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QUANTIFICATION OF STREAM CHANNEL MORPHOLOGICAL FEATURES:

Recommended Procedures For Use In Watershed Analysis and TFW Ambient Monitoring

Prepared by:

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Submitted to:
Northwest Indian Fisheries Commission

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I. INTRODUCTION

Tire detrimental effects of forestry practices in the physical and biological characteristics of forest streams in the Pacific Northwest have been extensively documented for the past 40 to 50 years. Forest management practices (such as road construction-maintenance and usage, harvesting, slash burning, etc.) have effects on channel morphological features because they affect the major input factors controlling channel morphology. These are: water discharge, sediment input, and large woody debris loading. Hydrologists, geomorphologists, and stream ecologists have recognized that streams in forested landscapes of the Pacific Northwest have a limited number of characteristics that respond to any change in these input factors. These characteristics are known as diagnostic features and they have been used by the Washington Forest Practices Board and other private and public agencies as measures to evaluate the impacts of forest management practices in stream channels. The diagnostic features used for watershed analysis are:

- channel morphological type
- pool characteristics
- channel dimensions (width, depth, slope)
- fine sediment in riffles
- surface particle patchiness
- subsurface particle size
- scour depth
- bar characteristics
- pool frequency
- fine sediment in pools
- channel roughness
- channel pattern
- bank erosion
- general aggradation/degradation

The main purpose of this report is to provide guidance for the implementation of monitoring plans that evaluate the effects, of forestry practices in the morphological characteristics of low-order streams in forested landscapes of the Pacific Northwest. The specific objectives of this report are:

- To provide methods to identify and delineate the spatial distribution of channel morphological types within the study area in order to help in the site selection process.

- To provide analysts with guidelines to identify the expected sensitive diagnostic features of specific channel reaches.

- To give detailed description of the data collection and analysis methods used to characterize the sensitive channel diagnostic features.

The monitoring protocols presented in this report will provide very useful data for biological and geomorphological interpretations of low-order streams in forested landscapes in the Pacific Northwest that could be of great value to forest managers. We believe that this monitoring effort will be incomplete until both channel effects and input processes are incorporated into one monitoring program. Knowledge of only the characteristics of a channel section may give very uncertain conclusions about the general condition of a watershed, which could cause costly mistakes during management decision making. The procedures presented in this report use a reach-scale approach to detect trends in the sensitive channel diagnostic features in both a local and a watershed scale. These procedures require setting up monitoring reaches at different locations within the channel network in an attempt to evaluate its spatial variation and average conditions. As implied above, these procedures will be used in conjunction with an input process monitoring protocol which will be available in 1997. This combined approach will allow analysts to make accurate evaluations of the effects of forestry practices in both the input factors and the resulting changes in channel features.

We consider that conducting a watershed analysis before implementing any monitoring plan is crucial in fulfilling the goals of the entire watershed study program. Ideally we would like to monitor the entire landscape and fluvial system, but that is an unfeasible task. This places a big burden on our site selection procedure. A watershed analysis provides the means to identify and locate specific problems in the watershed where monitoring sites should be located. This step is not only crucial in locating good sites to conduct channel monitoring, but it is also very important in fulfilling the goal of improving habitat condition. Monitoring channel characteristics alone will not improve habitat condition. Only through the integration of watershed analysis with hillslope and channel monitoring efforts, will managers and scientists be able to understand the processes affecting channel conditions and confidently implement prescriptions to mitigate their effects.

The procedures presented in this report provide no framework to evaluate data in terms of general channel habitat condition. According to the Stream Channel Assessment Module (WFPB, 1993) there is currently no scientifically-validated channel condition index available that estimates rates of input factors with quantitative channel measures. The multiple factors controlling the morphological characteristics of stream channels are both spatially and temporally variable, and they are very sensitive to local conditions. Only through monitoring of channel morphological characteristics and input processes will it be possible for analysts to understand the precise effects of forestry practices in affecting specific channel conditions. For this reason we believe that the monitoring setup suggested in this report is more useful than a "reference site" type of monitoring based in comparisons between "impacted" and "non-impacted" channels.

How to use these guidelines

The monitoring methodology presented in this report is based on the following assumption. Given a specific change in one or more of the input factors, all channels belonging to the same morphological type (as described by Montgomery and Buffington, 1993) will suffer similar responses in their diagnostic features. By similar responses it should be understood that the diagnostic features are expected to have similar trend directions, but this does not imply that the magnitude of change will be the same.

The procedure recommended by the monitoring methodology presented in this report follows these steps:

1) Identification and delineation of the distribution of morphological unit types within the channel network.

2) Selection of segment to be monitored and delineation of specific reach boundaries.

3) Recognition of the input factors affecting the conditions of the selected reaches.

4) Identification of the diagnostic features expected to respond to specific changes in input factors for the selected reaches.

5) Selection of the methods which will he used to characterize the sensitive diagnostic features.

6) Data collection and analysis.

This report provides guidelines for all of the steps mentioned above except for Step 3. Steps 1, 2, and 4 are discussed in Section II and Steps 5-6 are discussed in Section III. If a watershed analysis has been conducted in the study area using the procedures recommended by the WFPB (1993) guidelines, the analyst should use this data and analysis to complete steps 1 through 3. If no watershed analysis has been conducted we strongly recommend conducting at least a low level analysis before commencing with the monitoring effort in order to identify the locations where specific changes in input [’actors have affected channel conditions.

II. SEGMENT DELINEATION AND STUDY REACH SELECTION

The segment delineation and reach selection procedure generally follow the guidelines suggested in the Stream Channel Module (WFPB, 1993) and the Stream Segment Identification Module in the TFW Ambient Monitoring Manual (Schuett-Hames et al., 1994). The main objective of this section is to determine the distribution of morphological types within the study area and to provide a procedure that considers the project objectives when selecting the location of reaches to be monitored.

II.A. SEGMENT DELINEATION

The purpose of this step is to be able to locate segments within a watershed in a way that data collected from them can be useful for resource managers, and at the same time maintains requirements needed for geomorphic analysis. The specific objective of this section is to identify the distribution of morphological channel types found within the stream network from topographical map analysis and field visits.

It is important to point out the limitations of the topographical map analysis. Channel type delineation made from topographical maps only indicates the locations of expected channel types according to general tendencies of fluvial systems. Montgomery and Buffington (1993) discuss that stream gradient and confinement play a very important role in controlling channel morphological features. The accuracy of stream gradients and confinement measurements taken from topographic maps are usually not very reliable. Stream gradients are typically not accurately portrayed in topographic maps, so the results from this analysis should not be taken as final. Also, other very important factors (such as large woody debris loading) which play a crucial role controlling channel morphological type cannot be considered in the topographic map analysis. Even though field visits are essential in verifying the channel type of specific segments, most of the time the entire fluvial system cannot be visited. The topographic map approach, though, allows us to have a general idea of the distribution of expected channel types in the watershed.

II.A.1 Topographical Map Analysis Procedure

a) Determine stream gradients from topographical maps. Break the channel network into segments based on six gradient categories (See below). For a section to be selected as a segment, its gradient has to be consistent for at least three consecutive contours or be continuous for at least 300 meters. A digital map wheel is very useful in this part of the analysis.

[Note: Use of computer calculated stream gradients from digital elevation data significantly decreases the time needed to complete this step, but the procedure requires very complicated computer skills that are beyond the scope of this report. Government agencies in the State of Washington are currently trying to produce digitized maps of the entire state which might be available for public use within the next few years (Schuett-Hames, personal, comm.).]

The gradient categories are:

Categories	Range of Gradients (%)
1	less than 1
2	1-2
3	2-4
4	4-8
5	8-20
	greater than 20

h) Record the length of each segment and label each with a number. Start numbering at the downstream end of the channel network and work your way upstream. Whenever a junctions are encountered continue up the tributary on the right until the end of the channel is reached. Once that point is reached, continue numbering upstream from the last junction encountered and follow the same procedure.

c) Determine channel confinement from maps, aerial photos, and knowledge of the channel network. Place each segment in one of three categories: confined, moderately confined, and unconfined. Channel confinement is defined as the ratio of valley width to channel width at bankfull (See Appendix B for a description of bankfull). Channel confinement is determined by choosing several points within a segment where these two measurements can be taken or estimated. Classify channel confinement in one of the following categories:

Unconfined	Confinement greater than 4
Moderately Confined	Confinement less than 2 but greater than 4
Confined	Confinement less than 2

d) Label each segment with the following format:

segment number (gradient category confinement category) I

For example if segment number five has a gradient of 2-4% and is moderately confined, its label should read like this: 5 (3, MC).

e) Tabulate segment numbers into Form E-I in the Stream Channel Assessment Module (Shown as Figure I in this report) and identify channel type and response potential of each segment.

f) Sum up the lengths of all the segments within each category. Determine proportions of each channel type within the watershed and prepare histograms of frequency of occurrence. Do the same for channel response potential.

g) Prepare maps delineating the location of the different channel types and segment response potential within the channel network.

II.A.2 Field Analysis Procedure

Field check specific segments to determine their channel types and response potential. Obviously not all of the segments will be field checked and guidance in how to choose those segments to be visited will be based according to the goals of the monitoring effort. We recommend visiting at least 10-25 percent of the entire length of the channel network. When selecting segments to be visited follow the same criteria as selecting segments for monitoring (described in section if-B). Field check consists in measuring gradient, determining confinement and identifying the morphological types of different sections of the channel.

Channel gradient can be measured by two operators using a hand level, a rod, and a measuring tape. The eye elevation of the cooperator using the hand level (LO) must have. been .previously determined (See Habitat Unit Survey Module-TFW Ambient Monitoring Manual- pages 5-6). LO should stand in the middle of channel holding the zero end of the measuring tape. The rod operator (RO) should walk upstream stretching the measuring tape along the center line of the stream. Sightings should be shot over a length of about 15-20 channel widths (generally, gradients shot at distances shorter than 15 to 20 channel widths tend to overestimate the average slope of the entire reach). Both cooperators should stand in the thalweg of the channel and at a Similar morphological location. Riffle crests are good locations, but other units also provide good measurements. The (RO) reads the distance from the level to the rod. The LO sights the rod and takes a reading. Gradient is calculated by the following formula:

$$\text{Gradient} = (\text{eye level} - \text{rod reading}) / \text{distance} \qquad \text{(eq. 1)}$$

Most of the time no confinement measurements have to be taken because the confinement categories are very broad and easy to recognize. Generally, unconfined channels refer to channels with an extensive floodplain. Moderately confined channels typically have a small floodplain that measures about 4 channel widths across (from valley wall to valley wall). Confined channels have no floodplain and they can transport all of the discharge from even the most extreme storm events without overflowing. If an analyst still desires to measure confinement, the following three step procedure should be followed at several different sections of the channel. First, measure the width of the channel from bankfull to bankfull with a measuring tape or a rod (See Appendix F for a definition of bankfull). Second, measure tile distance from valley wall to valley wall, making sure that the tape lies perpendicular to the channel general direction. Third, calculate confinement by dividing valley width by channel width and classify the segment according to the guidelines shown above.

For each individual section in which gradient and confinement have been determined the operator should take notes on the following features:

- dominant particle size
- general idea of type and frequency of some morphological units (pools and bars)
- general idea of number and effectiveness of large woody debris
- stream bank composition

Once all of the features have been identified use Table I to determine the channel type. This is best done out on the field while looking at the segment. Table I should only be considered as a guide for experienced analysts to identify channel morphological type. For analysts with no experience identifying channel types we recommend reading the paper by Montgomery and Buffington (1993) in which they give detailed descriptions and show examples of each type. Field visits with experienced analysts could also be very instructive.

Segments should be delineated in the field according to their channel morphological characteristics. Differences in channel morphological features should be noted and located in the map even if they are not causing a change in channel morphological type. Examples of these subtle differences that should be considered are changes in pool or bar frequency and size, channel width and depth, and changes in dominant particle size. These differences may be a response to different topographical characteristics of the channel (slope or confinement), but they can also be caused by differences in channel input factors (sediment and large woody debris loading, and water discharge). Most of the morphological changes are gradational and the analysts must use their judgment in identifying channel type boundaries, but much time should not be spent in trying to pin*point the location of these boundaries. Analysts should only identify these sections of the channel as separate segments if they are continuous for more than 300 m.

Locating a section of a stream while standing inside a channel is sometimes a very difficult task. In order to help solve this problem we suggest the following. Accurately locate the point of entry into the stream. Start taking confinement and gradient measurements following the methods described above. Once measurements are taken on a reach, the cooperator with the hand level should move to the location where the rod was last positioned. Stretch the tape upstream again and take another set of gradient measurements. In this way a record of the length of channel that has been covered is kept and segment boundaries can be plotted more precisely on the map.

Once the field visit has been completed the analysts need to make any necessary changes to the map prepared from topographical data. There is no need to renumber the entire channel network. You may change numbered segment boundaries as needed or you may lump segments with different numbers into one segment. Calculate an average gradient for each segment. Determine proportions of each channel type within the watershed by preparing histograms of frequency of occurrence. Do the same for channel response potential.

We suggest using a format similar to Field Form A to collect all of the data necessary to complete this section.

Table 1. Table showing the morphological characteristics of different alluvial channel types (from Montgomery and Buffington, 1993).

Channel Type	Slope	Flow	Confinement	Width-Depth ratio	Textural Organization	Rougness ratio (D84/bfull depth)	Dominant particle size	Bed armoring	Bank material	Bed Morphology
Cascade	0.04-0.20	strongly 3-D	confined	small	disorganized	high (>1)	boulders & cobbles	yes	bedrock-alluvial	-pools span a portion of channel width; pool frequency <1 -no riffles; no bars; pockets are fairly common
Step-Pool	0.02-0.08	primarily vertical	confined	small	large clasts in steps; fines in pools	high (close to 1)	boulders & cobbles	yes	bedrock-alluvial	-pools are separated by steps; pool frequency 1-4 -bars and riffles are unlikely -steps provide most of the elevation drop and roughness
Plane bed	0.01-0.04	weak lateral component	variable	small	heterogeneous grains in a homotextural bed	high to intermediate	gravel & cobbles	variable	alluvial	-variable pool size; pool spacing may range from 3-13 (10-13 most common) -planar channel bed predominates -some channel spanning rapids may be observed -bars, riffles, and glides are common
Pool-riffle	0.001-0.04	strong lateral component	unconfined		heterogeneous beds: bars & riffles in gravels; pools dominated by fines	intermediate	gravel & cobbles	yes	alluvial	-varied pool size; pool spacing for free-formed channels- 3-7; pool spacing forced pool riffle channels- <1-4. (Montgomery et al., 1995) -channel spanning riffles common -bars, glides and tailouts are commonly observed
Dune-ripple	<0.001	weak lateral component	unconfined	large	well sorted	small	sand	poorly armored	alluvial	-pools size varied; pool frequency 5-7 -bars and riffles may be observed

Field Form A.

Date: ________________ Stream Name: ________________ Reach Location: ________________ Location of Access Point: ________________

Name of RO ________________ Name of LO ________________ Eye level of LO 1.60 m

Segment Id #	Dist. LO-RO (m)	Net dist. (km)	Rod Reading (m)	Gradient (%)	Confinement	Surface Particle Size	# forced pools	# natural pools	# point bars	# other bars	# LWD pieces	# Debris Jams	Bank Composition	Tributary Location	Other Features	Channel type
24	100	0.6-1.6	1.00	0.6	unconfined	grav-fines	II	IIIIII	IIIII	II	IIII	0	85% alluvial; 15%bedrock	n/a	culvert @ rb-1.7 km	pool-riffle
24	85	1.6-2.45	1.00	0.7	unconfined	grav-fines	III	IIII	IIIII	I	IIIII	0	80% alluvial; 15% bedrock	left bank @ 2.55km	skid trail @ rb-2.65km	pool-riffle
25	95	2.45-3.4	.95	0.7	unconfined	grav-fines	IIIIII	III	IIIII	I	IIIIIIII	0	85% alluvial; 15% bedrock	n/a	n/a	forced pool-riffle

Dist. LO-RO refers to the distance from the hand level to the rod while taking gradient measurements.

Net distance refers to the distance along the channel where gradient measurements are being taken and where all of the features are being identified.

Surface particle size refers to the dominant and subdominant particle sizes found on the streambed. Care should be taken in order to include areas below and above the current active channel area. Refer to the Surface Particle Size Section for an indication of the range of sediment sizes for each size category.

forced pools refers to the number of pools found within the surveyed area that appear to occur due to the presence of large woody debris or any type of obstruction. See Appendix B for a description on how to identify a forced pool.

#natural pools refers to The total number of naturally occuring pools found within the surveyed area. See Appendix B for a description on how to identify naturally occuring pools.

point bars refers to the number of naturally occuring point bars found within the surveyed area. See Appendix B for a description on how to identify naturally occuring point bars.

other bars refers to: mid-channel bars, bars formed due to the presence of obstructions, and bars found on the outside of meander bends. See Appendix B for a description on how to identify these types of bars.

LWD pieces refers to the number of LWD pieces found in the channel below bankfull. At this point there is no need to categorize the pieces by size, but pieces should be larger than the minimum size requirements discussed in the Large Woody Debris Section.

Bank Composition refers to the dominant and subdominant composition of the stream banks. For the purposes of this step it is enough to identify the percent of the bank area in alluvial and bedrock material.

Tributary location column identities any tributary found along the channel Analysts should identify two things: 1) the distance along the channel where the tributary is located; and 2) the side of the channel where it is found.

Other features refers to roads, culverts, bridges, skid trails, etc. found along the channel. Identify on what side the feature is located (right bank, left bank, or spanning the channel) and the distance where it is located.

Channel type- use the data collected in this form together with information provided in Table ! to identify the morphological type of the channel.

II.B. SELECTION OF SEGMENTS FOIl MONITORING

As geomorphologists we consider that even though analysis of important resource segments is valuable, the analysis should also consider other areas of the fluvial network. We should not forget that the stream channel network is a system in which all of its components are interconnected and any change in one component of the system may cause changes in some or all of them. The fluvial system is a continuum in which not only changes in the factors controlling direct input from hillslopes affect the conditions in a section of a channel, but also changes in channel conditions upstream and even downstream may have considerable effects in channel characteristics. Obviously the whole river network cannot be monitored. A segment selection protocol should provide a systematic method to select sections and reaches so that our hypothesis can be extended beyond our reach boundaries. Given the fact that economic and human resources pose limits on the total area covered by the monitoring effort, a very detailed study that spans a considerable portion of the fluvial system is very unlikely. Because of these limitations we recommend that the monitoring effort should concentrate efforts in reaches that are very sensitive to changes in the input factors and at the same time have an important resource value. Generally, we consider following this criteria when selecting sites to be analyzed (criteria are in order of importance):

a) segments likely to respond significantly to changes in specific input factors
b) segments of known resource importance
c) number of segments of a given type
d) representative physiographic and geologic areas of watershed
e) segments subject to inputs from hillslope hazards

As previously stated, the segment select[on process will vary according to the goals of the monitoring effort. It is recommended that if a watershed analysis has been conducted in the area, monitoring cooperators should review the report and contact the analysts in order to choose the best sites for monitoring. The site selection guidelines in ibis report are very general and they allow some flexibility in choosing segments. This is done on purpose because there is a large number of different situations that could be encountered by the cooperators which would require an enormous amount of different selection procedures. This lack of rigidity allows the team to consider factors such as: access, ownership boundaries, disturbance of habitat activity, etc. We have recognized two main general objectives of an? stream channel monitoring effort:

1) Monitoring only response reaches with resource importance

For this approach at least 10% of all response reaches should be monitored. We suggest using the following criteria during selection (in order of utility):

a) select segments most likely to respond to input factors

b) locate response segments with resource importance

2) Monitoring all segment types with emphasis on important resource areas

For this approach we suggest modifying the order of segment selection criteria presented in the Stream Channel Assessment Module (WFPB, 1993). We suggest using the following criteria (in order of importance):

a) at least 5-10% of the total length of each channel morphological type should be monitored

b) wherever possible, monitor segments with some resource importance

II.C REACH SELECTION

Once a segment has been selected we are ready to select the monitoring reach. A *reach* is defined as a section of a segment with a length of at least 20 to 30 channel widths. If a segment is longer than this minimum requirement only a portion of it will be monitored. If your goal is to monitor response reaches with resource importance then follow the indications presented in the Salmonid Spawning Gravel Composition Module (TFW, 1994). This criteria is based mostly in finding reaches with a large number of riffle crests or gravel patches so that enough subsurface streambed samples can be taken to satisfy minimum sampling requirements.

If your objective is to get an overall picture of the condition of the channel then follow these three simple criteria:

„ Try to select the reach so that it incorporates most of the variability of channel characteristics existing in the segment.

· Make sure that permanent benchmarks can he placed at some distance from the channel on both upstream and downstream ends of reach.

„ Consider the distance from access point(s).

Delineation of reach boundaries takes place in the field, but before conducting your field visit you should have a general idea of where you would prefer your reach to be located. Observations made during watershed analysis or during the field analysis component of the Segment Delineation Section (Section II.A of this report) can be used at this point. Once a section has been selected analysts are ready to identify the diagnostic features to be monitored.

II.D iDENTIFICATION OF DIAGNOSTIC FEATURES

Before proceeding with this section analysts must have knowledge of:

· reach channel type

· which input factors have been affected by forest practices to a degree that they have caused changes in channel morphological features

Identification of channel diagnostic features to be monitored is very simple and it only requires the use of Tables 2a 2c.

· If' changes in sediment input are expected, use Table 2a.

· If changes in discharge are expected use Table 2b.

· If changes in large woody debris loading are expected, use Table 2c.

In many situations a combination of two or even three factors may be affecting channel condition. In those cases use Tables 2a-2c to identify all diagnostic features that may respond to all of the changes and monitor all of them. To use these tables locate the respective reach channel type column in the table and identify which diagnostic features are sensitive to the expected input factor.

There are two different ways to use Tables 2a-2c:

1) Use the five category system shown in the tables as follows:

· Features with a "+ +" are considered to be very sensitive and the related variables are expected to increase in value. These features should receive priority in the monitoring effort and they should be monitored by at least Level B methods.

· Features with a "+" are not very sensitive to the input factor and if they respond at all, they are expected to increase in value. These features should be initially monitored by Level A methods and if after several years of monitoring significant changes arc detected, the intensity of the effort should increase to at least Level B methods.

· Features with a "0" are not expected to respond to changes in input factors and we recommend that no time should be spent monitoring these features.

· Features with a "-" are not very sensitive to the input factor and if they respond at all, they are expected to decrease in value. These features should be initially monitored by Level A methods and if after several years of monitoring significant changes are detected, the intensity of the effort should increase to at least Level B methods.

· Features with a "- -" are considered to be very sensitive and the related variables are expected to decrease in value. These features should receive priority in the monitoring effort and they should be monitored by at least Level B methods.

[Note: To keep this procedure as simple as possible we decided to make the following assumption: values of tile diagnostic features in the tables can be reversed if the change in the input factor is in the negative direction. For example, if a if a particular diagnostic feature is identified by a "++" (meaning that it is very sensitive and its value is expected to increase) due to increases in LWD loading, the feature should be assigned a "- -" if LWD loading decreases. Even if this assumption is not valid for all cases it should not affect this procedure. The main purpose of' this procedure is to identify the sensitive diagnostic features for each channel type. Most likely the diagnostic features sensitive to specific input factors should not vary even if changes in the in put factors are in opposite directions.]

2) Simplify the categories found in the table into two groups:

· Features that are expected to respond- Features identified by a "++", "+", "- -', or a "-" fall into this category,

· Features that are not expected to respond- Identified by a "0'.

When using this approach analysts should :get up levels of effort on a sliding frame. That is, analysts should initially monitor all features that are expected to respond with Level A methods to determine which features are showing the most response in that particular reach. The monitoring effort should then concentrate on those features by increasing their level of effort. It is up to the analysts if they want to keep monitoring with Level A methods those features that appear to be showing no response to the changes in the input factors, or if they want to eliminate them from the monitoring effort.

Once the diagnostic features that will be monitored have been identified, analysts are ready to identify measuring methods (and levels of effort). Detailed descriptions of these methods are shown in Section ill

Table 2a. Channel responses to increases in sediment input.

Diagnostic Features	Cascade	Step-Pool	Plane bed	Pool-Riffle	Dune-ripple
gravel bar area-volume	n/a	n/a	+	++	+
pool area-volume	- - (where present)	- -	n/a	- -	-
pool frequency	0	0	n/a	0	0
channel width	-	- (when unconfined)	++	++	++
channel depth	-	-	- -	- -	- -
channel slope	+	++	+	++	++
fine sediment in pools	++	++	n/a	++	+
fine sediment within riffles	n/a	n/a	+	++	+
channel roughness	-	- -	-	- -	-
bed roughness ratio	-	-	-	- -	-
surface particle size	-	-	-	- -	-
surface particle patchiness	++	++		+	0
channel pattern (sinuosity)	0	0	+	+	+
bank erosion	+	+	++	++	++
scour depth	0	+	+	++	+

Table 2b. Channel response to increases in discharge.

Diagnostic Features	Cascade	Step-Pool	Plane bed	Pool-Riffle	Dune-ripple
gravel bar area-volume	n/a	n/a	n/a	+	+
poo1 area-volume		++	n/a	++	++
pool frequency		+	n/a	+	+
channel width	0	- (+ if unconfined)	++	++	++
channel depth	0	+	+	+	+
channel slope		....			
fine sediment in pools	- - (where present)	..	n/a	..	
fine sediment within fifties	n/a	n/a		..	
channel roughness	+	++	++	++	++
bed roughness ratio	+	+	++	++	++
surface particle size	+	+	+	++	+
surface particle patchiness					0
channel pattern (sinuosity)	0	0	+	+	+
bank erosion	0	0	++	++	++
scour depth	0	+	++	++	+

++ expected increase
+ possible increase
0 changes unlikely
possible decrease
\- expected decrease

Table 2c. Channel response to increases in LWD loading.

Diagnostic Features	Cascade	Step-Pool	Plane bed	Pool-Riffle	Dune-ripple
channel type	forced step-pool	forced step-pool	forced pool-riffle	forced pool-riffle	
gravel bar area-volume	+	+	+	++	++
pool area-volume	++	++	++	++	++
pool frequency	++	++	++	++	++
channel width	0	++ or 0*	++ or 0*	++ or 0*	++ or 0*
channel depth	0	+	+	+	+
channel slope	-	-	-	-	-
fine sediment in pools	+	+	+	+	+
fine sediment within riffles	n/a	n/a	+	+	+
channel roughness	++	++	++	++	++
bed roughness ratio	-	-	-	-	-
surface particle size	-	-	--	--	--
surface particle patchiness	+	+	++	+	++
channel pattern (sinuosity)	0	+ or 0*	+ or 0*	+ or 0*	+ or 0*
bank erosion	0	++ or --*	++ or --*	++ or --*	++ or --*
scour depth	0	+	+	+	+

++ expected increase
\+ possible increase
0 changes unlikely
\- possible decrease
-- expected decrease
* Channel effect depends on position of LWD in respect with the flow and the stream banks and channel confinement. If LWD pieces are casuing flow convergence towards the banks erosion will occur, channel widening may occur, sinuosity can increase causing a decrease in channel slope. If LWD pieces are lying adjacent and parallel to banks they will protect the banks from erosion and prevent channel migration. Unconfined channels may respond, while confined channels will not.

III. DATA COLLECTION AND ANALYSIS OF CHANNEL DIAGNOSTIC FEATURES

Once the analysts have completed the tasks required for Section II of this report (Segment Delineation and Monitoring Reach Selection) they are ready to identify which methods are going to be used to collect the data. This section has two main objectives. First, to serve as a guide for analysts to identify the data collection methods to be implemented. Second, to provide detailed descriptions of the data collection methods and analysis procedures recommended in this report.

As shown in Table 3, for most diagnostic features there are several different ways to collect the data. These different options are called *levels* and they have no direct relationship with levels 1 and 2 presented in the Stream Channel Assessment Module (WFPB, 1993). Level A methods provide a simple way to collect data with a low level of accuracy. Level B methods require more effort but they produce higher accuracy and increased confidence in the results. Level C methods produce very accurate results, but they require either the use of very expensive equipment or a higher level of effort by analysts. This higher level of effort is due to either increased training requirements and/or increases in the time required to install the equipment or to collect the data.

The method chosen by the analysts depends on the following: a) the sensitivity of the particular diagnostic feature; b) the accuracy requirements of the monitoring effort; and c) the limitations of the monitoring team. Table 3 and the descriptions of the individual methods presented in this section will help analysts decide which data collection methods are more appropriate for their needs and limitations.

The first step analysts should follow when they are ready to select the data collection methods is to refer to Table 3 to have a general idea of the requirements and capabilities of each of the recommended methods. This table was prepared using the following format In each ceil there are several items identified by a number and a letter from "a" to *"d"*. Items in a cell with the same number refer to the same data collection method. Items with the letter *'a"* identify the name of the method being recommended for that specific level, while "*b"* refers to the names of the variables that can be evaluated by the method. Letter *'c"* refers to the expected accuracy of the methods, Most of the methods presented in this report have not been thoroughly evaluated by statistical analysis and the exact accuracy of the procedures are unknown. Those that have been evaluated by previous studies will be identified in Table 3 by an asterisk (*). Other methods will show expected performance of the methods according to literature reviews, interviews with practitioners, and the expected performance of the method in capturing the typical spatial variability of the features being measured. Finally, items with the letter *'d"* present estimates of the amount of time needed to complete collecting the field data.

Most of the changes in channel morphological characteristics in the Pacific Northwest occur during the wet winter months. During this time peak flows commonly match or surpass bankfull conditions. These changes typically last over the entire dry summer season. This is a very important reason why we suggest collecting field data during summer low flow conditions. Collecting data during this time of the year also provides other advantages:

Table 3. Brief description of the methods and variables used to quantify channel diagnostic features at three different levels of effort.

Diagnostic Features	Level A	Level B	Level C
channel type	1a) channel type field observations guided by Field Form A 1b) n/a 1c) n/a 1d) about one hour for entire reach	no methods for Level B	no methods for Level C
bar area	1a) planform analysis-visual estimation of bar area 1b) bar area, % channel area in bars 1c) fair quantification bar area; subject to strong operator bias in delineating bar boundaries and in visually estimating the % area covered by them 1d) 5-10 min. for every 10 m section (depending on morphological unit boundary identification method used-See Section B)	1a) planform analysis-determination of bar boundaries and measurement of bar area by approximating its shape to regular geometric shapes 1b) bar area, % channel area in bars 1c) good quantification of bar area-subject to some operator bias in delineating bar boundaries 1d) 10-15 min. for every 10 m section (depending on morphological unit boundary identification method used-See Section B) 2a) aerial photographs- determination of bar boundaries and measurement of bar area 2b) area in bars, % channel area in bars 2c) fair quantification of bar area-subject to limitations of aerial photographs and bias due to the flow dependency of the measurements	1a) planform analysis-determination of bar boundaries; measurement of bar area and planform map preparation 1b) bar area, % channel area in bars 1c) excellent quantification of bar area-subject to some operator bias in delineating bar boundaries and in drawing them in the map 1d) 5-10 min. for every 10 m section (depending on morphological unit boundary identification method used-See Section B)
bar volume	not possible with Level A planform analysis and surveying	1a) planform analysis together with bar top readings taken during long profile surveying 1b) gravel bar volume, agg/degradation of bars 1c) fair measurement of bar volume	1a) planform map together with bar top readings taken during long profile surveying 1b) gravel bar volume, agg/degradation of bars 1c) good measurement of bar volume
pool area	1a) planform analysis- visual estimation of channel area covered by pools 1b) pool area, % channel area in pools 1c) fair quantification; subject to strong operator bias in delineating pool boundaries and in visually estimating the % area covered by them 1d) same as bar area	1a) planform analysis-determination of pool boundaries and measurement of pool area by approximating its shape to regular geometric shapes 1b) pool area, % channel area in pools 1c) good quantification of pool area; subject to some operator bias in delineating boundaries 1d) same as bar area	1a) planform analysis- determination of pool boundaries, measurement of pool area, and planform map preparation 1b) pool area, % channel are in pools 1c) excellent quantification of pool area; subject to some operator bias in delineating pool boundaries and in drawing them in the map 1d) same as bar area
pool volume	1a) Level A pool area planform analysis together with residual depth readings taken during long profile surveying 1b) pool volume, agg/deg of pools, changes in residual depth 1c) poor estimation of pool volume based on residual depth and estimated pool area	1a) Level B pool area planform analysis together with residual depth readings taken during long profile surveying 1b) pool volume, agg/deg of pools, changes in residual depth 1c) fair estimation of pool volume based on residual depth and measured pool area	1a) Level C planform analysis together with residual depth readings taken during tlong profile surveying 1b) pool volume, agg/degradation of pools, changes in residual depth 1c) good estimation of pool volume based on residual depth and measured pool area 2a) V* measurements 2b) pool volume, volume of fine sediment, V*, detailed pool topography 2c) excellent determination of pool volume
pool frequency	1a) Levels A, B, and C planform analysis-determination of pool boundaries 1b) total number of pools, number of pools per channel width, number of channel widths per pool (these variables can be stratified by naturally occuring pools and forced pools) 1c) good estimation of pool frequency s	no methods for Level B	no methods for Level C

a) refers to the methods used to measure the diagnostic features; b) to the variables that can be used for analysis of the data; c) briefly discusses the relative accuracy and/or precision of the methods; d) time estimates to complete measurements

Table 3 (cont.).

Diagnostic Features	Level A	Level B	Level C
channel width	1a) Level A cross section surveying 1b) width of active channel, bankfull width 1c) excellent estimator of individual cross section width; fair estimator of reach mean width and variability 1d) about 10-15 min. measuring each x-sect 2a) Level A and B planform analysis 2b) bankfull width 2c) good estimator of mean channel bankfull width and variablity based on actual field measurements taken at 10 m intervals 2d) few minutes for each 10 m interval	1a) Level B cross section surveying 1b) width of active channel, bankfull width 1c) excellent estimator of individual cross section width; good estimator of reach mean width and variability 1d) about 10-15 min. measuring each x-sect	1a) Level C cross section surveying 1b) width of active channel, bankfull width 1c) excellent estimator of individual cross section width; excellent estimator of reach mean width and variability 1d) about 10-15 min. measuring each x-sect 2a) Level C planform analysis 2b) bankfull width, active channel width 2c) excellent estimator of mean bankfull and active channel widhts based on actual field measurements (taken every 10 m) which are drawn in map; excellent estimator of variablity in channel width 2d) 10-15 min. for every 10 m section
channel depth	1a) Level A cross section surveying 1b) bankfull depth = area below bankfull/ bankfull width 1c) excellent esimator of individual cross-section channel depth; fair estimator of reach mean depth and variability 1d) about 10-15 min. measuring each x-sect	1a) Level B cross section surveying 1b) bankfull depth = area below bankfull/ bankfull width 1c) excellent estimator of individual cross-section channel depth; good estimator of reach mean depth and variability 1d) about 10-15 min. measuring each x-sect	1a) Level C cross section surveying 1b) bankfull depth = area below bankfull/ bankfull width 1c) excellent esimator of individual cross-section channel depth; excellent estimator of reach mean depth and variability 1d) about 10-15 min. measuring each x-sect
channel slope	1a) long profile surveying 1b) mean slope along thalweg, mean slope along water surface 1c) excellent estimator of channel slope 1d) about 2-3 days (includes channel gradient and cross section surveying)	1a) long profile surveying 1b) mean slope along thalweg, water surface, bankfull, terraces, and bar tops; slope within specific morphological units 1c) excellent estimator of channel slope 1d) about 2-3 days (includes channel gradient and cross section surveying)	1a) long profile surveying with high precision instruments (transit or laser surveying equipment) 1b) mean slope along thalweg, water surface, bankfull, terraces, and bar tops; slope within specific morphological units 1c) excellent estimator of channel slope 1d) about 2-3 days (includes channel gradient and cross section surveying)
fine sediment in pools	1a) determination of fine sed. in pools-Level A 1b) area of pools covered by fine sediment- based on visual estimates of the amount of fine material lying on the bottom of pools 1c) poor estimator of the amount of fine material in pools 1d) few minutes for every 10 m section	no Level B methods available	1a) V* methods 1b) V*, volume of fine sediment on pool bottom 1c) excellent determination of the amount of fine material in pools
fine sediment in stream gravels	1a) surface particle size determination-visual estimates 1b) determination of dominant and subdominant particle sizes within every 10 m interval 1c) very poor estimator of fine sediment on the surface 1d) few minutes for every 10 m section	1a) surface particle size determination- reach averaged grid-sampling pebble count 1b) determination of reach averaged particle size based on grid sampling with pebble count method on long sections of stream 1c) poor determination of fine sediment deposition on the surface of the streambed 1d) about 20 minutes for every pebble count	1a) surface particle size determination- calibration of facies units by pebble counts 1b) determination of surface particle size characteristics (median size, cummulative frequency curves, % fine material) of individual facies units based on several pebble count calibrations; to determine the surface particle size characteristics of riffles this method has to be combined by a Level C planform analysis 1c) fair determination of fine sediment deposition 2a) subsurface particle size determination (based on TFW Ambient Monitoring Manual- Spawning Habitat Module) 2b) percent fine sediment, median size, cummulative frequency curves 2c) good determination of the subsurface particle size characteristics of riffle crests

Table 3 (cont.).

Diagnostic Features	Level A	Level B	Level C
channel roughness- channel morphology	1a) Level A, B, or C long profile surveying 1b) channel roughness is calculated by adding the net values of the residuals of the best fit line plotted on the thalweg surveying data 1c) fair determination of channel morphology roughness because it only considers the thalweg (bars and other features are neglected) 1d) see channel slope	no level B methods	no level C methods
channel roughness- large woody debris	1a) LWD count 1b) number of lwd pieces per channel width is determined by counting the number of pieces within every 10 m interval; relationship of lwd pieces with morphological units is possible 1c) good determination of the number of lwd pieces; good determination of the relationship of obstructions with morphological units is possible; no volumetric estimates of lwd possible 1d) 5-10 minutes for every 10 m section	1a) LWD count and size determination 1b) number of pieces per channel width; lwd count can be stratified by size and by general bearing relative to banks; volume of lwd pieces by channel width; relationship of lwd pieces with morphological units is possible 1c) good determination of the number and volume of lwd pieces; fair relationship determination with morphological units 1d) about 10-15 minutes for every 10 m section	1a) LWD count and size determination; individual pieces located in map 1b) number of pieces per channel width; lwd count can be stratified by size and by general bearing relative to streambanks; volume of lwd pieces by channel width; relationship of lwd pieces with morphological units 1c) good determination of the number and volume of lwd pieces; excellent determination of the relationship with morphological units 1d) about 10-15 minutes for every 10 m section
channel roughness- other obstructions	1a) Level A planform analysis- count of number of obstructions- boulders, debris dams, beaver dams, etc 1b) number of obstructions per channel width- stratified by type; relationship of obstructions with morphological units is possible 1c) good determination of the number of obstructions; fair relationship of obstructions with morphological units 1d) about 5-10 minutes for every 10 m section	1a) Level B planform analysis- count of number of obstructions; visual estimate of obstruction size 1b) number of obstructions per channel width; relationship of obstructions with morphological units is possible; area covered by obstrucions; volumetric estimate of obstructions in channel is possible 1c) good determination of the number of obstructions; fair relationship of obstructions with morphological units; fair estimation of the volume of obstructions in channel 1d) about 10 minutes for every 10 m section	1a) Level C planform analysis- count of number of obstructions; measurement of obstruction size; obstructions are located in planform map 1b) number of obstructions per channel width; volumetric relationship of obstructions with specific morphological and facies units is possible; area covered by obstructions; volumetric estimate of obstructions in channel 1c) good determination of the number of obstructions; excellent relationship of obstructions with specific morphological and facies units; good estimation of the volume of obstructions in channel 1d) about 15 minutes for every 10 m section
channel roughness- bed material	1a) surface particle size determination-visual estimates together with cross sectional surveys 1b) bed roughness = mean bankfull depth/ largest particle size transported as bedload 1c) poor estimator of bed roughness	1a) surface particle size determination (reach averaged grid-sampling pebble count) together with cross sectional surveys 1b) bed roughness = mean bankfull depth/ reach averaged D_{84} 1c) fair estimator of bed roughness	1a) surface particle size determination (calibration of facies units by pebble counts) together with cross sectional surveys 1b) bed roughness = mean bankfull depth/ reach averaged D_{84} 1c) good estimator of bed roughness
surface particle size	1a) surface particle size determination-visual estimates 1b) determination of dominant and subdominant particle sizes within every 10 m interval 1c) poor characterization of surface particle size 1d) few minutes for every 10 m section	1a) surface particle size determination- reach averaged grid-sampling pebble count 1b) determination of reach averaged particle size based on grid sampling with pebble count method on large sections of stream 1c) fair characterization of surface particle size 1d) about 20 min. for each pebble count	1a) surface particle size determination- calibration of facies units by pebble counts 1b) determination of surface particle size characteristics (median size, cummulative frequency curves, % fine material) of individual facies units based on several pebble count calibrations; to determine the surface particle size characteristics of riffles this method has to be combined by a Level C planform analysis 1c) good determination of surface particle size 1d) difficult to estimate

a) refers to the methods used to measure the diagnostic features
b) refers to the variables that can be used for analysis of the data
c) briefly discusses the relative accuracy and/or precision of the methods

Table 3 (cont.).

Diagnostic Features	Level A	Level B	Level C
surface particle patchiness	not possible by Level A analysis of particle size	not possible with Level B analysis of particle size	1a) surface particle size determination- identification of different facies units on streambed 1b) number of patches per channel width; number of facies units per channel width; if combined with a Level C planform analysis, a relationship between patches and obstructions can be determined 1c) excellent determination of number of patches; excellent relationship with obstructions can be determined
channel pattern (sinuosity)	1a) channel pattern- use of aerial photos or topographic maps 1b) sinuosity = length along channel/ length along valley 1c) good determination of sinuosity 1d) if channel is clearly seen-about 10 min.	no methods available for Level B	1a) planform analysis- Level C 1b) sinuosity = total length of reach along mid channel/ net distance from downstream end of reach to upstream end 1c) excellent determination of sinuosity 1d) about 10-15 minutes
subsurface particle size	no methods available for Level A	no methods available for Level B	1a) subsurface particle size determination (based on TFW Ambient Monitoring Manual- Spawning Habitat Module) 1b) percent fine sediment, median size, cummulative frequency curves 1c) good determination of the subsurface particle size characteristics of riffle crests
bank erosion	1a) visual estimates of the percentage of streambank area composed of different parent material types; visual estimate of the percentage of the streambank area covered by vegetation or protected by obstructions are taken at every 10 m intervals; identification of mass wasting features 1b) % bank area in different parent materials; % area protected by vegetation or obstrucions; estimation of area suffering from active mass wasting events; erosion rating index 1c) fair estimation of parent material and protected streambank areas; fair estimation of the area suffering from active mass wasting processes;excellent relationship between bank erosion and obstructions 1d) about 5-10 minutes for every 10 m section	1a) same as Level A, but measurements of the streambank mass wasting features are taken 1b)same as Level A; volume of material produced by mass wasting processes 1c) same as Level A; good estimation of the area suffering from active mass wasting processes and volume of material being deposited in the stream by this process; excellent relationship between bank erosion and obstructions 1d) about 15 minutes for every 10 m section	1a) same as Level A; use of erosion pins, bank profiling techniques, and/or radial surveying; these techniques should always be accompanied by a Level A or B bank erosion analysis 1b) volume of material produced by mass wasting and surface erosion processes; the relationship of bank erosion with individual obstructions can be determined 1c) excellent determination of the amount of material being produced by mass wasting and surface erosion processes; excellent relationship between bank erosion and obstructions 1d) variable
scour depth	no methods available for Level A	no methods availabel for Level B	1a) scour chains- Schuett-Hames et al. (1995)

a) Safe and more "comfortable" data collection conditions. There is no need for analysts to be out in the field during hazardous high flow winter conditions.

b) Minimal impact on salmonid habitat condition.

c) Good exposure of streambed composition, which allows easier usage of various methods. Even at low flow conditions there is a risk of measurement error due to the flow dependency of some measurements This error is considered in this report specially on the areal and volumetric quantification of morphological units within the channel (See Section III.A and Appendix E).

Different diagnostic features do not respond at the same rate as other or to the same conditions. For example, while the particle size arrangement of the streambed might change significantly at a flow close to bankfull conditions, changes in channel plan form might be too slight to be detected. To avoid complicating the monitoring system recommended in this report we will suggest simple guidelines to determine the frequency of measurements and the total amount of time needed to detect general trends.

Frequency of measurements

For most of the diagnostic features data should be collected as frequent as once every year if bankfull conditions were matched or surpassed at least once during the previous wet season, if bankfull flow conditions were not reached we recommend a quick visit to the site. Analysts should go out to the reach with copies of all of the data collected in the previous year (maps, field notes, and photographs). The analysts should evaluate whether changes in channel diagnostic features are visually detectable. Special attention should be paid to: new obstructions in the channel, stream bank landslides, new colluviaI deposits on the stream bed, revegatation of banks, new fine sediment patches specially in the vicinity of obstructions and road drainage structures, etc. If after a careful examination no changes appear to have occurred no analysis should be conducted that year. If a change in any of the variables is detected a complete analysis should be conducted. Measurements should be taken at least once every two years even if bankfull conditions have not been matched. These guidelines apply to all diagnostic features except those related to channel plan form. Changes in channel plan form typically occur much slower and require more time to respond. The recommended frequency of these measurements range from once every year to once every three years. These exceptions will be discussed in the individual method descriptions.

Time needed to detect trends

Most diagnostic features suffer responses that exponentially decrease with time (Waiter Megahan, pars. comm.). Typically one to three years after an area has been impacted by high sediment and discharge producing events (caused by either natural conditions or by forest practices) net changes in diagnostic features are several times larger than the natural variability of the area. During this time trends are very obvious and only about three to five consecutive years of data collection are needed to confidently detect significant trends. About five years after an area has been impacted changes in the diagnostic features diminish to a magnitude similar to their natural variability. To avoid confusing natural variability with real trends in areas that were impacted more than five years from the start of the monitoring effort, we recommend collecting at least five to seven years of data before attempting to identify a significant trend.

Organization of this section of the report

This part of the report is subdivided into nine sections, each one describing the different data collection levels. The descriptions are shown in the following order:

A) Plan form Analysis
B) Long Profile Surveying
C) Cross-Section Surveying
D) Surface Particle Size Characterization
E) Subsurface Particle Size Characterization
F) Quantification of Large Woody Debris
G) Bank Erosion Analysis
H) Channel Pattern Characterization
I) Determination of Fine Sediment in Pools

Each method description includes the following items:

· An introductory statement discussing: the variables measured by the method; a brief discussion on how to diagnose the channel condition for that particular variable (only applies to a few variables and it is based on Table E-3b from the Stream Channel Assessment Module [WFPB, 1993]); frequency of measurements; approximate time needed to install equipment and to collect data; brief discussion on possible analysis procedures; training requirements; and comments on the accuracy and/or precision of the methods.

· A list of materials needed for data collection

· A detailed description of the data collection methods

· A description of the suggested analysis that should be conducted in order to make interpretations on the data.

III.A. PLANFORM ANALYSIS

The plan form analysis section provides the basis from which most of the data collection and analysis procedures are organized. Levels A and B subdivide the reach into 10 meter long sections in which the following channel characteristics can be determined: channel width, location and dimensions of different morphological units and obstructions, and particle size and spatial distribution. Differences between Levels A and B are simply a result of differences in the way measurements are made. Level A only requires visual estimates of the area covered by different channel features, while Level B requires actual measurements of the features. Level (2 requires the preparation of a detailed plan form map in which the same data collected for Levels A and B can be collected and drawn on map. Generally, the procedure consists of the following steps:

a) *Set up*- Consists in the installation of rebar stakes along the centerline of the channel in order to subdivide the channel into 10 meter long sections.

b) *Data collection*- We recommend collecting data in two or three individual runs depending on the level chosen and the number of sensitive diagnostic features. This section only provides guidance in measuring channel width and determining the areal extent of morphological units. All other data collection procedures that can be used in conjunction with this section are explained in individual sections later in this report. The guidelines presented in this report are flexible enough so that most data collection procedures related to the characterization of surface particle size, obstructions, and bank condition can be integrated into any level of effort chosen for the plan form analysis. It is up to the analysts to integrate all procedures so that data collection for these particular features can be well organized and easily collected.

III.A.1 Plan form Analysis Levels A and B

At this level the plan form analysis subdivides the reach into 10 meter long sections so that most data can be collected in each one of these sub-sections individually. The procedure can be divided in two:

· *Set up* (steps 1-4)- This step requires setting up a tape along the center line of the channel so that the reach can be subdivided. This step does not require any special training and can be performed by two operators in about half a day.

· *Data collection* (Step 5)- As mentioned above, only guidelines in how to collect channel width and morphological unit data are explained in this section. Channel width measurements at every 10 mi long sections can be taken in just a few minutes by one or two operators and it only requires minor operator training in correctly identifying bankfull indicators. Accuracy of the channel width measurements is expected to be good because about 30 measurements are taken for each channel, which provides a good estimate of both channel width variability and central tendency.

Measuring or estimating the areal extent of morphological units within channels is subject to strong operator bias. This can be a result of various uncertainties. First, morphological units in natural systems have very complex and diverse arrangements, and most morphological unit boundaries are transitional and not very sharp. As a result of this, current definitions of the different morphological units are not very strict and practitioners have not been able to establish a solid consensus on how to determine the boundaries of morphological units. Also, many of the procedures currently in use are unable to avoid the effects of flow dependency of the measurements. In an attempt to partly solve these problems we recommend two changes in the commonly used procedures:

a) Simplifying the definitions of the morphological units so that the number of morphological units that have to be recognized by analysts is reduced. We recommend analysts to use the following three categories when identifying the morphological features found in the channel (refer to Appendix E for definitions on all morphological units mentioned in this section):

1) *Pools*- Composed only of features that satisfy the pool characteristics in Appendix E.

2) *Pool-related features*-Composed of features that fall in the tailout or glide category.

3) *Bar-riffles*- Composed of features that fail in the bar, riffle, and run category. This approach follows the definition of riffles suggested by Knighton (1984) in which riffles are considered as channel storage features (bars) that do not have enough elevation to be exposed during low flows.

Obviously, differentiating bars from riffles have important geomorphological implications, but in this report we recommend only to make the distinction for biological considerations. It is well understood by geomorphologists that the higher a streambed feature is the higher the shear stress it exerts on the flow. Until now there is no simple way to calculate these effects and for that reason we will not attempt to include them in our analysis. The methods presented here, though, allow to calculate changes in the amount of sediment stored in these features.

b) Provide suggestions on how to delineate several morphological unit boundaries. In order to help solve these problems we suggest using one of the following options.

1) Estimate the best location of the boundary between morphological units according to the descriptions given in Appendix E. You may use morphological or flow characteristics, but make sure the criteria used is described in your field notes so that it can be reproduced in the next channel survey.

2) Use the pool boundary criteria developed by Lisle (1987) based on riffle crest elevation to determine pool boundaries. It is important to point out 1hat this procedure will work only on freely formed pools with riffle crests. For forced pools with no riffle crests use the procedure described above. Analysts should locate the riffle crest and attempt to determine its elevation so that an imaginary contour line on the pool bed surface with the same elevation as the riffle crest can be visualized. This imaginary contour line will delineate the pool

boundaries which can be identified with bright colored flagging attached to lead weights. This method requires first delineating the pool area and then identifying all of the remaining morphological features.

3) This approach uses the same criteria as in #2, but it requires more strict methods to locate pool boundaries. This method requires the use of a hand level and a rod to determine the exact location of the pool boundaries. The procedure is as follows:

i) Level Operator (LO) stands at a location where the entire pool is visible, while the rod operator (RO) sets the rod on top of the riffle crest (See Appendix E for definition of riffle crest and ways on how to identify it).

it) LO takes a reading and notes the elevation.

iii) RO moves the rod to a new position inside the pool with an elevation similar to the riffle crest elevation. LO helps RO locate the rod a the correct elevation by indicating when a level reading equal to the elevation of the riffle crest is taken.

iv) RO identifies this location with bright colored flagging tied to lead weights.

v) Continue method until pool boundary locations have been determined on all sides of the pool. Mark at least three locations on both sides of the pool and at least one location on the upstream end in order to accurately define pool shape.

Estimating the time needed to complete measurements of channel morphological features is very difficult because it depends on the complexity of the channel, the boundary identification method selected, and the level of effort chosen to determine areal extent of the units. 'We estimate that it would take 2 operators about 5 to 20 minutes to complete measuring the morphological units located in each I0 meter section.

If analysts desire to make a general diagnosis using the bar and pool characteristics of the monitoring reach we recommend refering to Table E-3B from the Stream Channel Assessment Module (WFPB, 1993). This table shows that if most of the bars located in the channel are small point bars this is an indication of low sediment input conditions, while large medial bars or bars on the outside of meander bends indicate very high sediment supply. This table also suggests that a decrease in pool size (volume and area) are a response to increases in the amount of sediment reaching the channel. Analysts should be very careful to evaluate whether these changes in bar and pool characteristics are a caused by important changes in input factors or if they are just responding to temporary conditions, such as the passage of sediment waves. No special guidelines can he provided to differentiate between one or the other. The only suggestions that can be provided is to collect data for a prolonged period so that significant trends can be detected, and to evaluate the changes in channel features together with the channel input factor monitoring procedures. The monitoring effort should continue at least until the channel conditions go back to a background level or until they stabilize at a new equilibrium.

Analysts should take advantage of the channel sectioning procedure suggested in this section to collect data to characterize other diagnostic features such as: surface particle size, obstruction size and location, and streambank condition. To prevent confusion during data collection the data collection procedure should be divided in two. We have found that grouping them as follows allows for efficient data collection procedures:

i) channel width, morphological units, surface particle size (surface particle size applies only if a Level A or C of the Surface Particle Size section is being used)

ii) large woody debris and other obstructions, streambank composition

III.A.1.a Materials Needed for Planform Analysis Levels A and B

-1/2 inch diameter rebar stakes (about 0.75 to 1 meter in length)- the number of rebars varies depending on the length of reach and on its sinuosity, but typically about 15 to 20 individual pieces are needed
-bright colored flagging
-permanent ink marker
-three to eight pound sledge hammer
-two or three 100 m long measuring tapes
-survey rod
-hand level (optional)
-several 4-8 ounce lead weights (optional)

III.A.1.b Planform Analysis Levels A and B Data Collection Procedure

1) Pound a rebar stake with the sledge hammer into the gravel in the center of the channel at the downstream end of the reach.

[Note: Sometimes the bed material will be too coarse or compacted and it will not allow the insertion of stakes. Do not place stakes too far away from the center of the channel. Preferably move the stake location a few meters upstream or downstream when stake insertion is difficult. In some channels stake insertion is impossible. In these channels operators should find ways to keep the tape securely in the center of the channel by placing the tape under boulders or by tying it around logs or any other debris. If tape is tied around a large object make sure to note how much of the tape is tied around the object so that it can be subtracted from the channel length measurements.]

2) Walk upstream and pound other stakes into the gravel in the center of the channel. Subsequent stakes should be placed so that when a tape is tied to them it follows the general planform pattern of the channel section. Generally, for channels with abrupt bends, at least three stakes should be placed at every bend in the channel. For channels

with gentle bends, two stakes can be placed at every meander. Follow this procedure until the upstream end is reached.

3) Attach a measuring tape to initial (downstream) stake and tie it to up stream rebars until you get to the end of the reach.

4) Identify the position of rebars along the length of the mid-channel with bright colored flagging. Identify each stake by writing the following information on the flagging:

Name of stream/Project name/Date/length along the centerline]

At the same time operators should subdivide the reach into 10 m long sections and identify the boundaries with flagging by using the format used for stakes (shown above). Flagging should be tied up to trees, logs, or other features that are visible from the channel. If nothing is available, nails can be pounded into the stream bank at every 10 meter section boundary.

5) Identification of unit boundaries- This section is composed of several sub-steps which are performed at every 10 meter section of the channel. Only those diagnostic features that were identified as sensitive to change should be included in this part of the survey.

a) Measuring channel width- At every 10 m interval channel width is measured with the stadia rod or the measuring tape from bankfull to bankfull (See Appendix F for an explanation on how to determine bankfull location). The rod should lie perpendicular to bankfull channel flow when these measurements are taken.

b) Determination of morphological unit area- Identify the boundaries of all morphological units [bars, riffles, glides, pools, tailouts, runs, and other habitat units (optional)] inside the channel and determine their area. Remember to group them according to the recommendations provided above: pools, pool-related features, bar-riffle features, bedrock exposures, and obstructions. Level A analysis onIy requires estimating the percentage of area inside the i0 m section composed of a given unit. Level B analysis requires actually measuring the area of channel covered by a given unit with a measuring tape or rod. When measuring the dimensions of complex shaped units we suggest two options: i) for lower level of accuracy, simplify their morphology by approximating the shape of the units to regular simple geometric figures and then measure its major axis (for rectangular or ellipsoidal shapes) or diameters (for circular shapes); and ii) for increased accuracy use methods described in the Habitat Unit Survey Module of the TFW Ambient Monitoring Program Manual. Indicate the general location of morphological units [left or right bank (lb or rb), mid-channel (mch), or spanning the entire channel width (sp)] and whether it continues to the next upstream or downstream section.

c) Determination of surface particle size- If particle size is considered to be an important variable, choose a level from particle size characterization methods [See Section Ill.D].

d) If channel cross-sections are going to be surveyed determine the length of morphological units found along thalweg. This data can be then be used to help locate where permanent cross-section sites are going to be located (See Cross-Section Surveying Section for details.). Identify the longitudinal boundaries of channel morphological units located along the thalweg and determine its length by referring to the center line tape. (See Appendix E for an explanation on how to identify the different morphological units)

Field Form B. Suggested data collection sheet setup for Levels A and B-Planform Analysis

Section # ________ Distance along thalweg: from ________ to ________

Channel width at upstream end ________ Channel width at downstream end ________

Morphological Unit	Distance along CL	Cross-sectional location (lb, rb, mch, sp)	Length along thalweg	% area	Dimensions (length-width)	Freely Formed or Forced
riffle	121 m	sp	4 m	30%	4-7	freely formed
pool	125 m	rb	7 m	40%	7-3.5	forced

6) Characterization of other diagnostic features

a) Determination of stream bank condition- See Section III.H.

b) Determination of large woody debris loading- See Section III.G.

c) Determination of fine sediment in pooh;- See Section III.J.

lll. A.l.c Plan form Analysis Levels A and B Data Analysis

Channel width

Calculate reach mean bankfull width and prepare a plot of individual channel widths versus distance along center line as shown in Figure 2. This type of plot enables the analyst to visually interpret changes in channel characteristics along the monitored reach. The analyst is able to observe whether: changes in average channel characteristics are statistically significant; if changes occur over the entire reach or if only a few measurements are responsible for the change; and if the graph is compared to similar graphs of other diagnostic features, the analyst can determine if a relationship between channel width and other channel characteristics exists.

Total reach area

To estimate the total reach area multiply the total length along the center line of the channel by the average bankfull width. Do the same type of calculation for each individual 10 meter section.

Length of morphological units along thalweg

Divide the total length of each morphological unit type by the total length of reach. Prepare a histogram of percent frequency by length as shown in Figure 3, [Note: This will be later used for selecting cross-section locations.]

Channel morphological unit area

Three different types of graphs can be plotted to visually present this data. (See Figures 4a, 4b, and 4c). A reach scale histogram (Figure 4a) is done by determining the percentage of each morphological unit within each 10 meter segment and then calculating the mean value for the entire reach. If graphs showing the abundance of specific morphological units within each 10 m interval (Figure 4e) are used then site-specific and overall reach comparisons with large woody debris loading (and other variables) are possible. The analysis would also allow to determine: whether the changes are statistically significant or not; and whether the changes are a result of changes in short channel sections or if they are widespread over the entire reach.

Number of pools per reach (pools/rh)

This variable was identified by Smith and Buffington (1996) as a good discriminator of land use condition. They observed that disturbed reaches tend to have smaller values of *pools/rh* than undisturbed reaches. We believe that this variable can be used to monitor the frequency of pools in the monitored reach. A decrease in the value of the variable indicates increases in the detrimental effects of forestry practices on channel habitat quality. To calculate it simply count the total number of' pools (including both free-formed and forced pools) found in a particular reach, If comparisons between two different reaches are desired, divide total channel length (in meters) by average channel width (in meters). The resulting variable is known as *pool frequency* (number of pools per channel width) and it has been used as a variable to determine the effects of LWD on the number of pools found in a reach (Montgomery et al.. 1995). The inverse of *pool frequency*, called pool spacing (channel widths/pool), may also be used.

III.A.2 Plan form Analysis Level C

The object of this level is to prepare a general plan form map showing channel bankfull boundaries and the location of benchmarks, cross-section survey stakes, mid-channel rebars, and other features. The procedure generally follows the guidelines suggested in Collins and Dietrich (in prep.). The general plan form map produced during this level is used to accurately represent the location and size of different features in the channel. By overlaying maps containing different types of data, very reliable interpretations can be made of the relationship between specific features in the channel.

It takes analysts about one day to complete the initial plan form map showing the channel boundaries and the location of benchmarks and cross-section stakes. About one to two more days are needed to include most of the important channel morphological features. This depends mostly on the methods chosen to characterize each one of them. Preparation of the plan form map requires some training and operators with some artistic skills. We recognize that the procedure is very labor intensive, but we strongly recommend it because it produces a visual representation of the channel that can be used very effectively by geomorphologists and biologists to recognize specific and general changes in channel features.

The entire procedure presented here does not have to be reproduced every time data is collected. Channel plan form characteristics generally do not change significantly from one year to another. We recommend analysts to make a quick field visit to determine (with the help of photographs and plan form maps) if any major changes in channel plan form has occurred. If no changes have occurred the analysts may skip steps 1-16 of this section by using a copy of the last channel boundaries map prepared for that reach. If changes in channel width and/or location are identified then the analysts should use a map *containing* only benchmark and survey stake *locations to* complete the channel boundary location map. We recommend preparing a new channel boundary map about every three years.

lIl. A.2. a Materials needed for Plan form Analysis Level C

- 1/2 inch diameter rebar stakes (about 0.75 to 1 meter in length)- the number of stakes varies depending on the length of reach and on its sinuosity, but typically about 15 to 20 individual pieces are needed

-bright colored flagging

-permanent ink marker

-small sledge hammer

-2 or 3 100 m long measuring tapes

-survey rod

-grid paper and colored pencils

-ruler (in cm)

-protractor

-Brunton compass

III.A.2.b Plan form Analysis Level C Data Collection Procedure

Follow steps 1 through 5b from the Level A and B procedure description and then:

6) Set up benchmarks and cross-section stakes as described in the long profile and cross-section surveying sections [See Sections III.B and III.C].

7) Prepare a legend of features that are going to be identified in map (at this point of map preparation the following features should be included: bankfull channel boundaries, mid-channel rebars, benchmarks, cross-section survey stakes, large trees, trails, roads and any other feature that could be used as a location reference point).

8) Find out what is the maximum width of channel from step 5a and scale your map so that channel width is smaller than the dimensions of the paper. A one centimeter per meter scale is a reasonable and easy to use scale.

9) Stand above the initial (downstream) rebar and plot it in center-bottom section of grid paper. Identify this location by putting the number 0.0 in right next to it. Identify due North direction on paper with an arrow.

10) Visually locate benchmark #1 and determine its bearing with the Brunton compass. Measure the distance from the benchmark to the stake and plot it on the map with the aid of a ruler and protractor. Do the same with benchmark #2.

11) Determine the bankfull width at this location with a survey rod (measure width perpendicular to centerline tape or perpendicular to the expected general direction of flow at bankfull conditions). Take two measurements to determine bankfull width, one to the left bank and one to the right and plot these points on the map with a colored pencil with the aid of a ruler. [Optional: For higher accuracy, take the bearing reading of rod direction while making bankfull width measurements].

12) While standing above the initial stake use the Bruntcn compass to take a bearing reading on the next up stream stake. Find out the distance between the two stakes and plot their location on the map with the aid of a ruler and protractor. Draw a line from one to the other and identify every 10 meter interval.

13) Walk 10 meters upstream, and repeat bankfuIl width measurements, as explained in Step # 11. Sketch the shape of the channel bankfull boundaries between measurements by looking at the banks and drawing them on the map with a black colored pencil. If channel shape changes drastically between the I0 meter intervals, the operator might opt to take additional bankfull width measurements. Whenever these measurements are taken make sure to determine the net center line distance where they are being taken and identify them with red colored pencil on the map.

14) Identify natural features (for example: large live trees) or man made structures (roads, trails, bridges, etc.) that could help in relocating areas in the channel. Determine its location relative to the center line tape.

15) Continue steps I 1-14 until you get to the upstream end of the reach. Don't forget to locate benchmark #2t.

16) In your office, trace a clean copy of the map and make several copies. These copies will be used for the next steps.

17) Take plan form map copies to the field. Only the sensitive diagnostic features identified during Section II should be included in map, except thalweg location and active channel boundaries which should be always included. Tire analysts can choose any level of effort for each one of these features. For example, the analyst can choose to use a Level B analysis for facies units and a Level C analysis for large woody debris sampling. Diagnostic features could be mapped individually producing one map for each diagnostic feature. Doing this drastically increases the amount of time to be spent in the field. We recommend arranging them in two groups:

- thalweg location, active channel boundaries, morphological and habitat units
- facies units, large woody debris, and stream bank condition

To locate unit boundaries or other features of interest in the map, use the center line tape as a reference. Before plotting a point in the map, determine the distance along the center line tape and the distance from the tape to the point of interest (distance should be taken perpendicular to center line tape). This could be clone two ways: i) take measurements at every 10 meter intervals and sketch the boundaries in between measurements; or ii) take measurements at any distance along the tape. For most features any approach would work, but for large woody debris mapping we recommend using the second one.

18) In the office, prepare clean copies of the map. Make some copies on tracing paper or in transparencies so that maps can be overlaid on top of each other.

lll. A.2.c Plan form Analysis Level C Data Analysis

Determination of channel width, total reach area, and the area of morphological and facies unit are done in the same way as for Levels A and B. The main difference is that the plan form map provide a way to visually interpret the site-specific relationships between different channel features. This is the main advantage of the Level C plan form analysis and we strongly recommend its use whenever possible. For example, if you overlay the large woody debris map with the morphological unit map you could determine if certain morphological or facies units are freely formed or if they are forced by the presence of wood. Also, by overlaying the facies unit map with the morphological unit map you could determine the surface particle size of specific units in the reach [See Section III.D.3].

III.B. LONG PROFILE SURVEYING

The long profile surveying methodology is.a very important part of any channel monitoring effort. While the plan form analysis provides a way to detect changes in channel pattern, the long profile survey provides the means to determine changes in the vertical dimension of channel features. This is important when analysts want to determine if the channel is going through an aggradation or degradation stage and when volumetric analysis of different channel features is desired. Volumetric analysis of channel morphological units is not possible if the plan form analysis data is not combined with long profile data. Another very important product of the long profile survey is to determine the reach average gradient. Channel gradient is very important in determining the rate of sediment transport and deposition, thus it is a very important factor controlling channel type and the arrangement of sediment and morphological features in the channel. Stream gradient, together with mean bankfull depth, will be used to calculate the median size of particles that is expected to be transported along the reach. This predicted median size is used to determine the median size of particles lying on the surface of the streambed. By comparing this value with the actual size of sediment found in the streambed analysts may be able to determine how the transport rate of the channel compare with the rate of sediment input. Comparisons are based by computing the ratio of the critical shear stress for the reach-averaged median surface grain size (D50) to the reach-averaged bankfull shear stress (Smith and Buffington, 1996). Appendix F shows a more complete description of this analysis.

Long profile measurements can be taken as often as once a year and at least once every two to three years. If the channel being surveyed has been impacted in the last few years before starting the monitoring effort, only three consecutive years of data are needed to deject any significant changes. If channel was impacted more than three years before monitoring started, up to five consecutive years of data are needed.

Long profile and cross-section surveying are typically done together. Installation of the instruments needed to conduct both surveys usually takes about one whole day for one or two operators. Surveying the long profile and all cross sections takes about two or three days depending on the complexity of the channel and the levels of effort chosen. Some training requirements are required for analysts performing these tasks. Operators must be able to: use surveying equipment (hand levels, transits, total stations, or laser surveying equipment); plot and analyze data with computer data analysis programs; and identify channel morphological units.

III.B.I Long Profile Surveying Level A

Level A long profile procedures allow analysts to collect data needed to determine the general channel gradient of the entire reach. The procedure consists in using a level instrument (hand level, transit level, or laser surveying equipment) a measuring tape stretched along the center line of the channel and stadia rods to survey the thalweg of the channel. The procedure and analysis provide very accurate results of channel gradient.

lll. B.I.a Materials Needed for Long Profile Surveying Level A

- 1/2 inch diameter 1 meter long rebar stakes (about three or four are needed per reach)

-small sledge hammer

-hip boots or chest waders

-several 100 m long measuring tapes

-hand level, transit level with tripod (total station or laser surveying equipment may be utilized but guidelines on how to use them will not be included in this report)

-stadia rod

-field notebook

-bright colored paint

-flagging

-permanent ink marker

lll. B.l.b Long Profile Surveying Level A Benchmark Setup Procedure

The first thing that should be done before setting up any benchmarks is to determine whether any permanent benchmarks have been previously set in the area. If previously set benchmark is found within a reasonable distance from study reach, make sure to survey-in the new benchmarks that are being set for your monitoring project so that the surveying can be done with actual elevations above sea level. If no previously set benchmarks can be located then you should assign an arbitrary elevation to your main benchmark (a 100 m elevation is typically used).

When choosing the location of the benchmarks keep in mind the following:

· benchmark disturbance by humans or animals

· benchmark permanence (avoid locating benchmarks in places where they can be affected by high flow (.'vents)

· difficulty in relocating benchmark due to vegetation cover

· distance from channel

We recommend setting up at least two benchmarks at the downstream end and one benchmark at the upstream end of reach. Four different types of benchmarks are commonly used and they are all described in Harrelson et al. (1994). We recommend using two different types: 1) nails pounded horizontally into durable trees (target juvenile, slow growing plants with excellent vigor and rooting [Cbarles Chesney, pers. comm. D.; and 2) 1/2 inch diameter- 1 meter long rebar stakes vertically pounded into the ground. Six inch long nails should be horizontally pounded into a large healthy tree that is relatively close to the channel but that does not appear to have a high potential of falling to the ground or into the channel. About 2 inches of the nail should be left protruding from the tree. Paint the tip of the nail and identify it by tying a flag to it with the following information:

Name of stream/Project name/Date/BM # __ ______________ --1

If rebar stakes are used pound them into the ground at some distance from the channel, but at a place that is still visible from it. The idea is to try to make a level reading to the benchmark and the thalweg at 0 in along the channel center line stake without having to move the leveling instrument. This is not essential for perforating long profiles but it increases the accuracy of the first measurements. Pound stake in and leave about 10 cm protruding from the ground. Paint this end with bright colored spray paint and identify it with flagging using the same format described above. Be careful when using this type of benchmark because sometimes rebar stakes can be easily pushed into the ground when a rod is placed on top of them, causing an elevation change, if this is the case we recommend changing its position slightly, using a longer rebar, or hiding it so that humans or animals won't disturb it. If cattle have access to the area we recommend either avoiding the use of this type of benchmark or try to get the cattle out of the area.

Place a third benchmark at the upstream end of reach. This benchmark will be the last point measured before starting to close the survey. This benchmark could serve as a way to recalibrate the level readings to see whether measured changes in the elevation of the thalweg and other features are due to real changes in channel elevation or caused by errors during surveying.

Ill. B.l.c Long Profile Surveying Level A Procedure

The long profile surveying procedure could be performed by two operators. A third operator could be assigned to help in moving and resetting tapes, taking notes, and/or moving vegetation out of the level field of view. The first time the survey is done we recommend doing a specially careful survey by using very accurate equipment (transit level with tripod or laser surveying equipment) or being extremely careful with the hand level. This would allow reD' accurate calculations of the exact elevations of benchmarks and survey stakes. Cross-section survey stakes could then serve like benchmarks that could help correct errors in future surveys. We recommend the following procedure.

1) Stretch 100 m tapes along center line rebars and other tapes at cross-section locations (See Section III.C for tape setup)

2) The operator handling the rod (RO) starts by placing the rod on top of one of the two downstream benchmarks. The level operator (LO) finds a spot where readings to both benchmarks and to the thalweg at 0 m can be made. Take readings and include them in the field notes.

{Note: LO using either a hand level or a transit should avoid moving the instrument from its position unless it is absolutely necessary. Try to locale the instrument at a point where a long section of the roach can be viewed. We recommend this because most of the error during surveying occurs when the instrument has to be moved. When it is absolutely necessary to move the instrument (when vegetation or other features block the view of the rod or when the rod is too far from the instrument to take accurate measurements) a surveying technique known as a *turning point* is performed. A *turning point* is defined as a reliable point upon *which foresight* and *back sight* readings are taken to establish a new elevation of the leveling instrument and to continue a line of levels (Harrelson et al., 1994). A *foresight* is a rod reading taken on any point to determine its elevation, while a *back sight* is a repeated reading of a point of known elevation taken when the leveling instrument is moved to a new elevation. The turning point procedure requires taking a foresight of a point in the channel. While the rod maintains the same location, the leveling instrument is moved to a new location from where a relatively long section of the reach that is going to be surveyed is visible. From that new location a reading of the turning point is taken again (back sight). The difference between the foresight and the back sight readings is the elevation difference between the previous instrument location and the new one. Back sight corrections are cumulative so that individual instrument elevation corrections affect all of the survey readings taken after the particular turning point.]

3) The survey is performed along the thalweg and the water surface of the stream. Water level readings should be taken at thalweg locations every 10-20 meters or just upstream and downstream of obstructions spanning a significant portion of channel. Thalweg measurements must be taken at least on all:

· obvious changes in slope
· changes in morphological units
· just upstream and downstream of obstructions
· deepest portions of pools
· all riffle crests
· obvious changes in facies units
· bedrock exposures

[Note: In order to accurately calculate the average *residual depth* of individual pools (defined below) make sure several thalweg readings are made inside every pool. Space these reading so that a reasonable pool depth average can be calculated from them. That is, avoid biasing your data by taking many measurements in deep or shallow areas of the pool.]

RO should tell the LO (or operator taking notes) the morphological unit where the reading is being taken, the dominant streambed particle size, and also the distance along the center line tape. Thalweg location changes drastically from one side to the other along the channel, and sometimes it does not follow a continuous line. Since the thalweg is not necessarily located right in the middle of the channel, distance readings along the center line tape will not be that accurate. Take readings perpendicular to the center line tape to the nearest tenth of a meter. At the intersection of cross-sections with center line tape take a reading of the thalweg and then survey the cross-section following the instructions given in Section III.C. Once the cross-section has been surveyed, continue surveying the long profile following the same procedure described above.

At the end of the reach, survey the third benchmark and start closing the survey. Closing the survey consists in running a line of differential levels from benchmark/43 to the main benchmark. The difference between tile original elevation of benchmark #3 and the new or calculated elevation is the error. To do this start moving downstream (back to benchmarks 1 and 2) while taking foresight and back sight readings along the channel. Start by taking another reading of benchmark//3. Without moving the instrument move the rod to a new location down stream and take a foresight reading. This is your first turning point. Move the instrument further down stream from where the rod is located and take a back sight reading. Continue doing this until you get to the downstream boundary of the reach and take for sight readings of the main and the secondary benchmarks. Calculate the difference in elevation between the downstream and upstream benchmarks with the data collected while moving upstream and compare this with the elevation difference calculated from the data collected while moving downstream. Harrelson et al. (1994) indicate that differences smaller than 0.02 ft (0.6 cm).

[Note: no distance measurements are needed when closing the survey because the purpose: of this step is only to calculate the elevation difference between the upstream and the downstream benchmarks.]

Field Form C suggests a field notes setup format for Level A data collection procedures.

Field Form C. Level A, B, and C field data collection sheet for long profile surveying procedure.

Distance along CL	Foresight reading	Backsight reading	**Observations**
125 m	1.4m		thalweg-gravel
128 in	1.3 m		riffle crest-gravel

1ll. B. l.d Long Profile Surveying Level A Data Analysis

Long profile plot preparation and calculation of channel gradient

If absolute elevation of benchmarks is not known assume that the main benchmark elevation is 100 m to avoid negative numbers in your plots. The best ,say to plot this data is by using a computer data analysis program that is able to conduct simple calculations of different data columns and to do scatter plots and linear regressions. We suggest setting the spreadsheet as shown in Table 4.

Table 4. Spreadsheet setup for plotting long profile readings.

Distance (m)	Main BM elev. (In)	Initial BM reading (m)	FS thalweg reading (m)	FS wtr. lvl. reading(m)	FS turning pt. reading (m)	BS turning pt. reading (m)

To calculate the elevation of any given reading use the following formula:

Elev. = BM elev. + BM corr. + (FS tp reading - BS reading) - Level Reading (eq. 2)

where,

BM elevation is the elevation of the main BM and it is assumed to be 100 m if the actual elevation is unknown.

BM corr is the reading taken of the main BM at the beginning of the survey and it is the same number for the entire data set.

FS tp reading is the turning point reading taken before the level instrument is moved.

BS reading is the reading of a turning point taken after the level instrument has been moved to a new location.

Level Reading is a particular foresight thalweg or water surface reading..

When preparing the data for your plots do not forget that back sight adjustments are cumulative and that their effects have to be carried over the entire survey data. This adjustments are shown in parenthesis in equation #2 (FS tp reading - BS reading). When using a computer spreadsheet you can add a column called "turning point corrections" (TP corr.) showing the values of these differences and performing a running sum on it. If that is done then equation #3 may be used.

Elev. = BM elev. + BM corr. + TP corr.-level reading (eq. 3)

To determine the channel gradient make a plot of elevation versus distance along the center line for both water surface and thalweg, then let the computer program determine the best fit regression line through the points. Data analysis programs such as Excel ®, Kaleidagraph ®, or JMP ® are relatively easy to use programs that are capable of calculating regression lines. The slope of the regression line is considered to be the average gradient of the channel [See Figure 5]. This gradient is used for boundary shear stress calculations which are described in Appendix F.

Determination of channel roughness caused by morphological unit topography along thalweg

A method that has been suggested to quantify channel roughness requires the calculation of residuals of the best fit thalweg profile line. The procedure suggests determining the best fit regression line of the thalweg profile data and then finding the residuals of the data. Residuals are the difference between the value predicted by the linear equation and the true value in the population. Most of the data analysis computer programs previously mentioned can easily calculate it. The sum of the residuals is then used as a measure of morphological unit channel roughness. We have determined that this approach cannot be used for monitoring purposes because the stun of the residuals is a factor of the number of data points collected. Changes in channel roughness calculated with this method may then be caused by differences in the long profile survey density and not due to real changes. We recommend a slightly different approach that requires only the use of maximum pool depths. The procedure requires plotting the best fit line of all of the thalweg data and then calculating the sum of the residuals of the maximum pool depths. Increases in pool maximum depth or increases in the number of pools (both of which indicate changes in channel roughness) would show up as changes in the sum of residuals. This measure is not very accurate because it discards the very important effects of morphological units not found along the thalweg (i,e. bars), but it is used because no other simple method to determine changes in channel roughness has been developed.

[Note: A method that is commonly used calculates the Manning's roughness coefficient from water velocity data. This method is not recommended as part of this methodology because it requires discharge and/or velocity measurements, which are not described in this report.]

Another way to determine channel roughness, which may prove to be much simpler, is to use the residual depth of pools as a measure of channel roughness. The sum of the residual depths o1' all pools in a reach can be used as a parameter determining channel roughness. Calculation of residual depths are explained just below.

Residual depth of pools

Residual depth is the depth that, if flow were reduced to zero, water would fill pools just up to their lips that are located at riffle crests downstream. It can ;also be defined as the difference in depth or bed elevation between a pool bottom and the downstream riffle crest (Lisle, 1987). Residual depth of pools can be calculated individually or collectively for the entire stream, A plot of residual depth versus distance along center line can be plotted together with reach mean residual depth. To calculate residual depth determine the difference in elevation between these measurements and the elevation of the riffle crest just downstream of each pool. Determine the average residual depth of each pool and then use those results to calculate a reach average residual pool depth. Lisle (pers. croton.) believes that residual depths are not very sensitive to changes in input processes and that they will only be useful in occasions when these changes are producing extremely high depositional rates on the deepest portions of pools. He recommends using methods to measure the fraction of pool volume filled with fine sediment (V*) whenever field observations indicate that the pools are being filled with fine sediment. We recommend using the residual depth of pools during the first few years of monitoring to identify whether pool filling by fine sediment is occurring in the channel. If reach average residual depth seems to be decreasing after two years of monitoring, we strongly recommend analysts to use the V* methods discussed in Section III.J.3 to accurately determine the rate of pool filling by fine sediment.

Pool Volume

The average depth of pools cannot be easily determined by the suggested method of long profile surveying. The long profile surveying method allows only measurement of maximum pool depths because it is performed along the thalweg of the channel (the deepest point at every cross section). A very detailed method is needed to determine the average residual depth and volume of pools (V* method discussed in Section III.J.3). Level A long profile survey methods allows only the calculation of biased approximations that tend to overestimate the actual volume of pools. These calculations should be used more as a way to quantify changes in pool volume than an attempt to calculate actual values. To calculate pool volume multiply the average residual depth of an individual pool by its plan form area.

Estimation of Charm el Aggradation or Degradation

Aggradation or degradation *(agg-deg)* of specific points in the thalweg of the channel could be determined by calculating the elevation differences of the thalweg at specific points along the channel. Changes in residual depths and pool volume are ways to quantify aggradation and degradation in pool features. The cress-section surveying methods will provide data to quantify aggradation and degradation at specific cross-sections. Calculation of agg-deg occurring at bars needs the application of a Level B or C Long Profile Surveying Procedure. The Level A Long Profile Surveying Procedure provides data on the magnitude of agg-deg occurring at specific locations along the thalweg. We recommend using the elevation of the thalweg at cross-sections and at riffle crests as a means to quantify the general channel agg-deg along the thalweg of the reach. To do this simply calculate the difference in elevation of each one of these points. The results can either be plotted individually against channel length or they can be averaged over the entire reach.

III.B.2 Long Profile Surveying Level B

Long Profile Surveying Level B closely follows the procedure described for the Level A methods. The main differences are that Level B requires surveying bank hill indicators, terraces, and bar tops. Bankfull and terrace data is used to complement data collected in cross-section surveys, while bar top data is used to quantify the amount of sediment stored in bars. The method has the same operator skill requirements needed for the Level A procedure.

lll. B.2.a Long Profile Surveying Level B Benchmark Setup Procedure

Use the same guidelines suggested in Section IlI.B.2.a (Long Profile Surveying Level A Benchmark Setup Procedure).

lll. B. 2. b Long Profile Surveying Level B Data Collection Procedure

Level B data collection procedure basically consists in the same procedure needed for a Level A analysis, with only minor differences. One of the differences is that the long profile is not only measured along the thalweg and water surface of the channel. A profile along bankfull indicators and/or along terraces are simultaneously surveyed with *the* thalweg and water *surface* profiles. (See Appendix F for descriptions on how to *identify* bankfull indicators). Readings on bankfull features on stream banks and/or terraces should be taken at least every 10 to 20 meters or: at very clear and obvious bankfull indicators; just upstream and downstream of tributaries; and in areas where channel width changes drastically.

The second difference between both levels is that for the Level B procedures bar top readings at specific bars are taken. Bar top measurements are survey readings taken at the surface of bars. These measurements are taken to approximate the volume of specific bars in the channel At least 4 readings should be taken for each bar: one at the downstream end, one at the upstream end, and two in between. For bars with a cross-sectional shape similar to the one shown in Figure 6a, follow this procedure:

1) Conduct survey along the channel thalweg, water surface, bankfull, and terraces as explained above.

2) Take thalweg and water surface readings at the downstream end of bar feature to be analyzed.

3) Project an imaginary line perpendicular to the center line tape, extending from the tape to the bar feature.

4) Identify the highest point of the bar along this line and measure the horizontal distance from the thalweg to the this point with the stadia rod.

5) Place the rod vertically on top of this point so that a foresight reading is taken of this point.

6) Repeat steps 2 through 5 at least four times over each bar. Note the distance along the channel center line between each one of the bar top measurements. Make sure a bar top measurement is taken at the upstream end of the feature.

When the bar being surveyed has a cross-sectional shape similar to Figure 6b follow steps 1 through 6 described above. After step 5 measure the horizontal distance (perpendicular to center line tape) from this point 1o the lowest point on the bar side that lies opposite to the thalweg (shown as "b2" in Figure 6b) and then continue with step 6.

Field Form C is a suggestion on how to set up your notebook when taking notes for Level B profile surveying.

Field Form C. Level A, B, and C field data collection sheet for long profile surveying procedure.

Distance along CL	Foresight reading	Backsight reading	Observations
125 m	1.4 m	-	thalweg-gravel
125 m	0.8 m	-	bartop-xsec type 1/4 elipse b measurement = 2.0 m

lll. B. 2.c Long Profile Surveying Level B Data Analysis Procedure

Analysis of residual depth of pools, pool volume, aggradation/degradation, channel gradient and roughness use the same procedure described in Section III.B.l.d (Long Profile Surveying Level A Data Analysis Procedure).

Bar Volume

1) From field notes determine the general cross-sectional shape of the bar of interest. (Refer to Figures 6a and 6b.)

2) Calculate the bar top elevation difference between every bar top measurements and its corresponding thalweg readings. [Note: in order to be able to determine changes in the volume of sediment stored in bars through time, all volumetric calculations have to be compared to a constant elevation. We suggest using the thalweg elevation measured during the first survey to make these comparisons. In order to be able to use this thalweg and bar top measurements have to be measured at the exact locations every time the survey is repeated. The distance along the channel center line will then have to be used to relocate these points. If bar features are migrating then tim accuracy of the methods is reduced and only comparisons of sediment stored above the thalweg may be performed.]

3) Calculate the cross-sectional area of each bar top measurement by assuming that bar shape can be approximated by an ellipse as shown in Figures 6a and 6b.

If bar cross-sectional shape is similar to Figure 6a use the following equation:

A=l/4(~*a*b) (eq.4) I

where,

A is the approximated cross-sectional area of the bar.

a is the elevation difference between the bar top measurement and the corresponding thalweg elevation (taken during the initial channel survey).

b is the distance (perpendicular to centerline tape) between thalweg and bar top measurement points.

If bar cross-sectional shape is similar to Figure 6b use the following equation:

$$\boxed{A = 1/4\, \pi * a * (b_1 + b_2) \quad \text{(eq. 5)}}$$

where,

b_1 is the distance (perpendicular to the centerline tape) from the thalweg to the bar top measurement point.

b_2 is the distance (perpendicular to the centerline tape) from the bar top measurement point to the lowest point on the bar side that lies opposite to the thalweg (See Figure 6b).

4) Calculate the volume of each bar by using the following formula:

$$\boxed{\sum_{i=1}^{n-1} \frac{Ai + Ai+1}{2} \bullet Li \quad \text{(eq. 6)}}$$

where,

Ai *and* $Ai+1$ are bar cross-sectional areas calculated from either equation 4 or 5.

Li is the distance (parallel to the centerline tape) from one bar top measurement to another.

n are the number of bar top readings taken for particular bars.

111.11.3 Long Profile Surveying bevel t;

Field procedure and data analysis for Level C are exactly the same as for Level B analysis with the only difference being that for Level C more sophisticated surveying equipment is used. Generally, the use of this type of equipment has the advantages of providing higher three dimensional accuracy and providing a much faster method of performing the tasks. Laser levels or total station surveying equipment can be used not only to perform the long profile and cross-section surveying procedures but also to make topographical and plan form maps of the channel. A topographic map would be very useful in defining both the plan form and the vertical dimensions of morphological units so that areal and volumetric analysis can be performed with a much higher accuracy. The main disadvantage

of the method is that it is costly because it is equipment intensive and it requires training of personnel for performing field work, processing data, and conducting analysis.

III. C CROSS-SECTION SURVEYING

The main objective of this procedure is to determine the average bankfull cross-sectional area, width, and depth of the entire reach. The procedure also allows the calculation of the mean active channel width and depth which are useful for analysis of habitat units. Bankfull depth is used in conjunction with channel gradient to conduct: critical boundary shear stress analysis. A complete description of this analysis is shown in Appendix F.

Cross-sections can be surveyed as often as once a year. It takes a crew of two people about one to two days to set up all cross-sectional and long profile stakes, and about two to three days to survey both the long profile and all of the cross sections. Operators performing the cross-sections need some previous training in handling the surveying equipment and in plotting and analyzing the data. The three procedures discussed here provide data that is expected to give excellent reach-scale estimates of channel width and depth.

Differences in the levels are due to differences in the density of cross-sections set up in each channel reach:

Level A

Four to six cross-sections per 30 channel widths are set (an average of one cross-section every 5-8 channel widths).

Level B

Six to ten cross-sections per 30 channel widths are set (an average of one cross-section every 3-5 channel widths).

Level C

Tea to thirty cross-sections arc set every 30 channel widths (an average of one cross-section every 1-3 channel widths). The Level C procedure also has the option of performing a detailed survey of vertical stream banks.

III.C.1 Cross-Section Surveying Level A

lII. C. 1.a Materials Needed for Cross-Section Sun, eying Level A

-several measuring tapes (30 In long measuring tapes can be used)

-stadia rod

-hand level or transit level with tripod

-field book

-1/2 inch diameter by 0.75-1 meter long rebar stakes

-6 inch long nails

-f1agging

-permanent ink marker

-sledge hammer

-bright spray paint

-hip boots or chest waders

III. C. 1.a Cross-Section Surveying Level A Permanent Stake Setup

1) After the histogram of channel morphological units found along the thalweg has been prepared (See Figure 3), the next step is to set up the location of the permanent cross-sections. For this level four to six cross-sections per 30 channel widths should be set (an average of one cross-section every 5-8 channel widths). Cross-section site selection should be guided by the channel morphological units histogram. When selecting sites for permanent cross-sections, priority should be given to pools and riffles because: they are very important for both physical and biological interpretations; and incorporating them will provide a good representation of the bankfull depth variability within the reach. For example, consider setting 10 cross-sections in a reach with a morphological frequency distribution like the one shown in Figure 3. In this case, this method would suggest to set up 4 cross-sections in riffles (adding both riffle and run features), and 6 in pools (adding pools, glides, and tail out features). If not enough pools or riffles are available in the reach to satisfy these recommendations, set up cross-sections in other morphological units. In the example used above, if the reach only had 4 pools and 4 dries, we would recommend to set up one cross-section in a glide and one in a fallout. Never set more than one cross-section in the same individual morphological unit and always select sites so that they are spread over the entire length of the reach.

2) When selecting the specific sites where tire permanent cross-sections are going to he set, consider the following (in order of importance):

· Make sure bankfull marks on the stream banks are Clearly visible.

· Try to set the cross-sections in the deepest portions of pools and relatively shallow portions of riffles.

· if high erosion rates are evident, make sure stakes can be set at a safe distance from the channel.

· Make sure that vegetation or other features make it possible to take survey readings of cross-.sectional stakes.

· Try to avoid setting up stakes in sections of the channel where the difference in elevation between left and right banks is very large. If this is not possible you might either pound nails into trees at some elevation above the ground, or make simple trigonometric corrections to the survey data. This is clone to avoid errors in the data that might be caused by a tape that is not lying horizontally when the cross-section is being measured.

3) Use a sledge hammer to pound in a rebar stake or nail (barn spike) at a location above bankfull several meters from the left bank edge (if active erosion is apparent, you can increase this distance). When using stakes, pound them vertically into the terrace or floodplain and leave about 10-20 cm of the stake protruding from the ground. Be careful when using this type of stake because sometimes rebar stakes can be easily pushed into the ground when a rod is placed on top of them. If this is the case we recommend changing its position slightly, using a longer rebar, or biding it so that humans or animals won't disturb it. If cattle have access to the area we recommend the following: removing cattle from the area; using nails (barn spikes) instead of stakes; or placing stakes right at the foot of trees, where they are protected from cattle. If nails are used, pound them horizontally into healthy trees and leave about an inch of the nails protruding from the tree. Once the stake has been pounded in, paint it with bright colored spray paint and identify by tying a flag to it with the following information:

name of stream/project name/date/cross-section #/length along center line]

If stakes are not easily visible from the channel, place a second flag with the same information in a very visible place.

4) Pound a second stake above bankfull along the right side of the channel. Locate it so that a tape tied to both stakes lies perpendicular to what you expect to be the flow direction at bankfull.

5) Continue until the desired number of cross-sections has been set.

li1. C. 1. c Cross-Section Surveying Level A Data Collection Procedure

Cross-sections are measured at the same time the survey team is conducting the long profile survey. When the 100 m long center line tapes are being stretch along the channel, set up other available measuring tapes at the cross-sections. To do that, attach the zero meter end of the tape to the left bank survey stake (bank on your left while looking downstream) and stretch it to the right bank stake. Once a cross-section is measured the tape should be removed and set at the next upstream cross-section location. Once all of the available tapes are set, the team may strut the long profile survey.

When the rod operator (RO) approaches a cross-section, take notes on the cross-section number, the distance along the center line tape, and thalweg elevation. Then you might start your cross-sectional survey by following these steps:

1) The level operator (LO) should be located at a spot where the entire cross-section (including the stakes) can be surveyed without the need of turning points (See discussion in Section III.B. 1 .c Step 2). [f the operator does not have a good view of the entire cross-section, a turning point measurement has to be taken before starting the cross-sectional survey.

2) The RO places the rod on top of the left bank survey stake and LO takes a reading. These readings on top of the survey stakes are very important because they are used as local benchmarks for the individual cross-sectional survey data and they could also be used to correct for errors made during future lung profile surveys.

3) A reading at 0 m distance is taken by placing the rod on the ground right next to the stake. Continue surveying the entire cross-section. The Re reads off the distance along the tape and identifies the location where the measurement is taken while the LO takes foresight readings and records the information. The Re should be able to identify several channel features so that useful cross-sections can be plotted. The Re should place rod at the following locations along the cross-section:

· obvious breaks in slope

· bankfull marks on stream banks

· floodplain (or terrace)-bank boundary [also known as bank edge]

· bank-streambed boundary

• morphological unit boundaries

· thalweg

· water surface at thalweg

· edge active channel (edge of water)

· bar tops

· bedrock

4) Continue until the right bank survey stake is surveyed.

5) Continue surveying the long profile until the next upstream cross-section is reached. Then, repeat steps I 4,

We recommend using a field notes setup similar to Field Form D.

Field Form D. Data collection sheet for Levels A and B of cross-sectional surveying procedure.

Cross-section #   Distance along center line tape __

Distance along x-sectional tape	Foresight reading	Back sight reading	Observations
0 m	.8 m		top of left bank stake
.... _0 m	1.05 m	t	next to left bank stake
2 In	1.15 m -	1	edge of left bank

III. C. 1.d Cross-Section Surveying Level A Data AnalYsis Procedure

The first time the channel is surveyed, analysts should determine the exact elevation of all survey stakes by doing a very careful survey with a hand level or by using high accuracy leveling equipment (transit with tripod, laser level system, or a total station). During subsequent surveys use the elevation of the left bank stakes as a reference elevation for all readings taken at cross-sections. Use the elevation of the right bank survey stakes measured during the initial survey to determine if any errors occurred during the cross-sectional survey.

To determine the elevation of all readings made during the first survey use the following formula:

$$\text{Elevation} = -1 * (Tr - Yi) + Telev \quad \text{(eq. 7)} \quad [$$

where,

Tr is the thalweg foresight reading taken while performing the cross-sectional survey.

Yi is any reading taken during the cross-section survey.

Telev is the thalweg elevation at the cross-section determined from the long profile survey.

[Note: if back sights were necessary in order to complete the cross-sectional survey, this equation cannot be used because corrections to Yi have to be made.]

For subsequent cross-section surveys use the left bank survey stakes as benchmarks for cross-sectional measurements. We suggest using the following equation:

$$\text{Elevation} = Ss\ elev + (Ss\ reading - Yi) \quad \text{(eq. 8)} \ \}$$

where,

Ss elev is the elevation of the left bank stake determined from the first survey.

Ss reading is the foresight reading of the left bank stake during cross section survey.

Yi is any foresight reading taken during the cross-section survey.

[Note: If back sights were necessary in order to complete the cross-sectional survey, this equation cannot be used because corrections to Yi have to be made,] *Channel width and depth*

The main objectives of measuring cross-sectional surveys are to: determine channel average width and depth, and to determine changes in thalweg elevation. This could be done by following these simple steps:

1) Use a data analysis computer program to make an elevation versus distance plot. Identify bankfull elevation readings and plot a horizontal line across them to delineate the area submerged during bankful events.

2) Determine the bankfull channel width by measuring the horizontal distance of bankfull elevation line from one bank to another.

3) Determine the bankfull channel area by determining the actual area represented by each grid cell and counting the number of cells inside the bankfull channel area.

4) Calculate the average bankfull depth by dividing the bankfull area by bankfull width.

5) Determine the change in thalweg elevation by subtracting the value calculated in the initial survey to subsequent measurements.

Perform the same calculations for all of the cross-sections and determine mean value and standard error of the entire reach. To visually present this data you can prepare plots of individual or reach-average cross-sectional bankfull width, depth, and area versus distance along the center line (See Figures I and 7a-7b). These plots provide a simple way of determining if changes in channel characteristics are statistically significant, and to determine if the changes are due to large changes in a small section of the channel or if they are spread over tire entire reach. Useful interpretations can be observed by comparing these plots with similar plots produced from the large woody debris survey.

III.C.2 Cross-Sections Surveying Level B

III. C. 2.a Materials Needed for Cross-Section Surveying level B

Same materials needed for the Level A cross-sectional surveying procedure (Section IIIC. l.d).

lll. C. 2. b Cross-Section Surveying Level B Permanent Stake Setup

Use the same procedure described for Level A (Section IIIC. l.b), except that for Level B six to ten cross sections per 30 channel widths should be set (an average of one cross-section every 3-5 channel widths).

Ill. C. 2. c Cross-Section Surveying Level B Data Collection Procedure

Use the same procedure described for Level A (Section III.C.l.c).

III. C. 2.d Cross-Section Surveying Level B Data Analysis Procedure

Use the same procedure described for Level A (Section III.C.l.d).

111.C.3 Cross-Sections Surveying Level C

III. C. 3.a Materials Needed for Level CCross-Section Surveying

Same materials needed for the Level A cross sectional surveying procedure (Section III.C.I.d), if bank profile is going to be measured a 3 m long metallic tape and a stadia rod with a vertical level are also needed.

Ill. C. 3. b Cross-Section Surveying Level C Permanent Stake Setup

Use the same procedure described for Level A (Section III.C. 1 .b), except that for Level C ten to thirty cross-sections are set every 30 channel widths (an average of one cross-section every 1-3 channel widths).

III. C.3.c Cross-Section Surveying Level C Data Collection Procedure

Use the same procedure described for Level A (Section III.C.l.c), but if a detailed survey of the shape of the stream bank is desired follow the procedure described in this section. This method is useful for nearly vertical stream banks with very complicated morphology and for measuring bank undercutting rates.

1) Follow the same procedure explained in Section III.C. 1 .c and once completed, place the rod with level vertically at the bank-streambed boundary.

2) The RO keeps the rod vertical with the aid of the level and makes a reading of the location where the rod intersects the cross sectional tape.

3) The LO or other operator takes the metallic tape and measures the horizontal distance from the rod to the bank, starting at the bottom of the bank. Distance measurements should be taken at: changes in stream bank composition and slope, and at bankfull indicators. Continue moving upward until the top of the bank is reached. Problems arise when the top of the stream bank is higher than the reach of the operator taking the horizontal measurements. (See Appendix D for more details.)

We recommend setting your field notes like Field Form E.

Field Form E. Suggested field book setup for bank profiling procedure of Level C cross-sectional surveying

Cross-section #   Distance along center line tape __

Distance along **x-sectional tape**	Foresight reading	Back sight reading	Observations
0 m	.8 m		top of left bank stake ....
0 m	t.05 m		next to left: bank stake
2 m	1.15 m		edge of left bank

Distance along x-sectional tape ___   Left Bank

elevation along rod	distance from vertical rod to bank	Observations
0.25 m	0.75 m	moderately weathered bedrock
0.35 m	0.64 in	highly weathered alluvial _

Distance along x-sectional tape __   Right Bank

elevation along rod	distance from vertical rod to bank	Observations
0.50 m	0.85 m	highly weathered alluvial
0.40 m	0.90m	highly weathered alluvial

III. *C. 2.d Cross-Section Surve3ing Level B Data Analysis Procedure*

Use the same procedure described for Level A (Section III.C.1 .d). If the bank profiling procedure was applied follow the analysis described in this section. Bank profiling data can be plotted in separate graphs (See Figure 8) or it can be incorporated into the cross-section data. When plotting it by itself always use the distance along the tape as reference point so that net changes in bank shape and/or location can be observed. To incorporate the bank profiling data to cross sectional plots: 1) for left banks subtract the horizontal distances measured during profiling from the distances along the cross-sectional tape (add distances for right banks); and 2) add the vertical readings to the elevation of the bed where the rod was placed during bank profiling.

III. D. CHARACTERIZATION OF THE SURFACE PARTICLE SIZE DISTRIBUTION

Characterization of the surface texture of the stream bed is very important for biologists and geomorphologists Fish biologists may use this data to identify gravel patches that are suitable for fish spawning. Geomorphologists use this data to calculate critical boundary shear stresses needed to initialize bed movement (Calculations are shown in Appendix F). Once critical shear stress has been calculated it is compared to shear stress calculations based on field data for bankful1 flow conditions and the results can be analyzed as follows:

· When critical shear stress is much greater than bankfull shear stresses, channel sediment input rates are much lower than the transport capacity of the stream.

· When critical shear stress has about the same magnitude as bankfull shear stress, channel sediment input rates are about the same as the transport capacity of the stream.

· When critical shear stress is much lower than bankfull shear stress, channel sediment input rates are much higher than the transport capacity of the stream.

III.D.1 Characterization of the Surface Particle Size Distribution- Level A

This procedure consists of visually determining the dominant and subdominant particle size classes of stream bed sediment within every 10 meter section of channel. Some disadvantages of the method are: categories used arc very broad (See Table 5); the method provides a poor quantification of the surface material size characteristics; it is subject to operator bias; and the boundary shear stress analysis described above cannot be used with the data produced from this level. The main advantages of the method are that it is very quick and requires minimum operator training.

Table 5. Particle size categories used for characterizing the surface particle size distribution of stream gravels.

Size Class	Size range in mm	Size range in phi units
Clay	less than 0.002	less than +9
Silt	0.002 to 0.06	+9 to +4
Sand	0.06 to 2.00	+4 to -1
Gravel	2 to 64	-1 to -6
Cobbles	64 to 256	-6 to -8
Boulders	greater than 256	-8 to -ll

HI. D. 1.a Materials Needed for Level A Characterization of the Surface Particle Size Distribution

-field notes

ruler (in cm)

III. D. L b Characterization of the Surface Particle Size Distribution- Level A Data Collection Procedure

Within every 10 m long section of the channel operators have to identify, the dominant and subdominant particle sizes found on the surface of the bed. The operators should refer to Table 5 to identify the size class of this sediment. We recommend using a field notes setup when determining the dominant and subdominant particle sizes of the entire reach.

Field Form F. Suggested field notebook setup for Level A surface particle size analysis.

Particle Size	Frequency	Sub-Totals	Class Totals
Boulder-dominant	IIIII	5 * 1 = 5	7.5
Boulder-subdominant	IIIII	5 * .5 = 2.5	
Cobbles-dominant	IIIII	5 * 1 = 5	7.5
Cobbles-subdominant	IIIII	5 * .5 = 2.5	
Gravel-dominant	IIIIIIIIIIII	12 * 1 = 12	17.5
Gravel-subdominant	IIIIIIIIIII	11 * .5 = 5.5	
Fines-dominant	IIIIIII	7 * 1 = 7	11
Fines-subdominant	IIIIIIII	8 * .5 = 4	

1H.D.l.c Characterization o f the Surface Particle Size Distribution Data Analysis Procedure

To determine the dominant and subdominant particle size for the entire reach follow the example shown above. For each size class, multiply the frequency by one for dominant sizes and by one-half for subdominant sizes. Acid up the class totals and the size class with the highest and second highest values are the dominant and subdominant size classes, respectively. In this example, the reach dominant particle size is gravel and the subdominant particle size is fines.

111.I).2 Characterization of the Surface Particle Size Distribution- Level B

The Level B analysis provides a fair method to construct a reach averaged cumulative frequency curve. The method requires performing two pebble counts each consisting of one hundred pebbles over two relatively large sections of the reach. The two samples are then used to determine a reach averaged median particle size. The procedure is done after the planfnnn analysis for the entire reach has been conducted, st) that the operators have been able to see the entire streambed and they have a good idea of the variability of particle sizes found on the surface. This method does not allow analysts to characterize the particle size distribution of specific morphological or facies units (i.e., gravel patches or riffles). When choosing an area to sample, cooperators should try to incorporate both the dominant modes and the size variability found within the entire reach. If the cooperators believe that the entire range of particle sizes cannot be incorporated in two pebble counts, they are encouraged to conduct the number of pebble counts necessary to sample most of the particle sizes represented on the streambed. The results from the procedure described in this section can be used for the boundary shear stress analysis described in Appendix F.

Each pebble count can be performed by two operators in about 20 minutes Operator training requirements lot completing the tasks described in this section are minimal One of the operator takes notes while the other has the responsibility of setting up the grid and collecting the sample. The note taker or a third operator should keep an eye on the trajectory of the sampling lines being followed by the operator picking up the pebbles to make sure that particles are being picked under a relatively well-spaced grid. The same operator should pick up all pebbles in all of the pebble counts performed because operator bias can be a significant source of error (See discussion in Appendix A).

III.D.2.a Materials Needed for Characterization of the Surface Particle Size Distribution-Level B

-ruler (in centimeters)

-field book (preferably use a metric field book type- with columns and rows in one side and grid paper on the other)

-hip boots or chest waders

-calculator

-camera and film

III.D. 2. b Characterization of the Surface Particle Size Distribution- Level B Data Collection Procedure

1) The first step is to determine what areas to sample. We suggest choosing areas that are a good representation of the mode and size variability found on the stream surface.

2) The operator assigned to pick up the pebbles (SO-sampling operator) stands on the down stream end of the selected area right next to the bed-bank boundary on any side of the channel. The SO should face the opposite bank and locate a point on that bank at relatively the same distance along the center line tape as his actual position..

3) Without looking down the SO touches the leading boot toe (a pencil or any pointy objects could also be used), then slides the index finger vertically down onto the channel bed until it makes contact with a particle on the bed. SO removes the particle that first touched the middle of the index fingertip. Then the SO uses a ruler, or a specially designed gravelometer, to measure the diameter of the intermediate or b-axis in ram, and announces this value to the note taker who records the exact number on the notebook. If a particle is too heavy or if it is stuck and the SO is unable to remove it from the bed, the SO should take a measurement of the smallest of the two exposed axes. Particles finer than 2 mm cannot be easily removed from the bed or accurately measured with a ruler, so they arc assigned to the "fines" category (finer than 2 ram).

4) SO looks up, locates the chosen point on the opposite bank, takes a step in that direction, and repeats step #2 [Note: For wide rivers, instead of taking samples at every step, they could be taken at every pace or two steps]. 'Try to avoid changing the direction and/or the length of your steps, specially when large boulders are in the way. For areas in the channel that are deeper than the length of the SO's arm try to estimate the diameter el' the particles lying at the tip of your boot. Also, pick up particles that are part of the bed material and avoid all material in the channel that was obviously supplied by mass wasting processes, bank erosion, or coming from other tributaries (these materials belong to different populations and they should be sampled separately).

5) SO continues steps 3 and 4 until the opposite bank is reached. Then he moves one pace (two steps) upstream and repeats steps 2 through 4.

6) When 100 particles are collected sampling is completed and the note taker starts to prepare a histogram and a cumulative frequency curve. This step is to be performed in the field and operators should follow these guidelines:

a) Set up grid paper by following the example shown in Figure 9.

b) Tully the number of particles in every category and determine the individual and cumulative frequencies.

c) Prepare the cumulative frequency curve by plotting the mean size of each category by its cumulative frequency, and by drawing a smooth line over all of the points.

d) Determine the median size of the sampled particles (See Figure 9).

c) Look at the sampled area and see whether the histogram and cumulative frequency plots agree with the SO's visual impression of the size distribution. This is done to calibrate the SO's eye so that operators with plenty of experience can rely on visual estimates to determine the median size of gravel patches with some certainty.

7) Use the camera to take pictures of the areas sampled by the pebble counts. Take pictures of the entire urea covered by the pebble count and of specific patches inside that area. When taking pictures of specific patches, take

them vertically and always include a scale (a ruler with a cm scale is preferred). Don't forget to identify the roll and picture number on your notes.

III.D. 2.c Characterization of the Surface Particle Size Distribution-Level B Data Analysis Procedure

Even though part of the analysis is performed in the field some office work is required to determine the reach scale median size. Data from both pebble counts (n = 200) should be entered in a data analysis program capable of calculating medians and quartiles.

III.D.3 **Characterization of the Surface Particle Size Distribution- Level C**

Although the suggested procedure for Level C analysis is considered to be the best method to describe the particle size characteristics of the streambed surface, the accuracy and precision of the method has never been exhaustively evaluated. The method consists of:

- Identifying the different facies units found on the streambed (Section III.B.3.b).

- Calibrating the particle size characteristics of the units (Section III.B.3.c).

- Determining the total area covered by each of the facies units and calculating a reach average size distribution by a really averaging the calibration values (Section III.B.3.d).

The surface particle size analysis shown in this section can be integrated to any of' the plan form analysis levels described in this report. This entire procedure generally follows the guidelines originally suggested by Leopold (1970), which have been later incorporated in facies unit mapping procedures such as the ones described by Collins and Dietrich (in preparation), Buffington (1995), and WFPB (1993).

Ill. D. 3.a Materials Needed for Surface Particle Size Distribution- level C

-ruler (in centimeters)
-field notes (preferably use a metric field book type- with columns and rows in one side anti grid paper on the other)
-hip boots or chest waders
-calculator
camera and film
-plan form map (if a Level C- Plan form Analysis Procedure is being used)

HI.D. 3. b Level C Surface Particle Size Distribution Identification of Facies Units Procedure

The first step is to visualize the particle size distribution of the streambed as being composed of distinct size classes and that the bed is some mixture of these individual classes. Facies units are categorized and named according to their dominant and subdominant particle sizes. For example, a unit composed mostly of gravel with stone sand, is called a gravel-sand unit. Once the units have been defined, take at least two photographs (taken vertically) of each unit and make sure to identify the name of the unit and its location. These pictures could be used to help identify facies units along the reach and to help observe any changes in facies unit composition in Future surveys. The number of facies units within a channel reach depends on the Following: patchiness of channel, desired accuracy, and operator bias.

Patchiness is related to both morphological unit type and large woody debris loading. Buffington (1995) found in his studies performed in Alaska and Washington that typically plane bed channels have about one to four different facies units while pool-riffle types have about three to seven facies units. Generally, the number of textures increases with greater complexity of channel roughness.

It is commonly considered that increases in accuracy can be achieved by setting more rigorous criteria defining each facies unit type. This could be achieved in two ways: defining each type by its dominant, sub-dominant, and other frequently found particle sizes (i.e. units could be called: gravel-sand with some cobbles); and by subdividing the dominant particle size categories into fine, medium, or coarse (i.e. a unit could be called a coarse grained gravel-sand unit). If this is done the number of suggested pebble counts needed to calibrate teach individual unit can be reduced to one, but the time spent mapping the location and borders of these units, and in calculating their areal extent from a plan form map would increase. Also, it is not certain whether this would effectively increase accuracy oF reach-scale characteristics because it could increase errors in defining and drawing the unit boundaries on the map.

Although the facies identification process is considered to be repeatable (Collins and Dietrich, in prep.) and operators consistently tend to choose the same number and facies unit types (Buffington, 1995; Mosley and Tindale, 1985) some training is always necessary to make sure the operators have a systematic, repeatable method of defining facies units. Special cam should be taken when defining facies unit boundaries. Many operators tend to confuse morphological unit and water edge boundaries with facies unit boundaries, but they do not necessarily coincide. Be very careful when defining, mapping, and calibrating unit boundaries. Boundaries are also typically gradational, making them difficult to define.

If this method is used with a Level A plan form analysis, the percentage area of each unit within every 10 meter section of the channel is visually estimated. If used with a Level B analysis, the percentage area is based on measurements made by approximating the facies unit shapes to simple geometrical shapes. For these two levels an analysis of median particle size for the entire reach and within each 10 m section is possible. A plot showing the reach average median particle size (and 95% confidence intervals) and the median particle size of each 10 m section versus distance along the channel center line could provide some interesting interpretations (such as tire effects of

LWD loading or tributaries on surface particle size). When used with Level C plan form analysis, the facies unit boundaries are mapped and the areal extent of each one is determined from the map. This Level provides a clear visual representation of the particle size spatial distribution within the reach, which allows analysts to understand much more clearly the relationships between sediment sources (i.e., tributaries, landslides, etc.), obstructions (LWD pieces, boulders, etc.), and streambed surface composition, it also permits the calculation of particle size characteristics of individual morphological units.

A decision whether to include boulders as part of the streambed or as obstructions has to be taken at this stage. To simplify the process we will only consider boulders larger than 2 meters (diameter of b-axis) as being potentially included in the obstruction category. The goal of the analyst is to determine whether the boulders have been transported as bedload or not. If it appears that the boulder has not moved since it was supplied to the channel from hillslope or stream bank mass wasting processes it should be classified as an obstruction; if it appears to have moved, then consider it as part of the streambed (Collins and Dietrich, in preparation). In channel reaches with many boulders, a Level C planform analysis of particle size should include a boulder category. If channel bed is not dominated by boulders they could be drawn individually on the plan form map.

III.D.3. c Level C Surface Particle Size Distribution Calibration of Facies U~its Procedure

I) Identify, facies unit boundaries [Optional: Identify the boundaries with flags tied to I oz. lead weights] to set the boundaries of the sampling area.

2) The sampling operator (SO) stands on the downstream end of selected area right next to the left or right boundary.

3) Without looking down the SO touches the leading boot toe (a pencil or any pointy objects could also be used), then slides the index finger vertically down onto the channel bed until it makes contact with a particle on the bed. SO removes the particle that first touched the middle of the index fingertip. Then the SO uses a ruler, or a specially designed gravelometer, to measure the diameter of the intermediate or b-axis in ram, and announces tiffs value to the note taker who records the exact number on the notebook. If a particle is ton heavy or if it is stuck and the SO is unable to remove it from the bed, the SO should take a measurement of the smallest of the two exposed axes. Particles finer than 2 mm cannot be easily removed from the bed or accurately measured with a ruler, so they are assigned to the "fines" category (finer than 2 ram).

4) The SO looks up and takes a step perpendicular to the channel direction, and repeats step #2. (Note: For large facies units, instead of taking samples at every step, they could be taken at every pace or two steps.] Try to avoid changing the direction and/or the length of your steps, especially when large boulders are in the way. For areas in the channel that are deeper than the length of the SO's arm try to estimate the diameter of the particles lying at the tip hi' your boot.

5) The SO continues steps 2 and 3 until the opposite boundary is reached. Then the SO movers one step (or pace) upstream and repeats Steps I through 3.

6) When 70 particles are collected the SO stops sampling and the note taker starts to prepare a histogram and a cumulative frequency curve:

a) Set up grid paper by following the example shown in Figure 7.

b) Tally the number of particles in every category and determine the individual and cumulative frequencies.

c) Prepare the cumulative frequency curve and draw a smooth line over all of the points.

d) Determine the median size of the sampled particles (See Figure 7).

e) Look at the sampled area and see whether the histogram and the cumulative frequency plots agree with your visual impression of the size distribution of the facies unit.

7) Repeat steps 1-5 in another area composed of the same facies unit type and compare the results from both areas. If the difference is too big the analyst might consider including those units under separate categories.

8) Repeat steps I-7 for all facies unit types.

[Note: For units composed exclusively of fine sediment either assign a median size value of I mm to them, or take a bulk sample and analyze its particle size composition in the lab.]

III.D.3. d Level C Characterization o[the Surface Particle Size Distribution Data Analysis Procedure

Calculation of Reach-Average Particle S&e Distribution

a) Determine the total area of the channel and the percentage of that are covered by each one of the facies units.

b) Determine the cumulative size characteristics of each unit type by combining data from the two pebble counts.

c) To calculate the reach averaged particle size characteristics use the following formula:

[Dx =EDxi*(Area unit Yi/Total channel area)(eq. 9)]

where,

Dx is the reach average cumulative frequency characteristic (D50, D16, D25, etc.).
Dxi is the cumulative frequency characteristic for each facies type.

Critical shear stresses calculated from the median particle size of the reach arc then compared to the boundary shear stresses expected to occur at bankfull conditions. This procedure is explained in Appendix F.

Average particle size composition of each 10 meter channel section

a) Determine the total area within each 10 m long section and the percentage of that area covered by each one of the facies units.

b) determine the cumulative size characteristics of each unit type within every 10 m section by combining data from both pebble counts.

c) To calculate the average particle size characteristics of each section use the following formula:

[Dx =EDxi * (Area unit Y_i in section i/ Area section i) (eq. 1[])]

where,

D_x is the 10 m section average cumulative frequency characteristic (D50, D16, D25, etc.).
Dxi is the cumulative frequency characteristic of each facies type.

A plot of D_x versus distance along the center line (also showing the reach average particle size characteristics) could be plotted so that analysts may determine whether reach-average changes in channel surface particle size are a result of large changes that occurred in isolated areas or if it responds to widespread changes.

Average particle size composition of morphological units

[Note: this is only possible if a Level C Plan form Analysis is being used.]

The procedure is as follows:

a) Overlay facies unit map with morphological unit map.

b) Determine the total area of each facies unit within the boundaries of the morphological unit of interest.

c) Determine the total area of tire morphological unit.

d) Calculate the particle size characteristic of the morphological unit with the following formula:

$$D_X = Z\ Dxi * (\text{Area unit Yi in morphological unit} / \text{Area morphological unit}) \qquad \text{(eq. 11) J}$$

where,

Dx is the morphological unit cumulative frequency characteristic (D50, D 16, D25, etc.).
Dxi is the cumulative frequency characteristic of each facies type.

The total number of patches or facies units in the reach can provide some data for geomorphological analyses of stream channels. Generally an increase in channel roughness caused by increases in large woody debris loading, sediment input, and/or a change of channel type causes increases in the number of patches and facies unit types found in the channel. Changes in both sediment input rates and size composition might also result in changes in patchiness. Patchiness can also be used for biological reasons as a variable determining habitat diversity. This variable can be analyzed by determining the total number of individual patches and dividing it by the total length of the reach (in meters or scaled to channel width). Patchiness could also be determined for each 10 meter section and plotted versus distance along the channel. This plot could be compared to a large woody debris versus distance graph to determine the effects of this type of obstruction in controlling the number of patches in the channel.

III.E. QUANTIFICATION OF FINE SEDIMENT ON THE SURFACE OF THE STREAMBED

The pebble count method that has been suggested to characterize the surface material of stream beds suffer from one major disadvantage. That is, it is unable to adequately sample fine sediment, in an attempt to be able to partially solve this problem we have added this section. The methods included in this section provide crude methods to quantify the amount of fine sediment on the surface of the bed. These methods are unable to provide data for the entire range of particle sizes commonly found on the streambed. For this reason we suggest performing these methods in areas where the procedures discussed in Sections III.D.2 and III. I).3 (Levels B and C- Characterization of the surface particle size distribution) have been applied.

The methods require minimal training of operators and they can be performed by one or two operators in a few minutes. The procedure should be repeated every year in the exact same locations in order to be able to make accurate comparisons of the same sediment patches.

III.E.1 Quantification of Fine Sediment on the Surface of the Streambed Level A

This method is very simple and requires no materials except a field notebook and a pencil, but it produces a very poor quantification of the amount of fine sediment found on the bed. Before applying this method the channel must have been previously divided into I0 m long sections (See Sections III.A. 1 through III.A.3). In every 10 m long section estimate the percentage of the bed area covered by fine sediment to the closest 10%. For the purposes of this analysis, fine sediment is defined as that portion of the sediment finer than 2 mm (which includes sands, silts, and clays). Then use these estimates to calculate a reach-average mean percentage of bed area covered by fine sediment.

III.E.2 Quantification of Fine Sediment on the Surface of the Streambed Level B

The procedures recommended for a Level B analysis require making visual estimates of the amount of fine sediment in small areas of the channel. The method requires the use of hoops or squared wooden flames so that visual estimates are performed in each one of them. The method provides fair quantification of the fine sediment m each one of these small areas, but a large number of samples need to be taken in order to sample the spatial variability of the streambed (See Discussion on Appendix A, page 10). The procedure requires minimal training requirements and it can be performed in several minutes by one or two operators. It requires only the following materials: field notes, and a 30 cm diameter plastic hoop, or a 30 cm squared wooden or plastic frame. The procedure is as follows:

I) Select area to be sampled. Areas that should be sampled with this procedure should have been previously analyzed by pebble counts. If a Level B-Surface Particle Size Characterization approach is being used, select only one of the areas where a pebble count has been conducted. If a Level C-Surface Particle Size Characterization approach is being used, select one of the two facies units where a pebble count has been conducted.

2) An operator takes the hoop or the wooden frame to the downstream end of the area. This operator then places the hoop or the frame on the streambed at the left-hand side of the area. Then the operator visually determines the percentage of fine sediment on the surface of this area to the nearest 10%.

3) The operator then moves one pace in a direction perpendicular to the channel direction towards the right-hand side of the selected area and repeats Step 2.

4) Once the right-hand border of the area is reached, move one pace upstream and repeat Steps 2 and 3. Continue until the entire area has been covered.

5) Calculate the average percentage of the streambed covered by fine sediment for the entire area selected.

III.E.3 Quantification of Fine Sediment on the Surface of the Streambed Level C

The procedure described in this section requires the use of a specially designed sampling grid. The method has been identified as an areal-grid hybrid sampling technique in Appendix A. (page 8) The sampling grid consists el' a wooden frame (22 by 22 inches) with a grid composed of 144 two-inch squares. Sampling consists in counting the number of grid points overlying fine sediment. This method provides a more reliable and repeatable method than the ones described for Levels A anti B because it reduces the bias introduced by different operators, but it still suffers from the main disadvantage of all areal sampling methods: a relatively large number of samples have to be collected to be able to sample the spatial variability found on the streambed. As suggested for the Level B method, we recommend only using this method in areas that have been previously sampled by pebble counts. A single sample can be collected by a single operator in a few minutes. Operator training requirements arc minimal and materials needed for the construction of the grid are very cheap.

1) Select area to be sampled. Areas that should be sampled with this procedure should have been previously analyzed by pebble counts. If a Level B-Surface Particle Size Characterization approach is being used, select only one of the areas where a pebble count has been conducted. If a Level C-Surface Particle Size Characterization approach is being used, select one of the two facies units where a pebble count was performed.

2) An operator takes the grid to the downstream end el the area. This operator then places the grid on the stream bed at the left-hand side of the area. Then the operator counts the number of grid points over lying fine sediment and records this number.

3) The operator then moves one pace in a direction perpendicular to the channel direction towards tire right-hand side of the selected area and repeats Step 2.

4) Once the right-hand border of the area is reached, move one pace upstream and repeat Steps 2 and 3. Continue until the entire area has been covered.

5) For each individual sample divide the number recorded by the total number el' grid points inside the frame (144 if the same grid discussed here is used) to determine the percentage of that particular area covered by fine sediment. Calculate the average percentage of fine sediment for each of the areas sampled.

III.F CHARACTERIZATION OF SUBUSURFACE STREAMBED MATERIAL

Sampling the subsurface material of gravel bedded rivers is very important for biologists and gcomorphologists. Biologists have identified that particle size distribution of the subsurface is a critical factor controlling the survival of embryos and alevins during incubation and emergence. Geomorphologists have identified that under certain conditions the subsurface material is a good representation of the particle size distribution of the material transported by bed load. Subsurface samples have then been used to back calculate the critical boundary shear stresses needed to move the bed, and it has led to variables such as q* (Dietrich et al., 1989; Kinerson, 1990) and Buffington's (I 995) ratio of actual textural fining to potential fining. Sampling the subsurface material of the streambed is not recommended for geomorphological analysis for the following reasons:

I) Characterization of the subsurface particle size analysis is too intensive fur its potential information yield. Hence, characterizing only the surface particle size distribution is recommended. Analysis of the textural response of surface materials, as compared to boundary shear stresses calculated from field determined bankfull conditions should provide interpretations that are as useful to scientists and managers as those produced from a very complicated analysis of the subsurface material.

2) Due to the effects of fine sediment infiltration, the subsurface material and the bed load do not necessarily have the same particle size distribution, so back-calculations of critical boundary shear stresses from subsurface material characteristics might not produce realistic results (See Appendix C).

3) The analyses that require the sampling the subsurface material of stream beds are nut useful for channels with a complex channel pattern and/or a high number of obstructions.

The Salmonid Spawning Gravel Composition Module in the TFW-Ambient Monitoring Program Manual (TFW, 1993) recommends taking subsurface samples for fish habitat characterization efforts from riffle crests or other gravel patches. These riffle-crests samples could be used for geomorphic analysis (such as q* anti Buffington's textural fining ratio), but "the problem will be knowing what the local boundary shear stress is at the crest it could be different than the reach average" (Dietrich, pers. comm.). The shear stresses at rift]e-crests have not been calculated. This provides another reason why we do not recommend any geomorphological analysis of the subsurface stream bed material

This section will describe various recommendations that we believe are necessary to improve the actual subsurface sampling analysis procedures described in the Salmonid Spawning Gravel Composition Module.

I) Before collecting a sample with the McNeil sampler (page 17), tire surface armored layer has to be removed to avoid including it as part of the sample. The surface and subsurface materials belong to two different populations and they should be sampled separately. Since the surface layer does not occupy a predetermined volume no bulk sampling methods can be used to collect the sample. We recommend the following:

a) After identifying the site to be sampled a grid-based pebble count (n=70) should be performed on the area.

b) Scrape off surface material to a depth equal to the diameter of the largest particle found on the surface, in submerged riffle crests scraping off with a shovel can cause bias in the subsurface sample by removing a considerable amount of fine material. Since the actual sampling area is only 15 cm in diameter for individual cores, the surface layer could be carefully removed by hand.

c) Identify the largest particle in the subsurface and note its diameter. This information could be used to check whether individual samples (or the total weight of all samples) is greater than the weight recommended by Church et al. (1987) for an unbiased sample. Then follow the procedures described in pages 17-20 of' the module.

2) For both volumetric and gravimetric analysis, it would be useful to have sieve sizes that provide a phi-scale progression of categories, always making sure that 0.85 mm and 3 mm sieves are included. This should not be a strict requirement, but it would aid in identifying the weight percentages o1' individual size categories (silts, sands, gravels, etc.) since these categories were developed by using phi units.

3) During step 7 of the volumetric analysis procedure (settling of fines in graduated cylinder) we recommend evaluating the use of hydrometers. Settling takes about an hour for every reading while hydrometer readings take about I minute to complete.

4) Volumetric analysis can't be directly translated into gravimetric data by simply multiplying it by the bulk density of the materials. A size and bulk density dependent correction factor is needed. Due to the action of capillary forces, water is retained between particles even after draining for 15 minutes, and the amount of water is dependent on the particle size and density of the sample. Correction factors were developed by Shirazi and Seim (1979). In order to use this table, a sub-sample has to be collected to determine the bulk density of the sample.

5) When drying samples in an oven during the gravimetric method we recommend the following:

a) Preweigh drying pans.

b) Place samples in drying pans and place in an oven for about 8 hours.

c) Weigh sample and trays, and put back in an oven for about 4 hours.

d) Reweigh sample, if the difference from previous weight reading is greater than 5% of the total weight, place sample back in the oven for 4 hours and repeat this step. if the difference is smaller than 5%, sample is ready for analysis.

6) While shaking the sieves when following the gravimetric procedure, the sieved samples do not have to be removed from the sieves into weighting pans if all of the sieves (empty and clean) have been pre-weighed.

7) In the data analysis section (page 30), we suggest:

a) Including a description on how to determine geometric mean grain size.

b) Analysis should also determine the median size of every sample.

c) Use material finer than 0.85 mm as a measure of gravel condition for incubating embryos and use the amount of material finer than 3 mm as a measure of expected survival during the emergence stage of embryos (Kondolf, **1988).**

8) Typically the McNeil corer extracts about 10 to 20 kg of sample in each attempt. According to the requirements suggested by Church et al. (1987) [largest particle has to account for less than 1% of the total sample weight, each individual core extraction would be unbiased if the largest stone was smaller than about 40 and 50 mm (for sample weights of 10 to 20 kg, respectively). When the largest particles are bigger than these requirements, results from individual samples should not be analyzed independently. Most likely the total weight of all samples combined is greater than the minimum requirements. This implies that lumping all sample results into a single size distribution always produces an unbiased sample. Tiffs approach is known as a random-stratified composite sample and it has been determined by Wolcott and Church (1991) as the most accurate and time effective way of collecting samples for determining reach average conditions.

III.G QUANTIFICATION OF LARGE ORGANIC DEBRIS

Large organic debris (LED) can be subdivided into three categories: root wads, large woody debris, and debris jams. All of them may have very important effects in channel morphology. Changes in LeD may cause localized changes in water flow direction and velocity at both high and low flows that can cause changes in the rate and location of sediment transport and deposition processes. On a reach scale, an overall increase in LeD can cause changes in the morphological unit type of the channel. The influence of LeD on channel morphology depends on its size relative to channel size, orientation relative to the flow, and height above the bed (Montgomery et al, 1995).

Large organic debris is the only input factor being monitored as part of the channel morphology monitoring effort. Until the input factor monitoring procedure is developed it will be very difficult to determine which one u[' them is responsible for causing most of the changes in channel morphotogy. The procedure presented here allows us to determine whether LeD could be a factor in controlling the shifts in the channel morphological features or not. The main objectives of these methods are to determine the amount (number and/or volume) of large woody debris (LWD) pieces in the channel and to help identify if they are causing any general shift in the variables that quantify the diagnostic features of the channel.

III.G.1 Quantification of Large Organic Debris Level A

This method basically consists in determining the number of LeD pieces inside the channel based on counts performed in every 10 m section of the reach. Minimal training requirements are required for the operators: differentiate LWD, root wads, and debris jams; be able to categorize LWD by size; and identify when a morphological unit is being affected by LOt). it takes one or two operators several minutes to complete the procedures in every 10 m long section of the channel. The method provides a good quantification of the number of LeD pieces in the channel.

IlL G.l.a Materials Needed for a Level A Quantification of LOD

-field notes set up according to Field Form G

III. G. I.b Quantification of LOD Data Collection Procedure Level A

This procedure requires that any level of the plan form analysis methodology is already set up. The procedure is very simple: at every 10 m section identify the LWD pieces inside the channel (See Appendix G for a description of LWD pieces) and categorize them according to size and location within the channel. If a piece spans both zones (See Appendix G for a description of channel zones) then include it as being inside the active channel [Zone 1]. If a piece crosses the boundary between two 10 m sections include as part of the downstream section. Use the second part of the data collection sheet to identify the morphological features that appear to be controlled by the presence of LWD pieces. This could include: bars, pools, bank erosion features, etc.

Field Form G. Suggested field notes setup for Level A- LeD analysis.

Length along center line: from ___ meters to ___ motors

LWD Type	**Inside** **Active Channel (Zone 1)**	**Inside** Bankfull (Zone 2)	Totals
root wads			
small LWD			
medium LWD			
large LWD			
debris jams			
Totals			E all LWD=

LWD Type	**Channel Effect and location (left-right bank or mid-channel)**	**Distance along center line (meters)**
i.e.: medium LWD	i.e.: bar on left bank	i.e.: 135 m

II.G.l.c Quantification of LOD Data Analysis Procedure Level A

Number of pieces per channel width or pieces per channel unit area

The field form setup shown above allows analysts to easily stratify the data by channel zone or by size, or simply to lump all of the data into one single number. Reach average pieces per channel width or pieces per channel unit area can be easily calculated by adding up all of the LWD pieces (either collectively or categorized by zone and/or size) and dividing by total channel length (which could be scaled to channel width) or channel area, respectively. This calculation should be performed for every 10 m section to produce a plot of the number of LWD pieces per channel width (or the number of LWD pieces per channel unit area) versus distance along the center line tape.

III.G.2 Quantification of Large Organic Debris Level B

The Level B analysis follows the same procedure as Level A, but it requires measuring the length and diameter of LWD pieces and determining the general hearing and location of these pieces relative to the channel banks. This procedure has the same training requirements discussed for the Level A methods It takes two operators about live to fifteen minutes to complete this procedure in every 10 m long section of the channel. The main advantage of this procedure over the Level A methods is that it allows volumetric quantification o1: LWD pieces inside the channel.

III. G.2.a Materials Needed to Complete the Quantification of LOD Level B

-field notes set up according to Field Form H

-stadia rod, plan form map, ruler (if combined with Level C plan form analysis)

-short measuring tape

11l. G. 2.b Quantification of LOD Data Collection Procedure Level B

Since measurements of the LWD pieces are taken, there is no need to categorize the data in the field by size. The only distinction that should be done is between root wads, LWD pieces, and debris jams, and their location within the channel zones. Measure the length of individual pieces from the root wad (if present) to the end of log with a tape or stadia rod. For debris jams measure their length, width, and height. When taking diameter measurements of logs measure them at a location that appears to be representative of the average diameter of the log.

Bearing should be categorized as follows:

· *parallel* when the LWD piece makes an angle between 0 and 30 degrees with the general bank direction

· *sub-parallel* - when LWD piece makes an angle between 30 and 60 degrees with the general bank direction

· *perpendicular*- when LWD piece lies between 60 and 90 degrees from the direction of banks.

[Note: Do not spend too much time determining the angle between the bank and the log bearing because these categories are arbitrary and an actual measurement should not significantly increase the confidence in our analysis,]

When determining the location of individual pieces relative to the bank categorize them like this: next to left (lb) or right bank (rb), in the middle of the channel (mch), or spanning the entire channel width (sp). Also, determine whether the piece is considered a ramp, bridge, or a raft.

I['a Level C plan form analysis is being used then the length along the LWD does not have to be measured (do not use Field Form G). First, locate the downstream end of individual LWD pieces and determine the distance along the center line where it is located. Measure the perpendicular distance from the tape to the LWD piece and locate this on the map with the aid of a ruler. Then use a tape, calipers, or rod to measure the diameter of the piece and again plot this on map. Find the upstream end of the log and repeat the procedure. Performing this procedure might be very tedious in reaches with a lot of LWD pieces. One thing that could be done is to only include in the map pieces larger than certain size criteria or include only the pieces having an effect in morphological features and debris jams.

Field Form H. Suggested field notes setup for Level B- LWD analysis.

Length along center line: from___ meters to __ meters

LWD id #	CL distance (m))	length (m)	diameter of piece or Db dimensions (m)	general bearing (ll, sub-ll, or I)	Location within channel	Channel Zone effects	Position
1- Lg	175 3.3		0.7	sub ll	right bank	bar i I	raft

Identify the type of LWD piece being measured with the following format: Root wads (Rt), individual pieces (Lg), and debris jams (Db).

11. G. 2. c Quantification of LOD Data Analysis Procedure Level B

Similar analysis done for Level A can be performed with this data. Data could also be stratified by bearing relative to banks and location of pieces within the channel. The same analysis can also be done with volumetric estimates of LWD inside the channel. Volume of individual LWD pieces can be calculated from this data by using the following formula:

$$V = L * \sim (d/2)^2 \qquad \text{(eq. 12)}$$

where,

V is the volume of individual LWD pieces.
L is the length of the LWD piece.
d is the diameter of the LWD piece.

Volumetric relationships between specific LWD pieces and morphological features can be determined. Also, reach scaled volumetric quantification of LWD loading can also be calculated by adding up all of the LWD pieces in the channel and dividing that number by either the total length of the channel (which could be scaled to channel width) or the total area of the reach.

III.G.3 Quantification of Large Organic Debris Level C

Level C conducts the same analysis done for Level B, except that it is more strict in determining the portions of the individual pieces found within each channel zone (See Appendix G for definition of channel zones). Since measurements of the LWD pieces are taken, there is no need to categorize the data in the field by size. The only distinction that should be clone in the field is between root wads, LWD pieces, and debris jams. This procedure has the same training requirements discussed for the Level A methods. It takes two operators about five to fifteen minutes to complete this procedure in every 10 m long section of the channel. The main advantage of this procedure over the Level A methods is that it allows volumetric quantification of LWD pieces inside the channel

III.G.3.a Materials Needed to Complete the Quantification of LOD Level C

field notes set up according to Field Form I
-stadia rod, plan form map, ruler (if combined with Level C plan form analysis)
short measuring tape

III.G. 3.b Quantification of LOD Data Collection Procedure Level C

Follow the same procedure described for Level B, but first identify the height of the zone boundaries found within each 10 m section. Then measure the length of each piece within each one of the two zones. We recommend using a field notes format similar to the one shown as Field Form I.

Field Form 1. Suggested field notes setup for Level C- LOD analysis.

Length along center line: from ___ meters [o meters

LWD id#	CL [distance	**length** in Zone 1 (m)	**length** in Zone 2 (m)	**diameter (m) or Db dimensions**	**general bearing** (11, sub-ll, or I)	Location within **channel**	**Channel effects**
#1 Lg	**[175**	2.0	1.3	0.7	sub ll	**right** bank	

Identify the type of LOD piece being measured with the following format: Root wads (Rt), individual pieces logs (Lg), and debris jams (Db). For debris jams measure the length width and height.

If a Level C plan form analysis is going to be used together with this LOD procedure then Field Form i should not be used. First, locate the downstream end of individual LOD pieces and determine the distance along the center line where it is located. Measure the perpendicular distance from the tape to the LOD piece and locate this on the map with the aid of a ruler. Then use a tape or rod to measure the diameter of the piece. Find the location where the piece crosses the zone boundaries and repeat the procedure (do the same for upstream end of log). Performing this procedure might be very tedious in reaches with a lot of LOD pieces. One thing that could be done is to only include in the map pieces that appear to be affecting morphological features.

III.G. 3. c Quantification of LOD Data Analysis Procedures

Use the same data analysis procedure used for Level B (Section III. G.2.c). Level C analysis produces the same results as for Level B analysis, but the data may also be stratified by channel zone.

III.H BANK EROSION

Determining the rate of bank erosion is very important for channel monitoring purposes. An increase in bank erosion rate not only creates different localized changes in the channel hydraulic conditions, but also increases the amount of sediment being supplied to the stream which can induce further changes in channel morphology. Given the fact that bank conditions may change abruptly from year to year we strongly recommend performing the procedures presented in this section once a year.

The Level A procedure described below provides a method to describe stream bank composition and weathering state. The area covered by each composition-weathering state category and the area covered by stream bank mass wasting features is then used to calculate a general erosion rating for the stream banks. Level B uses the same stream bank identification method described for Level A, but it also requires measuring the size of stream bank landslide features. By performing these measurements the method provides a way to determine the volume of sediment being dumped into the channel by mass wasting events occurring on the banks. Level C may use the same approach described for levels A or B, but it also provides methods that allow the quantification of the volume of sediment being eroded by mass wasting and/or surface erosion processes from relatively large portions of the channel.

Ill. ILl Level A Bank Erosion Methods

The Level A procedure requires the identification of: bank composition (general rock type and weathering stage classification); areas in the bank suffering from the effects of flow convergence; bank cover density; and stream bank landsliding features. Identification of bank composition has to be performed only during the initial channel survey. Monitoring at this level is based on determining changes in bank cover density, changes in flow convergence, and by identifying and quantifying the number of landslides found along the hanks. This method is based on an arbitrary rating system and the values that result from the procedure should not be treated as absolute. That is, differences in the magnitude of the rating values between two different stream bank sections should nut be considered as if they directly relate to differences in the amount of sediment being eroded from them. The main goal of this procedure is to produce a qualitative description of stream bank condition, not to accurately determine their actual erosion rates.

The methods should be performed by one or two operators inside every 10 m long channel section and it only requires about five to ten minutes to complete. Operators must be able to: differentiate between alluvial, colluvial, and bedrock deposits; estimate cover density; determine the weathering and strength state of banks; and identify stream bank landslide features.

III. H./.a Materials Needed to Complete Level A Bank Erosion Methods

- field notes prepared as Field Form J

III. H. /.b Level A Bank Erosion Data Collection Procedure

The procedure may be included as part of any level of the plan form analysis procedure (Section HI.A). The method consists of three steps.

· Visually estimating the percentage of the stream bank area composed of different lithological types, their respective weathering-strength classifications, and covet' density. A very detailed description is unnecessary, it is enough to identify whether stream bank is: alluvial, colluviaI, or bedrock; determine its weathering state and strength (based on Tables 6 and 7); and estimating its cover density based on (Table 8).

· Identifying stream bank areas being affected by the convergence of flow due to the general plan form of the channel or forced by obstructions.

· Estimating the percentage of stream bank area affected by stream bank landsliding.

Identification of Stream bank Lithological Type

Identify bank lithological type by determining its general origin of formation. Operators should identify whether the bank materials were "recently" deposited by alluvial or colluvial processes or if they can be classified its bedrock. For alluvial or colluvial deposits operators should determine their dominant particle size: course grained (mostly boulders and cobbles), medium grained (mostly gravels), or fine grained (mostly sands, silts, and clays) [Refer to Table 5 for particle size classification system.].

Identification of Stream bank Weathering and Strength Condition

Use Tables 6 and 7 to determine the weathering and strength classification of the materials making up the stream banks.

Table 6. Weathering Classification

Name	Description
flesh	no visible sign of weathering
faintly weathered	weathering_limited to surface of major discontinuities
moderately weathered	weathering extends through the rock mass, but rock is not friable
highly weathered	weathering extends through the rock mass and rock is partly friable
thoroughly weathered	wholly decomposed and friable, retains rock structure and texture
residual soil	soil with the original rock texture, structure, and composition completely destroyed

Table 7 Strength classification.

Name	Description
very strong	resists heavy ringing hammer blows
strong	withstands heavy ringing hammer blows, but yields large fragments
moderately strong	withstands few ringing hammer blows before breaking into pieces of various sizes
weak	unfractured bank crumbles under light hammer blows
friable	crumbles by rubbing with fingers
plastic	easily deformed by finger pressure

Identification of Stream bank Cover Density

This analysis is based on a visual estimate of the total bank area that is protected from the direct action of water flowing through the channel. Things that can be considered as coverage arc: large boulders, logs lying along the bank, living trees, any other types of vegetation, etc. Use the simple classification shown in Table 8 to identify stream bank cover density.

Table 8. Cover density classification.

Cover Density (%)	..... **Name**
0- 30	uncovered
30 - 70	moderately covered
70- 100	covered

We recommend using a format similar to Field Form J for data collection.

Field Form J. Suggested setup format for a Level A procedure.

Distance along center line: from to .

	Composition	% Area	Weathering	Strength	Cover Density	Vertical Location	Flow Convergence
Left Bank	fine grained igneous rock	50	highly weathered		0	<If	No
	coarse grained alluvial	40		rood. strong		lf-bf	Y LWD
landslides	alluvial	10				> bf	No
Right Bank	fine grained igneous rock	50	highly weathered	friable	**100-1wd** piece	<If	No
	coarse grained alluvial	30		mod. strong	30	If-bf	No
landslides	alluvial	20				> bf	No

Note: In column named *vertical location,* identify the approximate vertical location of each unit relative to low and bankfull flow using the following guidelines: below low flow- (<11); above low flow but below bankfull- (If-bf); above bankfull (>bf). In the column named flow *convergence* identify whether it occurs on the bank with a "yes" or a 'no". If it is a "yes" identify what is causing it: LWD, boulder, bend in the channel, bar, or any other feature.

IlL H. 1. c Level A Bank Erosion Data Analysis Procedure

The first task that should be completed when analyzing the data collected in the previous step is to describe the bank condition in every 10 m long section. In order to do this we will present a procedure that provides a simple repeatable method that integrates all of the data collected to qualitatively describe the relative erosion rates of the stream banks. This procedure is based on arbitrarily assigned values of erosion rates to the different characteristics that arc identified during the channel field survey. The main purpose of this procedure is to identify the stream bank areas suffering from high and low erosion rates and not to quantify the actual rate of stream bank erosion. Erosion rates are largely dependent on bank composition, cove)' density, and flow convergence, and the procedure described here uses these characteristics in a very simple qualitative approach. In this approach bank composition (hank type and weathering-strength class) provides the initial erosion rate value that describes the potential of bank erosion.

Cover density and flow convergence data are then used to adjust these initial numbers to produce a erosion potential rating. Table 9 shows the arbitrarily assigned bank erosion potential values according to bank composition type, weathering stage, and strength characteristics. Tables 10 and 11 show the adjustments that have to be made to the erosion potential values determined from Table 9 based on cover density and flow convergence respectively.

Table 9. Arbitrarily assigned bank erosion potential values based on bank composition type and weathering strength characteristics.

Weathering-Strength Characteristic	Coarse-Grained Alluvial	Medium-Grained Alluvial	Fine-Grained Alluvial	Bedrock
fresh to faintly weathered very strong to strong	1	**2**	**3**	l
rood. to highly weathered rood. strong to weak	2	3	4	2
thoroughly wealth to res. soil friable to plastic	3	4	5	3

[Note: All areas covered by stream bank landsliding features should be assigned the highest rating (number 5).]

Table 10. Cover density adjustments made to bank erosion potential values assigned from Table 9.

Cover Density (%)	**Adjustment**
0- 30	add I
30 - 70	no adjustment ....
70-100	subtract I

Table 11. Flow convergence adjustments made to bank erosion potential values assigned from Table 9.

Flow Convergence	**Adjustment**
Yes	add 1
No	no adjustment

Once the total bank erosion rating value of both right and left stream banks has been calculated for every I 0 m long section, analysts should use Table 12 to describe stream bank erosion. If a Level C plan form analysis procedure is being used, these descriptions should he included in the plan form map.

Table 12. Bank erosion rating descriptors.

Value Total	Erosion Rating
1	Low
2	Moderate
	High
>4	Very High

To calculate the average rating for each bank at every 10 m section use the following formula:

I ER = 15 (ER rating i)* (Area i) (eq. 13)]

where,

ER is the average erosion rating for each bank in every 10resection.
El? rating i is the erosion rating value {'or every bank composition type.
Area i is the percentage of the total area covered by each composition type.

Ill the sample data presented in Field Form J, the erosion ratings calculations would be conducted as follows.

Left Bank

igneous rock

ER		= 2
Cover density adjustment		= +1
Flow convergence adjustment		= 0
Total ER		= 3
Category	High Erosion Rating	

Coarse-grained alluvial

ER		= 2
Cover density adjustment		= 0
Flow convergence adjustment - 1		
Total ER		- 3
Category	High Erosion Rating	

Right Bank

igneous rock

ER		= 2
Cover density adjustment		= -1
Flow convergence adjustment		= 0
Total ER		-1
Category	Low Erosion Rating	

Coarse-grained alluvial

ER		= 2
Cover density adjustment		= 0
Flow convergence adjustment - 0		
Total ER		= 2
Category	Moderate Erosion Rating	

Left Bank ER Totals = 3 (50%) 4- I (40%) + 5 (10%)	-- 23.2	High Erosion Rating
Right Bank ER Totals - I (50%) + 2 (30%) + 5 (20%)	- 2.1	Moderate Erosion Rating
Average ER for entire section	- 2.65	Moderate High Erosion Rating

The results from this analysis could be plotted in two different ways. A histogram showing the frequency of each of the erosion rating categories calculated for the entire reach could be prepared. Also, the erosion rating results from each one of the 10 m sections of the channel can be plotted versus distance along the reach center line. This plot would then permit comparing the effects of changes in LWD loading in bank erosion rates at specific sections of the channel.

III.H.2 Level B Bank Erosion Methods

Level B stream bank monitoring generally follows the same field data collection procedure as Level A, but it requires calculating the amount of sediment being supplied by stream bank landsliding. Volumetric analysis of the amount of sediment being supplied by stream bank mass wasting processes can be conducted with this procedure. Operator requirements fur conducting this procedure are the same as for Level A. One or two operators may perform the procedure described in this section in about 10 minutes.

IIII.H. 2.a Materials Needed to Complete Level B Batik Erosion Methods

field notes prepared as Field Form J and K
-stadia rod or tape measure

III.H. 2.b Level B Batik Erosion Data Collection Procedure

Follow the same procedures described in Section III.H.2.b.

When collecting stream bank landsliding data we recommend using a field book setup similar to Field Form K. While conducting survey attempt to determine the average dimensions of the landslide scars and measure them with a tape. Approximate the shape of the feature to any simple geometrical shape and measure its main axis. The most common geometrical shape encountered is a rectangular or "box-shaped" feature. When this is the case measure its width, height, and depth. This method provides a good calculation of the amount of sediment deposited into the stream from stream bank mass wasting processes.

Field Form K. Level B stream bank landsliding data collection format

Distance along CL	Bank	Height	Width	Depth	Vertical location
175 m	right bank	1.5	2	.5	>bf

III.H.2.c Level B Bank Erosion Data Analysis Procedure

To calculate landslide scar volume simply multiply height, width, and depth assuming that the volume of the scar can be approximated by a box-shaped feature. Add up volume calculations of all landslide scars encountered in the reach to determine the amount of sediment that has been supplied to the channel by this process.

III.H.3 Level C Bank Erosion Methods

The Level C bank erosion procedure consists of the application of one or several methods that provide a very good quantification of erosion rates over a section of the study reach. Level C analysis should not be conducted without previously determining the condition of the banks by either a Level A or B procedure. The specific objectives of the survey should drive site selection for instrument installation. In order to do this, well defined goals of the stream bank survey have to be established. The two most common goals of a stream bank survey are:

· To determine roach maximum erosion rates- This is done by installing instruments at bends or at other high erosion rate areas that have been identified during the Level A or B survey.

· To determine reach average erosion rates-- This is done by selecting sites based on a random-stratified selection procedure. The procedure should be as follows:

a) Conduct a Level A or B stream bank composition analysis.

b) Prepare a stream bank rating category histogram.

c) Determine the total number o[stream bank sections to be monitored (this depends on time and economic restrictions).

d) Use the stream bank erosion rating histogram to determine the number of sites to be monitored per rating category

e) Randomly select the specific locations to be surveyed from Level A or B data.

f) install equipment and take measurements.

The methods recommended for a Level C analysis are:

· bank profiling

· radial surveying

· erosion pins

III.H.3.1 Bank Profiling

The main advantages and disadvantages of this method are discussed in Appendix D. The method is most useful and accurate for vertical or nearly vertical banks with a very complicated geometry, if the equipment is well located, it can measure even extremely high rates of bank erosion by mass wasting and/or surface erosion. The method can be performed by two operators, but three arc recommended.

III.H.3. l.a Materials Needed for Bank Profiling

several 0.75 to 1.0 m long *1/2"* diameter rebar stakes

-sledge hammer

-measuring tape

-2 stadia rods (one of them with vertical leveling bubble)

-Brunton compass

-metallic tape

IlL H. 3./.b Bank Profiling Data Collection Procedure

Once the specific channel section where the measurements are going to be taken is chosen, the operators may follow the procedure described in this section. The procedure consists of two steps: setting temporary benchmarks and conducting profile survey.

Temporary Bench Mark Setup

Temporary bench marks (TBM's) have to be set on relatively flat ground at an elevation higher than bank edge. Typically they are set on floodplains or on low terraces right next to the bank edge. TBM's have to be set far enough from the bank so that they are not affected by bank erosion. At least two TBM's have to be set but more than two are usually used. The idea is to set TBM's st) that a tape attached to them generally follows the direction of the channel banks. Pound stakes vertically into the ground with the sledge hammer and leave about 20-30 cm protruding from the ground. Make sure you include the location of the stakes in the sketch or plan form map. Label each stake with the following format:

Name of stream/Project name/bank profile/date/rebar id. # I

The stake identification number is actually composed of two numbers. The first one is the bank profile number (bank profile group number) and the second one is the individual stake number that identifies the stake location within each set (both are assigned starting at the downstream end of reach).

Bank Profile Survey

a) Attach a tape along all TBM's (attach zero end to downstream TBM and stretch the tape up stream).

b) Take a bearing reading from downstream TBM to next one lying upstream.

c) The operator with the rod stands right next to the downstream stake.

d) Place one of the rods horizontally on the ground lying perpendicular to tape direction.

c) Take rod with level and place it at the bed-bank boundary (rod bottom should be resting on the bed), use the level to keep it vertical, and use rod lying horizontally to determine the horizontal distance from the tape to this rod.

l) While one operator keeps the rod vertical right next to the bank, another one measures and records the horizontal distance from the rod to the bank at several elevations: bottom of rod, compositional boundaries, obvious changes in slope, water level, bankfull indicators, and top of the bank.

g) Once the entire height of that section of the bank has been surveyed, move upstream along the tape (at a predetermined constant length), record this distance, and repeat steps 2d-2e I Note: Bank profiles measured in subsequent years should be performed at the same distances along the tape where initial surveys were conducted.] Continue until the upstream TBM is reached.

We suggest setting up field book following the format shown in Field Form L.

Field Form L. Data collection setup recommended for Bank Profiling

Bank Profile # __ Distance along center line tape from to

rod **elevation**	distance from vertical rod to bank	**Distance** along bank profile tape	Distance from tape to vertical rod	Elevation where horizontal rod intersects vertical rod	Observations

III.H.3.1.c Bank Profiling Data Analysis Procedure

To determine the amount of sediment that has been eroded by mass wasting and/or surface erosion processes, a plot of elevation versus distance from the tape should be prepared (See Figure 8). Plot it with a grid so that the area of sediment lost by erosion can be estimated. To conduct volumetric analysis, average these individual areas and multiply them by the total length of the bank profile. To get erosion rates use the following formula:

I erosion rates = V / (t * A) (eq. 14)_]

where,

erosion rates have the dimensions of m/yr.
V is the volume of sediment lost by erosion (m3).
t is the time between profile surveys (years).
A is the total area of the stream bank where the profile was conducted (m2).

Erosion rates could be either averaged for the entire reach or stratified by rating classification. Reach averaged results should be interpreted with care because the site selection criteria only considers the channel bank characteristics and neglects other criteria that could be very important in determining bank erosion rates (i.e., bank slope).

III.1t.3.2 Radial Surveys

Radial surveys are very useful when stream bank erosion rates of cutbanks at sharp bends need to be determined. In these areas the bank profiling technique (described in section III.H.3.1) is difficult to set up, and erosion pins will likely be lost due to the high erosion rates typical of these areas. Radial surveys can be performed in three different ways:

a) Following a cross-section surveying approach. This is useful for gently sloping banks and when a very detailed description of the active channel is needed.

b) Following a bank profiling approach. This is useful filE' very steep banks with complex shapes.

c) Using a combined cross-section surveying-bank profiling approach. Useful when a detailed description of both channel and bank is required.

III.H.3.2.a Materials Needed for Radial Surveying

-rcbar stakes 1/2" diameter by I m long [Note: one rebar is needed if the bank profiling approach is used, and several are needed for the other two methods]

-sledge hammer

2 measuring tapes (at least 30 m long)

-bright colored spray paint

-flagging

-permanent ink marker

-Brunton Compass

-stadia rod (if bank profiling technique is going to be used a rod with a vertical level is needed)

-metallic tape (only needed if bank profiling is done)

-hand level (only needed if cross-section surveying approach is used)

III.H.3.2.b Radial Survey Data Collection and Analysis Procedure

TBM Setup Procedure

Once the site where monitoring is going to take place has been chosen, select the upstream and downstream boundaries of the survey. Attach measuring tapes to banks in the cutbank side of channel at these locations and stretch to the point bar side of channel. Find the location (on point bar side) above bankfull (if vegetation permits) where the distance from the upstream boundary location to that point equals the distance from the downstream boundary location to that point. In that exact location the TBM should be installed. Pound rebar stakes plumb and leave about 20 cm protruding from the ground. Spray paint protruding end and tie up flagging with the following information:

Stream name/project name/radial survey point bar TBM/distance along center line tape/date I

If a cross-sectional surveying or a combined surveying and profiling approach is being used, several TBM's have to be set on cutbank side of channel. The number and spacing between TBM's vary depending on desired accuracy and bank complexity. Pound stakes plumb into the ground above bankfull at a distance from tile bank where the), will not be affected by bank erosion. Leave about 20 cm protruding from the ground, paint them with bright colored spray paint and identify these with a flagging containing the following information:

Stream name/project name/radial survey cutbank TBM #/distance along center line tape/date]

[Note: TBM identification numbers are assigned from downstream to upstream end. Make sure to include the TBM locations in the sketch or plan from map.]}

If a bank profiling procedure is being used then a different approach may be applied to determine the exact location where measurements are going to be taken. An operator with a Brunton compass stands right above the TBM on the point bar side of channel and takes a reading to the exact location where the bank profile is going to be measured. The operator has to be very precise when doing this because, for a very precise analysis, it is recommended that subsequent profiles are measured in the exact same spot. This approach eliminates the need to set up TBM's on the cutbank side of the channel.

Radial Surveying Procedure

· If the cross-section survey procedure is being used, follow the procedure and analysis discussed in Levels A and B Cross-section surveying methods (See Sections III.C. 1 and III.C.2).

· If the bank profiling technique is used on it's own, follow the instructions described in this section for bank profiling (Section 1II.3.1.b).

· If the combined method is being used, follow the data collection and analysis procedure described in Level C Cross-section surveying methods (Section III.C.3). [Note: The only difference is that instead of choosing profiling or cross-section sites based on a tape lying parallel to the channel direction or distance along the channel center line, specific locations of sites are identified by bearing readings taken from the TBM on the opposite bank.]

III.H.l.3.3 Erosion Pins

Erosion pins are useful to quantify relatively low erosion rates caused by the action of water flowing in the channel, but they can't be used to determine high erosion rates. They are very cheap, easy to install and measure, and require minimal operator training. [See Appendix D for a complete discussion on the method.)

III.H.3.3.a Materials Needed to use Erosion Pins

-sledge hammer

-metallic measuring tape

-field book

-bright color spray paint

-pins- Pins could be from 2 rain diameter nails to 1/2" diameter rebar stakes (8" inch barn spikes are commonly used). Thinner pins are preferred but they should be thick and strong enough so that they do not bend while they are being pounded into the banks. Length of pins can range from about 30 cm to about 1 in.

111. H. 3.3. b Erosion Pin Data Collection Procedure

Pits setup

a) Choose measurement site locations according to the objectives of the stream bank survey [use the same guidelines discussed in Section III.H.3]

b) Once specific areas have been selected pound in erosion pins so that they lie normally to bank surface. Leave 5 or 10 cm of pin protruding from bank and make notes of this length in your field book. At least three columns and fore' rows of pins should be installed in each site. If the objective of the survey is to determine the reach-average erosion rates or only the maximum rates, pins should be set the following way: Columns should be about I m apart and spacing between rows is variable depending on bank height and the location of bankfull indicators and low flow conditions. We recommend setting one row close to low flow conditions, one row between low flow and bankfull, one at about bankfull height, and the last row placed above bankfull If the analysts want to determine the erosional rates of specific compositional milts found along the banks then a row should be set at every compositional unit found in the section. Make sure pin locations are identified in the sketch or plan form map.

c) Paint the pin heads with bright spray paint.

d) Identify pins by using Field Form M.

Field Form M. Suggested field notebook format for erosion pin setup

Erosion Pin group #

Height of low flow above bed ___ Height bankfull above bed

Total Height of stream bank __ Initial pin protrusion length __

1

Pin Id #	**height of pin above bed**	**Compositional Unit**	**Vertical location** (<lf,lf-bf, or >bf)
130/2/3	0.50 m	fine grained alluvial	lf-bf

[

Measurement procedure

a) Identify pins by their location along the center line tape, column, and row. Always start at the bottom and downstream end of grid setup when labeling them. For example, a pin identified like this: 130/2/3, is the third pin (from bottom to top) of the second column found at about 130 m along the center line tape.

b) Measure the distance from the pin head to the bank surface with the metallic tape measure.

c) Use the sledge hammer to pound in pin until only 5 to 10 cm of pin is protruding from bank surface (whichever was used during the initial survey).

We suggest setting up the field notebook following the format shown in Field Form N.

Field Form N. Suggested field notebook setup for collecting erosion pin data.

Date of last pin survey

Pin Id #	Protrusion length
130/2/3	0.25 in

111. H. 3.3.c Erosion Pln Data Analysis Procedure

Erosion data from erosion pins can be easily converted into erosion rates with the following formula:

$$\text{erosion rate} = (L1 - L0) / t \qquad \text{(eq. 15)}$$

where,

erosion rate has the dimensions of m/yr.

L! is the length measurement from the lop of the pin to the bank surface (m).

LO is the original length of the pin left protruding from the hank surface On).

t is the time elapsed between the two measurements (years).

Data can be analyzed in three different ways depending (m the specific goals of the stream bank monitoring effort:

a) Determining the erosion rate of the entire stream bank column.

b) Stratifying erosion rates by vertical location (below low flow, between low and bankfull flows, and above bankfull).

c) Stratifying erosion rates by bank compositional units.

These goals of the stream bank monitoring effort have to be considered when using equation # 16 (as explained below). This equation permits the calculation of the volume of sediment lost by surface erosion for any location.

$$V = \text{erosion rate} * \text{Area} \quad \text{(e\% 16)}$$

where,

V is the volume of sediment eroded from stream bank from: entire bank condition (objective a); vertical location (objective b); or individual compositional unit (objective c) [units: m^3]-

erosion rate is the rate calculated by: averaging erosion rates from all pins (objective a); averaging rates from all pins located in a similar vertical location (objective b); or averaging rates from all pins located in the same compositional unit (objective c) [units: m/yr].

Area is: the total stream bank area (objective a); stream bank area within each vertical location (objective b); or stream bank area within each compositional unit (objective c) [units: m2).

To calculate the reach average erosion rates all values have to be already weighed. Stream bank areal surveys performed during Level A or B analysis should he used in this step.

III.I CHANNEL PATTERN

Channel pattern is described as the configuration of a river as it would appear from an airplane (Leopold et al., 1964). A way of measuring channel pattern is called *sinuosity* and it is defined as the ratio of channel length to down valley distance. Rates of changes in channel sinuosity are a factor of frequency and magnitude of channel floodplain forming flows, bank and riparian vegetation condition, and sediment loads. Data from aerial photographs, topographic maps, or plan form maps could be used to calculate the sinuosity of a channel. Changes in sinuosity occur over a long period of time and the procedures discussed here should be performed every 3 to 4 years (or us often as aerial photographs or topographic maps arc prepared).

Ill. I.1 Channel Pattern Level A

Level A channel pattern methodology uses maps and aerial photographs to determine the sinuosity of a channel. Frequency of measurements depends on how frequently aerial photographs or maps of the area are produced. Accuracy of the calculations is expected to be fair because usually topographic maps are not very accurate in plotting specific channel locations, if aerial photographs are used, vegetation can block the view of the channel increasing the error of the measurements.

IlL 1. l.a Materials Needed for Level A Channel Pattern Analysis

topographic maps (any scale) and/or aerial photographs
-map wheel

111.1. l.b Level A Channel Pattern Data Collection Procedure and Analysis

1) Locate the upstream and downstream boundaries of the monitored reach in topographical maps or aerial photographs.

2) Measure the net distance from the downstream boundary to the upstream end of reach.

3) Use the map wheel to measure the total channel length between both boundaries.

4) Calculate sinuosity by using equation 17.

Sinuosity = channel length / down valley distance (eq. 17) I

Ill. I.2 Level B Channel Pattern

No Level B channel pattern methods are suggested in this report.

III.l.3 **Level C Channel Pattern**

The Level C channel pattern methodology requires producing a plan form map by using the Level C Plan form Analysis procedure. Accuracy of the calculations is expected to be excellent and they depend on the accuracy of the plan form map in representing the actual channel pattern. If this level is chosen we recommend making this calculation every 3 4 years.

III.I.3.a Materials Needed for Level Channel Pattern Analysis

-materials shown in Section III.A.3.c

-map wheel

III. l. 3. b Level C Channel Pattern Data Collection and Analysis Procedure

1) Measure the net distance from the downstream boundary to upstream end of reach from the plan form map.
2) Use map wheel to measure the total channel length between both boundaries.
3) Calculate sinuosity by using equation # 17.

III.J FINE SEDIMENT IN POOLS

The amount of fine sediment in pools is a channel diagnostic feature that is both useful for biologists and geomorphologists. Large quantities of fine sediment on the bottom of pools indicate hazardous conditions for fish habitat because it not only reduces the area available as fish habitat but it also indicates high sediment inputs which might be causing increases in fine sediment intrusion rates into spawning gravel patches. In theory, the amount of fine sediment in pools appears to be very sensitive to increases in sediment loading for most channel types (See Tables 2a-2c), but practitioners do not appear to fully agree with this. Practitioners in Washington have observed that methods such as V* are not sensitive to increases in sediment input rates, unless the amount of sediment being (lumped into the channel is extremely high and is close to the surveyed pools. Seasonal changes m the amount of sediment in pools also pose another problem for analysts when trying to interpret this data. We still consider that this diagnostic feature is too important to neglect and that some attempt to describe it (either qualitatively or quantitatively) should accompany every monitoring effort.

III.J.1 Fine Sediment in Pools- Level A

The Level A procedure is based on visual estimates of the percentage of the pool bottom area occupied by fine sediment (defined as sediment finer than 6 mm). The method is more reliable when applied to shallow and small pools where the bottom of the pool is visible The method provides a poor estimation of the amount of fine material accumulating in pools.

III.J. 1.a Materials Needed for Fine Sediment in Pools Level A Analysis

-field notes prepared as in Field Form O

III. J. l.b Fine Sediment in Pools Level A Data Collection and Analysis Procedure

Operators visually estimate the percentage of pool bottom covered by fine sediment (fine sediment defined as fine gravel and finer material- finer than 6 ram). The downstream end location of the pool along the center line channel tape should be identified and noted, as well as: cross-sectional location (next to right or left bank, m mid channel, or spanning the entire channel width) and pool dimensions (approximate length, width and depth). This procedure could be performed while doing the morphological unit plan form analysis.

We recommend using a format similar to Field Form O when collecting field data.

Field Form O. Suggested format for collecting Level A-Free sediment in pools data

Section # __ Distance along center line: from to

Distance along CL	**x-sectional location (rb,lb,mch,sp) ....**	**length**	**width**	**depth**	**%area covered by** fines
125 m	rb	4 m	3 m	0.5 m	30

Averages of the pool bottom area covered by free sediment can be calculated lor every 10 m section and for the entire reach. We recommend plotting both of them in a percent area versus distance along center line graph. This will allow analysts to make comparisons with other diagnostic features and also to see if a given change in the reach average value is due to a reach scale trend or if it is just caused by a large change in a small section of the reach.

II1.J.2 Fine Sediment in Pools- Level B

No level B methods are suggested in this report.

111..1.3 Level C Fine Sediment in Pools- V*

Level C methods require making the measurements recommended by Lisle and Hilton (19!)2) and Hilton and Lisle (I 993) to calculate V*. The method requirements suggested by them are very strict and require a lot of time in the field. This has discouraged practitioners to use the methods as they are described in the references mentioned above. Some practitioners have changed the requirements of the procedure at will. These "new" procedures have not been tested and their accuracy, precision, and/or sampling requirements are not known. Other practitioners have opted not to use the V* methods at all. We believe that the amount of fine sediment in pools can provide very useful information on the amount of sediment entering the channel, but less cumbersome methods to determine V* should be developed and tested. Until then, the current procedure should be strictly followed. In the following section we summarize the guidelines suggested by Hilton and Lisle (1993) for conducting the V* analysis. Analysts interested in implementing the method should read the original papers on V* [Lisle and Hilton (1992); Hilton and Lisle (1993)] because these papers present a detailed description of the theory, the data collection and analysis procedure, and other important suggestions.

III.J.3.a V Methods Data Collection Procedure*

1) Select pools to be monitored. Data from plan form analysis and a long profile survey can be used to identify pools to monitor. Pools should have the following characteristics: significant residual depth; water surface gradient less than 0.05 percent; and they should span most of the channel width.

2) Determine what constitutes fine sediment in the channel. Fine sediment in a reach should be defined as: sediment accumulations much finer than the bed surface (about 10% of bed surface D50), or as all sediment finer than 6 mm. The important thing is that the selected size should be easily distinguished from the underlying coarser sediment when probing with the graduated rod.

3) Measure riffle-crest depth. Water depth at the riffle-crest is determined by taking the median of several depth measurements taken across the thalweg.

4) Set up and survey procedure:

a) Stretch a tape along the length of the pool (from upstream to riffle crest). Make sure the tape is kept straight and that it is tight.

b) Draw a sketch map of the pool including the upstream end, riffle crest, areas of fine sediment deposition, and other major features.

c) Decide on the number of cross-sections and the distance between depth-measurement points. Typically 4 to 10 cross-sections are measured in each pool and about 7 to 16 points are surveyed in each one of them.

d) Determine cross-section location. Zones within the pool with fine sediment deposits should be sampled more intensively than others. If fine sediment is evenly spread over the entire pool bottom divide the total length of the pool by the number of desired cross sections and the result is the distance between each one of them. Choose a random number between zero and this number to locate the first cross-section, anti add the chosen spacing to locate the remaining sections.

e) Stretch a tape across the channel at every cross-section location. Use graduated rod to measure water depth and the thickness of fine sediment at each measurement point.

Title authors make the following general suggestions:

- If a pool is composed of complex and simple sections, it can be divided into two segments, and the more complex segment can be sampled more intensely.

- If most of the fines in a pool are in a few discrete deposits or pockets, their volume can be measured separately.

- Measure all pools at moderately low flows.

- If a reach is being monitored over time, take measurements at approximately the same flow conditions.

- When the object of using the V* method is to monitor changes over time of a single reach, 4 to 5 structurally stable pools should be used for monitoring.

III.J. 3.b V Data Analysis Procedure*

1) Calculate the residual cross-sectional area of fines and water for each cross-section.

2) Set zero-area cross-sections at the upstream and downstream ends of each pool

3) Calculate the average residual cross-sectional area of fines and water between each pair of adjacent cross-sections and multiply it by the distance between them.

4) Add these volumes of water and fine sediment to find the pool totals.

5) Calculate V* for each pool by using equation 18.

[V* = residual fines volume / (residual fines volume + residual water volume) (eq. 18) [

6) Calculate V^*_W by using equation [9.

V^*_W = Z (residual fines volume,) / Z (scoured residual volume) (eq. !9)]

where,

*V*w* is the average of the V*'s for all the pools weighed by the scoured pool volume of each pool.
scoured residual volume is the sum of the residual fines volume and residual water volume.

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FIGURES

Figure 1. Segment Identification Worksheet (form E-1 in WFPB, 1993)

SEDIMENT	DISCHARGE	WOOD	CATASTROPHIC EVENTS
FS -- Fine Sediment Deposition CS - Coarse Sediment Deposition	SC - Scour Depth SF - Scour Frequency BE - Bank Erosion	WL - Wood Loss WA - Wood Accumulation	DFS - Debris Flow Scour DFD - Debris Flow Deposition DB - Dam Break Flood

VW > 4CW UNCONFINED						
2CW < VW < 4CW MODERATELY CONFINED						
VW < 2CW CONFINED						
	<1.0 Pool-Riffle	1.0 - 2.0 Pool-Riffle, Plane-Bed	2.0 - 4.0 Plane-Bed, Forced Pool-Riffle	4.0 - 8.0 Step-Pool	8.0 - 20.0 Cascade	> 20.0 Colluvial

VALLEY GRADIENT AND TYPICAL CHANNEL BED MORPHOLOGY

Figure 2. Example of plot showing channel width measurements at different distances along the center line of the channel

(Data collected at El Yunque National Forest Puerto Rico)

F

41

Bankfull width(m)
Std error bankfull width upper limit (m) J
Std error bankfull width lower limit (m)
Mean bankfull width (m)

50 100 150 200 250

Distance along thalweg (m)

Figure 3. Histogram of morphological unit length along the thalweg

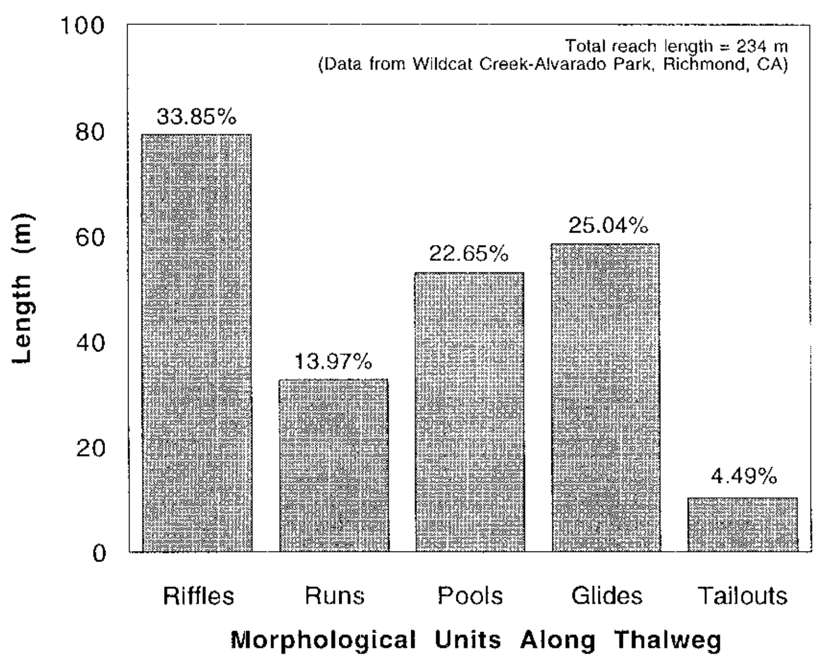


Figure 4a. Example plot of the areal extent of all morphological units within bankfull channel

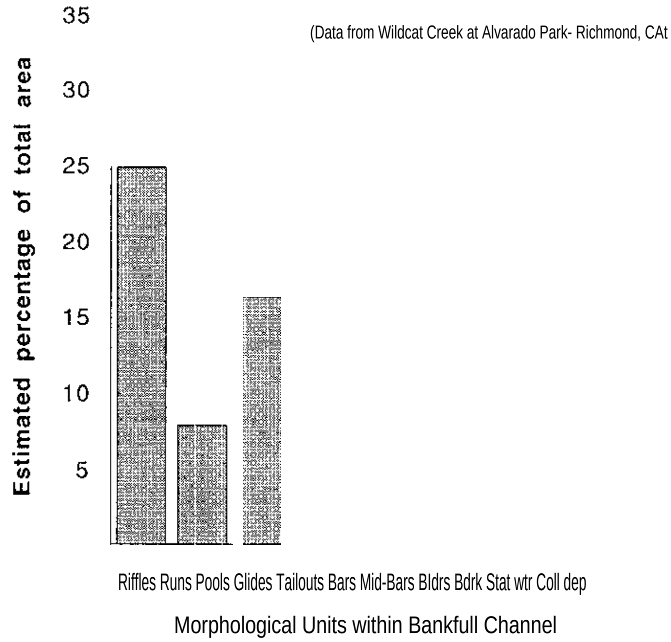


Figure 4b, Example of plot showing the variation in the percentage of different morphological units along the channel

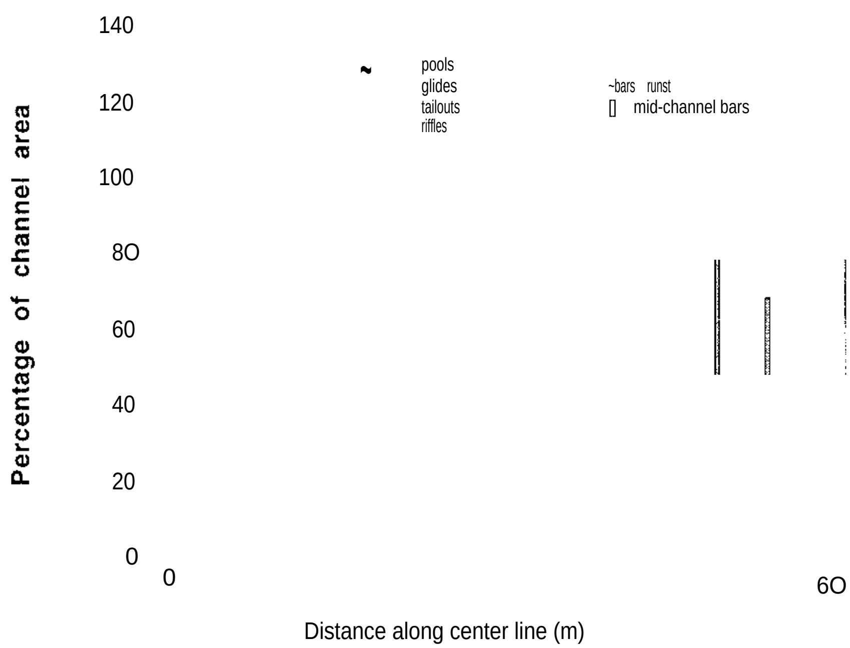


Figure 4c. Example of plot showing the percentage of channel area covered by pools along the channel centerline

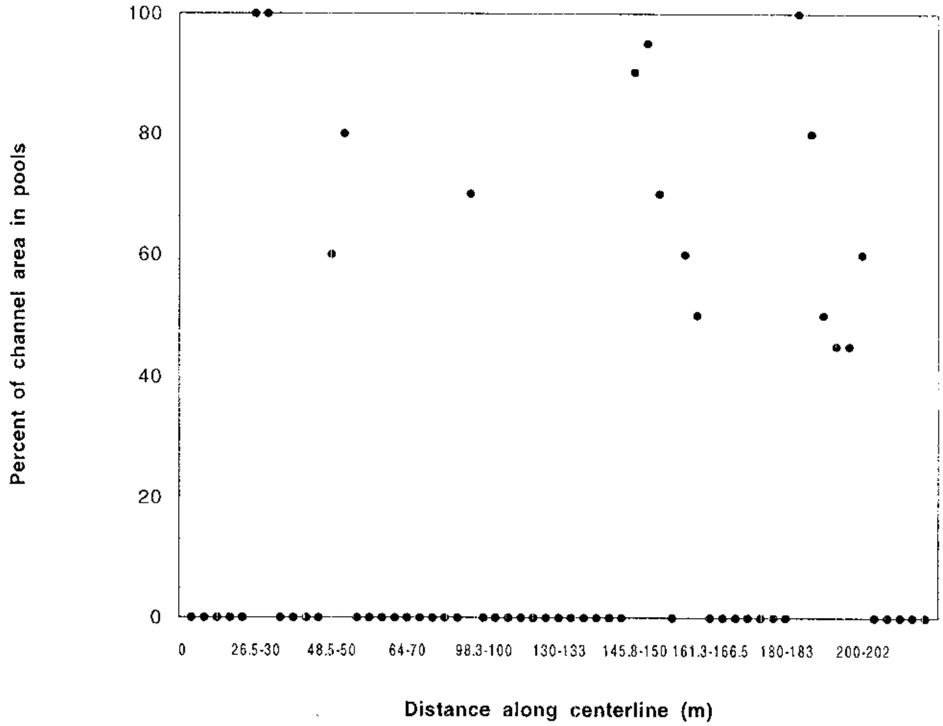


Figure 5. Example of long profile plot with regression line

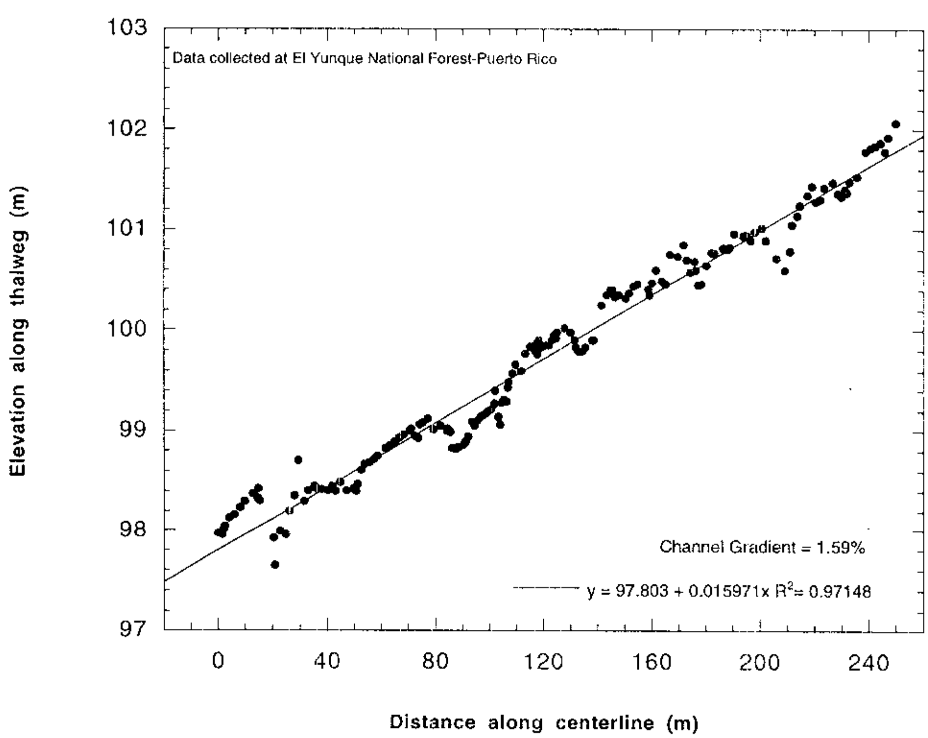


Figure 6a. Bar cross-sectional shape Type I (one-fourth of an ellipse).

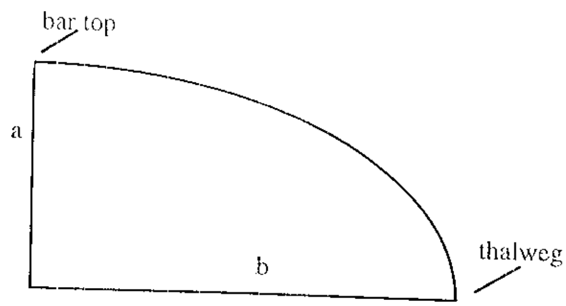


Figure 6b. Bar cross-sectional shape Type II (one-half of an ellipse).

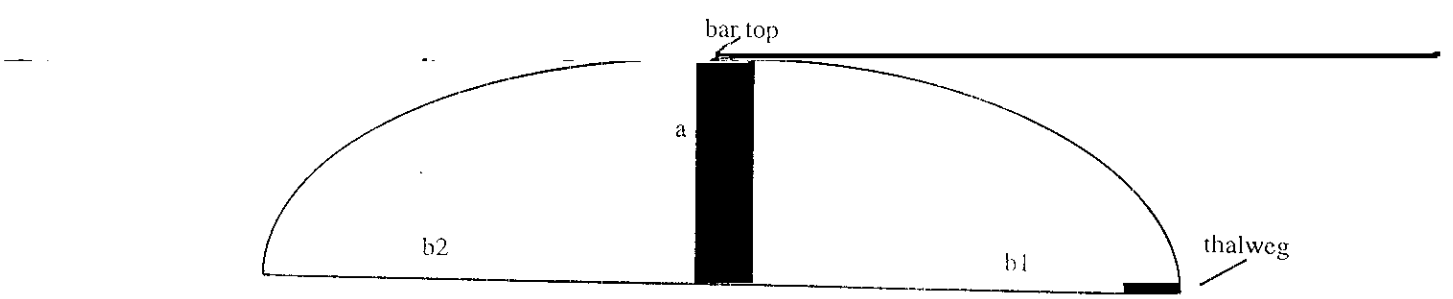


Figure 7a. Example plot of bankfull area versus distance used for analyzing cross-sectional data

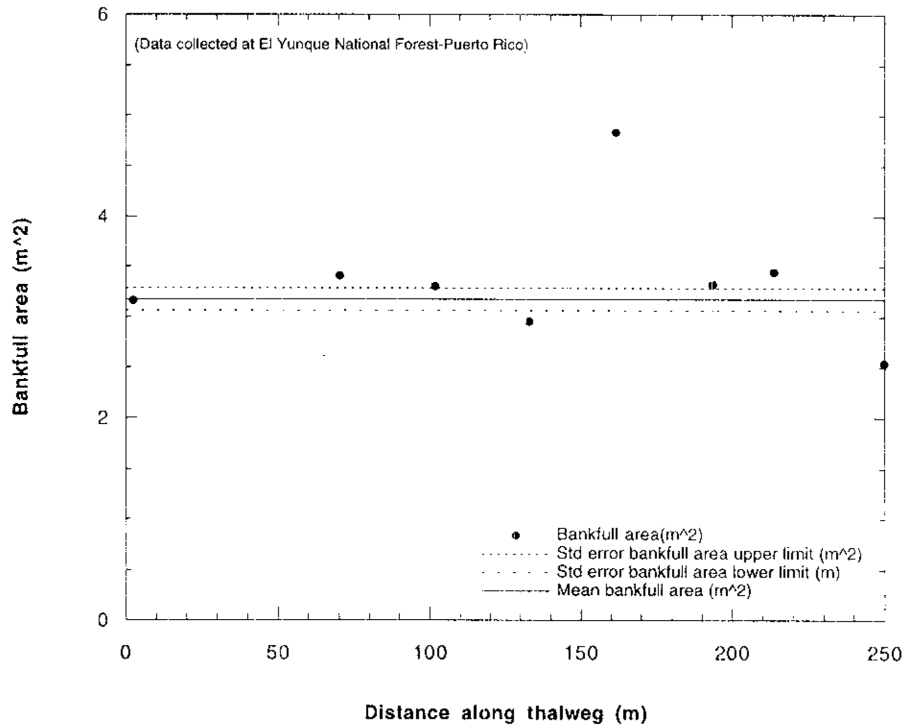


Figure 7b. Example plot of bankfull depth versus distance used for analyzing cross-sectional data

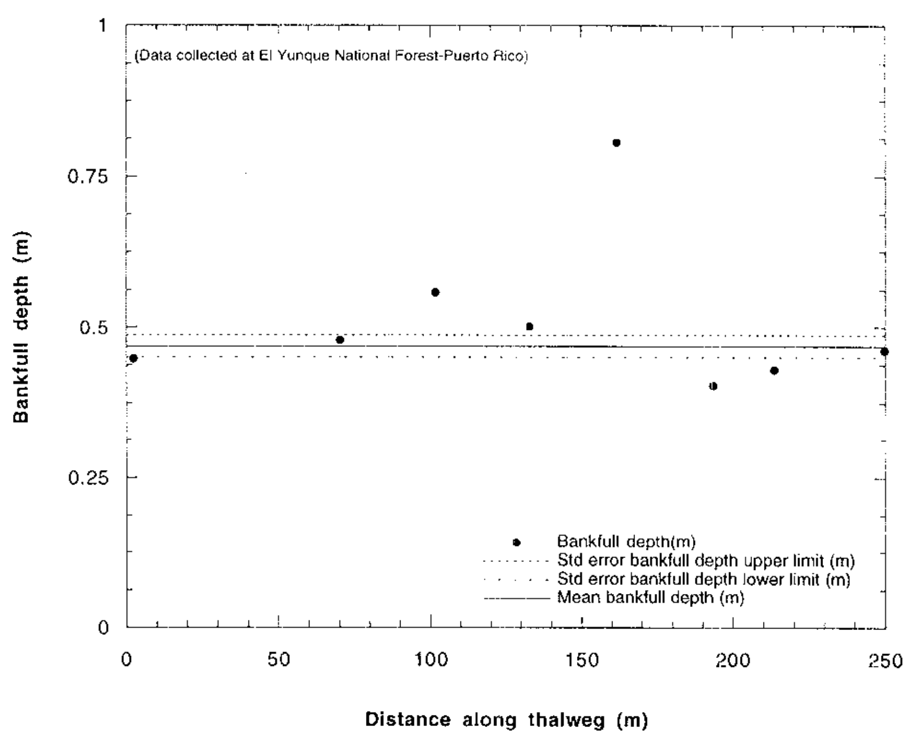


Figure 8. Example of bank profile plots
showing changes in bank shape and location

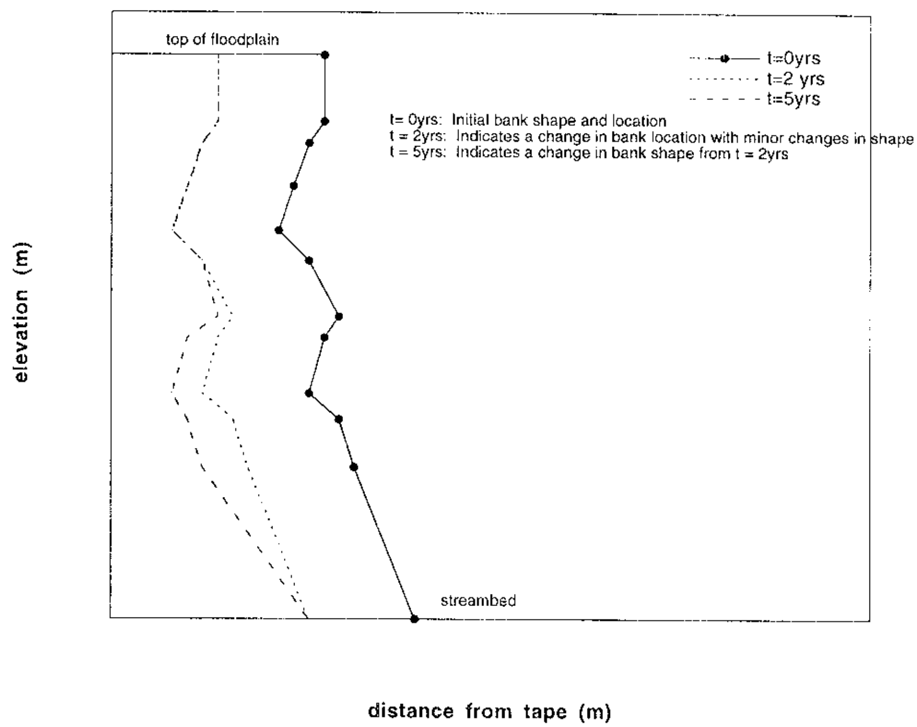
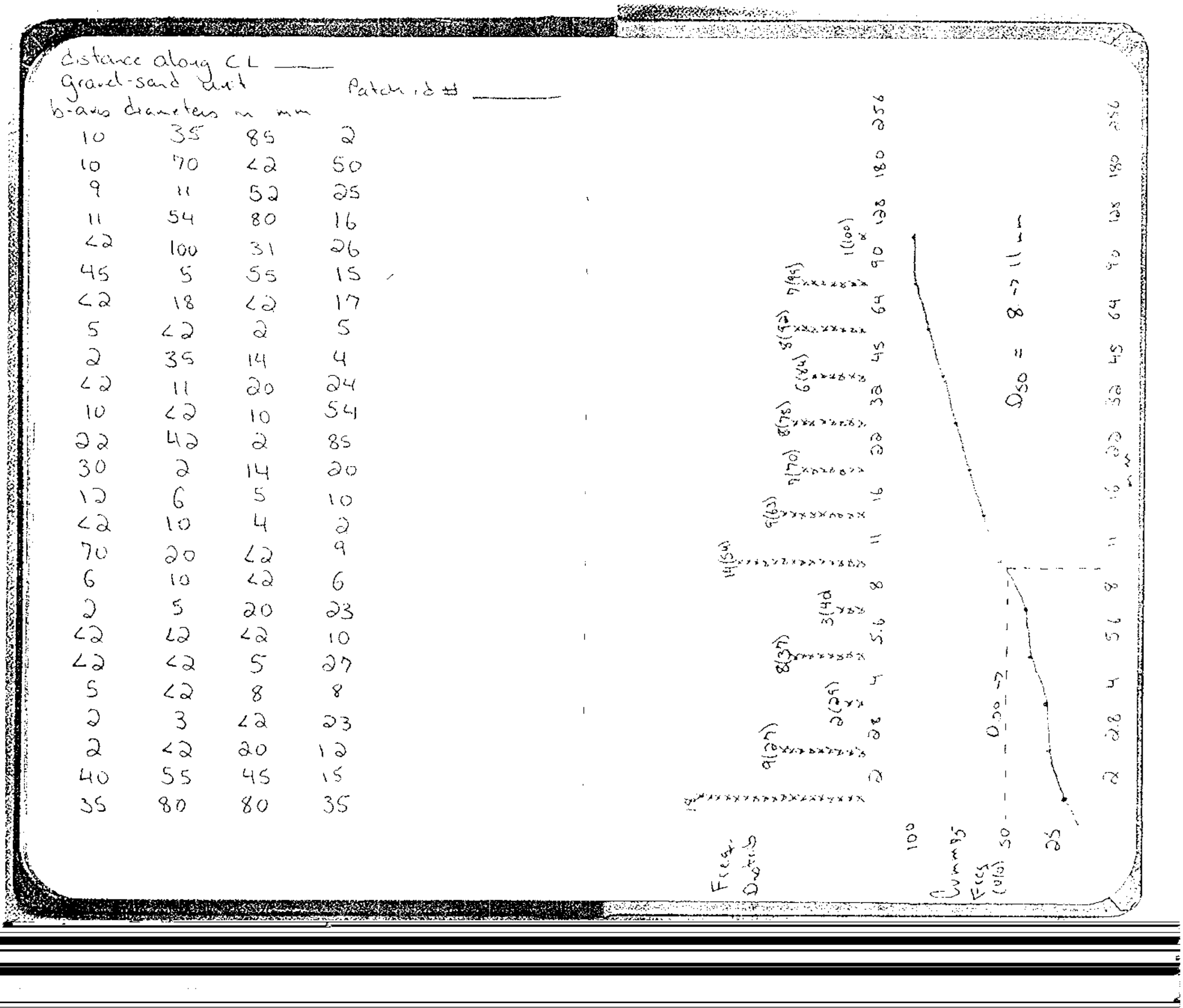


Figure 9. Example of field book setup for conducting pebble counts.



distance along CL ____
Gravel-sand unit
Patch id # ____
b-axis diameters in mm

10	35	85	2
10	70	<2	50
9	11	52	25
11	54	80	16
<2	100	31	26
45	5	55	15
<2	18	<2	17
5	<2	2	5
2	35	14	4
<2	11	20	24
10	<2	10	54
22	42	2	85
30	2	14	20
12	6	5	10
<2	10	4	2
70	20	<2	9
6	10	<2	6
2	5	20	23
<2	<2	<2	10
<2	<2	5	27
5	<2	8	8
2	3	<2	23
2	<2	20	12
40	55	45	15
35	80	80	35

APPENDIX A

STREAMBEI) SURFACE SAMPLING METHODS

A LITERATURE REVIEW

APPENDIX A

STREAMBED SURFACE SAMPLING METHODS- A LITERATURE REVIEW

1, INTRODUCTION

Characterization of the coarse bed surface material in gravel-bedded streams is a very difficult task. Accurate description of the bed surface is important for both geomorphic and biological considerations. Geomorphologists have determined that bed surface materials are essential in understanding processes related to water and sediment routing, streambed stability, and channel form. Biologists have studied the effects of bed surface texture on aquatic habitat condition in streams and they have found that it plays a crucial role affecting fish and invertebrate communities.

It is well known that land use and forestry practices usually cause changes in the particle size distribution of a stream and that these changes may have effects on its habitat condition and sediment transport characteristics. Many different studies have reported the effects of logging practices on stream particle size and the results indicate that changes of the bed surface is one of the most sensitive indicators to changes in watershed condition. As a result many different methods to quantitatively or qualitatively characterize the surface particle size distribution of stream beds have been developed.

An accurate empirically-based quantitative prediction of the effects of logging in the particle size distribution of a stream bed is very difficult to develop from the available studies because of the following reasons: the difficulty in generalizing results to areas with different geomorphic characteristics, different climate conditions, anti distinct channel architectural arrangements; deposition of particles is subject to localized conditions which arc impossible to predict (including both in-channel characteristics and hillslope conditions); impossibility to quantify how differences in the intensity or type of forestry practices applied to the area can affect the response of the bed surface; and unknown compatibility between the large number of surface sampling methods and analysis that have been used to collect the data.

The use of process-based models is currently being tested by researchers and analysts. The use of these types of models to predict surface particle size (for example) for watershed analysis methods is based in the idea that the model results produce the conditions that are expected to be present at specific locations if only the dominant channel processes are affecting the movement and deposition of sediment (W. Dietrich, personal communication). Results are evaluated by determining whether the deviations are caused by limitations of the data used/’or the model (i.e.., incorrect channel gradients resulting from digital elevation data errors or limitations) or by localized channel or hillslope conditions. This might include changes in the major input factors (discharge, sediment loading, and addition of large woody debris) which may be caused by either natural conditions or induced by land management practices. A major drawback of these models (specially at a watershed scale) is that they can only predict one characteristic of the entire particle size distribution, typically the median particle size.

In any case, calibration of these models require the use of an effective method to characterize the bed surface. An effective method should attempt to solve the major problems posed by the bed surface characterization exercise: two-dimensional spatial variability, time variance, and the wide variability of grain sizes found on bed surfaces.

The main purpose of this review is to evaluate the methods used by practitioners to characterize the surface material of stream beds in terms of how suited they are to be used as watershed monitoring tools. Although no field tests were conducted for most of these methods, previously reported data and practitioner experience will be used to make decisions on what methods will be added to the monitoring methodology. Decisions will be rased on all or some of tire following: accuracy, repeatability of measurements by same or different operators, cost of equipment, training requirements, portability of equipment, and analysis requirements. The methods can he divided into the following categories and sub-categories:

a) volumetric sampling

b) areal sampling: areal photos, adhesives, use of paint, and a freezing technique

c) transects: sample every pebble under transect, hybrid with areal sampling, visual estimates under transects, and use of transects on specific morphological units

d) pebble counts: grid sampling over the entire reach, hybrid with areal sampling, grid sampling within a specific Facies units, and the "zig-zag" procedure

e) sediment facies mapping

11. DISCUSSION OF METHODS

A. Volumetric Sampling

Investigators agree that methods used to sample bed surface particles should be fully compatible with conventional bulk sampling and sieving methods (Kellerhals and Bray, 1971; Hey and Thorne, 1983). In an attempt to do so practitioners have pursued the idea of using volumetric sampling and sieving to characterize the bed surface. Two fundamental problems make this approach impossible. First, a volumetric sample cannot be recovered because it does not occupy a pre-determined volume. In other words, the volume is not independent of the particles making up the sample (Kellerhals and Bray, 1971; Church et al., 1987; Diplas and Sutherland, 1988). Secondly, the surface layer becomes mixed with the underlying sediment when sediment is scooped from the bed surface by conventional scoops or dredges (Ettema, 1983). Due to these problems we do not recommend using volumetric sampling as a tool for monitoring the bed surface particle size characteristics. Nor do we recommend collecting a volumetric sample of the surface material separately from the subsurface material when using core samplers such as a McNeil sampler. In this cases techniques to adequately quantify and remove tire surface material must be used.

B. Areal Sampling

B.1 Photographic Analysis Techniques

Surface materials have also been sampled by taking photographs of the bed and analyzing them in the lab. Four basic approaches have been used:

* Use of the Zeiss particle-size analyzer.

* Use of a ruler to measure the b-axes of particles that directly fall under a set grid.

· Measuring the b-axes of all particles within the photographed area.

· Counting all visible grains within a specific area of the photograph and converting them to mean grain size by a previously developed calibration relationship.

Ritter and Helley (1969) used a Zeiss particle size analyzer to determine the particle size distribution of sediments based on a frequency by number analysis. Photographs are taken vertically to avoid scale distortion and a reference scale is placed in the picture field so that the reduction or magnification factor of the photograph can be determined. The authors claim that they were able to make successful measurements of particles submerged under 2 ft of clear water without significant refraction. The Zeiss particle size analyzer has an iris diaphragm that controls the size of a circular spot of light that is projected on the photograph of the streambed. The aperture of the diaphragm is adjusted until the diameter of the spot of light is equal to the shorter of the two observable axes of a particular grain. Then a foot switch is pressed, the particle size is automatically recorded, and the counted particle is marked to avoid measuring the same particle again. Up to 2,00 particles could be measured per hour. The instrument could analyze particles ranging only from I to 27.7 mm. Although the original method of sampling all particles in the photograph produces a bias toward smaller particles, it can be modified by using a grid sampling scheme. The technique has also been used to make estimates of the percentage of the area of the photograph covered by fine particles. Attempts to translate the frequency by number distribution to frequency by weight produced unsatisfactory results. The major disadvantages of the method are assuming that the b-axes of all particles are always exposed parallel to the bed surface and measurement bias caused by shadows, other particles, or water refraction. Also, a large number of photographs from different areas of the stream need to be taken in order to accurately sample the spatial wtriability of the streambed. Another disadvantage is the unavailability of the instrument. For this reasons we do not recommend using it as part of a monitoring methodology.

Adams (1979) used a very similar approach as the one discussed in the previous section with the only distinction that he manually measured (with a ruler) the long and short axes of particles larger than 8 ram. He also neglected all of the particles smaller than 8 ram. The photographic technique is the same as the one used by Ritter and Helley (1969), but he adds the recommendation of avoiding taking pictures early in the morning or late in the afternoon to avoid long shadows. Adams (1979) compared this method with conventional volumetric analysis and he concluded that the mean size measured from photographs is about 0.1 phi finer than the sieve-size equivalent, which translates in mm to a 7% difference. In a similar study Kellerhals and Bray (1971) found that photographic analysis produced mean particle sizes 5 mm finer than sieve analysis. Adams (1979) does not agree with this conclusion because he believes that the bias has to be dependent on grain size. In summary, Adams concludes that the analysis from photographs provides a rapid field method that produces results comparable to sieve analysis. Although this method allows sampling a wider range of particle sizes than the Zeiss particle analyzer, it suffers from the same disadvantages: assuming b-axes are always exposed on the surface, unavoidable measuring b-axis due to shadows or particle blocking, need to take a large number of photographs from different parts of the streambed to get a representative sample, and incapability of accurately measuring the dimensions of very fine material.

The approach used by Iriondo (1972) is rather complicated. In his method he uses two rods marked with contrasting colors divided in phi intervals. The rods are located perpendicular to one another in the upper and lower boundaries of the selected area of which a picture is taken. The method proposed by Iriondo does not require taking vertical pictures because corrections are made while taking measurements. First, the operator draws straight lines on the photograph perpendicular to the direction of the rods at phi interval markings. Clasts whose minor axes are longer than the interval between two consecutive lines are marked and counted. Then additional parallel lines halving the preexisting bands are traced. Clasts larger than these new lines are marked and counted. The procedure is continued until the resolution limit of the picture is reached. Iriondo estimated that several hundred clasts could be counted per hour. We do not recommend using this approach because the method introduces the limitations inherent in conventional photographic analysis and it has never been tested against conventional sampling methods. Also, the procedure is very tedious and impractical and this increased effort does not appear to produce any advantages over any of the other methods discussed in this report.

A method that was briefly mentioned by Church et al. (1987) and used by Rice (1995) relies on making a count of visible grains in a photograph and then converting that number into a mean grain size by means of a previously developed calibration relation. Rice (1995) used 14 samples to calibrate the relationship between grain size and number of particles and found that a better relationship was achieved by making a log transformation of the data. We believe that this method is only capable of giving a general idea of the median particle size. We presume that a similar accuracy can be achieved by performing simple visual estimates of the gravel. We do not suggest integrating this method to a monitoring methodology because it is insensitive to increases of fine sediment and because the greatest uncertainty of the calibrating relationship occurs in the gravel size range (Figure I). Also, the method cannot determine other descriptors of the particle size distribution (i.e.., sorting index).

General advantages of the photographic methods

- Methods are adequate for gravel and larger material when high accuracy is not required.
- They do not require transporting sediment samples to the lab.
- They require minimum time out in the field to collect samples.
- A large number of particles can be counted in a short amount of time.
- They are useful for use in hydraulic equations that are not sensitive to grain size and when a summary estimate of grain size is to be based upon data pooled from many sites.
- They could be used to calibrate sediment facies units.
- Median particle size results can be easily translated to conventional bulk sieving results because sieve and photograph measurements of size standard deviation are essentially equivalent.
- Photos taken at different times from the same reference point can provide a historical record of bed material changes.
- Methods are relatively cheap (excluding the Zeiss particle analyzer method) and easy to learn.
- Potentially they could be used to calibrate facies units.

General disadvantages of the photographic methods

- Sample area must be dry or under shallow clear water to avoid the effects of refraction or turbidity.

- Method has an unavoidable bias due to partial hiding of clasts by sand, shadows, or other particles.

- Bias due to imbrication angle is variable over a reach as sedimentary conditions change (it is not known whether imbrication angle is rather constant,over individual sedimentary facies units).

- To compensate for spatial variability many photographs of the same morphological or facies units are necessary.

- Methods are not accurate for particle sizes finer than 8 mm, so decreases in median sizes caused by the addition of fine sediment will go undetected by them.

- Reports recommend that the photographic measurements should be calibrated by pebble counts.

- The assumption that the intermediate axes of particles are always exposed on the surface is often erroneous.

We believe that photographs are very useful for keeping a qualitative record of changes in the streambed and they could be used for selecting sediment facies units for textural patch mapping and for keeping a visual record of them. We do not recommend using it for quantitative measurements mostly because its lack of sensitiveness to fine sediment loading.

B.2 Use of Adhesives

The techniques for the use of adhesives are thoroughly explained by Ettema (1984) and by Diplas and Sutherland (1988). The technique is commonly used in labs and it has two major variations: use of adhesive blocks and use of adhesive tapes. Wax, exposy resins, clay, and soap and grease have all been used with the adhesive block technique. Each one of these adhesives samples surface materials to different depths. Wax is recommended by Diplas and Sutherland (1988) because it is the most effective adhesive, it can pick up particles with diameters up to 32 cm, and because it produces the most consistent results.

The procedure most commonly used consists of four steps:

1) Adhesive is poured or pressed onto the surface (typically adhesive blocks are about 30 cm by 30 cm; tapes are 10 cm wide and usually three are place parallel to each other so a 30 cm by 30 cm area is sampled).

2) After hardening, adhesive and grains are removed from the bed.

3) A solvent is used to release the grains from the adhesive.

4) Particles are sieved and weighed.

Analysis of the compatibility of these sampling techniques with volumetric sampling and sieving have been conducted by Ettema (1984), Diplas and Sutherland (1988), and Kellerhals and Bray (1971). Kellerhals and Bray suggest the use of a conversion procedure to compensate for the finer particles in an armor layer, but Ettema claims that this conversion over-corrects and in turn biases the finer particles. He also suggests that two consecutive samples have to be removed from the streambed because he believes that the armor layer is more than 1 grain thick. Diplas and Sutherland (1988) consider that there is no need to remove two consecutive samples when wax is used as an adhesive. Wax sampling includes all particles that are exposed or nearly exposed to the flow. The effective depth of wax sampling is about D90 for samples bigger than 10 mm, and about D70 for samples finer than 10 mm. Conversion of results from this technique are easily transferable to volumetric sampling and sieving by using one simple equation (Diplas and Sutherland, 1988).

Advantages of the use of adhesives

· When wax is used as an adhesive results are very consistent.

· It's results are easily transferable to volumetric sampling and sieving.

Disadvantages of the use of adhesives

· When wax is used a heat source has to supply enough heat to melt it creating restrictions in the portability of the method.

· When the adhesive tape is pressed grains may be displaced and this may cause some mixing with the subsurface material making the sample non-representative of the surface layer.

· The surface of the material has to be exposed out of the water in order to use any adhesive.

· Very coarse material cannot be sampled effectively.

· Since a small area is collected per sample many of them have to be collected in order to collect an unbiased sample.

· Samples have to be taken to the lab for analysis.

· '['he technique is expensive and labor intensive

We do not recommend the use of adhesives as a monitoring tool because we find its procedure to be too impractical for field use.

B.3 Surface Freezing Technique

Gomez (1983) modified a volumetric freezing technique so that an areal sample could be removed from the bed. The technique requires the use of an open-ended cylinder (15 cm diameter and 20 cm long), a U-shaped plastic (about 30 cm in diameter and 30 cm high) used to block the flow of water, cling-wrap, and liquid nitrogen. One end of the cylinder is sealed with the plastic cling-wrap and it is inserted with the sealed end on the surface of the bed just downstream of the U-shaped plastic. Halt' a liter of the liquid nitrogen is poured on the cylinder, and after a few minutes the 177 cm^2 area of bed adhering to the cling-wrap is lifted away with the cylinder. The method produces samples weighing approximately 2 kg, which can be analyzed by dry sieving techniques. The method was used by Gomez only in sandy gravels with no material coarser than 32 mm in diameter. Although the technique seems to produce consistent results it is not recommended as a monitoring tool because: it is difficult to handle and transport the liquid nitrogen; the results are not easily transferable to conventional volumetric sampling and sieving; only material finer than medium-sized gravel can be sampled; and it requires transporting samples to the lab for analysis.

B.4 Use of Paint to Mark the Particles Lying on the Surface

This method is briefly mentioned in some of the papers reviewed for this report (Kellerhals and Bray, 1971; Gomez, 1983). The method consists of selecting an area, spray painting the surface particles, and carefully removing all of the painted particles. The analysis can be conducted by either frequency by number or frequency by weight. No report that we are aware of has studied the compatibility of this method to other sampling procedures. Gomez (1983) states that there is a minimum size of material (4-8 mm) which can be removed titan the bed surface by band. Although we believe that the cutoff size for fine sediment sampling is lower than 4-8 ram, we consider this to a major drawback of the method. Also, in order to be able to sample the spatial distribution of the sediment many different areas of the streambed would have to be sampled and this would make the use of the method very impractical. For these reasons we do not recommend the use of this method as a monitoring tool.

Muir (1969) tested a method very similar to the painting technique. The quadrant method, as he called it, consisted in marking or selecting a square area and collecting all particles within that area. The analysis can be performed either by weight or by number. Muir found that the method is biased toward finer particles because it was difficult to determine which particles were exposed on the bed surface, and particles form the subsurface were frequently incorporated into the sample. This method also suffers from the limitations of all areal sampling methods in incorporating the spatial variability present on streams due to the small area covered by each sample.

B.5 Areal-Grid Hybrid Technique

In an attempt to compensate for the inaccuracy of the pebble count method in determining the percentage of fine sediment on the streambed, Bauer and Burton (I993) suggest using this technique. Three sampling grids (22 by 22 inches with 2 inch squares) are located on transects where pebble counts have been performed. At each point the percent of fine sediment (< 6 mm) within the grid area is estimated. The method consists of counting the number of grid points overlying fine sediment and dividing this by the total amount of grid points (144 if the same grid is used). The exact sampling sites have to be revisited for subsequent monitoring. We believe that this method can over or under-sample the percentage of fine sediment in an area. Fine sediment typically occurs in streaks along the bed. If sampling is performed over these streaks it will overestimate the percentage of fine material. If sampling sites completely miss these streaks the results will underestimate the actual percentage. We consider that the method is most useful then for monitoring specific areas of the streambed, not overall condition. We believe that the use of the method suggested by Bauer and Burton (1993) is very useful to complement the data collected by pebble counts. If the method is applied to areas where pebble counts are conducted the method can be used to determine if any changes in the amount of fine sediment have occurred.

B.6 Visual Estimates

Fisheries biologists usually rely on visual estimates of the streambed to determine the dominant particle sizes of gravel patches that could be used as spawning areas by salmons. This method is described by Scbuett-Hames and Pleus (in review). First, patches are identified and delineated according to criteria that is relevant for biological studies. Then the dominant particle size is estimated by identifying the size that occupies most of the area within the patch. A particle that suits this size characteristics is removed from the bed and its b-axis is then measured. The patch is reassessed to make sure that the particle is a good representation of the dominant particle size. If the operator does not agree, another particle is removed and measured. Once the operator ha!; good confidence in his choice he assigns a code to it based on a truncated Wentworth scale. This type of visual estimates can produce results useful for biological assessment, but we do not believe they could be of much use to geomorphologists for the following reasons: operator bias is considerably high; it is not sensitive to small but considerable changes in the particle size distribution; it characterizes the patch only by its dominant particle size and it provides no information on the size distribution characteristics of the patch; and it is unable to accurately describe bimodal distributions. This approach could be used to initially name facies units while they are being identified and selected by operators.

C. Sampling Along Transects

Techniques using transects to collect samples of the stream surface can be divided into three different categories:

· Sampling every pebble lying directly under a transect line.

· Using a transect-areal sampling-visual estimate hybrid technique

· Using visual estimates.

A hybrid technique combining transects and pebble counts will be discussed in Section D of this report.

Muir (I 969) studied the reliability of a type of transect method in describing the characteristics of surface particles. The method consisted in taking a string, stretching it on the bed, and collecting all particles lying under it. The sample was taken to the laboratory and analyzed by sieving. Muir concluded that the technique is biased towards fine particles. As discussed for the quadrant method above, particles from the sub.-surface containing a larger percentage of fine material in armored stream beds are usually included in the sample because once collection starts it is difficult to determine which particles were originally exposed on the surface. The major drawbacks of this method are: how to incorporate the spatial variability of the streambed because samples are collected only along a single line; and if an attempt to compensate for the spatial variability limitation is made by increasing the total length of the transect line, the amount o[material to be collected could become too large. Also, in order to collect an unbiased sample for frequency by weight analysis, the largest particle in the sample has to account for a small percentage of the total weight of the sample (Church et al., 1987). In tire approach presented in this section the amount of material collected does not depend on this minimum requirements but on the length of the transect line. In order to solve this problem the sample would have to be truncated at a certain size dictated by the sample size requirements presented in Church et al. (1987), or a weighing balance has to be taken to the field to make sure that the weight of the material is larger than the minimum requirements for an unbiased sample. Because of this reasons we do not recommend using this technique as a streambed monitoring tool.

Rashin et al. (1993) suggests using an approach that combines transect, areal sampling, and visual estimates. The procedure requires setting up several cross-sectional transects on the stream. On each transect a series of 30 cm diameter hoops are placed from the left bank high water mark to the right bank. Then the operators visually determine the dominant and sub-dominant particle size classes and the percentage of fine sediment (defined as all sediment finer than 6 ram) in each of the hoops. The dominant and sub-dominant size classes can be either determined by a names (cobbles, gravel, sand, etc.) or by the actual dimensions in millimeters. The percentage of fine sediment on the surface should be estimated within +_ 10%. Data from all of the hoops in each transect is lumped to calculated its average', substrate composition. We do not recommend using this method on its own from monitoring purposes because: we believe it is not sensitive to minor changes in particle size distribution; distribution descriptors such as median size, quartiles, and others cannot be determined from the method; method is expected to be sensitive to operator bias; pebble counts take about the same time to be performed and they produce more reliable results; and process-based calculations, like critical shear stress, cannot be performed with this the results of this analysis. We believe, though, that this method can supplement data collected by pebble counts, by giving more precise estimates of the quantity of fine sediment found on the surface.

Visual estimation of surface particle size has been widely used to assess channel condition (Herrington and Dunham, 1967; Platts and Megahan, 1975; Platts et al., 1983; Bauer and Burton, 1993). Platts and Megahan (1975) were able to detect responses in the composition of spawning gravel due to increases in sediment loads by using this technique. The general procedure used by practitioners is as follows:

1) Set a transect across the channel from bankfull to bankfull.

2) Divide the transect into equal length subdivisions.

3) On each subdivision determine which particle size is more abundant on the surface of the bed and assign it to one of four sediment classes (sand, gravel, cobbles, or boulders).

4) Determine the dominant particle size and the relative percentages of each of the four sediment classes for each transect and for the whole reach.

In an attempt to make this technique quantitative (thus less susceptible to operator bias) and comparable to the pebble count procedure, Bauer and Burton (1993) suggest measuring the b-axis of randomly chosen particles at each subdivision. We recommend using a procedure similar to this one in special occasions when facies units cannot be calibrated by pebble counts because either tim units are composed of particles that are too large to be picked up and measured, or when the water is too deep to collect a sample. On those situations follow steps I and 2 described above and determine the dominant particle size by visual estimation [similar to the approach suggested by Rashin et al. (1993)], or by the method described by Schuett-Hames and Pleus (in review)-in which a particle that after visual examination appears to be representative of the dominant particle size is measured across the b-axis.

D. Pebble Counts

D.1 General Comments

In this section we will summarize the original grid-sampling methodology designed by Wolman in 1954, we will discuss several subsequent publications that discuss the usage and applicability of the method, and we will mention different variations in the sampling methodology derived from the original design. The original Wolman grid-sampling methodology consists of five steps:

1) Establish a grid system by pacing or by placing a measuring tape over a desired area on a reach (which could be the entire reach, a specific morphological feature, or a specific facies unit).

2) Randomly select pebbles from the streambed by diverting the eyes while picking up the sample. Wolman's practice was to select pebbles beneath the tip of his boot.

3) Measure the intermediate axis (b-axis) of the pebble.

4) Unless the actual diameters are of interest, tally each pebble within a grade class in the Wentworth scale.

5) Locate the next grid location by pacing or by using a tape. Repeat steps 2 and 3 until 100 pebbles have been collected.

6) Once all of the pebbles have been collected plot a cumulative frequency distribution curve for the sample.

Wolman showed concern about the compatibility of the method with the commonly used sieving and weighing analysis. He sampled the same areas with both pebble counts and volumetric sampling techniques and he compared the results. He found that the grid sampling frequency by number analysis consistently overestimated the median particle size of the sample. He suggested that the reason for this was spatial variability in the location of the samples. He explained that volumetric samples were taken from locations on the bed with a higher percentage of fine material than that presented by the entire streambed. Several publications, which will be discussed below, show that the grid sampling method and the frequency by number analysis produces results that can be directly compared to results from bulk sieving sampling and frequency by weight analysis. Although Wolman's explanation of two-dimensional variability could be an important factor in the lack of correlation in Iris test, we should consider the following issues:

· The grid sampling method can only sample the surface of the streambed. As discussed above, bulk sampling methods cannot provide a volumetric sample from the bed surface. If bed armoring was present in the streambed studied by Wolman, his attempt to compare both methods is not possible because it s impossible to determine whether the differences were due to the sampling methods, the sample analysis methods (frequency by number versus frequency by weight), or simply that the two samples come front two different populations.

· Individual particles are chosen from the streambed with the tip of the linger. The average dimensions of a finger tip is about 10 mm. It is very likely that the very fine particles will be under-sampled because the finger cannot get to the fine material on the surface which is typically located in the spaces between the coarser grains. Also, the probability of a rock being picked up is relative to its areal exposure, so large rocks will be picked up more frequently than smaller ones.

· Operator bias may be an important factor specially in the finer section of the size distribution curve. It appears that some operators tend to consistently miss the very fine material. By plotting the data from Tables 3 and 4 from Wolman (1954) [See Figures 2a and 2b] we can see that when very fine material is lumped into one broad category (less than 8 mm-Figure 2a) differences in the quantity of fine material are not considerable. When fine material consists of various categories (< 2 mm, 2-4 ram, 4-8 mm) it appears that operator bias turns into an important source of error. In Figure 2b, operator C under-sampled the amount of material finer than 4 mm, causing differences in the cumulative frequency of the samples up to about 40 mm. Although in this case the differences are not significant if we are only interested in the median values of the samples, they could yield significantly biased results of the percentage of very fine material in the sample.

D.2 Accuracy and Sources of Error of Method

Sample size

Although Wolman suggests that large areas with higher variability should be sampled more intensely than small areas with higher variability, he suggests constantly sampling 100 pebbles. According to the data collected by Wolman in Mines Run, 100 pebbles were enough to provide a mean median diameter within plus or minus ten millimeters, with a likelihood of being correct approximately two-thirds of the time.

The original design of the method described by Wolman (1954) suggests measuring 100 pebbles, although some of his analyses were done with 60 pebbles (Table 4) and others with 140 pebbles (Table. 3). As mentioned above, he suggests that sample size should increase with increasing sample area and particle size variability, but he does not state any specific guidelines on bow to do so. Leopold (1970) suggests using the same number of samples as Wolman (100 pebbles), but recommends taking individual samples within individual "river locales" (or facies units) to decrease sample variance.

Several studies have dealt with the problem of determining the minimum size required to produce constant results. By using a simple computer cube model, Kellerhals and Bray (1971) determined that 50 pebbles (> 8 ram) are enough to characterize the bed surface. Brush (1961) conducted some simple field experiments and determined that 60 pebbles are enough to get a reasonable estimate of the median size of a reach with no operator bias. Mosley and Tindale (1985) point out that their experience with the pebble count method indicates that a sample size of 70 is enough to define the grain size distribution parameters of he stream bed surface.

In a very exhaustive study, Hey and Thorne (1983) did not find any significant difference between samples taken by the same operators for samples consisting of 40, 60, and 100 pebbles. By using statistical theory they calculated that for an accuracy of 15% and a typical sample standard deviation of 0.3 phi, the required sample size is 97 particles. For an accuracy greater than 10% the sample size becomes much larger (20'7 for 10% accuracy and 790 for 5% accuracy). No tests were performed to prove that these calculations apply to the pebble count method.

Church et ah (1987) indicate that setting sampling standards for the characterization of surface materials based on a frequency by number basis can be done by standard statistical methods, but some attention has to be given to the distribution characteristics and the effects of log transformations. They state that no sampling program has thoroughly investigated the precision of the pebble count method. In order to solve this problem they suggest taking replicate samples of percentiles of the grain size distribution and treating the sequence of estimates of each percentile as a normally distributed variable.

Operator bias

Wolman (1954) concluded that the grid sampling methodology could be performed without any major concern for operator bias. He got to that conclusion by comparing median sizes and variance in samples ranging from 60 to 140 pebble counts. As mentioned above, even though differences in the central tendencies of the samples may not vary considerably, differences in the fine end of the distribution are apparent in Figure 2b. Differences between operators can be introduced by: differences in establishing the grid, bias while removing particles, and differences while measuring the b-axis of the particles.

Potential bias can be introduced by slight but important differences in the ways that operators establish the grid. Although Wolman (1954) claimed that shifting the grid location did not affect the results we consider that it might have an important effect. We understand that the effects can increase when the operator is pacing and certain portions of the channel (deep areas, areas close to the bank-bed boundary, or constantly diverting transect lines to avoid very large particles, etc.) are consistently avoided.

Another source of bias may result while removing particles from the bed. Most publications and practitioners suggest that the finger should be vertically approached to the streambed. This is so because in that way the observer can increase the probability of touching the very fine material between the larger particles. Not doing this could be a major source of operator bias. Even if the operator is consciously aware of this; caution should be taken so that the particles being picked up are the particles touching the center portion of the fingertip. Not doing this could cause significant bias because operators may tend to consistently pick up very fine or coarse particles. Some practitioners prefer to use pencils or other pointy objects instead of using the finger to approach the streambed.

Hey and Thorne (1983) conducted a very complete study of the effects of different operators in introducing significant bias to a sample. They found that the choice of particle sample form the bed was not precisely defined and that this was responsible for most of the differences between operators. Creating the grid by pacing introduces a random element in choosing a particle within a small area. They found that the use of the finger to select the particle for counting introduces operator bias towards either large or small particles. They point out that this effect is constant, irrespective of sample size, and that it augments as sample size increases. This means that for all sample sizes, operator error is small compared to sampling error. They found that no significant differences occurred between operators for samples smaller than 100, but for larger samples significant differences were noted. They recommend conducting several calculations before collecting samples to determine if one or more operators can sample the bed. Basically the procedure is as follows. First, determine the required sample size for a given bed by entering sample standard deviation, chosen sample accuracy, and expected confidence level to theoretical statistical equations. If the required sample size according to the equations is smaller than 100, then several operators can sample the bed. If more than 100 particles are required or if high sampling accuracy is desired they recommend using one operator to collect all samples. We consider that the method is the best approach that has been developed until now, but it has a few drawbacks. We believe that the larger an area the more intensely it should be sampled but these effects cannot be included in the equation. Also, the approach requires taking initial samples to determine their standard deviation so that it can be entered into the equation. The need of this initial sample could be avoided if a simple graph relating dominant particle size with maximum expected sample standard deviation could be developed. Whether tire production of this graph is possible or not is unknown to the author of this report.

Some bias can also be introduced by differences in measuring the b-axis of the particles. Although the bias from this effect should be small if the operator has received some training, it has been considered as a problem by other studies. Hey and Thorne (1983) decided to avoid error from this effect by noting the smallest aperture the particle passed through on a specially constructed gravelometer. This in turn introduces a few problems like: producing smaller diameters than those measured with calipers or rulers because particles can pass diagonally through the holes; and the difficulty of measuring the diameter of very small particles. We consider that the effects of this type of error are minor as compared to other sources of bias, specially if the measurements are tallied to size classes in the Wentworth scale.

D.3 Sample Analysis Procedure

Leopold (1970) made various suggestions to analyze pebble count data. First, he suggested converting the results from frequency by number to frequency by weight based on an empirical relationship of pebble size to average weight. Although this correction appeared to be necessary according to a publication by Sahu (1964), more recent studies concluded that grid sampling with frequency analysis by number is the only sampling procedure capable of describing a surface layer in equivalence with customary bulk sieve analysis (Kellerhalls and Bray, 1971). Secondly, Leopold recommended adjusting for rock diameter to eliminate the bias due to the increased probability of picking up large particles. He suggested that the number of rocks in each size class should be weighted by a factor inversely proportionate to the square of the b-axis diameter. We can imply that Leopold was concerned in whether the pebble count method was truly a frequency by number analysis or an already weighted analysis. Since he desired to directly compare the data with frequency by weight analysis by using his conversion factor, he chose to make sure that the analysis was normalized by the area covered by each particle. Whether the pebble count method produces frequency by number or frequency by area results is not discussed by any of the papers reviewed and it is not known whether this might have any relevance in the results.

Leopold (1970) also suggested dividing the percentage-by-weight results by the log diameter interval so that the cumulative curve results are independent of the interval used. These results are then plotted against particle size. The resulting graph can be defined by three coefficients: slopes of the two limbs, and the size at which the curve peaks. We do not recommend making the corrections suggested by Leopold because: it requires calibration to determine the pebble size to weight relationship; the conversion from pebble size to weight can introduced some error specially in oddly-shaped particles; its results cannot be easily read from graphs; it has not been widely used by researchers or practitioners; and recent studies have proved that the results of the method can be directly compared to frequency by weight analysis.

D.4 Discussion of pebble count sampling strategies

The Wolman (1954) pebble count has been used in many different ways and its variations are a response to different objectives for research or channel assessment projects. We will arrange them in three different groups: reach scale methods (grid sampling over an entire reach and the "zig-zag" method), pebble counts over specific morphological units, and pebble counts along transects or cross-sections.

D.4.a Reach scale pebble counts

Reach scale pebble counts have been used widely for channel assessment projects. The USFS (Harrelson et al., 1994), the EPA (McDonald, 1991), and the WFPB (1993) all recommend a grid-sampling reach-scale approach for pebble counts. The procedure consists in doing cross channel sampling from bank to bank at every step. Once the opposing bank is reached the operator constantly moves either upstream or downstream at a predetermined distance and continues the procedure. Usually the procedure is continued until 100 pebbles are counted and the results give us a general description of the particle size distribution of the entire reach. The WFPB (1993) recommends walking the stream before sampling in order to observe the variability in surface textures so pebble counts can be performed in areas that are representative of the general textural conditions of the channel. This procedure could be modified so that particle size distributions of specific morphological or facies units could be determined. The process is called facies unit calibration and is used for facies unit mapping method described later in this report.

Bevenger and King (1995) recommend a different pebble count procedure that they consider useful for assessing watershed cumulative effects. The procedure is called the "zig-zag" procedure and it attempts to get a reach average particle size distribution. The procedure consists of the following steps. First, on a chosen reach select a random location on one bank at bankfull stage. Then, identify a target point upstream on the opposite bank and collect samples at every three to four steps along that line. Locate another target point on the opposing bank and repeal the procedure until the entire reach has been sampled. Pebbles are measured across the b-axis and their sizes are tallied to the appropriate Wentworth size classes. The authors state that the angle of the zig-zag should depend on the meander pattern of the reach, but they do not give precise instructions on how to do this. They simply recommend that for low sinuosity reaches the angle of the zig-zags should be less sharp than for highly sinuous reaches. We believe that the angle should also vary according to the complexity of the tied, but no comments on that issue are presented in the paper by Bevenger and King (1995). The survey is completed when 100 particles have been sampled. Although we believe that the zig-zag method has the potential of being included as a low level surface particle size monitoring tool, we do not recommend its use until it is tested against grid-sampling pebble counts and facies unit map techniques. It should not be used until its sample size requirements and general procedure are better defined.

We emphatically do not recommend the data analysis approach suggested by Bevenger and King (1995). Their approach consists of comparing "disturbed" against "undisturbed" streams. Given the high spatial and temporal variability of surface sediment for both disturbed and undisturbed streams, the unknown precision and accuracy of the zig-zag method, and the lack of any process-based analysis (no considerations to slope-area-bankfull depth characteristics are used), we believe that their approach cannot be used as a reliable assessment tool. Also, this type of analysis does not provide any input on the specific processes causiug changes in channel physical condition. Knowledge of these processes is crucial when prescribing solutions to improve channel condition.

D.4.b Pebble counts on specific morphological units

Another approach that has been widely used is to perform pebble counts on specific morphological units. Several studies have taken samples exclusively from bars. Church and Kellerhals (1978) chose to perform pebble counts on bars during low flows in an attempt to study the general behavior of mean grain size downstream. They sampled the upstream end of bars in an attempt to sample sites that were uniform with respect to depositional environment and to select sites that contained the coarsest active material dominating the reach. This was done because the authors were interested in the coarsest exposed materials (which for that particular stream were located on bars) because they were studying the effects of this bed material in the flow of water.

In another study, Hogan (1986) sampled bar tops in tin attempt to determine the effects of logging on stream particle size of reaches with habitat importance. [logan compared the surface particle size distribution of bars in reaches with different disturbance levels but similar slopes. He chose bars because he considered that this material is sensitive to changes in discharge and sediment loading. He used a grip sampling approach and sampled from 60 to 90 particles with b-axes greater than 8 mm. Harrelson et al. (1994) recommend taking samples at different morphological units, but that each morphological unit should be sampled in the same proportion as they occur in the study area.

Channel assessment procedures recommend performing pebble counts on specific morphological units. The WFPB (1993) recommends doing pebble counts on high velocity core cross-over locations on point bars in channels where flow is not dominated by LWD pieces. This approach does not allow for an accurate representation of the full range of grain sizes present on the streambed. In the suggestions presented by Knopp et al. (1993) pebble counts are used to determine the median particle size of riffles. The procedure consists of establishing a transect on 3 riffles per reach and taking 200 pebbles in each one. The data collected is then used to determine the median particle size of riffles and for an analysis procedure called the RASI [See Knop et al., 1993)].

Kinerson (1990) explored the possibility of using the "q*" parameter as a tool to determine the rate of sediment loading. In Iris study he chose to sample both the surface and the subsurface bed materials in areas with subdued bed topography in an attempt to replicate the original "q*' analysis on a plane bedded flume. By doing this he was able to minimize variations in local boundary shear stress and avoid additional form drag effects. He also avoided choosing sites where obstacles could have major impacts on controlling the transport and deposition of particles. Pebble counts were performed during low flow conditions and they consisted of grid sampling 100 particles coarser than 1 mm.

D.4.c Pebble counts along transects

Another approach to using pebble counts has been to conduct them on specific locations along the reach, typically on cross-section locations. Mosley and Tindale (I985) sampled the streambed along 12 cross-sections using the pebble count method. Cross-sections were located at 180 meter (0.5 bankfull width) intervals. Samples were collected directly under the cross-section at every two paces for a sample total ranging from 77 to 201 particles. They study assumes that the results are reliable since the different facies units present in the river are weighted according to their areal extent even though the transects are located so far from each other. They calculated that in order to estimate the overall mean grain size to within 10%, 64 cross sections (about 7680 particles) had to be sampled. Fourteen cross sections (1680 particles) are necessary to be within 20% of the actual mean grain size. It is not known whether the same sample requirements apply to streams of different dimensions and with different sediment spatial distribution.

Buffington (1995) used bank to bank random pebble counts at regularly spaced cross-sections to determine reach averaged median particle sizes. Five cross-sections were set at each reach and they were located at about 4 channel widths apart. Although the description of the method does not mention the area covered by each pebble count, Figure 3.19 of his thesis suggests that they covered an area equal to half of the square of channel width [area = 1/2 * (channel width)2]. Bauer and Burton (1993) use a very similar approach. Transect spacing is about one to two channel widths apart. Although the manual specifies that samples are taken at each step and a typical survey consists of about 100 pebbles, it is not clear whether 100 particles are sampled at each transect (for a reach total ranging from 1000 to 2000 particles) or if the total sample size for the reach is 100.

Buffington discusses that the results from this type of approach are identical to facies mapping results for mono-textural channels, but for streams with complicated textures accuracy depends on the areal extent of sampling and the spatial distribution of the different facies units within the channel For some of his reaches he estimates that about 15 to 30% of the total reach area was sampled and he assumed that this was enough to make this method comparable to facies mapping.

General advantages of the pebble count method

· Results are presented in percentage by number which makes it possible to use better statistical analysis than with percentage by weight or volume.

· Results are directly comparable to conventional sieve analysis.

· Method is cheap and requires minimum training.

· Results are easily analyzed and interpreted:

· It does not require taking a sample back to the lab for analysis.

· Large areas can be covered in a relatively short amount of time.

· Samples submerged less than 1 meter of water can be easily sampled.

· A reach scale grid sampling technique allows for the different sediment facies within a reach to be sampled in the same proportion as they occur on the streambed.

· It can be used as a training tool for calibrating the eye for performing visual estimates because data can be easily analyzed out on the field.

· Method has been widely used so comparisons with previous studies are possible.

General disadvantages of the pebble count method

„ Unknown accuracy and unknown sample requirements for a desired precision.

u Underestimates the presence of fine material and overestimates the coarse material.

„ Operator bias increases with sample size and it could be statistically significant for samples greater than 100 particles.

· Particles in deep sections of the river (> 1 m) cannot be sampled.

E. Facies Unit Mapping

Most practitioners agree that by preparing a map that portrays the surface extent of the different sediment facies found on the streambed an accurate estimate of reach-scale grain size can be obtained. The technique involves identifying, calibrating, and spatially averaging the different sedimentary facies units within a channel. The idea of partitioning the channel into discrete textural patches was suggested by Wolman (1954). He recognized that his pebble count method could be useful not only to determine reach average particle size distributions, but also to characterize the non-random areal distribution of material in different morphological units. Leopold (1970) pointed out that different morphological units in a river contain sub-units having somewhat different size distributions. He named them "river locales" and they were defined as any geographic area within which the size distribution of surface rocks is, to the eye, the same. He suggested that pebble counts should he performed within river locale boundaries so that their individual size distributions could be described. Mosley and Tindale (1985) misused this type of approach by identifying 153 individual textural patches in a reach and performing individual pebble counts in 141 of them, but they made the mistake of not weighting each unit according to its areal extent and subsequently their reach-scale size distributions were wrong. Hogan (1986) and Kinerson (1990) mapped sediment facies units according to their dominant and subdominant particles but they did not calibrate the facies because they only wanted to have an idea of their spatial distribution. The approach used by Buffington (1995) and the one presented by Collins and Dietrich (in prep.) describe the complete use of the method- facies unit mapping and calibration.

The general procedure can be divided into the following steps:

1) Identify the different facies units found on the streambed. This is done by walking the reach and identifying the different textural patches present on the streambed. Patches are identified by determining their dominant and subdominant particle sizes. A key element in selecting textural patches is that the differences between patches have to be discernible by eye (Collins and Dietrich, in prep.). Buffington (1995) has found that plane bed and LWD-poor pool-riffle streams in Alaska and Washington usually have on to four textural facies, while LWD-rich pool-riffle channels commonly exhibit front three to seven different facies units on their stream beds. Channel textural complexity increases with channel sinuosity and slope [Environmental Forestry Division, Weyerhaeuser Co., unpublished report] and with increasing complexity of channel roughness (Buffington, 1995).

2) Calibrate each one of the facies units by performing pebble counts on representative textural facies units. The WFPB (1993) Channel Assessment Module recommends performing one or more pebble counts on each of the different textural types and assumes that the results are representative for that textural type over the whole reach Buffington (1995) performed several pebble counts on visually identical patches and found that they had similar grain size distributions. This supports validating the procedure of characterizing textural patches by sampling a single unit. Although some facies identified as distinctive from visual identification in the field show similar grain size distributions, differences in sorting coefficients supported fire field differentiation. A very important issue relevant to the use of this method as a monitoring tool is not discussed in any of this papers. None of them discuss whether the facies identification and calibration procedure has to be repeated every time a map is prepared or if the same classification and calibrations can be used year after year.

3) Delineate the boundaries of the different textural patches. Boundaries of the patches are usually gradational so operator bias could be considerable. Areal extent of each sediment patch could be determined in the field by actual measurements or by performing visual estimates. There are two ways of keeping track of the location and extent of individual sediment facies: by locating the boundaries of individual patches in a plan form map, and by determining the areal extent of individual patches within sub-sections of the reach.

4) Determine the total areal extent and relative proportion of the different facies units within the entire reach.

5) Determine average particle size characteristics of the entire reach or sub-sections by using the following formula:

$$[\ E(A_{i/At}).(Dxi) \qquad \text{(eq. 1)}\ ]$$

where,

A_i is the amount of area covered by facies unit Yi inside the area of interest

A_t is the total area

Dxi is the size distribution parameter of unit Yi (median size, quartiles, etc.) determined during calibration

Advantages of the facies unit mapping technique

- It can account for different textural patterns over the entire reach.

- It can capture the actual complexity of heterogeneous mixtures of sediment (Collins and Dietrich, in prep.)

- The effects of high flow events on surface texture size and spatial distribution can be determined if mapping is repeated after these events.

- Particle size characterization of individual morphological units, selected areas within the stream, or the entire reach can be determined by using the same data for all of them.

- It is considered to be the most accurate method of characterizing the particle size distribution of stream reaches.

- It permits determining the effects of obstructions in surface texture distribution.

- The results are easily interpreted because they provide a visual representation of the stream bed.

· Although several pebble counts have to be performed to describe the different sediment textures, the sample size required for accurate characterization of individual textures is expected to be low because of smaller sample areas and reduced variability.

Disadvantages of the facies unit mapping technique

*, Method requires a high level of effort both in the field and in the lab.

., Training from experience personnel is required to ensure the quality and the reliability of results.

„ Artistic skills are required to produce high quality maps.

· Operator bias could be introduced in all of the steps: selecting and calibrating facies units, determining facies boundaries, and drawing facies boundaries on maps.

· Strict requirements for pebble count calibrations have to be developed.

Although this method is a very time consuming technique we recommend its use when a high level of effort is possible because the results are considered to be very accurate, and because very useful biological and geomorphological interpretations could be developed by preparing a plan form map and overlaying different kinds of data over the facies map.

III. METHODS INCLUDED IN THE STREAM CHANNEL MONITORING METHODOLOGY

The main objective of this review was to select streambed surface sampling methods to be included in a stream channel monitoring methodology. We have divided the methods into two groups: 1) determination of the particle size distribution; and 2) determination of the percentage of the streambed surface covered by fine sediment. The monitoring methodology will provide several levels of effort to measure each one of these streambed characteristics. The methods chosen for each one of these levels are mentioned below.

Methods to determine the particle size distribution of the streambed

Level A

Consists in making visual estimates of the dominant and subdominant particle sizes in every 10 m long section of the channel.

Level B

Perform a reach-scale grid-sampling pebble count over large sections of the monitoring reach (Pages 15-16).

Level C

Requires identifying, calibrating, and determining the areal extent of each of the facies units found on the surface of the bed (Pages 1%20).

Methods to determine the percentage of **the streambed** covered by fine **sediment**

Level A

Consists in making visual estimates within every 10 m section of the channel.

Level B

Requires making visual estimates inside hoops or square frames placed on the streambed (See Rashin et al. (1993) method in Page 10).

Level C

Consists in using an areal-grid hybrid sampling approach (Page 8).

Figure 1. Photographic survey calibration data (Rice, 1995-Appendix 1)

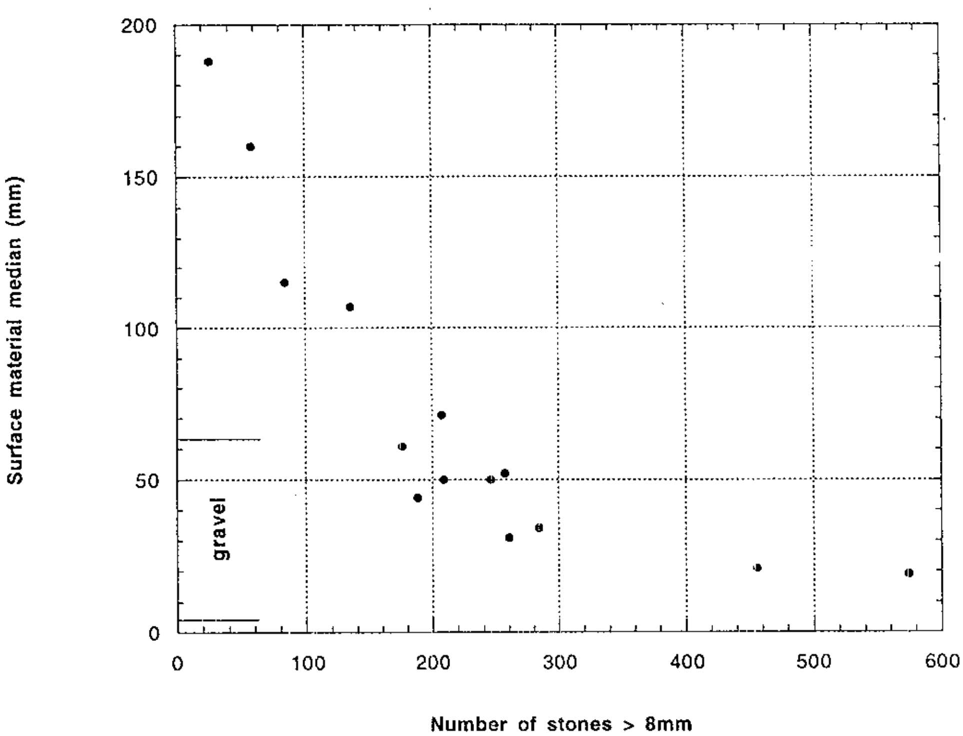


Figure 2a. Cumulative Frequency Curve (Wolman, 1954- Table 3)

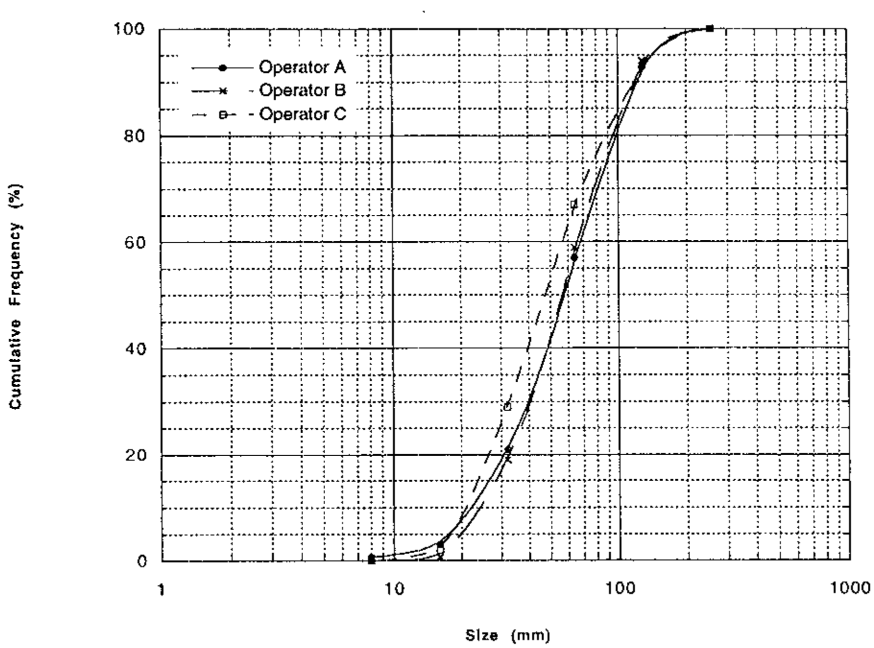
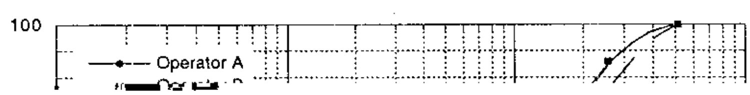


Figure 2b. Cumulative Frequency Curve (Wolman, 1954- Table 4).



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APPENDIX B

SUBSURFACE SAMPLING AND ANALYSIS

A LITERATURE REVIEW

· APPENDIX B

SUBSURFACE SAMPLING AND ANALYSIS- A LITERATURE REVIEW

I. INTRODUCTION

Sampling and analyzing the subsurface material of streambed gravels is a very difficult task. Geomorphologists use this analysis to draw conclusions about the physical responses of stream channels caused by natural or anthropogenic changes in input factors, while biologists try to relate those physical changes to potential effects to channel habitat condition. Although geomorphologists have developed several process based models relating input factors with subsurface particle size characteristics, their assumptions are not fully applicable in the field and they only apply to special conditions in the channel that not necessarily reflect the condition of the entire stream. Biologists have found that the particle size distribution, specially the amount of "fine" material in the substrate, plays a very important role in determining the survival of anadromous fish during several of their life stages.

Large quantities of fine sediment in spawning beds can have very important effects during the incubation and emergence stages of anadromous fish. During incubation increases of fine material within a gravel bed causes a decrease in the hydraulic conductivity of the bed. Most of the oxygen available inside the bed is supplied by surface water· As the hydraulic conductivity of the bed decreases, the amount of water, and thus oxygen, coming from the stream and passing through the bed material decreases· Oxygen is used up by organisms living in the gravel, and if oxygen demand is greater than the amount being supplied from the surface water, the development of organisms will begin to suffer. Low oxygen concentrations can cause delays in hatching of eggs, decreases in the size of fry, and death of the embryos·

As the amount of fine sediment increases the volume and connectedness of the pore spaces within the gravel decreases. Emerging fry use these spaces to find their way to the surface of the stream and if the available routes for their emergence are blocked, the fry get trapped and starve to death.

Accurate predictions of the physical and the consequent biological effects of changes in input factors are very difficult to determine for many reasons· Characterization, analysis, and interpretation of the subsurface bed material in gravel bedded rivers suffers from more problems than surface material analysis:

- Two-dimensional spatial variability
- Stratification or vertical variability
- Time variability
- Large range of particle sizes
- The need to remove large quantities of material from the streambed to collect unbiased samples
- Particle size characteristics are an indirect measure of habitat condition
- Studies have concentrated in attempting to find a single parameter that could be used to relate particle size characteristics of gravels to subsurface habitat condition, but most of them have yielded inconclusive results·

The main objective of this review is to discuss the different sampling methods that are used to collect subsurface material from the streambed, and to evaluate their possible use as monitoring tools. Methods are being evaluated according to their: cost, portability, equipment and labor intensity, training requirements, safety, accuracy and precision.

Data presented in NCASI (1986) was used to determine: 1) the accuracy of the McNeil and the single and tri-tube freeze core samplers in collecting material finer than 4 mm and 8 mm; 2) observe whether sample weight made a difference in increasing sample accuracy or precision for individual methods; and 3) determine if methods that tend to collect bigger samples performed much better than the ones extracting small samples.

Most of the data analysis shown in this report was coducted by Young et al. (1991). In this study the authors prepared 10 different sample gravels with median sizes ranging from 1 mm to 10 mm, then they used the single probe freeze core method, the tri-tube freeze-core method, the McNeil sampler, and a pointed shovel to remove samples from these test substrates. It is important to indicate that the tests performed by Young ct al. (1991) do not provide absolute accuracy and precision values because the samples were collected in special conditions that do not necesarily resemble field conditions. For this review we used the data very kindly provided by Michael Young, to establish the relative accuracy and precision of these methods in determining the median size, and the cumulative percentage of sediment finer than 1.7 mm, 0.85 mm, 0.42 ram, and 0.21 ram. *Accuracy* is defined as the nearness of a measurement to the actual value of the variable being measured and *precision* refers to the closeness of each other of repeated measurements of the same quantity (Zar, 1984). The difference between the minimum and maximum values and the standard error of the extracted sample data were used as ways to determine precision.

It. SAMPLING METHODS

A. Single Probe Freeze-Core Sampler

Poor accuracy and precision of the methods conventionally used in the 60's and 70's to determine the amount of fine sediment in stream gravels was the main motive for developing the single probe core sampler. Walkotten (1973) designed the first single probe freeze-core sampler and it was widely accepted because: it provided a means of sampling a nearly undisturbed stratified sample that contained gravel, intragravel water, and organic material: and because it allowed sampling in gravely stream beds. It is claimed that this method can extract samples up to 4 feet 3eep, weighting from 0.5 to 5 kg in several minutes. Available techniques include freezing with liquid nitrogen. a solid carbon dioxide and acetone mixture, and freezing with liquid CO2. Although the original descriptions of the method describe it as a very accurate and precise method of sampling streambed materials, later studies (i.e., Young et al. 1991) have shown that the method is unable to remove an unbiased sample. For this reason we do not recommend the use of the method in a stream gravel monitoring effort.

Materials

- cooling agent (liquid C02, liquid nitrogen, or a solid carbon dioxide and acetone mixture)
- device to transport and supply cooling agent (fire extinguishers are commonly used)
- cloth covered hose and a gate valve
- rigid copper pipe
- a 3-4 ft probe with a pointed steel cap and handles

Procedure

11 Probe is pushed into the stream bed.

2) A copper tube is inserted into the probe and it is fastened to the probe handles.

3) Once the hose is connected, operators may start the flow of cooling agent into the copper tube.

4) After several minutes the sample is frozen and it can be removed from the streambed.

5) The sample can be thawed with the aid of a blow torch. The sample can he collected in any container or in a specially designed container that allows to subsample the material with depth.

Advantages

· Equipment allows stratification of samples by retaining its primary structure (Platts et al., 19831.

· In theory, method is more versatile than other coring methods because it is not restricted to shallow or slow-moving water (Carling and Reader, 19811, and it can be used during arctic winter conditions (Platts et al., 19831.

· It allows collection of intragravel water, eggs and alevins in a redd at any stage of development.

Disadvantages

· The device under samples particles ranging from 6.3 to 9.5 mm and less than 0.212 mm (Young et al., 19911 because: 11 smaller particles may fall off in a higher weight ratio than larger ones during core extraction (Plats and Penton. 19801, and 2) because disturbance of the substrate can cause fine sediment to be displaced deeper into the stream bottom.

· The instrument over samples particles ranging h'om 25 to 50 mm (Plats and Penton. 198(1; NCASI. 1986; Young et al.. 19911 because sample volume is indeterminate so an irregular core is collected, often with large particles adhering to the outside of the frozen mass, creating bias towards large particles (Rood and Church, 19941.

· It produces very large and very variable geometric mean particle sizes (Young et al., 19911.

· Only submerged or saturated gravels can be sampled with this method.

· It produces small samples ranging from 0.5 to 5 kg, this increases the number of individual cores necessary to collect an unbiased sample.

· High water velocities and great water depths can limit the operability and the size of cores produced

· It is difficult to drive the probes into substrate when it contains many particles over 25 cm (Platts et al., 1983)

· The method is equipment intensive (Platts et al., 1983) when compared to other methods, so vehicular access may be a factor when deciding sampling site location.

· If samples are going to be subdivided by depth, the number of samples required for an unbiased sample is very large (Platts et al., 1983).

· Instrument takes uneven amounts of substrate in the vertical direction, thus collecting more sediment at certain depths than others (Plats and Penton, 1980).

· Some caution is necessary when working with compressed CO_2 (Walkotten, 1973).

· A leverage device may be necessary to loosen the frozen core from the streambed if large samples are being removed.

· Training of personnel has to be conducted very carefully to make sure freezing of substrate can be done very effectively and hazardous situations can be avoided.

Accuracy and Precision

The following observations can be derived from the NCASI (1986) study £See Figures 1 and 2a-2d):

· There are no definitive effects of varying sample size or varying percent of sediment finer than 4 mm and 8 mm in increasing either the accuracy or precision of this method.

· Deviations from actual percentages of fine sediment range from about + 4% to - 12%.

· For fine sediment less than 4 mm and 8 mm the method tends to underestimate the amount of fine sediment relative to the McNeil sampler, while for cumulative frequencies of sediments finer than 0.063 mm and 1 mm tire differences between this method and the McNeil sampler are less pronounced.

The following conclusions can be derived from Young et al. (1991) (See Figures 3-5):

· Method tends to under sample the amount of fine sediment in the test substrates.

· Accuracy of method is comparable to the other three methods only for sizes smaller than 0.42 mm.

· It seems that the method produces fairly accurate results in sampling particles finer than 0.42 mm, but significant error occurs when sampling particles between 0.45 mm and 1.7 mm.

· By combining precision and accuracy we can conclude that the method produces unreliable results when sampling particles ranging from 0.42 mm to 1.7 ram, while particles ranging from 0 mm to 0.42 mm are sampled as well as other methods.

· For the cumulative and individual frequency of material finer than 1.7 mm:

-accuracy and precision increase with increasing sample median size;

-overestimation of the amount of fine material in the gravel occurs only on samples with small median sizes;

-deviations greater than 10% occur at all median sizes.

· For the cumulative and individual frequency of material finer than 0.85 mm or 0.42 mm:

-accuracy and precision increase with increasing median size;

-overestimation of the amount of fine sediment in the sample tends to be much more common for samples with smaller median sizes;

-at small median sizes deviations from actual values can be greater than 10%.

· For material finer than 0.21 mm:

-accuracy and precision increase with increasing median size;

-overestimation of the amount of fine sediment in the sample tends to be much more common for samples with smaller median sizes;

-no deviations greater than 10% occurred at any median size.

B. Tri-Tube Freeze-Core Sampler

Several years after the single probe freeze core sampler was introduced by Walkotten (1973) practitioners discovered that it did not produced very accurate and precise results. Operators using the single probe method believed that the bias was mostly due to the small sample size extracted by the instrument. In an attempt to solve this problem Lotspeich and Reid (1980) developed the tri-tube freeze core sampler. The method was later modified by Everest et al. (1980) by improving accessories that made the handling of the cooling agent much safer, increasing freezing efficiency, and making it much more simpler to partition samples into subsamples. Sample weights typically range from 5 to 10 kg, but samples up to 20 kg can be extracted. Everest et al. (1980) were able to collect, thaw, and store up to four samples per hour. Although the method produces quite accurate and precise results that are comparable to extraction by shovels, we do not recmmnend its use because it is equipmem and labor intensive, it is not very portable and it is expensive.

Matet~als

- 3 stainless steel probes with stainless steel points
- probe template (serves three purposes: an adjustable depth-gage for the probes; holds the three probes in a fixed triangular array; and serves as the extractor for removing probes with frozen samples from the substrate)
- carbon dioxide delivery system composed of: 20 LB capacity aluminum fire extinguishers, valves, and hoses
- flow shunt~ it consists of a piece of a galvanized sheet metal formed into a teardrop shape
- core subsalnpler-consisting on a series of open-topped boxes made of galvanized sheet metal
- blow torch

Procedure

Method generally follows the same procedure described l~,r the single probe freeze core method (See Section A).

Advantages

- It allows stratification of samples (Platts et al, 1983).
- In theory, method is more versatile than other coring methods because it is not restricted to shallow or slow-moving water.
- It allows the collection of eggs and alevins in a redd at any stage of development.

· It provides an advantage over the single probe freeze-core sampler because it extracts a larger sample, which decreases individual sample bias and the number of samples needed for a representative sample.

· Accuracy and precision are comparable to extraction with shovels:

Disadvantages

· Method under samples particles ranging from 6.3 to 9.5 mm and less than 0.212 mm (Young et al, 199 i).

· It over samples particles ranging from 25 to 50 mm because sample volume is indeterminate so an irregular core is collected, often with large particles adhere to the outside of the frozen mass, creating bias towards large particles (Rood and Church, 1994).

· Disturbance of substrate can cause fine sediment to be displaced deeper into the stream bottom or downstream by the current and could lead to under sampling of fine particles (Young et al., 1991).

· Only submerged and saturated gravels can be sampled with this method.

· Very high water velocities and great water depths can limit the operability and the size of the extracted cures.

· Difficulty in driving probes into substrate, containing many particles over 25 cm (Plats et al. I983).

· Method is equipment intensive, costly, and requires some training in order to be used effectively and safely (Platts et al., 1983).

· Since the method requires several pieces of equipment, vehicular access might be a factor when deciding on sampling site location.

Accuracy and Precision

The following conclusions can be derived from the NCASI (1986) study (See Figures 1 and 2a-2d):

· There are no definitive effects of varying sample size or varying percent of film sediment in increasing either the accuracy or precision of this method.

· Deviations from actual percentages of fine sediment range from about + 4% to -4%.

· For film sediment less than 4 and 8 mm the method tends to underestimate the amount of fine sediment relative m the McNeil sampler, while for cumulative frequencies of sediments finer than 0.063 and I mm the differences between this method and the McNeil sampler are less pronounced.

· Method provides more precise results than the single probe freeze core method.

The following conclusions can be derived from Young et al., (1991) [See Figures 3-51:

· Method tends to under sample the amount of fine sediment in the sample gravels.

· Accuracy of this method is comparable to the shovel method for all sizes of fine sediment and it is comparable with the McNeil sampler for sediment finer than 0.85 ram.

· It seems that the method produces fairly accurate results for particles finer than 0.85 mm but is loses its accuracy with material ranging from 0.85 to 1.7 mm.

· By combining precision and accuracy we can conclude that the method produces reliable results when sampling particles ranging from 0 to 0.85 ram, while particles ranging from 0,85 to 1,7 mm are not accurately sampled.

· For the cumulative percentage of material ranging front 0.85 to 1.7 mm:
  -generally accuracy decreases and precision improves with increasing median size;
  -overestimation of the amount of fine material in the gravel occurs only in samples with small median sizes;
  -deviations greater than 10% occur at all median sizes,

· For the cumulative frequency of material finer than 0.42 mm:
  -there is no general trend in accuracy with varying median size;
  -precision tends to increase with increasing median size;
  -no deviations greater than 10% at any median size;
  -overestimation of the amount of fine material is common at small median sizes and rare at larger sizes

C. Multiprobe Freeze-Core Sampler

The multiprobe freeze-core sampler was developed by Platts and Penton (1980) in an attempt to improve sample accuracy by increasing gravel sample sizes. The method takes advantage of the positive attributes of the other freeze core methods, and it was believed that sample bias that occurred with the single and tri-tube methods was to be eliminated with the increase in sample size that the multiprobe method provides. The equipment freezes the pore water inside the gravel with CO_2 that is introduced to the gravel through 32 probes. The method produces samples typically weighting about 900 kg (1900 LB) with dimensions of 30 by 54 by 17 inches deep. The method is not recommended for monitoring gravel condition because: 1) it is extremely labor and equipment intensive; 2) causes severe disturbance of redds; and 3) most likely, it will underestimate the spatial variability of the conditions in an entire stream system because high cost and effort requirements number of samples that can be collected.

Materials

- 32 probes and caps
- CO_2 supply system

lilting apparatus and ice anchors

temperature indicator and switch equipment

- insulated boat for transporting sample over the stream
- hydraulic hose, manifold and filters

Procedure

1) Drive probes into the streambed.
2) Place caps with throttle valves, pressure gages, and relief valves on probes.
3) Place water flow shield around the probes to stop surface water circulation.
4) Place lifting equipment over sample area and install ice anchors into the bed.
5) Connect hoses to probes and CO_2 tanks.
6) Conduct general check of equipment.
7) Start the flow of CO_2.
8) Extract sample with lifting equipment after sample has been thoroughly frozen.
9) Transport sample in specially constructed boat and placing it in proper storage for transportation to the lab.

Advantages

· It allows vertical stratification of samples.

· h allows the collection of eggs and alevins in a redd at any stage of development (Plaits and Penton, 1980).

· The method functions at most air-water temperatures or stream depths (Platts and Penton, 1980).

· It reduces perimeter bias that occurs in single and tri-tube samplers.

· It takes a vertically uniform sample, which eliminates the effects of vertically uneven samples that are characteristic of the single and tri-tube freeze corers (Ptatts and Penton, 1980).

· One sample provides enough material for art unbiased sample of a given redd or riffle.

Disadvantages

- Only submerged gravels can be sampled with this method.
- Some fine sediment at the edges of the extracted sample can be lost when the sample is removed from the stream bottom.
- High water velocities and great water depths can limit the operability of the method.
- It is difficult to drive probes into any substrate containing many particles over 25 cm (Platts et al., 1983).
- Method is equipment and labor intensive.
- It causes severe disturbance of stream gravels and redds.
- Water circulation must be reduced with a shield for complete freezing to take place (Platts and Penton, 1980)
- Extraction and transportation of the heavy samples produced by this method requires special equipment and good vehicular access.
- Since a very reduced number of samples can be taken with this method, variability of the conditions found in the entire stream system may be underestimated.
- It requires one half to a full hour to freeze entire sample (Platts and Penton, 1980).

Accuracy and Precision

Accuracy and precision of method are unknown, but it is expected to be much better than the single or tri-probe methods in an individual basis because of bigger sample weight. It is unknown whether the method maintains this accuracy and precision advantage if enough samples are taken with the single and tri-probe corers to match the sample sizes typically removed by the multiprobe method.

D. Excavated-Core Sampler

The best known excavated-core sampler was developed by McNeil and Abnell (1964) in an attempt to solve the main deficiency of the methods utilized in the 50's and 60's: they were not able to effectively retain the fine sediment in the gravel. Some of these samplers worked with a mechanically operated closure that did not function correctly all of the time. The McNeil sampler is stainless steel and it is round in cross-section. The instrument extracts samples ranging from 10 to 20 kg depending on the depth at which the corer can be worked into the gravel. Even though the sampler is quite bulky and it is not able to preserve the vertical distribution of the sample, users agree that it provides the most accurate and precise method of sampling stream gravels. The instrument is relatively cheap, durable, and requires little maintenance. For these reasons we recommend its use as a stream gravel monitoring tool.

Materials

· McNeil cylinder with.coring and carrying handle

· Koski plunger or plastic caps

· plastic buckets for storage

Procedure

I) The sampler is worked into the channel substrate.

2) Encased sediment core is dug out by hand and deposited in a built-in basin.

3) Once all sediments have been removed to the level of the lip in the core tube, there are three possible ways to extract the fine sediment in suspension:

a) place a cap is placed over the tube to prevent water and collected sediments from escaping when the corer is lifted out of the water;

b) determine water volume in tube, agitate water and take a subsample; the total amount of fine sediment is determined by multiplying the sediment concentration by the total volume of water in the device;

c) agitate water inside corer and slowly insert plunger; once it is fully inserted the entire sample can be poured into a clean bucket.

Advantages

· In the study conducted by Young et al. (1991), this sampler produced geometric mean particle sizes which were comparable with those of the test substrates. They concluded that this sampler is the most accurate device for assessing overall substrate composition.

· The effects of water flow in causing sampling error could be significantly reduced by installing a portable stilling well just upstream of sampling site (Young et al., 1991).

· It is the most economical method available to obtain estimates of channel substrate particle size (Platts et al., 1983).

Disadvantages

· It under samples particles ranging from 6.3 to 9.5 mm and less than 0.212 mm (Young et al, 1991).

· Considerable operator skill is required to avoid under sampling the finest suspended matter (Rood and Church, 1994).

· Disturbance of substrate can cause fine sediment to be displaced deeper into the stream bottom or downstream by the current which could lead to under sampling of fine particles (Young et al., 1991).

· It does not permit vertical subsampling of the streambed (Platts and Penton, 1980; Platts et al., 1983).

· Its use is limited to water depth less than 60 cm deep.

· Maximum particle size able to be incorporated into the sample is limited by the size of the coring tube (Platts et al., I983; Platts and Penton, 1980).

· Coring depth is limited to the depth the core can penetrate the channel substrate (Platts et al., 1983; Platts and Penton, 1980).

· Instrument can produce a biased sample if the core tube pushes the larger particles out of the collecting area (Plats et al., 1983; Plats and Penton, 1980).

· It allows suspended sediments in the core to be lost at an unknown rate (Platts et al., 1983).

· It cannot be used if the particle sizes are so big or the channel substrate so hard that the core cannot be pushed to the required depth (Platts et al., 1983).

Accuracy and Precision

The following conclusions can be derived from the NCASI (1986) study (See Figures I and 2c):

· It is not clear whether the weight of the extracted sample or the amount of fine sediment in tim artificial gravel have effects on the accuracy of the method.

· Deviations from actual percentages of fine sediment in the samples range from about + 0.5% to -9%.

· For cumulative percentages of sediment less than 4 and 8 mm the method tends to overestimate the amount of fine sediment relative to the single and tri-tube freeze core methods-for cumulative percentages of sediments less than 0.063 mm and 1 mm the differences are less obvious.

The following conclusions can be derived from Young et al. (1991) [See Figures 3-5]:

· Method tends to under sample the amount of fine sediment in the sample gravels.

· Accuracy of method in portraying the actual cumulative frequency of sizes smaller than 0.85 mm is comparable to other methods, but for cumulative frequencies of particles smaller than 1.7 mm the method is much more accurate than any other device.

· Method is not as accurate as the freeze cure methods in sampling material finer than 0.42 ram, but it is very effective in sampling particles ranging from 0.42 to 1.7 ram.

· By combining precision and accuracy we can conclude that the method produces reliable results for all sizes of sediments finer than 1.7 ram, but specially for cumulative frequencies of particles finer than 0.42 and 1.7 mm.

· For the cumulative frequency of material ranging from 0.85 to 1.7 mm:

-no general trend in accuracy is evident with increasing median size;

-some increase in precision with increasing median size is observed;

-overestimation of the amount of fine material in the gravel occurs more frequently and is more pronounced with materials with smaller median sizes than with materials with coarser particle sizes;

-deviations greater than 10% occur rarely but at most median sizes.

· For the cumulative percentage of material smaller than 0.42 mm:

-at very small median sizes (about I ram) the method is very inaccurate, but accuracy seems to be constant for all other median sizes;

-no general trend in precision with increasing median size is observed;

-overestimation occurs slightly and exclusively at small median sizes;

-deviations greater than 10% occur only on samples with median sizes smaller than 1 mm.

· For the cumulative percentage of material smaller than 0.21 mm:

-at very small median sizes (about I ram) the method is very inaccurate, but accuracy seems to be quite constant for all other median sizes;

-precision appears to increase with increasing median size;

-no overestimation of percent fines occurs at any median size;

no deviations greater than 10% occur at any median size.

E. Shovels and Scoops

Shovels and scoops are the least expensive methods to sample streambed gravels. Scoops such as the one presented by Curtin (1978) have been designed to avoid loss of fine material during sample extraction. The following discussion will exclusively apply to the use of pointed shovels because they have been widely used and studied by fisheries biologists. Pointed shovels produce very accurate and precise results, specially when used with stilling wells (Schuett-Hames, pers. comm.) and they require minimum training in order to be accurately used. For these reasons we recommend incorporating shovels as tools to monitor stream bed gravels.

Materials

-pointed shovel
-stilling well or some type of flow shunt
-buckets for sample storage

Procedure

1) Place stilling well just upstream of sampling site.
2) Insert shovel straight down into tire substrate and lift sample.
3) Allow sample to drain for about 2 to 3 seconds and transfer it to bucket.

Advantages

· Effects of water flow in causing sampling error could be significantly reduced by installing a portable stilling well.

· They produce results very similar to McNeil samplers (Young et al., 1991).

· They accurately estimate the proportion of large particles (Young et al., 1991).

· Method is very easy to use and only minimum training is necessary.

· Shovels are portable which permits sampling in remote areas.

· Shovels can sample unsaturated or saturated gravels.

· The method is expected to produce very representative samples of unsaturated gravels.

· Sample size can be easily varied.

· Samples are extracted in a few seconds.

Disadvantages

· Under samples particles ranging from 6.3 to 9.5 mm and less than 0.212 mm (Young et al, 1991).

· Disturbance of substrate can cause fine sediment to be displaced downstream by the current and this could lead to under sampling of fine particles (Young et al., 1991).

· Method does not preserve the stratigraphic arrangement of streambed material.

Accuracy and Precision

The following conclusions can be derived from Young et al. (1991) [See Figures 3-5]:

· Method tends to under sample the amount of fine sediment in the sample gravels.

· Accuracy of method in sampling the actual cumulative frequency of sizes smaller than 0.85 mm is comparable to the McNeil sampler (ranging from about ~3% to -2%), but for cumulative frequencies of particles smaller than 1.7 mm the method is less accurate (about -4%).

· Shovels appear to have problems sampling material ranging from <0.21 mm to 0.45 ram, and also for material ranging from 0.85 mm to 1.7 mm; shovels appear to accurately extract material ranging form 0.45 to 0.85 ram.

· By combining precision and accuracy we can conclude that the method produces reliable results for all sizes of sediments finer than 0.85 ram, but for cumulative frequencies of material less than 1.7 mm shovels appear to lose some accuracy.

· For the cumulative percentage of material ranging from 0.85 to 1.7 mm:
  -no general trend in accuracy or precision is evident with increasing sample size;
  -overestimation of the amount of fine material in the gravel occurs more frequently with materials with smaller median sizes;
  -deviations greater than 10% occur at the smallest and largest median sizes.

· For the cumulative percentage of material smaller than 0.42 mm:
  -method is very inaccurate for very small median sizes (at about I ram);
  -no general trends in accuracy or precision are observed with increasing median size;
  -overestimation of fine material occurs at small median sizes.

· For the cumulative percentage of material smaller than 0.21 ram:

-some increases in accuracy and precision with increasing median size is observed;

-no deviations greater than 10% occurs at any median size;

-overestimation of fine material is not observed at any median size.

F. Excavated-Freeze Core Hybrid Sampler

Rood and Church (1994) developed a new sampling method that combines freeze-core and excavated-core sampling components, in an attempt to take advantage of the positive attributes provided by each method. They mention that the freeze core technique is the only means to remove all materials (including fines) from the substrate, and that McNeil-type samplers provide a constant sample volume that reduces the bias towards coarse particles. Initial equipment cost is about US $1,825 (1992 prices), and $1,000 to 2,000 for the liquid nitrogen required to sample about 50 cores. We believe that this method has the potential of being a very reliable way of extracting samples from the streambed. The method should not be included as part of a monitoring effort until its precision and accuracy are tested against known particle size compositions, and until practitioners agree that the procedure is simple and repeatable.

Materials

- core barrel consisting of a 20-cm outside diameter piece of hydraulic tube
- attached to core barrel is a 1-m length of 6.5-cm inside diameter steel pipe with handles at the top
- freeze core probe
- sledge hammer

Procedure

1) Work core barrel at least 30-cm into the substrate.
2) Insert freeze-core probe into the substrate with a sledgehammer, until the tip of the probe extends below the bottom of the core barrel.
3) Pour 6-8 L of liquid nitrogen from a Dewar flask or pail into the probe through a metal funnel.
4) After five minutes the liquid nitrogen votalizes and the core barrel is then removed from the substrate.
5) The frozen core is removed flora the core barrel and it could be either chipped off the probe with a small hammer or it may be left in a container.

Advantages

· It conserves the advantages of both core and freeze-probe samplers: constant sample volume, an effective method of particle removal from the substrate, and preservation of sample stratification.

· it can be effectively operated in water depths up to 1.1 m.

· It is not greatly affected by water velocity.

· Method operates at greater depth and over a wider range of velocities than the McNeil sampler.

· Two to three person crew usually averages from 4 to 8 cores per day.

· Individual cores can be up to 13.5 kg in weight.

Disadvantages

· Although material up to 128 mm has been cored, it is a difficult job that requires large volumes of liquid nitrogen.

· It cannot be used if the particle sizes are so big or the channel substrate so hard that the core cannot be pushed to the required depth.

· Maximum particle size able to be incorporated into the sample is limited by the size of the coring tube.

· Since liquid nitrogen has to be taken to the site, accessibility of the site and portability of equipment becomes a factor when selecting sampling sites.

· Disturbance of substrate can cause fine sediment to be displaced deeper into the stream bottom or downstream by the current and could lead to under sampling of fine particles.

· Up until now no study has determined the accuracy and precision of the instrument.

G. Containers and Infiltration Bags

Containers can be subdivided into two: solid-walled and porous-walled. Solid-walled containers are usually buckets or cans that are filled with gravel of known size and then are buried into the bed. Porous-walled containers are usually open-work baskets or containers with openings which are filled with gravel of known size and then buried. A more elaborate discussion on these methods appears in Lisle and Eads (1991).

Procedure

Infiltration bags consists of burying a collapsed bag under an unbounded cylindrical section of' experimental gravel. Bags are made of tough fabric and have a metal hoop sewn into the opening. The method requires more effort in installing the device than for containers. This method permits the detection of changes in framework materials as well as fine material because the experimental gravel is unbounded. Since the bag is installed at the bottom of the experimental gravel it is very unlikely that it will be affected by scour and fill events. The bags have a major disadvantage in that is might lose water-bearing sediment during extraction from the bed. We believe that infiltration bags provide a cost-effective method of sampling streambed materials, but they should not be used for monitoring until tests are conducted to determine their precision and accuracy under various; conditions.

Advantages

- They are easy to set up and remove.
- Provides a good way to quantify fine sediment infiltration rates.

Disadvantages

- Scour can expose a container above a moving layer of bed load.
- Fill can cover the opening with a protective seal.
- They are able only to determine a change in the amount of fine sediment in the container, so important sediment transport events that change the composition of even the coarse sediments can't be sampled.
- Solid-walled containers also have the disadvantage that they do not permit the inclusion of fine sediment transported by intergravel flow.
- Porous-walled containers suffers from the big disadvantage that water bearing infiltrated sediment flows out of the containers while they are being lifted from the bed.

We do not recommend the use of containers to monitor streambed materials.

III. CONCLUSIONS

Many different methods to sample the subsurface gravel material from stream beds have been discussed in this literature review. We recommend the use of the McNeil core sampler and pointed shovels as tools for monitoring stream gravels. The McNeil sampler provides the most accurate and precise method, while shovels are the most practical method to obtain acceptable results. The excavated-freeze core hybrid sampler has the potential of producing the most reliable and consistent samples of all the methods discussed, but its accuracy, precision, and practical use have yet to be tested. The need fur more accurate results than those produced by the McNeil sampler has to be evaluated. As discussed in Appendix C, the hydraulic conductivity of gravels is very sensitive to the amount of fine sediment in them, but these effects can vary widely for gravels with different frame work characteristics and/or different initial content of fine sediment. We believe that an increase in the accuracy of the current sampling methods should be accompanied by an increase in the knowledge of the effects of fine sediment intrusion into stream gravels. A multi*variable relationship between hydraulic conductivity and several characteristics of the particle size distribution should be developed in an attempt to improve the correlation between the physical attributes of the gravel and their potential biological condition. This relationship, together with an improvement in the accuracy of the sampling methods should provide a significant increase in the quality of the biologically related interpretations made form subsurface particle size analysis.

Figure 1. Variation of the Accuracy of Three Sampling Methods with Sample Weight (Data Taken from NCASI, 1986)

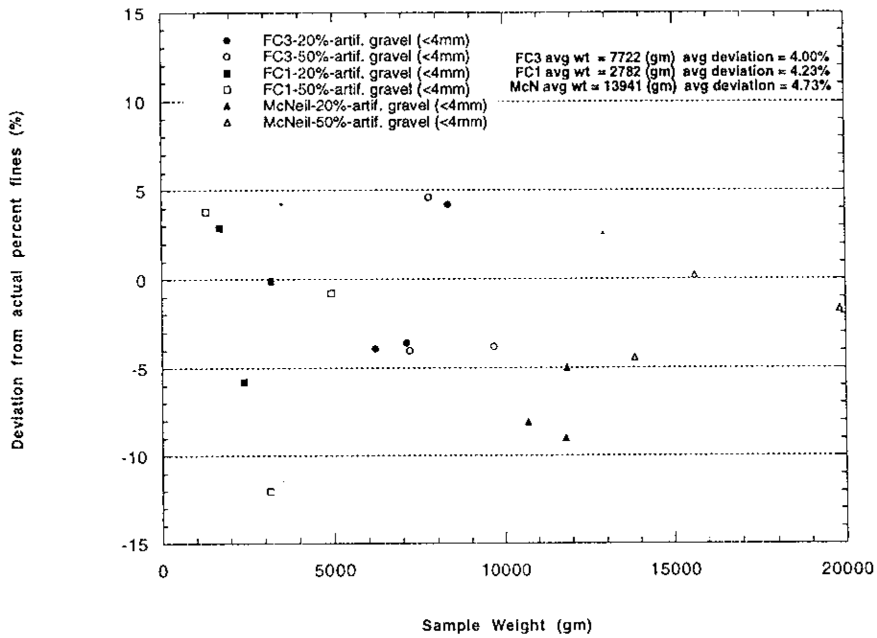


Figure 2a. Differences between four gravel sampling methods in determining the cumulative frequency of material finer than 8 mm.

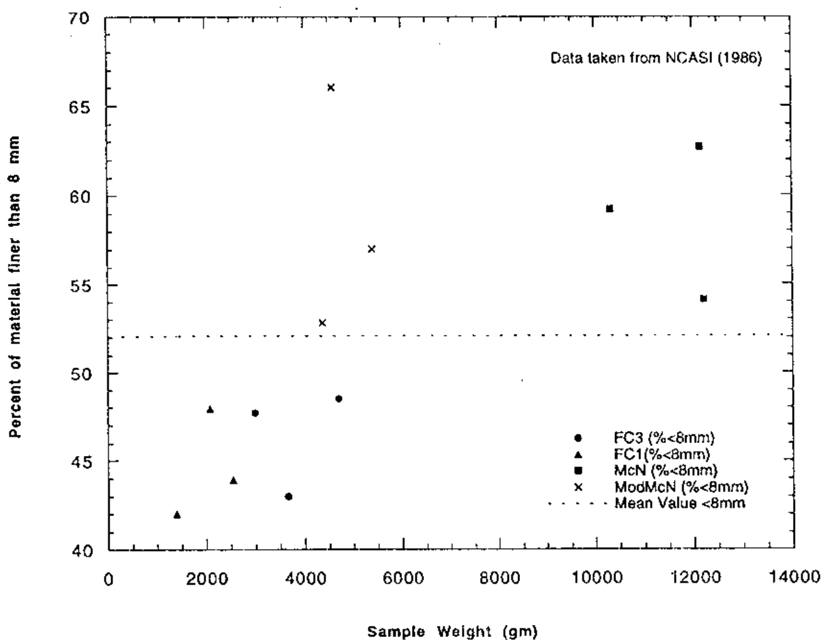


Figure 2b. Differences between four gravel sampling methods in determining the cumulative frequency of material finer than 4 mm.

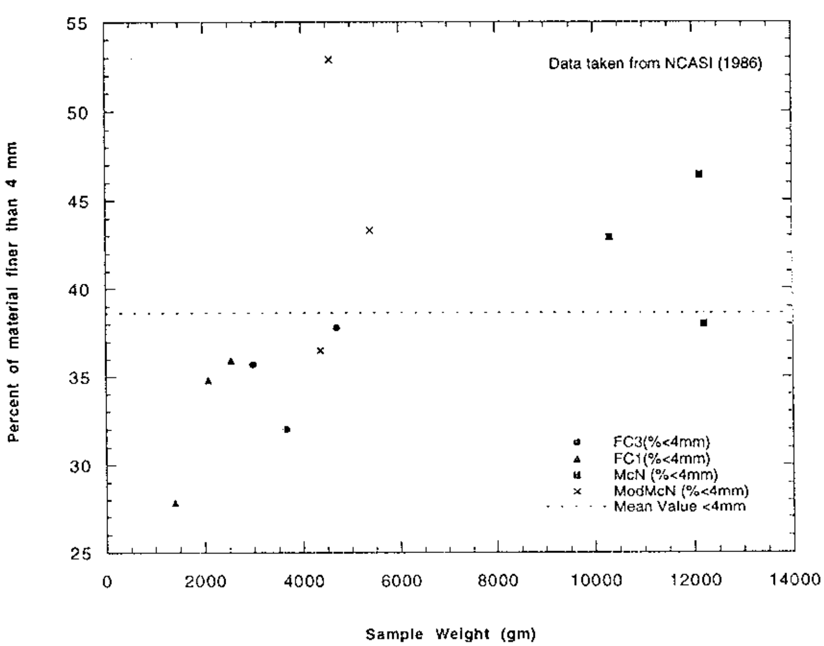


Figure 2c. Differences between four gravel sampling methods in determining the cumulative frequency of material finer than 1 mm.

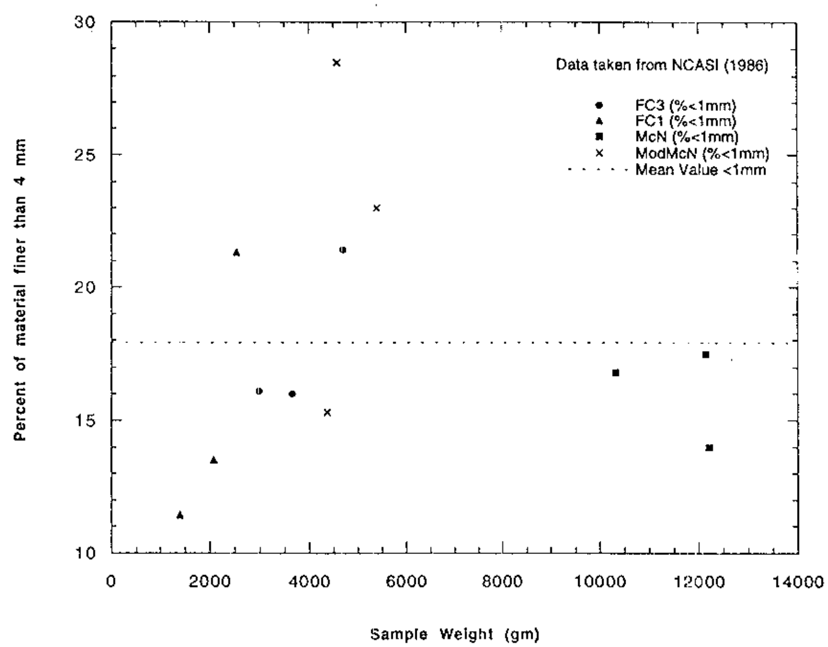


Figure 2d. Differences between four gravel sampling methods in determining the cumulative frequency of material finer than 0.63 mm.

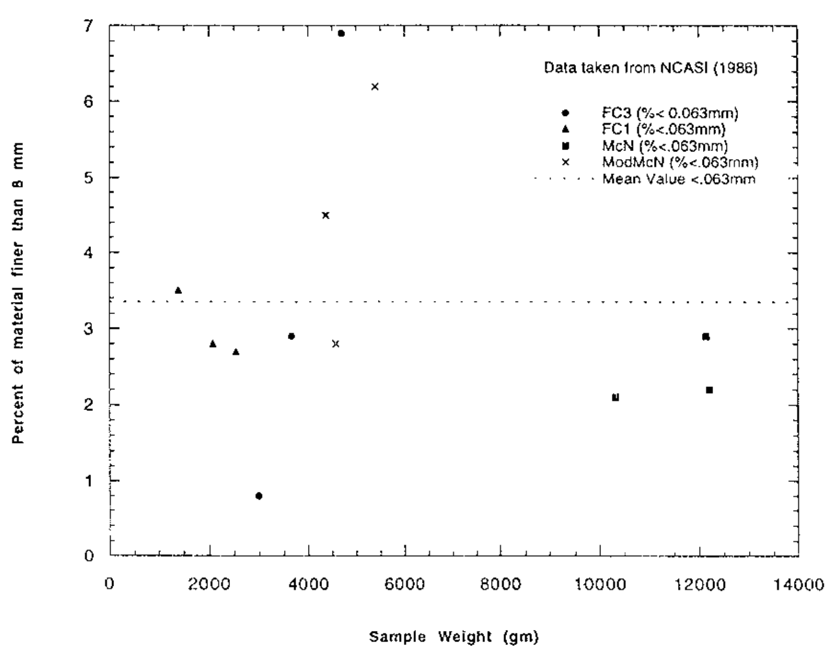


Figure 3. Accuracy of four sampling methods.

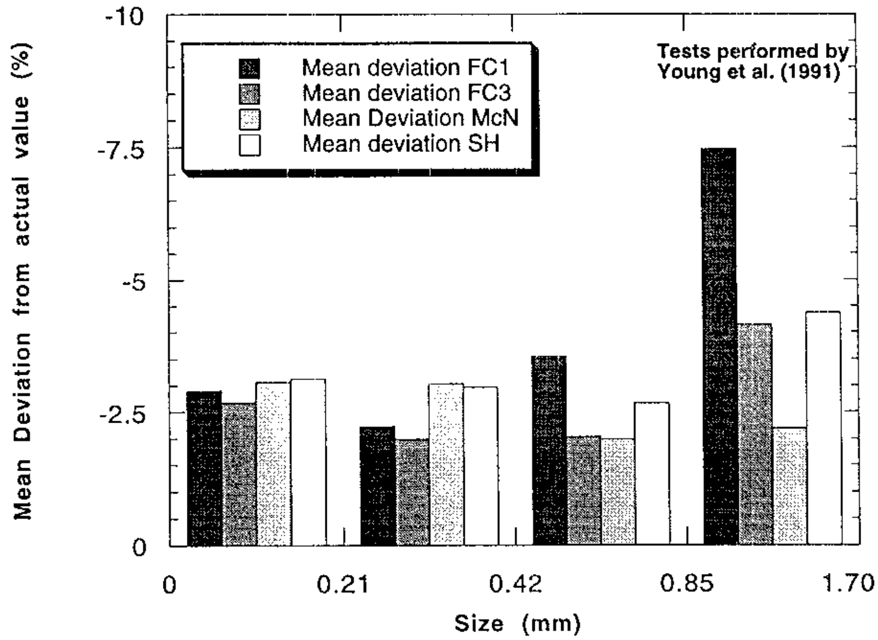


Figure 4. Precision of four sampling devices.

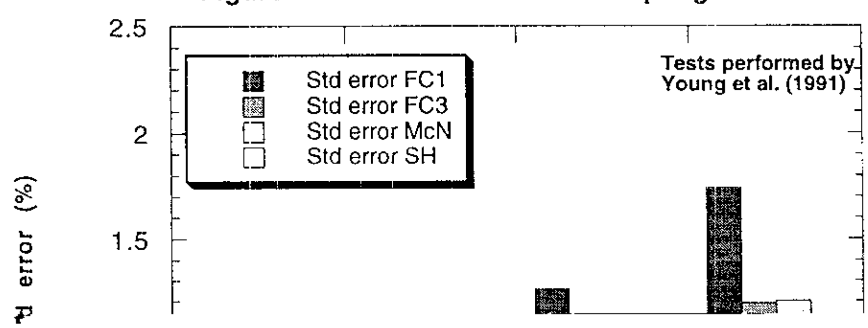
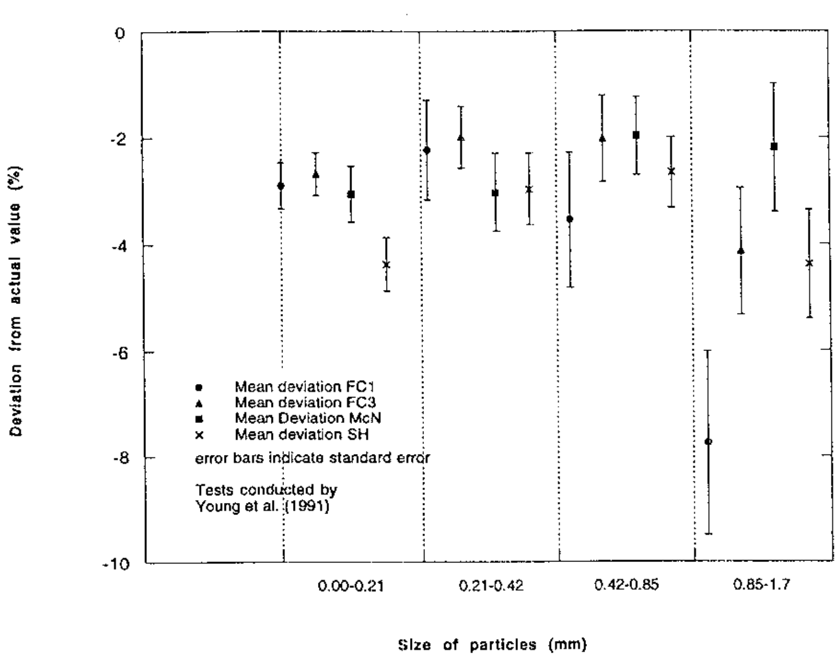


Figure 5. Accuracy and precision of four sampling devices.



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APPENDIX C

INFILTRATION OF FINE SEDIMENT AND ITS IMPLICATIONS ON THE HYDRAULIC CONDUCTIVITY OF STREAM GRAVELS

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INFILTRATION OF FINE SEDIMENT AND ITS IMPLICATIONS ON THE HYDRAULIC CONDUCTIVITY OF STREAM GRAVELS

GENERAL INTRODUCTION

Increases in hillslope erosion processes caused by forestry practices have detrimental effects on the biological quality of stream gravels. Typically most of the sediment produced that actually reaches the stream channels is fine sediment (sand, silt, and clay). Although the ultimate fate of this sediment is to be removed out of the system, it can stay in it for some time before being transported downstream. Fine sediment can be deposited on flood plains during high flow events or in areas of very low flow velocities (such as pools) during low flow events, but it can also infiltrate through stream gravels. When fine sediment infiltrates through gravels it settles in the pore spaces found between the coarser particles causing a reduction in the hydraulic conductivity of the gravel and a subsequent decrease in the rate of water flowing through it. Salmonid embryos buried in the gravel depend on this flow of water as its main source of oxygen and as a means to remove metabolic wastes from the redds (salmonid egg nests constructed in streambed gravels). A reduction in the amount of oxygen available may cause a delay in incubation time, reduced size of alevins, or even death of some or all of the embryos found in the gravel.

The main purpose of this review is not only to describe the complex processes of fine sediment infiltration into stream gravels and its effects on hydraulic conductivity, but also to discuss how important complexities of the processes can be overlooked by the field dam collection methods that are currently in use.

This review is organized in two sections. Part I discusses the variables controlling the rate of fine sediment infiltration and it also describes how differences in the relative importance of these variables create important variations in the vertical arrangement of the deposits resulting from this process. Part **11** first defines hydraulic conductivity and describes how the this property is affected by the addition of fine sediment. Then we evaluate several formulas developed for groundwater use, which predict the hydraulic conductivity of materials from their size distribution. We also briefly describe how water flows through riffles by showing a typical flow line arrangement through them and discuss why it is important to consider the flow paths when collecting subsurface gravel samples. At the end we present a quick description of the methods used to measure in-situ hydraulic conductivity of stream gravels.

PART I. INFILTRATION OF FINE SEDIMENT INTO STREAM GRAVELS

A. INTRODUCTION

Before we start the discussion on the processes conducive to the deposition of fine sediment into stream gravels, we understand it is essential to define several concepts. "Matrix" material is defined as the fine sediment that infiltrates the bed, while "framework" is the material forming the pores through which fine sediment passes (Lisle, 1989). "Porosity" is a measurement of both the size and quantity of pores in a sample. It is partly a function of sample packing, sorting, and roundness, but it is highly dependent on the framework particle size characteristics. Generally, the coarser the framework material the bigger and more numerous the pore spaces. According to these definitions the size of the material that should be defined as "fines" or matrix should be a function of the size of the pore spaces. Since porosity depends on the characteristics of the framework particles, the size distribution of the framework particles defines the size of the sediment that is considered as "fines". This definitions can be applied for well-defined bimodal distributions, but for other types of distributions it is very difficult to differentiate the matrix particles from the framework material.

Infiltration of fine sediment into stream gravels largely depend on the following things:

„ The size of the sediment being transported relative to the size of available or "open" pores.

*, The amount of "fine" sediment being transported by the flow.

· The number of "open" or "clean" pore spaces ill areas where fine sediment comes in contact with the streambed.

. The number and size of bed topographical features and obstructions causing convergence of sediment-bearing flows into the streambed.

The complexities of the fine sediment infiltration process are often overlooked. We believe it is important to understand these processes for the following reasons:

„ To help define the particle sizes that should be considered as "fines" for different framework size distributions. so that better correlation between fine sediment intrusion and the ability of gravel to provide suitable habitat for fish embryos can be achieved.

- To be able to understand the processes controlling the vertical stratification of both framework and matrix in stream gravels and their effects on infiltration rates and hydraulic conductivity. This could help in evaluating the usefulness of currently used gravel sampling methods in producing meaningful results.

· To locate areas in the streambed that are most likely to be affected by fine sediment infiltration so that the monitoring effort can be concentrated on these areas.

· To know at what time of the year it is most likely to expect increases in the percentage of fine sediment in gravels.

This review does not intend to provide solutions to any of these problems: The brief discussion on the different variables controlling the infiltration of fine sediment into gravels only provides and insight on the complexity of the problem. We believe it is necessary to remind ourselves about the complexity of the processes so that we can reevaluate our efforts and hopefully come out with either more confidence in the currently used analysis or completely new approaches to evaluate the problem.

B. DISCUSSION OF THE VARIABLES CONTROLLING INFILTRATION RATES

There are two main processes by which fine sediment can be deposited into the stream bed. These are infiltration after the material has been deposited and simultaneous deposition of fine and coarse sediment. Infiltration processes have been more extensively studied because until recently it was believed that it was impossible for fine and coarse sediments to be deposited simultaneously. Velocities necessary for fine sediment deposition are much lower than velocities necessary for deposition of coarse particles and it was thought that it was very unlikely that both velocities could occur in close proximity as to create deposits with both fine and coarse particles. Now it is understood that this is possible because when coarse particles start to deposit they create localized pockets of low velocities which can cause settling of fine sediment right next to them. This process of simultaneous deposition will not be discussed in this review.

Infiltration or "particle straining" is defined as the process by which fine particles move into the porous media until they encounter pore spaces too small to let them pass (Jobson and Carey, 1989). This process can occur at either high or low flows. At low flows fines can either infiltrate the bed and accumulate at depth or they can clog the material by depositing on the top layer of' the bed [called "surface caking" by Jobson and Carey (1989)]. At high flows infiltration may occur between scour and fill events creating layered deposits of intermittent fine and coarse material

Beschta and Jackson (1979) subdivide the infiltration process into two steps: 1) transport and deposition of sand particles into the surface voids of the gravel bed; and 2) settling of the particles into deeper gravel voids. These two steps depend on six interrelated variables:

· availability of pore spaces

· size distribution of sediment load relative to the size of available pore spaces

· concentration of sediment close to the water-stream bed boundary

· flow conditions

· flow convergence into the streambed

· occurrence of scour and fill sequences

B.1 Availability of Pore Spaces

It is generally accepted that tile potential for fine sediment infiltration into the gravel is largely dependent on the size and abundance of pore spaces in it simply because more pore space means that a larger surface area is available for infiltration. We should also consider that larger pores allow larger material to be considered as matrix, which means that more material can potentially infiltrate the bed. In order to allow free passage of fine sediment through the bed, pore spaces have to be "clean" or open.

Material with a size similar to tile size of the pores usually cannot penetrate it. When this happens the streambed becomes "clogged" and fine material that approaches it will tend to accumulate on the surface of the bed. This type of clogging completely stops the infiltration process and causes net aggradation of the bed. Scour of only this surface layer is necessary to "unclog" the pore spaces so that the infiltration can be reactivated once again.

During simultaneous deposition of fine and coarse material or during scour and fill events gravels are sometimes deposited in layers with alternating high and low content of fine sediment. The layers containing high percentages of fine sediment are typically clogged. Since these deposits prevent fine sediment from infiltrating deep into the deposit only small amounts of sediment can infiltrate it before its top becomes clogged and aggradation starts to occur on its surface. These gravels can be unclogged only daring high flows that are capable of reworking the entire depth of the deposit and can effectively remove the fine sediment from it.

In other situations gravels allow fine sediment to settle throughout the entire depth of the deposit. On these gravels clogging occurs from the bottom up and fine sediment may potentially infiltrate this material until most of the pore spaces have been filled by matrix. Because typically no signs of this process are visible on the surface this scenario might hide a high fine sediment loading problem from analysts unless subsurface sampling efforts are conducted.

The availability of open pores for infiltration is a very important factor that should be considered when the application of gravel cleaning solutions are being suggested to improve the quality of gravels in an area. Using specialized gravel-cleaning machinery or releasing high quantities of water from a dam to clean stream gravels can provide only temporary increases in gravel quality. Since a cleaner gravel has a higher potential of being infiltrated by fine sediment, large quantities of fine material can infiltrate the clean gravels after a single storm event. An effective solution can only be achieved by providing a way to remove the fine sediment from the gravels, but also by providing a means to reduce the amount of fine material entering the channel.

B.2 Size Distribution of Sediment Load Relative to the Size of Pores

The relationship between particle size-shape and pore size strongly controls the passage of particles through the pores of the bed both on the surface and through the entire depth of the gravel layer (Beschta and Jackson, 1979; Frostick et al., 1984; Jobson and Carey, 1989; Lisle, 1989). Several parameters have been developed in an attempt to relate the size of material that can infiltrate a given framework and which sizes would clog it. Jobson and Carey (1989) discuss the findings presented by Sowers and Sowers (1970) in which they determined that the effective pore diameter of a filter equals one fifth of the 1) 15 of the framework. They discussed that in order for finis to move through a gravel framework the following relationship has to be achieved:

DI5 fines < (1/5)* D15 framework < D85 fines]

In another study Sherard et al. (1984) stated that fines could not penetrate coarser sand if the following relationship was true:

I D15 framework < (9)* D85 fines I

In another attempt to understand the problem Lisle (1989) suggests using the ratio of the median size of the framework to the median size of the matrix *(Df/Dm)* as a good parameter for determining the potential of fine particles to intrude into the gravel framework. His findings can be summarized as follows:

.. For *Df/Dm* values less than 6.5 no infiltration is expected and fines are expected to accumulate on the surface of the deposit.

.. For *Df/Dm* values ranging from 6.5 to 60, fines are expected to infiltrate just the surface layer and to clog the pores. This would create a seal that effectively prevents further infiltration of even very fine material.

.. For *Df/Dm* values greater than 60 infiltration of fines is expected to occur over the entire depth of the streambed. When this is the case, fines will start filling the voids from the bottom up and the infiltration process will not be interrupted. Lisle mentions that silt-sized particles are so fine that they will fall in this category most of the time because they can penetrate most interstices.

In another study Frostick et al. (1984) measured the size of the pore spaces on the surface of the streambed and found that the maximum pore size equals about 0.41 times the median size of the bed. They discuss that this result compares to the study done by Fraser (1935) in which he found that the maximum particle size capable of moving through the pore spaces of a gravel deposit was 0.414 times the median size of the framework.

Data from several publications was used to calculate each one of the parameters described above, so that we could check how reliable each one is in predicting the infiltration of fines through sample stream beds (Results are shown in Table 1). Some of the size distribution characteristics were not directly presented in the publications so they were read off from graphs prepared from data presented in the reports, or by combining numerical with qualitative descriptions of the bed samples. Accuracy of predictions ranged from 40 to 60% and the parameter suggested by Sowers and Sowers (1970) proved to be the best in predicting accurate results. Most of the errors in the predictions occurred when the parameter predicted passage of fine sediment through the pores and clogging of the pores near the surface occurred. The object of this table is by no means to suggest which parameter is best in predicting infiltration of fine sediment, but to show that infiltration is a complicated process which cannot be simply explained by the particle size characteristics of the streambed and of the fine material trying to infiltrate it.

B.3 Concentration of Fine Sediment Close to the Bed Surface

Most publications agree that the concentration of sediment in transport is a controlling factor determining the intrusion rate of fine sediment into gravels, but some controversy exists in determining the relative importance of bed load and suspended load. While some studies suggest that the concentration of suspended sediment is important, others consider that is minimal when compared with the fine component of the bed load.

Most of the papers reviewed for this report indicate that the concentration of suspended sediment in the flow was a very important factor controlling the rate of fine sediment infiltration (Einstein, 1968; Carling, 1984; Jobson and Carey, 1989; Schalchli, 1992). Einstein (1968) indicates that the concentration of suspended sediment at the bed-water surface is very important because it controls the rate at which fine sediment is deposited on the bed. Carling (1984) agrees that the infiltration rate is related with the deposition rate because it is linearly correlated with the concentration of suspended sediment. He adds that the downstream decrease in infiltration rates from a point source is a negatively exponential function of distance from that source. In other words, he staled that intrusion of fines into stream gravels is most likely to occur in areas of high fine sediment input where high concentrations of fine sediment in transport are very likely.

Jobson and Carey (1989) discuss that suspended load is very unlikely to become deposited anywhere on the bed because it is easily transported by even low flows and it does not come frequently in contact with the bed. They agree though that fine sediment intrusion is a possibility in areas where sediment-bearing water flows into the streambed. The ability of this process to transport fine panicles is an important factor in determining the vertical distribution of fine sediment below the active bed. They suggest that most of the fine sediment intrusion should occur during the rising part of the hydrograph, when concentration of fine sediment is high and water is flowing into the bed.

Although all of the papers reviewed agree that fine sediment in suspension always composes a portion of the sediment found in the pores inside the gravels not all agree on its importance relative to the contributions of material transported as bed load. Frostick et al. 0984) compared the size distribution of suspended load and bed load with that of the intruded material and found that very fine material that is not carried as bed load is part of the material composing the matrix. With this they concluded that the coarser components of the matrix came from the finer particles of the bed load while the finer components of the matrix came from sediment in suspension. In the other hand, Lisle (1989) discussed that although suspended sediment accounted for 80-95% of the total sediment load of several events, only 10% of this size material intruded into the gravel. He stated that accumulations of very fine sediment are inhibited by winnowing from the surface layers (even under low flow conditions when bed mobilization is not occurring), and by infrequent contact with the bed during transport.

B.4 Flow Conditions

In the past, infiltration models were based on the particle settling theory which states that particles will settle only when flow velocities and turbulence are so low that particles cannot be sustained in suspension by the flow. These models predicted that infiltration of fine material could only occur at extremely low-velocity flows that allowed particles to settle down into the streambed. Later studies have shown that deposition and infiltration of fine sediment may occur at higher flows than those needed for settling of fine particles.

In several flume experiments conducted by Einstein (1968) he observed that under very small variations of flow velocity (ranging from I to 2 ft/sec) the rate of deposition of fine sediment appeared to be only slightly disturbed. Schalchli (I992) also conducted flume experiments and found that the occurrence of infiltration had a strong dependency on the dimensionless shear stress (dss) of the flow. He found that at flows with a shear stress just higher than that needed to mobilize the bed (dss values between 0.047 and 0.056) infiltration is possible as evidenced by clogging of the bed materials. At moderate flows (with dss values between 0.063 and 0.078) no infiltration was possible because fines are winnowed from the bed. At high flows (those with dss values higher than 0.078) no infiltration was possible because the entire bed was mobilized.

In another study, Jackson and Beschta (1979) found that the flow condition, indexed by the Froude number, had significant effects in intrusion rates. Apparently, the main influence of flow condition was to vary, within a narrow range, the depth and rate of formation of a sand seal (or a sandy "clogging" layer). At Froude numbers less than 0.9 a sand seal quickly developed in the upper 5 cm of the test gravels. At Froude numbers larger than 0.9 sand infiltrated the upper 5 to 10 cm of the grovels. At these high Froude numbers, turbulent pulses seem to inhibit the formation of the sand seal near the surface.

Frostick et al. (1984) discuss that there is considerable scatter in the relationship between the size distribution and concentration of suspended sediment with discharge due to differences in the availability of fine material on the streambed. They found that seasonal differences in sediment supply were reflected in the size distribution of the matrix material and form this they concluded that the availability of fine sediment is more important than the flow conditions. Although this might seem to be an oversimplification of the infiltration process we consider that it holds true for flows that do not winnow fine sediment from the bed or flows that mobilize the bed. They also found that this conclusion was applicable in a local scale. In their study, sediment traps that were placed in the same cross-sectional transects as others but that lie on areas of flow convergence caused by localized channel morphology experienced higher sediment accumulation rates. It is impossible for us to say at this point whether this higher infiltration rate was caused by flow convergence into bed or, as the authors claimed, caused by higher concentration of fine sediment.

In summary, flow conditions appear to have a significant effect on the occurrence of infiltration. In order for infiltration to occur flow conditions have to he within a certain range. Flow has to be high enough so that fine sediment is mobilized, but it cannot be too high as to winnow away fines or as to cause bed mobility. For relatively low flows the effects of flow conditions appear to be overshadowed by the amount of fine material in suspension. During high flows instantaneous localized fluctuations in the flow conditions may cause scour and fill sequences that are very important in determining the amount of fine sediment in gravels (this will be explained later in this report).

B.5 Flow Convergence into tire Streambed

By definition, fine bed load has a high potential of being incorporated into the streambed because it is intermittently but continuously in contact with it. In the other hand, contact between the bed and sediment in suspension is very infrequent unless water is forced to flow into the bed. Forced flows can be caused by local channel topography or obstructions. Changes in channel plan form or other topographical features on tire bed can cause local disruptions in the pressure gradients of the flow which may create zones of positive and negative flow convergence even on homogeneous beds. It is known that riffle crests, "redd mounds", and other similar features on the bed cause a disruption in the flow of water over the bed that causes an increase in the hydraulic gradients inside the gravels. This results in an increase in the rate of water flowing through it (Jobson and Carey, 1984). As- it will be discussed in Part II, obstructions may have a similar effect in the magnitude and direction of intragravel flow.

Although flow into the bed can increase the potential for infiltration it can also cause winnowing of fines from the bed. When sediment-bearing water enters the pore spaces its velocity is usually reduced, and at low flow conditions, this cause deposition of fine material. At high flows water velocities may be so high that they may cause the fine sediment in tire pores to be removed from them.

Jobson and Carey (1984) discuss that flow convergence into the bed can vary within single storm events. They state that during the rising limb of storm hydrographs flow convergence should be higher because water tends to flow into the bed, thus increasing infiltration rates. They also claim that during the falling limb of' hydrographs water would tend to flow out of the pores and into the channel causing a reduction of infiltration rates or even removal of fine sediment in the pores. The effects of this process in controlling infiltration rates are yet to be supported by field data.

B.6 Importance of Scour and Fill Events

Lisle (1989) stated that scour and fill events were sufficiently deep and frequent to affect particle size composition of spawning gravels as much or more so than infiltration of fine sediment. Channel plan form, large woody debris, and other obstructions can play a very important role in determining the location, magnitude, and frequency of scour and fill events. Scour cleanses the gravel of fine particles and it exposes a fresh unclogged surface to the flow. Usually at discharge events high enough that cause scour of the bed, large amounts of fine sediment are being transported by the flow of water. These are optimal conditions for high infiltration rates-clean gravels and high concentration of fine sediments in the flow. Subsequent filling provides more surfaces on which infiltration can occur. This results in a stratified deposit composed of layers with alternating high and low percentages of fine sediment. This process can also produce clean gravels if the bed fills rapidly and fines are removed faster than they can infiltrate the bed.

C. TYPES OF DEPOSITS RESULTING FROM INFILTRATION PROCESSES

As described by the previous section, the variables controlling fine sediment intrusion into stream gravels are very complicated. The complicated interrelationships between these variables are evident when we observe the various types of deposits that can be produced by the infiltration process. Depending on the local conditions the infiltration process may produce one of the three possible types of deposits. In this report we will refer to them by the following names: "coarsening upward", "clogged surface", and "stratified". In this section we will briefly describe them and we will discuss the implications of each one of them in controlling further infiltration of fine sediment, the rate of water flow through the deposit, and habitat quality.

A coarsening upward deposit may be formed when very fine sediment (relative to the size of the pores of the gravel framework) infiltrates through a thoroughly clean gravel deposit. In these deposits fine sediment freely moves through the entire gravel column until it settles at its bottom. This process can occur at relatively low discharges in areas where flows with a rather high concentration of fine sediment are converging into thoroughly "clean" stream beds. When this occurs the intruded fine sediment does not clog the pore spaces. In other words, in these cases the conditions allow for further infiltration of fine material, and potentially most of the pore spaces m the deposit could be filled by fine sediment. For hydraulic conductivity purposes the deposits may affect the rate and direction of water flow only in the section of the deposit where settling of particles have occurred- the bottom of the deposit. When the conditions leading to this type of deposit predominate in an area, gravel patches that might seem suitable locations for building redds might become completely filled with sediment after one or various high-sediment load events. In the other hand, if discharge events with high concentrations of fine sediment do not occur these deposits provide excellent conditions for embryo development and alevin emergence.

When the size of the particles in suspension is about the same size or larger than the size of the pores on the surface of the streambed fine sediment is not able to infiltrate it and deposition of fine sediment on or just below the bed may occur. This basically creates a two layer deposit referred to by Jobson and Carey (1989) as "surface caking". They are composed of fine material on or close to the top of the deposit with a coarser layer on the bottom-the inverse of an armored layer. When "surface caking" occurs it may completely stop the infiltration of fines through the material lying below the clogged surface, so further increases in the amount of fine sediment being transported or any decreases in the size of this sediment are not likely to have an effect on infiltration rates. None of the papers reviewed for this report discuss the effects of this type of deposit in the rate and direction of water flow through gravel patches, so we may only speculate on its effects on embryo survival (see Part II of this review). An obvious effect on habitat condition of this type of deposit is that it effectively blocks the passage of alevins during their emergence stage.

Analysts collecting samples for "q*" calculations should consider the "surface clogging" process in their analysis. Dietrich et al. (1989) found that with increasing sediment loads the differences between the size distribution of the armored bed surface and the subsurface layer diminished, and that at extremely high sediment loads a fine layer could form on the surface of the streambed. According to the description of the processes just discussed, we can determine that extremely high fine sediment loading is not necessary to create a bed similar to the one described by Dietrich et al. (1989). Accumulation of fine sediment on the surface of the deposit can occur during relatively low flow conditions on areas where the size of the fine sediment being transported is large relatively to the size of the pores. In other words, a "clogged surface" created by infiltration processes should be differentiated from a fine sediment layer deposited during simultaneous deposition. At the present time there is no procedure to distinguish one from the other in the field.

Stratified deposits are caused by scour and fill events during high flow conditions. Daring scour the gravel .is typically cleansed of fine sediment, exposing a "clean" streambed surface to flows having a high concentration of fine sediment. These are optimal conditions for high infiltration rates. A subsequent fill event covers this surface, provoking two important effects in the arrangement of the final deposit. This layer protects the already infiltrated surface from the effects of the flow and, at the same time provides a new surface where fine sediment can infiltrate. The result is a stratified deposit having alternate layers of high and low fine sediment concentration. Stratified deposits effectively stop any further infiltration of fine sediment during low flow conditions. The effects of this type of deposit in controlling the rate and direction of water flowing through it are not discussed by any of the papers reviewed for this report. We will only speculate on these effects and their relevance to embryo survival in Part II of this report. An obvious effect of a stratified deposit is to block the passage of alevins during their emergence stage.

Most of the studies conducted by fisheries biologists determining the effects of fine sediment intrusion in survival rates offish embryos have ignored the spatial arrangement of fine sediment in the gravels. Laboratory studies conducted in flumes have used gravels with no vertical variability and with flow conditions that do not simulate actual redds. Field studies have usually used gravel sampling methods (shovels or core samplers) that do not conserve the vertical arrangement of the deposits. Those that have used methods that conserve the vertical arrangement of gravels have not considered how this variability may affect the flow of water through individual deposits. Whether the three different types of deposits create special conditions that should be considered while conducting survival rates studies is yet to be determined. We understand that this issue should be solved promptly considering that most habitat condition analysis are based on those laboratory and field studies that ignored the spatial arrangement of fine sediment during their experiments. If tests prove that the effects of fine sediment on embryo survival are independent of the spatial arrangement of fine particles, we may use sampling devices that vertically integrate the sample and we can continue using the previously developed "survival to emergence-fine sediment content" relationships to analyze gravel condition. If tests prove that fine particle arrangement is important, a new strategy will have to be developed to evaluate gravel condition. Studies might then need to exclusively use sampling methods that conserve the vertical arrangement of the sample or instruments that either measure hydraulic conductivity or the actual rate of flow through the gravel.

D. CONCLUSIONS

The following characteristics provide the optimal conditions for infiltration of fine sediment:

· When the size of fine sediment being transported is very fine relative to the size of the pores.

· Areas in the stream where water carrying high concentrations of fines converge into clean gravels.

„ Flows transporting high concentrations of fine load. On a stream scale we can generalize that the closer to the source of fine sediment the higher the potential for infiltration. On a local scale, stream morphology can create zones of high sediment concentrations that can increase the spatial variability of infiltration rates even on homogeneous beds.

„ Large areas covered by "clean" gravels containing large quantities of pore spaces.

· Areas ,.*,,here bed morphology, channel plan form, and/or obstructions induce increases in the rate of water flowing into the bed.

Differences in the stratigraphic arrangements of infiltrated gravels (coarsening upward, clogged surface, or stratified) can have important effects in the survival of embryos and emergence of fry. A single thin layer of fine sediment may potentially reduce the rate of interchange between surface water and water in the pores, together with a reduction in the infiltration rate of fine sediment. Most currently used streambed sampling strategies do not take into account the different stratigraphic arrangements when the sample is removed and analyzed. Most *sampling* equipment does not preserve the actual *arrangement* of the material *and* most *analysis* is *done* by integrating the entire sample.

We encourage that future research should consider the real arrangement of stream gravels. If laboratory studies are going to be conducted they should reflect as close as possible the three.-dimensional spatial arrangement of particles and flow conditions present in the field. Field studies should employ sampling devices that preserve the stratigraphic structure of the stream bed. Analysis should be conducted so that the three dimensional spatial arrangement of the gravel material is used when interpretations are made. These studies should try to answer the questions related to the processes affecting fish survival but they should also evaluate the need of this knowledge for conventional gravel analysis. Researchers should evaluate how much more knowledge of the process would be gained from a thorough analysis of the spatial distribution of fine sedimem within the gravels and if this new knowledge significantly improves the quality of our interpretations and prescriptions in a watershed scale approach.

PART II. HYDRAULIC CONDUCTIVITY EFFECTS CAUSED BY THE INTRUSION OF FINE SEDIMENT INTO STREAM GRAVELS

A. INTRODUCTION

Increases in the amount of fine sediment found inside the pores of any porous material causes changes in the ability of that material to conduct water through it. in the case of stream gravels making up salmonid redds a decrease in the ability of the material to conduct water may cause hazardous conditions for the embryos inside the gravels. In this section we will first define hydraulic conductivity and we will describe how the hydraulic conductivity of any porous material is affected by the addition of fine sediment, Then we will present several formulas that predict the hydraulic conductivity of materials from their size distribution characteristics. These formulas were developed for groundwater uses and in this report we will evaluate their application on stream gravels. In this section we will also show the direction of flow lines through redds and how differences in the vertical stratification of deposits may affect them. At the end we present a quick description of the methods used to measure in-situ hydraulic conductivity of stream gravels. These methods present an option to the most commonly used volumetric sampling methods.

B. HYDRAULIC CONDUCTIVITY

Hydraulic conductivity is a coefficient of proportionality describing the rate at which water can move through a permeable medium (Fetter, 1988). We should emphasize that it is only a measure of the potential of water flow through the gravel and not an actual measure of the flow rate. Hydraulic conductivity is related to flow rate by Darcy's Law:

$$q = -K\ (dh/dl) \quad \text{(eq. 1)]}$$

V, here,

q is the flow rate (in units of length per time)

K is the hydraulic conductivity (in units of length per time)

dh/dl is the hydraulic gradient (dimensionless).

Hydraulic conductivity is both a function of the fluid properties (density and kinematic viscosity) and of the permeable material, The material characteristics affecting hydraulic conductivity are:

· Size of particles making up the framework of the material. Generally, the coarser a material is (typically .measured by median size) the higher its hydraulic conductivity.

· Sorting- Poorly sorted material usually has its pore space occupied by matrix while well sorted materials have a lower percentage of matrix material in them.

· Modality- Typically unimodal samples have greater hydraulic conductivity than bimodal samples.

· Bulk density or packing of' material- Generally, the higher the bulk density the less pore space available and thus the lower the hydraulic conductivity.

· Structure of the material- The detailed arrangement of the individual grains and their shape can affect the size, number, and connectedness of the pore space between particles.

· Percent of fine sediment in the sample- The higher the percentage of fine sediment the lower the hydraulic conductivity of the sample.

The relationship between all of these material characteristics and hydraulic conductivity can he easily understood if we understand how water flows through porous media. For water to infiltrate and move through a medium, both the flow and the medium need to posses certain characteristics. The flow has to provide enough force to move the water through the medium, and the medium must provide enough open avenues so that the water can move through it. Hydraulic gradient (dh/dl) is the way we measure how much force is being applied by the flow and hydraulic conductivity (K) is a means to measure the ability of the medium to allow the passage of water through it. A simpler way to visualize hydraulic conductivity is to see it as a measure of the size, number, and connectedness of the pore spaces in the medium.

As described in the first part of this review the porosity (determined by the size and amount of pore spaces in a medium) is strongly controlled by the size of the framework material. Changes in the porosity of a particular material can be caused by the addition of matrix to the medium. When porosity is reduced the size, amount, and cennectedness of the pores decreases, causing a reduction in the space available for water flow. This reduction in turn increases the forces applied by the material on the flow. Referring to equation 3, this means that higher hydraulic gradients are needed to get the same flow rate because the hydraulic conductivity value (K) has been reduced.

All of the material characteristics listed above are interrelated, so a change in one of them inevitably causes changes in all of the other parameters. This implies that each one of them could be used to quantify changes in the hydraulic characteristics of any medium. The most widely used parameters that have been used for this purpose are median size and other percentiles of the size distribution curve. Relationships between material characteristics and permeability are difficult to establish because:

1) Porosity is not only controlled by the size of the material. As described above porosity is also controlled by the detailed arrangement and shape of individual grains, characteristics that cannot be quantified by conventional analysis.

2) It is sometimes difficult to differentiate the framework material from the matrix. Six basic particle size distributions have been identified by researchers: normal with a broad range of sizes, normal with a narrow grain size range, bimodal, even distribution with a broad range of sizes, skewed right distribution, and skewed left distribution. Differentiation between framework and matrix material can be determined with some ease in materials with bimodal and the skewed distributions, but in other types of distributions differentiation is very difficult.

C USE OF EQUATIONS TO PREDICT HYDRAULIC CONDUCTIVITY

As fine sediment intrudes into stream beds it settles in the pore spaces between the grains. This reduces the size, quantity, and connectedness of open pores through which water can flow by reducing the hydraulic conductivity of the material. Ground water hydrologists have developed many equations that relate characteristics of the size distribution of materials with hydraulic conductivity. The following section discusses a few of these equations. Attempts to check whether these equations accurately predict the hydraulic conductivity values of actual stream gravels used in previous studies were unsuccessful because published reports did not provide all data necessary to run the calculations. By using the size characteristics of a single gravel sample we will try to determine whether the equations at least predict the general behavior of hydraulic conductivity with increasing fine sediment.

The pioneer work in trying to develop a sample size distribution-hydraulic conductivity relationship was done by Hazen (Fetter, 1988). He developed the following equation by performing several tests on sand samples:

$$K = C\,(D_{10})^2 \qquad \text{(eq. 2)}$$

where,

K is hydraulic conductivity in cm/sec
DiO is known as the effective grain size in cm
C is a coefficient based on size of sand and sorting.

No C coefficient values were found for gravel materials and for this reason we were not able to include this equation in the tests performed in this report.

An equation following the same approach of using a single effective grain size (median size) and empirically derived coefficients that vary according to dominant particle size and sorting was developed by Shepherd (1989):

$$K_i = a\ D50^b \qquad \text{(eq. 3)}$$

where,

K is intrinsic permeability

a is an empirically determined dimensionless coefficient that varies according to dominant particle size and sorting; it ranges from about 1,000 to 200,000

D50 is the median size in mm

b is an empirically determined exponent which varies according to dominant particle size and sorting; it ranges from 1.11 to 2.05

Another equation was developed by Alyamani and Sen (1993). This equation is based on several characteristics of the size distribution:

$$K = 1300\ [I_0 - 0.025\ (d50 - dl0)]^2 \qquad \text{(eq. 4)}$$

where,

K is hydraulic conductivity in meters/day

Io is the intercept when the observed straight line in the fine end of the cumulative frequency curve crosses the horizontal axis

d50 median size (ram)

d10 is the effective diameter and it corresponds to 10% passing of the sample during sieve analysis

We were not able to test whether these equations predict hydraulic conductivity of real gravel samples. The only tests that we were able to perform were to use the equations to check whether the equations correctly predicted the general behavior of hydraulic conductivity with increasing fine sediment. The results were compared to some data randomly selected from Table 2 in McNeil and Ahnell (1964). We took the size distribution presented by McNeil and Ahnell and we eliminated all of the sediment finer than 0.833 mm from it. We then added fine sediment in five percent intervals and determined the size distribution for each increment (Figure I). Fine sediment consisted in five parts finer than 0.833 mm and coarser than 0.208, three parts ranging from 0.208 to 0.104, and 12 parts finer than. 104. The median sizes of the sample range from 10.25 mm at 0% fines to 1.5 mm at 40% fines. Figure 2 shows how median size changes with the amount of fine material found in the gravel. This Figure shows that this relationship is linear throughout most of the entire range of values. This graph shows that if a gravel does not suffer any changes in the size distribution of its framework materials, it does not make any difference whether percent of fine sediment or median size is used to detect any changes in the quality of the gravels.

Figures 3a and 3b show the hydraulic conductivity values calculated from equations 5 and 6 fort the sample gravel shown in Figures 1 and 2. Figure 3a is a plot of percent of fine sediment versus hydraulic conductivity. McNeil and Ahnell data comes from actual hydraulic conductivity measurements taken in the lab. Unfortunately. the size distribution of the samples was not provided in the publication and we were not able to make direct comparisons with the values predicted by equations 5 and 6. Even though the McNeil and Ahnell data come from different gravel samples we will assume that they have similar size distributions because they all come from potential pink salmon spawning redds. If this is valid we can then assume that the changes in hydraulic conditions caused by the given changes in fine sediment content shown in the graph are similar to the changes that would be observed in a single sample.

We would like to comment on two important observations. First, in Figure 3a there is an obvious difference in the hydraulic conductivity values predicted by each one of the equations, and the magnitude of this difference decreases with increasing percentage of fines or with decreasing median size (Figure 3b). Secondly, there is an obvious difference between the general slope of the predicted values and the slope of the values measured by McNeil and Ahnell. This could be the result of one of the following:

a) Differences in the size distribution of the framework materials. These differences would be expected if the material used by McNeil and Ahnell was coarser than the sample used in the equations.

b) The equations predict a too gentle reduction in hydraulic conductivity with increasing fine sediment content. This could have significant effects '.*.'hen changes in particle size distribution curves are being interpreted. These differences could be reduced by changing the empirically derived coefficients in equation 5.

Researchers have determined that hydraulic conductivity values of stream gravels less than 100 cm/hr are considered hazardous because they dramatically reduce the survival rate of fish embryos. If the equations tested constantly dampen the effects of fine sediment in causing changes in the hydraulic conductivity of gravels then hazardous levels of percentage of fine sediment can be erroneously mistaken for acceptable conditions. In the gravel samples used in this report, Shepherd's equation predicts hazardous conditions at 15% fines, Alyamani and Sem's equation predict these conditions at about 22%, but the McNeil and Ahnell data shows that this condition can be attained at about 8-10%.

This simple test proves two things. First, the behavior of hydraulic conductivity values of gravel samples cannot be easily predicted from the panicle size distribution characteristics of the sample, Secondly, if analysts desire to use particle size characteristics to determine specific changes in the hydraulic condition (and thus, quality) of gravels, tests have to be conducted to validate the approach.

Figures 4a and 4b show how a constant change in the amount of fine sediment causes changes in the hydraulic conditions of the gravels. The Figures show that these changes are dependent on the initial particle size characteristics of the sample. Figure 4a shows how hydraulic condition changes vary with initial percentage of fine sediment. Figure 4b shows how hydraulic condition changes vary with initial median size. From these graphs it is obvious that changes in hydraulic conductivity for a given increase in percent fines are higher for samples with low content of fine sediment (or higher median sizes) than for samples with high percentage of fine sediment (or lower median sizes). This is expected from equations because hydraulic conductivity varies with the square of the median size of the sample. Data from McNeil and Ahnell is also included in this graph. Direct comparisons between them and the equations are not possible because: a) The size distribution of the samples used by McNeil and Ahnell is unknown and this does not allow us to determine whether the differences are caused by framework characteristics or are due to errors in the equations, b) For the McNeil and Ahnell samples percent of fine sediment was increased in 2.5% increments while for the equations 5% increments were used. The data is then just presented to show that a dependency in the initial amount of fine sediment exists in real samples.

Interpreting the changes in the amount of fine sediment in stream gravels in terms of general watershed conditions is very complicated. First, analysts have to consider the complex effects on hydraulic conductivity discussed above. Secondly, they have to consider that changes in percent of fine sediment is not linearly correlated with the amount of fines infiltrating the gravel. The amount of material needed to increase the percentage of fines sediment in a streambed that already has a high amount of fine sediment is higher than that needed for a sample with a low percentage of fines. For example, an increase of fine sediment from 30 to 35% requires more sediment than an increase from 5 to 10% for the same material This statement implies that very large increases in the fine sediment yield of a watershed and the subsequent increases in infiltration rates are not linearly correlated with percentage of fine material in the gravels. In other words, a 10% increase in the percentage of fine sediment does not necessarily relate to any of these: a 10% increase in the amount of fine sediment entering the channel; a 10% decrease in the quality of the gravel; a 10% increase in infiltration rates; and thus,' a 10% decrease in the general habitat condition of a watershed.

Also, interpretations of gravel size distribution analysis have to consider that infiltration rates may vary according to the amount of matrix material found in them. As explained in Part I of this report, in some cases the rate of fine sediment infiltration decreases with increases in the percentage of fine sediment. When this occurs it might take a considerably high increase in the amount of fine sediment entering the channel to cause further deterioration of the condition of gravels containing a large amount of fine sediment.

Figure 5 shows a simplified hypothetical relationship between increases in the fine sediment being delivered to streams and the expected changes in gravel quality. The Figure shows that for a given increase in the amount of fine sediment delivered the corresponding change in the quality of the gravel is higher for gravels with initially low percentage of fines than for gravels with initially high percentages of fine sediment. This relationship has important implications for watershed monitoring purposes. The magnitude of the impact in gravel quality caused by increases of fine sediment delivered to streams depends largely on the pre-existing gravel conditions. A given increase in the percent of fine sediment content (and the subsequent decrease in hydraulic conductivity) of gravels containing an already large quantity of matrix indicates a much higher increase in the sediment yield of an area than the same decrease in gravels with an initial low fine sediment content.

D. FLOW LINES THROUGH RIFFLE CRESTS AND REDDS

The circulation between stream and intragravel water is called interchange and it can occur in either upward or downward flow (Vaux, 1962). Interchange is very important for egg survival because it is one of the ways that oxygen is supplied to the gravel forming the redds (together with diffusion and ground-water flow sources). Once water is inside the gravel its velocity vector probably has a major component parallel to the flow of water in the channel and some component perpendicular to the channel flow (Jobson and Carey, 1989).

Vaux (1962) studied the different variables controlling the rate, location, and direction of interchange. We will be discussing only two of the four variables discussed by Vaux. First, he found a relationship between the profile of the energy line (water surface) with the location, direction, and magnitude of interchange. Although he erroneously suggested that the energy profile is a direct reflection of the surface of the streambed in the absence of any obstructions, his analysis is still useful. He related channel topography along the channel with interchange rates and directions. He concluded the following:

- On straight profiles no interchange should occur.
- On concave profiles water flows out of the water.
- On convex profiles water flows into the gravel.

Riffles are typically convex, which indicates that interchange of water occurs into the gravel. Jobson and Carey (1989) presented a Figure (Shown here as Figure 6) that shows in two dimensions the expected flow lines through gravels. Although this Figure was developed for sandy dunes they state that similar flow lines are expected to occur in fifties. Vaux (1962) stated that extensive downward interchange can be expected if a hump of gravel was formed by a female salmon digging an egg pocket. Interchange rate is positively correlated with the magnitude of the concavity or convexity of the profile.

Vaux (1962) also found that large obstructions can have a big effect on water interchange. Large woody debris, boulders, or any other type. of large obstruction can disrupt the original shape of the energy line (taken here as the water surface profile) and this may cause changes in interchange flow location, magnitude, and even changes in the direction of interchange.

Another important factor that should not be overlooked is the hydraulic conductivity of the gravel. We should understand that the rate of water flowing into the gravel has to equal the rate of intragravel flow, so changes in hydraulic gradient or in hydraulic conductivity in any point along the flow path will affect both flow rates together. This is very important because the size characteristics of gravel deposits where infiltration of sediment occurs suffer from either gradational or sharp three-dimensional transitions. In order to make accurate interpretations on how the compositional and hydraulic changes of the gravel can affect the direction and rate of flow of water into and through the gravel, the location of these changes relative to the flow paths has to be considered. For example, a single relatively impermeable thin shallow gravel layer that is spatially continuous on a riffle (typical of clogged or stratified deposits) can cause a decrease in the flow rate through the gravel which can create hazardous conditions for fish embryos. In this case current sampling strategies that vertically integrate the gravel samples can overlook hazardous conditions. For example, if the gravel surrounding this fine sediment layer is "clean", analysts most likely will erroneously conclude that the riffle crest provides good conditions for embryos. We believe that any attempt to understand this process will significantly increase the time and effort employed in the analysis, but we believe that uncertainties that result from using current strategies can produce unacceptable results that are caused mostly by a lack of consideration of the fundamental processes.

E. METHODS TO MEASURE IN-SITU HYDRAULIC CONDUCTIVITY

Most of the publications reviewed that measure in.-situ hydraulic conductivity of stream gravels use the standpipe apparatus invented by Pollard (1955). The method consists in three steps:

1) Pounding the standpipe into the gravel.

2) Inducing a determined negative hydraulic head with a hand pump to cause water ill the gravel to flow into the pipe.

3) Measuring the rate of water flowing into the pipe.

A predetermined graph relating hydraulic conductivity to water flow rate is used to determine the hydraulic conductivity of the gravel. Recent laboratory experiments appear to indicate that using art equivalent to the Hvorslev slug test produces more precise results than the negatively induced head (Goldstein, unpublished report). The Hvorslev slug test consists of inducing a positive hydraulic head in the pipe and then measuring the rate of water flowing out of the pipe. Below, we present a list of' publications that explain thoroughly the construction process and usage of this method. This table is by no means complete and it should be only a starting point for researchers interested in this topic. Although we will not discuss the details pertaining to the construction or usage of the instrument, we will comment on the advantages and disadvantages of the method.

TABLE2

References for in-situ measurement of hydraulic conductivity

Barnard, K. and S. McBain, 1994. Standpipe to determine permeability, dissolved oxygen, and vertical particle size distribution in salmonid spawning gravels. Fish Habitat Relationships Technical Bulletin, n. 15. 12 pp.

Gangmark, H. A and R. G. Bakkala, 1958. Plastic standpipe for sampling streambed environment of salmon spawn. U.S. Fish and Wildlife Service-Special Scientific Report: Fisheries No. 261.20 pp.

Klein, R. D., 1993. Sediment flux, fine sediment intrusion, and gravel permeability in a coastal stream, Northwestern California. Proceedings of 1993 International Conference on Hydro-Science and Engineering. S. Wang, ed. Washington DC. June 7-1 l, 1993

Pollard, R. A., 1955. Measuring seepage through salmon spawning gravel. Journal of the Fisheries Research Board of Canada, 12(5), p. 706-741.

Terhune, L.D., 1958. The Mark V1 groundwater standpipe for measuring seepage through salmon spawning gravel. Journal of the Fisheries Research Board of Canada, 15: 1027-1063.

Young, M. K., W. A. Hubert, and T. A. Wesche, 1989.]Evaluation of variation in permeability measurements when using the Mark VI Standpipe. Canadian Journal of Fisheries and Aquatic Sciences. vol. 46, p 44%449.

Advantages of measuring in-situ hydraulic conductivity

· It does not require the removal of a sample from the bed. This reduces the disturbance on the redds and eliminates the effort needed to transport sample to lab for further analysis.

· It is a more direct measurement of gravel quality because it is more directly related to oxygen supply to embryos than particle size characteristics.

· Measurements can be taken very quickly so a large number of samples can be collected in a short amount of time.

· Results can be produced out in the field.

· Standpipes can be left inserted in the gravel for monitoring purposes.

Disadvantages of measuring in-situ hydraulic conductivity

· Method assumes hydraulic conductivity is an isotropic characteristic of the gravels. Anisotropy in hydraulic conductivity of stream gravels is expected because of imbrication and stratification of sample. This is very important because, as shown in Figure 6, flow lines do not follow straight horizontal lines through the streambed. Flow lines have components in three dimensions and the corresponding three-dimensional hydraulic conductivity vectors cannot be resolved with current methods.

· Since measurements are performed at specific depths, vertical variability in hydraulic conductivity cannot be detected.

· The insertion of the standpipe can disturb the gravel causing significant errors in hydraulic conductivity

F. CONCLUSIONS

Hydraulic conductivity is both a function of the fluid properties (density and kinematic viscosity) and of the permeable material. The size of the framework and the amount of matrix material in stream gravels are very important factors affecting hydraulic conductivity. The application of forestry practices in an area usually increases the amount of fine material entering the stream channels, and this increases the'. potential for fine sediment infiltration into gravels. The relationship between increases in fine sediment yield and deterioration of gravel quality are very complex. There exists a large dependency on the magnitude of this gravel quality deterioration with the pre-existing gravel fine sediment content. Changes in hydraulic conductivity for a given increase in percent fines are higher for samples with low content of fine sediment (or higher median sizes) than for samples with high percentage of fine sediment (or lower median sizes).

By conducting simple tests to evaluate the use of several equations in predicting the hydraulic conductivity of gravels we concluded that: a) the behavior of hydraulic conductivity values of gravel samples cannot be easily predicted from the particle size distribution characteristics of the sample; and b) if analysts desire to use particle size characteristics to determine specific changes in the hydraulic condition (and thus, quality) of gravels, tests have to be conducted to validate the approach.

By examining the flow line arrangements expected to occur in riffles we are able to determine that the presently used analysis could misleading analyst to draw erroneous conclusions. In order to make accurate interpretations on how the compositional and hydraulic changes of the gravel can affect the direction and rate of flow of water into and through the gravel, the location of changes in gravel hydraulic conductivity relative to the flow paths has to be considered. In-situ measurements of hydraulic conductivity seem to provide a good solution to this problem and we recommend that this approach should evaluated more closely.

GENERAL CONCLUSIONS

This review has shown that the processes of fine sediment infiltration into streambed gravels and the subsequent effects on hydraulic conductivity are very complex. We believe that current analyses of stream gravels could be producing inaccurate results, simply because they oversimplify the processes involved. The need of new or modified sampling devices and analytical techniques that are capable of capturing the actual three-dimensional spatial variability in the important variables controlling the physical processes should be evaluated. If there is a need for new strategies they should be evaluated not only in how much more knowledge of the actual processes we may gain from them, but also on how they could provide assistance in making better watershed management decisions.

TABLE 1

Reference	D_{matrix} (mm)	D_{frmwk} (mm)	$D_{15\,f}$ (mm)	$D_{15\,m}$ (mm)	$D_{85\,m}$ (mm)	I $D_f/D_m > 60$ (Lisle, 1989)	II $D_{15m} < (1/5)\,D_{15f} < D_{85m}$ (Sowers & Sowers, 1970)	III $D_{15f} > (9)\,D_{85m}$ (Sherard et al., 1984)	IV $D_m < (0.41)\,D_f$ (Frostick et al., 1984)	clogging near surface?	infiltration to bottom of streambed?
Schälchli (1992)	< 0.06	26	2	< 0.06	0.16	y (433)	y (.06 < .4< .16)	y (2 > 1.44)	y (.06 < 10.66)	y	n
Schälchli (1992)	.21	26	2	0.09	.28	y (123)	n (.09 <.4 < .28)	n (2 > 2.52)	y (.21 < 10.66)	y	n
Simons et al. (1963)	?	?	.3	?	0.01	?	n (? <.06 < .01)	n (.3 > .9)	?	n	y
Einstein and Chien (1953)	?	?	0.15	?	.4	?	y (? <.03 < .40)	n (.15 > 3.6)	?	y	n
Frostick et al. (1984)-coarse sub-armor framework	0.2	48	?	< 0.07	2.7	y (240)	?	?	y (.2 < 19.68)	n	y
Frostick et al. (1984)-medium sub-armor framework	0.25	24	?	< 0.07	2.7	y (96)	?	?	y (.25 < 9.84)	n	y
Frostick et al. (1984)-fine sub-armor framework	1.2	12	?	< 0.07	4.5	n (10)	?	?	y (1.2 < 4.92)	y	n
Frostick et al. (1984)-surface of lid	.55	27	19	<0.07	3.3	n (49)	n (.07 < 3.8 < 3.3)	n (19 > 29.7)	y (.55 < 11.07)	n	y
Beschta and Jackson (1979)	0.2	15	7	0.12	0.3	y (75)	n (.12 < 1.4 < .3)	y (7 > 2.7)	y (.2 < 6.15)	y	n
Beschta and Jackson (1979)	0.5	15	7	0.32	0.7	n (30)	n (.32 < 1.4 < .7)	y (7 > 6.3)	y (.5 < 6.15)	y	n
Einstein (1968)-prototype	0.011	60	32	0.0049	0.023	y (5454)	n (.0049 < 6.4 < .023)	y (32 > .27)	y (.011 < 24.6)	n	y
Einstein (1968)-model gravel	0.011	16	8	0.0049	0.023	y (1454)	n (.0049 < 1.6 < .023)	y (32 > .27)	y (.011 < 6.56)	n	y
Carling (1984)	0.15	25	11	0.12	0.16	y (166)	n (.12 < 2.2 < .16)	y (11 > 1.44)	y (.15 < 10.25)	n	y
Carling (1984)	0.19	25	11	0.16	0.2	y (131)	n (.16 < 2.2 < .20)	y (11 > 1.80)	y (.19 < 10.25)	n	y
Carling (1984)	1.4	25	11	1.3	1.5	n (17.8)	n (1.3 < 2.2 < 1.5)	n (11 > 13.5)	y (1.4 < 10.25)	n	y
Lisle (1989)-Jacoby Creek	0.3	22	17	0.09	0.8	y (73.3)	n (.09 < 3.4 < .8)	y (17 > 7.2)	y (.3 < 9.02)	y	n
Lisle (1989)-Prairie Creek	0.32	25.5	22.4	0.12	0.8	y (79)	n (.12 < 4.48 < .8)	y (22.4 > 7.2)	y (.32 < 10.45)	y	n
Lisle (1989)-North Fork Caspar Creek	0.3	21.5	15.4	0.09	0.9	y (71)	n (.09 < 3.08 < .9)	y (15.4 > 8.1)	y (.3 < 8.81)	y	n
Efficiency of predictions (%)	-	-	-	-	-	50	60	40	50	-	-

In columns I through IV:

y indicates that the conditions necessary for fine sediment infiltration are satisfied by the size characteristics of the gravel.

n indicates that the conditions necessary for fine sediment infiltration are not satisfied by the size characteristics of the gravel.

Figure 1. Changes in size distribution with increasing percentage of fine sediment

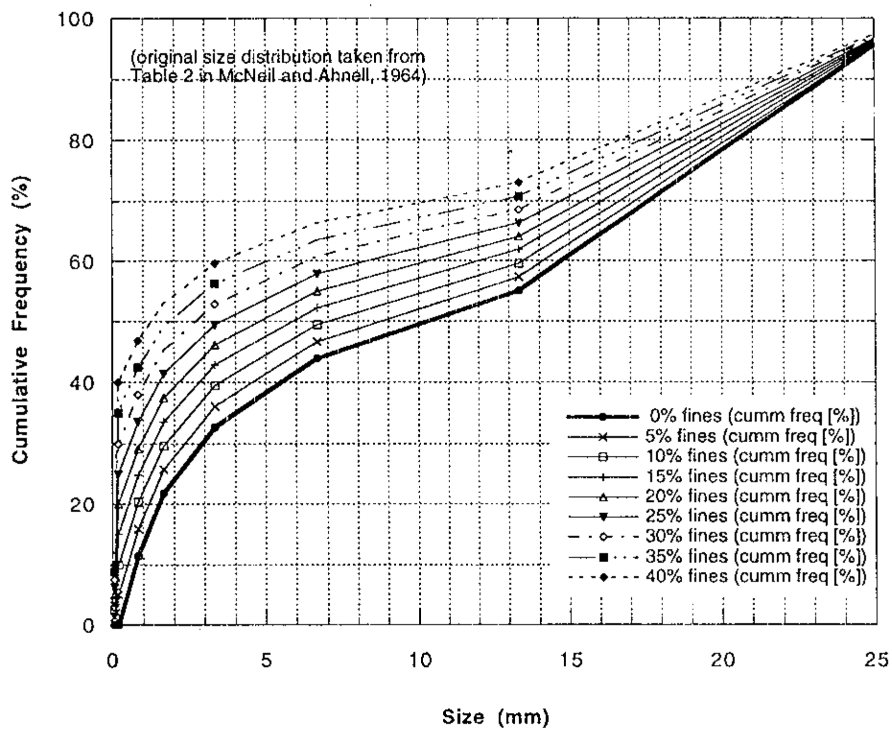


Figure 2. Decrease in median size with increasing percent of fine sediment in a sample gravel

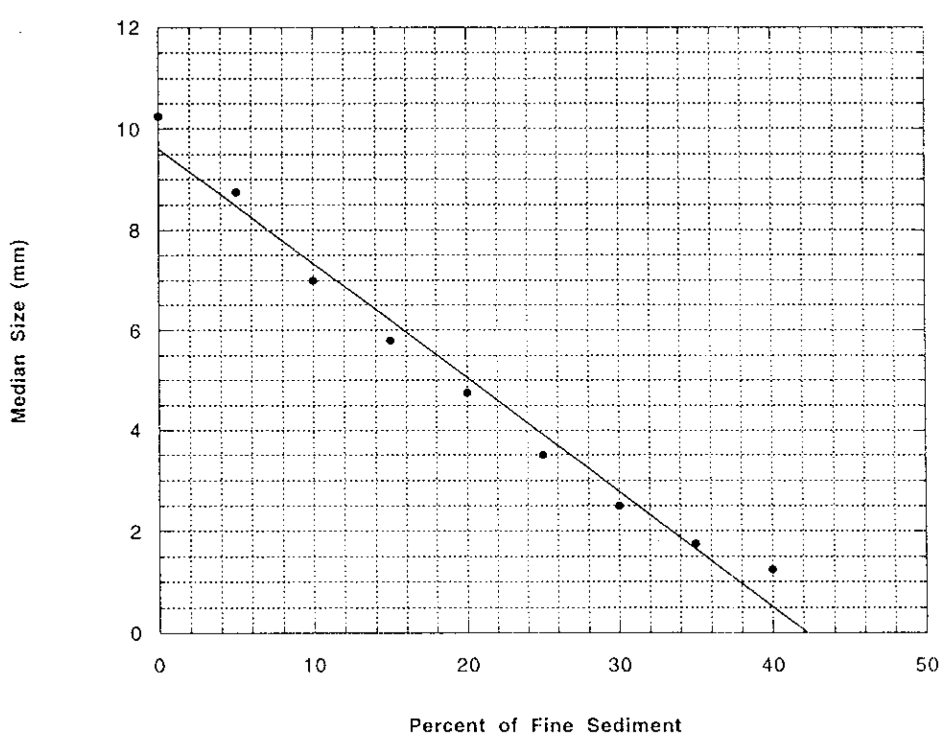


Figure 3a. Decreases in hydraulic conductivty of sample gravel with increasing percent of fine sediment

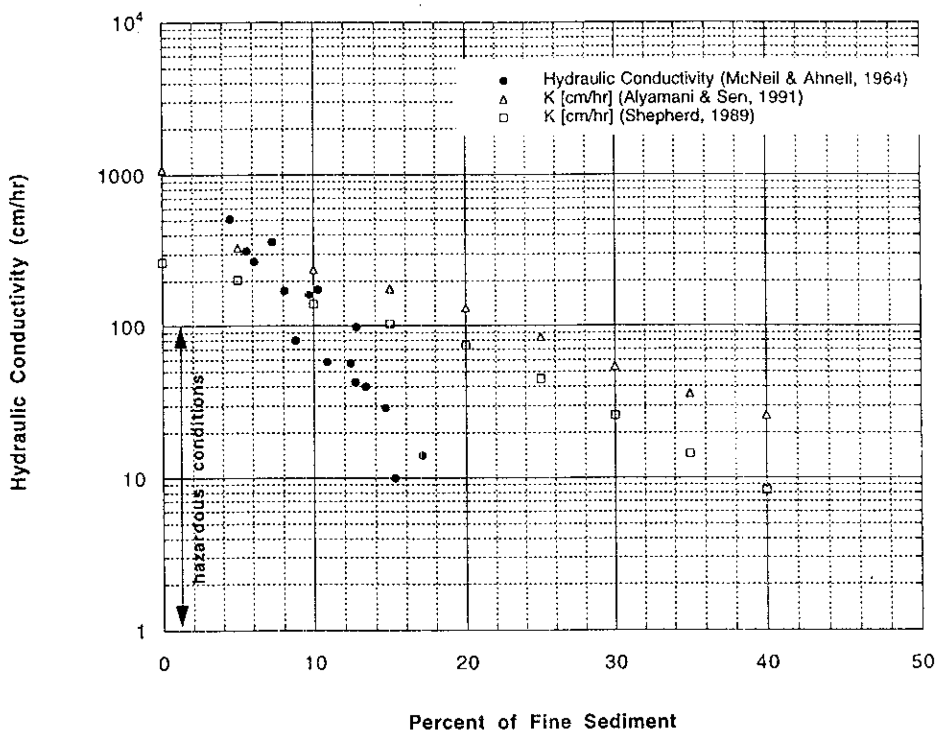


Figure 3b. Decreases in hydraulic conductivity of sample gravel with decreasing median size

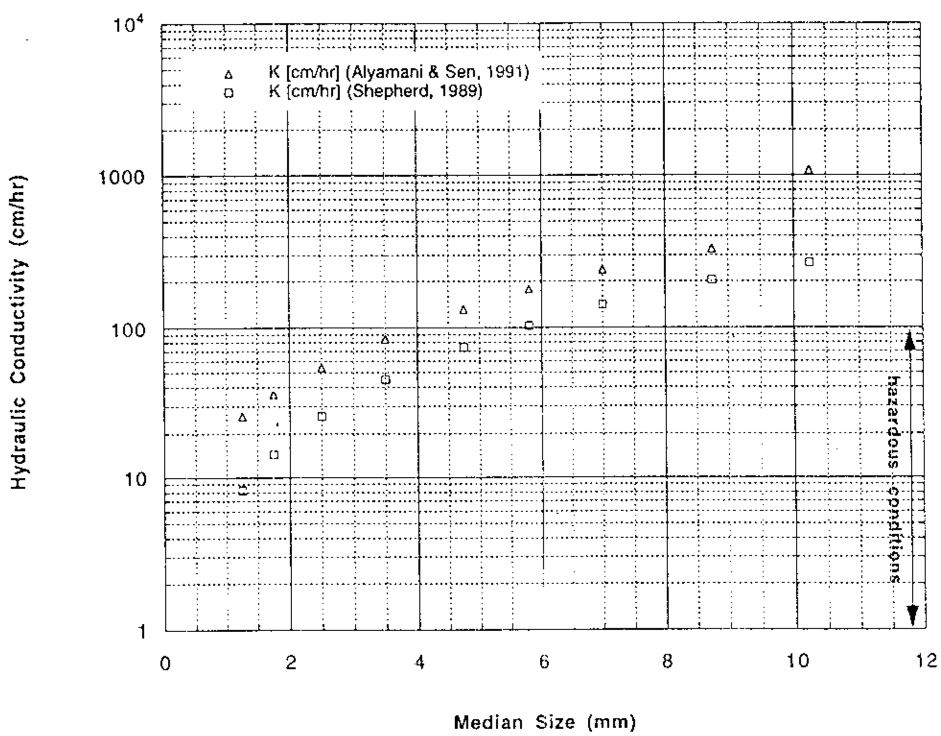


Figure 4a, Variation in hydraulic conductivity changes caused by differences in initial fine sediment content

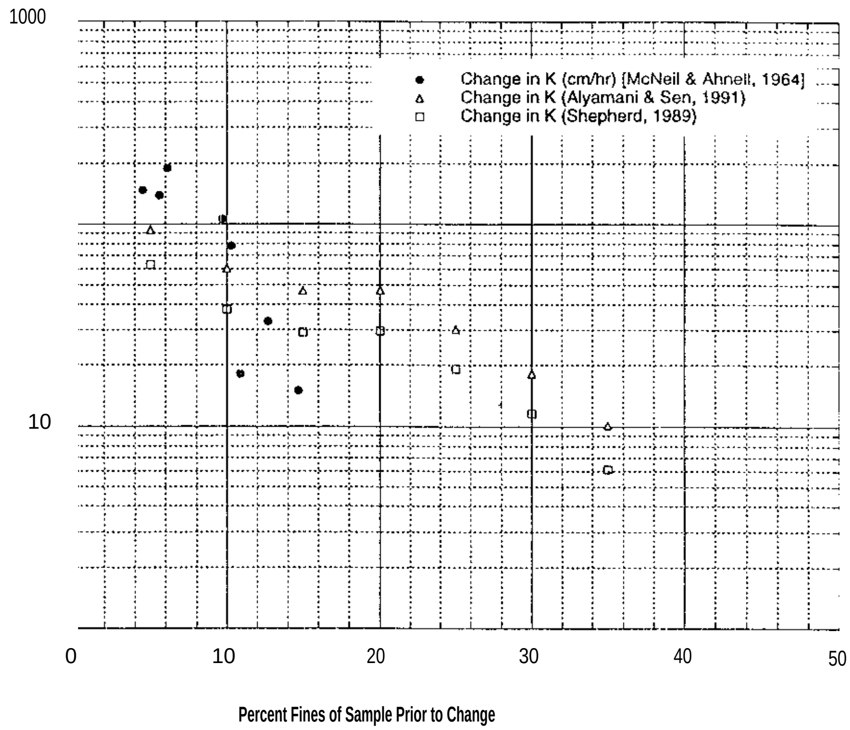


Figure 4b. Variation in hydraulic conductivity changes caused by differences in initial median size

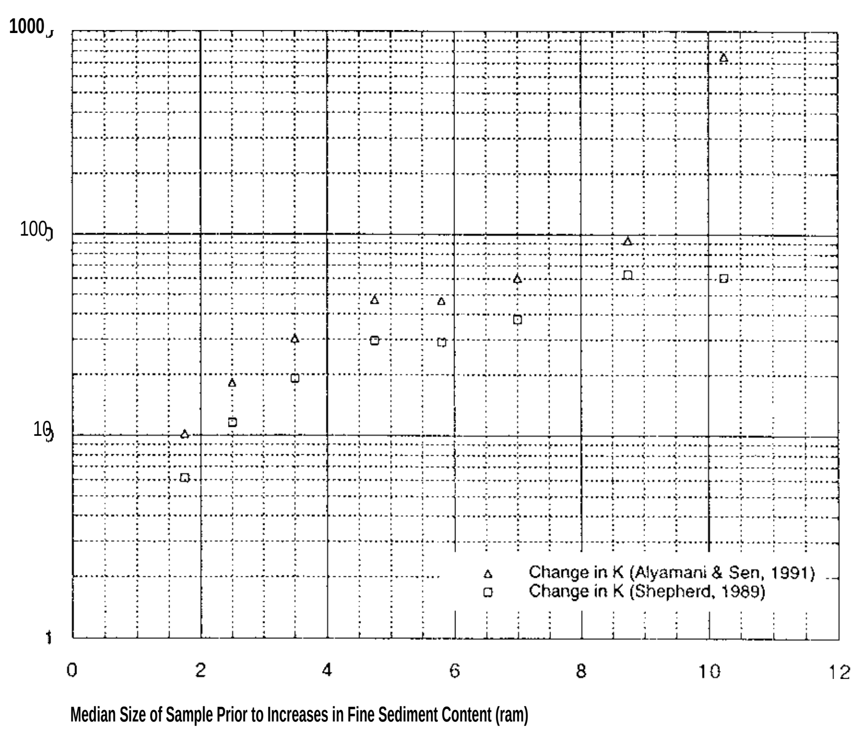
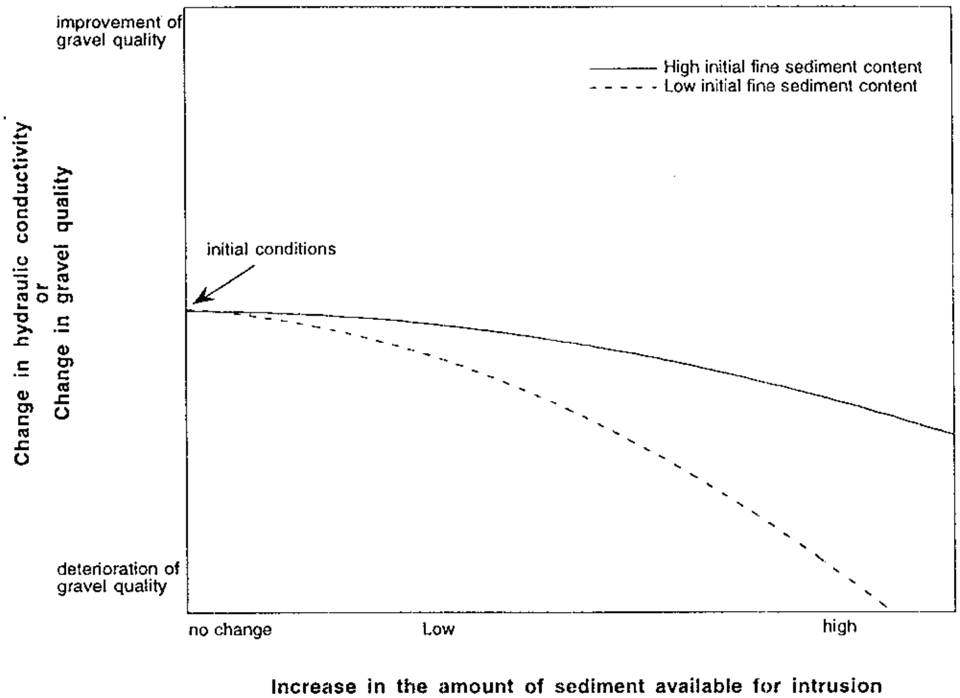


Figure 5. Hypothetical graph showing the expected decreases in gravel quality with increasing fine sediment content at two different initial conditions



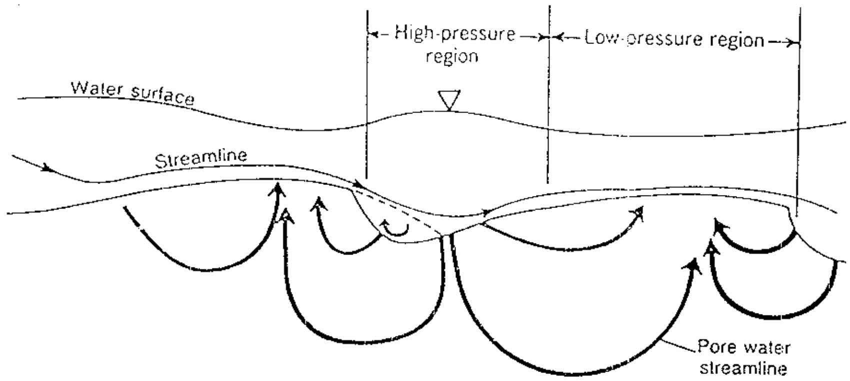


Figure 6. Typical intragravel flow paths in a dune or riffle bed.
(Taken from Jobson and Carey, 1989)

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APPENDIX D

BANK EROSION MEASUREMENT METHODS

A LITERATURE REVIEW

APPENDIX D

BANK EROSION MEASUREMENT METHODS- A LITERATURE REVIEW

I. INTRODUCTION

Although the erosion of stream banks is a naturally occurring process, abrupt changes the erosion rates may be an indication that major disruptances of the "normal" stream conditions are occuring. Changes in bank erosion rates can be caused by alterations in the frequency or magnitude of channel forming flows, bank and riparian vegetation condition, in-channel obstructions, and sediment loads. Disruptance of these input factors can be caused by unusual natural events and/or by land management practices. Bank erosion is very important for geomorphologists because it is not only a "passive feature" that reacts to other changes. Increases in bank erosion rates not only change the general plan form of a stream, which causes localized changes in the hydraulics of the channel, but it can also become an important sediment input factor which can induce further morphological change in the stream. For biologists these physical changes are important because they affect both the quality and the quantity of fish habitat.

II. DISCUSSION OF METHODS

A. Biological Evidence

A method that has been used to measure bank erosion in sediment budget-type of studies, uses root-mass overhang to estimate the volume of sediment that has been lost due to the process (Raines, 1991). This method consists in reconstructing the location and form of the "uneroded" stream bank. The procedure uses the extension of root-mass overhang or the morphology of adjacent uneroded banks to reconstruct the location of that initial stream bank surface.

Advantages

- It can be performed by one operator.
- It can be performed very quickly, making it possible to quantify bank erosion over long stream reaches.
- Procedure is very similar to the one suggested for erosion pins (discussed below).

Disadvantages

- It is very difficult to determine the time when erosion of the bank started.
- It is difficult to get accurate measurements from field visits at extended time intervals due to the growth or removal of roots.

· The procedure lacks precision in determining the uneroded bank surface.

We do not recommend the use of this method as a tool for monitoring bank erosion rates.

B. Airborne Laser

A technique using an airborne laser altimeter was developed by Ritchie et al. (1993). The method consists in mounting a laser altimeter in a small airplane. The instrument measures the distance from the plane to the landscape surface by reflection of the laser signal. Calculations show that the instrument has a vertical recording accuracy between 0.10 to 0.11 m. The major advantage of the instrument is that it offers the potential m accurately measure large areas quickly.

Disadvantages

· Procedure is very expensive. The method not only requires the laser altimeter and availability of a plane, but also requires a portable personal computer, and a video camera.

· The method requires complex operator training requirements. The data collected is not readily transferable into meaningful figures or plots. Laser data has to be corrected for aircraft pitch, roll, and vertical deviation from a straight line to allow for precise data. Also, a filter must be developed to reduce random and system error.

· The laser equipment has some important limitations, that restrict their use as a stream bank monitoring tool. The laser cannot penetrate water or a dense canopy cover

· Undercutting of banks and bank erosion occurring below overhangs will be overlooked by the method.

We do not recommend the use of this method as part of the stream bank erosion monitoring effort.

C. Maps and aerial photographs

Topographic maps and aerial photographs of different dates have been used also to estimate bank erosion rates (Hooke, 1980). The method consists in comparing the location and widths of a given channel using maps or photographs of different dates. Once the stream bank migration distances are determined, erosion rates are calculated by dividing that distance by the number of years between map preparation.

Advantages

- No field visits are necessary.
- Method is inexpensive.
- The procedure is very simple and it can be performed very quickly, This permits measuring bank erosion rates of large areas of the stream in a short amount of time.
- The method requires very little operator training.

Disadvantages

- The quality of the erosion rate estimates depend on the accuracy of mapped bank lines. The bank lines are typically generalized or estimated to some extent, and they may have been drawn by different mappers using different criteria to determine the bank edge.
- The method cannot quantify undercutting and it will tend to overlook erosion on banks where overhangs are common.
- It can only determine long-term erosion rates pre-determined by time intervals between map preparation. The effects of a single flow event can be rarely determined because of the unavailability of maps taken at short time intervals, although in some cases aerial photographs are taken right after big events.
- The procedure only allows the calculation of only large scale stream bank erosion. The accuracy of the method depends on map resolution, but even with high resolution maps, small scale erosion cannot be detected.
- The method always produces erosion rates that are lower than those calculated by field techniques (Hooke, 1980).
- When topographic maps are used, it is very difficult to determine the bank's edge from the contour lines.

There are two other possible variations to this method. One of them requires the use of maps based on digital elevation data. The maps produced by this method may have a better resolution than other topographic maps, but the cell grid size that is commonly used (several meters) is too big to capture small and moderate scale erosion rates. Also, the user would face the same problem as with other topographic maps in determining the bank edge by using only contour lines.

The second variation requires using very detailed plan form analysis maps to determine bank widening or bank migration. Methodologies for channel plan form analysis produce a high resolution map that use a well defined criteria for bank edge, and some of them even provide means to incorporate bank erosion processes such as mass wasting and undercutting (Collins and Dietrich, in preparation).

Disadvantages

- The preparation of detailed maps takes a long time, limiting the area that can be covered by a survey team.

- Method has some rigurous training requirements.

- Small scale erosion will not be detected even with the most rigorous and detailed mapping.

The use of the plan form map analysis to calculate bank erosion rates is not included in the bank erosion methods suggested in this report. The Level C Plan form Analysis described in Section III.A.3 has all of the data collection components necessary to calculate general bank erosion rates and analysts may choose to use this data lot their analysis. If this is done, we suggest analysts to also perform any of the methods suggested in Section III.H.

D. Debris collection trays

Debris collection trays have also been used to measure bank erosion (Hill, 1973). The method consists on fastening several trays (usually 0.30 m by 0.20 m) to the upper bank section at different points along the bank.

Advantages

Trays are easy to set up and measurements can be taken very rapidly.

- Method is very inexpensive.

- The method has the potential of detecting differences in the erosion rates between different sections of the bank profile (i.e., calculations can be categorized by elevation relative to bankfull or by bank composition).

Disadvantages

- Trays cannot be installed under the water, which means that the trays have to be located above flood stage levels and they are unable to determine erosional rates caused by the effect of water flow.

- There is always the risk of losing the trays and the material collected in them due to flushing out during high flow events or to mass wasting.

· *Trays* tend to lose fine material, so the amount of sediment collected in the trays will underestimate the actual amount of sediment that is being eroded. If particle size analysis of the collected material is to be conducted it will underestimate the percent of fine material

· The trays are unable to measure large scale erosion processes (for example, stream side landsliding); only surface erosion above water level can be measured by them.

We do not recommend the use of debris collection trays as part of the stream bank erosion methodology.

E. Erosion Pins

A method that has been widely used to measure surface erosion of stream banks is the installation of erosion pins (Wolman, 1959; Miller and Leopold, 1961; Twidale, 1964; Hill, 1973; Hooke, 1980; and Hudson, 1982). The method consists of driving iron pins (or barn spikes) horizontally into the bank, usually above the level of low water (Miller and Leopold, 1961). A pre-determined portion of the pin is left protruding from the stream bank. Bank recession is measured by measuring the length of the pin protruding from the stream bank after a given time and subtracting the original protruding length from this measurement. After the measurement is taken the pin is hammered in until the same pre-determined length of pin is protruding from the bank. Different pin sizes and set ups have been designed by different researchers. The following paragraphs summarize several of these approaches.

Hill (1973) completely inserted 10 cm long and 2 mm diameter pins into the stream bank. His setup consisted in two horizontal lines often rods each spaced about 60 cm apart. The lower line was placed close to the "normal" water level (assumed to be the low flow level) and the second line was placed 1.5 to 2 meters higher. Hill (1973) used a depth gauge to record the erosion to the nearest millimeter at 90 degree intervals around each rod and then the four measurements were then averaged to obtain the average erosion of each pin. Measurements were taken at fixed intervals every two weeks.

Miller and Leopold (1964) recommend the use of 1 to 2 ft (30 to 60 cm) long pins with no specifications for pin diameter. They suggest placing the pins above the low water level, but generally about halfway up the original bank. They recommend placing pins at a spacing between 5 to 10 ft (1.5 to 3 m) through [00 to 200 ft (30 to 60 m) long reaches.

Twidale (1964) used four pins 30 cm long and 8 mm in diameter placed at fixed intervals from top to bottom of bank. The author does not mention whether the bottom pin can be located under low flow stage and he does not suggest any protrusion length. For simple homogeneous banks he recommends locating pins at equal intervals on the bank, but on complex banks he recommends placing pins at near vertical portions of the bank. The author had problems with loss of pins and unsuccessfully experimented with 100 cm long and 1 cm diameter pins. No specification of time interval between measurements is given by the author. The pins were set up along a river bend in 5 sites equally spaced along the bank, so a total of 20 pins were used per river bend. In order to ease relocation of pins he recommends setting up a benchmark close to the bank edge and locating the pins relative to this location

Wolman (1959) used 1 ft (30 cm) long and 0.25 in (0.635 cm) diameter pins located about 1 ft (30 cm) below the flood plain at 5 ft (1.5 m) intervals along the stream bank for 65 to 70 ft (20 to 21 m) long reaches. He used a protrusion length of 0.05 ft (1.5 cm) and painted the end of pins to help relocate them. He does not state the time interval between measurements.

Hooke (1980) does not specify the dimensions of the pins used. He mentions that they were spaced 2 to 3 meters apart along several sections at unknown vertical locations. The section length depended on the stream dimensions and the extent of actively eroding zone, but no guidelines are presented. In most cases the whole active section around bends was included. The measurements were taken after each storm or peak flow.

Advantages

· Method is very inexpensive.

· Pins are easy to install and measurements can be taken very quickly.

· Method allows analysts to monitor relatively long reaches.

· Method is widely used, which permits direct comparison with published data.

· It has the potential of determining differences in erosion rates within the bank profile (i.e., different elevations relative to water flow or differences in bank composition).

Disadvantages

· Pins can be easily lost during high flow events or due to mass wasting.

· The thod is able to only measure small scale surface erosion.

· Minor scale bank erosion measurements can be biased due to the uncertain effects of swelling and contraction of stream bank deposits on the rods.

· Pins can be lost or moved by the effects of ice action.

· The resence of rods may induces and/or influence erosion, but these effects have not been documented.

· Extreme care should be taken when measurements are taken with a ruler, because contact with bank material may cause compaction and hence, erroneous readings.

· Pins cannot be installed in extremely competent stream banks.

· A very precise and time consuming reference system is required for high resolution data that eliminates bias from pin movement due to resetting, ice action, or swelling of bank material.

· Some of the setups reviewed here only recommend placing pins in very actively erosion areas such as bends. This only enables analysts to calculate maximum erosion rates. Calculation of an average bank erosion rate requires the development of a different pin setup criteria.

· In some of the setups reviewed in this report only one line of pins is recommended to be placed at the same elevation. This type of setup disregards any differences in erosion rates at different heights above water level

· No standards have been suggested for pin size, spacing between pins, length and location of sampling area, and frequency of sampling

We recommend the use of erosion pins as part of the stream bank erosion methodology only for a Level C analysis. The erosion pins may supply data on small scale surface erosion. Pins may also serve as a way to check on the accuracy of erosion measurements recorded by other methods.

F. Survey Methods

Wolman's (1959) study was initially designed to determine bank erosion rates by re-surveying established cross-sections, but he found out that measurements of a single cross-section were considered inadequate for bank erosion occurring during periods shorter than a year. He concluded that with this method, there is a problem in defining the bank edge and that the details of the bank profile are usually ignored. Also, cross sections are usually far apart, so that unless erosion rates are uniform along a river bank, it is very likely that calculated erosion rates could over- or under represent the average erosion rate (Hudson, 1981). Once Wolman realized the limitations of his initial design, he developed the baseline survey method. For this method baselines are established on the floodplain approximately parallel to the left bank. The position of the bank is determined by measuring the perpendicular distance from the baseline to the stream bank. The baseline should have a length of 65 to 70 ft (20 to 21 m).

Bank Profiling

Hudson (1981) has developed a method called *bank profiling.* The procedure is a hybrid of horizontal straight edge leveling, baseline surveys, and multiple erosion pins surveys. The method consists in the following steps:

1) Two temporary benchmarks (TBM's) are established 3 to 5 m from the bunk edge and referenced to other bench minks located farther away from the stream edge. A tape is strung between TBM's, and an interval between I to 5 m is used (depending on bank complexity) to survey the profiles.

2) Place a stadia rod on edge (lying horizontally) and measure its slope with a Brunton compass. Irregularities on the floodplain surface close to the bank edge can be measured using the stadia rod for horizontal control and a ruler for vertical control.

3) Place a second stadia rod close to the channel-stream bank slope change standing vertically and reference it to the horizontal stadia rod.

4) Measure the horizontal distances to the bank with a ruler or a retractable tape at given heights using the rod for vertical control. The measuring points should correspond to breaks in slope and variations in bank material.

Advantages

- Method is inexpensive.
- Procedure is capable of portraying even very complex bank morphologies.
- It has a precision of + 5 cm for complex banks.
- Requires only moderate operator training.
- Data is collected very quickly. According to Hudson (1981) a single profile for a complex two meter high bank can be surveyed in five minutes

Disadvantages

- Method cannot be applied on banks higher than the reach of the surveyor's arm.
- Difficulty in defining sufficient relevant points in the bank to accurately describe it (Hudson, 1981).
- It is very difficult to perform method on areas with very dense vegetation and on sharp stream bends.

We recommend the use of a modification of this method for a high level bank erosion monitoring methodology.

11I. METHODS INCLUDED IN STREAM CHANNEL MONITORING METHODOLOGY

LevelA

Method requires the identification of several bank characteristics (rock type and weathering state, flow convergence, and cover density) to produce a qualitative description of stream bank condition. It also requires the identification of stream bank landsliding features.

Level B

Procedure requires the same methods suggested for a Level A analysis, but it also requires measuring the average dimensions of stream bank landsliding features. This permits operators to conduct volumetric analysis of the amount of sediment being supplied by stream bank mass wasting processes.

Level C

The Level C procedure consists of the application of quantitative methods that allow the calculation of erosion rates. The methods suggested in this section are: bank profiling, radial surveys, and use of erosion pins. A Level C analysis should not be conducted without previously determining the condition of the banks by either a Level A or B procedure.

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APPENDIX E

CHANNEL UNIT DEFINITIONS

APPENDIX E- CHANNEL UNIT DEFINITIONS

Pool-General	Closed topographic depression with low water surface gradients (generally less than 1%) in which the elevation difference between the lowest point of the unit and the active channel margin is at least 0.05 of the width of the active channel width (this is only appropriate for a limited range in channel widths).
Free-Formed Pool	Pools, unrelated to any non-alluvial (including LOD) obstruction, that are formed by interactive adjustments of fluid forces, sediment transport, and bed and bank topography in alluvial channels; includes pools formed by tributary confluence.
Forced Pool	Pools scoured by a local increase in lift and drag forces caused by flow deflection, constriction, or increased local turbulence induced by non-alluvial (including LOD) obstruction. We consider channel banks to be obstructions if they sharply deflect flow and resist deformation to the extent of preventing meander development.
Plunge Pool	Scour is by flow plunging over an obstruction.
Underscour Pool	Scour is by flow constricted under an obstruction.
Lateral Scour Pool	Long, narrow pool scoured along the channel margin, caused by flow impinging on a resistant, non-alluvial bank.
Eddy	Lies downstream of an obstruction. Eddying flow separates from the main flow at the obstruction edge and commonly continues to the channel margin.
Scour	Obstruction-related, but not belonging to one of the above categories.
Shallow Units-General	Water depth is less than in a pool.
Glide (or run)	Bed slope is less than 0.02. Moderately shallow water with an even flow that lacked pronounced turbulence. Frequently located at the transition between a pool and the head of a riffle, but they can also be located in long, low-gradient stream reaches with stable banks and no major flow obstructions.
Riffle	Bed slope is between 0.02 and 0.04 inclusive. They exhibit surface turbulence associated with increased velocity and shallow water depth over gravel or cobble beds.
Cascade	Bed slope greater than 0.04. Cascades are often turbulent because they have numerous small pools and waterfalls
Slipface	Flow is over the slip face of a bar.
Step-Pool	Flow is over a sequence of cobble, boulder or woody debris clusters separated by pooled water.
Bars-General	Bars are large scale bed features having lengths in the order of channel width or greater which are usually exposed at certain stages of flow
Point Bars	Form particularly on the inner bank of meanders.
Alternate Bars	Distributed periodically along one and then the other bank of channel.
Channel Junction Bars	Develop where tributaries enter a main channel.
Transvers Bars	They may include riffles and they typically lie diagonal to the flow.
Mid-Channel Bars	They are typical of braided reaches.

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APPENDIX F

CRITICAL BOUNDARY' SHEAR STRESS CALCULATIONS

AND IDENTIFICATION OF BANKFULL INDICATORS

APPENDIX F

I. Critical Boundary Shear Stress Calculations

Bed surface textures are sensitive to changes in discharge, sediment supply, and the presence of roughness elements in the channel. As Buffington (1995) points out, surface textures can be used as indicators of channel condition with respect to these factors. The bankfull threshold model utilized here predicts the grain size characteristics of the streambed based on the assumption that the boundary shear stress that occurs at bankfull conditions provides the force necessary for incipient motion of the bed. This particle size prediction provides a reference point from which to analyze actual textural response to changes in the input factors. For a complete discussion on the development of the critical shear stress analysis, we encourage analysts to read Buffington's (1995) discussion on the topic. When this analysis is used, follow these simple guidelines to make interpretations:

· When actual D50 is much greater than the predicted D50, channel sediment input rates are much lower than the transport capacity of the stream.

· When the actual D50 has about the same magnitude as the predicted D50, channel sediment input rates are about the same as the transport capacity of the stream.

· When the actual D50 is much lower than the predicted D50, channel sediment input rates are much higher than the transport capacity of the stream.

It is important to note that the comparison between calculated and actual surface particle size may be interpreted as a measure of textural response to both sediment supply and hydraulic roughness elements (Wood-Smith and Buffington, 1996). Channel roughness in a channel could be increased by large woody debris pieces, morphological units, and other in-channel obstructions, and it can effectively reduce the transport capacity of the channel.

The bankfull threshold model uses the following equation:

D50s = 0.61 (h*S)/t*c50s (eq. 1)--[

where,

D50s is the predicted median particle size of the streambed surface.

h is the average bankfull depth of the reach (calculated from cross-sectional data).

S is the gradient of the reach in percent (determined as the slope of the best-fit regression line of the long profile data).

τ^*_{c50s} is the dimensionless critical shear stress and it has a constant value [Buffington (1995) suggests using a conservative value of 0.032.].

Wood-Smith and Buffington (1996) use a slightly different approach. They suggest using the ratio of the critical shear stress for the reach-average median surface grain size (D50) to the reach-average bankfull shear stress. In their analysis this ratio (τ_{c50}/τ_{bf}) proved to be one of the variables that could be used as good discriminators between disturbed and undisturbed reaches. Disturbed reaches tend to have larger values of this ratio than undisturbed reaches. For monitoring purposes, increases in this ratio may indicated increases in the magnitude of impact in a stream. If analysts desire to follow this approach, they should use the following equations.

$$\boxed{\tau_{c50}/\tau_{bf} \quad \text{(eq. 2)}}$$

where,

τ_{c50} is the critical shear stress for the reach-average median surface grain size (D50).

τ_{bf} is the the reach-average bankfull shear stress.

$$\boxed{\tau_{c50} = 0.05\ (\Psi_s - \Psi) * (D50) \quad \text{(eq. 3)}}$$

where,

Ψ_s is the specific weight of water.

Ψ is the specific weight of the sediment.

D_{50} is the reach-scale surface particle median size.

$$\boxed{\tau_{bf} = \Psi\ h_{bf}\ S \quad \text{(eq. 4)}}$$

where,

Ψ is the specific weight of water.

h_{bf} is the reach average bankfull depth (calculated from the cross-sectional data).

S is the reach average channel slope (calculated from the long profile data).

If. Bankfull indicators

Stream hydrologists and geomorphologists have recognized the importance of bankfull flow in controlling channel morphological features. Bankfull flow produces the amount of shear stress necessary to cause incipient motion of the streambed (see above) and bank erosion. Under normal weather conditions, this flow occurs frequently enough (about once a year) so that bankfull flow level features develop on stream banks. Several bankfull indicators can be identified in the field by looking at various features of the channel. Buffington (1995) said that in his experience most experienced practitioners usually agree with the selection of bankfull elevation. Our experience indicates the contrary. Bankfull indicators are not always obvious, specially when a channel has suffered from many years of drought or when it has been impacted by a very large storm event. Accurate recognition of bankfull elevation is important for correct determination of channel width and depth during cross-sectional surveying. Use the features listed below to recognize bankfull indicators (list is a modification of discussion presented by Harrelson et al., 1994). Look for all of these features at every point in the channel where the bankfull elevation needs to be recognized.

· *Change in slope*- Use of this bankfull indicator has to be carefully evaluated specially in channels with numerous terraces. The indicator is more useful for low-gradient meandering streams with a clearly developed stream bank-floodplain transition. In these channels the transition is typically very abrupt, easily identified by a change from a vertical bank to a horizontal surface. For other channels, the change in slope is typically not so obvious (if at all present). Subtle changes in bank gradient can indicate bankfull flow elevation specially in highly erodible banks.

· *Stain lines*- Look for frequent inundation water lines on stream banks typically marked by lichen. Stain lines can also occur at lower flow indicators, so identify the highest stain lines on banks as bankfull flow indicators.

· *Change in vegetation*- Identify the lower limit of perennial vegetation on banks, or a very distinct break in the density or type of vegetation. Be careful when using this indicator because vegetation is not an intrinsic property of the bank and it does not react as fast and effective as other features. This feature tends to also fluctuate with annual flow conditions. If stream has suffered dry conditions for several years, perennial vegetation may migrate down into the channel. Large storm flows may also alter vegetation pattern hut in the opposite direction.

· *Top of bars*- If no bankfull indicator is present on the banks use the top of bars as the minimum height of bankfull stage. We suggest using only freely formed point bars as indicators of bankfull stage.

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APPENDIX G

CHARACTERIZATION OF LARGE ORGANIC DEBRIS

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CHARACTERIZATION OF LARGE ORGANIC DEBRIS

Use the following criteria to determine to categorize LOD pieces found in channels (Taken from Large Woody Debris Survey Module-TFW Ambient Monitoring Program [TFW, 1994).

Rootwad	20 cm or greater at base of stein
Small Log	10-20 cm diameter at midpoint
Medium Log	20-50 cm diameter at midpoint
Large Log	greater than 50 cm diameter at midpoint

Individual wood pieces identified as logs must have the following characteristics:

- be dead
- have root system that is completely or partially detached
- have a diameter of at least 10 cm for at least 2 meters of its length
- intrude into the bankfull channel

Individual wood pieces identified as rootwads must have the following characteristics:

- must be less than 2 m long and have a root system attached to stem
- must be at least 20 cm in diameter at base of stem
- roots must be detached from their original position
- must intrude into the bankfull channel

Wood accumulations identified as debris jams must have the following characteristics:

- have 10 or more rootwads and/or logs (according to the descriptions shown above
- intrude into the bankfull channel

Location of LWD pieces in the channel could be described with tile following criteria (we encourage analysts to look at figure 5 in the Large Woody Debris Survey Module-TFW Ambient Monitoring Program for a visual description of these zones):

· Zone 1 is the wetted low flow channel, defined as the submerged area at the time of the survey.

· Zone 2 is the area under bankfull elevation and above Zone 1. Exposed bars are located in zone 2.

· Zone 3 (optional) is the area directly above the bankfull channel- from the projected bankfull flow waterline upwards indefinitely.

· Zone 4 (optional) is the area outside of the bankfull area. This zone may include upper banks and always includes terraces and floodplains.

To determine the role of LOD pieces in controlling the location and/or shape of morphological units we recommend following the same criteria used by Montgomery et al. (1995). The criteria used by them is presented in the following table.

LOD effect	**Visual Assesment**
dominant	-Interpreted to be the primary cause of the formation and specific geometry of a morophological unit. -Geometry and orientation of LOD-forced units typically mimicks and parallels that of the dominant obstruction
secondary	-Influences unit morphology by modifying the zone of channel bed scour and/or deposition, but are not believed to be responsible for the main geometry of that unit. ....
negligible	-Has no apparent direct effect in an)' morphological unit.

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