154
174	4050	306	213	3140	178
175	4080	326	214	3140	161
176	4050	318	215	2810	130
177	3710	285	216	2790	100
178	3680	284	217	2490	91
179	3600	285	218	2480	86
180	3340	270	219	2470	85
181	3230	248	220	2180	77
182	3370	233	221	2170	70
183	3230	206			
184	3170	178			
185	3230	188			
186	3340	215			
187	3110	218			
188	3000	189			
189	2940	155			
190	2920	124			
191	2890	105			
192	2920	98			
193	2940	94			
194	2940	94			
195	3000	96			
196	3000	100			

APPENDIX 9

Measured and interpolated daily channel hydraulic data: discharge (Q), flow depth (D), flow velocity (V), gauge height (G.H.) and stream-bed elevation (Be) and sediment concentration (C) on the rising (r) and falling (f) stages of some clockwise and anticlockwise hysteretic events in the Fraser River basin.

Event no.	Station	Date	Q (m^3/s)	C(r) (mg/L)	C(f) (mg/L)	D(r) (m)	D(f) (m)	V(r) (m/s)	V(f) (m/s)	G.H. (m)	Be(r) (m)	Be(f) (m)
77.	08LA001: 1972											
		*Jun 02	1250.0			4.682		3.054				
		Jun 07	1080.0	55		4.381		2.992		2.560	-1.821	
		08	1150.0	66		4.505		3.018		2.621	-1.884	
		09	1200.0	73		4.593		3.036		2.691	-1.902	
		10	1290.0	82		4.753		3.069		2.789	-1.964	
		11	1400.0	93		4.948		3.109		2.893	-2.055	
		12	1460.0	97		5.054		3.130		2.929	-2.125	
		*13	1360.0		78		4.877		3.094	2.816		-2.061
		14	1210.0		56		4.552		2.983	2.679		-1.873
		15	1100.0		43		4.314		2.901	2.588		-1.726
		*16	1060.0		41		4.227		2.872	2.566		-1.661
78.	08MC018: 1972											
		*Jun 05	4950.0	402		7.143		2.990		4.572	-2.571	
		06	4730.0	331		6.995		2.925		4.328	-2.667	
		07	4730.0	305		6.995		2.925		4.328	-2.667	
		08	4870.0	338		7.089		2.966		4.450	-2.639	

Event no.	Station	Date	Q (m^3/s)	C(r) (mg/L)	C(f) (mg/L)	D(r) (m)	D(f) (m)	V(r) (m/s)	V(f) (m/s)	G.H. (m)	Be(r) (m)	Be(f) (m)
		09	4870.0	323		7.089		2.966		4.450	-2.639	
		10	4960.0	212		7.150		2.993		4.511	-2.639	
		11	5320.0	228		7.391		3.100		4.785	-2.606	
		12	5490.0	308		7.505		3.150		4.907	-2.598	
		*13	6080.0	594		7.901		3.325		5.151	-2.750	
		14	6260.0	547		7.979		3.381		5.425	-2.554	
		15	6460.0	653		8.066		3.443		5.578	-2.488	
		16	6510.0	536		8.088		3.459		5.608	-2.480	
		17	6290.0		414		7.992		3.390	5.456		-2.536
		18	5920.0		356		7.831		3.275	5.212		-2.619
		19	5490.0		395		7.644		3.142	4.907		-2.737
		20	5070.0		339		7.462		3.011	4.602		-2.860
		*21	4700.0		329		7.301		2.896	4.420		-2.881
		22	4470.0		315		7.201		2.825	4.145		-3.056
79.	08MC018: 1976											
		*Apr 28	2220.0	303		4.727		2.247		4.968	0.241	
		29	2440.0	417		4.926		2.303		5.182	0.256	
		30	2680.0	604		5.143		2.364		5.425	0.282	
		May 01	3090.0	995		5.514		2.468		5.791	0.277	
		02	3540.0	1210		5.921		2.583		6.187	0.266	
		03	3990.0	1480		6.328		2.697		6.553	0.225	
		04	4470.0	1730		6.762		2.820		6.919	0.157	
		05	4730.0	1820		6.997		2.886		7.102	0.105	
		06	5180.0	1640		7.404		3.000		7.407	0.003	

Event no.	Station	Date	Q (m^3/s)	C(r) (mg/L)	C(f) (mg/L)	D(r) (m)	D(f) (m)	V(r) (m/s)	V(f) (m/s)	G.H. (m)	Be(r) (m)	Be(f) (m)
		07	5240.0	1490		7.460		3.016		7.437	-0.023	
		08	4870.0	1450		7.124		2.921		7.193	0.069	
		09	4870.0	1270		7.124		2.921		7.193	0.069	
		10	5040.0	1240		7.278		2.965		7.315	0.037	
		11	5350.0	1020		7.558		3.043		7.498	-0.060	
		12	5750.0	825		8.101		3.145		7.742	-0.359	
		13	5950.0	767		7.829		3.196		7.864	0.035	
		*14	5800.0		714		7.985		3.158	7.772		-0.193
		15	5550.0		591		7.844		3.068	7.620		-0.224
		16	5150.0		492		7.650		2.923	7.376		-0.274
		17	4670.0		400		7.418		2.752	7.071		-0.347
		18	4560.0		286		7.364		2.712	6.980		-0.384
		19	4590.0		282		7.379		2.723	7.010		-0.369
		20	4420.0		292		7.296		2.662	6.888		-0.408
		21	4110.0		274		7.146		2.550	6.645		-0.501
		22	3820.0		245		7.006		2.446	6.431		-0.575
		23	3710.0		230		6.952		2.406	6.340		-0.612
		24	3680.0		219		6.938		2.395	6.309		-0.629
		25	3790.0		240		6.991		2.435	6.401		-0.590
		*26	3790.0		217		6.991		2.435	6.401		-0.590
92.	08MF005:	1969										
		*May 30	6770.0			10.090		2.524				
		Jun 04	6370.0	173		9.883		2.395		7.266	-2.617	
		05	6740.0	201		10.074		2.514		7.458	-2.616	
		06	7110.0	257		10.266		2.634		7.629	-2.637	
		07	7500.0	325		10.468		2.759		7.824	-2.644	

Event no.	Station	Date	Q (m^3/s)	C(r) (mg/L)	C(f) (mg/L)	D(r) (m)	D(f) (m)	V(r) (m/s)	V(f) (m/s)	G.H. (m)	Be(r) (m)	Be(f) (m)
		08	7760.0	375		10.603		2.843		7.958	-2.645	
		*09	7820.0	350		10.634		2.862		7.986	-2.648	
		10	7760.0		325		10.603		2.846	7.952		-2.651
		11	7620.0		248		10.532		2.809	7.885		-2.647
		12	7620.0		249		10.532		2.809	7.879		-2.653
		13	7560.0		232		10.502		2.794	7.858		-2.644
		14	7450.0		216		10.446		2.765	7.800		-2.646
		15	7280.0		207		10.359		2.720	7.718		-2.641
		16	6970.0		213		10.201		2.639	7.562		-2.639
		17	6630.0		178		10.028		2.550	7.404		-2.624
		18	6310.0		144		9.866		2.466	7.245		-2.621
		*26	5580.0				9.494		2.274			

* Measurement day.