Channel Conditions and Prescriptions Assessment (Interim Methods)

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Watershed Restoration Technical Circular No. 7
July 1996

Draft #1, Subject to Revision

BRITISH COLUMBIA

Funded by:

FOREST RENEWAL BC

Watershed Restoration Program

Ministry of Environment, Lands and Parks
and Ministry of Forests

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D.L. Hogan[1], S.A. Bird[2] and D.J. Wilford[3]

[1] Ministry of Forests, 2204 Main Mall, The University of British Columbia, Vancouver, British Columbia, CANADA, V6T 1Z4

[2] FSR Inc., 106–1656 Martin Dr., Rm 179, White Rock, British Columbia, CANADA, V4A 6E7

[3] Ministry of Forests, Bag 5000, 3726 Alfred Avenue, Smithers, British Columbia, CANADA, V0J 2N0

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1.0 Introduction

There is a direct and critical link between stream channel morphology and in-stream fish habitats. Pacific salmon, trout and char (salmonids) use stream environments for specific phases of their life cycle. Special conditions are needed for successful spawning, for the development and hatching of eggs and for the growth and survival of their young (Toews and Brownlee, 1981). Salmonids spawn in riffles composed of clean, stable gravels with well-oxygenated streamflows. Certain species also require stable pools to rear in for periods of time ranging from months to years (young fish use pools to hide from predators, to feed in, and in general to grow in before migrating to the sea.). Adult fish require and unobstructed migration path between the ocean and the stream spawning grounds. Similarly, young salmonids (fry and juveniles) require access along the stream channel and into tributaries and side channels.

A central goal of forest and watershed management in British Columbia has been to minimize changes in sediment and debris production and delivery to streams, to avoid changes to runoff patterns and to eliminate direct disturbance of channel banks and beds. To accomplish this, harvesting plans are now designed to avoid landslide and erosion prone terrain, limit harvest rates, ensure high standards of road building and maintenance and prohibit tree falling and yarding adjacent to streams (Anon, 1995). Past practices, however, were not as carefully applied and serious environmental impacts on stream channels and aquatic ecosystems have been wide spread (Tripp, 1994).

The stream Channel Conditions and Prescriptions Assessment (CCPA) is one component of the Watershed Restoration Program (WRP) and is intended to supplement several other assessment procedures, particularly the Fish Habitat Restoration Procedures (FHRP). The CCPA incorporates the Channel Assessment Procedure (CAP) Guidebooks of the B.C. Forest Practices Code; the linkage between the CAP and CCPA is shown in Figure 1. The objective of CCPA is to integrate watershed processes that control channel conditions so that appropriate rehabilitation techniques can be prescribed and implemented with long term success. Emphasis is placed upon assessing the channel condition, prescribing the appropriate restoration activities, and assessing the risk to restoration works by considering sediment transfers along the drainage network.

1.1 Background

The CCPA is based on watershed principals and recognizes that specific channel types are associated with particular zones within a watershed (Figure 2). Although the characteristics of a stream channel depend on many factors, certain generalities are evident at the watershed scale. Primarily, channel morphology is determined by distance from the drainage basin divide. As distance increases, the amount of water, channel size

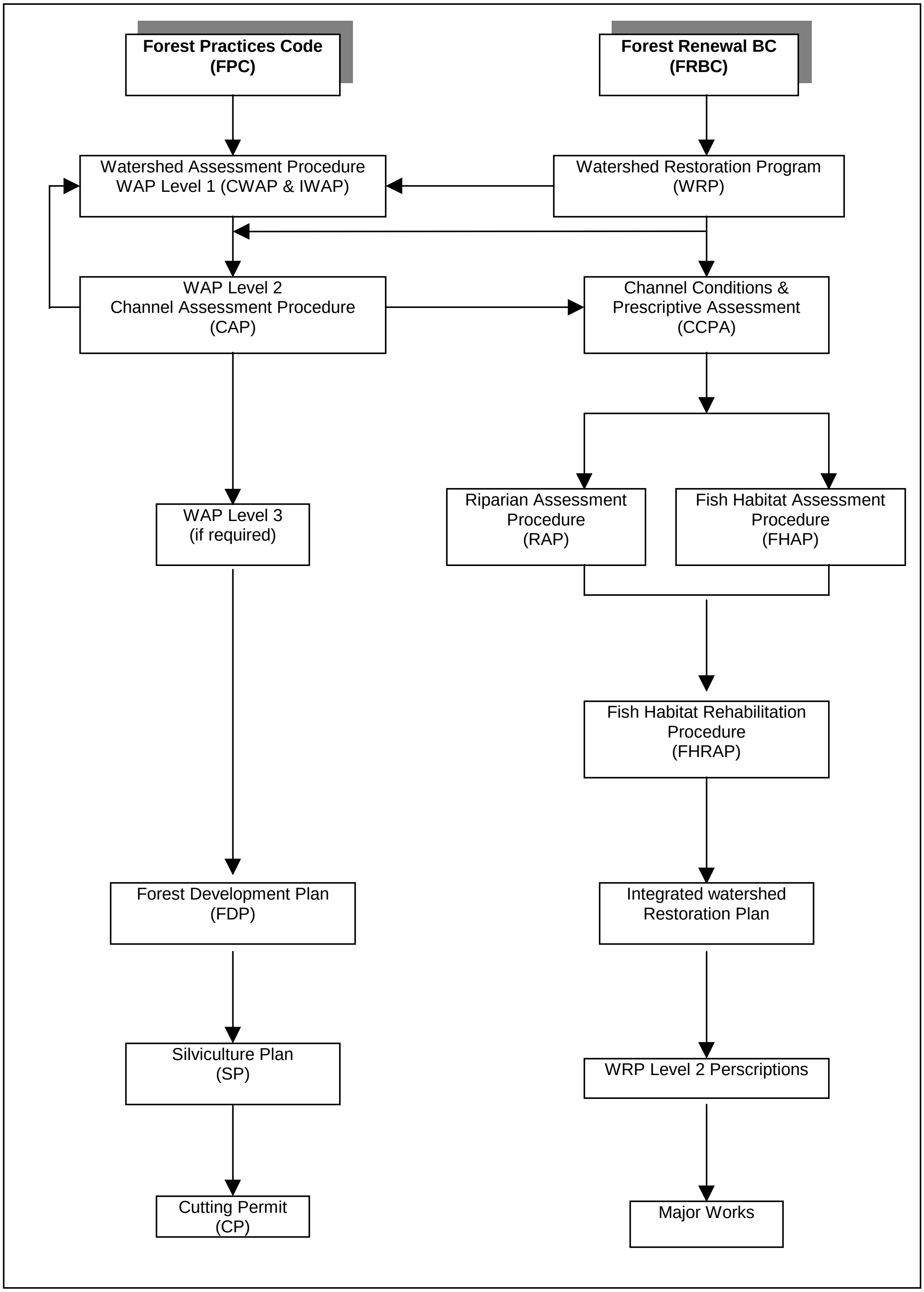

Figure 1. The linkages between the CAP and the CCPA.

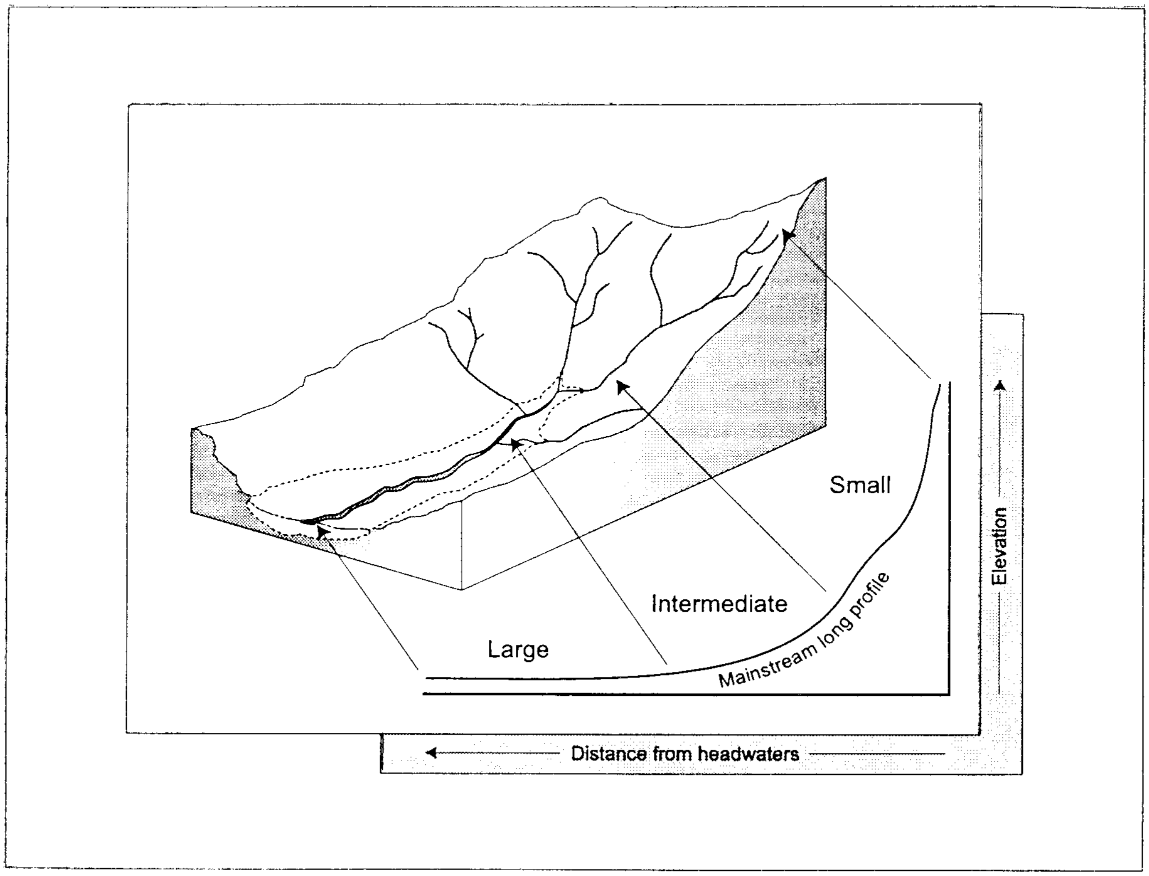

Figure 2. Relative channel size and location within a watershed (after Church 1992). Small channels - individual clasts constitute significant form elements sith pools damned behind individual rocks or a line of rocks. Intermediate channels - channel width is typically 20-30 m with a riffle-bar-pool sequence interrupted by LWD pieces and jams. Large channels - channel width is >20-30 m with a riffle-bar-pool sequence determined entirely by fluvial processes and geological constraints.

and water force increases while bed material sizes and overall channel gradient are reduced. As a result, streams range from those with a steep gradient, step-pool morphology with little or no floodplain, to those with a low gradient, meandering riffle-pool morphology flowing over wide floodplains. At each point along the channel network, channel morphology is determined by the amount and timing of streamflows, the gradient of nearby hillslopes, the nature and type of sediment and debris sources, and the extent of flat valley bottoms.

An assessment of stream channel conditions should recognize the spatial variation of channel types that occur throughout the channel network. The CAP provides a relatively simple, consistent and repeatable means of classifying a stream channel into a morphological type, and assesses the relative level of channel disturbance based on fundamental, morphological channel characteristics. The prescription of appropriate restoration techniques, based on the results of a CAP, should focus on duplicating the natural channel conditions of each zone within a watershed. This is best achieved when the processes associated with a disturbance are identified and measures introduced to reduce or reverse their effects.

In planning channel restoration actions, it is also important to recognize that the risk to restoration works is influenced, to varying degrees, by upstream channel processes-- there is a linkage from one portion of the drainage network to the next throughout the watershed. Therefore, after a channel disturbance has been identified, it is necessary to determine what watershed factors, besides those existing within the individual disturbed reach, will influence the design and success of rehabilitation measures.

1.2 The procedures involved

The CCPA integrates the results obtained from both the Watershed Assessment Procedure (WAP) and the CAP; these procedures identify impacted sub-basins and disturbed channels within the watershed. Because restoration of a watershed involves many interacting processes, successful restoration of a channel requires that all of the other related problems be resolved before the channel work begins. Further, even if the other watershed problems (such as hillslope or riparian zone impacts) have been rehabilitated, there remains the normal transfer of sediment and debris that can influence downstream channel restoration works. Therefore, the CCPA has been designed to incorporate the results of the CAP to make channel restoration recommendations. These recommendations are then linked back to the watershed conditions assessment via the WAP. Additional spatial information is then considered to determine the importance of upstream channel conditions on downstream restoration works.

The CCPA is based on key geomorphic factors that influence sediment production, transport and deposition. The assessment of downstream impacts is accomplished by viewing the overall watershed as a network of linked tributaries and mainstem channel segments that transfer both water and sediment to the drainage basin outlet. The system evaluates the sediment transfer characteristics *within* each tributary and mainstem segment and then evaluates the transfer *between* different areas of the watershed. Therefore, the configuration of tributary and mainstem stream channels determines whether and upstream sediment source has the potential (i.e., the channel network is connected) to impact downstream rehabilitation sites.

This methods manual consists of four sections and each explains, step by step, how to complete a CCPA. Section 2 provides a summary of the *Channel Assessment Procedure Guidebooks* and background on the assessment. Section 3 outlines the appropriate restoration activities associated with each channel condition (i.e., the level of disturbance). Section 4 relates the restoration activities back to the watershed conditions that may impair the effectiveness or long term success of the planned works. At this level, the links between channel restoration and watershed conditions are not site specific; that is , the overall conditions of the watershed are linked to channel restoration in general and no attention is paid to any particular segment of channel. Section 5 considers explicitly the channel network and details the linkages between watershed characteristics and downstream channel conditions.

2.0 Classifying stream channels and assessing disturbance

Stream channel *classifications* attempt to place entire channels or individual reaches into groups that share common characteristics. The channel properties chosen to distinguish individual classes typically reflects the objectives of the classification. In contrast, stream channel *assessments* attempt to place entire channels or individual reaches into a continuum of common characteristics in time or space. An assessment may include identifying the magnitude of change of some aspect of channel process or morphology from a previous condition. This "previous condition" of the channel may be measured directly in the field, inferred from historical accounts, predicted from regional inventories or empirical relations, or presented as some deviation from an stable or ideal condition.

The purpose of this section is to provide a summary of the channel assessment procedure (CAP) used in the CCPA. The CAP is a Forest Practices Code procedure published as the *Channel Assessment Procedure Guidebook* and the *Channel Assessment Procedure Field Guidebook*. The background and basic steps required to complete a CAP are described below. For further information, see the CAP guidebooks (Anon. 1996ab).

2.1 Channel size and morphology

The fundamental division of channels made in the CAP is based upon a consideration of the relative size of the channel. Channel size is defined by the relative roughness of the stream channel (relative roughness is expressed by the ratio D/d, where *D* is the b-axis diameter of the largest stone on the channel bed moved by flowing water and *d* is the depth of the channel). Church (1992) identifies and describes three sizes of stream channels based on relative roughness (small, $D/d > 1.0$; intermediate, $D/d = 0.1$ to 1.0; and large, $D/d < 0.1$), each with the specific morphological characteristics summarized below. From a channel restoration perspective, channel size is and important consideration because it dictates the characteristics of a stable channel morphology and determines the relative influence of riparian vegetation and LWD on channel processes.

2.1.1 Small channel morphology

Channels with a small morphology ($D/d > 1.0$) are most commonly referred to as step-pool channel where individual stones constitute significant form elements within the channel. Typically, the channel forms a sequence of pools dammed behind individual stones, or a line of stones (cobbles and/or boulders), over which streamflow falls or tumbles. In forests, large woody debris (LWD) can be incorporated into individual steps.

The channel banks of small channel are typically composed of bedrock, boulders, turf or heavy root mats. Channel gradients often have bedrock or debris controls and can range from 5 to > 35%, while channel widths are commonly <10 m (very approximate). In most cases, the channel pattern is either straight or slightly sinuous.

Although these channels are relatively steep, individual steps remain stabile due to interlocking of the largest boulders on the bed. Consequently, small channel are reformed only during exceptional floods or during debris torrents (note that increased sediment and debris inputs cause more frequent channel reformation). After a debris torrent or and extreme storm, normal flows re-establish the step-pool sequence by moving the larger stones back into a stable interlocking position. Boulders are moved mainly by undermining on the downstream side causing individual stones to fall forward into a scour hole, eventually to align back into an interlocking pattern.

2.1.2 Intermediate channel morphology

Channels with an intermediate morphology (D/d = 0.1 to 1.0) are most commonly referred to as riffle-pool or cascade-pool channels. Pools are characterized by deep, slow flowing water (at low flow), flatter gradients, and fine-textured sediment (variants include lateral scour pools, backwater pools, drawdown pools, scour pools and plunge pools.) In contrast, riffles have shallow rapid flow, steeper gradients, and coarse sediment from gravel to cobble size textures (variants include cascade riffles, rapids, glides, runs and chutes). Cascades are similar to riffles, except that flow occurs over a sequence of emergent boulders organized into stone lines that span the channel in a perpendicular to diagonal orientation.

Within the sequence of pools and riffles or pools and cascades, accumulations of sediment form bars in areas of flow divergence. Channel bars are often anchored at fixed locations by obstructions such as LWD, bedrock knobs or channel bends (a riffle often constitutes the front face of a bar). Typical bar-types include point bars, diagonal bars and mid-channel bars.

A sinuous channel pattern is usually associated with intermediate streams and range in gradient from approximately 1.5 to 5% (often controlled locally by LWD jams). Channel morphology is modified by normal fluvial transport, with most of the sediment being moved between successive bars, while the formation and decay of log jams controls the transfer of sediment and debris in those channels without abundant LWD loads.

Typically, in the absence of significant in-stream debris, intermediate channels have an average pool to pool spacing of 5 to 7 channel bankfull widths (in forested areas with abundant in-stream LWD, average pool to pool spacings are between 3 and 5 channel bankfull widths). The maximum channel widths are approximately 20 to 30 m in forest streams with channel roughness caused mainly by channel bars, LWD pieces and jams.

2.1.3 Large channel morphology

Channels with a large morphology (D/d < 0.1) are dominated by pool-riffle sequences among major bar forms, or by meandering bend-pool and crossover-riffle sequences. Large channels differ from both small and intermediate channels in that fluvial processes and geological constraints determine morphology; riparian effects do not dominate the channel, although laterally unstable channels in forests may recruit large volumes of LWD that accumulates locally to influence bar and channel development.

The minimum channel widths associated with large channels are approximately 20 to 30 m. Large channels are classified according to channel pattern, sediment storage characteristics and style of lateral instability and may be observed as straight or severely bent (tortuous meanders); with no islands or continuous vegetated islands (anastomosing); and/or have minimal bars or mostly unvegetated bars (braided); and usually associated with extensive floodplains which often have numerous back and side channels.

2.3 Channel types and patterns of channel disturbance

Changes in stream channel characteristics occur for many reasons. The intent of the CAP is to identify disturbed channels, if they exist, in a consistent and repeatable process. The cause of the documented disturbance will be evident in many instances, however in other cases the disturbance will not be easily attributed to a single, definitive cause such as past logging activities. An important factor in channel sensitivity to disturbance is the relative importance of natural sediment sources compared to possible forestry-related sources. In many mountainous areas, glaciers and major alpine-origin mass movement features can dominate the sediment regime. This issue should form a basis for analysis by a qualified Geoscientist---it is not addressed by the CAP (note that this analysis should recognize the unique conditions and history of a watershed in order to resolve the more complex situations where hillslope, valley-bottom, stream channel and landuse interactions make cause and effect relations difficult to determine).

The main ways in which forestry activities affect stream channels are by altering sediment and debris delivery rates, manipulation of both riparian vegetation and in-stream LWD architecture, and flood flow characteristics. The importance of each factor differs regionally. For example, in coastal areas the most important influence is usually on sediment and debris production and delivery to the stream. Changes in flood flows are often the main concern in interior zones.

Changes in streamflow, sediment and debris supply cause channels to undergo a sequence of morphological change; increased supply generally leads to aggradation while decreases in supply commonly lead to channel degradation. Each aggradation and degradation cycle involves many changes in the channel, including altered bed, banks and LWD conditions. Although many channel responses are similar in each type of channel, there are also important differences between each type. (Note that the CAP describes specific morphological channel types associated with each channel size--see Anon 1996ab). The response of each channel type to disturbance is summarized in Figures 4 through 6.

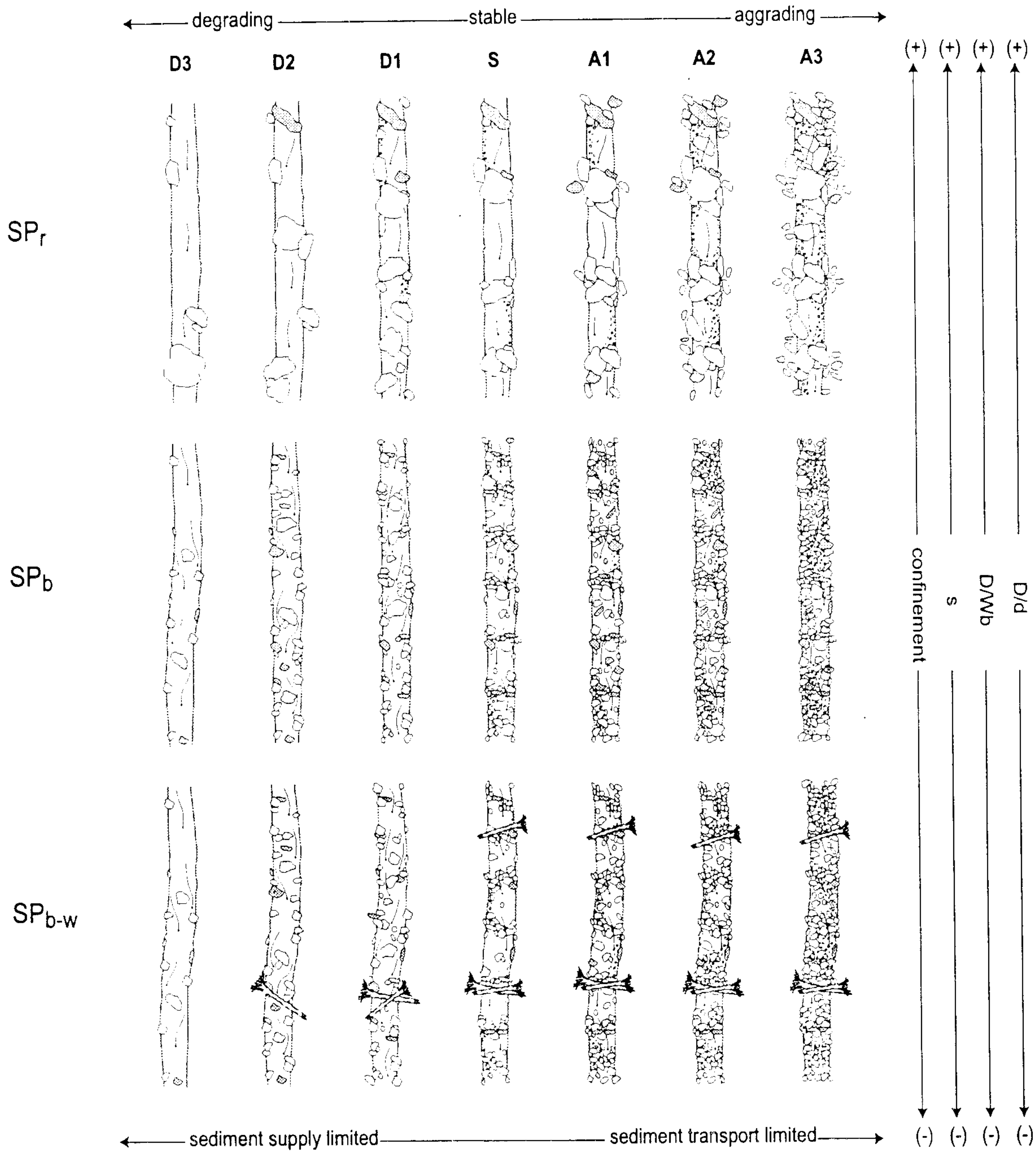

Figure 4. Patterns of channel disturbance associated with small channels. Channel types include boulder-block step-pools(SPr), boulder step-pools(SPb), and boulder step-pools with LWD (SPb-w).

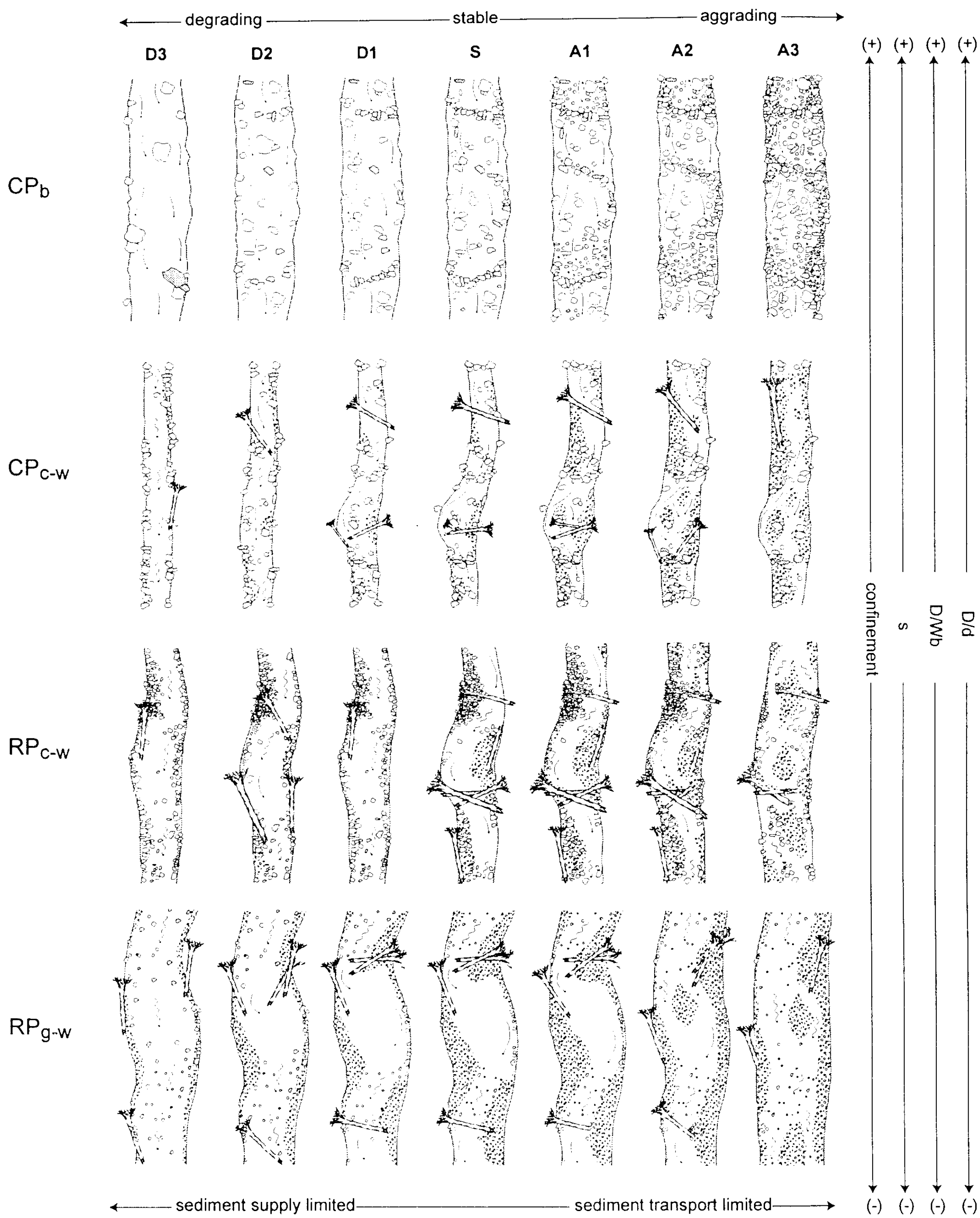

Figure 5. Patterns of channel disturbance associated with intermediate channels. Channel types include boulder cascade-pools (CPb), cobble cascade-pools with LWD (CPc-w), and gravel riffle pools with LWD (RPg-w).

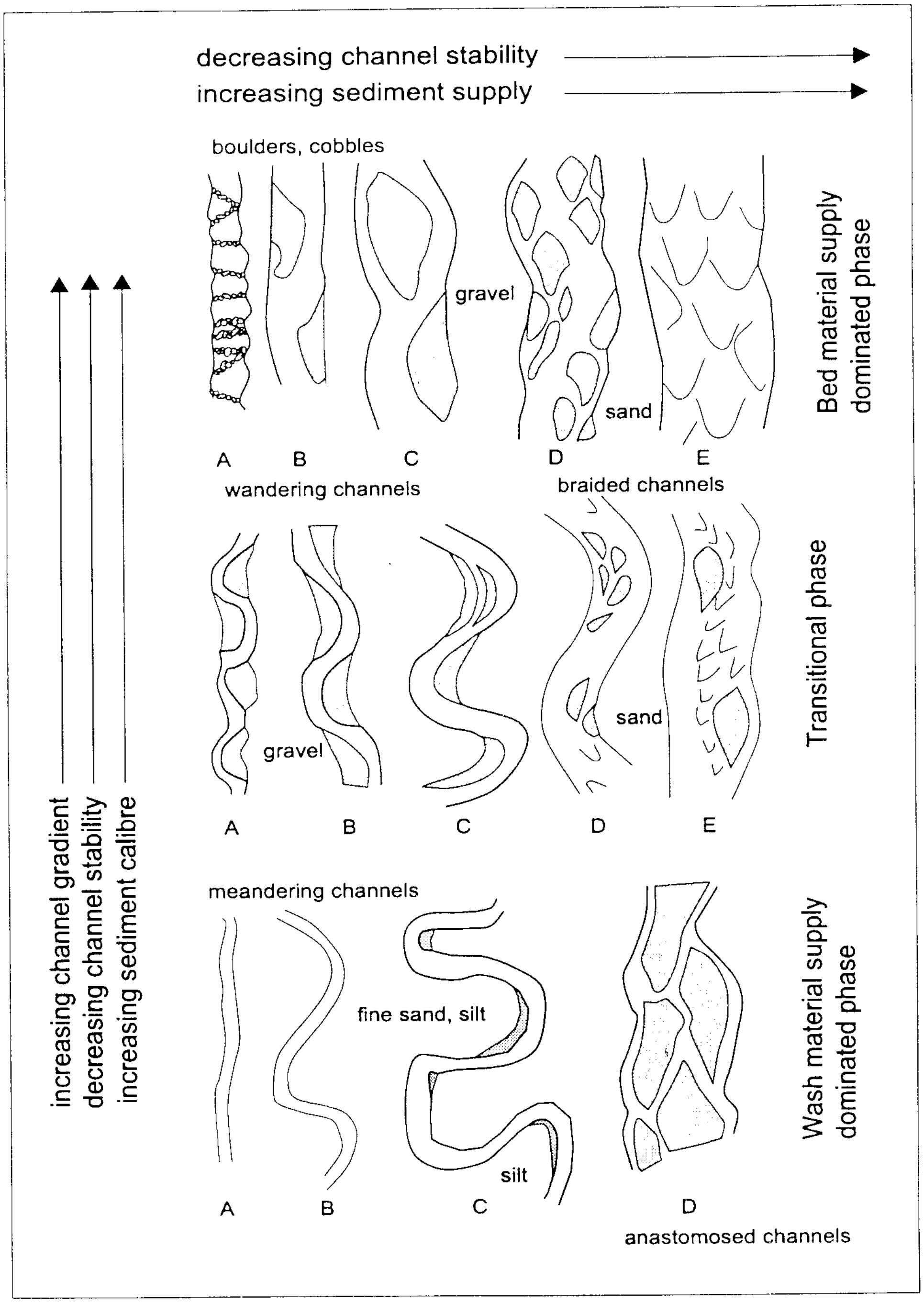

Figure 6. Patterns of channel disturbance associated with large channels (after Church, 1992). Channel types include a bed material supply dominated phase, a transitioanal phase, and a wash material supply dominated phase.

2.4 The channel assessment procedure

The major steps required to complete a CAP are outlined below. For a complete description and appropriate data forms, refer to Anon (1996ab).

2.4.1 Dividing the channel network into watershed links

The drainage network is partitioned into watershed links based on an interpretation of aerial photographs and topographic maps. The characteristics of each link are then described, placing each channel into a watershed context. Generally, links reflect the broad physical characteristics associated with relatively uniform erosional, transport, and depositional processes and rates. For example, a link may include the entire length of channel on a low gradient floodplain unconfined by valley walls and influenced directly by hillslope processes. Although the characteristics of the channel may vary somewhat along each link, the response of the channel to restoration activities is relatively uniform.

The most recent aerial photographs at a scale of at least 1:20 000 taken after logging are used to identify watershed links. Links are defined in the CAP as watershed-scale lengths of channel that have homogeneous sediment transfer routes from hillslope to stream channel (Church, 1983), streamflow discharge, channel pattern, and channel gradient. Each link is identified in numeric format and marked with macro-reach breaks on a 1:20 000 scale topographic base map. Guidelines to identify common macro-reach breaks include:

- A change in the relative coupling between surrounding hillslopes and the stream channel (after Church, 1983)
- A significant change in discharge (e.g., a tributary confluence resulting in a change in downstream stream order)
- Obvious changes in channel pattern (e.g., from a meandering to a straight channel)
- A significant change in average channel gradient, corresponding to one of the six gradient classes (Table 1).

Table 1. Channel gradient classes used in the CAP.

Gradient class	Channel gradient (%)
A	<0.5
B	0.5 - 1.4
C	1.5 - 2.9
D	3.0 - 4.9
E	5.0 - 12.9
F	13.0 - 24.9
G	25.0 - 59.9
H	> or = 60.0

2.4.2 Dividing watershed links into channel reaches

Each watershed link is subdivided into separate reaches, again based on an interpretation of aerial photographs and topographic maps. Generally, reaches reflect the variability of processes operating within any given link. For example, a link characterized by a low gradient floodplain unconfined by valley walls may incorporate individual reaches dominated by either depositional, transport, or erosional processes. Although the response of the channel to restoration activities is relatively uniform within a link, the *magnitude* of that response is controlled by the characteristics of the reach.

The aerial photographs taken after logging occurred in the watershed are also used to identify channel reaches. A reach is a fundamental channel unit and is defined as a length of channel having homogeneous channel pattern, valley flat - channel relations, and discharge (Kellerhals *et al.*, 1976). Partitioning the channel network into distinct reaches provides a systematic framework within which to assess channel characteristics and enables comparison of consistent channel types throughout the watershed.

Guidelines to identify common reach breaks include:

- a tributary confluence ($\geq 2^{nd}$ order streams on the aerial photographs)
- changes in sediment supply (e.g., large point sources of sediment such as an actively eroding landslide scar or deposit)
- changes in stream channel form (e.g., from a straight to sinuous channel or a single-thread to multiple-branched channel)

- changes in stream channel confinement (e.g., from a wide floodplain to a confined canyon)

- changes in riparian vegetation (e.g., from grassland to forest)

- changes in channel gradient ($\geq$2%)

- changes in streambed or streambank materials (e.g., cohesive to non-cohesive banks)

For the purposes of CCPA, changes in landuse (e.g., from forest to clear-cut) may also be used as a reach break. Although this criterion is arbitrary (i.e., there are no necessary changes in channel characteristics), it is useful in a land management context.

2.4.3 Assessing channel morphology

Each reach downstream of any forestry-related activities with a large channel morphology is assessed for changes in channel morphology by comparing the sequential aerial photographs. Figure 6 should be used as a guide to help identify these changes, with special attention placed upon the identification of relevant morphological features, including:

- within-channel sediment storage patterns (see Figures 7 and 8)
- channel pattern (see Figure 9)
- lateral instability (see Figure 10)
- channel width
- meander wavelength
- sinuosity

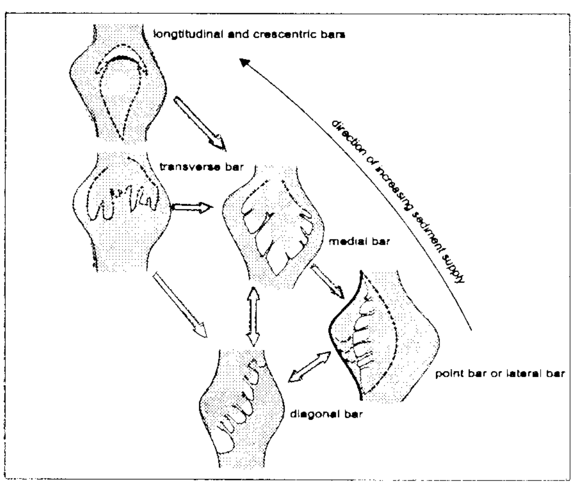

Figure 7. Unit bar classification (after Church and Jones, 1982)

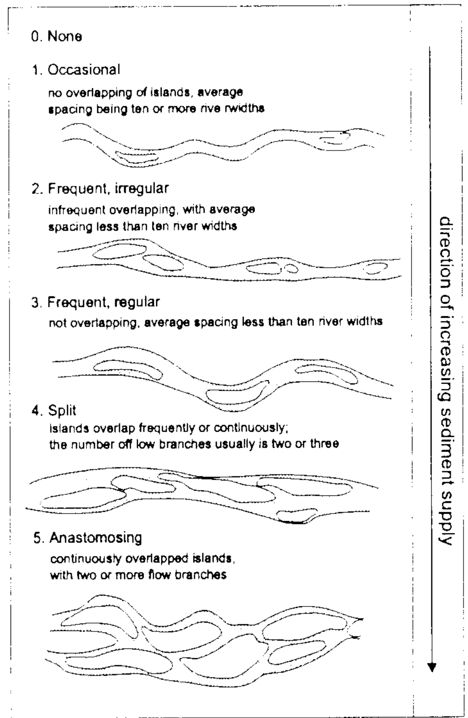

Figure 8. Channel island classification
(after Kellerhals et. al., 1976)

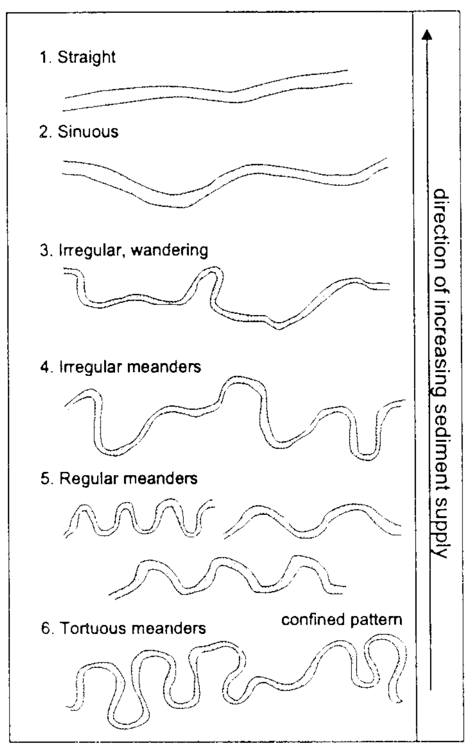

Figure 9. Channel pattern classification
(after Kellerhals et. al., 1976)

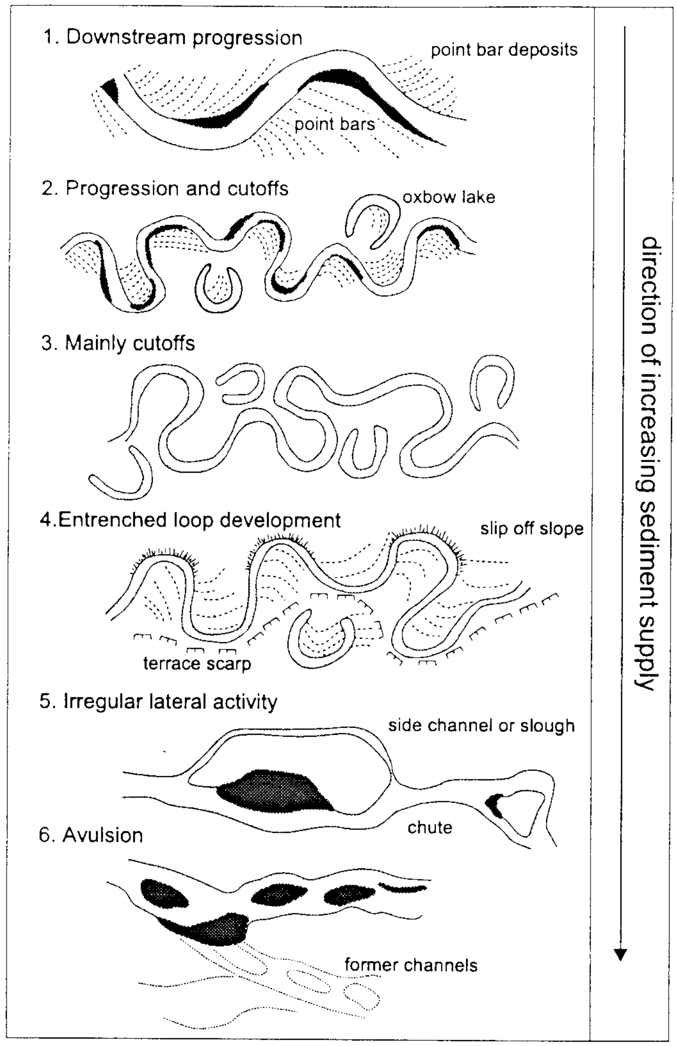

Figure 10. Classification of lateral channel stability (after Kellerhals et. al., 1976)

Each reach downstream of any forestry-related activities with a small or intermediate channel morphology is assessed for changes in channel morphology in the field by identifying the channel type and level of channel disturbance. The type of morphology is determined by using field measures of bankfull channel width (Wb), bankfull channel depth (d), channel slope (s), and the size of the largest stone on the bed moved by flowing water (D). The level of channel disturbance is identified by referring to a series of channel keys (see Anon. 1996b).

2.4.3.1 Measuring channel bankfull width

The average channel bankfull width is calculated from five evenly spaced measurements made along a reach. Bankfull channel width is defined as the width of the water surface at bankfull stage which occurs just prior to flooding when the brim-full channel overflows with no banks exposed (see Figure 11). At low flow, bankfull width includes the width of the water surface and *all* unvegetated gravel bars. At any cross-section, if two or more channels are separated by a vegetated island, the sum of each channel width is used as the total bankfull width.

A number of standard criteria can be used to determine bankfull width in the field (after Leopold 1994). Only those relevant to the field site need be used. Look for:

- a change in vegetation from bare ground with no trees to vegetated ground with trees; from no moss to moss covered ground; or, from bare ground to grass covered ground (particularly in range lands)

- a topographic break from vertical bank to a flat floodplain

- a topographic break from steep bank to a relatively gentle slope

- the highest elevation below which fine woody debris (needles, leaves, cones or seeds) does not occur

- a change in texture of deposited sediment from clay to sand; from sand to pebbles; or, from boulders to pebbles

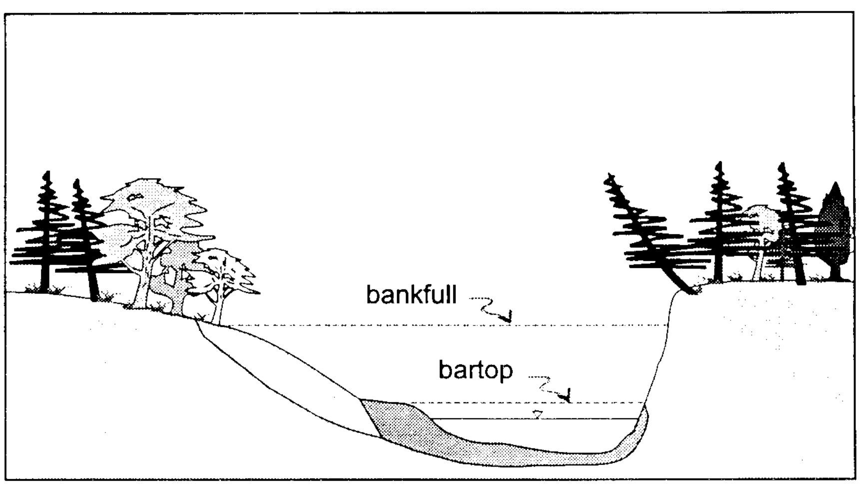

Figure 11. Identification of channel bankfull depth at a cross-section (after Church, 1992)

2.4.3.2 Measuring bankfull depth

The average channel depth is calculated from five evenly spaced measurements made along a reach. Channel depth should be measured at the thalweg (generally, the deepest portion of the channel) with reference to the height of the banktop along a channel cross-section. In addition, because channel depth varies directly with the structure of the bed (e.g., riffles and pools), the depth of the channel should be consistently measured at either a rifle-pool or a step-pool break.

2.4.3.3 Measuring channel slope

The average channel slope is calculated from five evenly spaced measurements made along a reach. Use a hand-held inclinometer (e.g., Sunnto level) and measure the slope over the longest length of channel possible (i.e., the greatest distance visible between field workers); a minimum length of several channel widths should be used for each measurement. Level shots should be taken between two field workers, each standing at the water's edge and sighting on the point of the other individual with the same distance to the ground (eye to eye for individuals of the same height). The distance between individuals, over which the gradient is being measured, should be approximately the same for each of the five measurements.

2.4.3.4 Measuring the largest stone moved by flowing water

The average size of the largest stone moved by flowing water is calculated from five evenly spaced measurements made along a reach. The largest stone does not include large lag boulders deposited during periods with very different streamflow regimes (e.g., immediately post-glacial) or those that have fallen into the channel from surrounding glacial moraines or colluvial fans or cones. The largest stone should not be covered in old moss or organic stains, and should be rounded or sub-rounded but not angular. Further, the largest stone should have evidence of movement by flowing water during the past decade and should be incorporated into the channel bed (other sediment knitted around the larger stones) and not isolated and distinctly different than all others in the near vicinity (i.e., several bankfull widths upstream and downstream). Once identified, measure the b-axis (intermediate length) diameter of the largest stone.

2.4.3.5 Calculating an index of channel morphology

The relative channel size and type of morphology are based on the ratios D/d and D/Wb calculated by the nomogram (see Figure 12; the nomogram simplifies the equation for ease of use in the field). First, the relative width is calculated by entering the measured values of D and Wb on Graph 1. Second, the relative

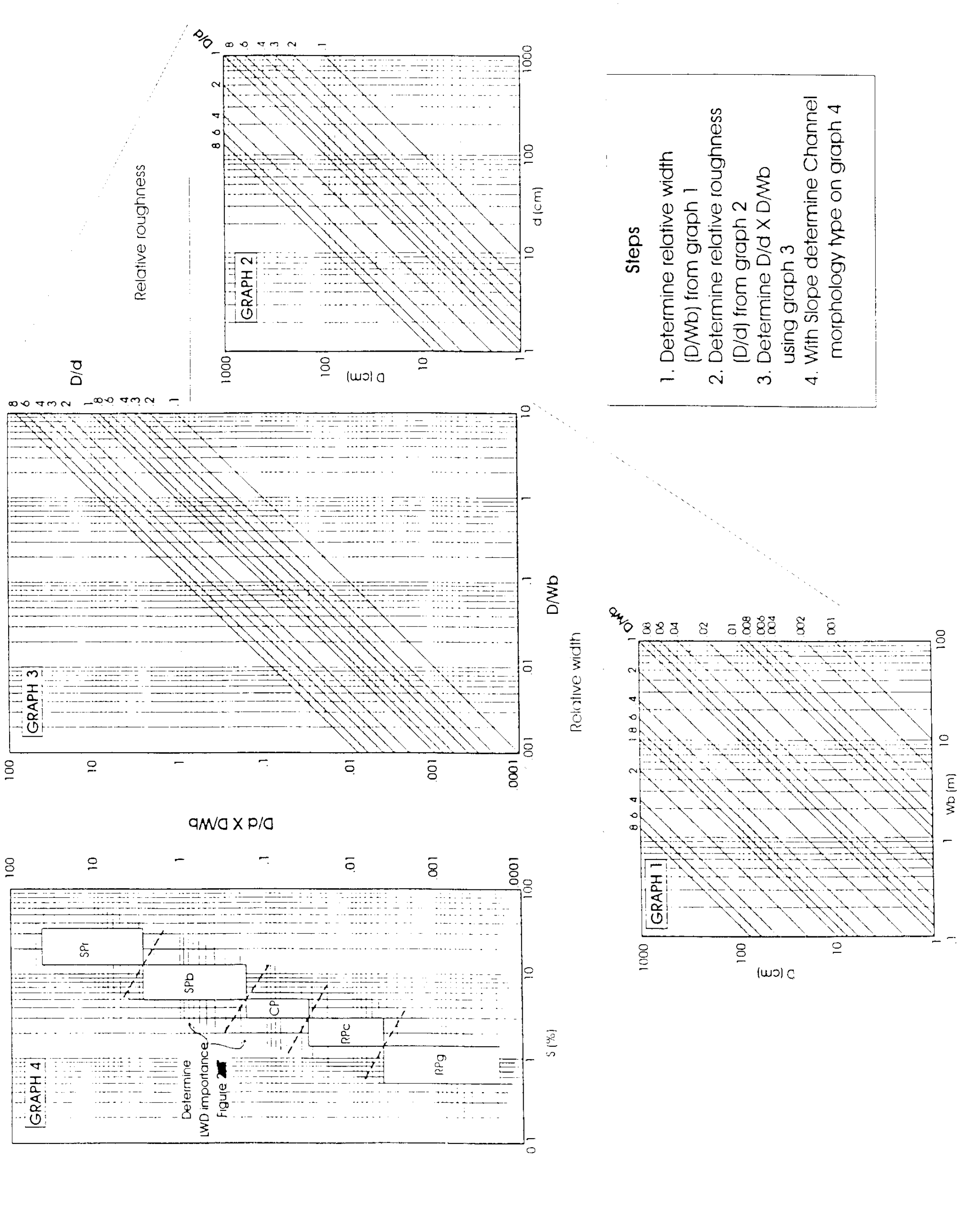

Figure 12. Nomogram used to determine channel morphology.

roughness is determined by entering the measured values of D and d on Graph 2. Third, the respective D/Wb and D/d values are transferred onto Graph 3 which calculates their product. Finally, the product of D/Wb and D/d is transferred onto Graph 4, with the intersection between this value and s giving the expected type of channel morphology.

As an example of the use of Figure 12, use:

D = 10 cm
d = 120 cm
W_b = 20 m
s = 1.5%

Following the lines in the nomogram produces a riffle-pool morphology with predominately gravel textured materials (RPg). Large woody debris (LWD) is important in this channel type (see Figure 13). If either the CP or SP morphologies are determined from Figure 12, it is necessary to determine if LWD is expected in that particular channel. The importance of LWD to channel functions is dependent on both stream power and the length of individual LWD pieces relative to channel width. Figure 15 plots channel width against slope to determine the functional role of LWD (when plotted against width, slope can be used as a surrogate for stream power).

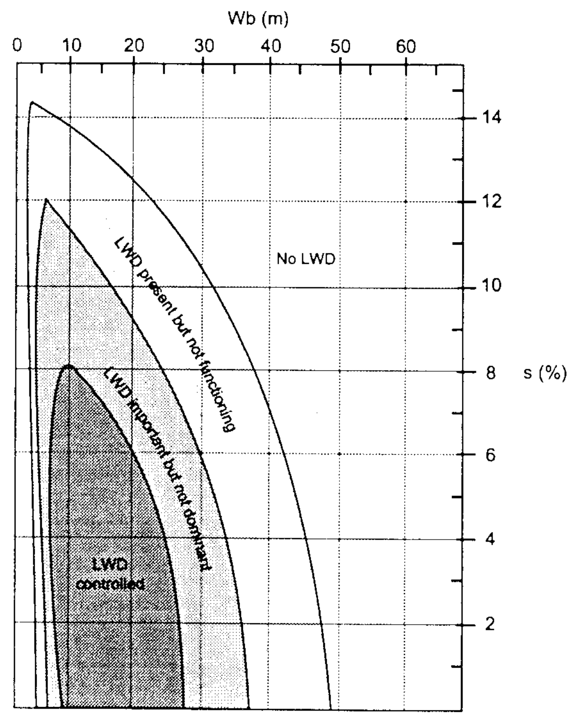

Figure 13. The importance of LWD to channel morphology, based on the slope and the width stream channel.

3.0 Channel conditions and restoration works

The channel types considered in the CAP are summarized in Table 2. These channel types are susceptible to disturbance by poor forestry practices. The objective of CCPA is to restore the disturbed channels to a stable morphology. Table 3 includes a series of lists indicating:

A) Channel conditions, including;
 i) the typical morphology of each type of stable channel;
 ii) the nature of disturbance in each channel type;

B) Restoration works, including;
 i) Suggested types of rehabilitation activities appropriate for each channel type;
 ii) The reference to the relevant chapter in the Fish Habitat Rehabilitation Procedures manual. Chapters are referenced in parenthesis where appropriate.

To select the appropriate channel rehabilitation activity, complete the following steps;

1) Determine the reach number from the CAP for the particular watershed;
2) Determine the channel type and level of disturbance from CAP;
3) Refer to the appropriate table (corresponding to the channel type and level of disturbance) in the CCPA (Table3Ai-3Avii).
4) Identify the suggested restoration activity (Table 3Bi-3Bvii);
5) Refer to the relevant chapter in the Fish Habitat Rehabilitation Procedures manual;
6) Ensure that restoration activity is justified by checking the watershed interaction matrices in Section 4;
7) Ensure that the site-specific rehabilitation is justified given the drainage network configuration by completing Section 5.

Table 2. Channel types and associated characteristics

Code	Morphology	**Sub-Code**	Bed Material	LWD
RP	Riffle-pool	**RPg-w**	Gravel	Functioning
RP	Riffle-pool	**RPc-w**	Cobble	Functioning
CP	Cascade-pool	**CPc-w**	Cobble	Present, minor function
CP	Cascade-pool	**CPb**	Boulder	Absent
SP	Step-pool	**SPb-w**	Boulder	Present, minimal function
SP	Step-pool	**SPb**	Boulder	Absent
SP	Step-pool	**SPr**	Boulder-block	Absent

Table 3Ai. RIFFLE-POOL (RP_g-w) CONDITIONS

Channel type *Attribute*	Degraded	Stable	Aggraded
Riffle-Pool			
Morphology	•Extensive riffles and bars	•Repeating riffle-bar-pool sequences	•Extensive riffles and runs
	•Small shallow pools (due to erosion of riffle crests)	•Diverse pool size, shape and depth	•Small, shallow pools (due to depositional in-filling)
	•Channel consists of less than 1/4 pool, approximately	•Channel consists of 1/2-3/4 pool environment	•Channel consists of less than 1/4 pool, approximately
	•One main channel (primarily single thread)	•One or two main channels	•Multiple channels on braided bed surface
	•Simple, uniform riffle and run shapes	•Diverse riffle shapes	•Simple, uniform riffle and run shapes (minimal depth variability)
	•Limited side channel bar	•Mainly diagonal and point bars	•Mainly mid-channel bars. Bars elevated to at or above elevation of surrounding bank tops. Steep downstream bar faces
Bed sediment	•Mainly cobbles and courser textures	•Cobble and gravels	•Mainly gravel and finer textures
Bank sediment	•Mainly cobbles and gravel	•Mainly cobbles, gravel and sand.	•Mainly gravels, sand and cobbles.
	•Banks primarily sloping and/or overhanging	•Large proportion of undercut/overhanging banks	•Extensive bank erosion (commonly complete absence of undercut banks
LWD	•Limited, those present are small sized and oriented parallel to the banks	•Oriented across, and spans, the channel	•Absent or buried. LWD present are small sized and oriented parallel to the banks

Table 3Bi. RIFFLE-POOL(RP_g-w) PRESCRIPTIONS

Channel type Attribute	**Degraded**	**Stable**	**Aggraded**
	Action	**Objective**	**Action**
Riffle-Pool			
Morphology	•Promote pool development (e.g. LWD placement)	•Repeating riffle-bar-pool sequences	•Promote pool development (e.g. LWD placement)
	•Increase pool size, shape, and depth diversity [8]	•Diverse pool size, shape and depth	•Increase pool size, shape, and depth diversity [8]
	•Re-connect or build off-channel habitats [9]	•Channel consists of 1/2-3/4 pool environment	•Build and enhance off-channel pond habitats [9, 13]
	•Interrupt long runs [8, 10, 12]	•One or two main channels	•Promote two main channel threads, cut-off other branches to become flood channels [11]
	•Increase riffle variability [8]	•Diverse riffle shapes	•Increase depth variability [8, 11, 12]
	•Place LWD and cobble clusters to increase sediment storage along channel margins [8, 10]	•Mainly diagonal and point bars	•Scalp (remove) elevated, mid-channel bars.
Bed sediment	•Increase textural variability by LWD storage [8]	•Cobble and gravels	•Promote local downcutting to increase fluvial sorting of sediment. Re-vegetate elevated bar tops.
Bank sediment	•Re-vegetate banks to enhance over-bank sediment trapping [RCAP]	•Mainly cobbles, gravel and sand.	•Re-vegetate banks to enhance over-bank sediment trapping [RCAP].
	•Place LWD to re-establish bank location and shape	•Large proportion of undercut/ overhanging banks	•Re-vegetate banks to enhance bank stability [RCAP].
LWD	•LWD piece and jam placement [8,9]	•Oriented across, and spans, the channel	•Excavate pre-disturbance LWD (exhume LWD). LWD piece and jam placement [8, 9]

Table 3Aii. RIFFLE-POOL(RP_c-w) CONDITIONS

Channel type *Attribute*	Degraded	Stable	Aggraded
Riffle-Pool			
Morphology	•Extensive riffles and bars	•Repeating riffle-bar-pool sequences	•Extensive riffles and runs
	•Small shallow pools (due to erosion of riffle crests)	•Diverse pool size, shape and depth	•Small, shallow pools (due to depositional in-filling)
	•Channel consists of less than 1/4 pool, approximately	•Channel consists of 1/2-3/4 pool environment	•Channel consists of less than 1/4 pool, approximately
	•One main channel (primarily single thread)	•One or two main channels	•Multiple channels on braided bed surface
	•Simple, uniform riffle and run shapes	•Diverse riffle shapes	•Simple, uniform riffle and run shapes (minimal depth variability)
	•Limited side channel bar	•Mainly diagonal and point bars	•Mainly mid-channel bars. Bars elevated to at or above elevation of surrounding bank tops. Steep downstream bar faces
Bed sediment	•Mainly cobbles and coarser textures	•Cobbles and gravels	•Mainly gravel and finer textures
Bank sediment	•Mainly cobbles and gravel	•Mainly cobbles, gravel and sand.	•Mainly gravels, sand and cobbles.
	•Banks primarily sloping and/or overhanging	•Large proportion of undercut/ overhanging banks	•Extensive bank erosion (commonly complete absence of undercut banks
LWD	•Limited, those present are small sized and oriented parallel to the banks	•Oriented across, and spans, the channel	•Absent or buried. LWD present are small sized and oriented parallel to the banks

Table 3Bii. RIFFLE-POOL(RP_c-w) PRESCRIPTIONS

Channel Type *Attribute*	**Degraded**	**Stable**	**Aggraded**
	Action	**Objective**	**Action**
Riffle-Pool			
Morphology	•Promote pool development (e.g. LWD placement)	•Repeating riffle-bar-pool sequences	•Promote pool development (e.g. LWD placement)
	•Increase pool size, shape, and depth diversity [8]	•Diverse pool size, shape and depth	•Increase pool size, shape, and depth diversity [8]
	•Re-connect or build off-channel habitats [9]	•Channel consists of 1/2-3/4 pool environment	•Build and enhance off-channel pond habitats [9, 13]
	•Interrupt long runs [8, 10, 12]	•One or two main channels	•Promote two main channel threads, cut-off other branches to become flood channels [11]
	•Increase riffle variability [8]	•Diverse riffle shapes	•Increase depth variability [8, 11,12]
	•Place LWD and cobble/boulder clusters to increase sediment storage along channel margins [8, 10]	•Mainly diagonal and point bars	•Scalp (remove) elevated, mid-channel bars.
Bed sediment	•Increase textural variability by LWD storage [8] and cobble/boulder clusters [10]	•Cobble and gravels	•Promote local downcutting to increase fluvial sorting of sediment. Re-vegetate elevated bar tops.
Bank sediment	•Re-vegetate banks to enhance over-bank sediment trapping [RCAP]	•Mainly cobbles, gravel and sand.	•Re-vegetate banks to enhance over-bank sediment trapping [RCAP].
	•Place LWD to re-establish bank location and shape	•Large proportion of undercut / overhanging banks	•Re-vegetate banks to enhance bank stability [RCAP].
LWD	•LWD piece and jam placement [8, 9]	•Oriented across, and spans, the channel	•Excavate pre-disturbance LWD (exhume LWD). LWD piece and jam placement [8, 9]

Table 3Aiii. CASCADE-POOL (CP_g-w) CONDITIONS

Channel type *Attributes*	**Degraded**	**Stable**	**Aggraded**
Cascade-Pool			
Morphology	•Stone line series disorganized (no recognizable pattern, due to erosional displacement)	•Series of repeating stone lines forming overall steep zone connecting lower gradient pools that are $\geq 1W_b$ in length	•Few distinct pools. Deeps in-filled with sediment (both stones originally in lines and finer materials)
Bed sediment	•Large stones remaining (strewn over bed) not moss covered	•Moss covered stone steps	•All sediment along the bed devoid of moss or vegetative cover •Boulder and cobble, localized bank erosion
Bank sediment	•Boulder and cobble	•Boulder and cobble	•Boulder and cobble, localized bank erosion
LWD	•LWD not present, if so it does has no (minimal) functional role	•LWD present and functioning to limited extent (forms steps, traps/scours sediment and protects banks)	•LWD present but not functional (does not trap/scour sediment in any substantial way

Table 3Biii. CASCADE-POOL(CP_g-w) PRESCRIPION

Channel type *Attribute*	Degraded	Stable	Aggraded
	Action	**Objective**	**Action**
Cascade-Pool			
Morphology	•Construct diagonally oriented stone liners using cobble clusters, LWD and/or boulders [10, 8, 11]	•Series of repeating stone lines forming overall steep zone connecting lower gradient pools that are $\geq$1 W_b in length	•Enhance flushing of fine textured sediment by re-establishing stone lines. Promote flow convergence by placement of LWD or cobble clusters or boulders [10, 8, 11]
Bed sediment	•Increase sediment textural variability by re-establishing stable stone lines (interstitial filling) [10, 8, 11]	•Moss covered stone steps	•Re-arrange stone lines for stability •Re-vegetate all elevated bar tops [6, RCAP]
Bank sediment	•Stabilize boulders and cobbles (intact steps) using cobble clusters, boulders or wood [10, 8, 11]	•Boulder and cobble	•Stabilize localized bank erosion sites with boulders [10]
LWD	•Place LWD to supplement clastic steps. Use LWD to enhance key-stones (main stone that traps other large stones ultimately forming the structural step) [10, 8, 11]	•LWD present and functioning to limited extent (forms steps, traps/scours sediment and protects banks)	•Place LWD to enhance trapping and scouring of sediment by planning flow convergence and divergence patterns

Table 3Aiv. CASCADE-POOL(CP_b) CONDITIONS

Channel type *Attribute*	Degraded	Stable	Aggraded
Cascade-Pool			
Morphology	•Stone line series disorganized (no recognizable pattern, due to erosional displacement)	•Series of repeating stone lines forming overall steep zone connecting lower gradient pools that are $\geq 1W_b$ in length	•Few distinct pools. Deeps in-filled with sediment (both stones originally in lines and finer materials)
Bed sediment	•Large stones remaining (strewn over bed) not moss covered	•Moss covered stone steps	•All sediment along the bed devoid of moss or vegetative cover
Bank sediment	•Boulder and cobble	•Boulder and cobble	•Boulder and cobble, localized bank erosion
LWD	•LWD not present, if so it does has no (minimal) functional role	•LWD present and functioning to limited extent (forms steps, traps/scours sediment and protects banks)	•LWD present but not functional (does not trap/scour sediment in any substantial way

Table 3Biv. CASCADE-POOL(CP_b) PRESCRIPTIONS

Channel type *Attribute*	**Degraded**	**Stable**	**Aggraded**
	Action	**Objective**	**Action**
Cascade-pool			
Morphology	•Construct diagonally oriented stone lines using cobble clusters and/or boulders [10, 11]	•Series of repeating stone lines forming overall steep zone connecting lower gradient pools that are $\geq 1W_b$ in length	•Enhance flushing of fine textured sediment by re-establishing stone lines. Promote flow convergence by placement of boulders [10, 11]
Bed sediment	•Increase sediment textural variability by re-establishing stable stone lines (interstitial filling) [10, 11]	•Moss covered stone steps	•Re-arrange stone lines for stability •Re-vegetate all elevated bar tops [6, RCAP]
Bank sediment	•Stabilize boulders and cobbles (intact steps) using cobble clusters, boulders [10, 11]	•Boulder and cobble	•Stabilize localized bank erosion sites with boulders [10]
LWD	•Of minimal importance. Use LWD to supplement clastic steps only. Use LWD only to enhance key-stones (main stone that traps other large stones ultimately forming the structural step) [10, 8, 11]	•LWD present and functioning to limited extent (forms steps, traps/scours sediment and protects banks)	•Of minimal importance. Place LWD to enhance trapping and scouring or sediment by planning flow convergence and divergence patterns.

Table 3Av. STEP-POOL (SP_b-w) CONDITIONS

Channel type *Attribute*	**Degraded**	**Stable**	**Aggraded**
Step-Pool			
Morphology	•No organized stone lines (due to erosional displacement)	•Intact stone lines -clast steps -intervening pools	•No organized stone lines (due to depositional in-filling)
Bed sediment	•Largely bedrock	•Largely moss covered	•Not moss covered
Bank sediment	•Not eroded	•Boulder, bedrock, turf or roots	•Banks cleaned of moss but not eroded (due to bedrock)
LWD	•Not important	•Present, minimal function	•Not important

Table 3Bv. STEP-POOL(SP_b-w) PRESCRIPTIONS

Channel type *Attribute*	**Degraded**	**Stable**	**Aggraded**
	Action	**Objective**	**Action**
Step-Pool			
Morphology	•Re-construct stone lines. Enhance sediment trapping at flow divergence sites upstream of step [10]	•Intact stone lines -clast steps -intervening pools	•Re-construct stone lines. Enhance sediment scouring at flow convergence sites downstream of step [10]
Bed sediment	•Increase sediment trapping with stone lines	•Largely moss covered	•Increase sediment scouring with stone lines
Bank sediment	•Not eroded	•Boulder, bedrock, turf or roots	•Banks cleaned of moss but not eroded (due to bedrock)
LWD	•Minimal importance; place LWD to assist stabilization of stone lines [10]	•Present, minimal function	•Minimal importance; place LWD to assist stabilization of stone lines [10]

Table 3Avi. STEP-POOL(SP_b) CONDITIONS

Channel type *Attribute*	**Degraded**	**Stable**	**Aggraded**
Step-Pool			
Morphology	•No organized stone lines (due to erosional displacement)	•Intact stone lines -clast steps -intervening pools	•No organized stone lines (due to depositional in-filling)
Bed sediment	•Largely bedrock	•Largely moss covered	•Not moss covered
Bank sediment	•Not eroded	•Boulder, bedrock, turf or roots	•Banks cleaned of moss but not eroded (due to bedrock)
LWD	•Not important	•Present, minimal function	•Not important

Table 3Bvi. STEP-POOL(SP_b) PRESCRIPTIONS

Channel type *Attribute*	**Degraded**	**Stable**	**Aggraded**
	Action	**Objective**	**Action**
Step-Pool			
Morphology	•Re-construct stone lines using boulder clusters [10] Enhance sediment trapping at flow divergence sites upstream of step [10]	•Intact stone lines -clast steps -intervening pools	•Re-construct stone lines using boulder clusters [10] Enhance sediment scouring at flow convergence sites downstream of step [10]
Bed sediment	•Increase sediment trapping with stone lines	•Largely moss covered	•Increase sediment scouring with stone lines
Bank sediment	•Not eroded	•Boulder, bedrock, turf or roots	•Banks cleaned of moss but not eroded (due to bedrock)
LWD	•Not important	•Present, minimal function	•Not important

Table 3Avii. STEP-POOL(SP$_r$) CONDITIONS

Channel type *Attribute*	**Degraded**	**Stable**	**Aggraded**
Step-Pool			
Morphology	•No organized stone lines (due to erosional displacement)	•Intact stone lines -clast steps -intervening pools	•No organized stone lines (due to depositional in-filling)
Bed sediment	•Largely bedrock	•Largely moss covered	•Not moss covered
Bank sediment	•Not eroded	•Boulder, bedrock, turf or roots	•Banks cleaned of moss but not eroded (due to bedrock)
LWD	•Not important	•Present, minimal function	•Not important

Table 3Bvii. STEP-POOL(SPr) PRESCRIPTIONS

Channel type *Attribute*	**Degraded**	**Stable**	**Aggraded**
Step-Pool			
Morphology	•Re-construct stone lines using very large boulders ($D \geq W_b$) Enhance sediment trapping at flow divergence sites upstream of step [10]	Intact stone lines -clast steps -intervening pools	•Re-construct stone lines using very large boulders ($D \geq W_b$) Enhance sediment scouring at flow convergence sites downstream of step [10]
Bed Sediment	•Increase sediment trapping with stone block steps	•Largely moss covered	•Increase sediment scouring with stone block steps
Bank sediment	•Not eroded	•Boulder, bedrock, turf or roots	•Banks cleaned of moss but not eroded (due to bedrock)
LWD	•Not important	•Present, minimal function	•Not important

4.0 Channel restoration and watershed interactions

In this section, the planned rehabilitation activities are related back to the watershed conditions, as determined by a Watershed Assessment Procedure--only those characteristics that may impair the effectiveness or long term success of the planned rehabilitation works are considered. At this level, the links between channel restoration and watershed conditions are not site specific; that is, the overall conditions of the watershed are linked to channel restoration in general and no attention is paid to any particular segment of channel.

Normally, restoration of the stream channel should not begin until the hillslopes are stabilized, the riparian areas are restored, and peak flows reduced. However, in some circumstances, there may be a need to begin channel restoration before the watershed is stabilized (e.g., desire to protect valuable spawning habitat before all other restoration actions are complete). The following procedures identify portions of the channel network where restoration may begin with the consultation of a geoscientist.

The CAP assigns a CIV (Channel Impact Value) to the entire channel network; the CIV's range from <0.5 (low impact), 0.5 - 0.7 (moderate impact), or >0.7 (high impact). Because the impact on a watershed is produced by all processes considered in the WAP (changes in landslides, surface erosion, peak flows, floodplains and headwater conditions), it is necessary to consider the combined (cumulative) effects of all changes. In accordance with the format of Anon. (1995ab), the following four matrices provide a means of considering these interrelated effects. Each matrix considers a combination of two hazard indices, grouping the results into three categories: low, medium and high. The categories are defined as follows:

Hazard Category	**Hazard Index**
Low	Less than 0.5
Medium	0.5 - 0.7
High	Greater than 0.7

The combination of two hazards in each matrix results in an interpretation value of 1 to 4 to assess the risk to proposed channel restoration works at the watershed scale. Associated with each value are interpretations and recommendations, described beneath each matrix.

Interaction Matrix 1: Peak flow vs. Channel instability

Peak Flow / Channel Instability	Low (< 0.5)	Medium (0.5 - 0.7)	High (> 0.7)
Low (<0.5)	**1**	**1**	**1**
Medium (0.5 - 0.7)	**2**	**3**	**4**
High (>0.7)	**2**	**3**	**4**

Recommendations:

Value = 1: Channel restoration is not required.

Value = 2: Low risk to restoration works. Channel restoration may proceed within the sub-basin, as required.

Restoration activities are not limited by ongoing peak flow conditions.

Value = 3: Moderate risk to restoration works. Channel restoration may proceed within decoupled macro-reaches characterized by erosion-resistant banks, as required, upon consultation with a geoscientist and the completion of a Level 3 assessment.

Restoration should not occur in coupled or partially coupled macro-reaches.

Value = 4: High risk to restoration works. Restoration should not occur within the sub-basin until the ECA is reduced or upon consultation with a geoscientist and the completion of a Level 3 assessment.

Interaction Matrix 2: Landslide vs. Channel Instability

Landslide / Channel Instability	Low (< 0.5)	Medium (0.5 - 0.7)	High (> 0.7)
Low (<0.5)	**1**	**1**	**1**
Medium (0.5 - 0.7)	**2**	**3**	**4**
High (>0.7)	**2**	**4**	**4**

Recommendations:

Value = 1: Channel restoration is not required.

Value = 2: Low risk to restoration works. Channel restoration may proceed within the sub-basin, as required.

Restoration activities are not limited by ongoing landslide hazards.

Value = 3: Moderate risk to restoration works. Channel restoration may proceed within decoupled macro-reaches, as required, upon consultation with a geoscientist.

Restoration should not occur in coupled or partially coupled macro-reaches until the hillslopes are stabilized.

Value = 4: High risk to restoration works. Restoration should not occur within the sub-basin until the hillslopes are stabilized or upon consultation with a geoscientist.

Interaction Matrix 3: Riparian vs. Channel instability

Riparian / Channel Instability	Low (< 0.5)	Medium (0.5 - 0.7)	High (> 0.7)
Low (<0.5)	**1**	**1**	**1**
Medium (0.5 - 0.7)	**2**	**3**	**4**
High (>0.7)	**2**	**4**	**4**

Recommendations:

Value = 1: Channel restoration is not required.

Value = 2: Low risk to restoration works. Channel restoration may proceed within the sub-basin as required.

Restoration activities are not limited by riparian disturbance.

Value = 3: Moderate risk to restoration works. Channel restoration may proceed within reaches upstream of any riparian logging, and in reach-types CP and SP downstream of riparian logging, as required, upon consultation with a geoscientist.

Restoration should not occur in RP reach-types downstream or adjacent to areas of riparian logging until restoration of the riparian area is completed.

Value = 4: High risk to restoration works. Restoration should not occur downstream or adjacent to areas of riparian logging within the sub-basin until riparian restoration is completed or upon consultation with a geoscientist.

Interaction Matrix 4: Headwaters vs. Channel Instability

Channel Instability \ Headwaters	Low (< 0.5)	Medium (0.5 - 0.7)	High (> 0.7)
Low (<0.5)	**1**	**1**	**1**
Medium (0.5 - 0.7)	**2**	**3**	**4**
High (>0.7)	**2**	**4**	**4**

Recommendations:

Value = 1: Channel restoration is not required.

Value = 2: Low risk to restoration works. Channel restoration may proceed within the sub-basin, as required.

Restoration activities are not limited by ongoing headwaters hazards.

Value = 3: Moderate risk to restoration works. Channel restoration may proceed within decoupled macro-reaches, as required, upon consultation with a geoscientist.

Restoration should not occur in coupled or partially coupled macro-reaches until the headwaters are stabilized.

Value = 4: High risk to restoration works. Restoration should not occur within the sub-basin until the headwaters are stabilized or upon consultation with a geoscientist.

5.0 Channel restoration and drainage network interactions

This section considers explicitly the channel network and details the linkages between watershed characteristics and downstream channels that have been identifies as candidate rehabilitation sites.

5.1 Sediment transfer within and between watersheds

The movement of sediment from a source to a downstream rehabilitation site involves many hillslope and stream processes. The movement of sediment through a watershed is illustrated in a sediment transfer model (Figure_). Hillslope materials are moved downslope by various processes; for example, rockfalls, debris slides and soil creep transfer sediment from the hillslope to the valley bottom. Eventually this material enters a stream channel, often as a result of stream bank erosion, and moved downstream by fluvial sediment transport mechanism. The transfer of sediment is rarely continuous over time or space, so the downslope/downstream movement through the watershed is sporadic and sediment is stored in specific landscape zones for various time periods.

The efficiency of sediment transfer within a watershed can be anticipated from the surrounding terrain and hydraulic characteristics. The CCPA links these features to provide an operational planning tool for restoration planners. The approach has been generalized in Figure_ to show the importance of channel and sub-basin arrangement with respect to the downstream rehabilitation sites. Figure _ also illustrates the kinds of questions and issues considered and the steps followed. A simplified schematic showing the general features considered in sediment thoughput to downstream zones is given in Figure _.

The system involves five main steps (Figure _): delineating the rehabilitation sites and the connecting drainage patterns; describing the geomorphically important features of the watershed; determining sediment delivery potentials; evaluating channel sediment throughputs by reach and tributary; and integrating this information to define the downstream hazard potential of upstream processes. This information is presented on a large scale map.

(NOTE: This section is currently under further revision and will be available for distribution shortly.)

6.0 References

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