ASSESSING GRAVEL SUPPLY AND REMOVAL IN FISHERIES STREAM

Prepared by

SUTEK SERVICES LTD.

and

KELLERHALS ENGINEERING SERVICES LTD.

March 1989

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Prepared for

DEPARTMENT OF FISHERIES AND OCEANS

and

B.C. MINISTRY OF ENVIRONMENT

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FOREWORD

This report has been prepared on behalf of the Department of Fisheries and Oceans and the B.C. Ministry of the Environment and is designed to assist fisheries personnel evaluate proposals for instream gravel removal. This manual is intended for general application to streams of British Columbia in situations where gravel extraction could alter the channel morphology of a river.

Section 35 (1) of the FISHERIES ACT (R.S.C. 1985, c. F-14) states in part that, "No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat". Extraction of stream gravels has the potential to alter fish habitat in a deleterious manner by affecting spawning, rearing and food production areas. The intent of this report is therefore to provide a technical approach to assess the physical conditions of rivers and avoid disturbances from gravel removal operations which may result in harmful changes to fish habitat.

Section 37 (1) of the FISHERIES ACT (R.S.C.1985, c. F-14) allows the Minister to request plans, specifications and studies for any proposal to evaluate potential harmful effects on fish habitat. Furthermore, this section allows the Minister to determine what measures would be required to prevent or mitigate potential harmful effects. Companies or agencies proposing to undertake gravel removal operations should be familiar with this report and with the Department of Fisheries and Oceans policy document, D.F.O. Policy for the Management of Fish Habitat (Section 4.1). It is recommended that industrial proponents consult fishery agencies regarding specific concerns and requirements when developing proposals for stream gravel removal.

The report was prepared by Ken Rood and Graham Seagel of Sutek Environmental Services and Rolf Kellerhals of Kellerhals Engineering Services Ltd with funding from the Unsolicited Proposals Fund of the Department of Supply and Services, and from the Department of Fisheries and Oceans and B.C. Ministry of the Environment. The views expressed in this document are those of the authors. However, we gratefully acknowledge the support of several Government agencies and are particularly grateful for the assistance provided by many Fisheries Officers and Fisheries Biologists. Valuable guidance was provided by John Payne, the Scientific Authority for our Contract and by the members of the Review Committee, representing both the Department of Fisheries and Oceans and the Ministry of Environment.

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ASSESSING GRAVEL SUPPLY AND REMOVAL IN FISHERIES STREAMS

Prepared for
Department of Fisheries and Oceans
and
B.C. Ministry of Environment and Parks

1.0 INTRODUCTION

1.1 Objectives and Scope

In comparison with other parts of Canada, British Columbia is blessed with enormous gravel resources. A major part of the known deposits occur in various glacio-fluvial features deposited at the close of the last ice age, roughly 10,000 years ago, by rivers originating at the retreating glaciers. These deposits generally occur well above present flood plain levels and they can be mined without interfering with the fish resource of nearby streams, except for possible water quality problems associated with poorly designed gravel wash plants. There are, however, some areas in B.C. where, due to lack or scarcity of glacio-fluvial gravels, there is a demand for extracting gravel from the second major source, the recent alluvial gravels, i.e. gravels associated with present rivers.

Mining such deposits is normally associated with a variety of direct and indirect effects on the fish resources of the affected stream. Direct effects include extreme sediment concentrations resulting from mining under water, removal of gravel containing fish eggs and direct habitat destruction. Not all effects on fisheries resources need be detrimental;and in some situations a well planned excavation might well create fish habitat directly, for example by opening up a blocked side channel or by providing a deep overwintering pool on the floodplain adjacent to a stream.

Direct detrimental effects are relatively easily avoided by such simple measures as timing constraints (which limit the mining operation to non-sensitive times or to low flow periods when the work can be carried out in the dry), by separating the mining operation from the active stream channel with dykes, or by restricting the mining operation to parts of the flood plain that are unlikely to become part of the active channel system in the foreseeable future.

The long-term indirect effects of gravel mining result from the fact that any removal of alluvial gravels constitutes an interference with the sediment transport regime of the stream. Since sediment transport and channel morphology are intimately connected and channel morphology provides the physical framework of all fish habitat, any significant changes to the sediment transport regime of a stream are likely to result in some corresponding fish habitat changes. The general nature of these changes is well known. The main ones are:

(i) channel degradation at, above and below the mining sites;

(ii) de-watering of side and back channels if the main channel is mined or full diversion into a side channel if the side channel is mined excessively;

(iii) development of coarse lag armors on the bed of degrading channels with corresponding effects on spawning success; and

(iv) lowering of groundwater tables near the stream with effects on spawning beds and back channel habitat.

Although exact quantitative relations between sediment transport rates, gravel extraction volumes and the resulting morphologic changes are elusive, it does appear feasible to make practical and conservative estimates of gravel quantities that can be mined from certain streams with relatively active transport without noticeable effects on fish habitat. Providing practical procedures for estimating such conservative gravel extraction volumes is the primary purpose of this report. The specific premises of the report are;

(i) that gravel bed streams actively transporting significant volumes of gravel are morphologically different from stable, inactive streams and can be readily identified;

(ii) that the order of magnitude of long-term average gravel transport volumes can be estimated by various means;

(iii) that the relationship between channel morphology and gravel transport volumes is not particularly sensitive to the exact long-term average transport volume; and

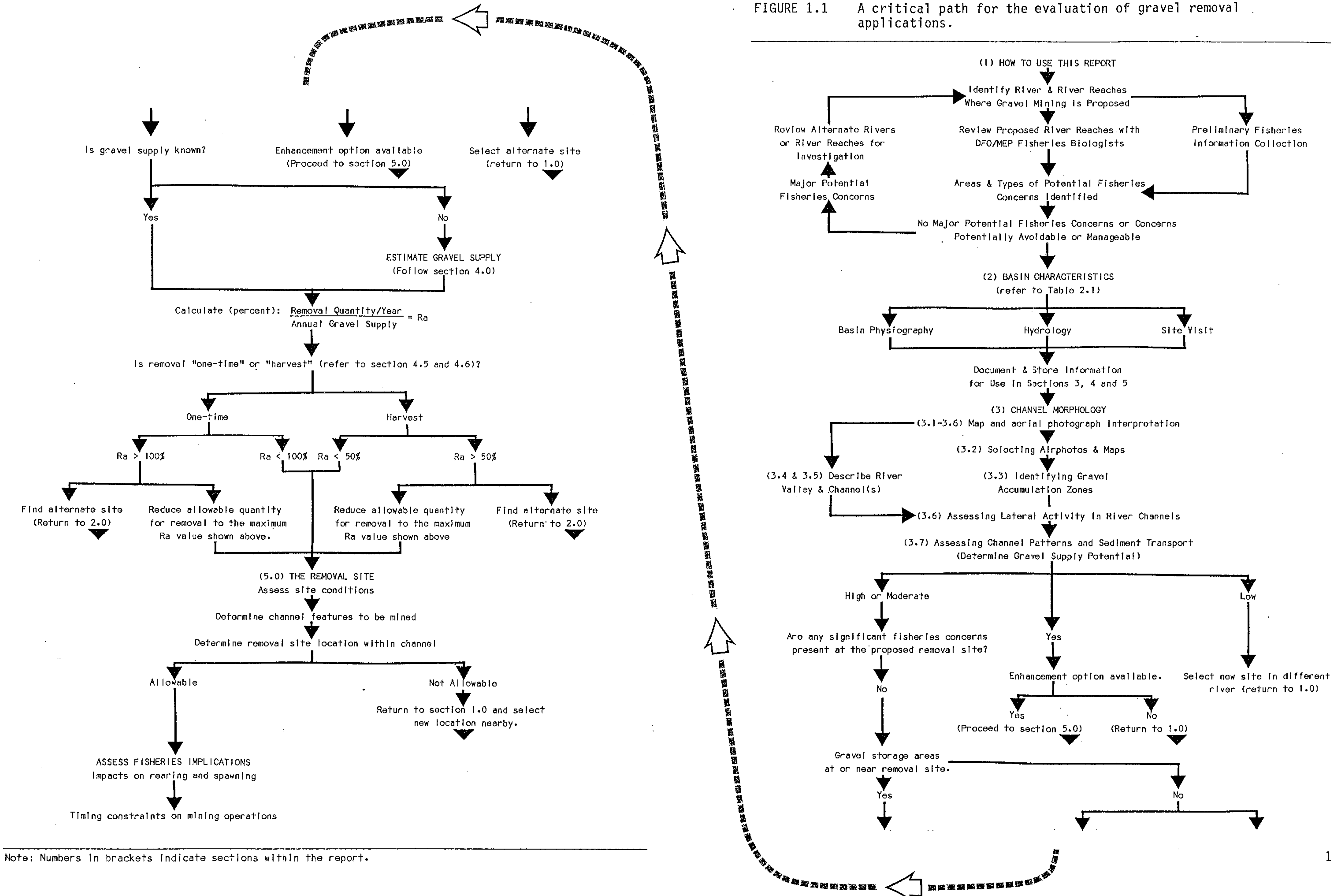
(iv) that there are no critical thresholds, where small changes in gravel transport volumes could result in major morphologic changes.

Accepting these premises, it is reasonable to assume that a long-term average gravel extraction rate that is small with respect to the transport volume will maintain the gravel transport processes that produce the particular channel morphology. Under these circumstances the general character of the river should also be maintained.

1.2 Using this Report

The general procedure used in this report for evaluating gravel removal applications is shown in a critical path presented in Figure 1.1 and discussed in Section 1.3. Since the report focuses more on the physical aspects of estimating gravel supply and availability the critical path presents more detail in this aspect than for the estimating of effects of gravel removal on fish. For this reason, and

FIGURE 1.1 A critical path for the evaluation of gravel removal applications.



Note: Numbers in brackets indicate sections within the report.

because the fisheries biologists of the Department of Fisheries and Oceans (DFO) and the Ministry of Environment (MOE) have both considerable knowledge of and responsibility for the fisheries, the authors recommend the following:

> Users of this report should discuss the rivers and/or sites under review with the fisheries biologists of DFO and MOE early in their investigations. It is anticipated that these discussions would occur prior to site visits or any detailed data collection and analysis.

It is anticipated that there are or will be personnel in each agency (DFO and MOE) who will have more familiarity with and expertise in the procedures and techniques referred to in this report. Early contact with the fisheries biologists will help the user to access these capabilities, resulting in the more appropriate and expedient use of the report.

The procedure, as laid out, reflects the logical progression in the use of information required by the techniques. The user of the report should read the whole report first, before trying to use the methods. The reason for this is twofold; firstly to enable the reader to grasp the implications of one step to another and, secondly, to ensure that the site selection considerations of Section 5 are understood before starting into the procedure or holding discussions with DFO and/or MOE fisheries biologists.

1.3 Report Structure

An instream gravel removal application may be evaluated by proceeding through this report from Sections 2 through 5. The document is organized so that Section 2 examines conditions in the overall drainage basin that affect gravel supply, Section 3 describes the character of the river reach near the proposed removal site, Section 4 provides techniques for estimating gravel supply within the river reach and recommendations for limiting removal volumes and Section 5 focuses on the removal site.

The document focuses on the estimation of gravel supply in British Columbia rivers. Seven different methods are described, which take into account varying levels of information available at different sites and the varying requirements for accuracy in the estimation of gravel load reflecting varying levels of concern over the fisheries resource. The simplest method, based on gravel yield per square kilometre of drainage area, requires only measurement of drainage area, classification of the river morphology and selection of a typical annual gravel yield from Table 4.3. Simple methods, based on typical conditions in British Columbia may often be inaccurate; consequently, we recommend this approach only for initial appraisals. More sophisticated approaches, related to the particular stream, are recommended if there is concern over the fisheries resource.

Gravel supply is affected by a host of regional and local factors. Sections 2 and 3 focus on those conditions which influence gravel supply, gravel transport and the opportunity for gravel removals. These Sections also include methods for collecting the basic data required when estimating gravel supply from the techniques described in Section 4. Summary tables are provided in Sections 2 and 3 to record information used in later Sections.

Estimation of gravel supply is only one part of the assessment of gravel removal applications. We have based our allowable removals on a percentage of the estimated gravel supply. The percentage is affected by the type of removal (whether it is a one-time removal or continued harvesting) and also by the geomorphic setting of the removal site.

A critical path for determining recommended removal rates is outlined on Figure 1.1. This figure is simplified because it was not possible to prepare a chart to include all the different possible combinations of basin characteristics, river morphology, and land use without the figure becoming too complicated to use.

In Section 7 the methods described in Sections 2 through 6 are applied to the Cowichan, Mamquam and Lillooet Rivers. On each river gravels have been removed over several years and the removals are well-documented. The case studies illustrate estimation of gravel supply in a variety of different river situations; they also describe the inadvertent and indirect effects of gravel removals. As such, the case studies provide part of the justification for our recommended removal volumes. Further case studies and evaluations are described in a pamphlet prepared for the State of Washington Department of Ecology, titled "Assessing the effects of gravel harvesting on river morphology and sediment transport" (Collins and Dunne, 1987).

We recommend that users proceed methodically from Sections 2 through 7 until they are familiar with the range of techniques that may be used in assessing instream gravel removal applications. Some techniques are only applicable in certain circumstances and this is best discovered through familiarity with the contents of the report.

2.0 COLLECTING PHYSIOGRAPHIC AND HYDROLOGIC DATA

2.1 Objectives

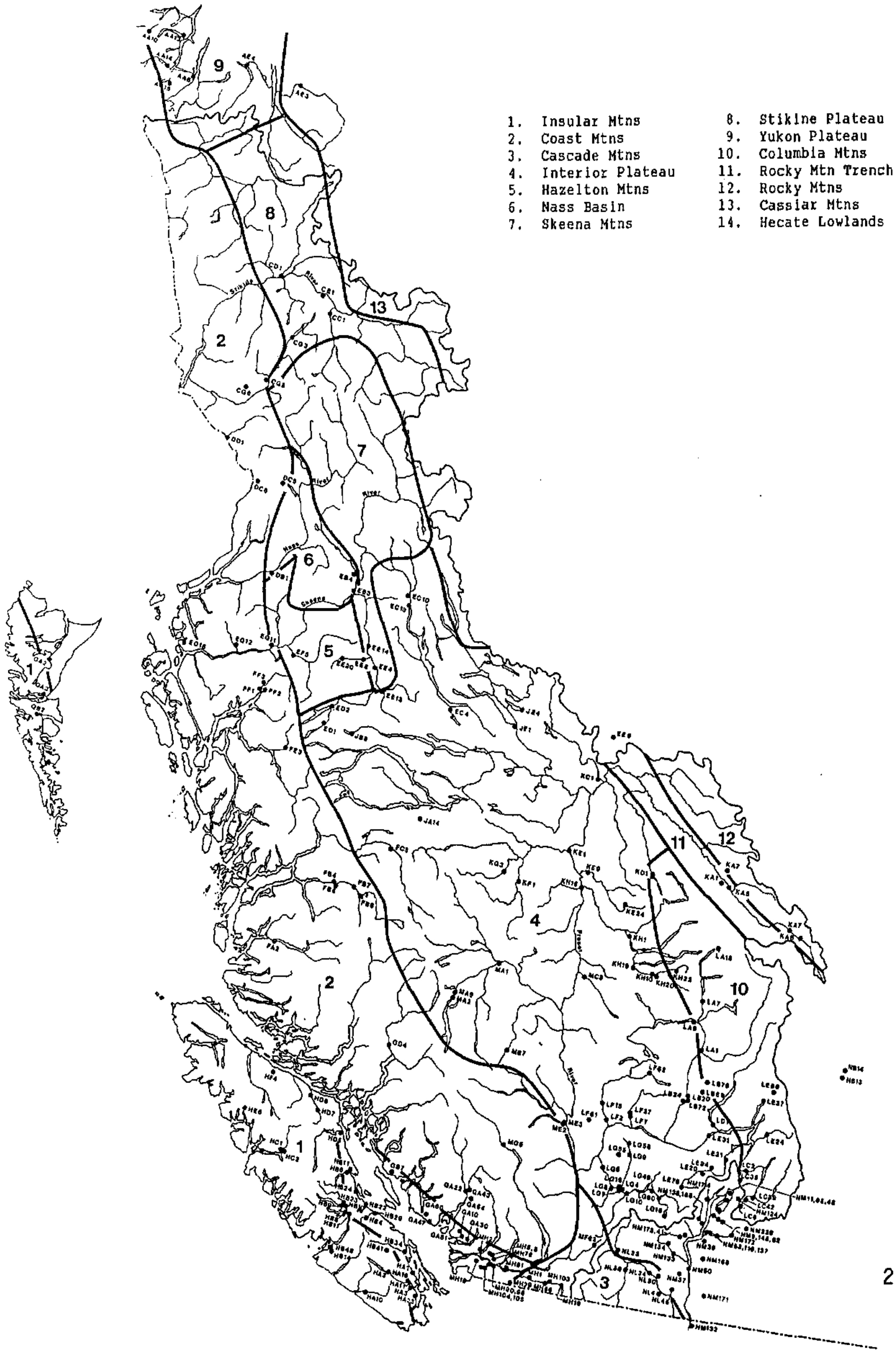
Gravel transport generally depends on the regional climate, hydrology, and physiography (Figure 2.1), as well as geology, glacial history and a host of local factors. While an appreciation of the role of these different factors is critical to assessing gravel supply it is neither practical nor desirable to completely describe or measure the character of the drainage basin since this knowledge is unlikely to greatly improve our estimate of gravel supply. However, several key factors which greatly influence gravel supply, can be relatively simply identified from review and analysis of maps and aerial photographs of the drainage basin.

While the document is designed to function essentially as an "office procedure", field visits can often collect valuable information not easily available in another fashion. The final part of this Section discusses information that can be usefully collected near the proposed removal site.

2.2 Basin Physiography

Basin physiography observations and measurements are most appropriately made from National Topographic Survey (NTS) maps. The largest available scale, usually 1:50,000, is preferable though smaller scales may be used for some large basins in order to have a manageable number of map sheets. Useful information is also available from Bedrock and Surficial Geology Maps, available from the Geological Survey of Canada (Energy, Mines and Resources Canada) and from Terrain Manuscript Maps (1:50,000) available

FIGURE 2.1 Physiographic regions for salmon-bearing streams in British Columbia (adapted from Holland, 1976). Water Survey of Canada stations operating from 1975 to 1984 are shown.



from Maps BC (Ministry of Environment, 1981; Ryder and Howes, 1984). Not all of British Columbia is covered by the latter two map series.

The NTS maps should be used to measure the drainage area (km^2) of the stream above the proposed gravel removal site. The basin boundary, connecting the high points along the basin divide, should be drawn on the map. The basin area is then simply measured with a polar planimeter or with a square grid as the area within the drainage boundary.

The slope of the channel, which approximates the water surface slope, should also be measured from the largest scale map available. Slope is estimated by measuring the distance, along the channel centreline, between contour crossings of the river. The slope should be averaged over several contour crossings surrounding the proposed removal site. However, to correctly determine the slope at the proposed removal site care should be taken to only measure the reach of the river similar to the removal site. Measurements should not extend into sections of the river with appreciably greater or lesser slopes than the removal site. Estimates of channel slope from 1:50,000 or smaller scale maps may vary from a field surveyed slope by a factor of two or more. This should be kept in mind when using map-derived slopes in Figure 4.1.

Major lakes within a drainage basin exert a profound influence on sediment transport. Even relatively small lakes may trap all or nearly all of the gravel load. Larger lakes, depending on their volume relative to the inflow volume, may also trap the major portion of the suspended load. The effect of a lake decreases downstream; hence immediately below the lake, sediment transport may effectively be zero, however sediment transport will increase downstream as tributaries join the mainstem and lateral erosion occurs. For this reason the effective "contributing" drainage area is measured from the site of interest upstream to the lake trapping (or limiting) the gravel supply from further upstream.

Major tributaries also exert an influence on gravel supply. These tributaries may be major sources of gravel supply to the mainstem along with local bank erosion and the load being carried into a reach by the mainstem channel (throughput load). Some tributaries, through development of their fans, may constrict the main river valley and cause deposition of main channel bed load material in the main stem above the fan, thus reducing downstream gravel supply. Tributaries lying between a major lake and a proposed removal site should be carefully examined.

Glaciers within the drainage basin act to greatly increase the supply of material available for transport by a river. The total effect on gravel supply depends on the approximate percentage of the basin that is glacierized and the distance upstream to the glaciers. Review of air photographs or large scale maps often indicates a rapidly changing pattern in the main stem of rivers downstream of glaciers. The pattern responds to decreased sediment transport and sediment availability as distance from the glacier increases.

In general, sedimentary, volcanic and metamorphic rock are more easily weathered and more subject to instability than granitic terrain. In some cases, though not all, this is associated with increased gravel supply and transport. In many instances, the effect of varying bedrock type may be masked by overlying unconsolidated sediments deposited during the last ice age or more recently.

Terrain stability affects gravel supply through provision of coarse landslide debris directly to streams (refer to Figure 2.2

Note: Landslides occurred upstream of air photo.

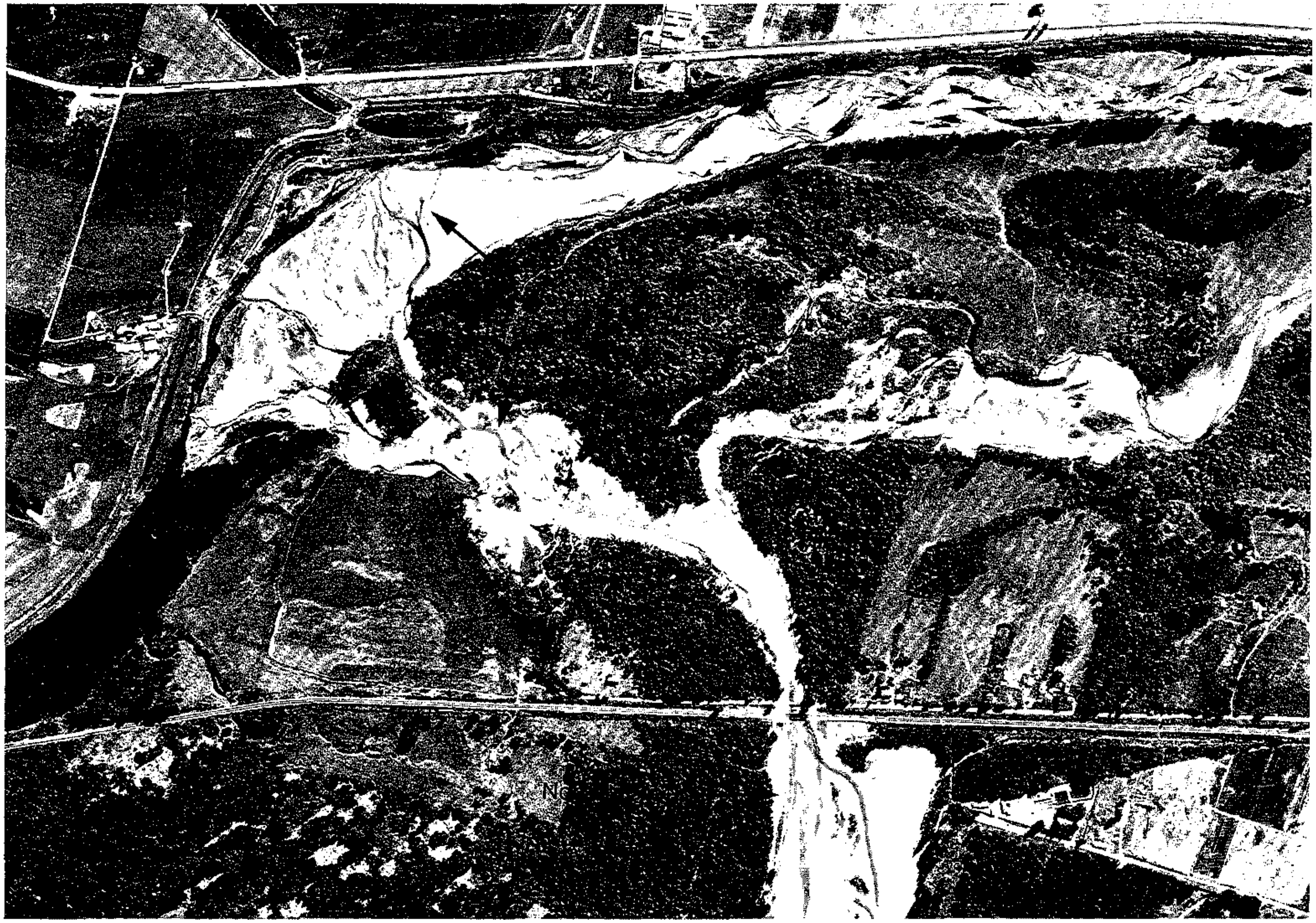


FIGURE 2.2 Norrish Creek (BCC 536:061). Landsliding and accelerated gravel supply and transport in a small basin.

for an example on Norrish Creek). Unstable terrain assures a large and continuing supply of gravel to the stream. Unstable or eroding gravel terraces along the river or sites where the river is in contact with a glacial or alluvial fill are particularly good sources of gravel supply. Terrain or slope stability is difficult to assess though it is related to basin steepness and geology. The presence of landslides on Terrain Maps or Forest Inventory Maps is a suitable indicator of unstable terrain. Terrain stability may be modified by land use, particularly logging.

If possible, it is often worthwhile to review the basin on appropriate scale aerial photography. Sediment production mechanisms, such as recent landslides or bank erosion, are often visible and may indicate gravel loads well in excess of those expected for a pristine or unaffected basin of similar size.

2.3 Hydrology

The prime hydrologic characteristics that affect gravel supply and gravel mining operations are the magnitude and timing of annual floods. The timing of peak flows primarily affects planning of gravel removal operations. Many rivers have peak flows only within a limited part of the year. Rivers with snowmelt floods tend to have high flows in the late spring or early summer; rainfall-produced floods may also only occur during a limited time period. On the west side of the Coast Mountains flood flows result from both these processes producing peak flows in two distinct periods of the year. In some years, the annual peak is the result of snowmelt though, often, the largest floods are generated by fall and winter rainstorms.

The Water Survey of Canada records streamflow at several hundred stream gauges in British Columbia. While gauges are located on nearly all of the largest rivers in the Province, only a small portion of the moderate and small-sized drainage basins are covered by the network (Figure 2.1). The gauges are also concentrated in southern British Columbia. Consequently, it will often be necessary to estimate hydrologic characteristics at the proposed gravel removal site from other nearby gauged basins or from regional studies.

For those proposed mining sites where nearby gauging records are available it is preferable to use these records, adjusted if necessary for increased or decreased drainage area, to estimate flood flows. The Water Survey of Canada publishes the Surface Water Data Reference Index which lists all active and inactive gauging stations in Canada. This index, which also briefly describes the stations, may be searched, or maps of inactive and active stations may be obtained from the Water Survey and scanned to determine if a gauging station exists or has existed on the stream. Floods at a given frequency may be either calculated from the Water Survey of Canada records contained in the Historical Streamflow Summary (available from Environment Canada), in the annual Surface Water Data publication for British Columbia (available from Environment Canada) or acquired from Data Services of the Water Survey of Canada. Alternatively, The Planning and Assessment Section of the Inland Waters Directorate has carried out flood frequency analyses for all stations in British Columbia with suitable record length (using data to 1985). The magnitude of floods at specific return periods may be obtained on request.

For ungauged sites, we recommend following the procedures developed by the Hydrology Unit of the Water Management Branch. A recent publication (Reksten, 1988) divides the province into regions, carries out flood frequency analyses for the available stations and provides methods to estimate floods at ungauged sites. While no adjustment is made for basin physiography with this technique it, at least, provides a consistent procedure that is easily applied throughout British Columbia.

2.4 Field Visits to the Proposed Removal Site

While it may not be practical to visit every proposed gravel extraction site a visit can provide information that is not easily gained in any other fashion. In particular, a site visit allows an opportunity to estimate the size of gravels in the river, the character of the river banks and, if suitable equipment is available, to obtain an accurate water surface profile. Consideration may be given to inviting DFO and/or MOE fisheries biologists along on the field visit in order to expedite future discussions with them.

Site information, concerning engineering works (eg, bank protection, dykes), and river surveys can be obtained from the Ministry of Environment, Regional Water Manager. In addition, bed material size estimates are available for some of the rivers where suspended sediment measurements are collected (refer to the Sediment Survey reports available from the Water Survey of Canada).

The slope of the water surface is best obtained along one or both banks, by a level and stadia survey or by electronic theodolite. The survey should extend over several pool and riffle sequences or a river reach several tens of channel widths long.

Grain size should be determined by the grid-by-number methods outlined in Wolman (1954) or Kellerhals and Bray (1971) and described in more detail in Appendix A (based on Yuzyk, 1986).

Samples of grain sizes should be collected on bar surfaces and also in the main channel if a dramatic difference is apparent between these two sites. These techniques estimate the size of the surface layer on the gravel bar or in the channel. For the purposes of gravel mining a volumetric sample (refer to Appendix A)including the subsurface material may be more useful, but is generally impractical. Estimation of the median (D_{50}) or average size and the D_{90} size (the size for which 90% of the gravel is smaller) by visual examination is often unsatisfactory, but is preferable to not having any estimate.

The banks at the proposed gravel mining site should be examined for evidence of erosion or channel shifting. Also, a description of the bank stratigraphy is required for one of the gravel supply estimation techniques. The height of bank, above the typical channel bottom, and the proportion of the bank that is gravel should be estimated at the proposed mining site and at sites where air photograph measurements of lateral erosion are to be made. The presence of non-alluvial banks should be noted.

A form to enable the reader to summarise the main points identified in Section 2 is shown in Table 2.1.

TABLE 2.1 Chapter 2 summary chart: a checklist of physiographic and hydrologic variables.

River:____________________ Site:________________

PHYSIOGRAPHY Slope of Channel from Map(s):________________

Lakes: present:_____ distance upstream:________ size: _____
absent:_____ distance downstream:______ size: _____

Major Tributaries present:_____ distance upstream:__________
absent:_____ distance downstream:________

Glaciers present:_____ % basin glacierized: ________
absent:_____ distance upstream:__________

Geology intrusive:_____ metamorphic:_____
volcanic:_____ sedimentary:_____
deep surficial fill:________________

Terrain Stability landslides yes _____ no _____
slopes - percent of drainage area - steep (>35%):________
flat (<25%):________

HYDROLOGY Water Survey Station on River? yes:_____ no:_____
Station Number:__________

Timing of Annual Floods snowmelt (April to July):__________
rainfall:________________
mixed (two or more periods):________

Magnitude of Floods at different return periods
two year:________ five year:________ ten year:________

FIELD VISIT (or derived from other information sources)

Surveyed water surface slope:__________

Bed Material Size (mm) Bar D_{50}:_______ Channel D_{50}:______
Bar D_{90}:_______ Channel D_{90}:______

Engineering Works in reach bank protection:______________
dyking:____________________
dredging/gravel removals:__________
bridges:____________________

Bank Character alluvial height of bank:__________
height of gravel:__________
non-alluvial bank material type:____________

Sources of information:____________________________

3.0 INTERPRETING RIVER MORPHOLOGY

3.1 Objectives

Gravel supply to a stream and in-stream movement and storage of gravel can be interpreted from air photos and maps. This section of the report provides an introduction to;

1. gravel accumulation areas and the geomorphic setting of the river;

2. consistent terminology to describe the features comprising river morphology;

3. Evaluation of the lateral stability of river reaches; and to the

4. Classification of gravel rivers (or reaches of rivers) to reflect relative gravel transport rates.

3.2 Selecting Air Photographs and Maps

Identification of gravel accumulation areas and proper interpretation of a river and its setting require maps or air photos at two different scales. The required scales depend on the size of the river under investigation:

1. The River Setting: National Topographic Survey (NTS) map or aerial photograph coverage is needed for a considerable distance upstream and downstream of the proposed extraction site. For larger rivers (channel widths exceeding 100 m and drainage areas of 500 km^2 or larger) 1:50,000 NTS maps or,

preferably, similar scale air photos are used to describe the setting. Because of the symbolic nature of river representation on maps, air photos are preferred.

For much smaller channels, it will be necessary to decrease the scale of coverage and use air photos.

For west coast streams, coverage should extend from the headwaters to tidewater, or to a junction with a major stream or large lake. For interior streams, coverage should extend downstream to their junction with a major stream, large lake or a major downstream tributary.

2. The Extraction Reach: Larger scale coverage is required for the reach where gravels are to be removed. The reach is defined as a length of river with uniform morphology.

Coverage should meet the following criteria:

a. Photos should be acquired for several different years ranging from the most recent available to 20 to 30 years in the past. A minimum of two sets of photos is required, although it is preferable to have coverage every 10 years. The availability of photos at an appropriate scale will depend on the particular location in B.C.:

b. Where possible scale should be chosen so that the river is in the order of one centimetre or wider on the air photos. The larger the image width of the river on the air photos, the better the information that can be obtained. The largest scale of air photos typically available in B.C. is 1:10,000:

Ideally, discharge at the time of photography should be near the long-term mean, or at least relatively low. Photographs taken at flood discharges are difficult to interpret because many of the channel features are not visible.

3.3 Gravel Accumulation Zones

In B. C. many gravel bed river reaches end in some type of gravel deposition zone, such as a lacustrine (lake) or a marine delta. Often, however, it is simply a flood plain reach with a rapidly decreasing slope, along which there is a transition (often quite abrupt) of the bed material composition from gravel to sand. These zones exhibit a relatively rapid and systematic decrease in median gravel size, from the coarsest available at the upstream end to approximately 16 mm at the gravel-sand transition.

Many such transitions occur in the upper reaches of deltas. A well-known example is the lower Fraser River on which there is an abrupt gravel bed to sand bed transition near Chilliwack. Other transitions are not associated with deltas but rather with tributary fans that obstruct the main valley and force the river to drop its gravel load. Several such gravel - sand transitions occur in the Rocky Mountain Trench along both the Kootenay and Columbia Rivers (Galay et al., 1983). Another example occurs in the Squamish valley, where the fan of the Cheakamus River obstructs the Squamish River and forces it to drop its coarse gravel load some distance above the confluence. Immediately below the confluence the Squamish River is a sand-bed channel. Gravels also frequently accumulate in lower slope reaches immediately downstream of steep canyon reaches, such as the Fraser River immediately downstream of Yale.

The accumulation zones are identifiable by a characteristic appearance on aerial photographs (Figure 3.1). A relatively abrupt transition occurs where a multi-channel gravel river with large bars and secondary channels changes to a sinuous or meandering sand-bed channel.

Many west coast rivers exhibit regularly-spaced laterally unstable reaches, where sediment is stored, that are separated by stable, paved reaches (Church, 1981; Church and Jones, 1982). The sediment storage reaches are sometimes associated with tributary fans where sediment accumulates in the reduced gradient reaches above the fans.

These sediment storage reaches (Figure 3.2: Big Bend, Thorsen, Snootli, and Nookilkonnik Reaches) are of practical interest to gravel mining. Gravel transport essentially occurs from zone to zone with little or no storage in the reaches between. The sedimentation zones provide suitable mining sites, because they have the broadest range of grain sizes (from sands to cobbles) and extensive bar surfaces at low water.

3.4 Describing the River Valley

Table 3.1 is used to describe the geomorphic and geologic setting of a river (Kellerhals, Church and Bray, 1976). Some of the items in the table are trivial and are only included to ensure that they are briefly considered. However, the influence of the valley on the river is particularly important. The valley may provide lateral or vertical control and its influence can vary widely. Lateral control by valley walls or terraces is readily apparent on air photographs. The degree of confinement can range from an entrenched or canyonized river with no genetic floodplain, through moderate confinement with a fragmentary

FIGURE 3.1 Lower Southgate River (BC77116: 150). Aerial photograph showing gravel accumulation zone and abrupt transition to a sand bed channel.

FIGURE 3.2 Sediment zones in West Coast gravel bed rivers. Type example from Bella Coola River (Church, 1981).

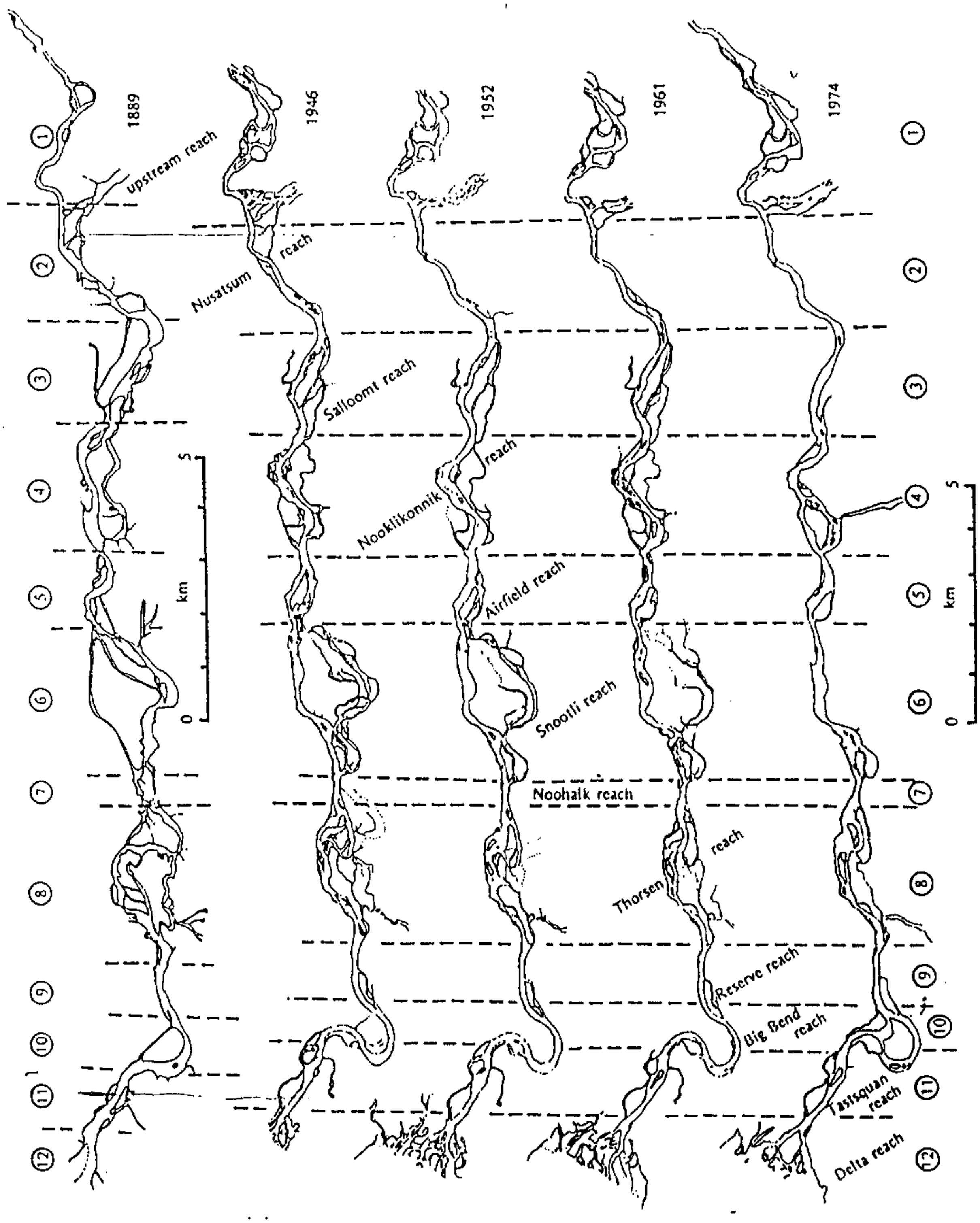


TABLE 3.1 Classification of river valley features. From Kellerhals, Church and Bray (1976).

River Name & Location: Cowichan River near Duncan
Reach Name: Near estuary Reach No.: 1 Date of Analysis: 1988 Analysis by: KMR.
Scale of Air Photos: Mozaic 86-7-1 (1:10,000 Scale of Maps: 1:50,000

NOTE: Complete codes by circling the appropriate number(s). Use "1" for unknown and "0" for not applicable.

General Description of the Terrain in the Vicinity of the Surveyed Reach, above Valley

Terrain	Vegetation	Forest Type	Land Use	Surficial Geology
1 Mountainous	0 0 0 not applicable	0 0 0 not applicable	0 0 no cultivation or built-up area	1 (1) 1 bedrock
2 foothills	1 1 1 almost none	1 1 1 deciduous	1 1 partly cultivated	2 2 2 ground moraine
3 uplands	2 2 2 grass	(2) 2 2 coniferous	2 (2) mainly cultivated	3 3 3 hummocky moraine
4 hills	3 3 3 shrubs		3 3 partly built-up	4 4 4 lacustrine deps.
5 plains	4 4 4 sparsely forested, 0-25%		4 4 urbanised	5 5 5 glacio-fluvial
(6) lowlands	(5) 5 5 moderately forested, 25-75%			(6) 6 6 fluvial deposits
	6 6 6 heavily forested, 75-100%			7 7 7 aeolian deposits
	7 7 7 swamp or muskeg			

Comments: River flows through town of Duncan.

Valley Characteristics above Valley Flat

Valley measurements:
_____ within reach
_____ within reach
Immediate vicinity
depth: / ft.
top width: / mi.
bottom width: / mi.

Slumping of valley walls:
(0) none
1 occasional
2 frequent

Vegetation on valley wall:
(0) 0 not applicable
1 1 almost none
2 2 grass
3 3 shrubs
4 4 sparsely forested
5 5 moderately forested

Forest type on valley wall:
(0) 0 not applicable
1 1 deciduous
2 2 coniferous

Comment: River is confined and entrenched upstream of reach.

Legth of reach with slumping valley walls (contact length in % of total length of banks): ____________

Terraces

Terrace presence:
(0) none
1 indefinite
2 fragmentary
3 continuous

Number of levels:
(0) not applicable
1 one level
2 two levels
9 several levels
__ ________ levels

Comments (particularly land use & vegetation): ____________

Relation of Channel to Valley

Valley type:
(0) not applicable
1 stream cut valley
2 stream cut valley in wide valley
3 wide mountainous valley

If no valley:
0 valley present
(1) on alluvial fan
2 on alluvial plain
3 in delta
4 in old lake

Underfit:
(0) not applicable or not obviously underfit
1 obviously underfit

Local lateral constriction:
(0) none
1 one
2 two
9 several cases
__ ______ cases

Relation of channel to valley bottom (vertical):
0 not applicable
1 not obviously degrading or aggrading
2 partly entrenched
3 entrenched
(4) aggrading

Relation of channel to valley walls or to high, resistant terraces (lateral):
(0) not applicable (no valley or terraces)
1 occasionally confined
2 frequently confined
3 confined
4 entrenched

Comments: Engineering interference (dyking, bank stabilization, gravel removal) within reach.

floodplain, to rivers flowing in their own alluvium on broad floodplains that are essentially unconfined. Lateral interaction of a river and its valley are summarized in the bottom half of Table 3.1. Lateral control of the river is indicated by local lateral constrictions within the river reach and by the frequency of confinement of the river by valley walls or high, resistant terraces.

"Floodplains" are those areas being deposited or constructed by the modern river as a result of flooding and lateral shifting and generally correspond to the area of seasonal flooding. There may be low terraces, that are areas of former floodplains now above the level of the present floodplain and subject to irregular flooding. These low terraces are difficult to distinguish from the present alluvial surface.

Vertical control of rivers is also exerted by valleys. Obvious examples include bedrock canyons, bedrock sills or accumulated lag boulders which produce rapids in some rivers. Many entrenched rivers, such as the Thompson River near Kamloops Lake, exhibit a thin layer of alluvial material or a cobble and boulder pavement, overlying glacial sediments, or bedrock. In these cases the valley exerts significant control over the river slope and over channel behaviour. These cases cannot always be easily recognized from air photographs, as some rivers that have degraded and entrenched since the end of the last glaciation have re-aggraded and now flow over their own alluvium. Significant vertical control on river behaviour may also be exerted by tributary alluvial fans. In some areas alluvial fan control produces characteristic river patterns consisting of anastomosed sections on the low gradient reaches upstream of the fans and steep confined reaches over the fan (Smith and Smith, 1980). The long-term vertical stability of the channel is described in Table 3.1. The end member of this class is the "entrenched" channel, where the river has no associated floodplain or valley flat, and flows on bedrock or lag boulders..

3.5 Describing the River Channel

Table 3.2 describes the valley flat and channel within the study reach. "Valley flat" refers to the low area near the channel that is subject to flooding and includes the genetic floodplain and may also include low terraces. Vertical control exerted by the valley is indicated by the presence of channel obstructions and the frequency of bedrock outcrops within the channel bed. Non-alluvial bank materials indicate lateral control over the river.

The planform of river channels as visible on maps and air photographs is described by four separate categories: channel pattern, islands, bars and the appearance of the floodplain (lateral activity; Table 3.2, Figure 3.3). The first category addresses the alignment of the main channel, an anabranch or any distributary. Channels are classified according to increasing sinuosity and their pattern. An irregular channel, while sinuous, has no repeating pattern. The irregular meanders, on the other hand, exhibit a vague repeating pattern (Figure 3.3). Tortuous meanders have a more or less regular pattern, and regularly exhibit angles of greater than 90 degrees between the channel axis and the general line of the valley. In split channel networks, different channels may have different patterns.

Bars and islands are distinguished by their elevation and degree of vegetation. Islands are stable, vegetated surfaces at or near the elevation of the surrounding floodplain; bars are lower, unvegetated, or lightly vegetated surfaces. In this classification it is the presence and number of islands that are

TABLE 3.2 Classification of valley flat and channel features. From Kellerhals, Church and Bray (1976).

Reach Name: COWICHAN RIVER near DUNCAN **Reach No.:** ______

Description of Valley Flat

Prescence:
- 0 none
- 1 indefinite
- 2 fragmentary
- (3) continuous

Extent:
- 0 none
- 1 narrow (<1Ws)
- 2 moderate (1.5Ws)
- (3) wide(>5Ws)

Average width: 2 Km
Maximum width: 2.8 Km
Channel length with valley flat: on left 100 % on right 100 %

Vegetation:
- 0 0 not applicable
- 1 1 almost none or bare
- 2 2 grass
- 3 3 shrubs
- 4 4 sparsely forested
- (5) 5 moderately forested
- 6 6 heavily forested
- 7 7 swamp or muskeg

Forest type:
- 0 0 not applicable
- (1) 1 deciduous
- 2 2 coniferous

Land Use:
- 0 0 not cultivated, not built-up
- 1 (1) partly cultivated
- 2 2 mainly cultivated
- 3 3 partly built-up
- 4 4 mainly built-up

Comments: Moderately forested along channel margins with cottonwood.

Channel Description (near long-term mean)

Channel pattern:
- 1 straight
- 2 sinuous
- (3) irregular
- 4 regular meanders
- 5 irregular meanders
- 6 tortuous meanders

Islands:
- 0 none
- (1) occasional
- 2 frequent
- 3 split
- 4 braided
- 5 tumbling flow

Type of flow:
- 1 uniform water surface
- 2 uniform with rapids in reach
- 3 irregular
- (4) pool & riffle sequence

Bar type:
- 0 0 0 none
- (1) 1 1 channel side bars
- 2 (2) 2 point bars
- 3 3 3 channel junction bars
- 4 4 4 mid-channel bars
- 5 5 5 diamond bars
- 6 6 6 diagonal bars
- 7 7 7 sand waves and large dunes

Meander dimensions:
- belt width______ mi.
- wave length______ mi.
- sinuosity______

Natural obstructions:
- 0 0 none
- (1) 1 logs
- 2 2 beaver dams
- 3 3 boulders (lag materials)
- (4) 4 vegetation

Degree of obstruction:
- 0 0 none
- 1 1 occasional minor
- (2) 2 occasional major
- 3 (3) frequent minor
- 4 4 frequent major

Comments: Meandering in estuary

Lateral Channel Activity

Lateral activity:
- 0 none detectable
- 1 downstream progression
- 2 progression & cutoffs
- 3 main cutoffs
- 4 entrenched loop devel.
- (5) irregular lateral activity
- (6) avulsion

Lateral stability:
- 0 stable
- (1) slightly unstable
- 2 moderately unstable
- 3 highly unstable

Comments: Log jams; many small side channels. Engineering interference; more unstable in past.

Channel Banks and Bed

Alluvial bank material:
- 0 0 0 no alluvial banks
- 1 1 1 clay & silt (cohesive)
- 2 2 2 silt & sand (non-cohesive)
- (3) 3 3 sand & gravel (< 64 mm)
- 4 4 4 sand to cobbles
- 5 5 5 sand overlain by silt
- 6 6 6 gravel overlain by silt
- 7 7 7 cobbles overlain by silt

Non-alluvial bank material:
- (0) 0 0 alluvial bank material
- 1 1 1 lacustrine deposits
- 2 2 2 till
- 3 3 3 easily erodible rock
- 4 4 4 moderately erodible rock
- 5 5 5 resistant rock
- 6 6 6 boulders

Percentage of left bank in alluvium: ______
Percentage of right bank in alluvium: ______

Bank vegetation:
- 0 none
- 1 weak
- (2) good
- 3 very strong

Predominant bed material:
- 1 sand
- 2 sand with local gravel
- (3) gravel
- 4 gravel with local sand
- 5 sand & gravel

Depth of alluvium:
- 0 no alluvium
- 1 shallow
- (2) moderate
- 3 deep

Estimated depth of alluvium: Unknown ft.

Comments: Bedrock banks upstream of reach.

Bed Rock Below Channel

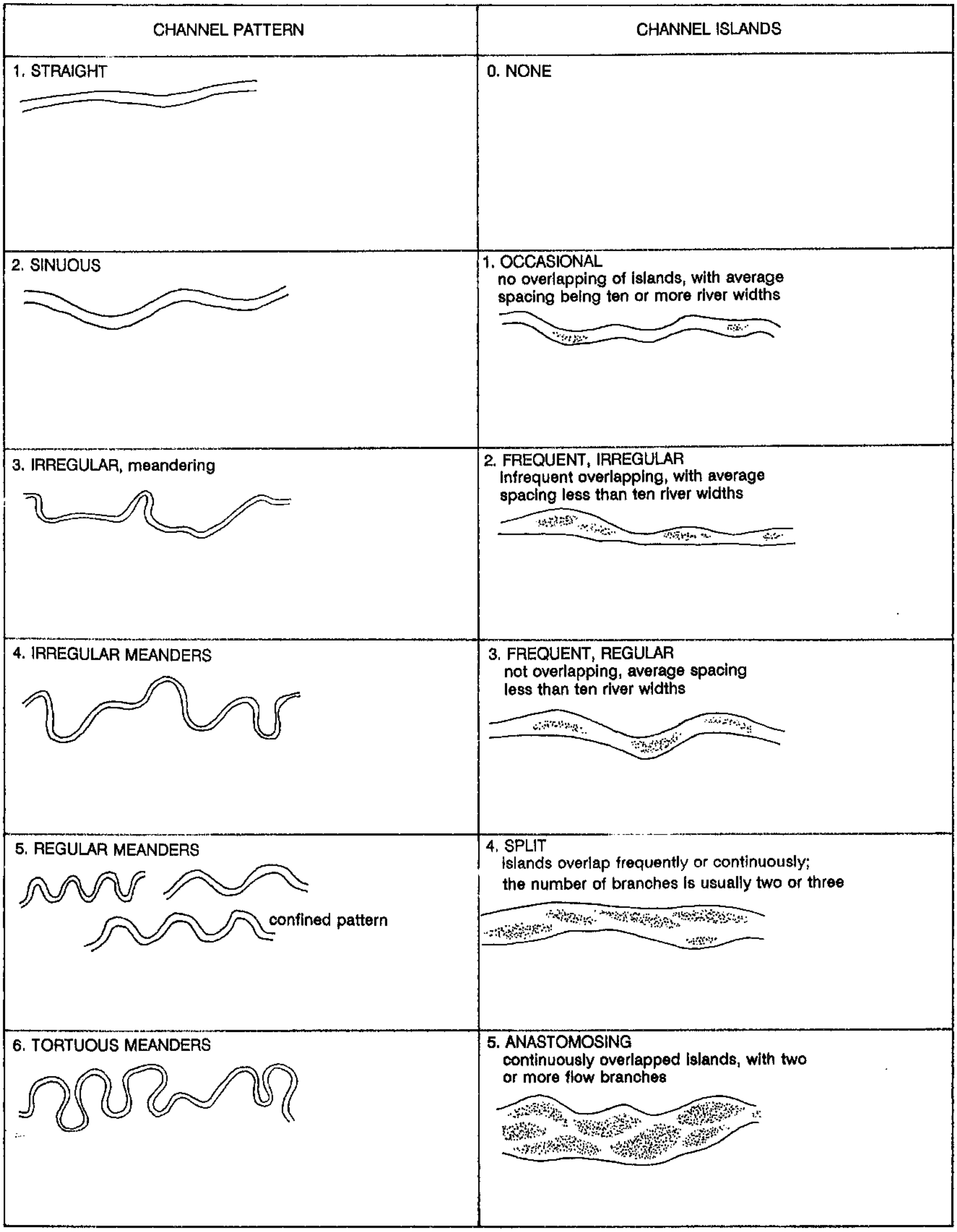
Prescence of rock outcrops in channel bed:
- (0) none
- 1 one occurrence
- 2 two occurrences
- __ ______ occurrences
- 9 several occurrences

Rock type at channel base:
- (0) 0 0 not applicable (none for great depth)
- 1 1 1 compact clay
- 2 2 2 shale
- 3 3 3 limestone
- 4 4 4 sandstone
- 5 5 5 conglomerate
- 6 6 6 granite
- 7 7 7 ______

Erodibility:
- (0) 0 0 not applicable
- 1 1 1 soft cohesive
- 2 2 2 easily erodible
- 3 3 3 moderately erodible
- 4 4 4 resistant

Comments: ______

FIGURE 3.3 Classification of channel pattern and channel islands. Modified from Kellerhals, Church and Bray (1976).



used to describe multi-channel streams. This, of course, creates a problem for some braided channels where the flow is split into many channels at moderate flows by unvegetated bars but which at high flows appears as one channel. Channel bars are divided into eight types (Figure 3.4; Table 3.2). Side bars often occur in entrenched straight or sinuous channels. These bars occasionally migrate but more often they are associated with slight channel bends. Point bars are accumulations of material on the inside of well-developed bends. Point bars are often associated with diagonal bars in gravel bed rivers.

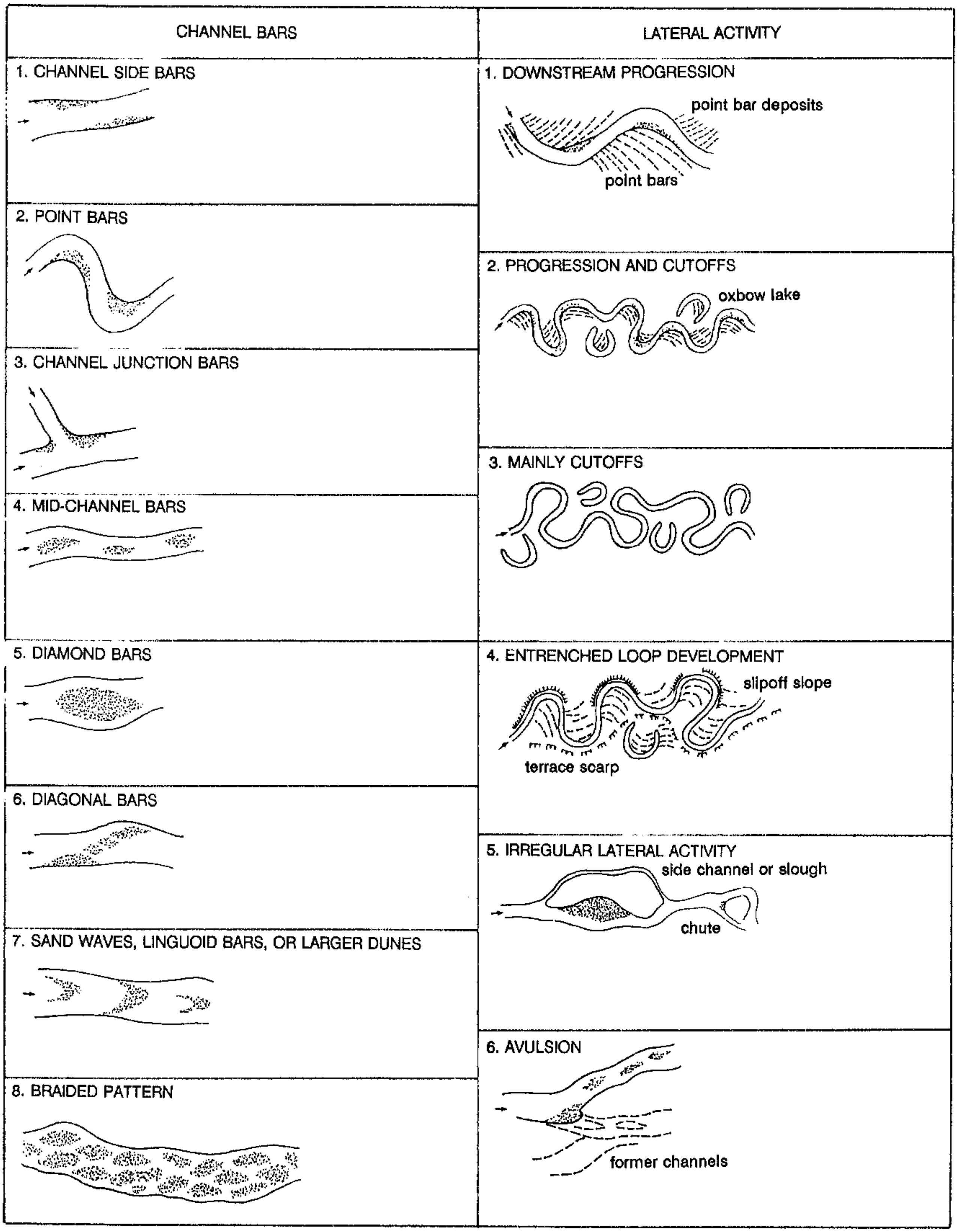
Channel junction bars are associated with tributaries and may develop upstream, downstream or on both sides of a tributary mouth. These bars are storage points for tributary sediments that are not immediately transported by the main stream.

Mid-channel bars are occasionally found in the larger gravel bed rivers, are often crescent-shaped and may remain stable over decades. Diamond bars are an extreme development of midchannel bars and are generally associated with braided rivers.

The diagonal bar is the most common form in gravel bed rivers. They generally cross the river, from bank to bank, at a steep angle and are associated, at low flows, with a riffle. On the other hand, linguoid bars are only found in active sandbed streams.

Bars, and other aspects of channel morphology, should be described from air photos taken at flows corresponding to the annual mean flow or lower, because at high flows many important features may be obscured. Channel bars enable an experienced interpreter to distinguish sand and gravel bed channels and also provide information on channel processes and rates of bedload transport (Church and Jones, 1982).

FIGURE 3.4 Classification of channel bars and lateral activity. Modified from Kellerhals, Church and Bray (1976).



Lateral channel activity is classified on Table 3.2 and Figure 3.4. Downstream progression is the slow downstream movement of the whole meander pattern without forming cutoffs This type of lateral activity may be recognized by the pattern of scroll bars on the air photos. Cutoffs mainly occur in low gradient streams with deep vertical accretion deposits on the floodplain. Irregular lateral activity is common in active gravel bed channels. No clear pattern is detectable, but the presence of secondary channels and sloughs indicates regular shifting of the position of the main channel. Further discussion is available in Kellerhals, Church and Bray (1976).

3.6 Lateral Activity in River Channels

The intensity of lateral activity may be interpreted from photographs from a single year but is more properly determined by comparing photographs from different years (Figure 3.5). Air photographs should be examined to determine;

- areas and approximate rates of erosion and deposition due to bend migration;

- areas and approximate rates of erosion and deposition along island and channel margins; and

- avulsive activity, where the main channel shifts course into a previous secondary channel or adopts a completely new course across the floodplain.

Lateral stability and bed transport rates are intimately connected (Section 4.4). Careful measurement of lateral erosion (or deposition) allows estimation of lower bound gravel transport rates. Determination of lateral activity is also important in

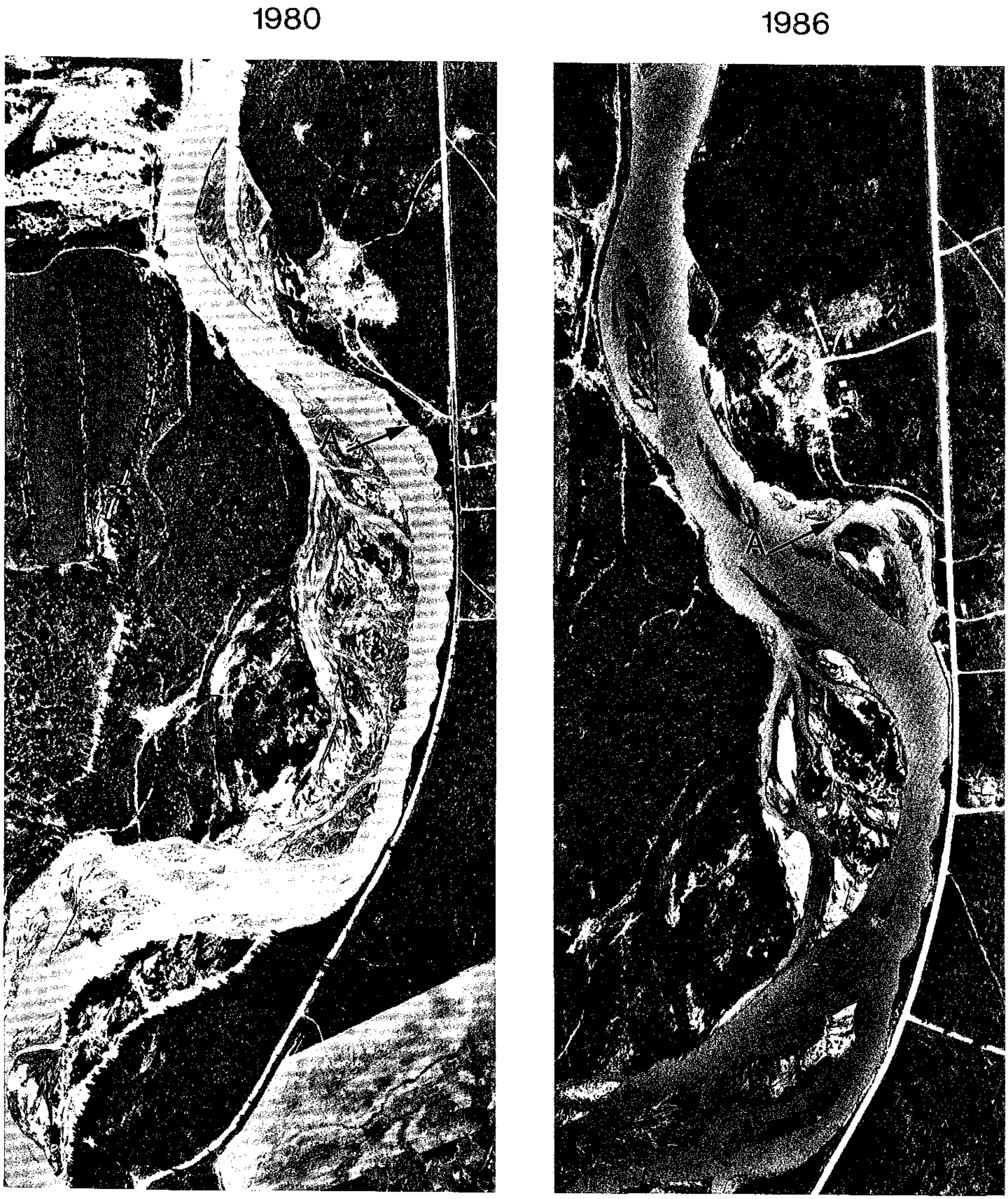


FIGURE 3.5 Lillooet River (BCC 212: 48 and BC86083: 151). Lateral activity visible from aerial photographs taken in 1980 and 1986.

assessing the effect of gravel removal on channel stability (Section 6.0)

3.7 Channel Pattern and Sediment Transport

Sediment supply, sediment transport and channel morphology are systematically related in certain types of alluvial rivers, where the channel morphology is self-formed and little or no lateral or vertical control is exerted by the valley. Only in such rivers, (see Tables 3.1 and 3.2) may channel pattern be related to sediment transport. Careful analysis of the interaction of a river and its valley is required before using channel morphology to assess relative sediment transport.

An extreme example of a situation where channel morphology is <u>not</u> related to sediment supply would be a river flowing in a bedrock canyon. Such channels tend to follow geologically defined lines, such as faults and might therefore exhibit the relatively straight, single channel pattern of a lake outlet channel. However, sediment transport rates may range from zero to large amounts and cannot be estimated from morphology or from morphologic methods. The load is indeterminate without direct measurement, or estimation in downstream or upstream alluvial reaches.

Channels occasionally confined by bedrock outcrops or by other resistant banks might exhibit quite irregular patterns with considerable channel splitting and large gravel bars, but the stability of the points of confinement will tend to assure an overall high degree of lateral stability. Such channels tend to shift very little because a few key bends are held firmly by the confining outcrops. These channels can be identified by comparing aerial photographs from different years (Section 3.6).

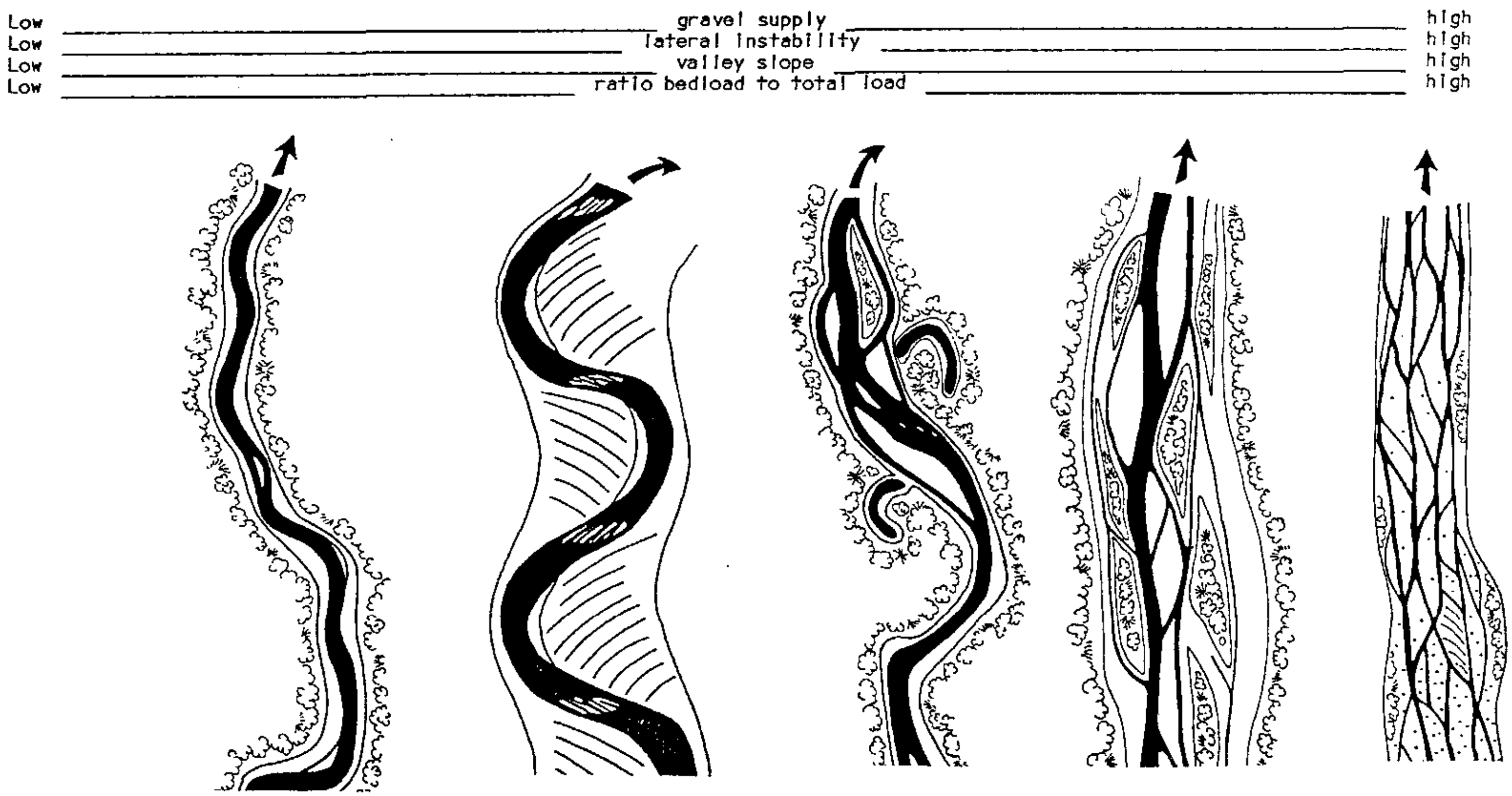
At one end of the range of typical sediment supply determined channel morphologies are lake outlet channels that carry practically zero bed load. They tend to be characterized by relatively trapezoidal and well-defined cross sections; absence of exposed bars except at very low stages; straight, irregular or sinuous, single channel pattern; and a high degree of lateral stability. The bed materials will tend to show a coarse surface armour with evidence of long-term stability such as varnish-like discoloration of exposed surfaces and algal growth.

At the other extreme are proglacial streams that tend to carry extremely high gravel loads. They are characterized by extremely wide channel zones through which the river flows in a highly unstable, braided pattern. The detailed pattern might change on an hourly basis (Fahnestock, 1963).

Between these extremes, gravel transport increases with valley slope, and higher rates are characterized by increasing width of the channel zone, increasing lateral channel shift rates, extensive exposed gravel bars at low river stages, and an increased degree of channel splitting and braiding.

Figure 3.6 is a preliminary gravel river classification relating sediment supply and lateral stability to channel type and is organized on the basis of increasing pattern complexity, decreasing lateral stability and correspondingly increased sediment transport.

The lowest transport rates are associated with alluvial channels with straight to irregular patterns, few islands and limited evidence of lateral erosion. Meandering gravel rivers, with regular or irregular patterns are the next class of rivers with higher gravel loads. Wandering channels are characterized by frequent islands, secondary channels and sloughs. The pattern of



TYPE	IRREGULARLY SINUOUS	MEANDERING	WANDERING	ANASTOMOSED	BRAIDED
PATTERN	straight, sinuous irregular	irregular or regular meanders	irregular	irregular	straight
ISLANDS	none, occasional	occasional	frequent; regular or irregular to split	split to anastomosed	(none)
BARS	none, side bars diagonal	diagonal, point bars	diagonal, point mid-channel	diagonal, point mid-channel	diamond mid-channel (braided)
LATERAL ACTIVITY	None, limited	downstream progression	irregular, avulsion	avulsion irregular	avulsion
SOURCES	Kellerhals, 1967	Carson, 1987	Neill, 1975 Church, 1981	Smith, 1983 Galay et al, 1983	Carson, 1987 Fahnestock, 1963

FIGURE 3.6 Sediment transport and gravel river types in British Columbia.

individual channels is often irregular and lateral activity is irregular with shifting main channel. The anastomosed channels represent the next higher class of gravel transport. These channels have split to anastomosed patterns of islands, irregular patterns, avulsive channel shifting and other evidence of lateral erosion. Braided gravel rivers exhibit the highest gravel transport rates.

Sediment transport rates are also reflected in bar types. Church and Jones (1982) describe a bar sequence related to declining sediment transport, sediment size and gradient as distance increases from the sediment source. The highest gravel transport rates are associated with overlapping medial (diamond) bars in braided rivers. Lower gravel transport rates occur in wandering rivers with medial bars and diagonal riffles (Figure 3.6), are lower again in meandering channels with medial and point bars, and still lower in meandering channels with point bars. The lowest rates of gravel transport (near-zero) are observed in paved gravel rivers with diagonal riffles and no bars.

Figure 3.6 applies only to alluvial, unconfined (or only occasionally confined) rivers of similar size and hydrology. In essence, relative sediment transport rate comparisons are only valid within similar hydrologic and physiographic zones for rivers of similar discharges. Rivers from different sized drainage areas can be compared in an approximate fashion using bedload concentrations, or bed load yields per unit drainage area (though this is less reliable because of the effect of drainage area on sediment yield per unit area; see Figure 4.2).

Gravel transport rates also vary within each broad gravel river type (refer to Figure 3.6). For example steeper valley slopes provide increased bed material transport. For single thread channels, slope may vary up to three to four times the stable slope (see Figure 4.1) depending on bed transport rates (Neill and Galay, 1967).

Many British Columbia rivers exhibit a variable pattern over their length (Figures 3.1 and 3.2). On a reach by reach basis, pattern varies in response to gradient control exerted by tributary fans and increased coarse sediment load introduced by these same tributaries. Downstream variation of channel pattern characteristic of high transport rates to one typical of low transport rate is indicative of gravel accumulation.

4.0 ESTIMATING GRAVEL SUPPLY

4.1 Objectives

Gravel supply rate calculations are not required if materials are to be taken from tributary fans or the floodplain. Equally, in some circumstances, fisheries habitat concerns may be paramount and justify no further consideration of the gravel removal application (refer to Figure 1.1).

The purpose of this section is to review methods for estimating gravel transport rates at the proposed mining sites. Gravel transport rates control the rate of replenishment at the mining site and are used in calculating maximum annual removals. This section provides seven different approaches to estimating this load, not all of which may be applicable at any particular site. Since none of these procedures provide consistently reliable, results, we recommend applying two or more of the techniques.

It is not necessary to calculate gravel supply for every mining application. In some cases, gravel supply may already be known; as for example on the Fraser River near Hope where it is known to amount to around 100,000 Mg/a. For some applications the proposed mining volume may be either a very small fraction or a large multiple of the likely load. In such cases further detailed calculation of gravel supply would not materially benefit the decision making process. Generally, if the proposed mining volume is a large multiple of the likely load (supply), the effects on river behaviour could be significant. If the proposed mining volume is a very small fraction of the likely load, the effects on river behaviour may be insignificant. The main decisions will be site specific and concern fisheries habitats, timing of operations or whether the operations could be designed to provide benefits to the fisheries.

Calculation of gravel supply is appropriate when the mining volume is suspected to be near to or in the same order of magnitude as the likely gravel transport rate.

4.2 Introduction

The sediment load of a river can be divided into a suspended load, consisting of fine material travelling in suspension in the water column and a bedload, including the coarsest material which rolls, slides or hops along the channel bottom. The total load can also be divided into a wash load, which is material that passes through the reach and whose volume is primarily determined by conditions upstream in the basin, and a bed material load, which continuously exchanges with local bed material and is of a comparable size to the local bed. In gravel bed rivers the two classifications are identical for most practical purposes, with the wash load corresponding to the suspended load and the bedload to the bed material load. The bed load normally consists of coarse sand, gravel and cobbles.

This simple classification has one main exception that may occur in very coarse-bedded channels where the gravels may move more as a wash load than as a bed material load, leaving few traces of their passage other than occasional deposits in low energy parts of the channel. Bedload in such rivers may be underestimated if this factor is not taken into account.

There are three complementary approaches to estimating gravel transport:

- bed sediment transport formulae;

- direct measurement; and
- estimates based on channel morphology.

Because gravel transport involves exchange between bed material and the travelling load, it is often assumed that the transport rate should depend only on the hydraulic parameters and geometry of the local reach and on the characteristics of the local bed material. This assumption underlies most bedload transport formulae.

For a variety of reasons, but particularly due to assumptions about the nature of flow that are not true in rivers and the difficulty of specifying bed material, bed sediment transport formulae do not work well. Different equations often differ in their predictions by factors of 10 or more (McLean and Mannerstrom, 1985). In general, we believe that at the present state of the art, bedload transport formulae are too difficult to apply and too unreliable to provide a practical tool for assessing gravel supply.

Direct measurement of gravel transport, while possible, is expensive and time-consuming. Measurement requires a major installation and a minimum of three to five years of records, which makes direct measurement impractical for gravel mining assessment.

4.3 Recommended Techniques for Estimating Gravel Supply

A variety of methods (refer to Table 4.4) are available for indirect estimation of gravel transport rates; these techniques are generally preferred to either application of bed load transport formulae or direct measurement. These indirect methods exhibit a broad range of applicability and accuracy. Some are essentially upper-bound or lower-bound estimates and many are only applicable to certain limited river types or in certain specific situations. For initial appraisals or quick estimates we recommend using either the technique based on suspended sediment or the one based on bedload yield estimates. Both of these techniques assume that the requisite typical conditions prevail in the river reach being assessed.

We recommend determination of gravel transport rates by as many techniques as are appropriate for a given situation. It is likely that actual gravel transport will lie within the range of values provided by the different techniques. For assessment of particular gravel-mining applications, either the minimum or maximum estimate may be all that is required. A completely accurate determination of average annual gravel transport is practically impossible and may not be that meaningful. For most of the techniques discussed, the actual transport rate probably falls into the broad range of -50% to +100% of the calculated value.

Finally, gravel transport is discontinuous over the year, occurring only during large floods, and is highly variable from year to year. In bedload rating curves, the bedload discharge generally increases with stream discharge at a power exceeding two and as a result, annual variation can be great if flood histories are variable. In the Snake and Clearwater Rivers (Jones and Seitz, 1980), minimum and maximum annual gravel transport varied by a factor of 20, partly due to regulation of flows. Knott, Lipscomb and Lewis (1987) observed differences of 2x to 4x between minimum and maximum annual loads over a 4 year period indicating that replenishment following gravel mining is influenced by the annual variability of gravel transport. This factor particularly affects monitoring programs for instream gravel removal sites, suggesting that monitoring may sometimes require a long term program (refer to Section 6).

Channel Stability Chart

An overall impression of relative transport rates for a given basin size can be gained from the general character of the basin and the river. High relative rates are expected for split channels with large bar accumulations, low rates for single thread channels, and near-zero rates for lake-outlet channels.

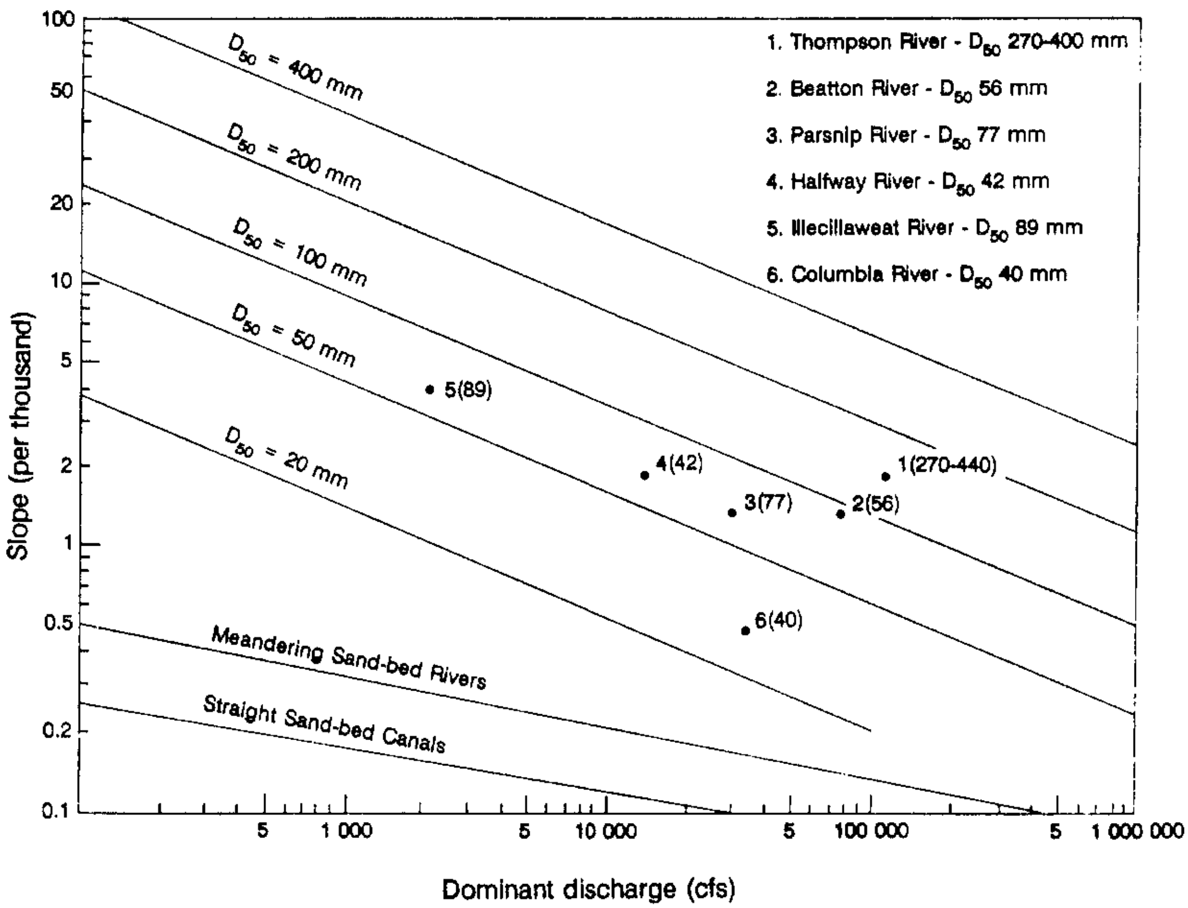
The relative magnitude of gravel transport can also be approached by considering channel stability. The hydraulics of flow in stable channels with negligible bedload transport are well-known and it is possible to develop relationships between dominant or channel-forming discharge, channel slope and grain size for stability. Such a relationship is illustrated in Figure 4.1, which is drawn from the data shown in Table 4.1 (see Neill, 1985). The diagonal lines on Figure 4.1 characterize rivers with zero or very low bed transport rates. The chart applies to single-thread, straight channels with a uniform cross-section. Rivers with negligible or zero bed transport should plot below or near the diagonal line characterizing their median grain size. Those rivers with significant bed load transport plot above their grain size line, indicating greater slopes than required for stability.

The following information is required to use Figure 4.1:

dominant discharge:	an estimate of the 5 to 10 year return period flood or of the bankfull flood in rivers with well-defined flood plains;
channel slope:	the slope of the water surface at high flow over a considerable distance or the slope of the channel bed over a considerable distance;

bed material: the median size of a grid sample of the bed armour layer (Kellerhals and Bray, 1971).

FIGURE 4.1 Slope versus discharge and grain size for low-transport channels (after Neill, 1985).



It is obvious, despite variability of bed material sizes along the Thompson River, that typical sizes exceed that required for stability. In such a case the bed would be predicted to be essentially immobile, which is consistent with hydrophone observations during floods at the Thompson River near Spences

TABLE 4.1 Geometry, flow and bed material data for the B.C. Rivers plotted on Figure 4.1 (Channel stability chart modified from Neill, 1985).

Location	Gauge	Discharge (m^3/s)	Slope	Bed D(50) (mm)	Comment	Source
Thompson River near Spences Bridge	08LF051	3250 (5 year)	.0019	270-400	irregularly sinuous, entrenched.	KESL and RCPL 1986
Parsnip R. above Misinchinka Ck	07EE007	850 (2 year)	.0012	77	stable	BCHPA 1977
Beatton River at confluence with Peace River	07FC001	2096 (bankfull)	.0012	56	degrading; some secondary channels	BCHPA 1975
Halfway River upstream of Peace River confluence	07FA003	1042 (bankfull)	.0019	42	some secondary channels	BCHPA 1975
Columbia River at 12 Mile Ferry	08ND006	929 (bankfull)	.00045	40	aggrading; laterally unstable irregularly sinuous	CBA Engineering 1967
Illecillewaet R. at Greeley	08ND013	55 (bankfull)	.0039	89	laterally unstable on fan; irregularly sinuous	CBA Engineering 1967

Bridge gauge. In this river, small gravel, which is in scarce supply, is transported as wash load and accumulates in a few low-energy environments away from the main river.

Rivers such as the Halfway and Beatton have bed material sizes smaller than necessary for stability (or slopes greater than the stable slope) and would be expected to have non-negligible bedload transport. Stable rivers such as the Parsnip and

Illecallewaet and aggrading ones like the Columbia have bed material sizes greater than or equal to their predicted stable sizes and would be expected to have negligible or small transport out of the reach.

Suspended Sediment Approach

It is commonly observed that bedload is a small proportion of total load or suspended load, and the proportion depends on basin size and the physiographic setting of the basin.

For British Columbia, typical proportions are presented in Table 4.2, below:

TABLE 4.2 Gravel Bedload as a Percentage of Suspended Load for Basins in British Columbia

	Gravel Load as a Percentage of Suspended Load
Small to intermediate size basins	2 - 8%
Glacerized basins	5 - 12%
Large basins (greater than 25,000 km^2)	1 - 2%

The initial estimates of gravel load should be based on the lower-bound percentage of the suspended load. This may be increased if there is reason to believe that the gravel loads are above minimum levels.

These estimated percentages do not apply to lake-affected channels, to highly disturbed basins or to those rivers draining Northeastern B.C. with exceptionally large suspended loads.

To use this technique, an estimate of the average suspended load is required. There are three sources for this information, listed in order of preference:

1. Environment Canada (1987a and 1987b): Historical summaries of suspended sediment loads published for their network of stations. This includes relatively few B.C. rivers;

2. Ministry of Environment: Water quality data include a measure of non-filterable residue (NFR, in mg/L), which is an estimate of suspended sediment concentration. It is necessary to convert the occasional measurements to a load by developing a relationship between NFR and discharge and then converting the daily discharge record to a suspended load record by reading concentrations (C) for each discharge (Q) off the rating curve and calculating 0.0864C x Q for daily loads. Daily loads can then be summed for monthly and annual values.

   There are two limitations to this technique. First, a gauging record with daily discharges is required near the mining site. Second, water quality samples are collected near the surface of the stream and underestimate the true sediment concentration. Consequently, annual loads will underestimate the true load, and gravel estimates will tend to be low.

3. Suspended Sediment Regionalization (Church et al., 1988): The available suspended data in B.C. have been plotted as yields against drainage area and curves drawn for different basin situations. While there is wide scatter around the trend line, the general relationship can be used to estimate sediment load in an ungauged basin (Figure 4.2).

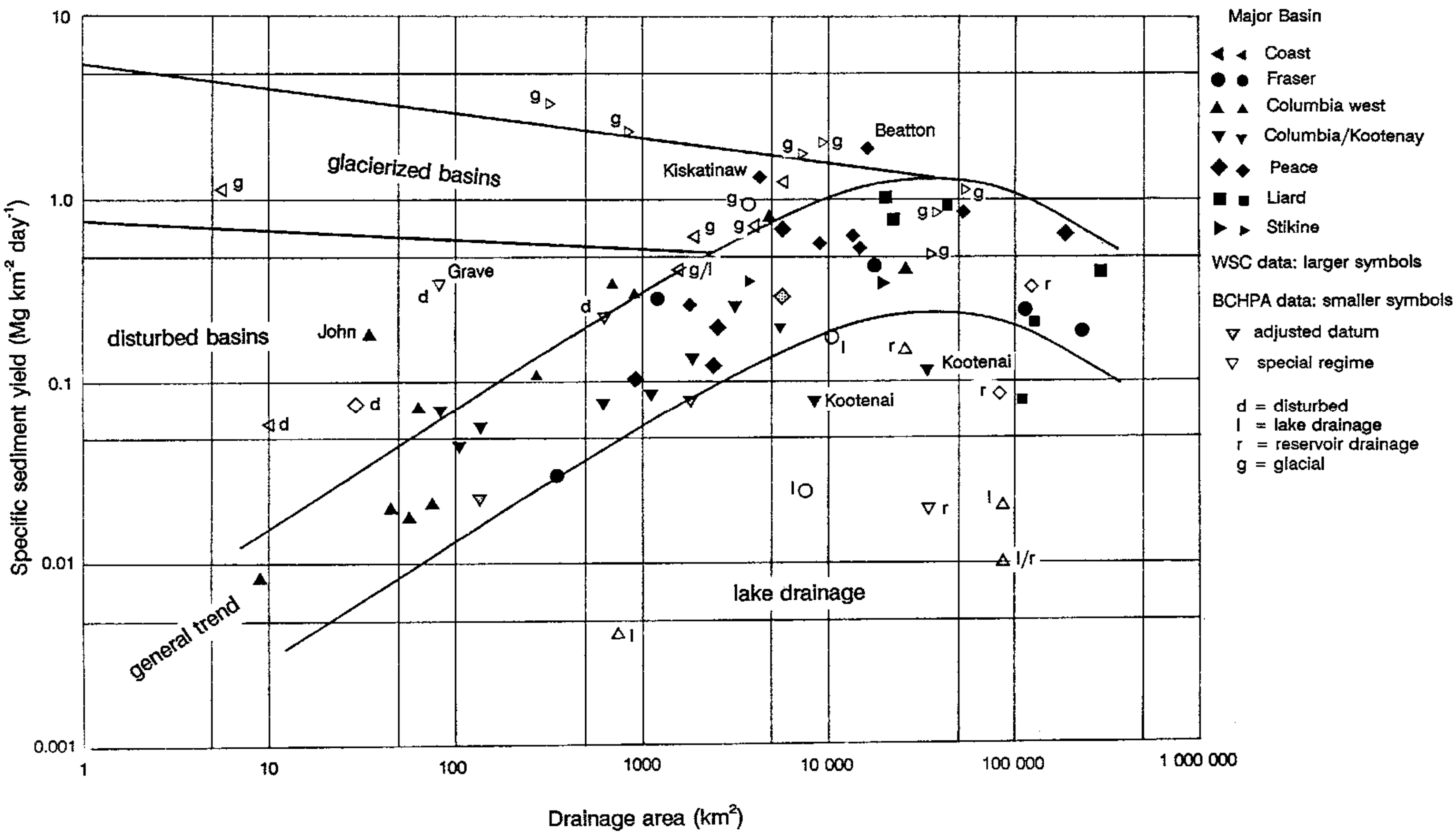


FIGURE 4.2 Suspended sediment yields in British Columbia (from Church et al, 1988).

Obviously, the third approach is the only one possible in many areas in B.C. Applying this to the Kingcome River, which has a drainage area of 1450 km^2, no lakes, no WSC gauge and is glacierized in the upper reaches of most tributaries, provides an estimated average annual suspended load of 800,000 Mg (1.5 Mg/km^2 per day; Figure 4.2). Since the basin is glacierized and on the west side of the Coast Mountains, the gravel load may be 8 to 10% of the suspended load, giving an estimated annual transport rate of 64,000 to 80,000 Mg (40,000 to 53,000 m^3).

Bedload Yield Estimates

Another approach to estimating gravel transport rates is through comparison with bedload measurements collected in other streams. The gravel yield from a basin might be expected to vary with drainage area, climate, geology and topography. Unfortunately, the available data are far too few to consider regionalizing gravel yields in British Columbia, though the eventual pattern may be not unlike that of Figure 4.2. Consequently, the basin yields (gravel volume per km^2 per year) are indexed to observed channel patterns. Table 4.3 was developed from a review of various sources of such data during the course of the study. There are probably even too few data for this approach.

These estimates are only applicable to alluvial streams; streams flowing in their own alluvium and with a pattern that has evolved with only limited interference from valley walls or high terraces. Geology, but more particularly, local gravel sources such as outwash terraces or erodible banks may cause differences in apparent load between nearby basins.

Table 4.3 is most interesting if used to estimate the size of basin required for a given replenishment. For replenishment rates of 100,000 m^3/a, the required basin size ranges from

TABLE 4.3 Bedload Yield for Gravel River Types

River Type	Gravel Yield ($m^3/km^2/yr$)
proglacial, braided	50 - 100
braided	10 - 20
anastomosed	approx. 5
irregular	less than 1

10,000 km^2 for a braided system to 100,000 km^2 or more for large single-thread channels. This obviously limits large ongoing mining operations to a relatively few sites in British Columbia.

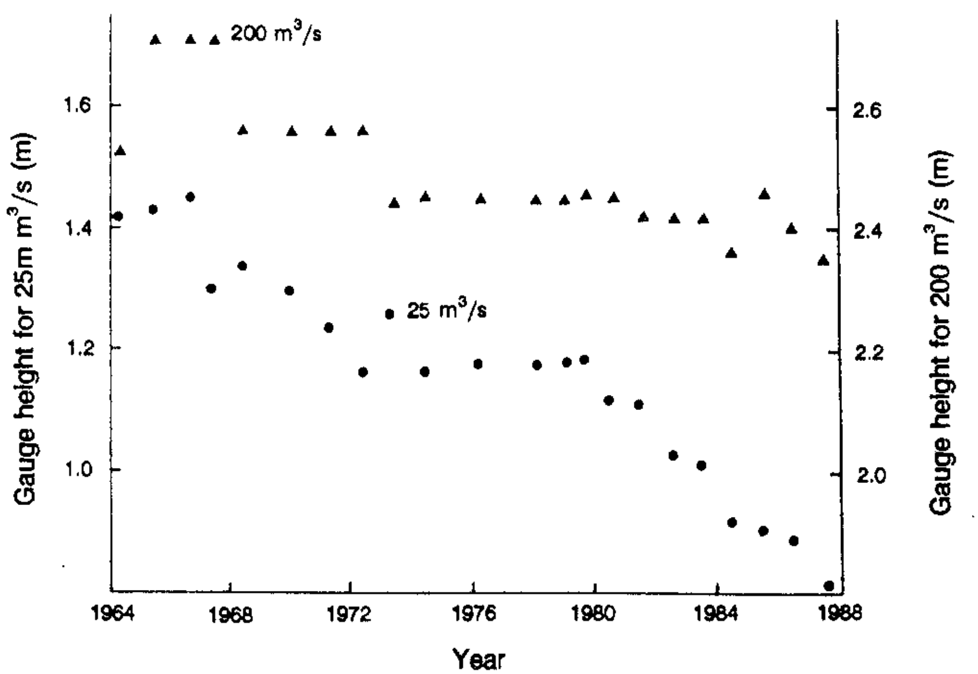
Gravel Accumulation Approaches

These approaches generally depend on estimating the accumulation rate of gravels in gravel accumulation zones, including deltas or fans. The methods used to determine accumulation rates vary with the size of the stream, the availability of engineering studies and the local gauging history. For small streams it may be possible to capture the annual bedload in a debris trap or behind a small in-stream structure and measure it either during removal or by surveys. For larger streams, accumulation may be measured by repeated surveys, analysis of specific gauge records or measurement of delta progradation.

Typically, these techniques provide an estimate of gravel transport that is superior to the regional approaches discussed in the previous sections because measurements are keyed to the specific stream. However, these techniques require that there is an accumulation zone to which they may be applied. In addition, a significant amount of data acquisition, processing and analysis, as well as professional judgement, is required which limits their applicability. Some brief details concerning these techniques follow.

<u>Specific Gauge Records</u>: The accumulation of bed material within or downstream of a particular reach can be determined from WSC gauge records. In an aggrading reach the rating curve for a gauging station would be continually updated and by plotting stage against a specific discharge from each of the different rating curves a measure of the accumulation rate can be obtained from the rise in stage over time (Figure 4.3). Generally, specific gauge curves are plotted for several different discharges.

FIGURE 4.3 Specific gauge curve for the Cowichan River near Duncan (08HA011) station.



The specific gauge curves are difficult to interpret because the effect of gravel bar shifting local to the gauge often masks more subtle long-term changes. As well, the gauge must be properly located, have sufficient record length, and, preferably, additional records available for upstream or downstream gauges which either confirm the observed trend or delimit the aggradational area. It is necessary to estimate, either from aerial photographs or maps, or local knowledge, the actual river bed area experiencing aggradation.

Repeated Surveys: Accumulation rates of bed sediments may also be estimated by surveys along the same cross-section repeated over time (Figure 4.4). Rates of accumulation are slow, and in most instances, annual accumulations are much less than survey accuracy. Local bar shifting and scour and fill may also disguise general aggradation. To accurately estimate aggradation, it is necessary to have regularly spaced survey lines that are repeatedly surveyed over periods as long as 20 to 30 years (McLean, 1985) and cover most of the accumulation zone.

For gravel mining studies, this approach is generally impractical. Relatively few rivers are surveyed in any detail and the expense of repeating and reducing old surveys is large. However, on rivers where dyking or gravel removals have been carried out by the Water Management Branch (Ministry of Environment, 1981) repeated surveys may be available. Gravel removals are generally located on alluvial or other aggradational areas and the surveys provide a rapid and accurate measure of the gravel load. In other instances, such as the Chilliwack River (McLean, 1985), where channel aggradation and flooding pose problems, surveys have been conducted, repeated and results analyzed as part of long term studies.

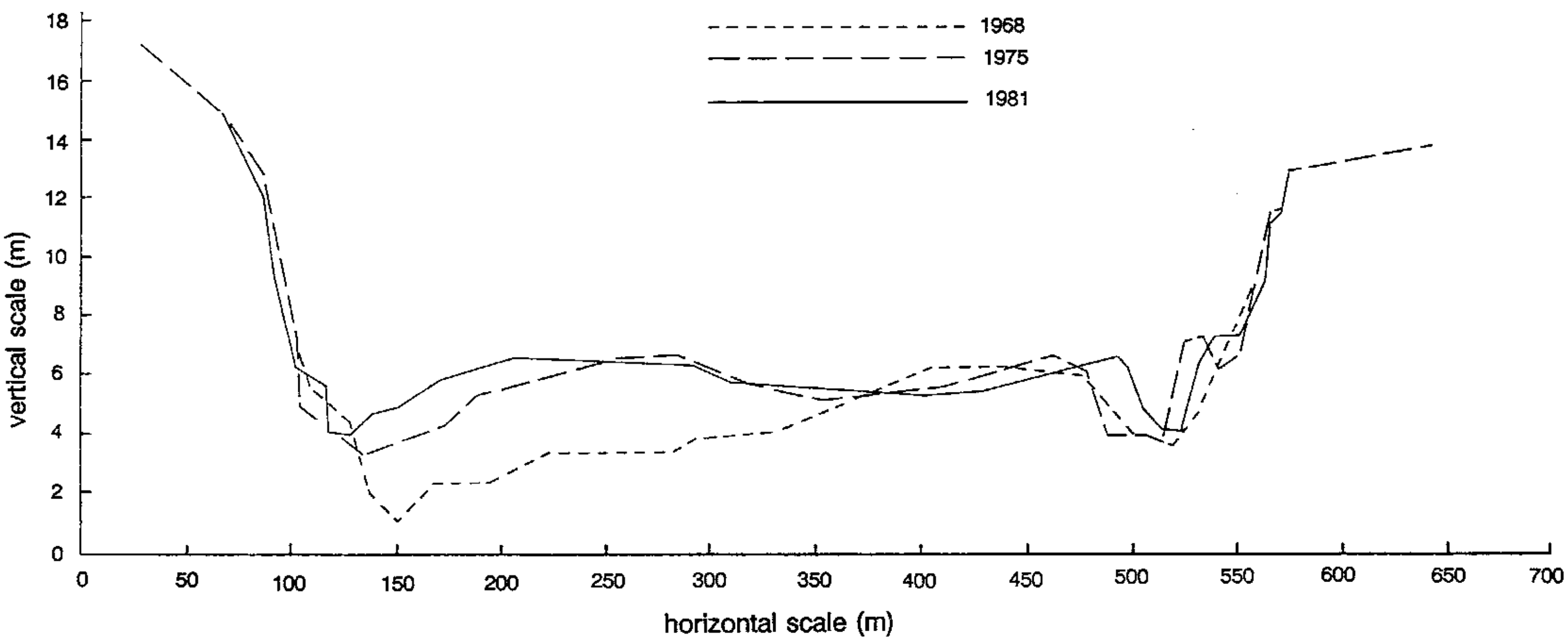


FIGURE 4.4 Estimation of aggradation from repeated cross-section surveys. Peace River at Taylor Bridge (from Church and Rood, 1981; Church, 1983).

Delta Progradation: Where rivers debouch into a fjord, lake or reservoir, the delta that forms is composed of the bed material carried to the water body. The gravel load may or may not reach the delta. In many areas in B.C. (Figure 3.2) gravel is deposited on the lower slopes upstream of the delta and rivers are essentially sand-bed channels in the estuary.

If gravels are carried to the sea, gravel transport rates may be calculated from the bathymetry of the delta, the progradation rate along the delta front, and the proportion of sand and gravel in the delta. Progradation rates may be determined from sequential aerial photographs, sequential maps, interviews or old ground photographs.

In other instances, if average progradation rates are known and an accurate river profile is available, the material deposited in a gravel accumulation zone may be estimated by shifting the profile by a distance equivalent to the delta progradation over a long period and measuring the accumulation as the area between the two profiles within the gravel accumulation zone. The volume of accumulation requires an estimate of the channel width.

In Figure 4.5, the low water profile of the Columbia River between Revelstoke and Arrow Lake is shown. Over a fifty year period the delta advanced approximately 1700 feet. The bedload, deposited in the Columbia River, was estimated from the area between the low water profile and the shifted profile. The total volume of the deposit was determined from the average width of the channel and the annual load calculated by dividing by the fifty year period. In this case, the annual load was calculated to be 70,000 m^3 of gravel, roughly 5% of the suspended load.

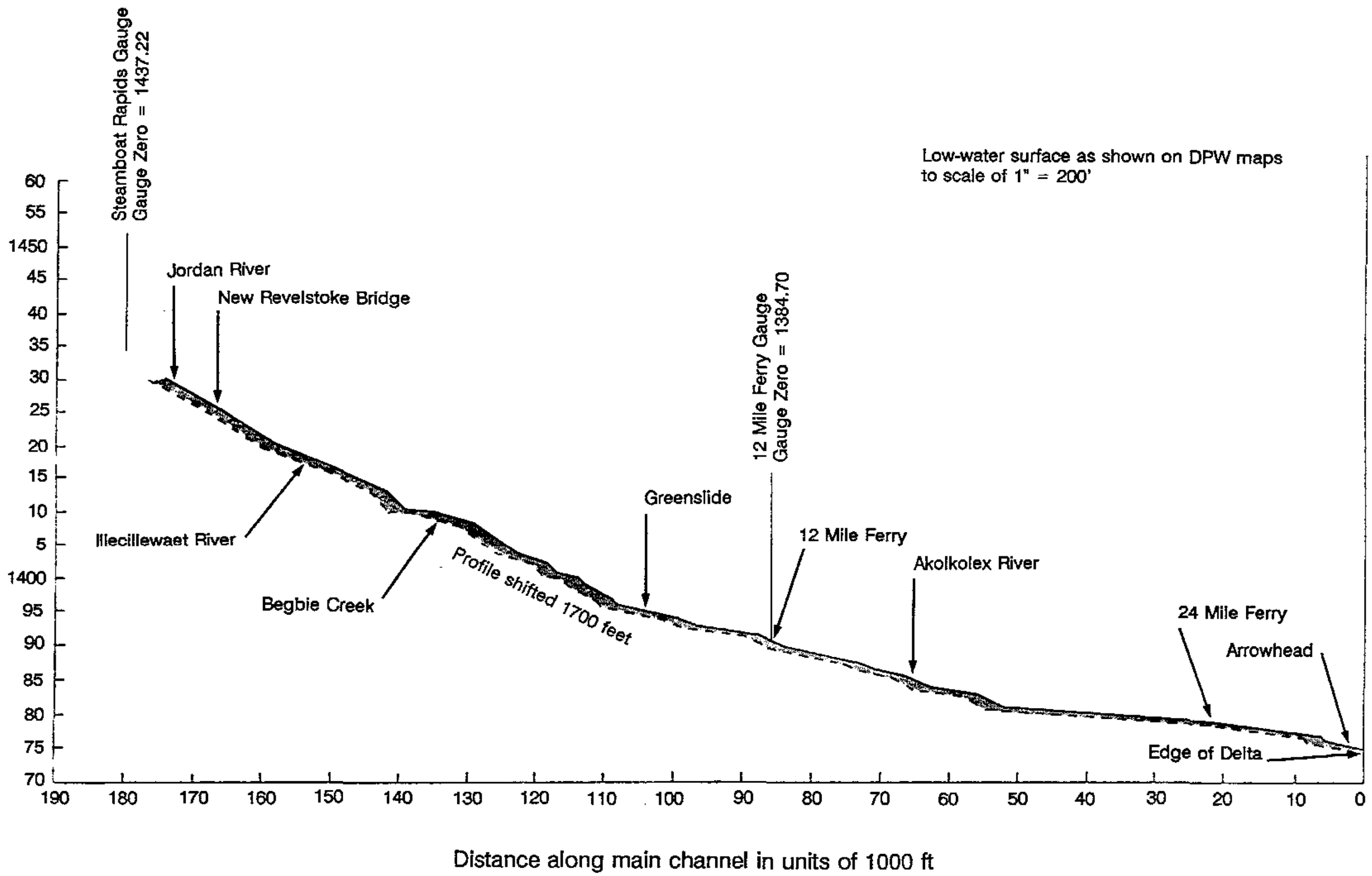
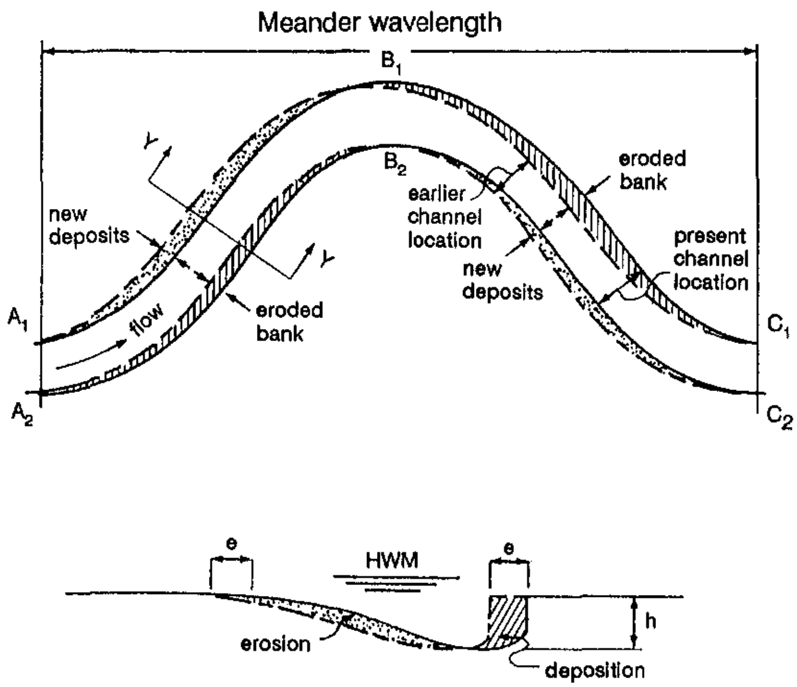


FIGURE 4.5 Estimation of accumulation of gravels along the Columbia River from delta progradation rates (CBA Engineering, 1967).

Gravel Transport and Lateral Erosion

Based on the study of a confined, very regularly meandering sand bed channel that also exhibited a regular slow downstream shift of the entire meander pattern, Neill (1971) advanced the idea that one might obtain a lower bound bed load estimate by assuming that all the material eroded out of the flood plain at the outside of one bend is deposited on the inside (point bar) of the next downstream bend. The basic method is illustrated on Figure 4.6.

FIGURE 4.6 Estimation of bedload transport rates from lateral shifting (after Neill, 1971).



Plan of Meander Loop Migrating Down-Valley

The bed load transport rate (in Mg/a) is:

$$G = l_t \times h \times V_m \times S_g \qquad (1)$$

in which l_t, the average single step or the transportation length, is equal to one half of the average meander length, h is the bank height, v_m is the meander progression rate or rate of bank erosion or bank construction, and Sg is the density of the floodplain gravel deposits. Note that in the case of gravel bed rivers, h is not the total bank height but only the height of bed material-like gravels in the bank. The overlying veneer of fine silty sand typically seen in B. C. has to be ignored because these materials are suspended load derived.

Bed loads estimated on the above basis are lower-bound estimates. The load has to be at least as indicated by Equation (1) to account for the observed channel shift rate but it can be larger by an unlimited amount since some particles may move more than one step at a time and bed material may move through the reach without participating in lateral erosion and deposition.

The method is not restricted to regularly meandering rivers, as illustrated in Figure 4.6 but can be applied to any river with one or more shifting channels. All that is required is an estimate of the average volume eroded or deposited per year (h x v_m in Eq. 1) and the average distance between bank erosion sites and the next downstream deposition site. This distance is approximately equal to the average spacing between major bars in an anastomosed reach. The approach worked successfully on the MacKenzie River (Church, Miles and Rood, 1986) though detailed mapping was needed to adequately define net areas of erosion and deposition and bathymetric surveys were required to convert air photograph measurements to a common water level and an estimated volume. More detail is available in the above reference.

The measurement program can be simplified in certain, special cases. Neill (1983) argues that rapid bank erosion rates are limited by bed transport capacity in alluvial streams. For rapidly eroding bends, a complete exchange occurs; bedload from upstream is deposited on the point bar and bank erosion provides new material for the load to the downstream reach. Neill applies this method to one bend of the Tanana River near Fairbanks, an unstable, anastomosing fine gravel bed channel, and finds excellent agreement with the measured load nearby.

To apply this method either the erosion volume or, preferably, point bar deposition volume per year (area times height of gravels) is estimated for a rapidly eroding bend from air photographs or maps. Estimates of deposition are preferred because point bar development seems to lag behind concave bank erosion in many bends (Nanson and Hickin, 1983). If complete exchange occurs, the net erosion or deposition per year is an unbiased estimate of the bedload, if the exchange is less than complete the estimate is lower bound.

4.4 Estimates of Gravel Available for Mining

Not all the total gravel load is available for mining. The portion that can be removed with minimal effect cannot be predicted theoretically. Case studies from Alaska, Washington and British Columbia are used to estimate the maximum volume that can be removed with limited morphologic consequences.

Regime theory, and general considerations, predict a response by an equilibrium river to any reduction in load. In thick alluvium, the river downstream of the removal site should degrade its bed until the downstream channel slope is lowered sufficiently and/or the upstream slope steepened to achieve a new equilibrium. In the short term, additional load would be generated by bed and bank erosion. In practice, few rivers are in equilibrium, gravel movement is infrequent and highly variable from year to year and it is difficult to distinguish small changes in gradient against a natural background of lateral erosion, channel shifting and bar development, particularly with the limited information on the channel that is usually available.

The recommended instream gravel removal quantities, for limited morphologic change, are expressed as a percentage of the estimated gravel supply. Our overall approach is to maintain the long-term processes of gravel transport and deposition, which determine the river morphology. In this fashion, the general character of the river should be maintained. The removal percentage is not fixed and varies with the nature of the proposed gravel removal - whether long-term harvesting or one-time removal - as well as the geomorphic setting (Section 3.3) of the removal site. Quite different limits are applicable for one-time removals and long-term harvesting.

Long-Term Harvesting: Gravel harvesting consists of regular, long-term removals at a reasonably fixed annual rate. The total harvesting volume within a reach may occur at one site or as a total volume distributed along a length of river. Mining rates should be less than supply rates for several reasons:.

1. Error in estimation of gravel supply: Typical confidence bands on estimates of gravel supply are roughly -50% to +100%. This should be kept in mind when considering removal amounts;

2. Availability for replenishment: Some portion of the total load passes by the removal site and, consequently, the total load is not available for replenishment; and

3. Downstream supply: A significant portion of the gravel supply must pass the site in order to maintain downstream morphology.

The requirement for downstream supply depends on the geomorphic setting of the removal reach. In some circumstances, such as the Fraser River between Mission and Hope, all the gravel load is deposited within an accumulation zone and, under natural conditions, none passes downstream. In this situation, close to 100% of the gravel supply can be removed without affecting downstream reaches, though there may be morphologic consequences within the removal reach. In other accumulation sites, particularly alluvial fans, some of the gravel load passes the site and may be important in determining river morphology further downstream. At these sites, removal rates should be much less than 100%.

In those reaches where downstream transport is important to maintain morphology the availability of other gravel sources will influence the portion that can be removed. If gravel supply is predominantly from upstream of the removal site or is generated locally by bank erosion in the removal reach, a smaller portion should be removed than if gravel is predominantly supplied by upstream tributaries and major tributaries join the main river downstream of the removal site.

It is our general feeling that up to 50%, in any one year, of the lower bound estimates of gravel supply can be removed depending on the supply of gravel to the main river downstream of the removal site, by bank erosion and from tributaries. The range up to 50% represents the total removal from all gravel mining operations along a given river reach during a single year.

<u>One-Time Removals:</u> The same limitations are not required for

one-time removals. Here concern is more for changes induced at the site than for downstream modification. As a rough guide, one-time removals should not recur for a period of five or more years.

There is still some upper limit to one-time removals based on gravel supply, since supply will control the rate of site restoration.

Experience from Alaska indicates persistent changes at sites with removals ranging from 10x to 100x the estimated gravel load (Woodward-Clyde Consultants, 1980). Obviously, the upper bound for removals is much less. We feel that one-time removals in the order of the lower bound gravel supply estimate are acceptable. This removal volume applies, of course, to the total sum of removals along a given river reach.

4.5 Developing Conclusions

It is our strong recommendation that any assessment of gravel supply be based on estimates using two or three of the techniques discussed in Section 4 and summarised in Table 4.4. We particularly feel that gravel load estimation from lateral erosion measurements from sequential aerial photographs provides the best available technique for lower bound transport estimates.

Our recommended removal volumes apply only to instream gravel removals or removals from the active channel zone. For proposed sites in the genetic floodplain or low terraces which are not connected to the present river the removal volumes from these sites need bear no relation to gravel supply.

TABLE 4.4 Chapter 4 summary: methods of estimating gravel supply.

Method	Basis of Approach	Required Information	Source of Measurements	Effort Required to Apply Technique	Relative Accuracy
Percent of Suspended Sediment Load	regional measurements	-drainage area -basin description -annual suspended load -measured or estimated	maps Figure 4.2 WSC	low	very low
Bed load yields	regional measurements pattern classification	-river pattern -drainage area	air photos and maps	low	low
Specific Gauge	WSC gauge records	-extent of gravel accumulation area; -analysis of WSC rating curves	WSC; air photos and maps	moderate	moderate
Repeated Surveys	measurement of cross section changes	-channel surveys, repeated extent over several years of accumulation area	Engineering surveys, WSC air photos	high; field measurements	moderate
Delta Progradation	delta bathymetry or shifting river profiles	-detailed river profile, extent delta bathymetry of accumulation area, -delta progradation rates	air photos, engineering surveys	moderate; office technique; high field measurements	moderate to low
Lateral Erosion	channel shifting as minimum bedload	-erosion or deposition -transport length, height of gravels in bank; -density	mapping from air photos field observation of bank.	moderate to high	lower bound; good
Bedload Exchange	control of bank erosion by transport capacity in bank	erosion or deposition rates, height of gravels	field observation of bank	low to moderate	lower bound; moderate.

Our recommended removal volumes can then be simply calculated:

		Allowable Removal
Harvesting:	sediment supply dominantly from upstream of the site.	25% of lower bound gravel supply.
Harvesting:	major tributaries downstream supplying coarse sediments.	50% of lower bound gravel supply.
Harvesting:	gravel accumulation zone. No downstream transport.	up to 100% of lower bound gravel supply.
One-time removals:	no further removal for 5 years.	up to 100% of lower bound gravel supply.

In harvesting situations, regular monitoring of the removal site and upstream and downstream bar and bed levels by the proponent will indicate whether these limits are appropriate for the particular river. If the monitoring techniques discussed in Section 6 indicate no morphologic change, the harvesting limits might be cautiously increased. The approaches to estimating gravel supply are conservative and the initial estimate may be low.

5. SELECTING THE REMOVAL SITE

5.1 Approach

This report is directed towards site selection and gravel removal operations within the active channel zone. Some brief consideration is given to removals from the genetic floodplain.

In Sections 1 through 4 the total allowable gravel removal for a specific reach of river was calculated. If gravel requirements are less than this amount, the next step is to select a specific site for the gravel removal operation, within the reach of river where gravel supply was determined. Alternatively, if the allowable gravel removal volume is less than the gravel requirements it is necessary to either consider removals from a different river or to consider removal of all, or part, of the required volume from the floodplain where removal volumes are not constrained by gravel supply.

Woodward Clyde Consultants (1980) identify three classes of factors that influence the suitability of a particular site for gravel removal:

1. Technical: Includes the quantity and quality of gravels, the method for removing the gravels and engineering problems associated with the removal:

2. Economic: Factors such as hauling distances and costs of site preparation and rehabilitation:

3. Environmental: The location of the site within the river valley and the fisheries characteristics surrounding the site.

Economic factors are beyond the scope of this report. The following sections discuss some aspects of the technical and environmental considerations that influence site selection and gravel removal operations. Tables 3.1 and 3.2, plus further review of the air photos, are particularly useful during an initial review of potential gravel mining sites within the reach.

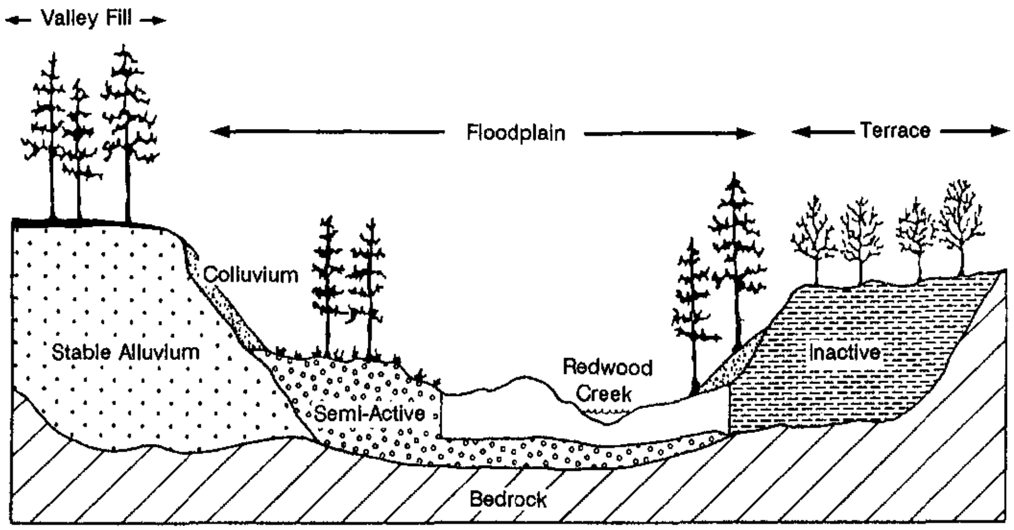
The reader is reminded that fisheries concerns affecting site selection and gravel removal operations is important to consider early in the process. An overview of such concerns is provided in Section 5.4. An appreciation of the general nature of these concerns aids in planning. However, the site specific nature of fish habitat means that these concerns are best addressed to agency fisheries biologists and during a site visit conducted jointly with DFO and MOE staff.

5.2 Gravel Removal Techniques

The river valley can be divided into different gravel storage zones or reservoirs as shown in Figure 5.1 (Kelsey et al., 1987). In B.C., gravels may be stored within the active channel zone (the "instream" area, between established vegetation), within the genetic floodplain of the modern river, within terraces, or as part of a Holocene or Quaternary valley fill. The relative volume of gravels in these zones varies with the river type and location in British Columbia. Many west coast streams, for instance, have neither terraces nor quaternary valley fills. This is, naturally, the main reason why mining the active channel zone and genetic floodplain often looks so attractive to the proponent.

These different zones have very different replenishment rates for gravels. Valley fills and river terraces are not replenished

FIGURE 5.1 Schematic of gravel storage sites within a cross-section (modified from Kelsey et al, 1987).



except by colluvium and essentially any gravel removal is a mining activity. Replenishment rates for gravels on the vegetated floodplain depend on the lateral instability of the channel (i.e. avulsion, meander migration), which controls the length of time required to rework the floodplain. Note, though, that rapid replenishment of gravel excavations with fine-grained materials through deposition of suspended load may occur.

The active channel, composed of unvegetated bars and the main channel bottom, is directly replenished by sediment transported from upstream, from tributaries, and by erosion of the other gravel storage reservoirs in the reach.

Gravel removal techniques differ in these various environments. Techniques commonly include:

1. Scalping of exposed or lightly vegetated gravel bars in the active channel zone or on the floodplain:

2. Pit excavation of gravels from the floodplain or low terraces. These sites often have mature vegetation cover and removal of overburden is often necessary:

3. Dredging of the bed of the main or secondary channels in the active channel zone.

In British Columbia, bar scalping is by far the most common technique for removal of gravels from the active channel zone.

5.3 Technical Requirements for Site Selection

From a technical point of view the removal site should have a sufficient quality and volume of gravel to meet requirements, receive adequate replenishment of gravels and cause no erosion or avulsion following removal.

The setting of a river may provide information about the quality and volume of gravels stored in bars. At one extreme are entrenched or canyonized rivers which are often degraded and seldom move their bed material. Generally, in such rivers gravel bars are composed of large material, are limited in size and number and are often difficult to access. At the other extreme are aggradational sites such as alluvial fans, deltas and within-river valley gravel accumulation areas. These settings generally exhibit a broad range of material sizes and extensive gravel storage areas, either in active bars or on the floodplain.

Between these extremes are alluvial channels exhibiting variable degrees of confinement and bar and floodplain development, depending on the nature of the valley, history of the river and supply of sediment from the drainage basin.

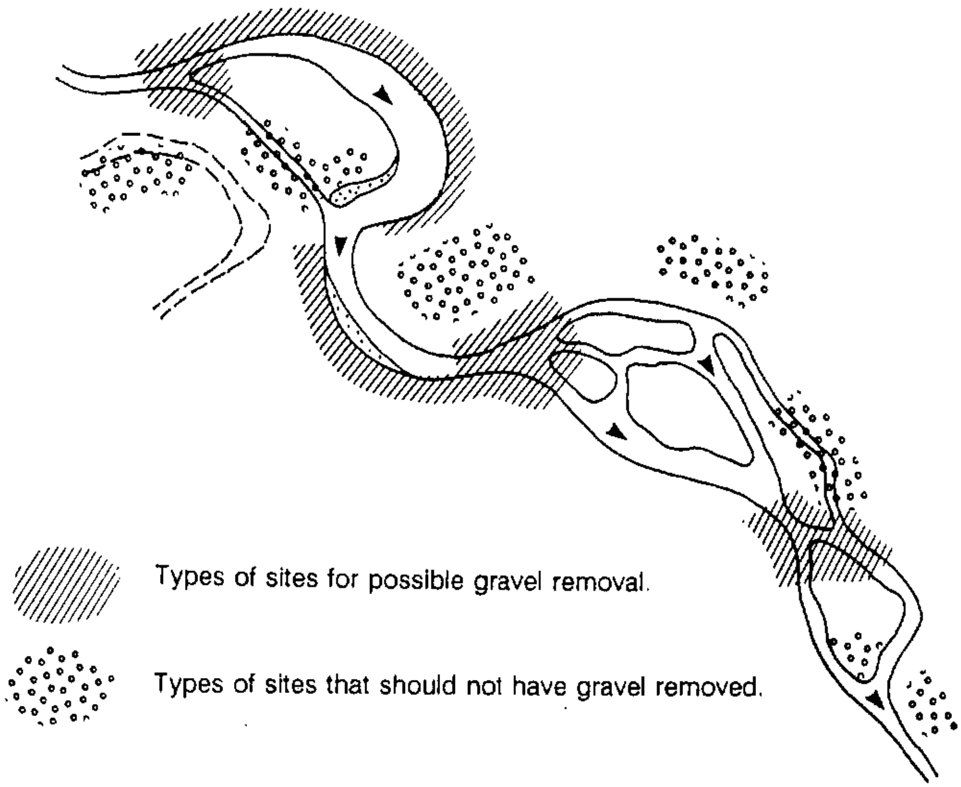
Within a specific reach, measurements may be made from air photos of the extent and approximate height of gravel bars. This allows a rough determination of the volume of gravel stored in the bars. These determinations may be confirmed, and the quality of the gravel examined during a subsequent site visit.

At the initial stages, several sites that meet the specific volume requirements should be selected because fisheries concerns may dictate that one or more of the sites are unacceptable.

The selected gravel removal sites should include bars where replenishment of gravels is likely. Generally, most active, unvegetated gravel bars within the main channel zone will experience regular replenishment, though replenishment rates may be low in secondary channels. A review of air photos from several different years may allow determination of which gravel bars are actively storing materials.

Finally, sites should be selected where gravel removals are unlikely to induce bank erosion near the removal site or avulsion of the main channel into a secondary channel. If bank erosion or avulsion is likely to result from the removal operations then such sites should be avoided (Figure 5.2). Sites on the outside of bends likely have low replenishment rates and gravel removal may induce erosion or avulsion. Removals from the head of active or inactive secondary channels have the potential, through degradation of the secondary channel, to induce avulsion of the main channel into the secondary channel. Figure 5.2 provides only a selection of the river engineering problems that may be associated with a particular gravel removal. If there is concern

FIGURE 5.2 Schematic of wandering gravel bed river showing removal sites that may or may not produce lateral erosion.



about erosion or avulsion at a specific site, a review by a specialist is encouraged.

Quite different technical requirements apply to excavations within the floodplain or on low terraces. Site visits are generally required to determine the depth of overburden and estimate the depth of gravels. Other technical considerations include determining whether the pit is to be connected or disconnected from the main river and ensuring that the pit is not threatened by lateral instability of the active channel zone. Further discussion of this topic is included in Woodward Clyde Consultants (1980).

5.4 Fisheries Considerations for Site Selection

River gravels are used for fish spawning, incubation and, in some cases, rearing. Removal of gravel from rivers can, therefore, have a number of both direct and indirect impacts on fish and fish habitat. The most obvious direct impact of gravel removal is disruption of eggs incubating in river gravels. Whereas this impact can be avoided by timing gravel removal operations so that they do not conflict with fish spawning and incubation, the loss or disruption of significant spawning areas must be considered. For example, summer gravel removal may leave areas that are heavily sedimented and unsuitable for fall fish spawning. Gravel removal may also affect subsurface flows in adjacent areas with a resultant reduction in incubation success. River gravels can provide cover and areas of low velocity for overwintering chinook salmon. For instance, in the Nicola and Thompson Rivers most overwintering juvenile chinook were found in interstitial spaces of boulder or cobble areas (Emmett and McElderry, 1986). Loss of such areas may affect the overwintering survival rate of this species. Gravels also provide a substrate for production of invertebrate food organisms in rivers. These organisms, produced in fast flowing riffle areas, emerge and drift downstream where they can be eaten by fish rearing in pools.

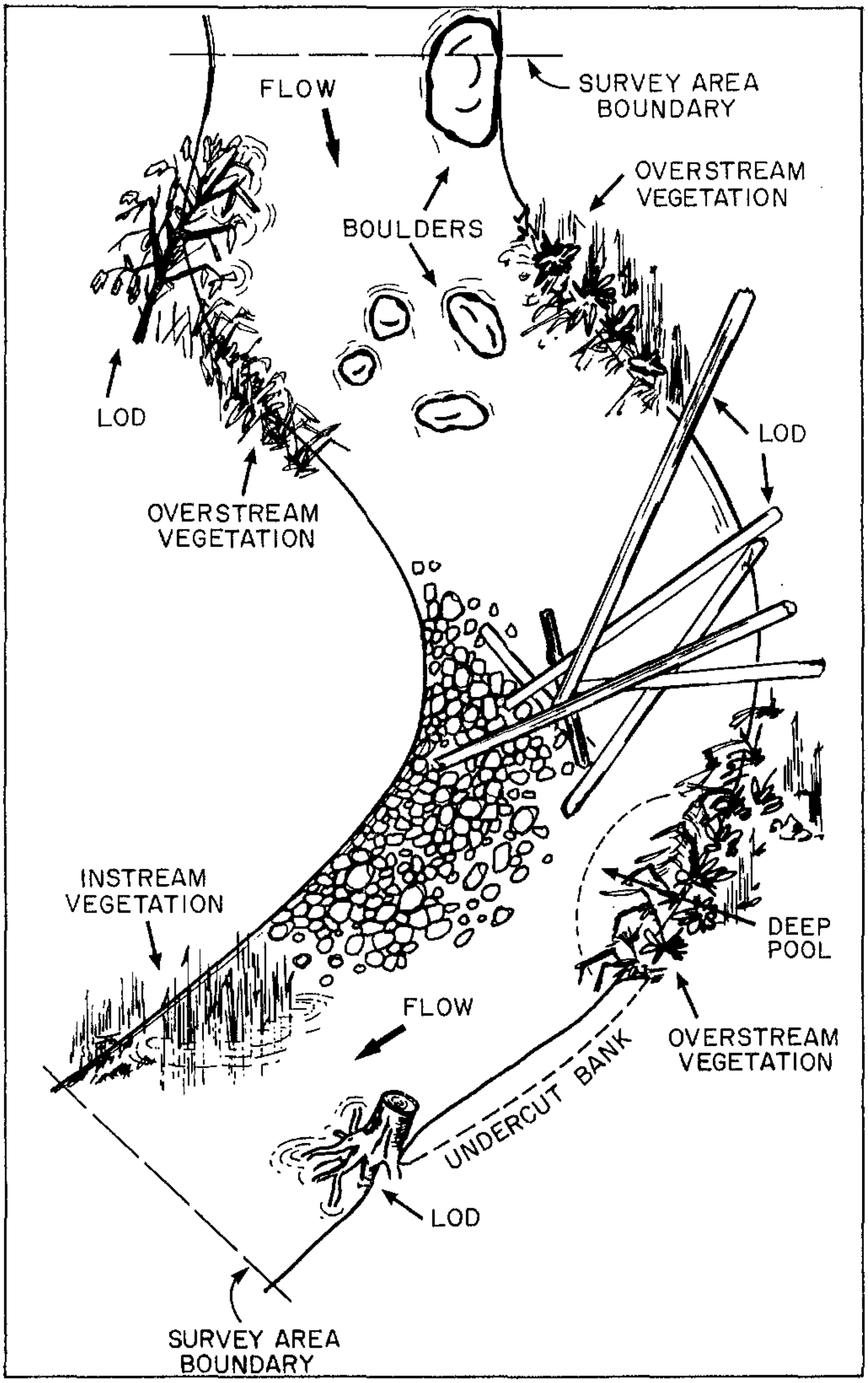
Gravel removal and associated gravel washing operations can affect fish by creating elevated concentrations of suspended sediments. Effects of suspended sediments have been extensively documented in the fisheries literature (see, for example, Newcombe, in press or Langer, 1980) and are only briefly discussed here. In high concentrations sediments can damage or coat fish gills resulting in mortality. At lower concentration, behavioral effects in fish include delays in migration, downstream movement and reduction in feeding Sediments can settle out filling in pools or riffles. Sediments in riffles can result in a reduction of egg incubation success and reduced invertebrate production.

Physical channel changes resulting from gravel removal can also alter fish habitat. Access to the removal site, removal of gravel, or downstream channel changes can disrupt fish habitat. Apart from stream bed changes discussed above, the main concern is loss of cover. Cover can be provided by a number of stream structures including large organic debris (LOD), undercut banks, overhanging vegetation, deep pools, large boulders or in-stream vegetation (Figure 5.3). All of these features may be altered by instream gravel removal operations. Not all of these features occur near a given site and rivers of different sizes may have a very different range of cover types.

Under certain conditions, the effects of gravel removal on fish habitat can be positive. For instance, gravel removal could be used to create deep pools which provide cover and holding areas for fish. Further, gravel removal operations can, if properly engineered, be used to create side channel areas for both spawning and rearing. On the Squamish River, removal of gravel for dyke construction was engineered so that side channels for chum spawning and coho rearing were created. Similarly, on the Cowichan River, gravel removal for dyking has been used to create side channel habitat

As can be seen, the effects of gravel removal can be both numerous and complex. Many of these impacts can be mitigated by

FIGURE 5.3 Stream Cover.



avoiding fisheries sensitive areas and application of the guidelines outlined in Section 5.5. The above discussion is intended primarily to sensitize users to the various potential impacts associated with gravel removal. Since fish utilization and habitat types vary considerably from site to site, a specific assessment of each proposed gravel removal site is required. This assessment should be conducted jointly with DFO and MOE staff. In many cases, these agencies will have specific knowledge of the use of a section of river, particularly, the location of spawning areas. Early consultation with DFO and MOE staff will greatly assist in designing measures to minimize negative impacts and maximize positive impacts.

5.5 Site Planning

Instream gravel removal operations must avoid or eliminate the negative impacts on fisheries discussed in the previous section. In some cases negative impacts are avoided by prohibiting gravel removal at sites near important rearing or spawning areas. At other sites specific constraints may be imposed to prevent negative impacts. Introduction of sediment to the stream is controlled by extracting gravels in the dry or in standing water only, by maintaining a buffer between the extraction site and a flowing stream and by construction of settling ponds for any contaminated flows. Further protection may consist of timing gravel removal operations to avoid conflict with different fish use periods.

Rehabilitation is also important to minimizing site impacts. Instream removals should be designed to maintain the approximate natural shape of the stream channel and to maintain the low flow channel. When removals are completed the removal site is generally contoured to remove any unnatural depressions and smoothed.

These approaches apply only to instream removals. Planning for pit excavations on floodplains, particularly if enhancement is intended, should be discussed with representatives of DFO and MOE.

The following subsections provide examples of typical constraints or guidelines applied to instream gravel removal operations by the Department of Fisheries and Oceans. The clauses are worded in a general manner and not all may apply to a specific removal operation.

Planning and Site Layout

1. Proposed gravel volumes for extraction shall not exceed the determined maximum available using the procedures described in this report. Repeated extractions from a removal site will not be approved unless full recruitment to the site is indicated by ground surveys.

2. Proposed sites for gravel removal will avoid significant fish habitat areas such as important rearing areas or stream reaches intensively utilized for fish spawning.

3. Stable instream islands with established vegetation will generally not be approved as gravel removal sites.

4. A ten meter buffer shall be maintained between gravel removal operations and any water body. River gravel shall not be removed to a level lower than the water surface of the river at the time of the operation.

5. Timing for gravel removal operations may be prescribed to

avoid conflict with fish utilization. Generally, the preferred timing for gravel removal operations is during the period of summer low flows. Gravel removal operations should not occur during periods of flooding.

Site Preparation and Access

6. The site should be surveyed to establish surface profiles and to locate significant features prior to commencement of work. Access road alignments and removal areas should be flagged prior to on-site agency inspections.

7. Stream crossings shall be constructed across all water bodies for access to the excavation site. Water bodies will not be dammed or diverted and road construction standards will be consistent with good temporary road building practices.

8. Organic debris and overburden shall be removed to a stable site where it will not re-enter the channel.

9. Fuel and other toxic substances shall be stored in a secure location away from any water body.

Conduct of Gravel Removal Operations

10. The proponent will provide adequate on-site supervision and engineering advice to ensure that operations are conducted in accordance with the prescribed guidelines.

11. Gravel removal and operation of equipment shall be conducted in the dry or in standing water only. Contaminated water from the worksite shall be impounded to allow settling of suspended fines prior to discharge into the mainstream. In

extraordinary circumstances, such as underwater river dredging, specific fisheries constraints will be prescribed for the operation.

12. Fish eggs shall not be present in the gravel during removal operations. In the event that fish eggs are discovered on-site, operations shall cease and fishery agencies shall be notified.

13. Gravel removal operations shall cease in the event that flood waters threaten to inundate the worksite. All equipment shall be removed to a secure site and temporary structures removed.

Site Restoration and Follow-up

14. The removal site shall be contoured to approximate the natural shape of the streambed, and to remove any depressional areas.

15. Profiles shall be surveyed following contouring of the site and the actual volume of gravel removed calculated.

16. All stream crossings and temporary structures shall be removed. Road surfaces shall be stabilized to prevent erosion.

17. Fishery agencies shall be contacted following completion of work. Removal volumes, site restoration measures, and profiles should be forwarded to the fishery agencies. A post inspection may be arranged.

6.0 MONITORING OF INSTREAM GRAVEL REMOVALS

6.1 Introduction

During the preparation of this report it became obvious that the many agency representatives working in different parts of British Columbia had considerable site specific knowledge but information was poorly documented and personnel frequently moved from one region to another. With relatively little effort, the information base on gravel mining in rivers in British Columbia could develop substantially. This, in turn, would assist in decisions made by users of this report.

Because of the uncertainties associated with estimates of gravel supply, it is important that the proponent survey the gravel mining site and the river upstream and downstream of the site.

6.2 Use of Ground Photographs

Good photographs taken at appropriate times can be an excellent way to document conditions at a mining site. It is important to take sequential (in time) photographs from the same location with the same view. Pictures should be timed to the activity at the site. Photographs should be taken before mining, after a season (or completion) of mining, before the first flood after mining and after the same flood, and so on. Photographs should be documented, dated and the site and view described.

6.3 Use of Aerial Photographs

Aerial photographs provide a convenient and rapid method of measuring depletion of gravels downstream of a mining site. For photographs at similar discharges the downstream bar surface areas can be measured prior to mining and several years following the initiation of gravel harvesting. Significant declines in bar surface area imply that gravel removal rates are too high in relation to the gravel supply. Likely the gravel supply was overestimated initially and removal volumes should be decreased.

Aerial photographs may also provide clues to other morphologic changes. Rapid establishment of successional vegetation on gravel bar platforms may indicate degradation of the main channel and lowering of local flood levels.

6.4 Use of Surveys

Cross section surveys are used to monitor changes in bed elevations and changes in the cross section. Sections should be surveyed both downstream and upstream of the mining site. Details are provided in Neill and Galay (1967) or Northwest Hydraulic Consultants Ltd. (1986). It should be noted that DFO guidelines (refer to Section 5.5, #15) may require surveys prior to gravel removal. Such survey lines should be documented and resurveyed as part of the monitoring program.

We recommend including the following procedures;

- establish benchmarks for each end of survey sections above likely flood levels;

- tie benchmark location to a local survey network if possible;

- repeat the initial surveys following gravel mining and the passage of a significant flood or resurvey on the basis of once every six months; and

- the surveys are most useful if notes show the location of such features as bank undercutting and vegetation and material boundaries.

Cross sections and water levels should be surveyed at the removal site and upstream and downstream of the site. Preferably, at least five sections should be established. Cross sections, when drawn, should show water surface elevation, dates of survey and the water surface slope should be calculated between the sections.

6.5 Gravel Sizing

Gravel sizes can be determined from two different techniques. It is important to estimate gravel sizes prior to mining for later comparison.

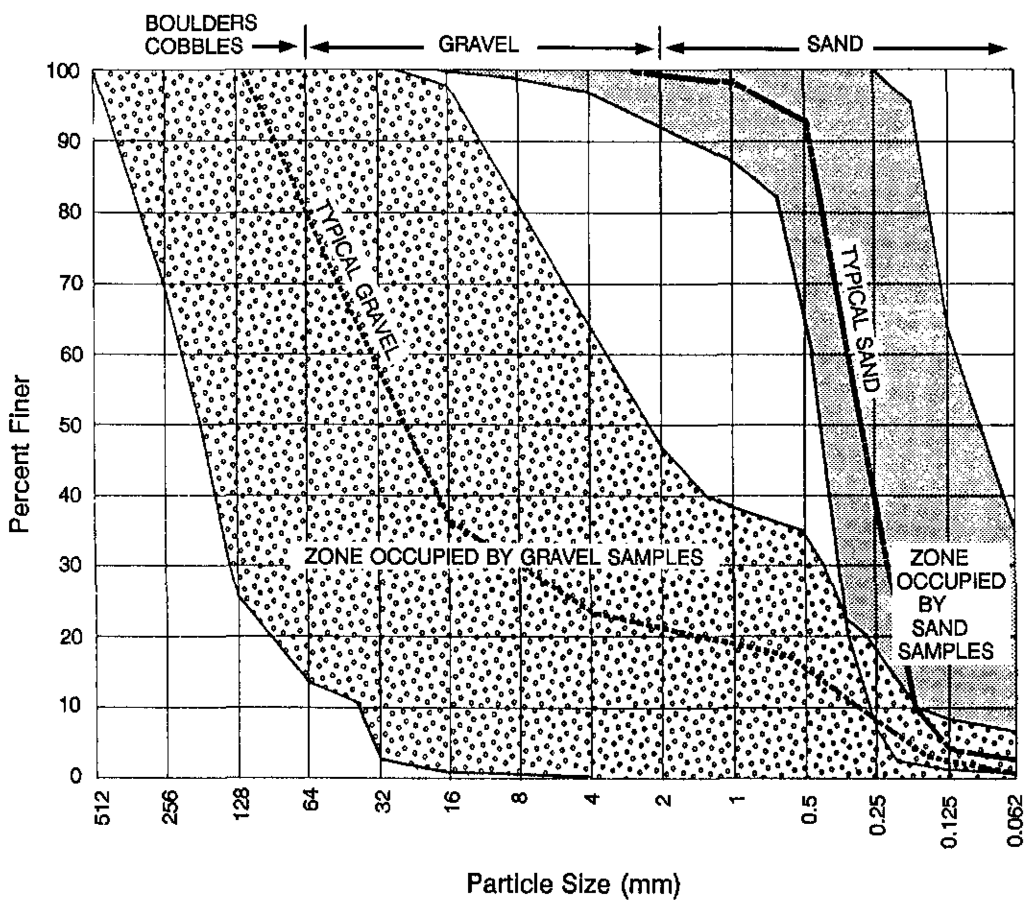
Photo Method: Photographs are taken vertically over a 50 x 50 cm grid or tape and microscope measurements of the b-axis (refer to Appendix A) are used to produce a grain size distribution curve (Adams, 1979);

Field Method: Following the grid-by-number method (Kellerhals and Bray, 1971), select particles at specified intervals along a tape which has been stretched over the bar surface. The b-axis of each particle of at least 50, and preferably 100, particles should be measured (refer to Yuzyk, 1986 and Appendix A).

The B-axis diameters are marked and plotted as size distribution curves. The frequency by number curves produced for these data are equivalent to standard sieve curves (Figure 6.1).

Measurement of subsurface materials requires removal of the armor layer and sieving of the underlying materials. Guidance on the required sample volume for a given level of accuracy is available in Church, McLean and Wolcott (1987), and in Yuzyk (1986; refer to Appendix A).

FIGURE 6.1 Typical gravel and sand distributions based on 174 Bed Material samples collected from Rivers in Alberta (from Kellerhals, 1982).



6.6 Quantity Estimates

Mining quantities can be adequately estimated from the number of truck loads removed and the truck capacity.

Gravel replenishment should be determined from repeated surveys of cross sections laid out at the mining site prior to any removals. These sections should be regularly spaced and extend across the mining site and, preferably, across the river. The cross sections should be re-surveyed after flood events which are expected to transport significant quantities of gravel.

6.7 Data Base Development

Initially, a repository should be formed for all information generated by applicants and/or agencies involved in gravel mining approval and review processes. This would create a library of information in hard copy. This repository should be with one of the two fisheries agencies, either DFO or MOE.

A format in which information could be prepared should be developed, with a view to allowing much of the data to be computerized. In the future much of the information in the repository could be accessible via computers. The development of the latter step can and probably should await the review of the repository to enable optimisation of the use of computers and use of other data sources which could make the repository of use to a wider range of potential users.

A directory of sites covered by the repository should be developed and maintained, to allow agency and gravel mining proponents to readily identify and access the information contained in the repository.

7. CASE STUDIES OF INSTREAM GRAVEL REMOVALS

7.1 Objectives

The case studies described in this chapter demonstrate the range of techniques that may be used to assess gravel supply in British Columbia rivers. The case studies also emphasize the importance of examining the geology, physiography and hydrology of the drainage basin and of assessing the geomorphic setting of the channel to accurately determining gravel supply.

All three of the rivers used as case studies have had several years of well-documented gravel removals. This allows an assessment of the indirect morphological consequences of varying levels of gravel removal and forms part of the background to our recommended allowable removals presented in Section 4.5. The indirect effects are strictly physical changes; no comparable review has been completed of the effects on fisheries.

7.2 Cowichan River near Duncan

Hydrology

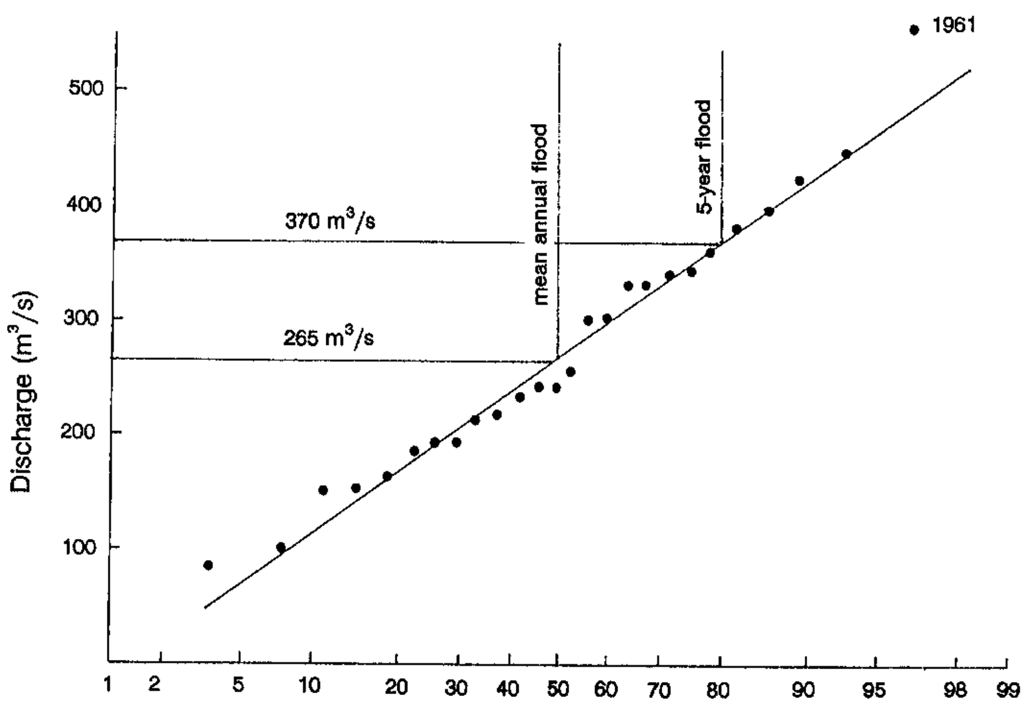
The Cowichan River, on Eastern Vancouver Island, drains a total area of 826 km^2 above Duncan. The Koksilah River, draining 282 km^2 enters the south fork of the Cowichan River estuary, downstream of the gauge at Duncan. Somenos Creek, draining 64 km^2, enters the North Fork of the Cowichan River.

The Cowichan River has long-term WSC gauging records at the outlet of Lake Cowichan (08HA009) and at Duncan (08HA011). The Koksilah River is also gauged (08HA003) upstream of its confluence with the Cowichan. The Koksilah River enters downstream of the removal area, and therefore does not contribute flow to the site.

596 of the total 826 km^2 drainage area lies upstream of Cowichan Lake. The lake is large (62.2 km^2 surface area) and has a control structure at the outlet which regulates the flows observed at Duncan. Regulation is primarily to increase low flows.

The mean annual flood at the Duncan gauge (25 years of record) is 265 m^3/s; the 5-year flood is 370 m^3/s (see Figure 7.1).

FIGURE 7.1 Flood frequency curve of the Cowichan River at Duncan (08HA011). Curve based on annual (calendar year) maximum daily discharges.



Sediment Transport

Cowichan Lake intercepts nearly all the sediment delivered from the upstream portion of the basin. Transport at Duncan is based on sediments supplied from the 230 km^2 contributing area downstream of the lake.

No suspended sediment monitoring station has operated on the Cowichan River and, in fact, no suspended sediment stations have been operated by the Sediment Survey on Eastern Vancouver Island.

Little is known of gravel transport rates in the lower Cowichan, though supply seems large relative to the small and low-lying contributing area. It is likely that the gravels transported past Duncan are derived from erosion of fluvio-glacial deposits and reworking of recent alluvium in the canyonized reaches between Skutz Creek and Duncan. Gravel supply reflects erosion rates of terraces rather than the supply of gravels from the entire contributing area.

Morphology

The Cowichan River, downstream of Cowichan Lake is approximately 40 km long. Over most of this length the river is entrenched with narrow, indefinite or fragmentary valley flats. In many reaches, the river is confined horizontally by valley walls or terraces and vertical control is exerted by bedrock in the valley floor of many of the canyonized reaches.

The average river gradient in the reach above Duncan is .0035 (measured from 1: 50,000 NTS maps). On this gradient, with a 5-year flood of 385 m^3/s, bed material smaller than 100 mm is unstable and subject to regular transport (Figure 4.1).

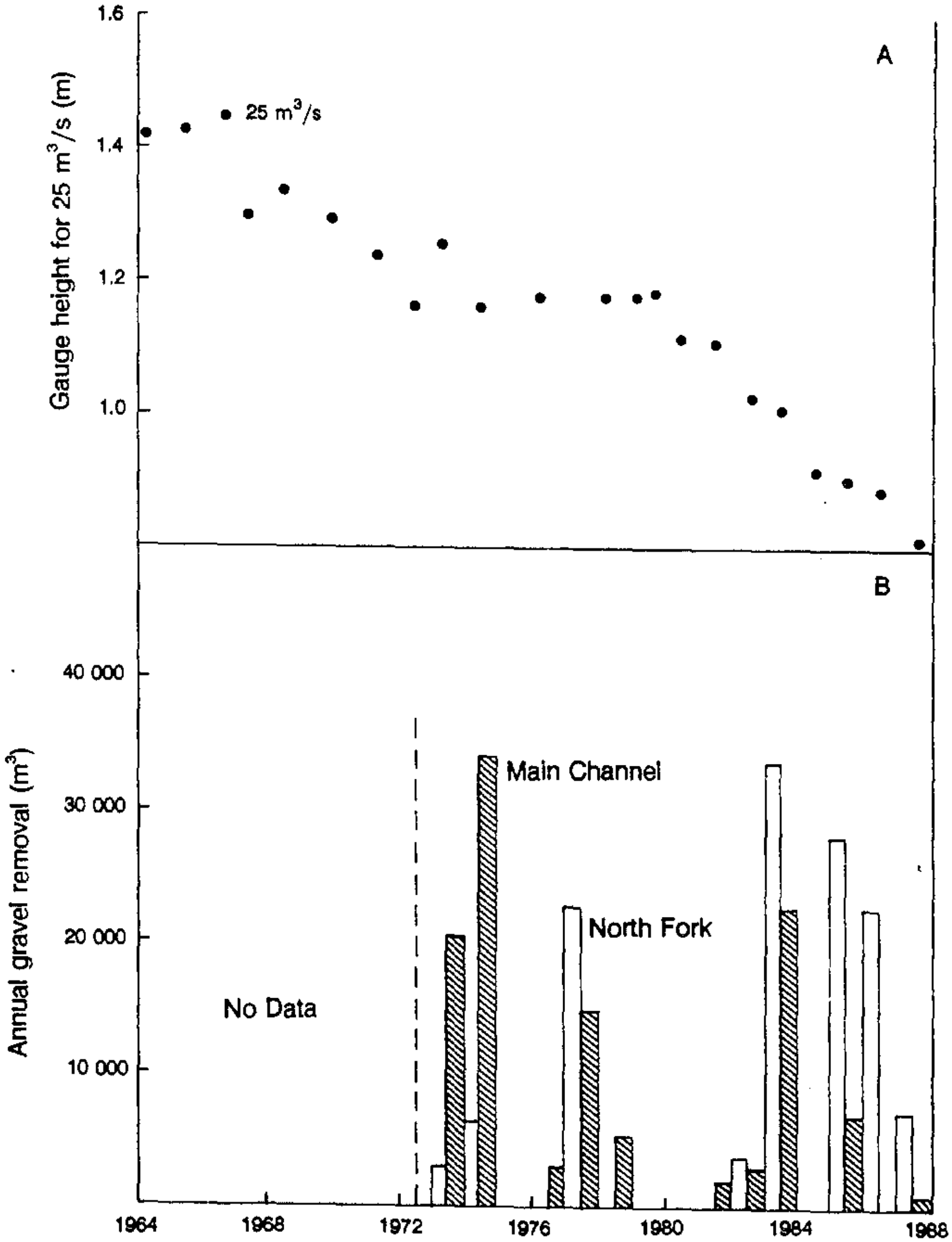
A gravel accumulation zone occurs downstream of the mouth of the canyon above Duncan in a gravel fan that extends approximately 9 km to tidewater. Based on Water Management Branch (of MOE) survey (WMB, Plan 86-2-25) the channel gradient is approximately 0.0015 over this reach. The river has an irregular channel pattern with large point and side bars. Lateral activity is irregular and old channel scars are visible on the valley flat. Tidal influence extends upstream of Tzouhalem Road (Cowichan Task Force, 1980) on both the North and South Forks in the estuary. Throughout most of this reach the natural river has been altered by dyking, bank protection and gravel removal.

Gravel Removal Activity

Total gravel removal between 1973 and 1987 amounted to 334,000 yd^3 (255,000 m^3). On Figure 7.2 (B), annual removals are split into two sites; main channel removals, extending from the Railway (Black) bridge to Major Jimmy's slough and removals from the North Fork (see Figure 7.3). Nearly all the gravel load in the main river passes into the North Fork. The present nature of the bifurcation prevents gravels from entering the South Fork. Gravel removals have varied from year to year in response to the influx of sediment and dyking activity.

Water Management Branch proposals for flood control on the lower Cowichan River include further dyking, gravel extraction and several minor diversions (Cowichan Task Force, 1980; Lambertson, 1987). Gravel supply is to be controlled, in part, by a settling basin constructed upstream of the Railway Bridge, near the head of the fan. The basin would catch incoming gravel load and be regularly excavated. In the long term, this structure will have an important influence on gravel distribution in the lower Cowichan.

FIGURE 7.2 A. Specific gauge curve for the Cowichan Rive near Duncan (08HA011). Gauge heights for discharge of 25 m^3.
B. Annual gravel removals along the Cowichan River. Records obtained from the Water Management Branch.



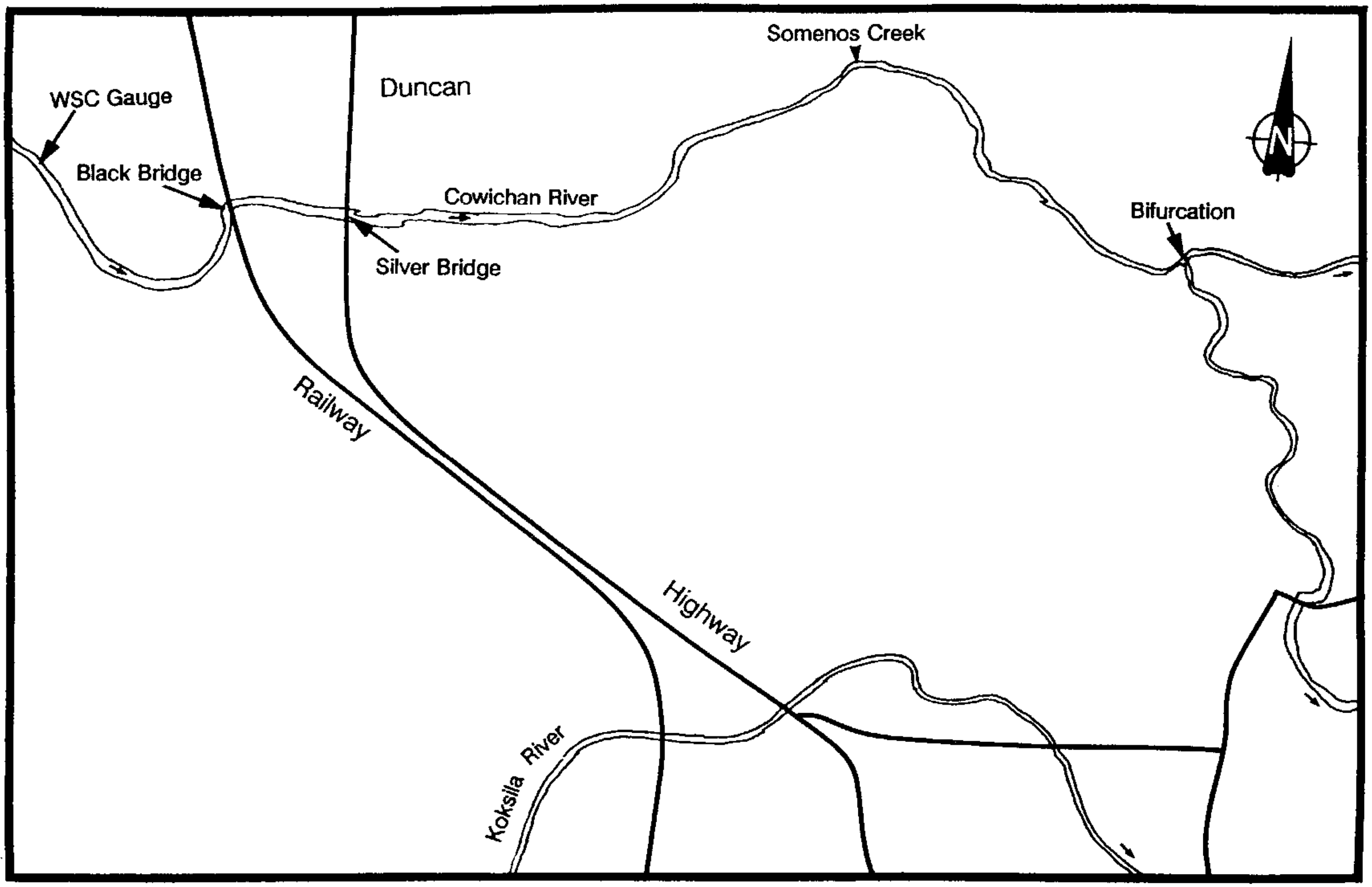


FIGURE 7.3 Location map for the Cowichan River near Duncan gravel removals.

Gravel Supply

Many of the techniques described in Section 4 of the report cannot be applied to the Cowichan River because of the nature of the gravel supply, the non-alluvial channel pattern, and engineering interference with river activity in the accumulation reach.

Gravel supply can be approximately estimated from a mass-balance based on surveys over the reach extending from the Island Highway (Silver) Bridge to approximately 1500 m downstream. Cross sections were surveyed in 1977, 1981, 1983 and 1987. Only 5 sections were surveyed in 1977 compared to 29 in 1983 and 1987; consequently, calculations for the period 1977 to 1983 are necessarily less accurate than for the period from 1983 to 1987.

TABLE 7.1 Estimation of Gravel Supply in the Cowichan River from a Mass Balance within the Surveyed Reach.

Period	Net Change from Survey (m^3)	Gravel Removal(m^3) Survey Reach	Gravel Supply (m^3)	Annual Load (m^3/a)
1977-1983	-1900	9000	7100	1200
1983-1987	+9300	5100	14400	3600

Since the gravel removal is greater than the degradation within the surveyed reach, between 1977 and 1983, the difference represents gravel deposition from bedload, within the reach. The estimates in Table 7.1 are minimum estimates since some unknown portion of the gravel load passes through the reach and is deposited further downstream, and some portion of the gravel load is intercepted upstream of Black Bridge. If the load calculated for the surveyed reach is adjusted to reflect the 4 km accumulation reach above Somenos Creek, then the total annual load is estimated at 3,000 to 10,000 m^3, and is likely near the upper end of this range.

Average annual gravel removal over the 1973 to 1987 period has been 17,000 m^3, roughly 200% or more of annual supply. Removals in the main channel amount to 8,500 m^3 per annum, roughly 100% or more of supply.

Morphologic Effects of Gravel Removal

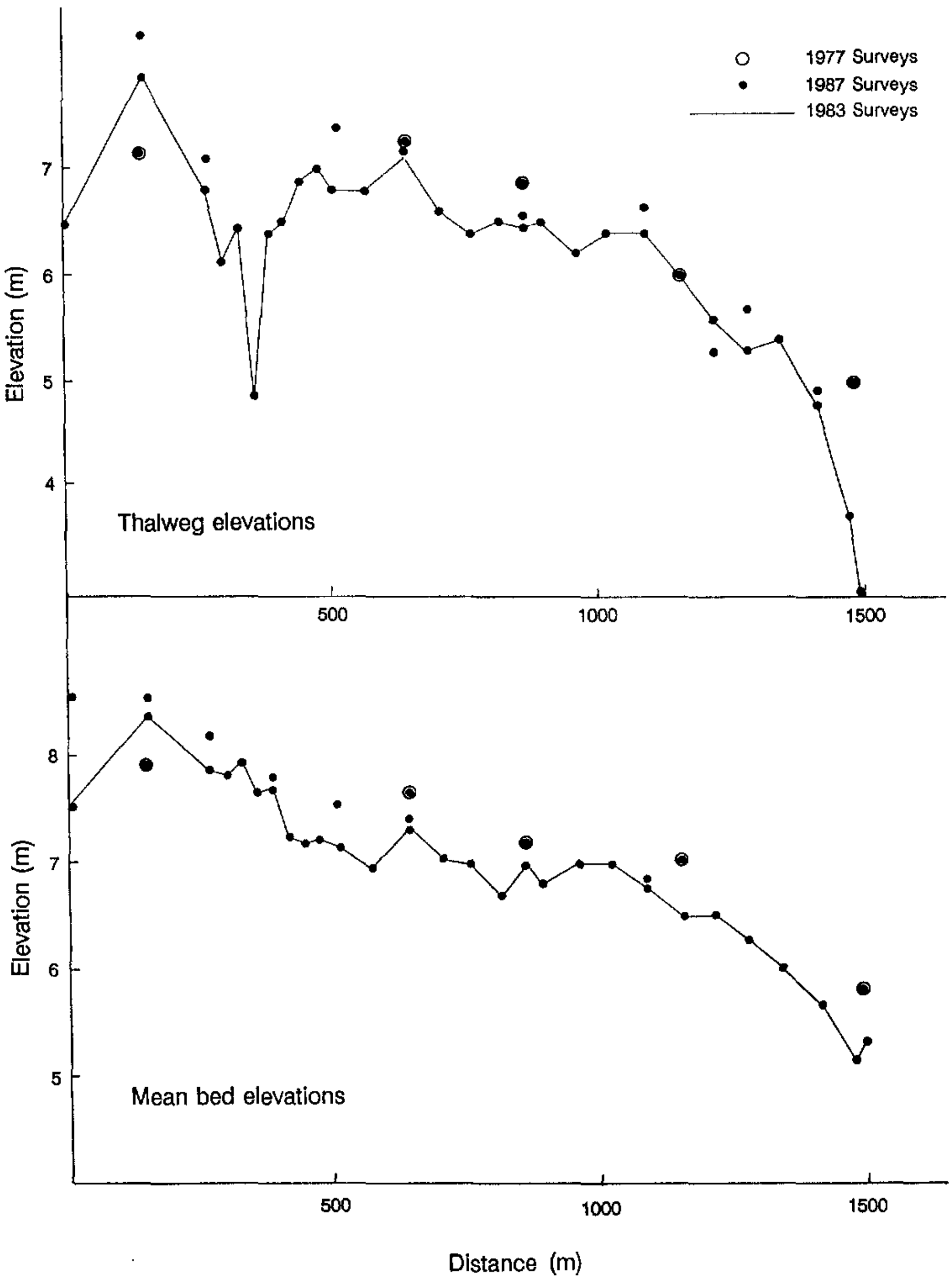
All gravel removals are downstream of the WSC stream gauge "Cowichan River near Duncan". The nearest removals are at Black Bridge, approximately 800 m downstream of the gauge. A large quantity of gravel in the order of 120,000 m^3, has been removed from this site between 1977 and 1987.

The gauge reach has been affected by the removals (Figure 7.2A). Degradation at the gauge, as a result of channel bed adjustment, amounts to roughly 40 cm over the 1977 to 1987 period. The degraded reach extends from the Black Bridge to some considerable distance further upstream of the gauge, with consequent changes in channel morphology and bed sediments.

The response to gravel mining in the surveyed reach from the Silver Bridge to 1500 m downstream is similar. Direct mining in this reach only amounts to 14,000 m^3 (Table 7.1) though gravel supply has been affected by interception and removal upstream at the Black Bridge site. Thalweg elevation and mean bed elevation both declined from 1977 to 1983 through this reach as a result of mining (Figure 7.4). Mean bed elevations have increased since 1983 in spite of gravel removals.

Bar scalping and gravel removals have produced characteristic

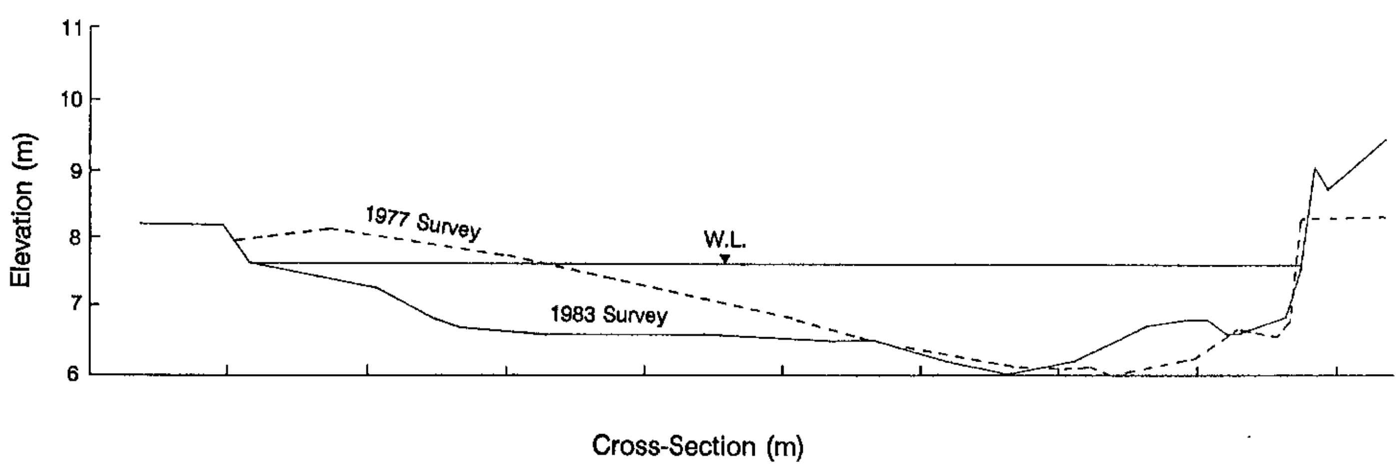
FIGURE 7.4 Bed elevations of the Cowichan River, Silver Bridge to 1500 m downstream. Surveys by the Water Management Branch; 1977, 1983 and 1987.



changes in the channel cross section at the downstream end of the reach (Figure 7.5). The removal of bars has produced a more rectangular cross-section, with steeper-sides and a flatter bottom. One consequence of bar removal is to produce a greater water surface width at a given discharge. When changes occur over a long reach, this also affects depths and velocities. Flows may become shallower and slower and, as a result, water temperatures may increase.

The change in the character of the river is also easily visible on aerial photographs. Photographs from 1974 (BC 7697), 1980 (BC 80078) and 1986 (BC 394) show a progressive decline in bar surface area and virtual disappearance of bars, even at very low flows, in certain sections of the channel. Upstream of Somenos Creek rapid growth of successional vegetation has covered the remaining surface of a large bar. This may be due to less frequent inundation following channel degradation. Degradation may also reduce flooding into side channels.

FIGURE 7.5 Changes in Cross Section 34 (1150 m downstream of the Silver Bridge) from 1977 to 1983. Surveys by the Water Management Branch.



7.3 Mamquam River near Squamish

Hydrology

The Mamquam River was gauged by WSC above Mashiter Creek (Mamquam River above Mashiter Creek; 08GA054) between 1966 and 1980 and from 1982 to 1987. Total drainage area at the gauge is 334 km^2; total drainage area at the confluence with the Squamish River amounts to 378 km^2.

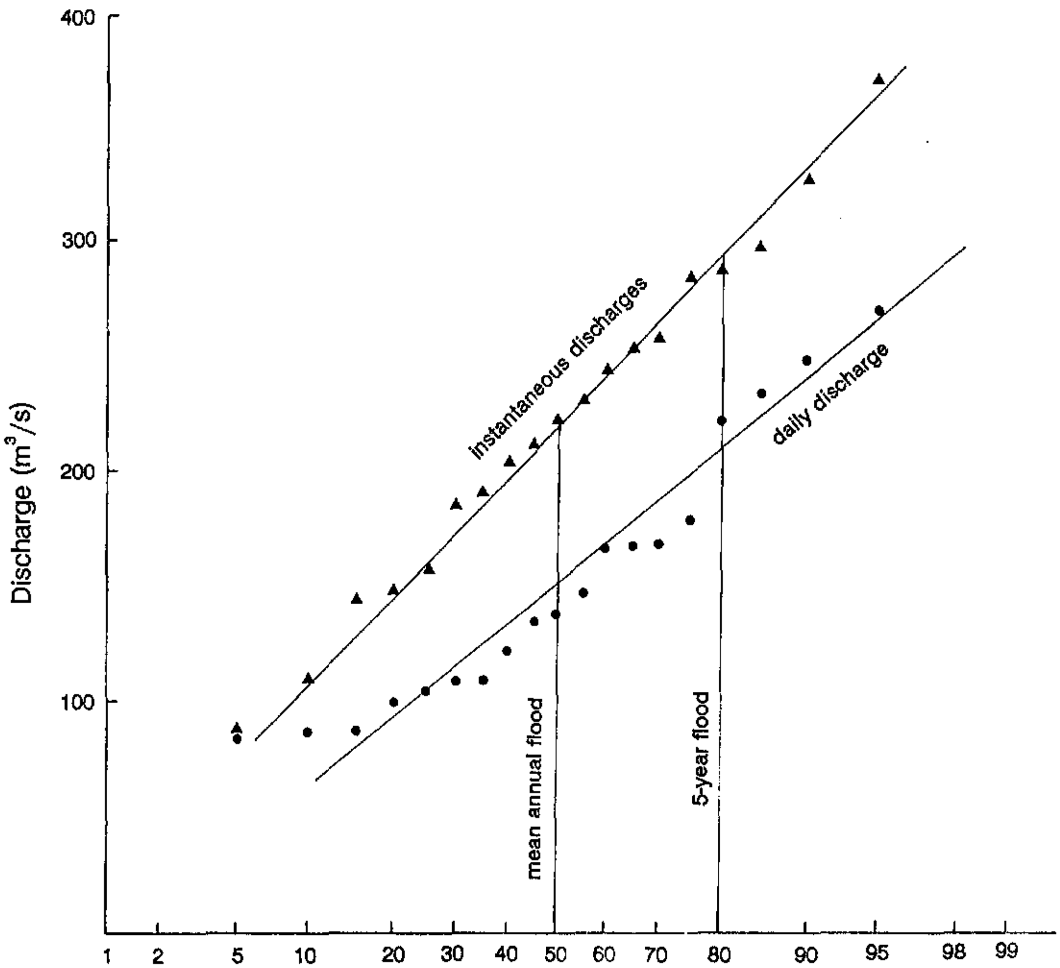
The mean annual flood at the Water Survey gauge, based on daily discharges is 155 m^3/s (Figure 7.6). The flood frequency curve is steep and the five year instantaneous flood is nearly twice as large as the mean annual flood.

Sediment Transport

No sediment survey station has ever operated on the Mamquam River. Gravel loads are expected to be large based on the general appearance of the river (large bars; wide channel zone) and the regular gravel removals for flood protection by the local Municipality.

Figure 4.2 indicates a suspended sediment load of approximately 0.1 Mg km^{-2} day^{-1} (0.15 m^3/km^2 per day), or 21,000 m^3 per annum. This estimate appears inappropriate for the Mamquam drainage. First, the basin is predominantly underlain by easily-eroded volcanic rock, which seems to be associated with increased sediment loads in other regions. Second, much of the lower portion of the Mamquam basin has been logged which often elevates sediment loads and, finally, the upper portions of the basin are extremely steep and active in producing sediment.

FIGURE 7.6 Flood frequency curve for the Mamquam River above Mashiter Creek gauging station (08GA054). Based on annual (calendar year) maximum instantaneous and daily discharges.



Channel and Basin Morphology

The fan of the Mamquam River (Figure 7.7) starts near the Water Survey gauge and extends for approximately 5 km to the Squamish River. The gradient of the Mamquam on its fan is approximately 0.005 (Figures 7.8 and 7.9). The gradient of the Mamquam River in the canyon upstream of the fan is approximately 0.08; over ten times as large as the channel gradient on the fan.

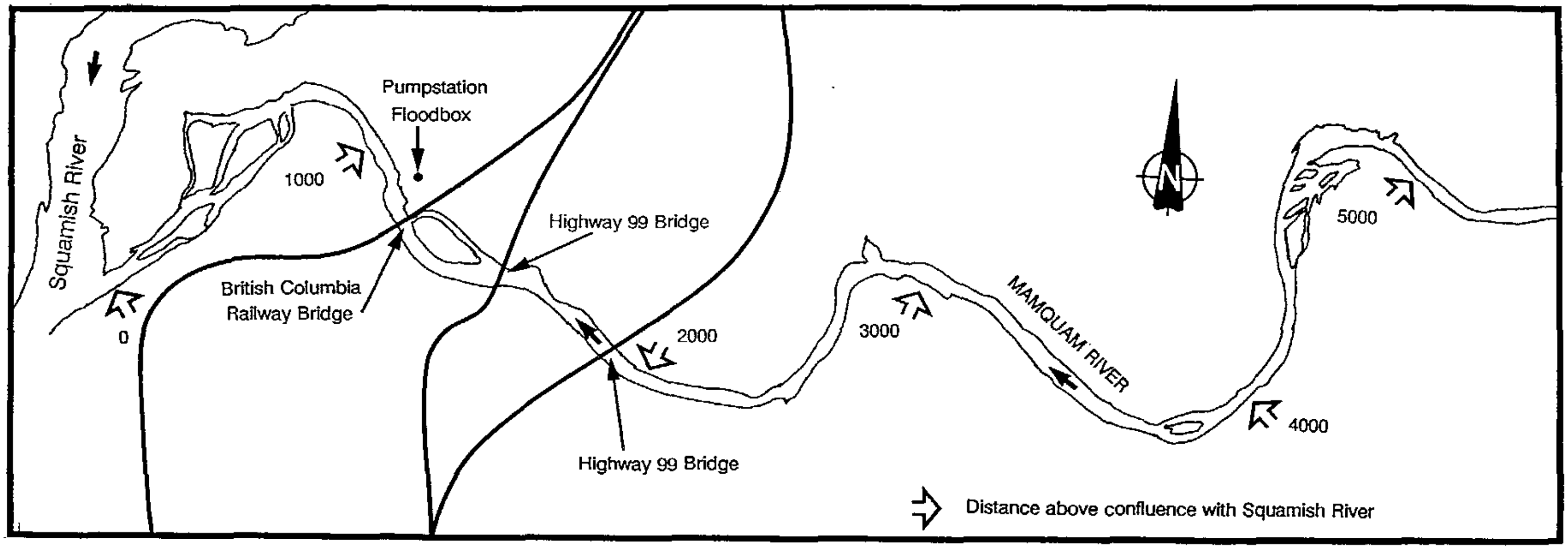


FIGURE 7.7 Location map for the Mamquam River near Squamish.

FIGURE 7.8 Thalweg profiles of the Mamquam River from 1971 and 1981. Surveys by the Water Management Branch.

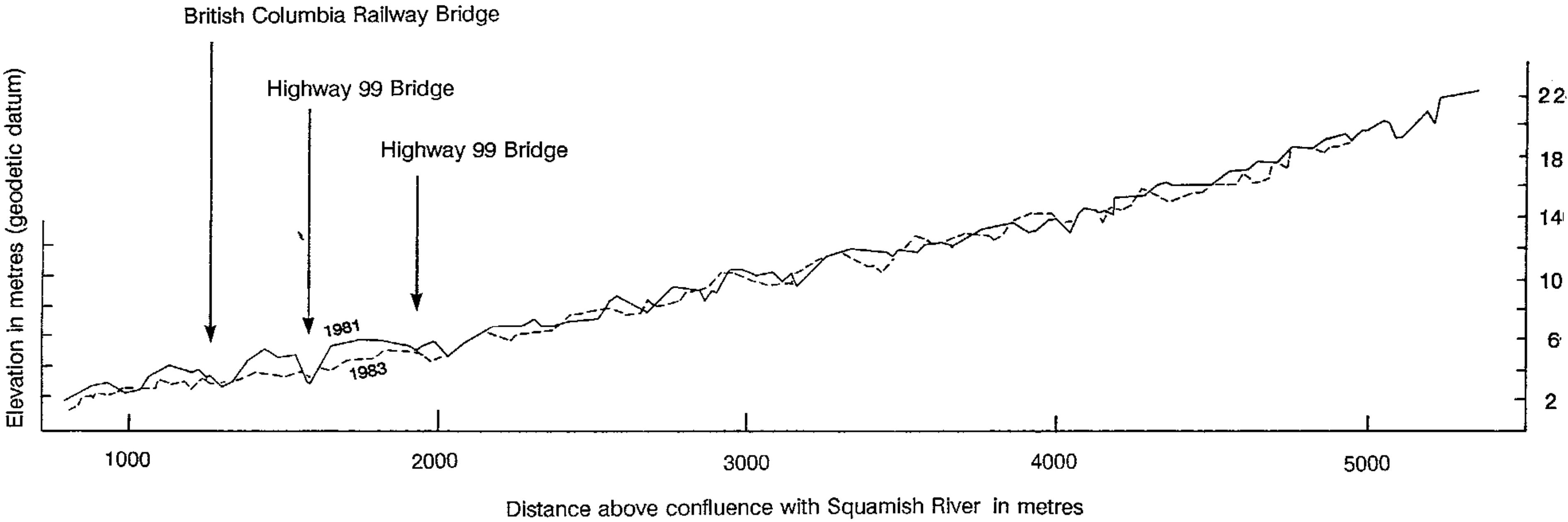


FIGURE 7.9 Thalweg profiles of the Mamquam River from 1981 and 1983. Surveys by the Water Management Branch.

On its fan, the Mamquam has an irregularly sinuous pattern with large point and lateral bars. The main channel shifts within the unvegetated active channel zone, often by occupying previous secondary channels. The course of the overall channel zone is controlled, in part, by dyking, bank protection and several highway and railway bridges.

Measurements of bar surface gravels in the vicinity of the Highway 99 Bridge (approximately 2 km from the mouth) indicate a median armour layer size of approximately 80 mm. On the fan slope of .005 with a mean annual flood of 228 m^3/s, material of this size would be unstable and regular transport could be expected (Figure 4.1).

Gravel Removal

Gravels have been removed at several locations along the Mamquam, at least since 1979 (Table 7.2). The volume or location of gravel removals from earlier in the 1970's are unknown. Total removals since 1982 amount to 570,000 m^3, roughly 140,000 m^3/yr over the period.

The removals by Water Management Branch for dyking were primarily taken in 1982. Removals were concentrated near the channel split above the large bar, marking the junction of the Mamquam and Squamish Rivers (to the left of the diagram in Figure 7.9). The initial removal consisted of a large "hole" which filled in during the next freshet.

Gravel Supply

A minimum estimate of gravel supply to the Mamquam fan can be obtained from the accumulation of gravels within the main channel between surveys in 1971 and 1981 when the known gravel removals

TABLE 7.2 **Gravel Removals along the Mamquam River, 1979 to 1986.** Records obtained from the Department of Fisheries and Oceans and Water Management Branch.

Year	Licensee	Site	Volume (m^3)
1979	District of Squamish	upstream and downstream of the Highway 99 bridge	-
1982-1984	Water Management Branch	between confluence with Squamish and BCR Bridge	375,000
1983	District of Squamish	confluence with Squamish to Government Road Bridge	113,000
1983	District of Squamish	upstream of Highway 99 bridge; bar 800 m upstream	38,000
1983	District of Squamish	right bank bar, near golf course	23,000
1984	District of Squamish	upstream end of right bank bar at golf course	11,000
1984	LCL Construction	between BCR Bridge and Highway Bridge	7,500
1985	LCL Construction	between BCR Bridge and Highway Bridge	-
1986	Coast Valley Construction	bar downstream of Mashiter Creek	6,000
TOTAL			540,000

were small. This is a minimum estimate because an unknown, but potentially large, portion of the gravel load passes over the fan and into the Squamish River.

The annual load estimate reported in Table 7.3 is strongly dependent on estimation of the volume of accumulation in the lower kilometre of the river. Much of the gravel accumulation occurs in this reach where, unfortunately, only one replicate cross section is available. No estimate of gravel supply was made from the change betwen the 1981 and 1983 surveys because of the short period of time between the surveys and the uncertainties concerning the total gravel removal in the period.

Based on the above surveys a lower-bound annual gravel supply rate of 25,000 m^3/a or 66 m^3/km^2 is obtained. This is an extremely high value compared to many of the other recorded supply rates in British Columbia. The only comparable estimate is from the fan of the Chilliwack River (MacLean, 1980). Gravel mining in the 1980's has proceeded at roughly four times the supply rate.

TABLE 7.3 Estimates of Gravel Supply Based on Repeated Surveys of the Mamquam River. Surveys are by the Water Management Branch in 1971 and 1981.

Period	Accumulation (m^3)	Gravel Removal (m^3)	Gravel Supply (m^3)	Annual Load (m^3/yr)
1971-1981	250,000	?	250,000	25,000

Gravel Mining and Channel Morphology

The pattern of gravel accumulation along the Mamquam River, prior to the major removals in the early 1980's, is shown on Figure 7.8. Over the 1971 to 1981 period gravel accumulations occurred in the lowest 3 km of the river with the greatest accumulation in the lowest kilometre. Upstream of this reach, the channel overall was stable, or slightly degrading, particularly in the upstream two sections which are above Mashiter Creek.

The effect of gravel mining is apparent on Figure 7.9, particularly for the lowest km of the Mamquam River. Bar and channel bed removals have initiated degradation amounting to approximately 2 metres in some portions of the channel and essentially removed the pool and riffle sequence. The upstream part of the Mamquam River shows a near-stable profile with variable scour and accumulation due to bar shifting and also to changes in the length of the thalweg, which confounds comparison of the two profiles.

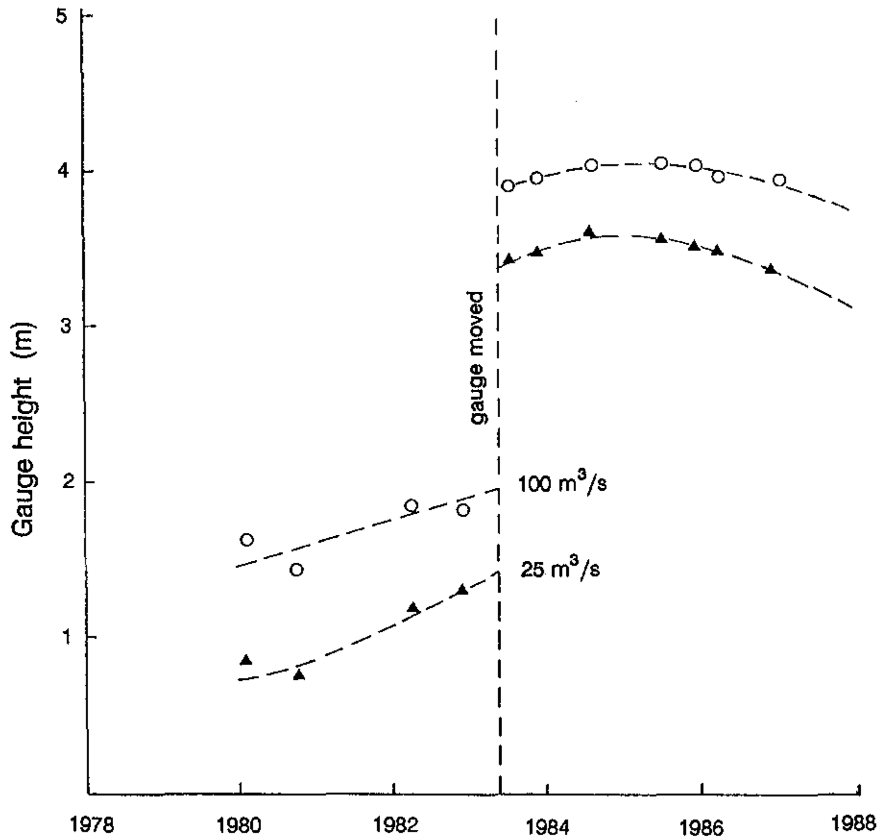
The Water Survey of Canada gauge is upstream of the gravel removal reach and also approximately 500 m upstream of the last survey section shown on Figures 7.8 and 7.9. The nearest removals are at the golf course, approximately 800 m downstream and below Mashiter Creek. These removals were primarily in 1983 and 1984 (Table 7.2). The specific gauge records (Figure 7.10) appear to indicate that the effect of removals extends into the gauge reach. Accumulation occurred until 1984; following gravel removals, the specific gauge curve stabilizes and then slightly declines.

7.4 Lillooet River near Pemberton

Hydrology

The Lillooet River WSC gauge (Lillooet River near Pemberton,

FIGURE 7.10 Specific gauge curve for the Mamquam River above Mashiter Creek gauging station (08GA054). Curves for discharges of 25 and 100 m^3/s. Gauging station moved in May 1983.



08MG005) is 18 river kilometres from Lillooet Lake and has a drainage area of 2160 km^2. Green River (Green River near Pemberton, 08MG003) and Birkenhead River (Birkenhead River at Mount Curie, 08MG008) join the Lillooet between the gauge site and Lillooet Lake and have a combined drainage area of 1790 km^2. Both these rivers join the Lillooet in the lake delta, downstream of the gravel reach.

At the Lillooet gauge the mean annual flood is 538 m^3/s (instantaneous); the 5-year flood is 677 m^3/s (Smith and

Vallieres, 1987). The maximum annual floods used in the flood frequency analysis are generated by several different processes. Most of the floods occur in June to August in response to snowmelt, rain on snow and glacier melt, though occassional large floods occur in the fall due to heavy rainfall. The flood of record occurred on October 8, 1984 and reached a discharge of 1110 m^3/s.

Sediment Transport

Approximately 22% (460 km^2) of the Lillooet River basin is glacierized. Typical daily yields of suspended sediment from glaciers may lie between 1 and 15 tonnes/km^2. Yields of bed material may amount to a major fraction of the suspended load.

The Lillooet basin is steep (relief is 2560 m; mean elevation is 1600 m: Gilbert, 1973) and underlain dominantly by intrusive rock, but also includes sedimentary, metamorphic and recent volcanic rocks. Many of the tributary basins to the Lillooet exhibit extensive, naturally unstable slopes; these conditions may have been exacerbated, in some areas, by logging.

No suspended sediment station has been operated on the Lillooet River by the Water Survey. Gilbert (1973), working in the delta, measured concentrations ranging from 50 to 2000 mg/L. Measurements in comparable basins (Church, Kellerhals and Day, 1988; see Figure 4.2) indicate suspended yields of approximately 1 to 2 Mg/km^2/day, giving an annual yield of 0.5 to 1.0 million m^3 for the Lillooet River basin. Total annual yield to the delta in Lillooet Lake would amount to 1.0 to 2.0 million m^3.

Gilbert (1973) estimated sediment loads from delta progradation into Lillooet Lake and bottom accumulation rates in the rest of the lake. Total annual load, adjusted for trap efficiency, was estimated as 1.1 million m^3 for the period 1859 to 1969. This is from the total drainage area of 3950 km^2; and by simple proration indicates a load of 0.6 million m^3 (1.1 tonnes/km^2 per day) at the Lillooet River gauge. The delta materials are all finer than coarse sand and are similar to the suspended load.

Delta progradation has increased since 1952 in response to engineering works on the Lillooet River and the suspended load measurements calculated from the delta advance show a corresponding increase over time (Gilbert, 1973).

Channel and Basin Morphology

Based on contour maps (NTS 1:50,000) the average slope of the lower Lillooet River is 0.0014. Water surface profile surveys near the gauging station showed slopes of 0.0020 at flood discharge (Smith and Vallieres, 1987). On this slope, bed material up to 80 mm would be unstable during the 5-year flood.

Near the Water Survey gauge the Lillooet River is altered by dyking, bank protection, and straightening and the pattern does not reflect sediment transport. Upstream of the engineered reach the Lillooet is an anastomosed river with a broad continuous valley flat. Comparison of aerial photographs indicates rapid bank erosion as well as avulsion of the main channel in secondary channels. This reach is a gravel accumulation zone which ends near the town of Pemberton, approximately 12 km from the river's mouth.

Engineering Modifications

The Lillooet River was straightened in the reach above Ryan River around 1950. Six cut-offs were used to move the river towards the left valley wall. The major cut-off at McKenzie Reach shortened the thalweg by 3300 m, doubling the local slope. The Water Management Branch estimates straightening removed 17 km from the total thalweg length. It has generally been assumed by the Water Management Branch that straightening and the consequently increased slope would produce profile adjustment and degradation upstream of the engineered reach. This is contradicted by survey evidence. The Water Management Branch attributes the lack of degradation to resistant materials underlying the river bed but it could also be due to cross sectional adjustments to engineering modifications.

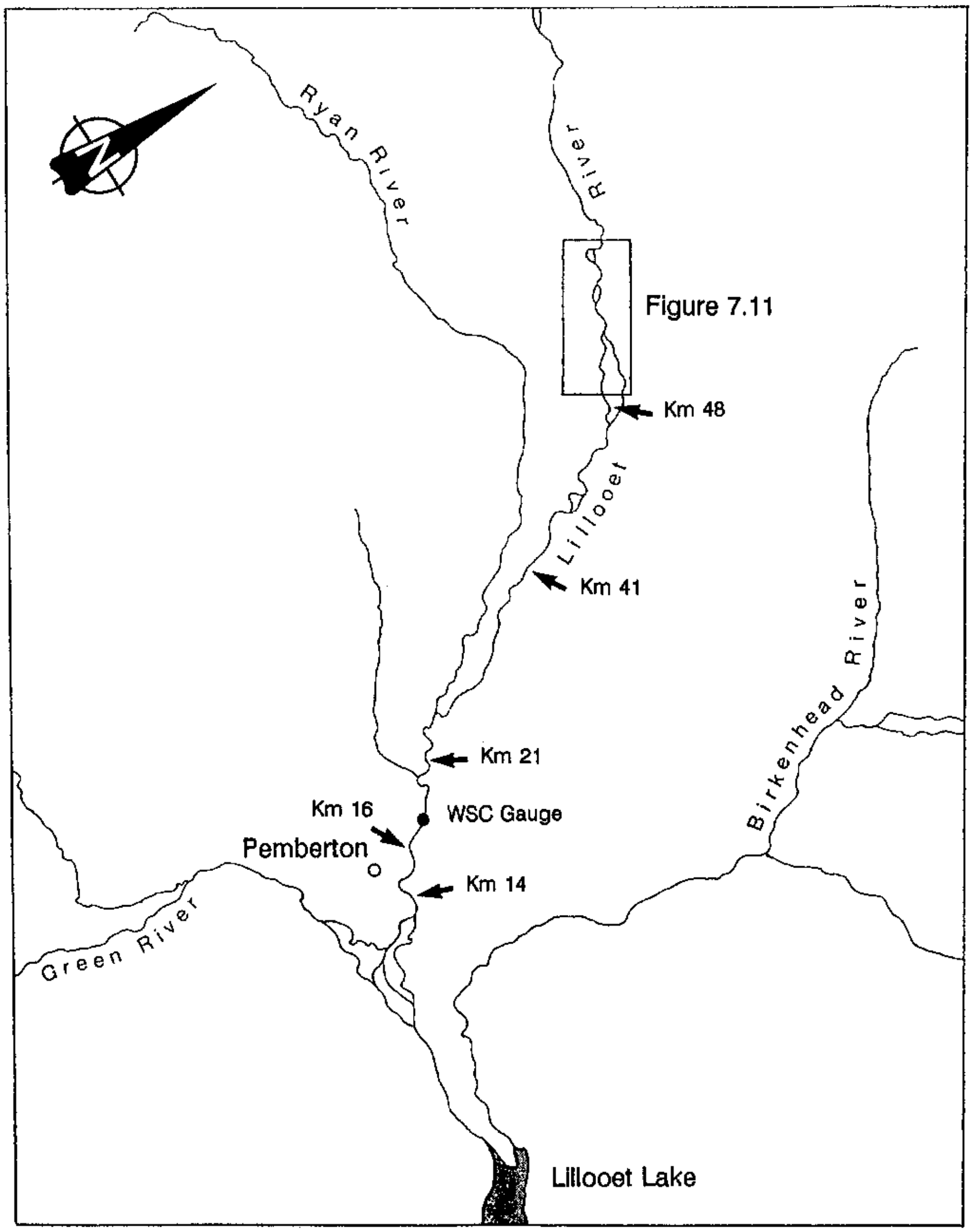
Further manipulation occurred in 1952. The outlet of Lillooet Lake was dredged, lowering lake levels between 2 and 5 m (Gilbert, 1973). The effect on the river channel has not been documented.

Gravel Removals

Since 1980, the Water Management Branch has removed gravel from the Lillooet River and its tributaries (Figure 7.11). Mr. Smuk and Mr. Dien have also been licensed to remove small amounts of gravel. In addition, the Ministry of Highways has removed gravel from some of the tributaries.

Total removals in the Lillooet area from 1980 to 1987 amount to 417,800 m^3. Removals have occurred in all years, although the major volumes were removed following the 1980 and 1981 floods. A large portion of the total removals are from tributaries to the Lillooet. 98,000 m^3 were removed from the Ryan River (79,000 in the upper river and 21,000 near the Highway crossing); 27,500 m^3 from the Pemberton River (near the Highway crossing); and 108,000 from Miller Creek (upstream of the Highway Bridge).

FIGURE 7.11 Location map for the Lillooet River near Pemberton gravel removals.



The balance of the removals, 204,000 m^3, were taken from the Lillooet River, amounting to 25,500 m^3 per year. Table 7.4 describes the volume removed from different sites.

TABLE 7.4 Gravel Removal Volumes, 1980-1987, from Different Sites along the Lillooet River. Records Obtained from the Water Management Branch.

Site	km from mouth	Bank	Removal Volume (m^3)
Oxbow, Outdoor School	48	right	20,000
Forestry bridge	41	right left	6,000 25,000
D/S of Ryan and Miller confluence (20,000 by L. Dien)	18-21	-	134,000
Sewage treatment plant	16	-	10,000
Upstream of airport	14	right	9,000
TOTAL			204 000

Gravel Supply

The nature of the Lillooet River, plus the availability of river gauging and river survey data allows estimation of gravel supply by several of the methods described in Section 4. Based on its channel pattern and the degree of glacierization in the basin the Lillooet River would be expected to transport a large gravel load. In this basin the bedload may amount to as much as 8% of the suspended load (Table 4.2), providing an estimated annual load of 48,000 m^3. For an anastomosed/braided stream annual gravel loads may range from 10 to 20 m^3/km^2 (Table 4.3), providing an estimated annual gravel load of 22,000 to 44,000 m^3.

The above estimates are very rough. More specific estimates of gravel supply on the Lillooet River may be obtained from rates of lateral erosion observed on aerial photographs, aggradation measured from replicate surveys of the Lillooet River or from profile shifting based on delta progradation. Table 7.5 summarizes the various estimates of gravel supply and provides some detail on methodology.

Figure 7.12 is a map of eroded and deposited areas between km 46 and 52, of the Lillooet River. Erosion and deposition are based on scale adjustment and overlay of maps produced from aerial photographs taken in 1979 (BCC 212; July 15) and in 1986 (BC 86083; August 4). By good fortune, the discharges are very similar on the two sets of photographs (227 m^3/s in 1979 verus 284 m^3 in 1986) so that no adjustment is needed for the effects of varying water level. Erosional volumes were calculated from the eroded areas on the map by assuming a 3 m depth of gravel in the eroded gravel bars and a 4 m depth of eroded gravel in the eroding floodplain. These values are, at best, approximate estimates. It is necessary to adjust the total erosion volume for the 5 km reach shown on the map by spacing between major deposition zones or bars. There appears to be six major bars (5 "repeating" lengths) in the mapped reach, hence the annual load was calculated from the total volume per "repeating" length divided by the 7 years between the sets of photographs.

Figure 7.13 shows the profile of the Lillooet River based on 1985 river surveys by the Water Management Branch and contour crossings taken from NTS 1:50,000 maps of the river. The delta progradation, from 1859 to 1969 of 1140 m (Gilbert, 1973) was used to "shift" the profile and approximate the river profile as

TABLE 7.5 Annual gravel supply for the Lillooet River as estimated by various techniques from Chapter 4 of the Handbook.

Method	Comment	Gravel Supply (m^3/yr)
Suspended Load	Estimated as 8% of the long term suspended load	48,000
Channel Pattern	assumed annual supply rate of 10 to 20 m^3/km^2 in anastomosed channels.	22,000-44,000
Channel Profile Shifting	Profile of bed levels from WMB surveys. Delta progradation amounted to 1140 m from 1859-1969. Accumulation zone extends upstream to km 80.	23,000
Replicate Surveys	Estimated as balance of accumulation and gravel removal from surveys for the 1975 to 1985 period for km 14 to 44. Adjusted to the entire accumulation zone extending from km 14 to km 80.	40,000
Lateral Erosion	Measurements of total lateral erosion from 1980 and 1986 aerial photographs over the km 61 to km 66 reach. Bank heights were assumed and travel distance was based on the spacing of major bars.	30,000

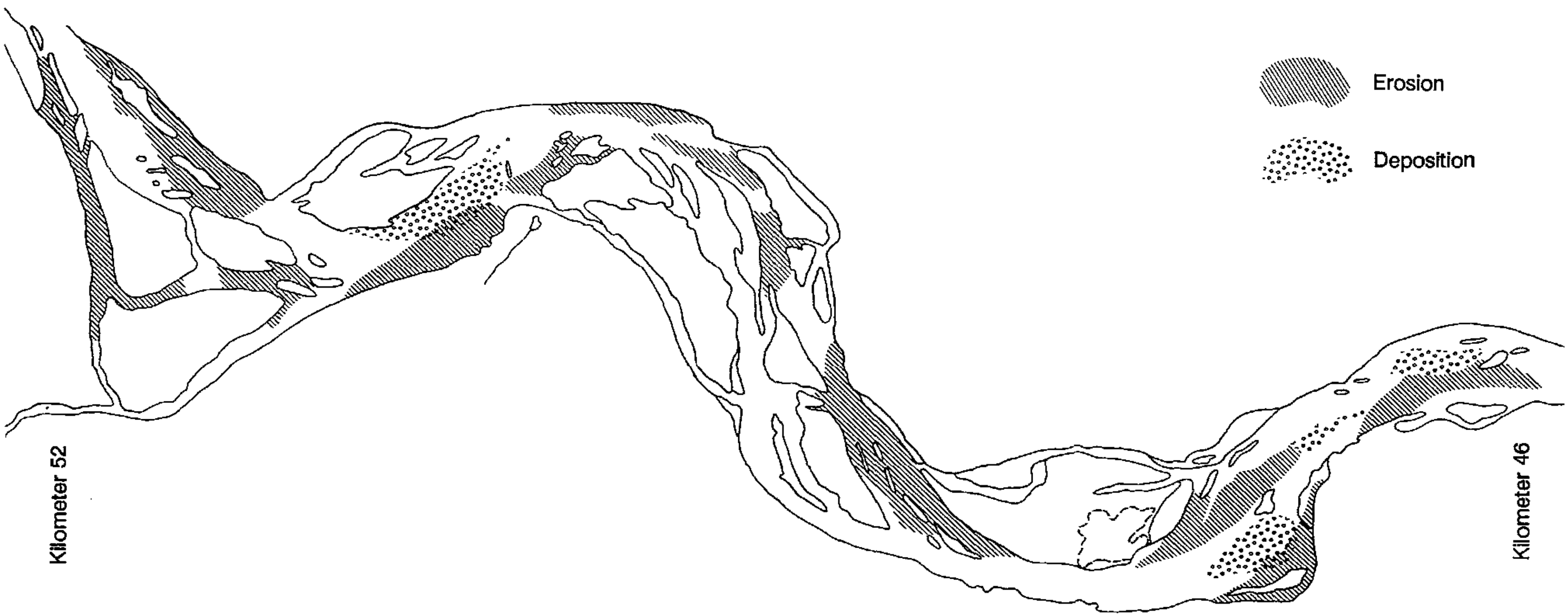


FIGURE 7.12 Erosion map of the Lillooet River, kilometres 46 to 52, based on aerial photography from 1979 (BCC 212) and 1986 (BC 86083).

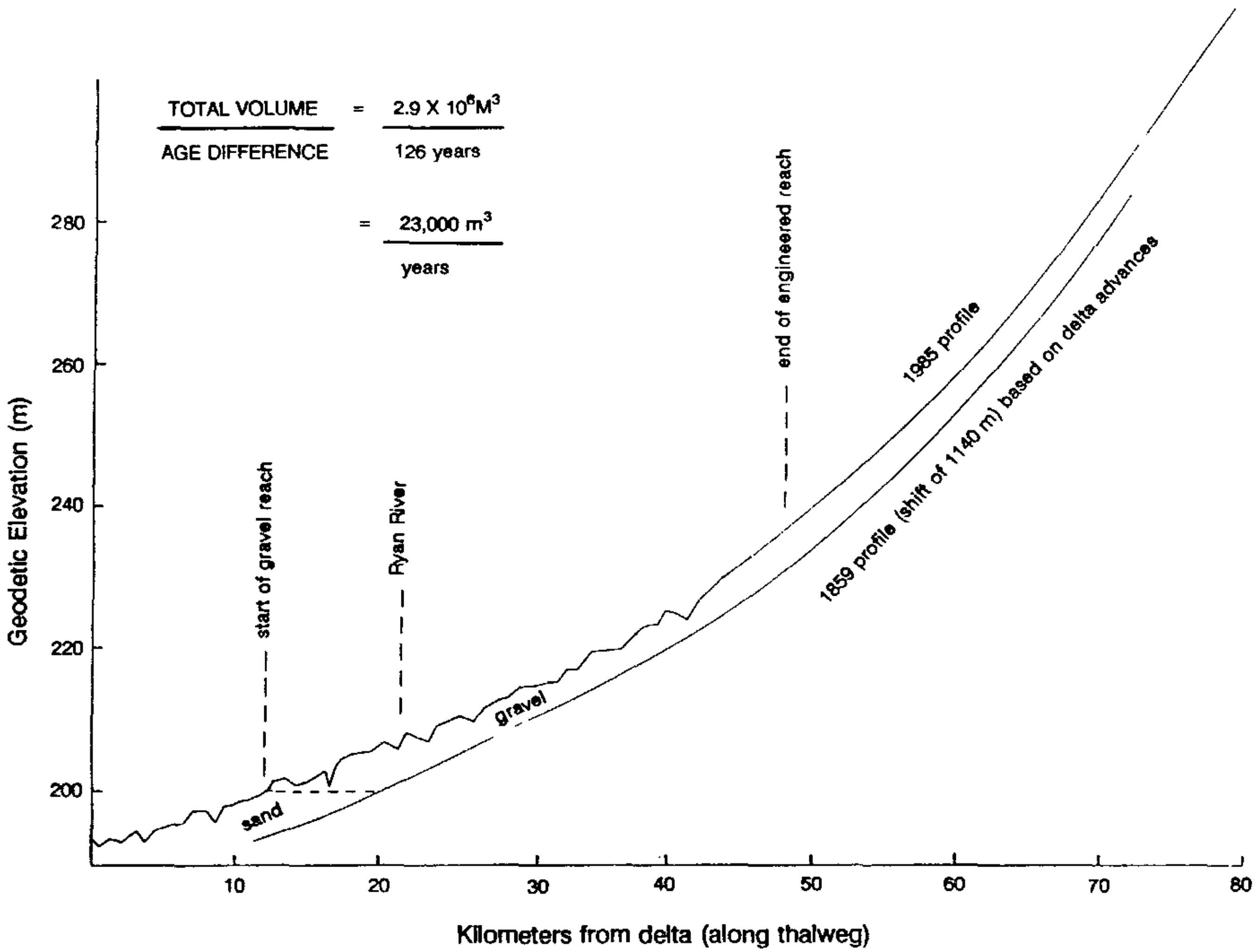


FIGURE 7.13 Sediment Transport calculation based on the shifting of the long profile of the Lillooet River. Long profile based on surveys by the Water Management Branch in 1985. Profile shifted 1140 m based on delta advancement from 1859 to 1969 (Gilbert, 1973).

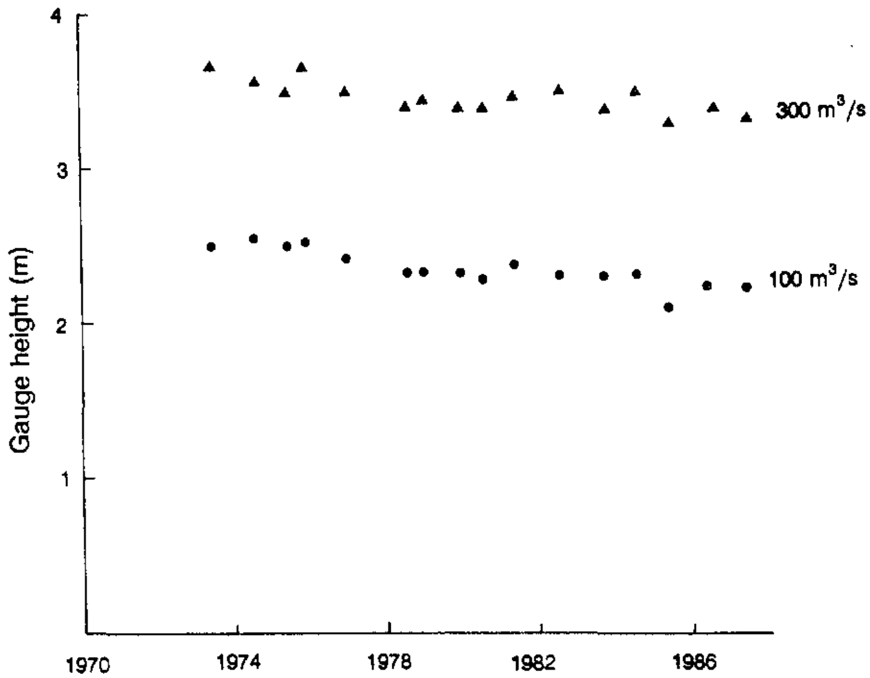
of 1859. Annual gravel supply was calculated from the cross-sectional area betwen the two profiles, an estimated channel width of 100 m and the 110 year period between the two profiles.

Estimates from the different techniques vary because of the different time periods used in the calculation of gravel supply and because of the general inaccuracy of the techniques. However, the contemporary annual gravel supply seems likely to be in the neighbourhood of 30,000 to 40,000 m^3, or just slightly in excess of the annual removals over the 1980-1987 period.

Morphologic Change and Gravel Mining

In an active river such as the Lillooet it is difficult to separate natural change, from those induced by channel straightening, lake level lowering or gravel mining. This is reflected in the specific gauge record for the Lillooet River near Pemberton (08MG005) gauge (Figure 7.14). The gauge is located at km 17, downstream of the junction with Ryan River and Miller Creek, and in the middle of the reach where gravel removal has occurred (Table 7.4). Despite this, there is little evidence of channel modification in the specific gauge record. Gauge heights show no apparent trend associated with the gravel mining occurring between 1980 and 1986.

FIGURE 7.14 Specific gauge curve of the Lillooet River near Pemberton (08MG005). Gauge heights are for discharges of 100 and 300 m^3/s.



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GLOSSARY OF TERMS AND UNITS

UNITS

D_{50}	Median grain size of a sample of sediment.
D_{90}	Size of particle in a sample of sediment such that 90% of the sample particles are smaller than this size.
km^2	Drainage area in square kilometers (1 km^2 = 0.3861022 square miles).
m^3/s	Discharge of stream in cubic meters per second (1 m^3 = 35.3147 cubic feet per second).
Mg km^{-2} day^{-1}	Milligrams per square kilometre per day.
Mg/a	Megagrams per annum (tonnes per year).

TERMS

ACCRETION	The gradual addition of new land to old by the deposition of sediment carried by the water of a stream. In Canada the term avulsion is also used for the same purpose.
ALLUVIAL FAN	a cone shaped deposit of alluvium formed by a river where the channel slope suddenly decreases; such as at the exit from a steep mountain valley onto a floodplain of a larger river.
ALLUVIUM	A general term for all sediment deposited by rivers.
ANASTOMOSED	A river with numerous channels that intertwine or interlace to form a net-like system (see also braided).
AVULSION	Sudden opening of a new channel resulting from a flood.

ACCUMULATION ZONE	An area of the river channel which is regularly subject to the deposition of sediment carried by the river.
BARS	Regularly shaped deposits of gravel (or sand) in the channel of a river. There are various types of bars with names that are associated with both shape and process by which they are formed.
BEDLOAD	The coarsest material that rolls, slides or hops along the channel bed (bottom) during a flood.
BED MATERIAL LOAD	Material that continuously exchanges with material with material of a similar size in the bed of a river during a flood.
BEDROCK	Solid rock underlying unconsolidated sediments such as river gravels. A resistant solid rock exposed by a river in its banks or valley walls.
BRAIDED (River)	See anastomosed - a river with multiple interlacing channels.
CANYONISED RIVERS	A river that has formed its own canyon, usually in bedrock; a river flowing in a canyon.
CUTOFF	A new and relatively short channel formed when a stream cuts through the neck of a "horseshoe" shaped bend in the river.
DISCHARGE	The rate of flow of water on a river at a specific location, expressed as cubic metres per second.
ENTRENCHED (Rivers)	Rivers that have cut a "trench" like valley, with almost no floodplain, in unconsolidated sediment
FLOODPLAIN	That portion of a river valley, adjacent to the river channel, which is built of river sediments during the present regimen (or by the present river) and which is covered by water when the river overflows its banks at flood stages.
INSTANTANEOUS (discharge)	Discharge is normally expressed as the mean daily (or average for the day) flow in the records kept by the Government agencies. However, during a

flood the actual highest discharge could be higher than the mean and frequently hydrologists refer to the highest flow during a day as the instantaneous flow. In the WSC records such a term is frequently used.

LAG DEPOSITS	A deposit of boulders that are too big for the present river to move, and which were probably left behind after the erosion of finer material from an older (likely glacial/fluvio-glacial) deposit.
MEAN ANNUAL FLOOD	That flood (discharge) which statistically is likely to occur each year.
MEANDER	One of a series of regularly shaped, loop-like bends in a river.
OVERBURDEN	Unwanted unconsolidated material that lies over the top of a useful material such as an ore body or deposit of mineable gravels.
PATTERN (of river)	The general alignment and form of a river as if seen from the above (eg. from a plane).
PAVEMENT	A layer of coarse material on the channel bed that the river is no longer cpable of moving.
RATING CURVE	This is a plot (or graph) of the measured water discharge versus water level (to a fixed datum) at a particular cross-section (or streamflow monitoring site). The plot will normally consist of discharges measured over a wide range of flows and water levels.
REACH (of a river)	A reach of a river is a section of the river in which the channel characteristics are relatively uniform.
RETURN PERIOD	This is the period (in years) in which a flood of a particular size may be expected to occur. It is

	usually expressed as 1 (chance) in x years, and written as 1 in 5 or 1 in 50, for example.
SINUOUS	A wave like pattern, whether regular or irregular (eg. amplitude and wave length variable).
SUSPENDED LOAD	Fine material (sediment) being moved by the water, in suspension in the water column.
TERRACES	Relatively flat, horizontal or gently inclined surfaces, of variable width and length, bounded usually by steeper ascending slopes away from the river and steeper descending slopes toward the river. There may be more than one terrace in a reach of the river, with each terrace at a different elevation.
TERRACES - OUTWASH	Terraces formed downstream from glaciers by the sediment deposited by rivers flowing from the glaciers (meltwater rivers)
TRANSPORT RATE	The rate at which sediment carried by the river is transported downstream.
VALLEY WALLS	The sides of the valley above the floodplain and terraces associated with the present river regimen in which the river is flowing
WASHLOAD	Material (sediment) that passes through the reach being investigated and whose volume is primarily determined by conditions upstream in the basin.

APPENDIX A

EXTRACTS FROM:

"BED MATERIAL SAMPLING IN GRAVEL-BED STREAMS"

by

YUZYK, 1986

BED MATERIAL SAMPLING IN GRAVEL-BED STREAMS

by

T.R. Yuzyk

SEDIMENT SURVEY SECTION
WATER SURVEY OF CANADA
WATER RESOURCES BRANCH
INLAND WATERS DIRECTORATE
CONSERVATION AND PROTECTION
ENVIRONMENT CANADA
1986
IWD-HQ-WRB-SS-86-8

2. PHYSICAL CHARACTERISTICS OF GRAVEL-BED MATERIAL

2.1 Definition of Gravel Beds

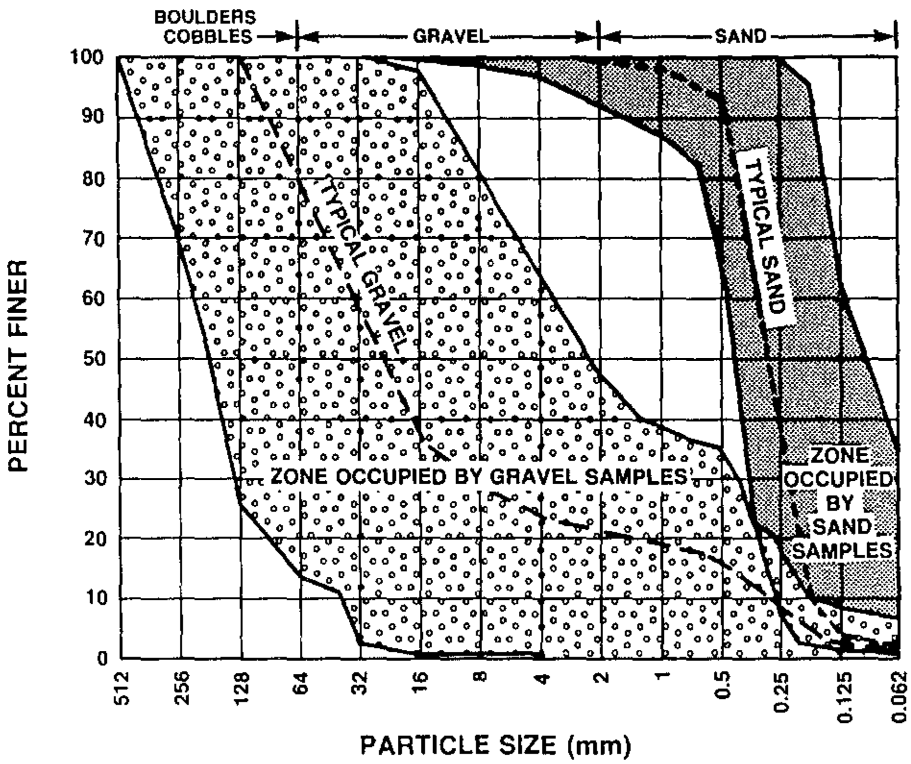
Gravel is defined texturally as material with a particle size between 2 and 64 mm (Table 1). Gravel-bed streams, however, are not restricted to the textural definition, and the term "gravel-bed stream" usually refers to any beds containing material larger than 2 mm. Based on the data from 174 bed material samples, Shaw and Kellerhals (1982) indicate that there is a threshold point between what should be considered a gravel and a sand sample. It appears (Figure 1) that gravel samples can comprise up to 50% sand by weight; beyond that, there is an abrupt transition to a sample that is nearly all sand (Kellerhals, 1982).

2.2 Bed Composition

High particle-size variability is a trait exhibited in most gravel beds, and it is not uncommon for a single sample particle-size distribution to span five orders of magnitude. Combine this with high spatial variability and it is apparent why sampling gravel beds is complex. However, recent studies are providing a better understanding of the variability that can be expected for different spatial scales: on a single bar (Bluck, 1982), among different lithofacies in a section of channel (Forbes, 1983), and among similar sampling environments along a river reach (Church and Kellerhals, 1978).

Table 1. Wentworth Scale

Class name	Millimetres (mm) Upper limit	Millimetres (mm) Lower limit	Phi (ϕ) Upper limit	Phi (ϕ) Lower limit
Very Large Boulders	4 096	2 048	-12	-11
Large Boulders	2 048	1 024	-11	-10
Medium Boulders	1 024	512	-10	-9
Small Boulders	512	256	-9	-8
Large Cobbles	256	128	-8	-7
Small Cobbles	128	64	-7	-6
Very Coarse Gravel	64	32	-6	-5
Coarse Gravel	32	16	-5	-4
Medium Gravel	16	8	-4	-3
Fine Gravel	8	4	-3	-2
Very Fine Gravel	4	2	-2	-1
Very Coarse Sand	2	1	-1	0
Coarse Sand	1	0.5	0	1
Medium Sand	0.5	0.25	1	2
Fine Sand	0.25	0.125	2	3
Very Fine Sand	0.125	0.062	3	4
Coarse Silt	0.062	0.031	4	5
Medium Silt	0.031	0.016	5	6
Fine Silt	0.016	0.007 8	6	7
Very Fine Silt	0.007 8	0.003 9	7	8
Coarse Clay	0.003 9	0.002 0	8	9
Medium Clay	0.002 0	0.001 0	9	10
Fine Clay	0.001 0	0.000 49	10	11
Very Fine Clay	0.000 49	0.000 24	11	12



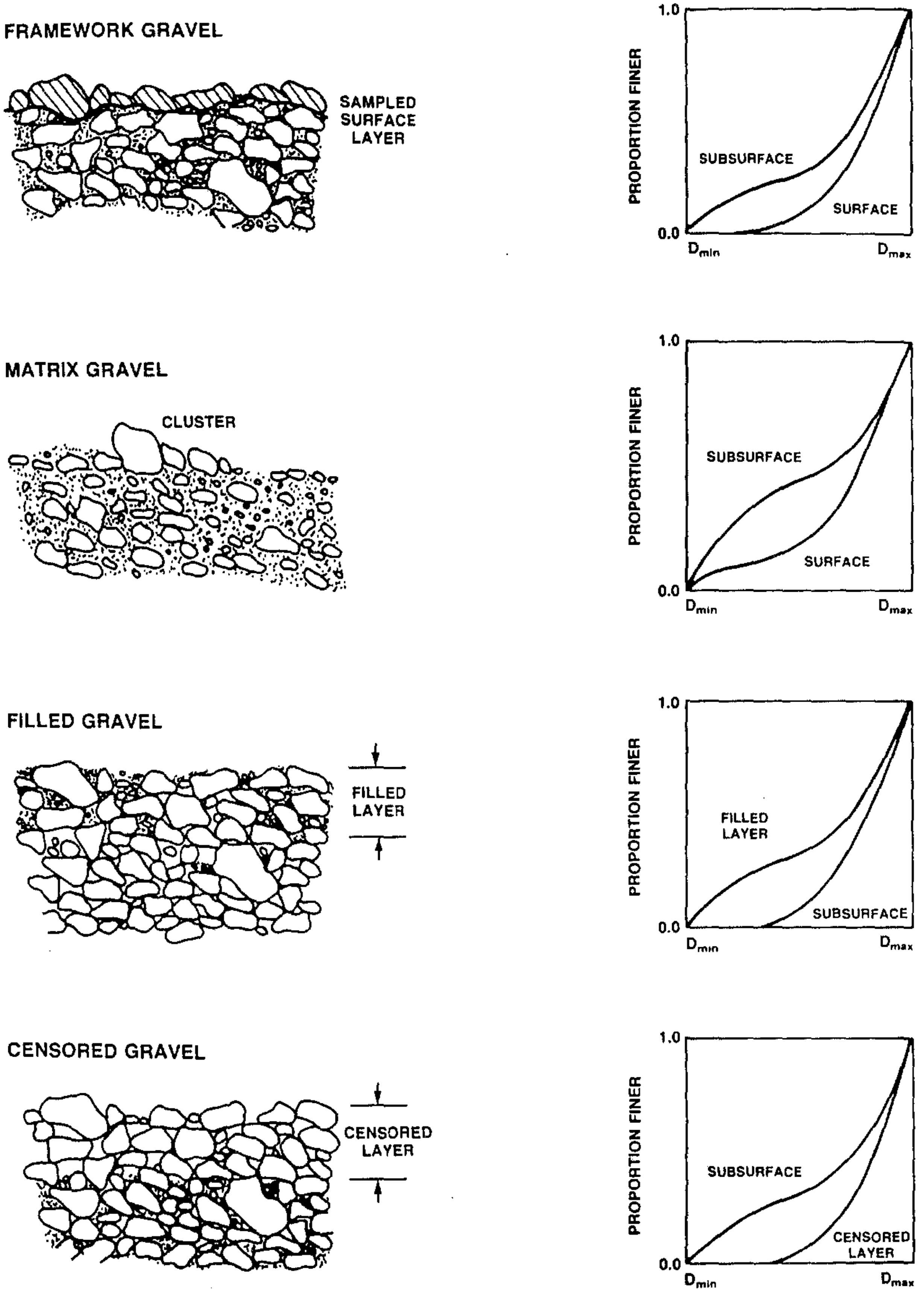
SOURCE: KELLERHALS, 1982.

FIGURE 1

TYPICAL GRAVEL AND SAND DISTRIBUTIONS BASED ON 174 BED MATERIAL SAMPLES COLLECTED FROM RIVERS IN ALBERTA

Gravel beds usually consist of two distinct particle-size populations. There is the coarse fraction, collectively referred to as the framework, and there are fines, which fill in the spaces forming the matrix. Church et al. (1985) illustrated four types of gravel-bed conditions identified in the field (Figure 2). In framework gravel, the coarse materials are in direct contact with each other, whereas in matrix gravel, fines are sufficiently abundant to separate framework contact. There are also two less common types, "censored" and "filled." In censored gravel, fines are nonexistent in a portion of the framework. This is considered to be caused by scouring or piping processes. Filled gravel, on the other hand, is gravel in which fines are present only in the upper portion of the bed. This condition is attributed to the entrapment of overpassing fine material washed into a reach. Matric gravels are believed to be formed by a continuous occurrence of this latter process.

For study and sampling purposes the gravel bed is subdivided into two components: (1) the surface, which is defined as being one grain in thickness, and (2) the subsurface, which is all the underlying material (Figure 2). Both populations have been considered to be characteristically lognormally distributed (e.g. in ISO Draft Standards, 1984). As this assumption is usually not valid, many researchers (Church et al., 1985) avoid making a formal distribution assumption, especially in the sample size specification problem.



SOURCE: CHURCH et al., 1985.

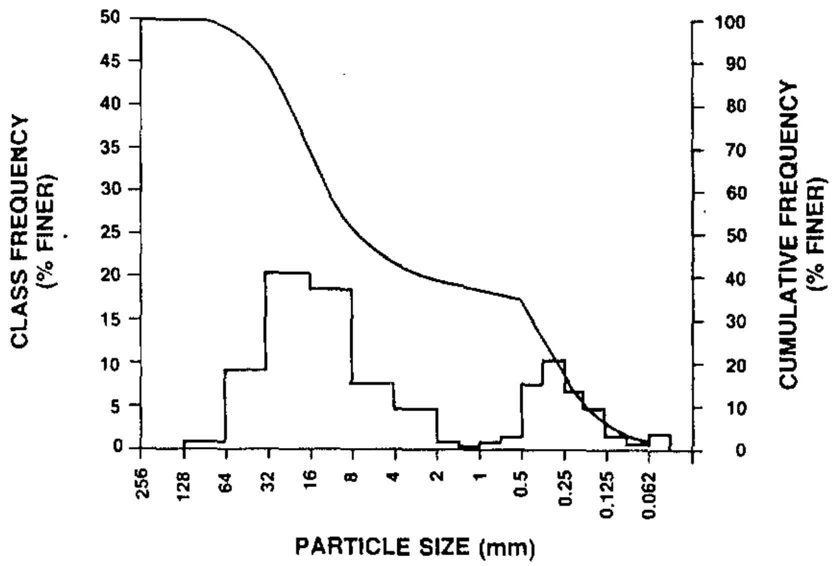
FIGURE 2

TYPICAL BEDDING AND DISTRIBUTIONS FOR FLUVIAL GRAVELS

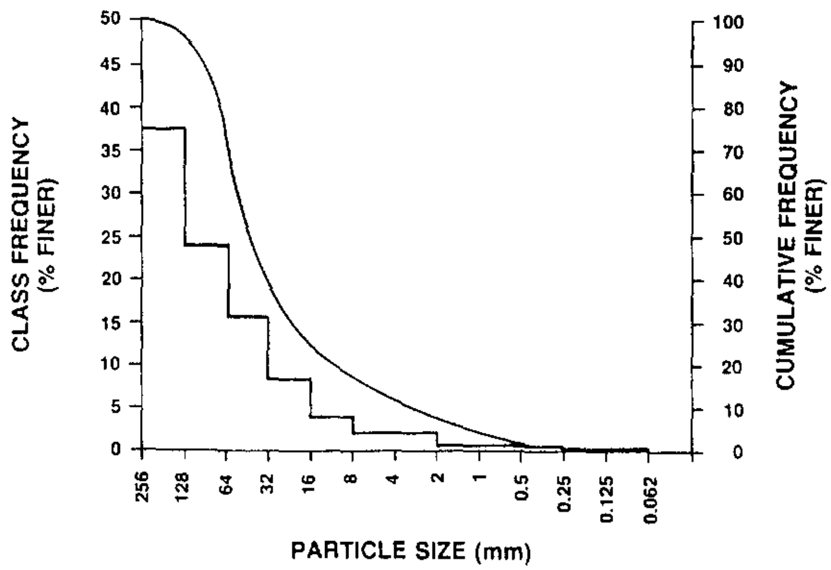
Typically, the surface is coarser than the subsurface in gravel-bed streams. Two explanations have been put forward to account for this. The first is that the fines are winnowed from the surface, thereby leaving only coarse material exposed (Kellerhals, 1967). The other is that surface coarsening is a result of "equilibrium transport," in which the coarse surface is the result of an equalizing mechanism by which more coarse grains are exposed, so that the frequency of grain movements of each size becomes proportional to the frequency of those grains in the bed material (Parker and Klingeman, 1982).

The most common term to describe the process whereby the surface of the bed becomes coarser is "armouring." In many cases, however, "paving" is used to describe this same state. Bray and Church (1980) attempted to clarify the use of these terms by stating that "armouring" be used to describe the case in which the bed surface is essentially the same as the subsurface material if the fines (<8 mm) are disregarded in the latter. "Paving," on the other hand, should be used when the surface is noticeably coarser than the subsurface material. This distinction has not readily been accepted and "armouring" is still widely used to describe either case.

Unlike the surface, the subsurface particle-size distribution is frequently bimodal, with modes being noticeable in both the gravel and the sand ranges (Figure 3). Another trait is the distinct lack of material in the size range from 0.5 to 4 mm. Many reasons have been



NORTH SASKATCHEWAN RIVER
SAMPLE #29
888 km FROM RIVER SOURCE



NORTH SASKATCHEWAN RIVER
SAMPLE #3
178 km FROM RIVER SOURCE

SOURCE: SHAW AND KELLERHALS, 1982.

FIGURE 3

BIMODAL AND UNIMODAL PARTICLE-SIZE DISTRIBUTIONS OBTAINED FROM NORTH SASKATCHEWAN RIVER given to explain this phenomenon, including mechanical instability of particles in the deficient grain size, mixing of independent populations, and selective transport (Shea, 1974). Shaw and Kellerhals (1982), however, dismiss these mechanisms and attribute this difference to the fact that coarse sand and granules are being transported as bedload and most frequently suffer the maximum attrition by crushing and abrasion, thereby being eliminated. Then the medium sands that are carried in suspension settle out into the interstices of the gravel, producing the observed bimodal distributions.

2.3 Measurement of Particle Size

Particle dimensions are normally expressed in millimetres. Yet it is quite common, especially in sedimentological literature, to find particle size expressed in phi (ϕ) units where ϕ is derived using the following equation:

$$\phi = -\log_2 d; \text{ d expressed in millimetres}$$

Since the actual measurements are recorded in millimetres and the Sediment Survey Section follows the SI system of measurement, the units in this report are expressed only in millimetres.

Frequency distributions are usually obtained by sieving, especially for bulk samples. In the case of surface samples where

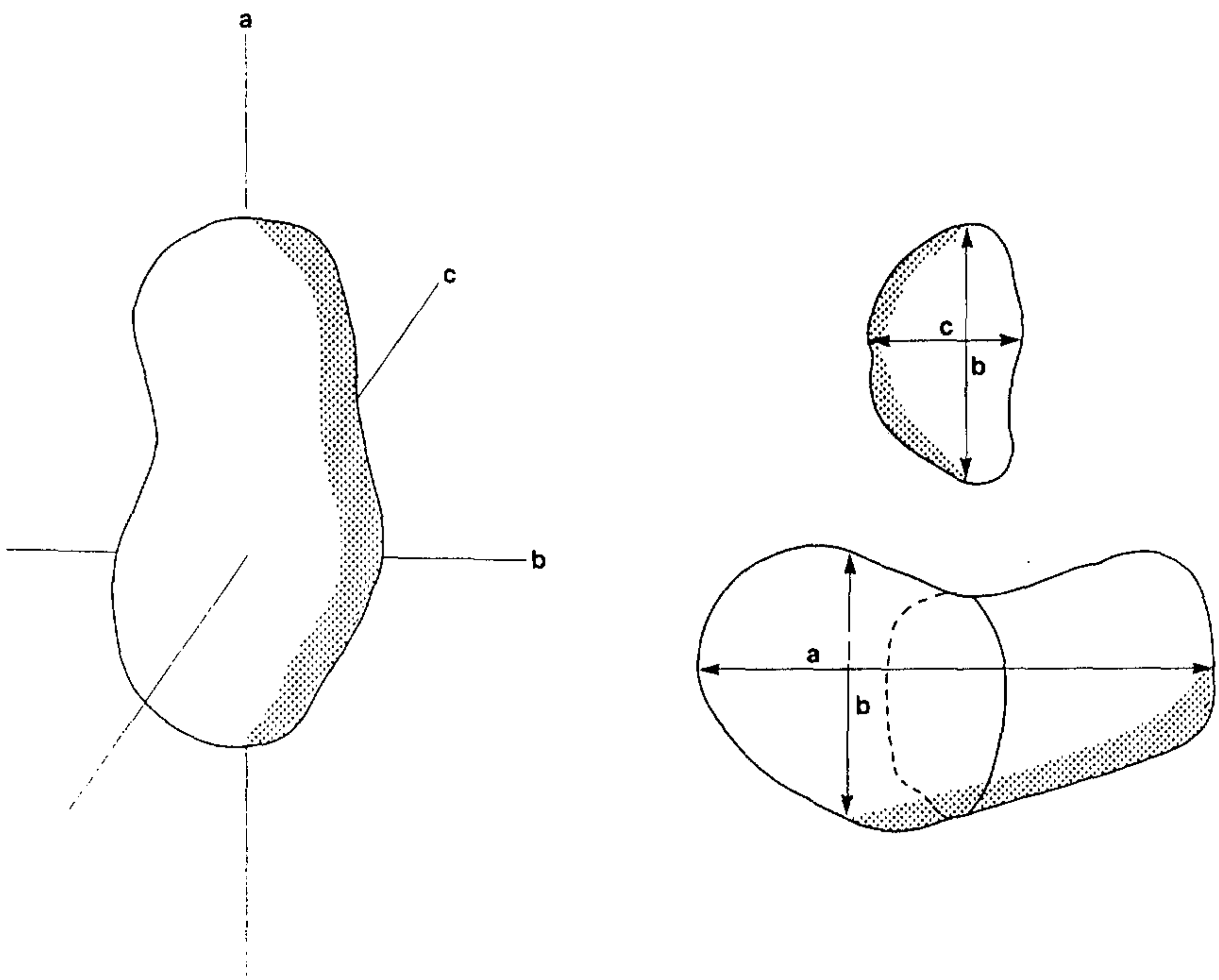


FIGURE 4

PARTICLE AXES

3. SAMPLING

3.1 Hand Sampling Methods

Four methods, which are referred to as hand sampling techniques, are commonly used to collect gravel-bed samples (Kellerhals and Bray, 1971). They are

(1) Bulk (Volumetric) Sampling - where a predetermined volume (or weight) of bed material is collected.

(2) Grid or Point Sampling - where all particles beneath the grid intersects are sampled.

(3) Areal Sampling - where all particles within a selected area are collected.

(4) Transect Sampling - where all the particles falling under a straight line are gathered.

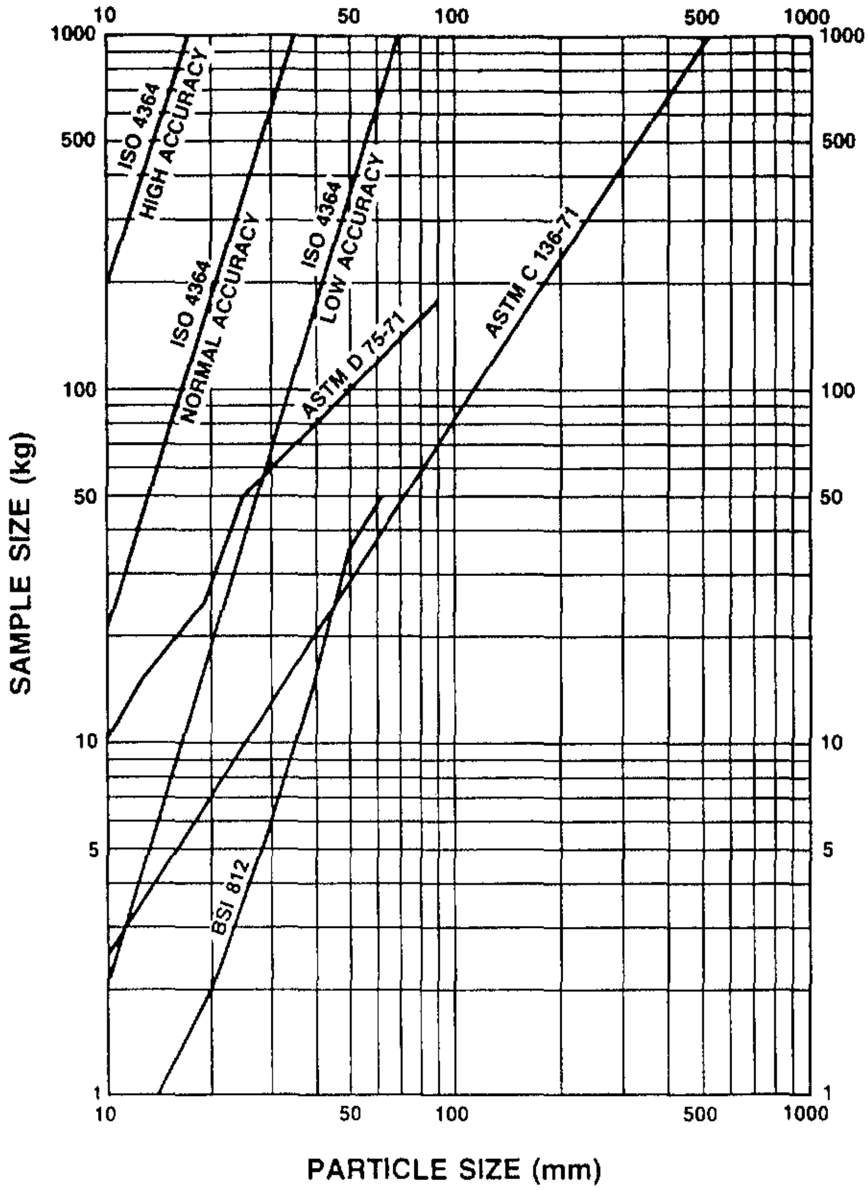
Bulk sampling is the only method used for collecting a subsurface sample; the other three are used for collecting surface samples. Bulk sampling is generally restricted to an exposed surface because of the practical limitations associated with collecting a submerged sample. The surface techniques are more adaptable and, depending on the method, may be used in shallow water.

3.1.1 Bulk Sampling

Once a suitable site has been selected (Section 3.4.1), it must be prepared for bulk sampling by scraping the surface material away to the depth of the deepest-lying exposed grain (Church et al., 1985). This procedure ensures that there is no mixing of the distinct surface and subsurface material. If this is not done, then the surface material, which is usually depleted of fines, will bias the subsurface results by producing a coarser distribution than is actually present.

The next step requires that the investigator determine the quantity of material to be collected to ensure that the sample will be adequate. An adequate sample is defined as one in which there are no particle-size biases attributable to the sampling procedure. To ensure that a large enough sample is collected to overcome such biases, many organizations have developed standards or guidelines dictating the amount of material to be collected. Common particle-size parameters used to determine sample size include the diameter (b-axis) of the largest particle, the weight of the largest particle, and d_{84} (the particle size for which 84% of sample is finer) of the sample.

A review of some of the more notable standards shows (Figure 6) that there is little agreement with respect to sample size requirements. Even the standards developed for sampling mineral aggregates are inconsistent. These standards are commonly used to determine sample size



* b-AXIS OF LARGEST PARTICLE USED FOR:
ASTM D 75-71, ASTM C 136-71, BSI 812.
* d84 OF SAMPLE USED FOR ISO 4364.

FIGURE 6

BULK SAMPLING STANDARDS
ESTABLISHED BY VARIOUS ORGANIZATIONS

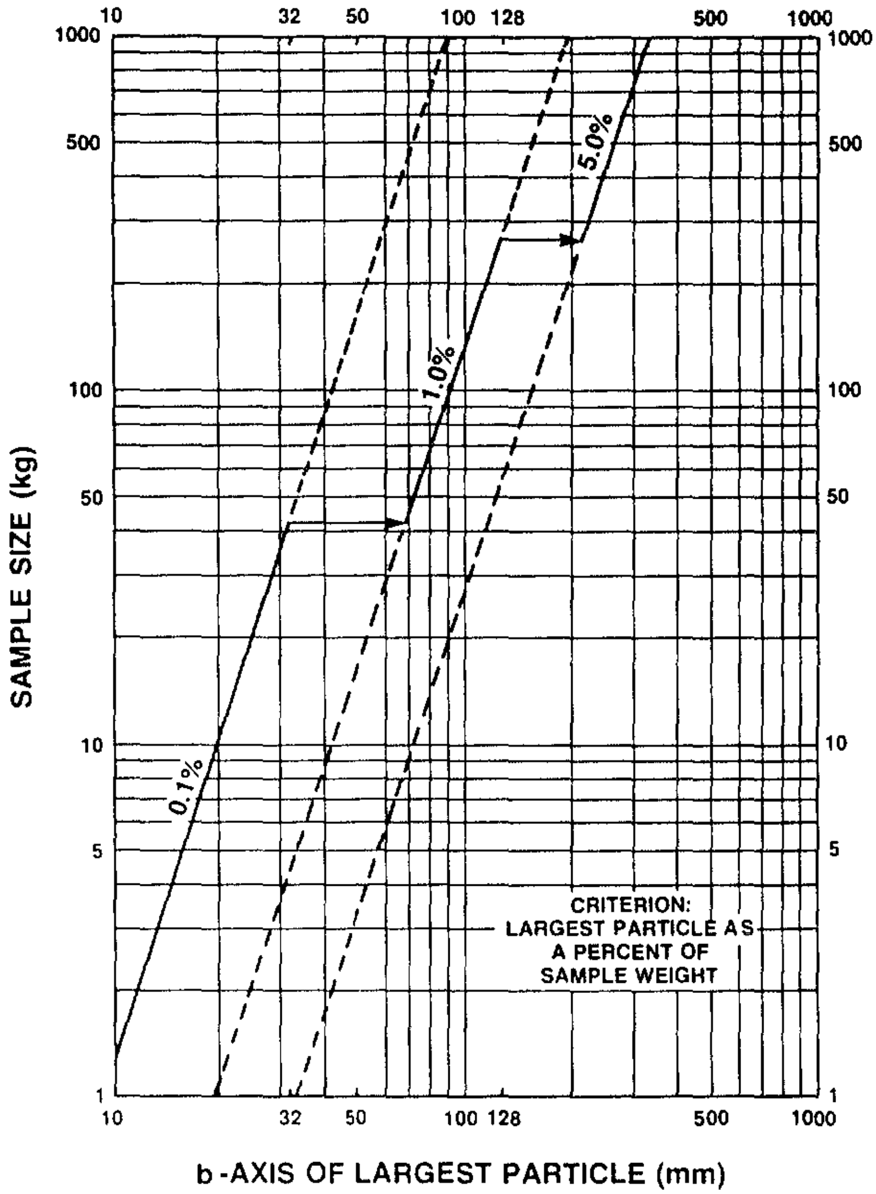
requirements in fluvial studies (Bray, 1972, Mosley and Tindale, 1983). These standards, however, are not very suitable because they were not developed using material as highly variable as fluvial gravels, and they cover only a portion of the size range that is encountered in most field studies.

ISO Standard 4364 (1977) is considered to be more relevant, as it is derived from work conducted on fluvial sand and gravel. The original work undertaken by de Vries (1970) involved developing a relationship between the sample size and error in the particle-size distribution. Based on his findings, de Vries developed design curves for sample mass as a function of d_{84} for high (1%), normal (3%), and limited (10%) accuracy. The major complaint about this standard is that sample size quickly becomes impractical to handle as particle size increases into gravels (Mosley and Tindale, 1983). Another drawback is that a sample must first be sieved to obtain the d_{84}, which is then used to dictate sample size: a very awkward procedure.

A more recent ISO Draft Standard (1984), which is being developed for sampling gravels, has a simpler criterion for establishing sample size. To avoid innaccurate estimates of the percentage in the coarser fractions, the largest stone in a single bulk sample should be less than 3% of the total sample weight. The rationale for choosing 3% however, is not given, nor a source quoted. However, it would appear the value was taken from Bray's (1972) original criteria for determining sample size. Mosley and Tindale (1983), however, find it too stringent for New Zealand rivers and prefer to use 5% to keep samples down to a manageable size.

Church et al. (1985) found this sample criterion to be arbitrary and undertook a field study to derive a criterion that could be scientifically supported. Twenty-one splits, each comprising 33.5 kg, were used to determine that 100 grains in a size class are required to obtain a stable measure of its proportion. Based on a stable coefficient of variation of about 0.10, for replicate estimates of the population in a size class, it was calculated that the largest particle should make up only 0.1% of the total sample weight to ensure that the sample is adequate. As particle size increases and sample size becomes unmanageable, this criterion must in practice be relaxed. It is advocated that in order to maintain sampling at a reasonable size, 0.1% be used up to 32 mm and 1% up to 128 mm. Above 128 mm, 5% would have to be used if hand methods only are being employed, and unless machinery is available, it appears impractical to sample full distributions that include material above 256 mm.

As this is the most rigorous and practical criterion that currently exists, it is recommended that it be adopted as a standard (Figure 7). For a step-by-step procedure on collecting a bulk sample, see Appendix A.



SOURCE: CHURCH et al., 1985.

FIGURE 7

BULK SAMPLING STANDARDS TO BE ADOPTED BY THE SEDIMENT SURVEY SECTION

3.1.2 Grid Sampling

Grid sampling consists of collecting a surface sample based on a predetermined grid spacing. The most commonly used approach is that devised by Wolman (1954), which involves a stepping grid. The investigator, while pacing along a selected path, collects a stone with each step from immediately in front of the foot. As a safeguard, the eyes should be closed or averted when picking up the stone to avoid any personal biases that may accompany selection (Leopold, 1970). This method has been the most popular because it does not require any specific equipment for establishing a grid, spacing can easily be adjusted to suit any size of material, and it can be done in shallow water, not just on exposed surfaces.

Other forms of grid sampling entail laying out a grid using either a survey tape or a preconstructed square grid. Unlike the Wolman technique these other techniques are suitable only for exposed surfaces. A preconstructed grid also has the drawback that one must have an idea of the size of surface material to be encountered so that the spacing will be suitable. The preconstructed grids are often used in conjunction with photographs to reduce time and effort in the field. (Since the photo approach differs significantly in methodology, it will be discussed separately.)

Each particle, upon collection, is categorized according to size class. The best approach is to use the template so that the results will be equivalent to sieving. If particle-size dimensions are being used, then all three axes should be measured to account for shape effects when categorizing (Church _et al_., 1985).

A slightly different approach to collecting a standard grid sample involves using photographs. The method was devised by Ritter and Helley (1968) to help reduce the time spent in the field collecting samples. It entails placing a preconstructed square grid of known grid spacing or tape on the bed, for scale, and photographing the area. The height that the camera should be above the surface is dependent on the focal length of the lens and the bed material size. Particle dimensions are then scaled off the photographs at the predetermined grid intercepts. It is assumed that the a-axis is the larger visible dimension, the b-axis the smaller visible one, while the c-axis is hidden. Some field samples are usually collected at the same time for comparison purposes.

Difficulties arise when converting particle size-dimensions from the photograph to real dimensions. Kellerhals and Bray (1971) found that the dimensions taken off photographs tended to be smaller than the real values based on samples collected from 11 different rivers. They attributed this bias to a number of possible factors: stone imbrication, infilling fines covering a portion of an axis, shadow effects, and scale distortion.

Adams (1979), by restricting his research to one river, was able to reduce the level of bias. The fact that the particles in this case were rounded and not highly imbricated certainly helped the results. In this study, the a-axis dimension obtained from the photographs overestimated the true value, whereas the b-axis tended to slightly underestimate it.

A recent attempt to evaluate the empirical correlations obtained in these studies proved unsuccessful (Church et al., 1985). Packing and imbrication factors were considered to have contributed to the highly variable results obtained in this latter study.

Recent work by Ibbeken and Schleyer (1986) is helping to overcome the limitations of standard photo-methods due to fully or partially hidden particle axes. This technique involved digitizing the outline of the particle from an enlarged print. Then, based on the size and shape of the projection area of the individual particles images, the computer determines the ellipsoids of revolution. The results are so comparable to those of sieving that the technique is referred to as "photo-sieving."

The question of grid spacing is rarely addressed in any detail, yet can significantly affect the results. Spacing is usually dictated in such terms as "preferably no two sampling points should fall on the same particle, but should they, then the particle should be counted twice" (Kellerhals and Bray, 1971). As Church et al. (1985) point out this may not be an acceptable criterion because there is a natural inclination for particles of similar size to lodge against each other. Therefore if the spacing is too small, a serially correlated sample can result. To avoid this problem, the spacing interval should be at least several grain diameters, using one of the larger nearby particles as the reference. Judgment will be required in many cases to ensure that the chosen spacing will not require an unrealistically long grid line.

The main operational concern with grid sampling has been to determine the minimum number of particles that need to be collected to yield a consistent estimate of a desired size parameter, in most cases the mean size. Over the years many researchers have determined, through various ways, what they consider to be the minimum number of stones that should be collected. As can be seen from Table 2, the values range anywhere from 50 to 200 particles.

Rather than let a predetermined sample size dictate the level of precision of the sample mean, the current emphasis is to collect a sample to obtain a desired level of precision. As long as the sample is not too strongly skewed, a statistical assessment can be made using the following:

$$d = \frac{t\alpha S_D}{\sqrt{N}} \qquad \text{or} \qquad N = \left(\frac{t\alpha S_D}{d}\right)^2$$

Table 2. Recommended Sample Size for Grid Sampling

Number of particles	Researchers	Rationale
50	Bray (1972)	Comparison of 31 adjacent grid samples of 50 stones showed that only two pairs differed in the mean ($\alpha = 0.05$).
	Bradley *et al*. (1972)	Based on the number of particles that can practically be measured during a 20-minute span.
	Church and Kellerhals (1978)	Based on Bray (1972)
60	Brush (1960)	Not specified.
70	Mosley and Tindale (1984)	From field work which indicates that in general, 70 particles need to be collected to stabilize the particle-size histogram.
80	Penning-Rowsell and Townsend (1978)	Analysis revealed that 40 particles will yield a representative mean value. Recommended 80 particles for highly variable sites.
100	Wolman (1954)	Repetitive sampling indicated that 100 particles are needed to adequately describe the distribution.
	Leopold (1970)	Based on Wolman (1954).
	Hey and Thorne (1984)	Statistical analysis of logarithmically transformed data collected by 8 different operators showed that there are no significant differences between samples within operators when up to 100 particles are collected.
200	United States National Handbook (1978)	Not specified.

where d = level of precision

(the maximum probable difference between the sample and population mean)

N = sample size

S_D = standard deviation of the sample

t = student's t for n-1 degrees of freedom

α = at the 95% confidence level

(see Appendix B for examples).

Gravel samples are generally considered to be lognormally distributed and therefore the data are subjected to a logarithmic transformation before making a statistical assessment (Hey and Thorne, 1983; ISO Draft Standards, 1984).

Church <u>et al</u>. (1985) note that fluvial gravels are not, strictly, normally nor even lognormally distributed and therefore prefer to avoid making formal distribution assumptions. They also point out that there are difficulties in interpreting transformed data. Instead, they suggest that the sample coefficient of variation be used to measure precision, thereby avoiding these problems.

The level of precision is dictated by the sensitivity of the application. However, a review of past studies can help determine the level of precision that could reasonably be achieved in routine sampling. Church and Kellerhals (1978), using a sample size of 50 stones, calculated a precision of the mean in the order of 10%, while

Hey and Thorne (1983) noted that using an initial sample size of 100 stones and a typical standard deviation (0.3) obtained from their sampling would provide for precision of ± 15%. The ISO Draft Standards (1984) state that standard deviations in gravels range from 0.15 to 0.45 (in log units), based on a sample size of 100. If one takes the worst case (0.45) the precision is still within ± 25%. These results indicate that a sample size of 100 stones, in routine sampling, should provide a reasonable estimate of the mean.

Based on these findings it is recommended that a standard of 100 particles be collected (preferably two lines of 50 particles) unless a predetermined precision is specified. A step-by-step procedure for collecting a grid-by-number sample (see Section 3.3) is detailed in Appendix C.

3.1.3 Areal Sampling

There have been a variety of approaches used to collect an areal sample. Lane and Carlson (1953) were the first to use the areal approach, and their technique involved marking all the surface particles within a selected area using spray paint, and then collecting all the marked stones. A review of the literature reveals that this approach has not been very popular, probably because it is tedious.

3.1.4 Transect Sampling

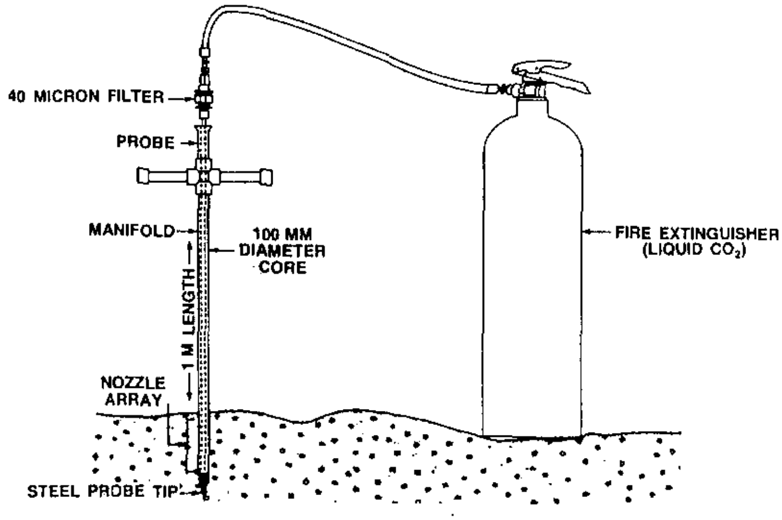
This approach involves collecting all the particles falling under a straight line (Muir, 1969). The precision of the mean is determined on the basis of the number of stones in the sample itself, the same as for grid sampling (ISO Draft Standards, 1984).

However, there is an inherent weakness in the approach, that probably accounts for why it is seldom used. It encourages serial correlation within a sample by collecting successive particles which are directly affected by one another. Serially correlated samples can be analyzed, but at the cost of a reduction in effective sample size and precision in the results (Church et al., 1985). There remains also the need to transform the results to be consistent with other methods (Section 3.3).

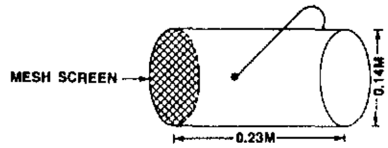
3.2 Bed Material Samplers

Selection of the appropriate sampler (Figure 8) depends on the population that requires sampling and specific site conditions. As can be seen from Table 3, all of the samplers have certain restrictions or limitations. Besides these drawbacks there are major problems such as loss of fines and a limited size of sample which severely reduces the value of the data.

8a FREEZE-CORE SAMPLER

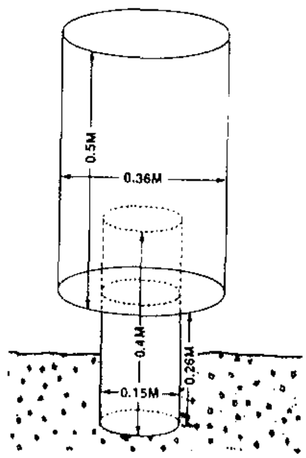


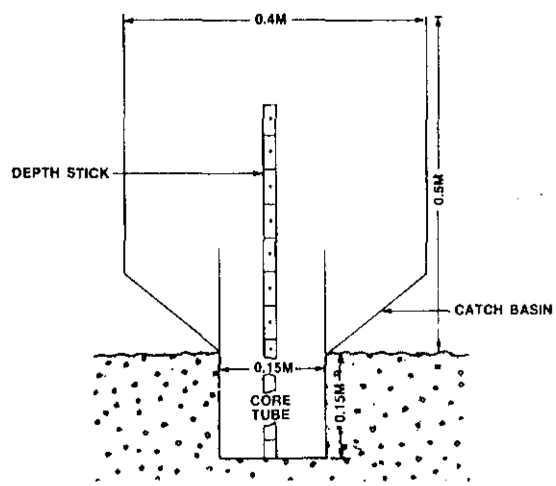
8b PIPE-DREDGE SAMPLER



8c PIPE SAMPLER

8d McNEIL-AHNELL SAMPLER





8e GRAVEL-CUTTER SAMPLER

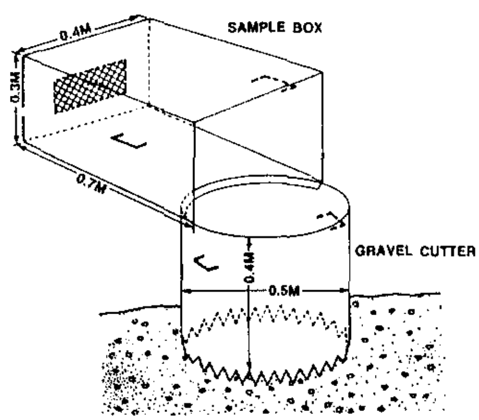


FIGURE 8

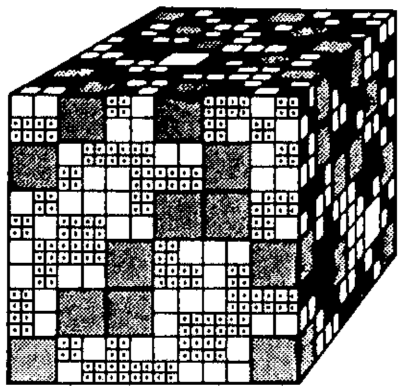
BED MATERIAL SAMPLERS SUITABLE FOR SAMPLING GRAVELS

However, in the cases where it is critical to sample the submerged portion of the bed (i.e. fish habitat studies), or where negligible exposed sampling sites exist, then samplers can be used. In such cases, a number of samples will have to be combined to ensure an adequate amount of material has been collected (Section 3.1.1).

3.3 Equivalence of Methods

The question of equivalence becomes important when the results from different methods are compared. High spatial particle size variability in gravel beds makes it exceedingly difficult to duplicate results and thereby make comparisons. Therefore, to overcome this problem, an idealized cube model (Figure 9) and geometric arguments were originally applied (Kellerhals and Bray, 1971). Given the number of cubes of different sizes it takes to displace a known volume, the relationships between the different methods were developed and formal conversions derived (Table 4). The factors are based on an idealized case, so it can be expected that observed value will deviate from the theoretical because gravel stream beds are not a random cut through a well mixed gravel accumulation. Conversions are available for either weight or number frequency. The transect method conversions were not included in the initial paper by Kellerhals and Bray (1971) but have since been derived (ISO Draft Standards, 1984).

When tested against actual field samples, the conversions produced comparable results (Kellerhals and Bray, 1971). Most important,



PARTICLE	LINEAR SIZE D	WEIGHT W	TOTAL NO. IN SAMPLE VOLUME	TOTAL NO. IN SAMPLE SURFACE
	1	1	4608	192
	2	8	576	48
	4	64	72	12

SOURCE: KELLERHALS AND BRAY, 1971.

FIGURE 9

CUBE MODEL: AN IDEALIZED CASE OF DENSELY PACKED CUBES

Table 4. Weighting Factors for Conversion of Sampling Procedures

	Conversion to						
Conversion from	Bulk-by-weight	Grid-by-number	Grid-by-weight	Area-by-number	Area-by-weight	Transect-by-number	Transect-by-weight
Bulk-by-weight	1	1	D^3	$1/D^2$	D	1/D	D^2
Grid-by-number	1	1	D^3	$1/D^2$	D	1/D	D^2
Grid-by-weight	$1/D^3$	$1/D^3$	1	$1/D^5$	$1/D^2$	$1/D^4$	1/D
Area-by-number	D^2	D^2	D^5	1	D^3	D	D^4
Area-by-weight	1/D	1/D	D^2	$1/D^3$	1	$1/D^2$	D
Transect-by-number	D	D	D^4	1/D	D^2	1	D^3
Transect-by-weight	$1/D^2$	$1/D^2$	D	$1/D^4$	1/D	$1/D^3$	1

Note: The weighting factors are derived for densely packed cubes in random arrangement.
Term D is the geometric mean size of the size range to be adjusted by the weighting factor.

Source: ISO (1984) (adapted from Kellerhals and Bray, 1971).

it was shown that the results from a grid-by-number approach are equivalent to those produced by bulk sampling for the same population. Because of this, the grid-by-number sampling approach has become by far the most popular method for collecting a surface sample.

All except one of these conversions has been accepted. The one in question is the conversion from area-by-weight to a bulk equivalent. A few researchers (Profitt and Sutherland, 1980; Gomez, 1983) have found that the original conversion overcompensates and that a factor of 0.5 needs to be applied. They attributed the difference to such factors as the pattern of voids, packing of graded sediments, and the nonrandom exposure of ellipsoidal grains, which are not accounted for in the model.

A controlled experiment, using a known size distribution, was recently undertaken to resolve this issue (Church et al., 1985). The results verify that the formal conversion factors developed by Kellerhals and Bray (1971) are correct.

3.4 Sampling Strategy

Now that the mechanics of collecting adequate samples have been discussed, this section will focus on: site selection; type of samples; number of samples; and sampling frequency. The sampling strategy developed here will primarily reflect an engineering perspective, as most of the uses for these data are in engineering projects.

3.4.1 Site Selection

To overcome the complex problem of high spatial variability exhibited in fluvial gravels, the initial approach to sampling has been to define a distinct sedimentary environment which would be considered to be indicative of the local bed conditions. This particular environment has been identified as the head of a major bar (Bray, 1972; Church and Kellerhals, 1978). The bar was chosen because it is readily identifiable, it is an exposed site, and the material on the bar is considered to be indicative of the material in the main channel. The head of the bar, which usually comprises the coarsest material, is considered the most appropriate site, based on the premise that it is the coarsest materials that will exert the predominant grain effect on channel behaviour and flow resistance. Although no work has definitively proved this hypothesis, this sampling approach is widely used.

A recent study was conducted by Mosley and Tindale (1983) to determine whether one type of sedimentary environment could really be considered to be characteristic of the whole river bed. In this study, 86 bulk samples were collected from identifiable depositional environments in a highly variable section of river. Individual particle-size distribution curves were then compared with the composite distribution to see whether any one distinct environment would produce,

GLOSSARY

Accuracy: refers to the agreement between the measured and the "true" value and has to do with bias.

Areal sampling: all the particles at the surface within a selected area are collected.

Armouring: the process whereby the surface of the bed becomes coarser.

Bed material: the sediment mixture of which the bed is composed.

Bed material sampler: a device for sampling bed material.

Bulk sampling: where a predetermined volume (or weight) of subsurface material is collected.

Clast: a fragment of rock (another term for particle).

Cluster: stable groups of imbricated large clasts resting against a keystone.

Framework: refers collectively to the coarse fraction of material found in the bed.

Gravel: material having a particle size between 2 and 64 mm.

Gravel-bed streams: streams with beds containing a sizeable amount of material larger than 2 mm.

Gravel template: an aluminum plate with squares cut out corresponding to standard sieve sizes (8-128 mm).

Grid sampling: where all the particles beneath the grid intersects are sampled.

Imbricated: when individual grains of similar size successively overlap the adjacent particle downstream - indicates flow direction.

Lithofacies: refers to a homogeneous body of sediment (based on either on physical, mineralogic or petrographic characteristics) deposited under essentially constant conditions.

Matrix: the fines that fill the spaces among the coarser particles.

Nominal diameter: the diameter of a sphere that has the same volume as the particles.

Paving: see armouring.

Particle size: a linear dimension used to quantify the size of a particle, usually expressed as a diameter in millimetres.

Particle-size distribution: a cumulative frequency distribution of the relative amounts of particles coarser or finer than specified sizes.

Particle-size axes: correspond to mutually perpendicular axes: with the largest dimension being the a-axis; the intermediate, the b-axis; and the smallest, the c-axis. Each axis is the maximum dimension in the corresponding plane.

Phi(ϕ): defined as the negative logarithm to the base 2 of the particle size in millemetres.

Precision: the agreement between the values of a number of measurements. The term is used to describe reproducibility of results.

River reach: a section of river having similar morphology. The length is usually restricted on the basis of it being a specified number of channel widths.

Surface: a single-grain layer of the top of the bed.

Subsurface: the material beneath the upper single-grain layer.

Transect sampling: where all the particles falling under a straight line are gathered.

Appendix A

Bulk Sampling Procedure

Step: 1. Choose suitable site (Section 3.4) and scrape surface material away to depth of deepest-lying particle.

2. Select largest particle on the surface in the immediate vicinity and measure the b-axis. Refer to Figure 7 for sample size requirements. Use 0.1% criterion for particles up to 32 mm, 1.0% to extend to 128 mm, and 5% thereafter.

3. Shovel subsurface material into a pail, weigh (field scale resolution ≈0.1%) and record, then sieve through 32-mm mesh onto the tarpaulin. Place particles larger than 32 mm into a separate pile. Continue process until the predetermined amount of material is sieved.

4. Using the gravel template (Figure 5), sort the coarser material (>32 mm) into individual piles corresponding to sieve classes and record class weights.

5. To provide information on shape and particle density, all three axes and individual weights of the largest 10 particles should also be recorded. The lithology of particles should also be noted, if known.

6. The material less than 32 mm is then sieved and the weight recorded for each class down to 8-mm mesh.

7. If there is a sizeable amount of material (<8 mm) left, then the sample is split into equal parts and a subsample of approximately 5 kg is bagged for laboratory analysis.

8. The final results should be checked by cumulating the weights and comparing with the original total weight. Handling errors in the order of 1% are considered acceptable. Moisture loss due to evaporation must be taken into account.

Appendix B

Example for Calculating a Grid Sample:

(a) Sample size required for a given precision

(b) Precision of sample mean

Equation: (1) (2)

$$N = \left(\frac{t\alpha S_D}{d}\right)^2 \qquad\qquad d = \frac{t\alpha S_D}{\sqrt{N}}$$

where: N = sample size

$t\alpha$ = student's t for N-1 degrees of freedom at the 95% confidence level

S_D = standard deviation of the sample (log units)

d = the acceptable difference between the sample (logx) and population mean (logX)

$$\log x - \log X = \log \frac{x}{X}$$

$\therefore$ for a precision of 10%, $\frac{x}{X} = 1.10$

Assuming an initial sample of 100 particles has a standard deviation of 0.3 (after logarithmic transformation).

(a) To calculate the number of particles required to be collected to obtain a precision of ±10%.

$\therefore t\alpha = 1.99$ (for 99 degrees of freedom at the 95% confidence level)

$S_D = 0.3$

$d = \log(1.10) = 0.0414$

Equation (1)

$$N = \left(\frac{t\alpha S_D}{d}\right)^2$$

$$N = \left(\frac{1.99 \times 0.3}{0.0414}\right)^2$$

$$N = 208$$

(b) to calculate the precision of the sample mean for a specified sample size.

$\therefore t\alpha$ = 1.99 (for 99 degrees of freedom at the 95% confidence level)

S_D = 0.3

N = 100

Equation (2)

$$d = \frac{t\alpha S_D}{\sqrt{N}}$$

$$d = \frac{1.99 \times 0.3}{\sqrt{100}}$$

$$d = 0.0597 \text{ or } \log 1.147$$

$$d = \pm 15\%$$

Appendix C

Grid Sampling Procedure

Step: 1. Choose suitable site (Section 3.4) and either lay tape along desired course or carry out the Wolman (Stepping) technique.

2. Grid spacing should be in the order of at least two times the largest particle diameter, based on the existing material.

3. Only particles $\geq$ 8 mm are collected to characterize the surface.

4. A standard of 100 particles should be collected (preferably from two lines of 50 particles), or if a predetermined precision is being sought, then it will dictate the sample size (Appendix B).

5. A particle is picked up from the identified spot and classified using the gravel template (Figure 5). If a template is not being used, then all three mutually perpendicular axes should be measured and recorded.

6. The class the particle falls within is recorded, and when the collection is complete, each class is tallied to enable the computation of a frequency-by-number distribution.

APPENDIX D

BED MATERIAL FORMS

Environment Canada
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Environnement Canada
Conservation et Protection

BED MATERIAL HAND SAMPLING EQUIPMENT LIST

(for 2 man crew)

- CAMERA (35mm) ☐
- FIELD SCALE (27.2 Kg) ☐
- ROCKER SIEVES ☐
- GRAVEL TEMPLATE ☐
- TARPAULIN (≃ 3m x 3m) ☐
- PAILS (3) ☐
- SHOVELS (2) ☐
- TRIPOD (With hook assembly for field scale) ☐
- TAPE (Survey and Measuring) ☐
- FASTENING TAPE ☐
- PLASTIC (Polyethylene) SAMPLE BAGS (350mm x 200mm x 0.1mm) ☐
- SMALL BLACKBOARD AND CHALK ☐
- BED MATERIAL FORMS ☐
- FIELD BOOK ☐
- PENCIL, PERMANENT MARKER ☐

NOTE: VERIFY FIELD SCALE READINGS OVER A RANGE OF WEIGHTS PRIOR TO USE

Environment Canada
Conservation and Protection

Environnement Canada
Conservation et Protection

PLAN VIEW OF BED MATERIAL SAMPLING SITE

SITE:	DATE:
SAMPLE NO.:	PHOTO NO.:
OPERATORS:	

Legend

X Sampling Site

■ Hydrometric Station

→ Flow Direction

REACH SKETCH

Comments:

02-9117-1 (09-86)

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Conservation and Protection / Conservation et Protection

SITE DESCRIPTION

SITE:	DATE:
WATER DISCHARGE (m^3/s):	WATER LEVEL (m):

TYPE OF SAMPLING ENVIRONMENT:

MID-CHANNEL BAR ☐ DIAGONAL BAR ☐ POINT BAR ☐ CHANNEL SIDE BAR ☐ RIFFLE ☐

MAIN CHANNEL ☐ SIDE CHANNEL ☐ OTHER ☐ ____________________

LATERAL POSITION IN CROSS SECTION:

LEFT BANK ☐ LEFT SIDE ☐ CENTER ☐ RIGHT SIDE ☐ RIGHT BANK ☐

SAMPLING SITE PHOTO

PHOTO NO. ______

COMMENTS: ____________________

____

____

____

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SUPPORT PHOTOS

SITE:	DATE:

UPSTREAM VIEW FROM SITE

PHOTO NO. ________

Comments: ____________________

DOWNSTREAM VIEW FROM SITE

PHOTO NO. ________

Comments: ____________________

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SURFACE PARTICLE – SIZE MEASUREMENTS

SITE:	DATE:	SAMPLE NO.:
GRID SPACING (m):	LINE NO.:	PHOTO NO.:

NO.	SIEVE SIZE (mm)	AXIS a	AXIS b	AXIS c
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				

NO	SIEVE SIZE (mm)	AXIS a	AXIS b	AXIS c
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37				
38				
39				
40				
41				
42				
43				
44				
45				
46				
47				
48				
49				
50				

NO.	SIEVE SIZE (mm)	AXIS a	AXIS b	AXIS c
51				
52				
53				
54				
55				
56				
57				
58				
59				
60				
61				
62				
63				
64				
65				
66				
67				
68				
69				
70				
71				
72				
73				
74				
75				

NO.	SIEVE SIZE (mm)	AXIS a	AXIS b	AXIS c
76				
77				
78				
79				
80				
81				
82				
83				
84				
85				
86				
87				
88				
89				
90				
91				
92				
93				
94				
95				
96				
97				
98				
99				
100				

02-9117-4 (09-86)

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Conservation and Protection / Conservation et Protection

SURFACE PARTICLE – SIZE FREQUENCY - BY - NUMBER

SITE:	DATE:	SAMPLE NO.:

SIEVE SIZE (mm)	TALLY	TOTAL COUNT	PERCENT OF TOTAL (%)	CUMULATIVE PERCENT FINER THAN (%)
1024				
724				
512				
362				
256				
181				
128				
90.5				
64.0				
45.3				
32.0				
22.6				
16.0				
11.3				
8.0				
	TOTAL			

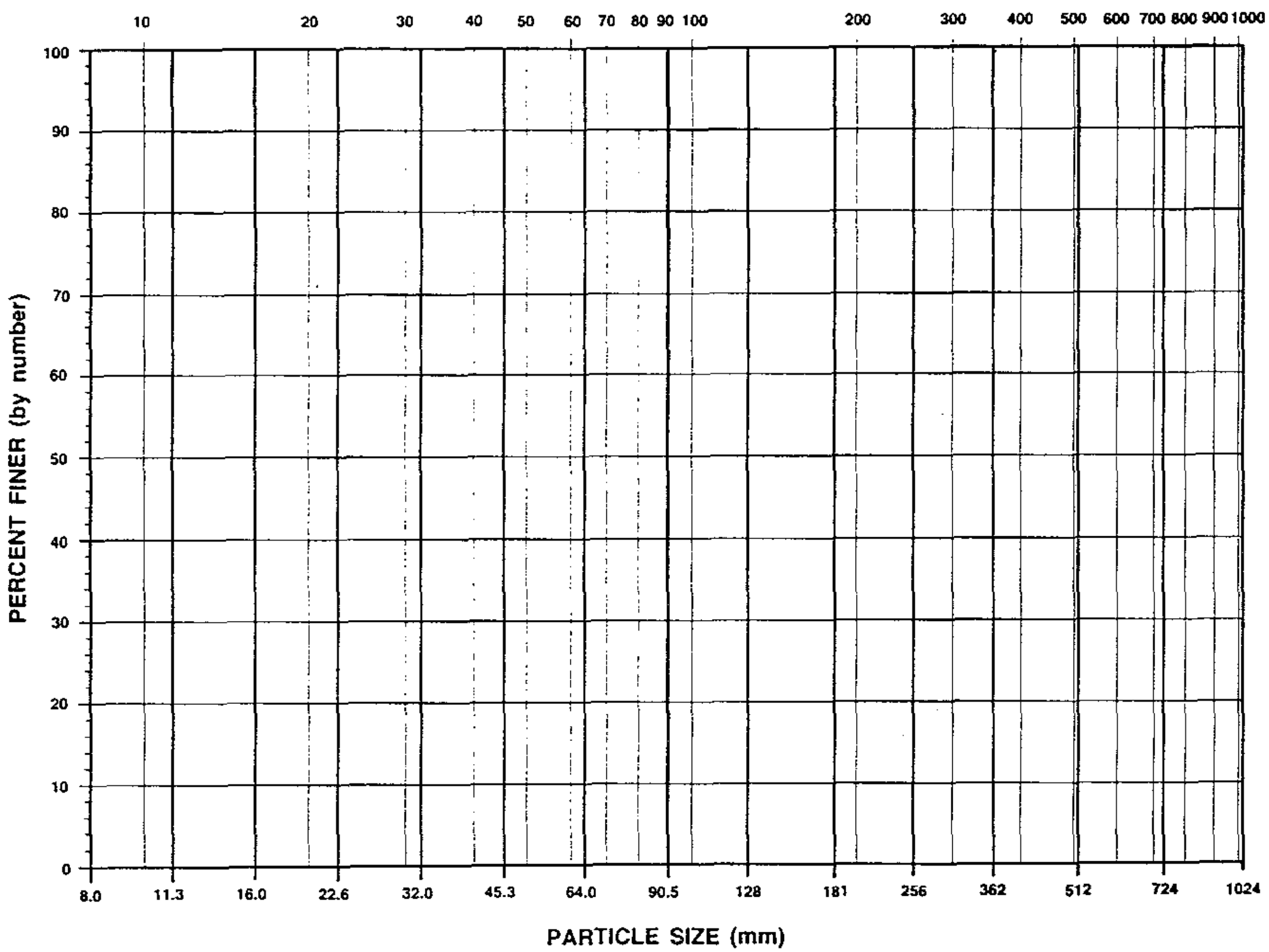
02-9117-5 (09-86)

Environment Canada / Environnement Canada

Conservation and Protection / Conservation et Protection

SURFACE PARTICLE - SIZE DISTRIBUTION

SITE:	DATE:	SAMPLE No.:



CHARACTERISTIC SIZE (mm)	
d_{max}	
d_{90}	
d_{84}	
d_{65}	
d_{50}	
d_{35}	
d_{16}	
d_{10}	
d_{min}	

02-9117-6 (06-86)

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FIELD ANALYSIS OF BULK SAMPLE

SITE:	DATE:	SAMPLE NO.:
b-AXIS OF LARGEST PARTICLE AT SAMPLING SITE (mm):	APPROXIMATE WEIGHT OF MATERIAL TO BE COLLECTED (Figure 7):	
GROSS WEIGHT: kg	TARE WEIGHT: kg	SAMPLE WEIGHT: kg (1)

SIEVE SIZE (mm)	GROSS WEIGHT (kg)	TARE WEIGHT (kg)	SAMPLE WEIGHT (kg)
1024			
724			
512			
362			
256			
181			
128			
90.5			
64.0			
45.3			
32.0			
22.6			
16.0			
11.3			
8.0			
<8.0			
		TOTAL	(2)

LARGEST PARTICLES				
NO.	AXIS (mm) a	b	c	SIEVE SIZE (mm)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

HANDLING ERROR

$$\frac{(1) - (2)}{(1)} \times 100 = \underline{\qquad} \%$$

(ACCEPTABLE UP TO 1 %)

WEIGHT OF MATERIAL (**<8.0 mm**) FOR LABORATORY ANALYSIS
kg (= 5 kg)

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LABORATORY ANALYSIS OF BULK SAMPLE

SITE:	DATE:	SAMPLE NO.:
ANALYSIS DATE:	ANALYZED BY:	

WEIGHT OF FIELD SAMPLE (FIELD SCALE): g (1)	WEIGHT OF FIELD SAMPLE (LABORATORY SCALE): g (2)	SCALE DIFFERENCE: (1) – (2) g $\frac{(1) - (2)}{(1)} \times 100 =$ ____
DRY WEIGHT OF FIELD SAMPLE: g (3)	MOISTURE CONTENT: (2) – (3) g $\frac{(2) - (3)}{(3)} \times 100 =$ ____ %	

SIEVE SIZE (mm)	GROSS WEIGHT (g)	TARE WEIGHT (g)	SAMPLE WEIGHT (g)	PERCENT OF TOTAL (%)
8.00				
5.66				
4.00				
2.83				
2.00				
1.40				
1.00				
0.707				
0.500				
0.354				
0.250				
0.177				
0.125				
0.088				
0.063				
<0.063				
		TOTAL	(4)	

CHECK:	
DRY WEIGHT OF FIELD SAMPLE (3):	g
TOTAL SAMPLE WEIGHT (4):	g
WEIGHT DIFFERENCE:	g

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COMPLETE BULK SAMPLE ANALYSIS

SITE:	DATE:	SAMPLE NO.:

SIEVE SIZE (mm)	RECORDED WEIGHT OF MATERIAL (g)	ADJUSTED WEIGHT (g) (due to sample splitting, moisture loss, scale correction)	PERCENT OF TOTAL (%)	CUMULATIVE PERCENT FINER THAN (%)
1024				
724				
512				
362				
256				
181				
128				
90.5				
64.0				
45.3				
32.0				
22.6				
16.0				
11.3				
8.0				
5.66				
4.00				
2.83				
2.00				
1.40				
1.00				
0.707				
0.500				
0.354				
0.250				
0.177				
0.125				
0.088				
0.063				
<0.063				
	TOTAL			

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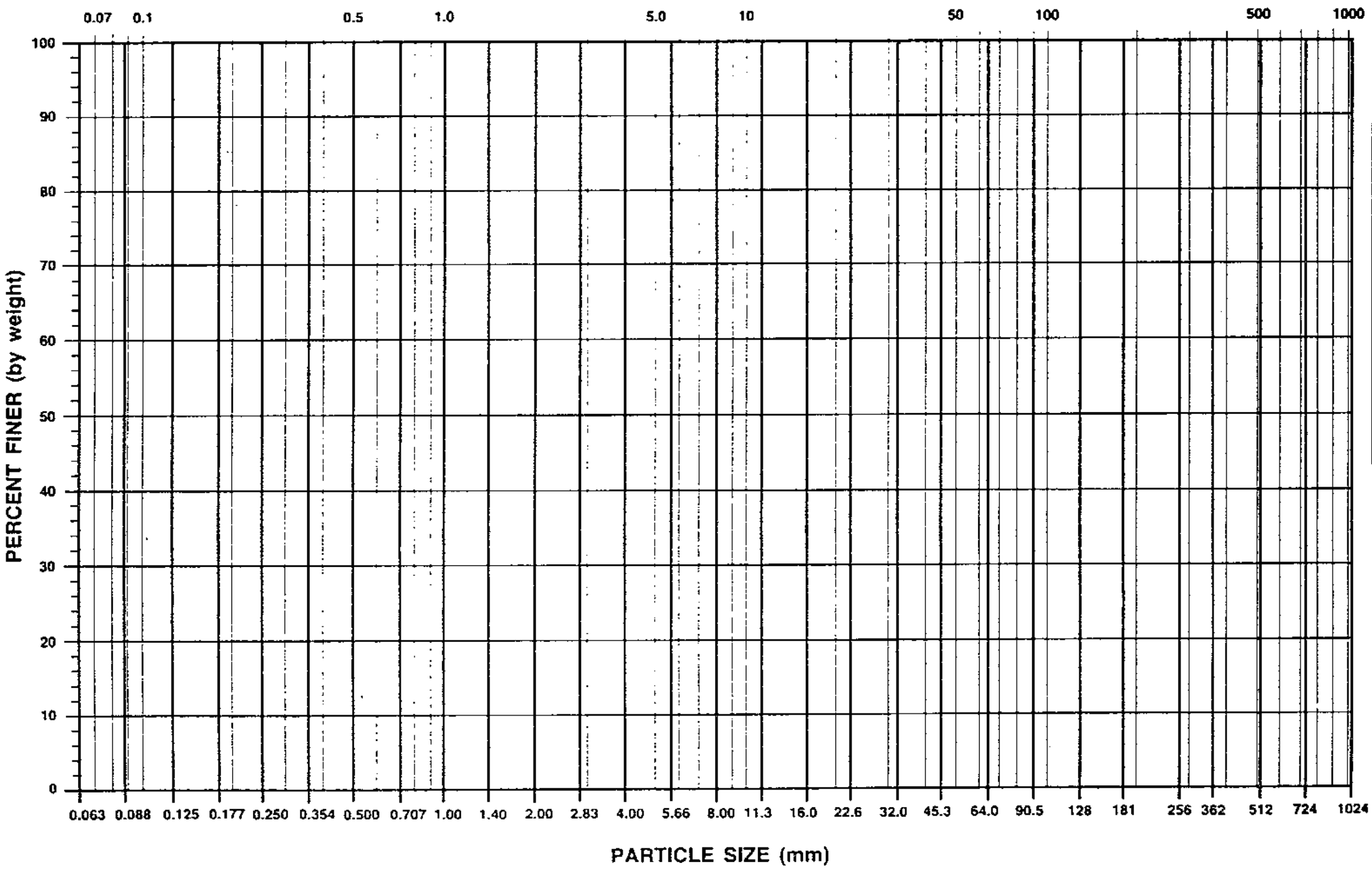
BULK PARTICLE - SIZE DISTRIBUTION

SITE:	DATE:	SAMPLE No.:



CHARACTERISTIC SIZE (mm)	
d_{max}	
d_{90}	
d_{84}	
d_{65}	
d_{50}	
d_{35}	
d_{16}	
d_{10}	
d_{min}	

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APPENDIX B

SAMPLE FORMS:

1. Classification of River Valley Faetures
2. Classification of of Valley Flat and Channel Features

(Refer to Section 3 for use of these forms)

Classification of Valley Flat and Channel Features

Reach Name: ______________________________ Reach No.: ____________

Description of Valley Flat

Prescence:
0 none
1 indefinite
2 fragmentary
3 continuous

Extent:
0 none
1 narrow (<1Ws)
2 moderate (1.5Ws)
3 wide(>5Ws)

Average width: ________
Maximum width: ________
Channel length with valley flat:
on left ________
on right ________

Vegetation:
0 0 not applicable
1 1 almost none or bare
2 2 grass
3 3 shrubs
4 4 sparsely forested
5 5 moderately forested
6 6 heavily forested
7 7 swamp or muskeg

Forest type:
0 0 not applicable
1 1 deciduous
2 2 coniferous

Land Use:
0 0 not cultivated, not built-up
1 1 partly cultivated
2 2 mainly cultivated
3 3 partly built-up
4 4 mainly built-up

Comments: ______________________________
____
____

Channel Description (near long-term mean)

Channel pattern:
1 straight
2 sinuous
3 irregular
4 regular meanders
5 irregular meanders
6 tortuous meanders

Islands:
0 none
1 occasional
2 frequent
3 split
4 braided
5 tumbling flow

Type of flow:
1 uniform water surface
2 uniform with rapids in reach
3 irregular
4 pool & riffle sequence

Bar type:
0 0 0 none
1 1 1 channel side bars
2 2 2 point bars
3 3 3 channel junction bars
4 4 4 mid-channel bars
5 5 5 diamond bars
6 6 6 diagonal bars
7 7 7 sand waves and large dunes

Meander dimensions:
belt width ______ mi.
wave length ______ mi.
sinuosity ________

Natural obstructions:
0 0 none
1 1 logs
2 2 beaver dams
3 3 boulders (lag materials)
4 4 vegetation

Degree of obstruction:
0 0 none
1 1 occasional minor
2 2 occasional major
3 3 frequent minor
4 4 frequent major

Comments: ______________________________

Lateral Channel Activity

Lateral activity:
0 none detectable
1 downstream progression
2 progression & cutoffs
3 main cutoffs
4 entrenched loop devel.
5 irregular lateral activity
6 avulsion

Lateral stability:
0 stable
1 slightly unstable
2 moderately unstable
3 highly unstable

Comments: ______________________________
____
____

Channel Banks and Bed

Alluvial bank material:
0 0 0 no alluvial banks
1 1 1 clay & silt (cohesive)
2 2 2 silt & sand (non-cohesive)
3 3 3 sand & gravel (< 64 mm)
4 4 4 sand to cobbles
5 5 5 sand overlain by silt
6 6 6 gravel overlain by silt
7 7 7 cobbles overlain by silt

Non-alluvial bank material:
0 0 0 alluvial bank material
1 1 1 lacustrine deposits
2 2 2 till
3 3 3 easily erodible rock
4 4 4 moderately erodible rock
5 5 5 resistant rock
6 6 6 boulders

Percentage of left bank in alluvium: ____________
Percentage of right bank in alluvium: ____________

Bank vegetation:
0 none
1 weak
2 good
3 very strong

Predominant bed material:
1 sand
2 sand with local gravel
3 gravel
4 gravel with local sand
5 sand & gravel

Depth of alluvium:
0 no alluvium
1 shallow
2 moderate
3 deep

Estimated depth of alluvium: ____________ ft.

Comments: ______________________________
____
____
____

Bed Rock Below Channel

Prescence of rock outcrops in channel bed:
0 none
1 one occurrence
2 two occurrences
___ ________ occurrences
9 several occurrences

Rock type at channel base:
0 0 0 not applicable (none for great depth)
1 1 1 compact clay
2 2 2 shale
3 3 3 limestone
4 4 4 sandstone
5 5 5 conglomerate
6 6 6 granite
7 7 7 ____________

Erodibility:
0 0 0 not applicable
1 1 1 soft cohesive
2 2 2 easily erodible
3 3 3 moderately erodible
4 4 4 resistant

Comments: ______________________________

Classification of River Valley Features

River Name & Location:______________________________

Reach Name:____________ Reach No.:______ Date of Analysis:________ Analysis by:____________

Scale of Air Photos:______________________ Scale of Maps:______________________

NOTE: Complete codes by circling the appropriate number(s). Use "1" for unknown and "0" for not applicable.

General Description of the Terrain in the Vicinity of the Surveyed Reach, above Valley

Terrain	Vegetation	Forest Type	Land Use	Surficial Geology
1 Mountainous	0 0 0 not applicable	0 0 0 not applicable	0 0 no cultivation or built-up area	1 1 1 bedrock
2 foothills	1 1 1 almost none	1 1 1 deciduous	1 1 partly cultivated	2 2 2 ground moraine
3 uplands	2 2 2 grass	2 2 2 coniferous	2 2 mainly cultivated	3 3 3 hummocky moraine
4 hills	3 3 3 shrubs		3 3 partly built-up	4 4 4 lacustrine deps.
5 plains	4 4 4 sparsely forested, 0-25%		4 4 urbanised	5 5 5 glacio-fluvial
6 lowlands	5 5 5 moderately forested, 25-75%			6 6 6 fluvial deposits
	6 6 6 heavily forested, 75-100%			7 7 7 aeolian deposits
	7 7 7 swamp or muskeg			

Comments:______________________

Valley Characteristics above Valley Flat

Valley measurements:	Slumping of valley walls:	Vegetation on valley wall:	Forest type on valley wall:
_____ within reach	0 none	0 0 not applicable	0 0 not applicable
_____ within reach	1 occasional	1 1 almost none	1 1 deciduous
immediate vicinity	2 frequent	2 2 grass	2 2 coniferous
depth:__________ ft.		3 3 shrubs	
top width:_______ mi.		4 4 sparsely forested	Comment:__________
bottom width:_____ mi.		5 5 moderately forested	

Legth of reach with slumping valley walls
(contact length in % of total length of banks):__________

Terraces

Terrace presence:
0 none
1 indefinite
2 fragmentary
3 continuous

Number of levels:
0 not applicable
1 one level
2 two levels
9 several levels
__ ______ levels

Comments (particularly land use & vegetation):______________________________

Relation of Channel to Valley

Valley type:	If no valley:	Underfit:	Local lateral constriction:
0 not applicable	0 valley present	0 not applicable or not obviously underfit	0 none
1 stream cut valley	1 on alluvial fan	1 obviously underfit	1 one
2 stream cut valley in wide valley	2 on alluvial plain		2 two
3 wide mountainous valley	3 in delta		9 several cases
	4 in old lake		__ _____ cases

Relation of channel to valley bottom (vertical):
0 not applicable
1 not obviously degrading or aggrading
2 partly entrenched
3 entrenched
4 aggrading

Relation of channel to valley walls or to high, resistant terraces (lateral):
0 not applicable (no valley or terraces)
1 occasionally confined
2 frequently confined
3 confined
4 entrenched

Comments:______________________________