Wildland Hydrology's submission to the Kootenai Tribe of Idaho illustrating a potential approach to Kootenai River Habitat Restoration.

This conceptual design was submitted to the
Kootenai Tribe of Idaho by Wildland Hydrology
in May 2008 as part of the Kootenai River Habitat Restoration Project.

Kootenai River Conceptual Design

May 15th, 2008

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Introduction

The effects of reservoirs and historical land uses on the Kootenai River have prompted significant change in the physical, biological and ecological river function. The adverse consequences of change have shown to be significant, and the cumulative effects of such have necessitated a large-scale restoration effort. The magnitude, duration and timing of streamflows influenced by the operational hydrology of Libby Dam with the corresponding change in the river morphological, sedimentological, hydraulic, biological and chemical river functions need to be mitigated to match the current controlling variables of river processes. The influence of backwater from the operation of the Corra Lynn Dam and Kootenay Lake in Canada has also been responsible for continued adverse river adjustment.

The driving impetus for this mitigation/restoration/enhancement proposal is the decline in the population of the Kootenai River white sturgeon. The sturgeon, an endangered species, have been adversely affected by the changes in the Kootenai River stability, morphology and overall loss of physical and biological river function (Anders *et al*., 2002).

In 1994, in response to adverse post-dam development alterations to the Kootenai River ecosystem, the goal of the KTOI-BPA Kootenai River Ecosystem Improvement project (BPA Project No. 199404900) was to recover a productive, functional and biologically diverse Kootenai River ecosystem, particularly within the Idaho segment. Emphasis was placed on native species assemblages, food web interactions and supporting habitat rehabilitation. This project has essentially taken an ecological concept approach from primary, secondary and tertiary aquatic productivity assessment, acknowledging linkage between the aquatic, riparian and terrestrial communities.

The Kootenai River ecosystem has been subject to many anthropogenic activities for the past century (Anders *et al*., 2002; KRSBP, 2004; KTOI, 2005). Since the 1920s, extensive agriculture, mining and land use practices have taken their toll on the river ecosystem (Northcote, 1973). From the mid-1930s through the 1950s, the construction of flood control dikes (levees) on the lower Kootenai River eliminated the river's historical floodplain habitat. In this lower meandering river section, the river became entrenched for two reasons: 1) the levees isolated the river from its floodplain, and 2) the revised bankfull discharge due to flow regulation was half of the previous stage making the bank heights greater above the normal high flow.

The availability of usable nutrients in streams and rivers can also influence the community structure and growth of periphyton and diatoms (Stevenson *et al*., 1991) affecting higher levels of the food web. Hauer and Stanford (1997) documented that large river systems that are regulated by dams may change the community structure of algae, aquatic insects and fish over time. Since its construction in the early 1970s, Libby Dam has significantly altered flow regimes and channel morphology. The quantitative evidence of this regulation is shown later in this report. According to Woods (1982) and Snyder and Minshall (1996), Libby Dam and Lake Koocanusa (reservoir) are responsible for the depletion of nutrients and the decline in primary productivity in the Idaho portion of the Kootenai River.

Sturgeon studies have been conducted for several decades to identify the cause in the decline of the sturgeon population and the obvious loss of recruitment. The primary

references that document such studies include: Anders and Richardson (1996), Anders *et al*. (2002), U.S. Fish and Wildlife Service (1999), U.S. Fish and Wildlife Service (2000), Pacific Watershed Institute and Resources (1999) (*Recovery plan for the Kootenai River population of white sturgeon*) and Berenbrock and Bennett (2005). The summary of these specific studies relating to spawning, migration, historical behavior and limiting factor analysis for all age classes has been related to changes in flow, sediment, river stability, nutrients, riparian loss and physical habitat changes. The adverse changes in the biological function are initiated with a change in the physical system. Interrelations between physical habitat with changes in sediment (bedload, suspended, size, concentration and supply); hydraulics (velocity, turbulence, shear stress, stream power, form and grain roughness); water quality (temperature, dissolved oxygen, nutrients and toxicity); streambed substrate size and character; bedforms; river morphology (dimension, pattern and profile); riparian vegetation; and floodplain connectivity, all have had adverse impacts on river processes and biological function.

The following excerpt is included as a good summary of the status of the Kootenai River white sturgeon from a USGS report (Barton, 2004, p. 3):

> Many local, State, and Federal agencies have concerns about the declining population of white sturgeon (*Acipenser transmontanus*) in the Kootenai River in Idaho. In 1994, the Kootenai River white sturgeon was listed as an Endangered Species, and fishing was prohibited. The white sturgeon population decline is reflected in fewer juvenile sturgeon and an overall decline in spawning success. The last successful recruitment of white sturgeon occurred in 1974 (U.S. Fish and Wildlife Service, 1999). Recruitment occurs when a spawning event produces juvenile fish that survive to create a new year-class of fish in sufficient numbers to maintain the fish population. Lack of recruitment has been attributed, at least in part, to changes in the natural streamflow regime of the Kootenai River after completion of Libby Dam, near Libby, Montana, in 1973 because these changes could have altered the channel substrate and sturgeon spawning habitat near Bonners Ferry, Idaho. Other changes in the Kootenai River that could have affected the spawning substrate are the construction of dikes on the natural levees, changes in backwater conditions near Bonners Ferry caused by changes in the level of Kootenay Lake, and loss of wetlands in the river valley.
>
> White sturgeon are broadcast spawners that release adhesive, negatively buoyant eggs that sink to the riverbed (Stockley, 1981; Brannon and others, 1984). Paragamian and others (2001; 2002) identified five primary reaches in the Kootenai River downstream from Bonners Ferry where white sturgeon spawned during 1994–99. These investigators collected most sturgeon eggs in the outsides of riverbends in the thalweg (the deepest part of any cross section of a river). Parsley and others (1993, p. 224) reported that in the Lower Columbia River, most sturgeon eggs were collected over substrates of cobble or boulder, where the eggs are sheltered by attaching to and incubating on the rocky substrate. Rocky substrate also provides cover for yolk sac larvae before they become free swimming.
>
> Egg suffocation and predation have been hypothesized as potential factors for white sturgeon egg mortality in the Kootenai River (Anders and Richards, 1996; Paragamian and Kruse, 1996; and U.S. Fish and Wildlife Service, 1999). More than

> 96 percent (428 of 444) of the naturally produced white sturgeon eggs collected between 1991 and 1995 in this reach were from sand substrate that appeared to be suboptimal for incubation (Anders and Richards, 1996; Paragamian and Kruse, 1996). The hypothesis of egg suffocation is supported by the observation that mats placed on the riverbed to catch sturgeon eggs typically are buried by sand within 48 hours of deployment (Vaughn Paragamian, Idaho Department of Fish and Game, and Sue Ireland, Kootenai Tribe of Idaho, oral commun., 1999). Gravel and cobble are optimal substrate for sturgeon spawning habitat, whereas sand is considered detrimental, a direct link to the biological impairment.

In addition to the sturgeon decline, the adverse habitat and water quality impacts have also reduced burbot, kokanee, bull and cutthroat trout populations. This proposed natural channel design for river restoration addresses these species as well as the sturgeon. Significant adverse effects of stream channel change have all been well documented due to historic land uses, including reservoir regulation, elimination of riparian vegetation, dredging, levees and floodplain disconnects, which have been responsible for changes in the sediment regime, river stability, increases in flood incidence and land loss due to accelerated streambank erosion.

The referenced scientific investigations sponsored or conducted by the U.S. Geological Survey, Idaho Fish and Game, U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, University of Idaho (Cramer Fish Sciences), Kootenai Tribe of Idaho, Bonneville Power Administration and other consulting firms have developed and documented invaluable essential information and interpretations used by Wildland Hydrology to formulate this site-specific, process-based mitigation through an ecological/ geomorphological approach to river restoration. A review draft of habitat design recommendations by Anders (2007) was also useful in identifying specific criteria to assist in the restoration design. This proposed restoration plan is designed to offset adverse impacts and specific habitat limitations posed by past land use, flow changes and other factors leading to the decline of the Kootenai River white sturgeon.

Goals

The proposed design addresses the causes and consequences of change related to the fisheries problems. The proposed design also addresses the causes of physical and biological impairment and makes specific recommendations to offset the limiting factors for specific fish species identified in previous studies and current understanding. Furthermore, the proposed design specifically addresses the physical characteristics to establish a stable balance between river morphology and the controlling variables that influence river processes.

General Objectives

The design addresses the following general objectives:

1. Offset specific limiting factors for various fish species and life stages of the Kootenai River white sturgeon
2. Develop a sustainable and self-maintaining river design
3. Decrease flood stage for same magnitude flows

4. Decrease streambank erosion
5. Reconnect floodplains
6. Reestablish riparian vegetation
7. Maintain the agricultural productivity and economic base of traditional life styles in the valley (farming and ranching)
8. Create a stable morphology of the channel to match the existing flow and sediment regime
9. Reduce risk to infrastructure (roads, bridges, etc.)
10. Reduce land drainage problems and pumping costs by lowering the water table in the meandering reach
11. Reduce high maintenance costs (levee repair, dredging)
12. Improve recreational boating and fishing access in the braided reach
13. Increase acres of usable land and improve land value in the braided reach
14. Improve the aesthetics of the river

Specific objectives are documented by specific categories and processes later in this report.

Geology and the Hydro-Physiographic Province

The Kootenai River originates in the Northern Rocky Mountains of Canada, flows into Montana into Lake Koocanusa behind Libby Dam, into Idaho between the Cabinent and Purcell range of mountains through the Purcell Trench, a glaciated valley. The Kootenai River flows North from Idaho into Canada and eventually into the Columbia River (**Figure 1**). The Kootenai River is the third largest drainage tributary of the Columbia River, comprising over 19,000 square miles, 70% in British Columbia, 23% in Montana and 7% in Idaho, and it supplies the second largest tributary flow to the Columbia River (Kootenai Tribe of Idaho and Montana Fish, Wildlife and Parks, 2004). Libby Dam, constructed in 1972 forming Lake Koocanusa in Montana, extending upstream into British Columbia, regulates 70% of the Kootenai River basin drainage area. The general vicinity map is shown in Figure 1. A more detailed map of the proposed restoration reaches broken into three major reach locations is shown in **Figure 2**. Specific vicinity locations, gage stations, river stationing and local landmarks are shown in **Figure 3**. The restoration emphasis showing photo examples of each of the three reaches and their locations under consideration for restoration are shown for the braided reach in **Figure 4**, the straight reach in **Figure 5** and the meandering reaches in **Figure 6**.

The mountain ranges to the West of the Kootenai River are the Selkirks and the Cabinet Range on the southern boundary. The gap in the mountains that the Kootenai River flows through into Idaho is the Purcell Trench, between the Cabinet and Purcell Mountains. The mountain ranges that form the Northern Rocky Mountains in this region are comprised of meta-sedimentary rocks of the belt supergroup. The mountains have subsequently been uplifted by igneous, intrusive rocks (tertiary, plutonic rocks). Detailed geologic descriptions of the region can be obtained in Aadland and Bennett (1979). The belt rocks in this region are notorious for nutrient deficiencies often associated with low biologic productivity.

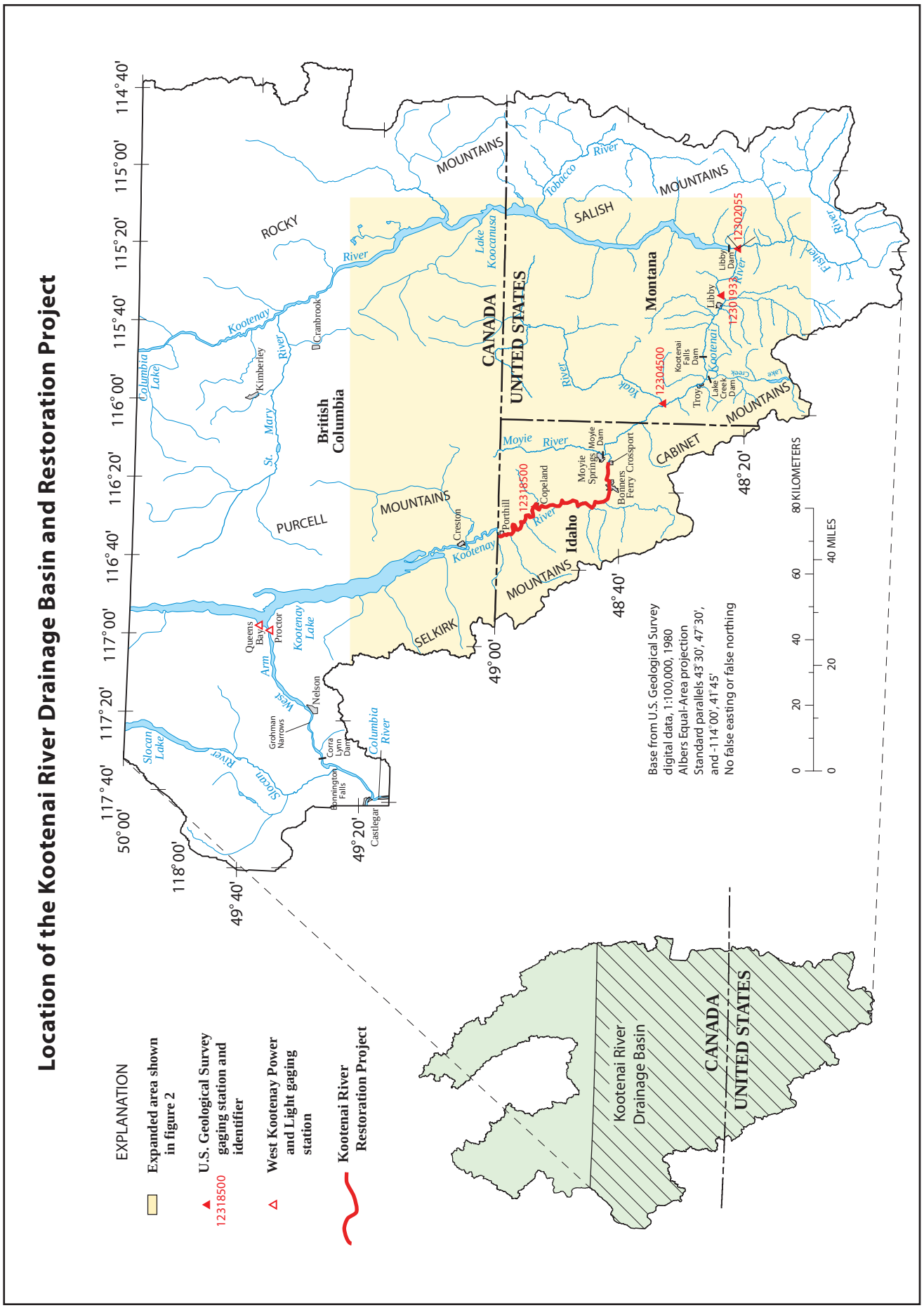


Figure 1. A general vicinity map produced by the USGS depicting the location and extent of the Kootenai River Basin in Canada, Montana and Idaho (extracted and modified from Barton *et al.*, 2004)

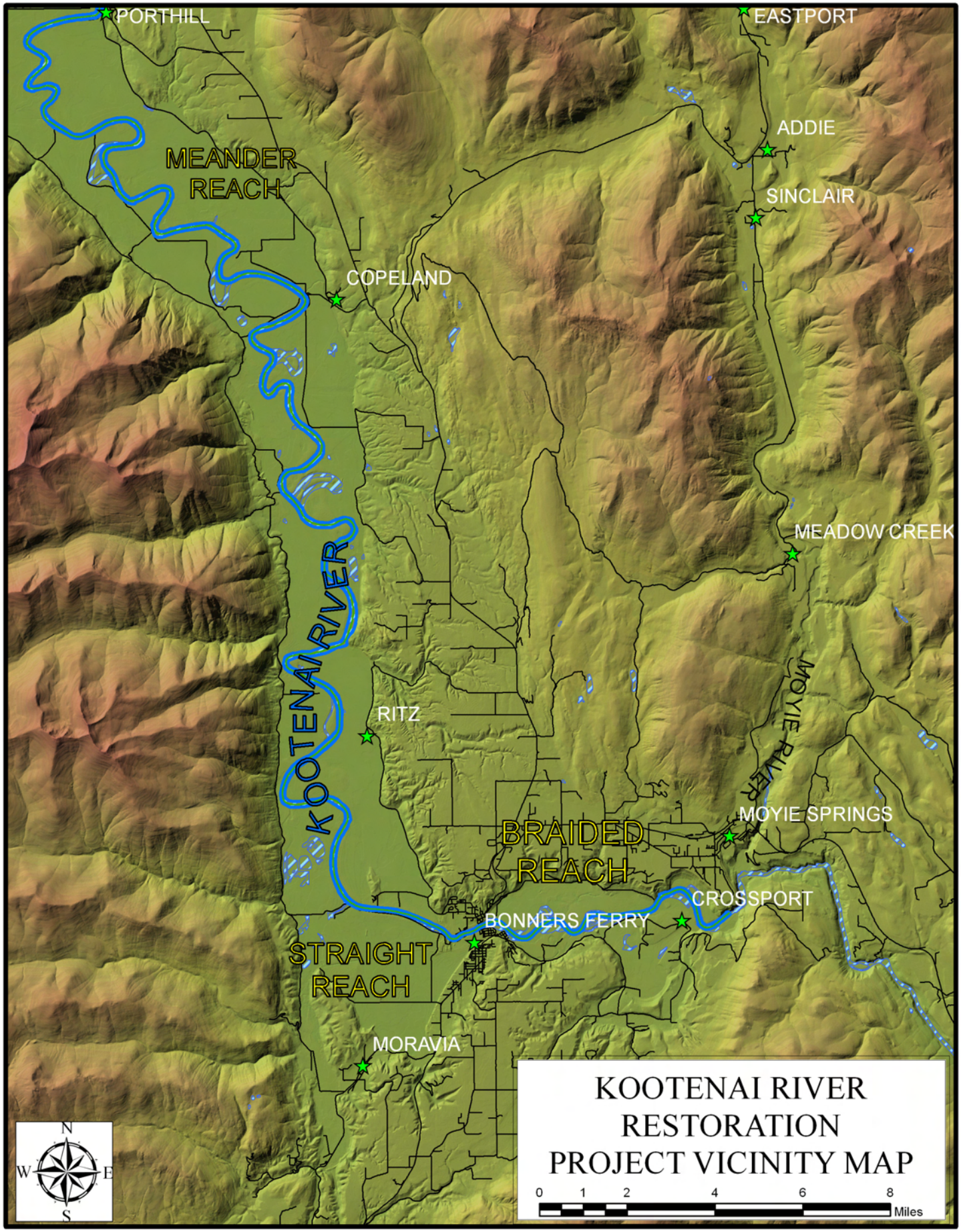


Figure 2. A Kootenai River location map depicting the three study reaches: the braided, straight and meandering.

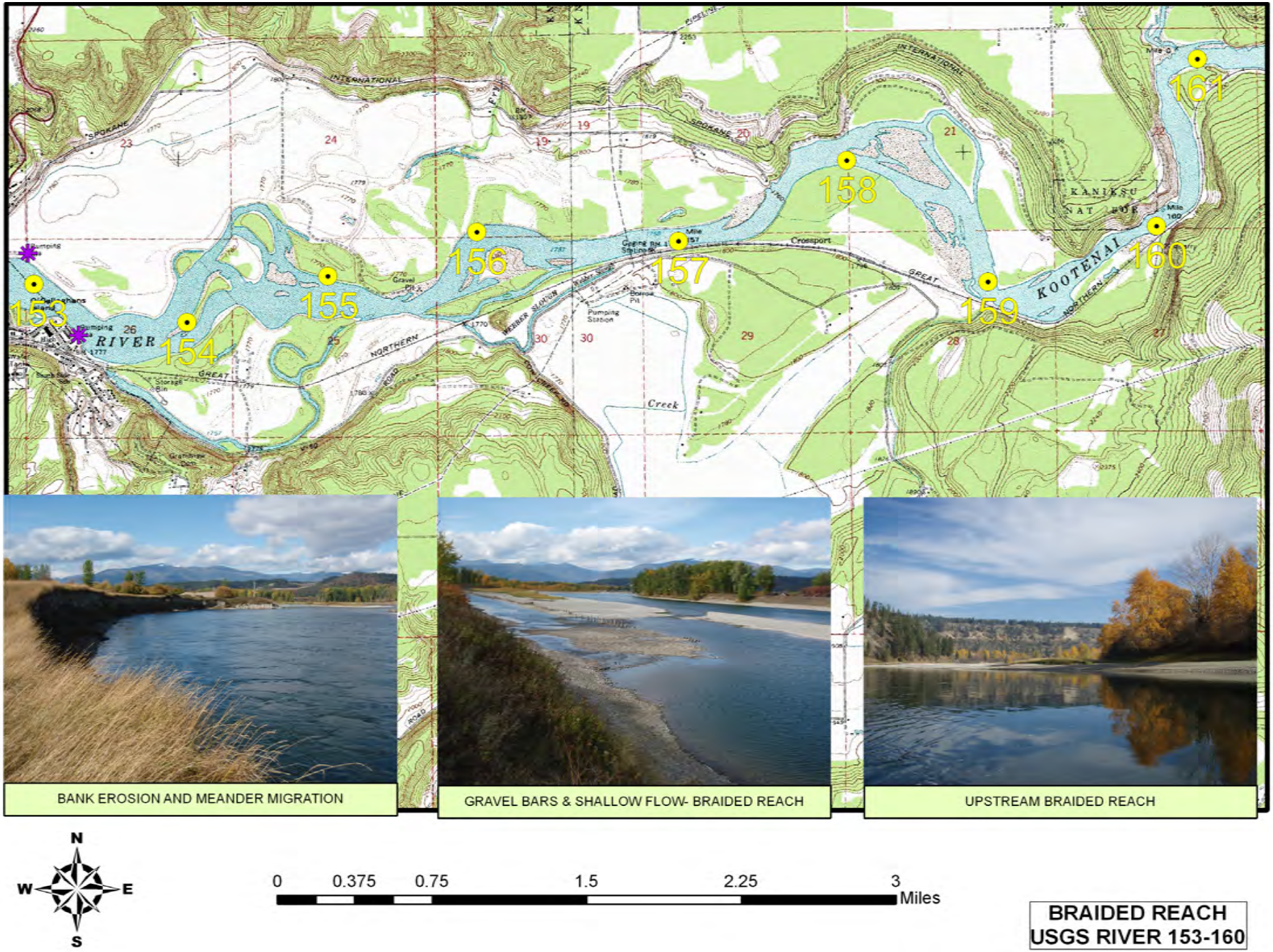


Figure 4. The location and examples of the braided reach in the Kootenai River study.

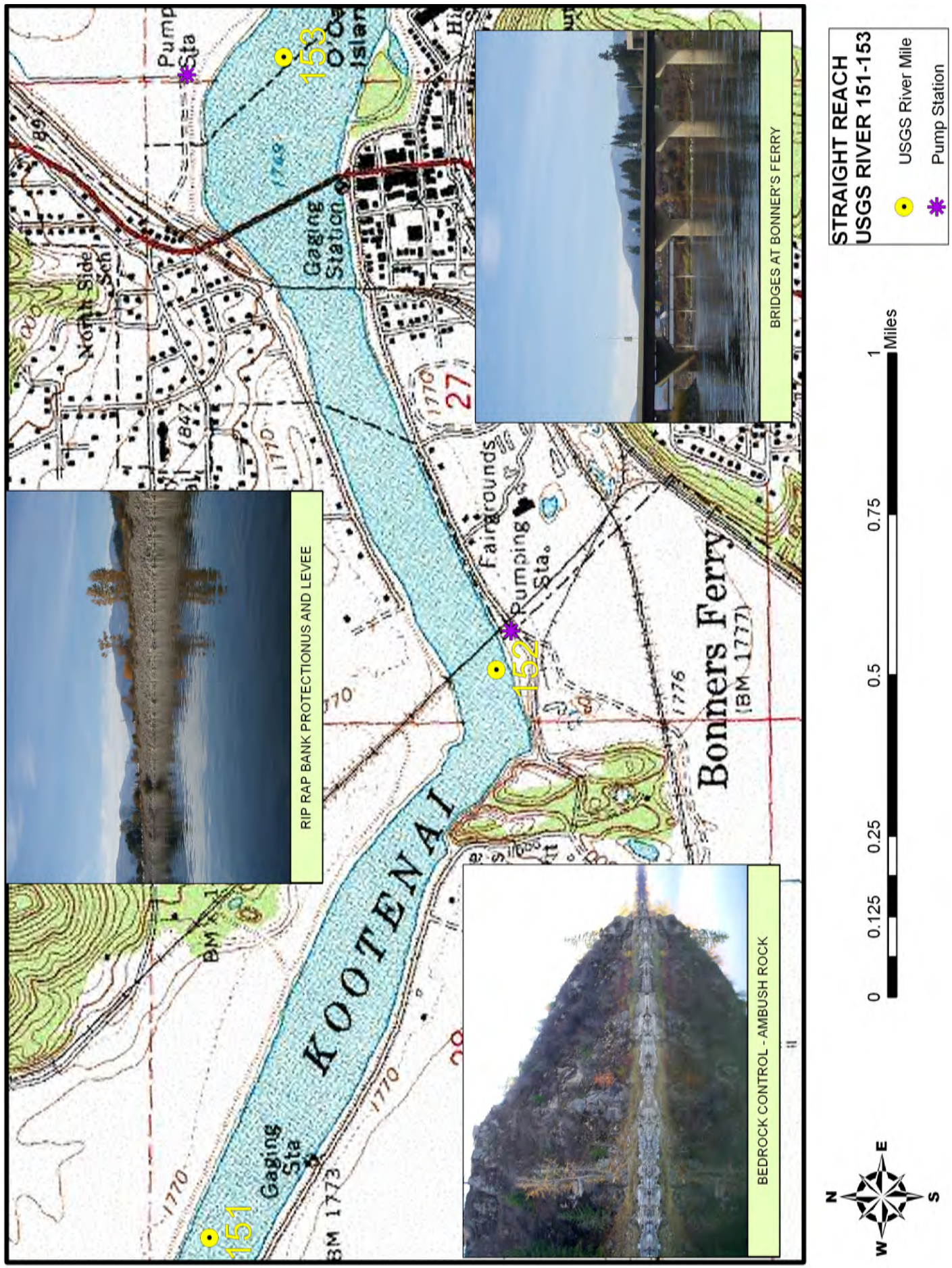


Figure 5. The location and examples of the straight reach and the entrenched F4/5/1 stream type with rock outcrops.

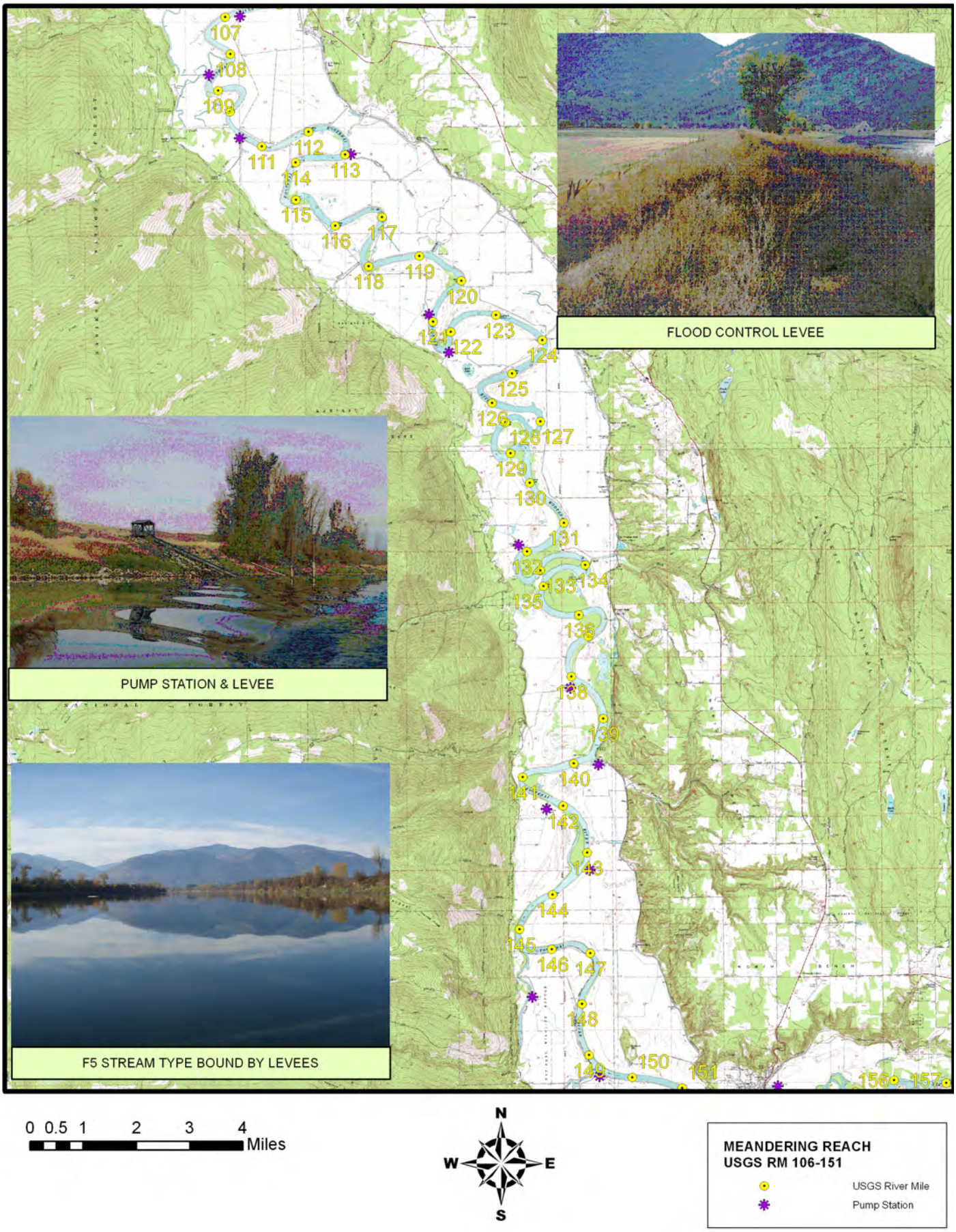


Figure 6. The location and examples of the lower meandering study reach of the Kootenai River characteristic of an entrenched, meandering F5 stream type.

Geomorphology

The dominant processes associated with the present landforms and surficial deposits of the region are primarily influenced by glaciation and alluviation. The ice sheet from continental glaciation covered most of the mountain and valleys leaving glacial till deposits on the landscape. The major ice sheet blocked the lower bedrock valleys in Canada creating a major glacial lake that extended up valley to present day Bonners Ferry. As the ice retreated, the glacial lake filled-in with fine lacustrine silts and clays, forming the present valley floor and the current floodplains and terraces of the Kootenai River. Kootenay Lake, 25 miles to the North of the Idaho border in British Columbia, is a natural lake remnant of this glacial lake. At the end of the Pleistocene period and at the start of the Holocene period (10,000 to 12,000 years ago), the landscape was reworked by fluvial erosion creating the majority of the fluvial landscapes influencing the Kootenai River.

Valley Types

The valley types associated with the various locations of the mainstem Kootenai River and its tributaries vary throughout its length. Valley types are mapped for the upper canyon, braided, straight and meandering reaches on topographic maps and aerial photos as shown in *Appendix I* (*Figures I-1a through I-7b*). Valley type descriptions and examples are outlined in detail in *Appendix II* (Rosgen, 1996). Starting at the upper end of the valley (*Appendix I: Figures I-1a through I-2b*), the reach below Libby Dam from Montana into Idaho is an inter-gorge, Valley Type IV, which is geologically entrenched (vertically contained) and laterally contained with meander width ratios less than two. Meander width ratio is defined as the belt width divided by the bankfull channel width that quantitatively determines degree of lateral containment or confinement.

As the valley opens up beyond the structural control that confines the upper valley downstream of the confluence with the Moyie River (**Figure 2**), the valley type changes in the vicinity of the braided reach to a terraced/alluvial valley (Valley Type VIII, *Appendix I: Figures I-3a and I-3b*). Across from the town of Bonners Ferry is a structurally-controlled Valley Type VI with bedrock outcrops between the bridges and Ambush Rock (*Appendix I: Figures I-4a and I-4b*). The valley type below Ambush Rock becomes a glacio-lacustrine valley (Valley Type X, *Appendix I: Figures I-4a through I-7b*). The tributaries vary from steep, entrenched valleys (Valley Type I), colluvial valleys (Valley Type II), alluvial fans (Valley Type III), terraced/alluvial valleys (Valley Type VIII) and glacio-lacustrine valleys (Valley Type X), as mapped in *Appendix I* (*Figures I-1a through I-7b*).

Stream Types

Stream types are an integration of physical processes involving controlling variables of streamflow, sediment vegetation, valley slope, width and other boundary conditions that integrate to form an identifiable river morphology. Their morphological character allows one to predict certain unique characteristics associated with a particular stream type. Each major stream type has a unique suite of morphological, sedimentological, hydraulic and biological interpretations (Rosgen, 1994, 1996).

Dimensionless ratio relations of the morphological variables are used from reference (stable) reaches to be extrapolated to impaired rivers for the purposes of assessment and stream restoration. Stream types also have been observed over time to change their morphology due to changes in boundary conditions (streamflow, sediment, riparian vegetation, etc.) as well as direct disturbance that alters their dimension, pattern and profile. Examples of various stream type evolution scenarios involving stream morphology succession are shown in **Figure 7**. This information is used later in the restoration proposal section of this report.

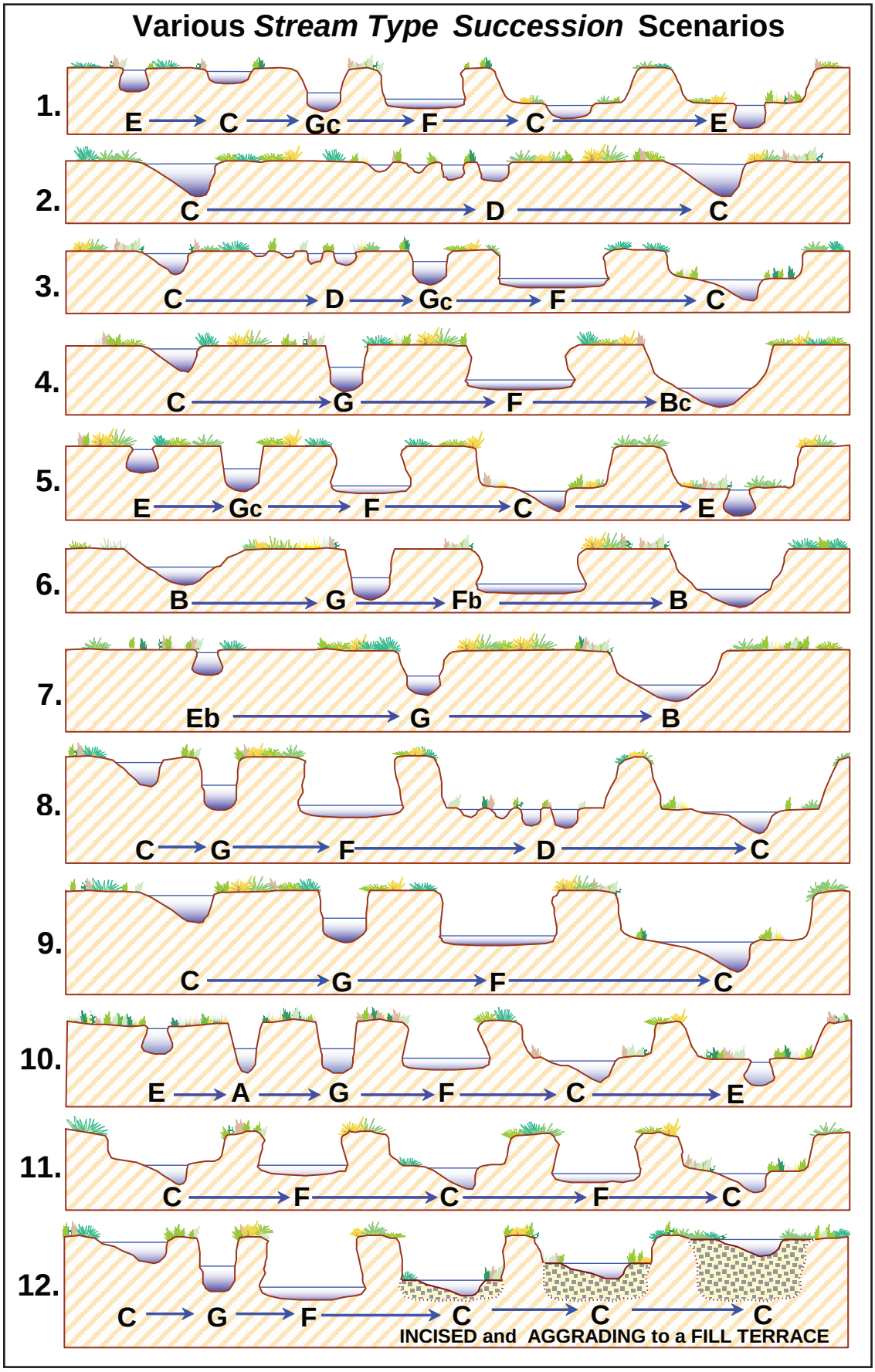


Figure 7. Various channel evolution scenarios involving stream type succession (Rosgen, 1999, 2001b, 2006).

F3 Stream Type

The corresponding stream types for the various valley types are mapped in the topographic maps and aerial photos shown in *Appendix I* (*Figures I-1a through I-2b*). The stream type in the Valley Type IV in the upper reaches of the Kootenai River from the Montana border downstream is an F3 (see description of F3 as and other stream types in Appendix III). The F3 stream type is a low sinuosity, cobble bed, entrenched and confined channel with a width/depth ratio greater than 12, and a slope less than 0.010 (**Figure 8**).

A2/1 Stream Type

"A" stream types are deeply entrenched and very confined channels with low width/depth ratios and cascading and step/pool morphology. They are associated with steep, narrow valleys (Valley Types I and VI) and are located within the tributaries to the Kootenai River as mapped in *Appendix I* (*Figures I-2a and I-2b*). An example of an A2/1, boulder-dominated, bedrock-controlled, steep, cascading, step/pool morphology that is totally entrenched and laterally confined in a structurally-controlled valley (Valley Type VI) is shown in **Figure 9**, below the dam on the Moyie River.

C3 Stream Type

As the width of Valley Type IV increases, the stream type changes from an F3 to a C3 stream type (an alluvial, riffle/pool, cobble-bed stream with a flatter slope of less than 0.01 and a confined floodplain. Additionally, the C3 stream type has depositional features such as point, central, transverse and side bars (C3 stream type). These C3 stream types are mapped as shown in *Appendix I* (*Figures I-1a through I-2b*). Examples are shown in aerial oblique photographs in **Figure 10** and **Figure 11**. **Figure 11** documents a tributary showing an alluvial fan (Valley Type III) and a corresponding D4 (braided) stream type (see mapping location in *Appendix I: Figures I-1a and I-1b*).

C4 Stream Type

A short distance downstream near the confluence with the Moyie River, the stream type changes to a C4 or gravel-dominated, low gradient, meandering stream with a floodplain (flood-prone area) (**Figure 10**, *Appendix I: Figures I-2a and I-2b*). **Figure 12** shows the cross-section features of the C4 stream type on the Kootenai River as it changes from a Valley Type IV to a Valley Type VIII, or a terraced/alluvial valley (*Appendix I: Figures I-3a and I-3b*). The slope of this C4 stream type is 0.00067.

D4 Stream Type

As the valley widens below the confluence of the Moyie River and the valley type changes to a broad, terraced, alluvial Valley Type VIII, a D4 stream type (gravel-dominated, multiple-thread, braided channel) occurs (**Figure 13**). The D4 stream type persists upstream from the U.S. 95 bridge for approximately 6.5 miles (*Appendix I: Figures I-3a and I-3b*). This reach is characterized by excessive sediment deposition, lateral migration and channel enlargement. The slope of the upper reach of the braided channel is 0.0006, and at the lower reach close to Bonners Ferry the slope is 0.0003. The energy slope of the lower braided reach is influenced by backwater from Kootenay Lake, which adds to the excessive sediment deposition and accelerated channel adjustment. In pre-dam periods, the sediment yield was orders of magnitude higher than present due to both the Libby and the Moyie River dams. The drop in gradient with the corresponding change in valley type would naturally be associated with an excess sediment supply and a drop in stream power, inducing a braided river morphology. It is likely that the historical morphology of this reach has been in this form since the Holocene period. The current condition of this reach and change in controlling variables is discussed later in this report.

Figure 8. Aerial oblique view of an F3 stream type in a Valley Type IV on the Upper Kootenai River (copyright 2008 Google).

Figure 9. Aerial oblique photo of an A2/1 bedrock-controlled stream type in a structural-controlled Valley Type VI on the Moyie River near the confluence with the Kootenai River (copyright 2008 Google).

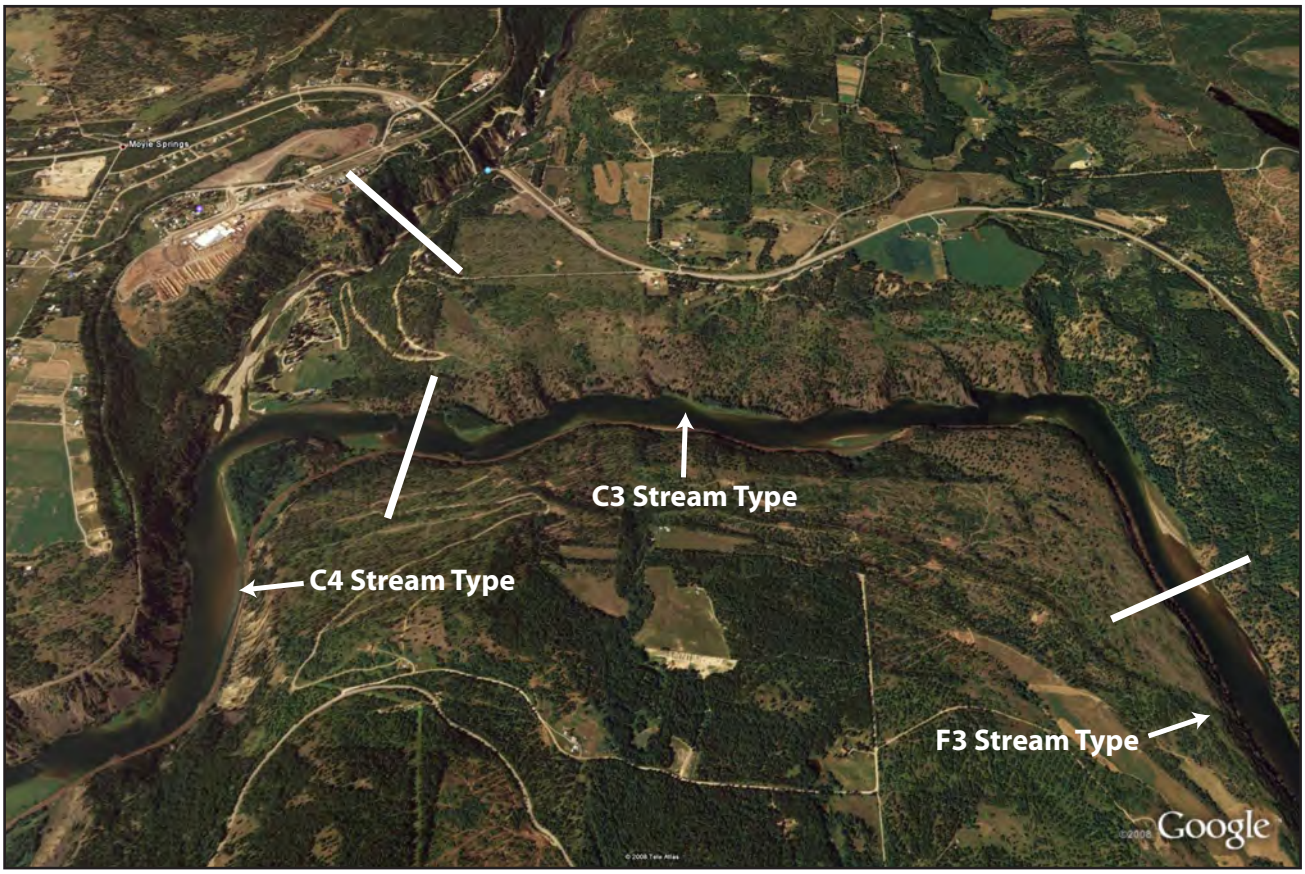


Figure 10. A transition from an F3 stream type to a C3 stream type – a single-thread, meandering stream with a floodplain at the confluence with the Moyie River in a Valley Type IV (copyright 2008 Google).

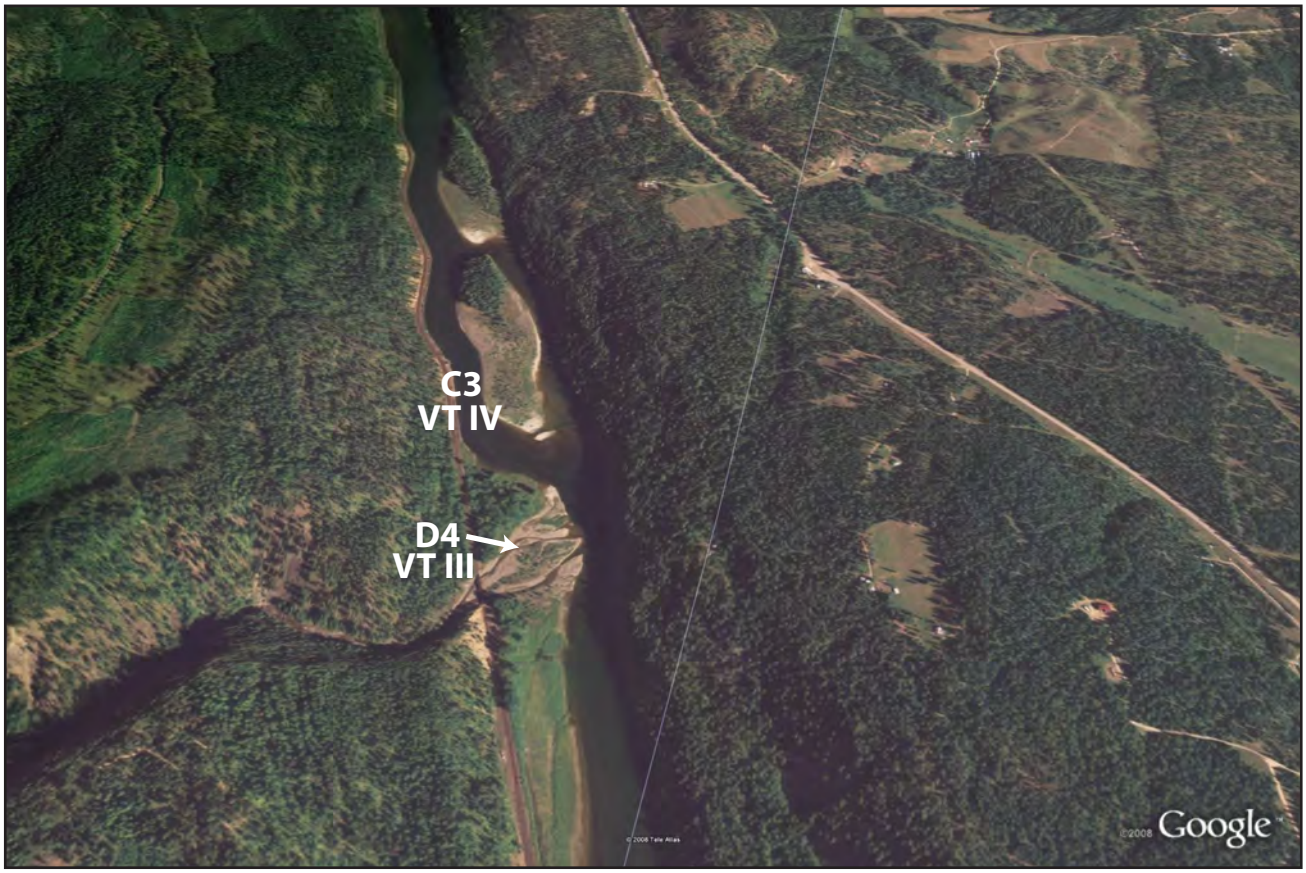


Figure 11. An aerial oblique view of a C3 stream type in a valley type IV on the Upper Kootenai River, downstream of the Montana border. The tributary stream type is a gravel, braided D4 stream type on an alluvial fan (Valley Type III) (copyright 2008 Google).

Figure 12. A C4 stream type on the Kootenai River immediately upstream of the braided reach (width/depth ratio = 36).

Figure 13. The braided reach of the Kootenai River, D4 stream type looking downstream (width/depth ratio =152).

F4/5/1 Stream Type

The straight reach (**Figure 5**, *Appendix I: Figures I-4a and I-4b*) between the U.S. 95 bridge and below Ambush Rock is a geologically controlled F4/5/1 (a sand invaded-gravel bed, entrenched, confined, high width/depth ratio, low gradient stream type). Highway U.S. 95 and the railroad bridge crosses the Kootenai River at this location due to the narrow, stable nature of the Kootenai River. The slope in this reach is 0.00031 and is associated with a bedrock controlled bed and several outcrops influence lateral containment (**Figure 14** and **Figure 15**). The valley type is a structurally-controlled Valley Type VI. This reach contains a very deep pool at the meander bend at Ambush Rock where the white sturgeon congregate and mostly turn around and return downstream to spawn. There are sand deposits over the gravel and cobble substrate due to a high sand load and high width/depth ratio of the F stream type.

F5 Stream Type

Less than a mile downstream of ambush rock, the valley type changes to a type X, or lacustrine valley, and the associated stream type is an F5 (**Figure 6**, *Appendix I: Figures I-4a through I-7b*). The F5 stream type is an entrenched and confined sand-bed channel with a high width/depth ratio with slopes less than 0.000046 (at low Kootenay Lake levels). This is the remnant of the glacial lake that previously existed then subsequently filled-in with silt and clay with discontinuous shallow layers of gravel river alluvium. The stream type would normally be a DA5 (multiple channel/anastomosed with cohesive streambanks, wetlands and oxbow channels and lakes). Another stream type that exists in these lacustrine and glacio-lacustrine valleys is an E5 (highly sinuous, single-thread channel with a well developed floodplain, cohesive banks and extensive riparian vegetation). The existing stream type, however, is an F5, an entrenched or vertically contained, meandering channel (**Figure 16**). The natural stable channel is not an F5, but it was created due to changes in flow regulation, levee construction (dikes) and channel dredging. Characteristics of this stream type are excessive streambank erosion, down valley meander migration and tributary rejuvenation (channel incision or headcuts due to the lowering of local base level and alteration of dimension, pattern and profile of the tributary streams).

G3/G4 Stream Types

The cobble/gravel gulleys are entrenched channels associated with headcuts due to tributary rejuvenation, or are incised due to local base level from the lowering of the Kootenai River from dredging, or are incised in active alluvial fan deposits. The tributary reaches to the Kootenai comprise a variety of stream and valley types; many are Valley Type III (alluvial fans) and G channels incised in the fan deposit. Many of the G channels have been caused by straightening and channelizing the streams near their mouth as they enter the Kootenai River (**Figure 17**, *Appendix I: Figures I-1a through I-7b*). Because the Kootenai River is entrenched, the lowering of the local base level created tributary rejuvenation. This affected the stream types, stability and function. A G4 stream type on an entrenched tributary is shown in **Figure 18**, Ball Creek, on the meandering reach of the Kootenai River.

Figure 14. Example of a rock outcrop in the straight reach across from Ambush Rock.

Figure 15. The straight reach of an F4/5/1 stream type showing rock outcrop at far end of reach at Ambush Rock (width/depth ratio = 52).

Figure 16. Example of an F5 stream type bounded on both banks with levees characteristic of an entrenched, meandering channel in sand and in a glacio-lacustrine valley.

Figure 17. Example of the straightening of the tributary Long Canyon Creek near the mouth as it enters the Kootenai River (copyright 2008 Google).

Figure 18. A G4 stream type on an entrenched tributary, Ball Creek, on the meandering reach of the Kootenai River.

B3/B4 Stream Type

The B3c stream types are moderately entrenched, cobble-bed streams with more rapids-dominated bed features with a channel that is moderately entrenched and confined (see stream classification descriptions in *Appendix III*). These stream types are generally associated with colluvial valleys (Valley Type II) and have a low sediment supply due to small amounts of channel source sediment. The locations of these valley and stream types are shown in *Appendix I: Figures I-1a through I-7b*.

Summary: Dimension, Pattern, Profile, Materials and Hydraulics

Table 1 summarizes the dimension, pattern, profile, channel materials and hydraulics of each major stream type in the restoration study reach on the mainstem Kootenai River. This information is used to compare existing to reference and proposed natural channel design later in this report. **Tables 2**, **3** and **4** show estimates of stream velocity using various roughness calculations for portions of the stream type data for the D4, F4 and F5 stream types, respectively.

Table 1. A summary of the dimension, pattern, profile, channel materials and hydraulics of each major stream type of the Kootenai River study reaches.

Stream Type:	F4/5/1	C4	D4	F5
Bankfull Discharge (cfs)	30,000	30,000	30,000	30,000
Bankfull Width (ft)	574	409	1,170	498
Bankfull Mean Depth (ft)	11.2	15.1	9	21.5
Width/Depth Ratio	51.3	27.2	130.0	23.2
Bankfull Cross-Section Area (ft^2)	6,314	6,161	10,530	10,707
Bankfull Max Depth (ft)	18.9	18.6	10.9	26.5
Width Flood-Prone Area (ft)	650	1435	1350	550
Entrenchment Ratio	1.1	3.5	1.2	1.1
Sinuosity	1.01	1.26	1.07	1.01
D_{15} (mm)	< 2.0	15	24	< 2.0
D_{35} (mm)	6	35	32	< 2.0
D_{50} (mm)	30	48	42	< 2.0
D_{84} (mm)	60	95	94	< 2.0
D_{95} (mm)	80	150	99	< 2.0
Water Surface Slope	0.00031	0.00067	0.00032	0.000046
Bankfull Mean Velocity (ft/sec)	4.8	4.9	2.8	2.8
Dimensionless Shear Stress (τ^*)	n/a	n/a	0.016	n/a
Shear Stress (τ) (lbs/ft^2)	0.22	0.63	0.18	0.06
Unit Stream Power (lb/ft s)	0.99	3.1	0.50	0.17
D_{50} Bar (mm)	n/a	n/a	17.5	n/a
Largest particle on Bar (mm)	n/a	n/a	80	n/a
Relative Roughness (R/D_{84})	58.0	48.3	27.7	43
Friction Facor (u/u^*)	12.8	12.4	10.7	12.1
Roughness Coefficient (n)	0.027	0.048	0.042	0.026

Table 2. Velocity and Discharge estimates using various methods for the D4, braided stream type in a Valley Type VIII.

Bankfull VELOCITY / DISCHARGE Estimates

Site:	**Kootenai River**	Location:	**@ RKM 251.2, Braided Reach**
Date:	**10/29/07**	Stream Type: **D4**	Valley Type: **VIII**
Observers:	**Rosgen**	HUC:	

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Cross-sectional AREA	10,070	A_{bkf} (ft^2)	Bankfull Mean DEPTH	9.0	d_{bkf} (ft)
Bankfull WIDTH	1,170	W_{bkf} (ft)	Wetted PERIMETER ~ $2 * d_{bkf} + W_{bkf}$	1188	W_p (ft)
D_{84} @ Riffle	94	Dia. (mm)	D_{84} mm / 304.8 =	0.31	D_{84} (ft)
Bankfull SLOPE	0.00032	S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	8.6	R (ft)
Gravitational Acceleration	32.2	g (ft / sec^2)	Relative Roughness R (ft) / D_{84} (ft)	27.7	
Drainage AREA		DA (mi^2)	Shear Velocity $u^* = \sqrt{gRS}$	0.30	u^* (ft / sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 \text{ Log}\{R/D_{84}\}]u^*$	3.2	ft / sec	33,214	cfs
2. Roughness Coefficient: a) Manning's 'n' from friction factor / relative roughness $u = 1.4865*R^{2/3}*S^{1/2}/n$ n = .027	4.08	ft / sec	41,133	cfs
2. Roughness Coefficient: $u = 1.4865* R^{2/3}*S^{1/2}/n$ b) Manning's 'n' from Jarrett (USGS): $n = 0.39S^{.38}R^{-.16}$ n = Note: This equation is for applications involving **steep, step-pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for stream types A1, A2, A3, B1, B2, B3, C2 and E3.		ft / sec		cfs
2. Roughness Coefficient: $u = 1.4865* R^{2/3}*S^{1/2}/n$ c) Manning's 'n' from Stream Type n = .04	2.75	ft / sec	27,765	cfs ★
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) Regional Curves $u = Q / A$ Return Period for Bankfull Discharge Q = 1.5 Year		ft / sec		cfs
4. Continuity Equations: b) USGS Gage Data $u = Q / A$	3.0	ft / sec	30,000	cfs

Options for using the D_{84} term in the relative roughness relation (R/D_{84}), when using estimation method 1.

Option 1.	For **sand-bed** channels: Measure the **"protrusion height"** (h_{sd}) of sand dunes above channel bed elevations. Substitute an average sand dune protrusion height (h_{sd} in ft) for the D_{84} term in estimation method 1.
Option 2.	For **boulder-dominated** channels: Measure several **"protrusion heights"** (h_{bo}) of boulders above channel bed elevations. Substitute an ave. boulder protrusion height (h_{bo} in ft) for the D_{84} term in estimation method 1.
Option 3.	For **bedrock-dominated** channels: Measure several **"protrusion heights"** (h_{br}) of rock separations/steps/joints/ uplifted surfaces above channel bed elevations. Substitute an average bedrock protrusion height (h_{br} in feet) for the D_{84} term in estimation method 1.

Table 3. Velocity and discharge estimates using various methods for the straight reach, an F4/5/1 stream type in a Valley Type VI.

Bankfull VELOCITY / DISCHARGE Estimates

Site:	**Kootenai River**	Location:	**Straight Reach**
Date:	**10/08/07**	Stream Type: **F4/5/1**	Valley Type: **VI**
Observers:	**Rosgen**	HUC:	

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Cross-sectional AREA	6,430	A_{bkf} (ft^2)	Bankfull Mean DEPTH	11.2	d_{bkf} (ft)
Bankfull WIDTH	573	W_{bkf} (ft)	Wetted PERIMETER ~ $2 * d_{bkf} + W_{bkf}$	582	W_p (ft)
D_{84} @ Riffle	60	Dia. (mm)	D_{84} mm / 304.8 =	0.19	D_{84} (ft)
Bankfull SLOPE	0.00031	S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	11.1	R (ft)
Gravitational Acceleration	32.2	g (ft / sec^2)	Relative Roughness R (ft) / D_{84} (ft)	58	
Drainage AREA		DA (mi^2)	Shear Velocity $u^* = \sqrt{gRS}$	0.33	u^* (ft / sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 \text{ Log}\{R/D_{84}\}]u^*$	4.22	ft / sec	27,183	cfs
2. Roughness Coefficient: a) Manning's 'n' from friction factor / relative roughness $u = 1.4865*R^{2/3}*S^{1/2}/n$ n = .027	4.8	ft / sec	30,593	cfs ★
2. Roughness Coefficient: $u = 1.4865* R^{2/3}*S^{1/2}/n$ b) Manning's 'n' from Jarrett (USGS): $n = 0.39S^{.38}R^{-.16}$ n = **Note:** This equation is for applications involving **steep, step-pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for stream types A1, A2, A3, B1, B2, B3, C2 and E3.		ft / sec		cfs
2. Roughness Coefficient: $u = 1.4865* R^{2/3}*S^{1/2}/n$ c) Manning's 'n' from Stream Type n = .034	3.8	ft / sec	24,295	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) Regional Curves u = Q / A Return Period for Bankfull Discharge Q = 1.5 Year		ft / sec		cfs
4. Continuity Equations: b) USGS Gage Data u = Q / A	4.7	ft / sec	30,000	cfs

Options for using the D_{84} term in the relative roughness relation (R/D_{84}), when using estimation method 1.

Option 1. For **sand-bed** channels: Measure the **"protrusion height"** (h_{sd}) of sand dunes above channel bed elevations. Substitute an average sand dune protrusion height (h_{sd} in ft) for the D_{84} term in estimation method 1.

Option 2. For **boulder-dominated** channels: Measure several **"protrusion heights"** (h_{bo}) of boulders above channel bed elevations. Substitute an ave. boulder protrusion height (h_{bo} in ft) for the D_{84} term in estimation method 1.

Option 3. For **bedrock-dominated** channels: Measure several **"protrusion heights"** (h_{br}) of rock separations/steps/joints/ uplifted surfaces above channel bed elevations. Substitute an average bedrock protrusion height (h_{br} in feet) for the D_{84} term in estimation method 1.

Table 4. Velocity and discharge estimates using various methods for the lower meandering reach, an F5 stream type in a Valley Type X.

Bankfull VELOCITY / DISCHARGE Estimates

Site:	**Kootenai River**	Location:	**Lower Meandering Reach**
Date:	**5/2/08**	Stream Type: **F5**	Valley Type: **X**
Observers:	**Rosgen**	HUC:	

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Cross-sectional AREA	10,702	A_{bkf} (ft^2)	Bankfull Mean DEPTH	21.5	d_{bkf} (ft)
Bankfull WIDTH	498	W_{bkf} (ft)	Wetted PERIMETER ~ $2 * d_{bkf} + W_{bkf}$	521	W_p (ft)
→ D_{84} @ Riffle	152	Dia. (mm)	D_{84} mm / 304.8 =	0.5	D_{84} (ft)
Bankfull SLOPE	0.00046	S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	21.5	R (ft)
Gravitational Acceleration	32.2	g (ft / sec^2)	Relative Roughness R (ft) / D_{84} (ft)	43	
Drainage AREA		DA (mi^2)	Shear Velocity $u^* = \sqrt{gRS}$	0.17	u^* (ft / sec)

substituted ave. dune height for D_{84}

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 \text{ Log}\{R/D_{84}\}]u^*$	2.1	ft / sec	22,000	cfs
2. Roughness Coefficient: a) Manning's 'n' from friction factor / relative roughness $u = 1.4865*R^{2/3}*S^{1/2}/n$ n = .026	2.9	ft / sec	31,511	cfs ★
2. Roughness Coefficient: $u = 1.4865* R^{2/3}*S^{1/2}/n$ b) Manning's 'n' from Jarrett (USGS): $n = 0.39S^{.38}R^{-.16}$ n = Note: This equation is for applications involving **steep, step-pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for stream types A1, A2, A3, B1, B2, B3, C2 and E3.		ft / sec		cfs
2. Roughness Coefficient: $u = 1.4865* R^{2/3}*S^{1/2}/n$ c) Manning's 'n' from Stream Type F5 n = .037	2.1	ft / sec	22,000	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) Regional Curves u = Q / A Return Period for Bankfull Discharge Q = 1.5 Year		ft / sec		cfs
4. Continuity Equations: b) USGS Gage Data u = Q / A	2.8	ft / sec	30,000	cfs

Options for using the D_{84} term in the relative roughness relation (R/D_{84}), when using estimation method 1.

Option 1. For **sand-bed** channels: Measure the **"protrusion height"** (h_{sd}) of sand dunes above channel bed elevations. Substitute an average sand dune protrusion height (h_{sd} in ft) for the D_{84} term in estimation method 1. ★

Option 2. For **boulder-dominated** channels: Measure several **"protrusion heights"** (h_{bo}) of boulders above channel bed elevations. Substitute an ave. boulder protrusion height (h_{bo} in ft) for the D_{84} term in estimation method 1.

Option 3. For **bedrock-dominated** channels: Measure several **"protrusion heights"** (h_{br}) of rock separations/steps/joints/ uplifted surfaces above channel bed elevations. Substitute an average bedrock protrusion height (h_{br} in feet) for the D_{84} term in estimation method 1.

Land Use History

The Kootenai River has changed materially from pre-white settlement conditions due to the change in land use, streamflow regime from dams, sediment loads, riparian vegetation, flood control and other activities. These changes have caused serious adverse and long-term stream channel instability and corresponding loss of physical, biological and chemical function. The ecological functioning of the Kootenai River in Idaho is seriously impaired. The causes and consequences resulting from various land use activities are discussed.

Riparian Forest Change to Agriculture and Flood Control

The photographs contrasting the present day vegetative type versus the composition in 1914 are indicative of the major changes that have taken place along the Kootenai River from Bonners Ferry to the Canadian border (**Figure 19**). The vegetation conversion in the valley from a forested and wetland riparian corridor to agricultural fields has altered the nutrient base as well as the positive influence of the forested riparian community on river stability, streambank erosion processes, land loss and corresponding water quality. The aerial oblique photograph depicting the typical lack of riparian vegetation along the meandering reach of the Kootenai River is shown in **Figure 20**. The causes of the lack of recruitment of cottonwoods and other riparian woody species that naturally occur are the flood control levees (dikes) that were constructed from the 1920s to isolate the channel from its floodplain. The constructed levees on both sides of the F5 stream type in the meandering reach essentially entrench and confine the river channel (**Figure 21**). Problematic of the levees along the F5 stream type in the meandering reach is accelerated streambank erosion requiring maintenance as shown in **Figures 22**, **23** and **24**.

Figure 19. Top photo taken in 1914 of the Kootenai River floodplain, looking South from the West side of the valley close to the Canada/U.S. border near Smith Creek (Photo from USDA, 1914). Bottom photo taken in 1998 at same location (photo by Idaho Fish and Game Dept). (Both photos extracted from Jameson and Braatne, 2001).

Figure 20. Aerial oblique view showing the typical lack of riparian vegetation along the meandering reach of the Kootenai River (copyright 2008 Google).

Figure 21. Levees on both banks at river's edge that essentially entrench and confine river channels.

Figure 22. Example of levee erosion and maintenance needs.

Figure 23. Boulder rip-rap to reduce levee erosion.

Figure 24. Example of failed rip-rap and levee erosion. Note lack of riparian vegetation and presence of annuals.

Streambank Erosion

A major adverse consequence due to the lack of riparian vegetation is the reduced stability of streambanks and accelerated erosion. The high banks associated with the levees *and* the reduced normal high flows (bankfull discharge reduction by 50%) have created a bank-height ratio greater than three, (bank height divided by bankfull height). The photographs in the meandering reach of the F5 stream type, as shown in **Figure 25** and **Figure 26**, indicate the significance of high bank-height ratios where the shallow rooting depth of the trees on top of the bank are ineffective to reduce the evident bank erosion. This erosion contributes to downstream habitat problems, loss of flood capacity due to aggradation, land loss and reservoir deposition in Kootenay Lake. The meandering reach due to the entrenched F5 stream type has numerous locations of accelerated streambank erosion as additionally documented in **Figure 27** through **Figure 30**. Some of these sites are being studied in detail to quantify the actual annual streambank erosion rate.

Accelerated streambank erosion on the braided reach (D4) stream type is shown in **Figures 31**, **32** and **33**. It is apparent that the riparian vegetation is primarily a grass/forb community, which is not helping stabilize these banks. Also the bank heights are associated with the previous high flow stage that is twice the existing normal high flow stage associated with the post-dam bankfull discharge, or Holocene river terraces. The streambank stability, very high sediment supply and land loss associated with the braided reach are related to other stability issues driven by sediment and flow regime. These variables are discussed in more detail. The streambank erosion rate is an indicator of large scale instability influenced by many factors, including the flow regulation of Libby Dam. The braided channel response to changes in flow and sediment regime are discussed in the river stability section.

The prediction of the sediment supply and land loss consequence of streambank erosion for the study reaches of the braided, straight and meandering reaches was accomplished using the Bank Assessment for Non-point source Consequences of Sediment (BANCS) model (Rosgen, 1996, 2001b, 2006b). A flowchart depicting the overview of the procedure is shown in **Figure 34**. Annual erosion rates for the Kootenai River were predicted using the Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) ratings, along with the empirical relation for Igneous, Metamorphic and meta-sedimentary geology from Colorado (**Figure 35**). The overview of the study sites is shown in **Figure 36**. The results of the BANCS model are shown in **Figure 37** through **Figure 41**. The predictions as indicated in these analyses are the result of lateral erosion rates multiplied by the bank height multiplied by the length of bank with a corresponding BEHI/NBS rating. The color code indicates the location of a given predicted rate and the erosional contribution from each location along the river reach.

The results indicate that 77,802 tons/yr from 36,800 ft of the braided reach are contributed, or 2.1 tons/ft/yr. This is a rate that is two orders of magnitude larger than other measured rates of large rivers. The straight reach of the F4/5/1 stream type is producing a much lower rate of 6,900 tons/yr for 8,900 ft, or 0.77 tons/ft/yr (mostly generated below the rock outcrop and the rip-rap banks). The meandering reach is producing 81,850 tons/yr from 58,000 ft studied, or 1.4 tons/ft/yr. If the erosion rates are similar for the entire 45-mile meandering reach, then approximately ***335,303 tons/yr*** would be lost. A considerable portion of this material is deposited in the streambed, while the smaller fractions would be transported into the growing delta in Kootenay Lake. These predicted rates will be

field checked in the summer of 2008 against measured annual erosion rate measurements. It is interesting to note that the suspended sediment load measured at Copeland since the construction of Libby Dam is ***299,000 tons/yr***. Only 15% of the pre-dam sediment is being delivered below Libby Dam and the majority of that load is being deposited in the braided reach (see sediment discussion later in this report). Thus, the main source of the sediment would be from the tributaries and streambank erosion within the valley.

For the braided reach, this land loss represents approximately 6,000, 10-yard end dump trucks leaving the site per year and 304,000 truck loads/yr for the meandering reach to the Canadian border. When people start to put these losses into perspective, it generates a valid concern. When landowners annually observe their land loss, their concerns will also be voiced. For the fish, however, who have no voice, the adverse effects of this sediment supply on their habitat is highly significant. This dilemma is discussed in the following sections on flow and sediment regime and is associated with the proposed design.

Figure 25. High bank-height ratio.

Figure 26. Even with a riparian community, the bank heights are much greater than the rooting depth promoting low root density and bank failures.

Figure 27. Accelerated bank erosion causing land loss associated with a very high bank-height ratio.

Figure 28. Accelerated streambank erosion against levee showing lack of riparian vegetation and very high bank-height ratio.

Figure 29. Streambank profile showing the nature of the erodible soils and various depositional layers.

Figure 30. Typical streambank on the meandering reach showing extensive erosion rate.

Figure 31. Accelerated streambank erosion in the braided reach showing grass/forb riparian vegetation and high banks that are contributing to the land loss.

Figure 32. Accelerated bank erosion in the braided reach causing channel enlargement, lateral migration, significant land loss and very high sand sediment supply.

Figure 33. Accelerated streambank erosion on the braided reach showing poor rooting depth and density, high banks and sandy materials.

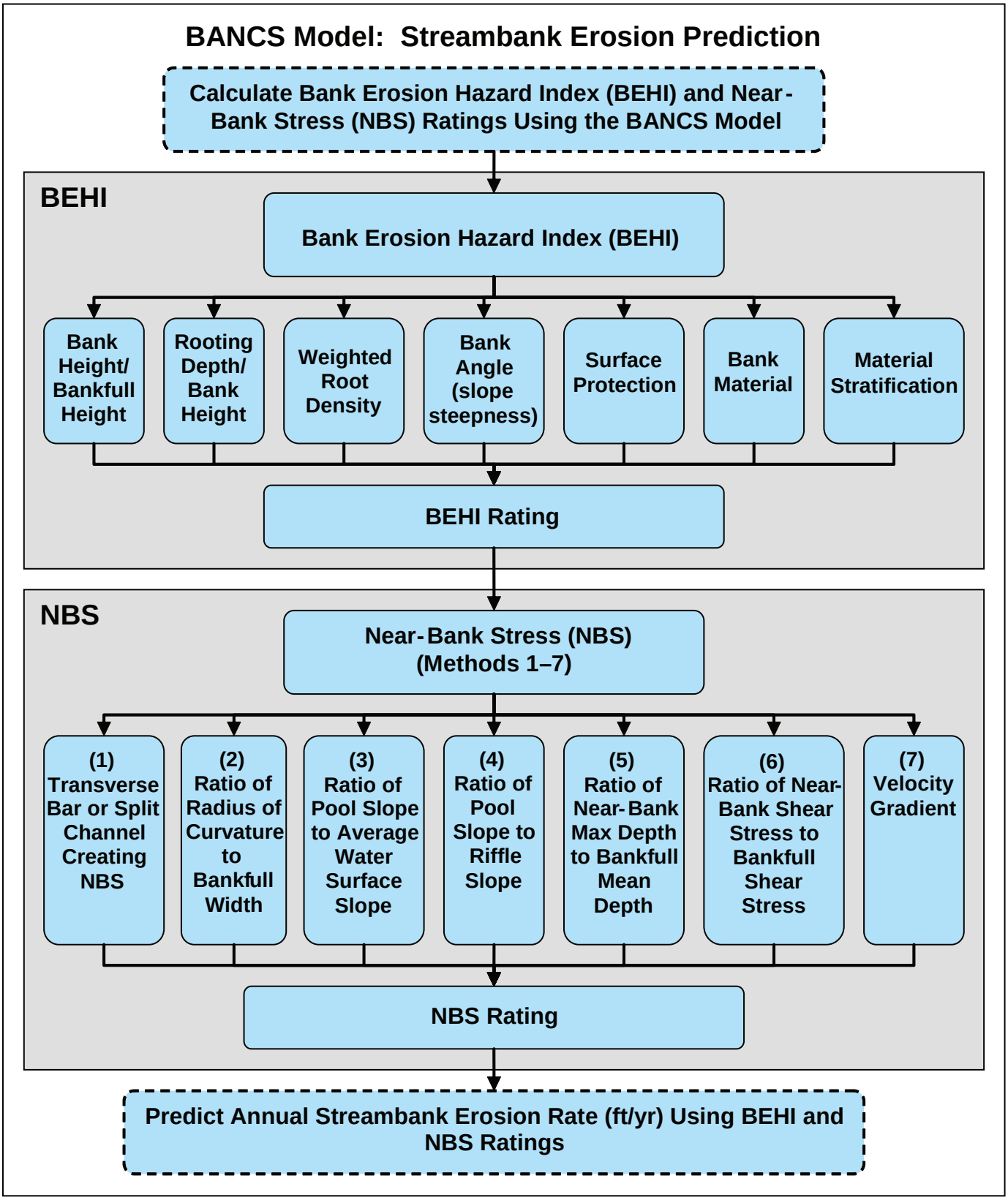


Figure 34. The BANCS model variables, ratios and procedures associated with the Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) to predict annual streambank erosion (Rosgen, 2006).

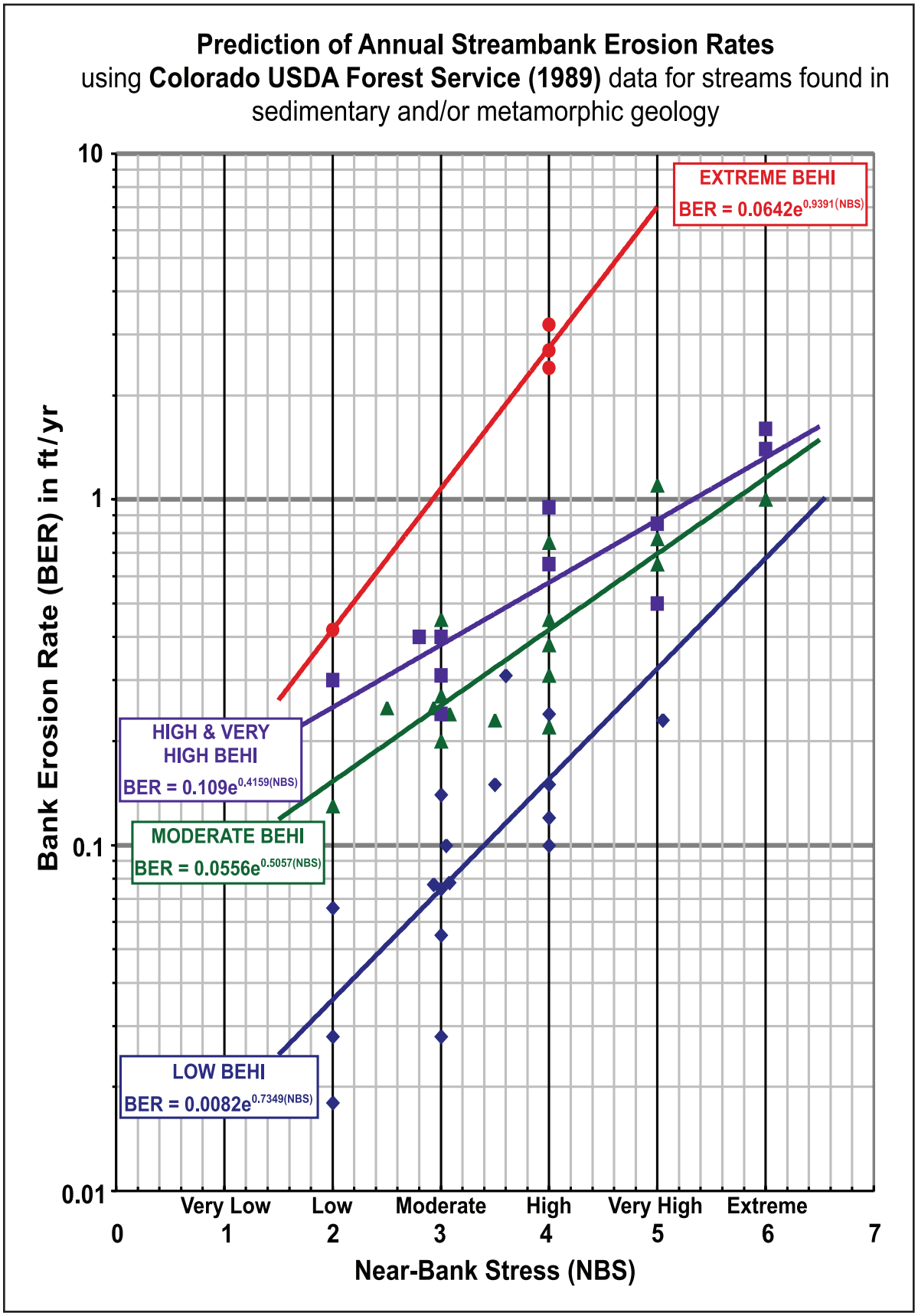
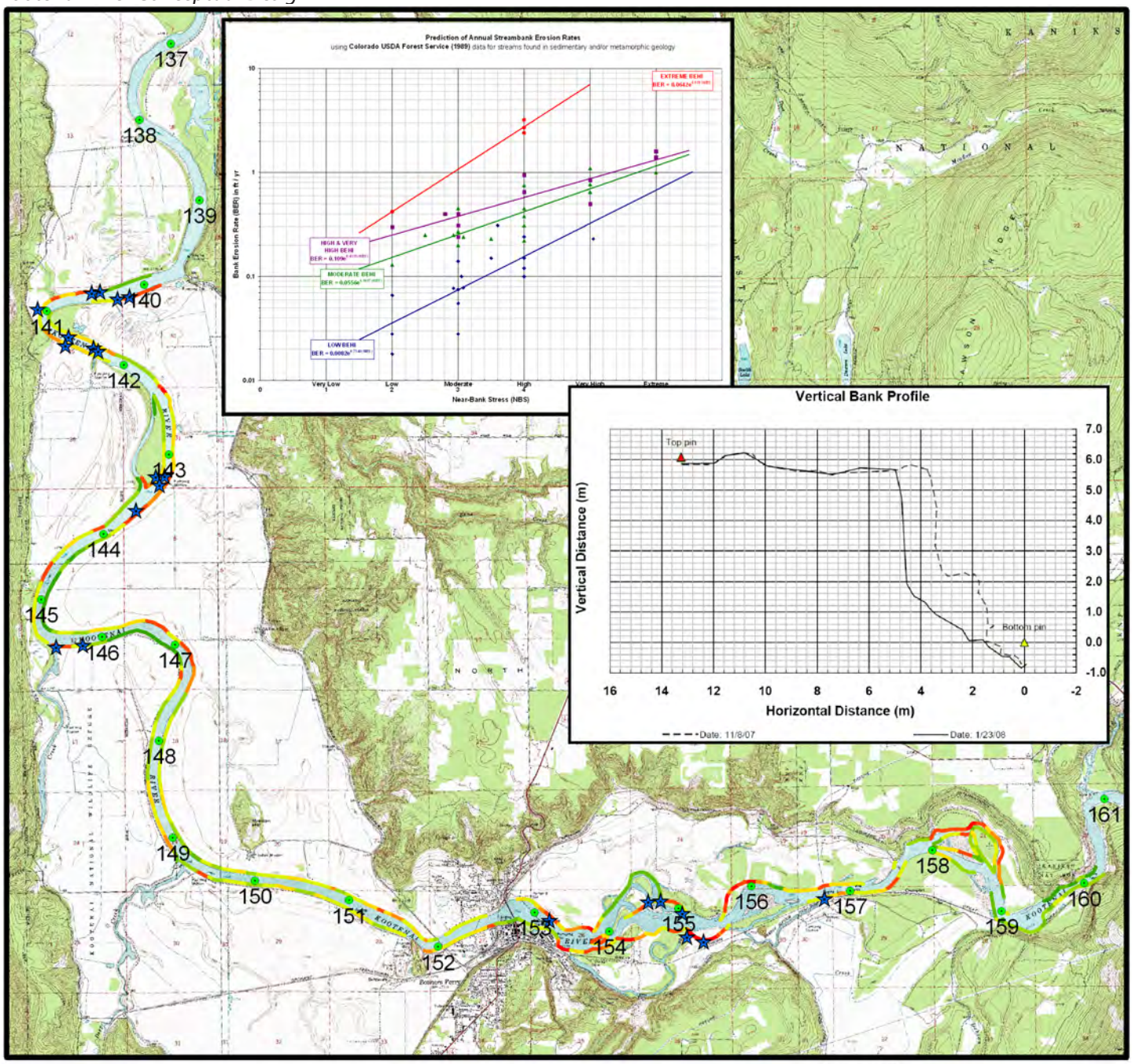
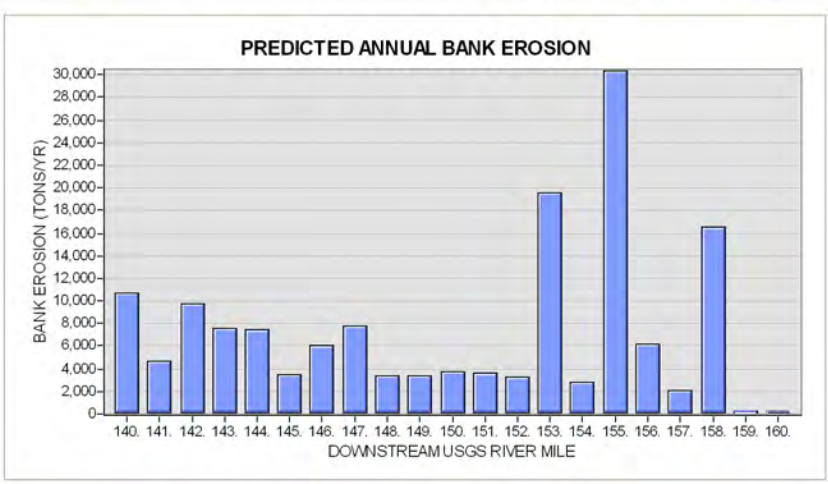


Figure 35. Relationship of the BEHI and NBS to predict annual streambank erosion rates from Colorado data (1989) for streams found in sedimentary and/or metamorphic geology (Rosgen, 1996, 2001a, 2006b).





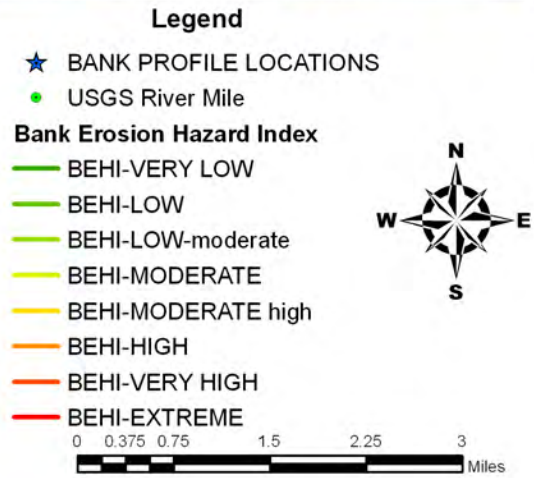


Figure 36. Location and extent of overall streambank erosion rates for all three river reaches evaluated for RM stationing 140-161.

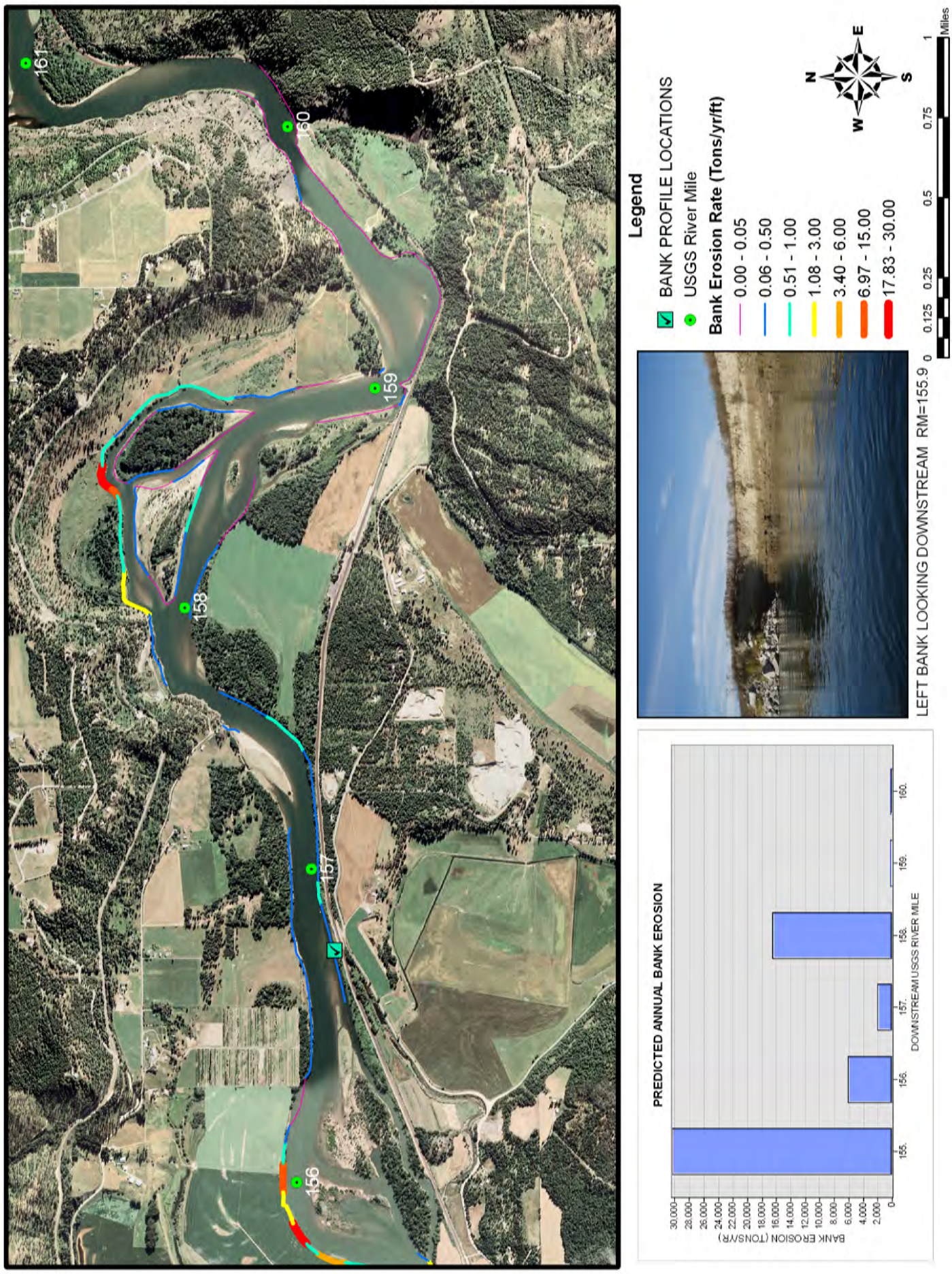


Figure 37. Streambank erosion rate prediction for the braided reach showing a typical eroding streambank. Erosion rates by specific location are documented.

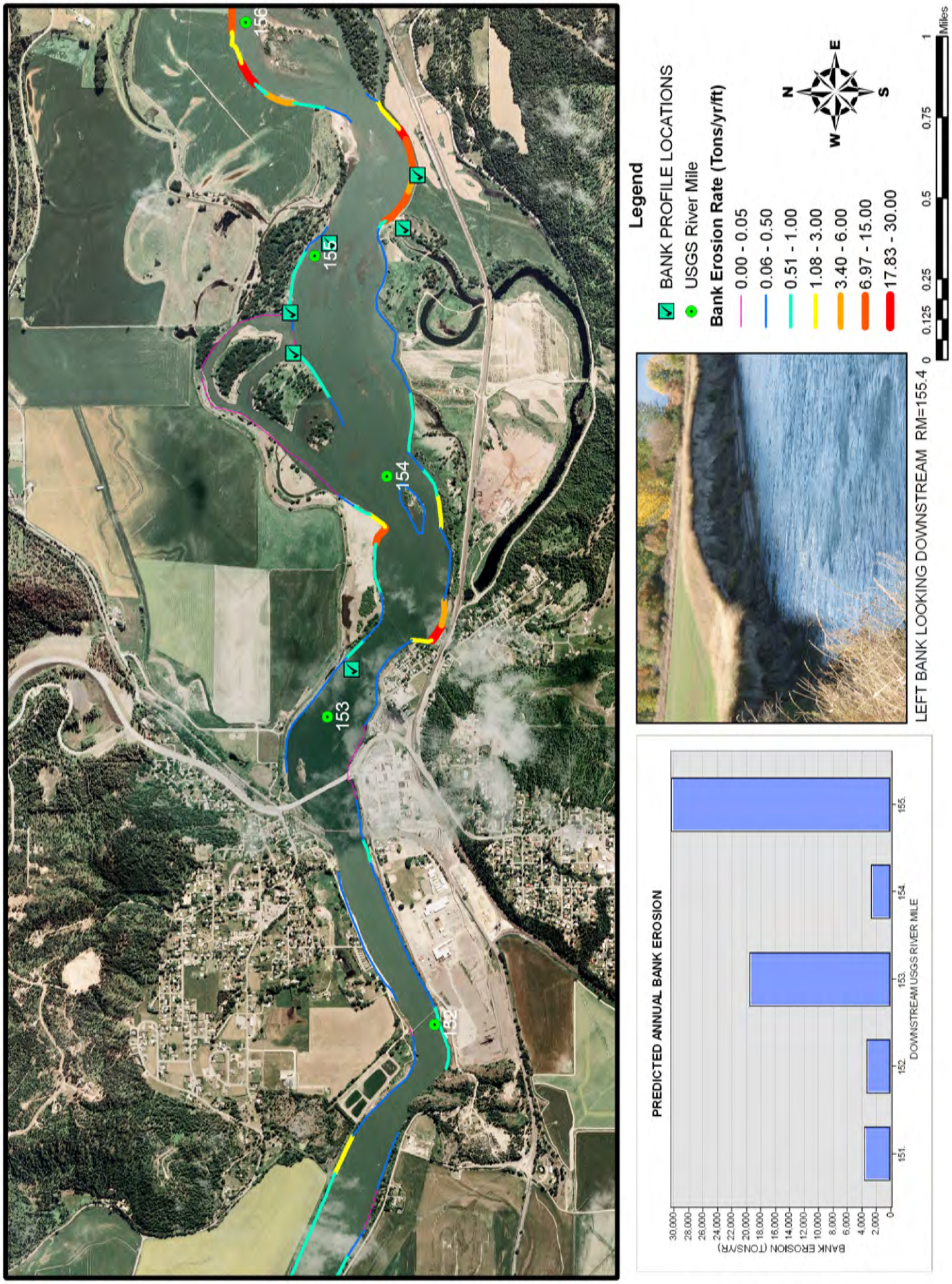


Figure 38. Streambank erosion prediction for the braided and straight reach locations showing a typical eroding streambank. Erosion rates are documented by specific location.

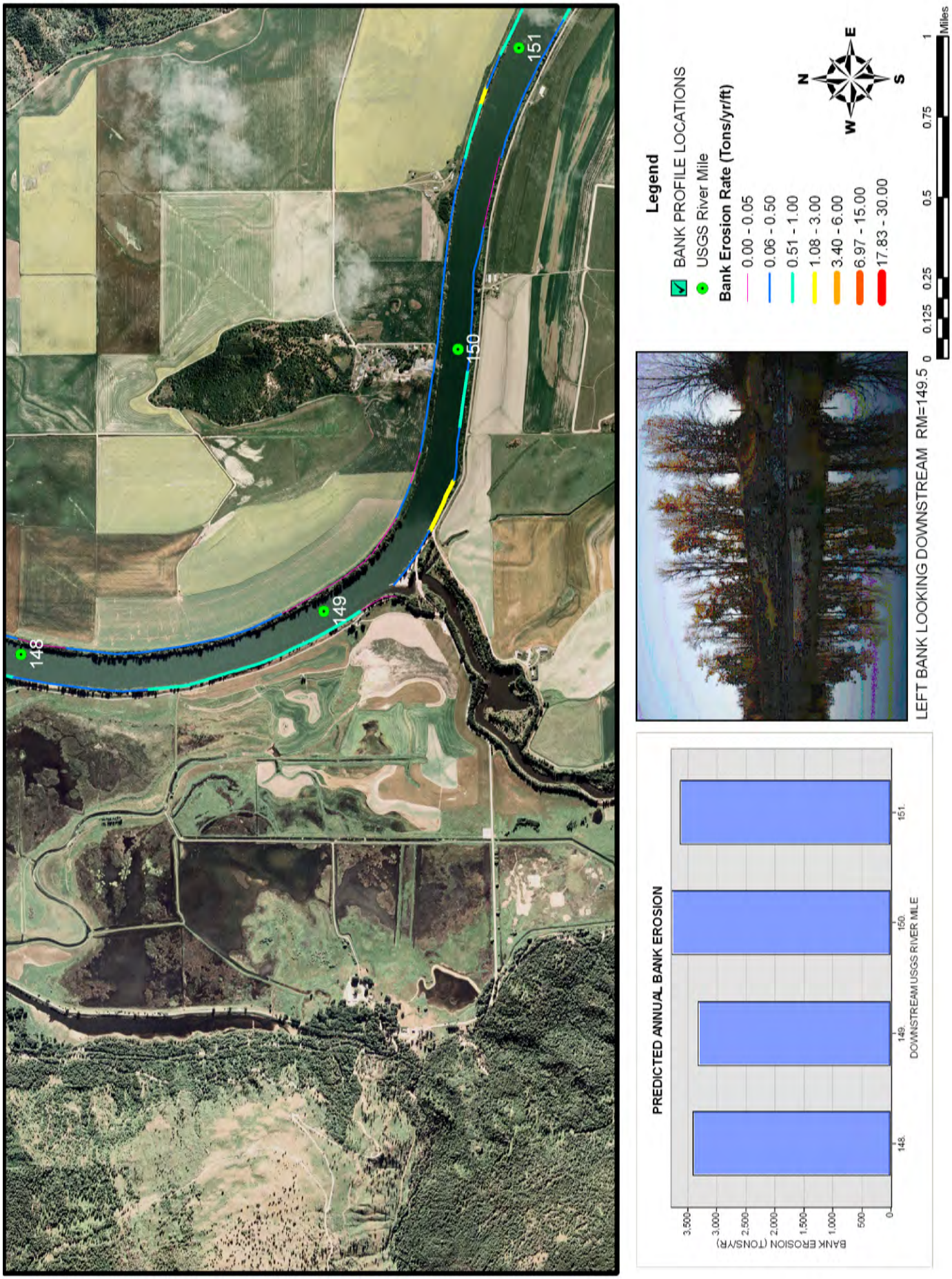
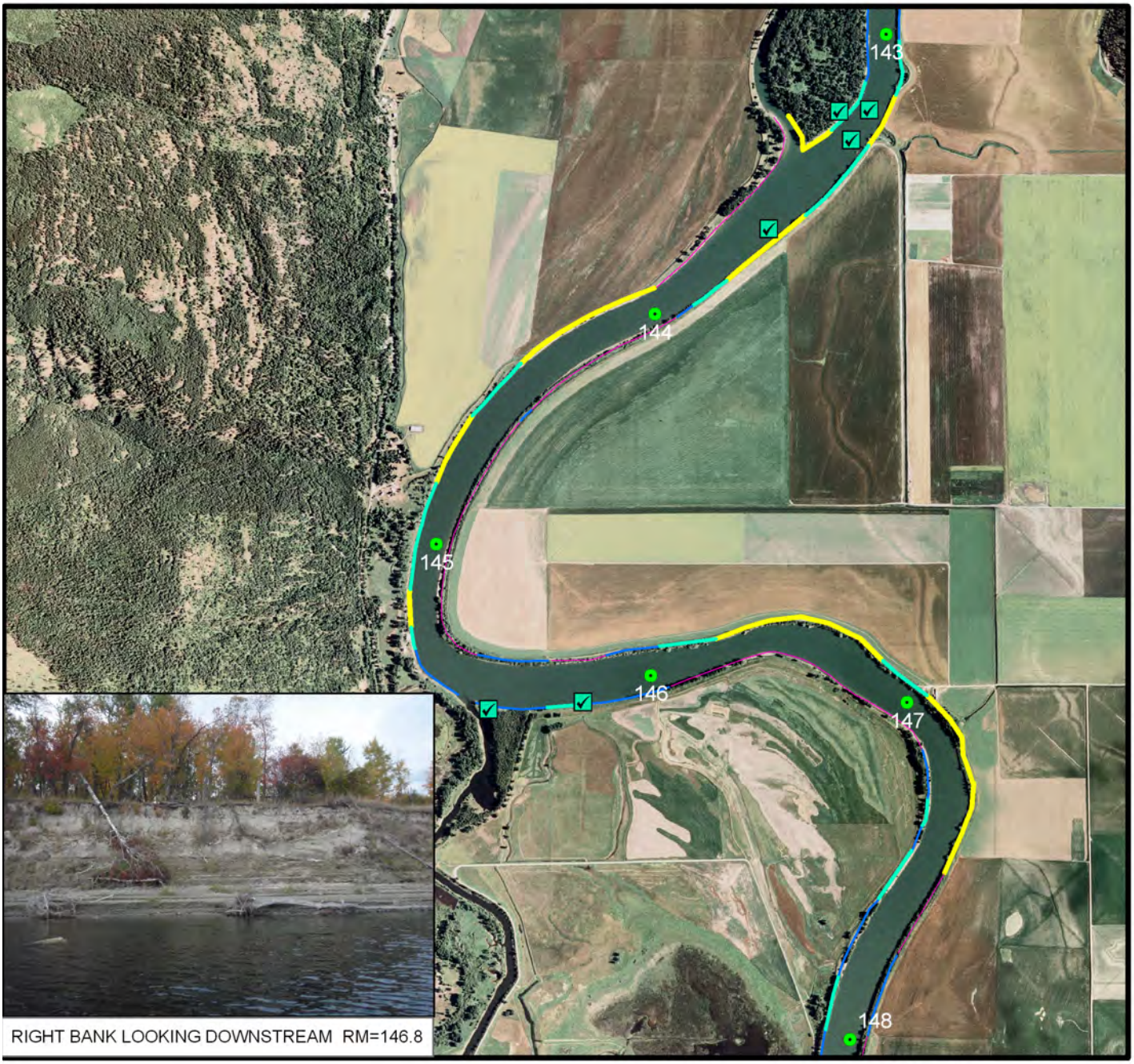
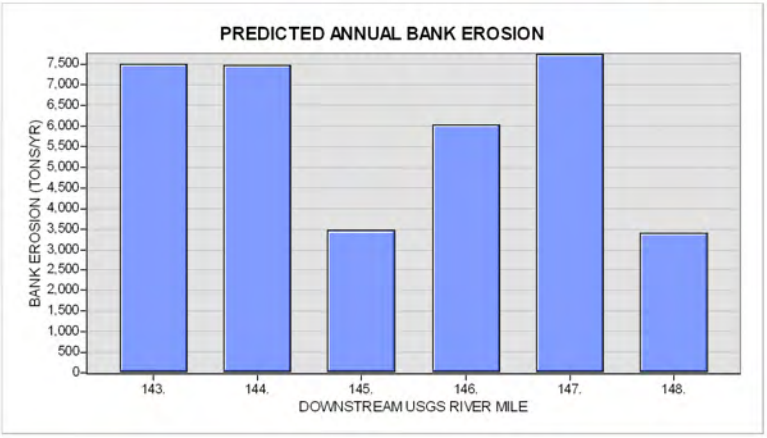


Figure 39. Streambank erosion prediction for an F5 stream type in the meandering reach showing a typical eroding bank. Erosion rates are documented by specific river location stationing 148-151.





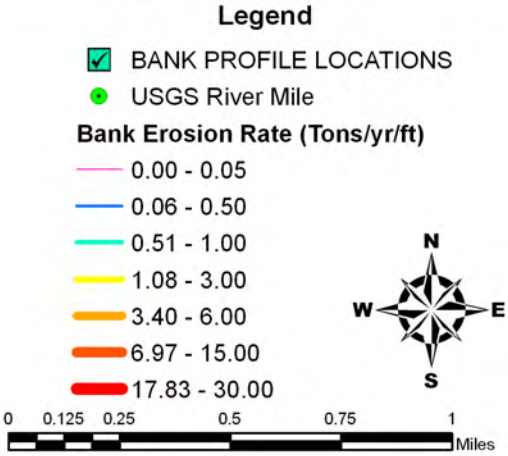
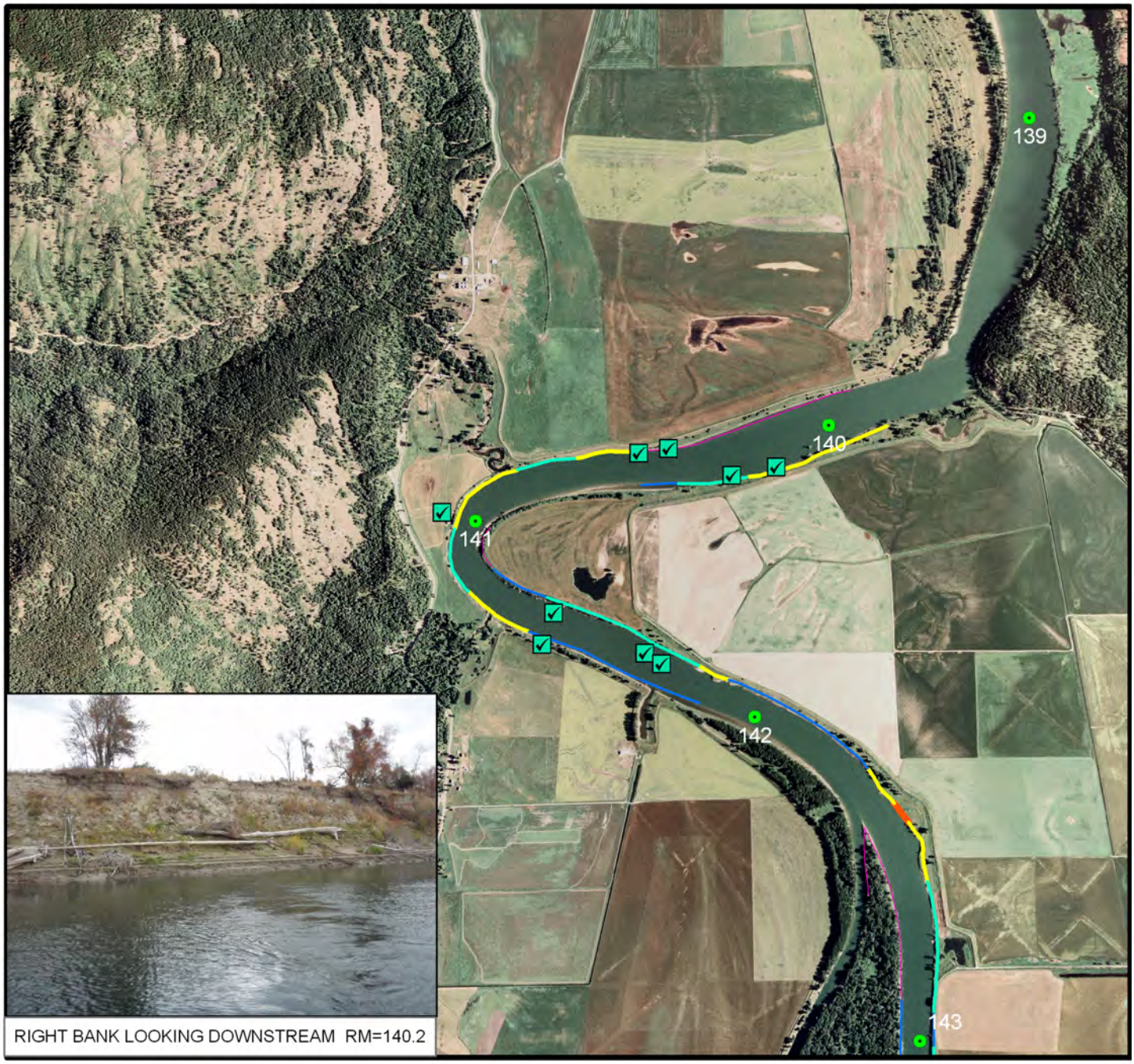
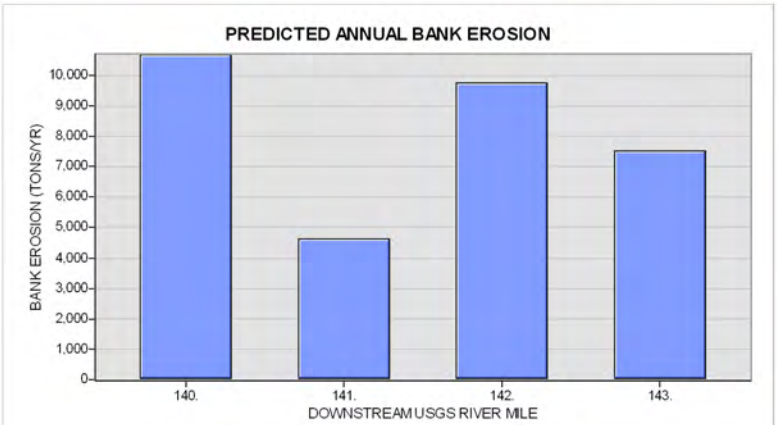


Figure 40. Streambank erosion prediction for an F5 stream type in the meandering reach showing a typical eroding bank. Erosion rates are documented by specific location for river stationing 143-148.





Legend

- BANK PROFILE LOCATIONS
- USGS River Mile

Bank Erosion Rate (Tons/yr/ft)

- 0.00 - 0.05
- 0.06 - 0.50
- 0.51 - 1.00
- 1.08 - 3.00
- 3.40 - 6.00
- 6.97 - 15.00
- 17.83 - 30.00

N W E S

0 0.125 0.25 0.5 0.75 1

Figure 41. Streambank erosion prediction for an F5 stream type in the meandering reach (RM 140-143). A typical eroding bank is shown and erosion rates by specific location are documented.

Dredging

The mainstem of the Kootenai River was dredged or the bed was lowered by excavation to provide the material to construct the levees and to reduce flood stage. This created a major problem for streambank erosion as it increased the streambank height that is exponentially related to erosion rate. The dredging was also not uniform in distance or in depth as shown on the longitudinal profiles shown in **Figure 42**, as collected by the U.S. Geological Survey. As noted in **Figure 42**, the height of a riffle bed is six feet higher than the same feature 2.8 miles upstream. The extent of these "high points" persists for over 1500 ft, creating backwater and zones for sand deposition. Specific locations on the longitudinal profile can be observed on the plan view map showing the same river stationing (**Figure 3**).

Dams

The flow regulation by Kootenay Lake creates backwater to and beyond Bonners Ferry into the braided reach depending on the season, river flow and active storage stage of Kootenay Lake. The extent of the stage based on streamflow magnitudes and lake levels are depicted in the energy slope that clearly shows the great extent of backwater caused by Kootenay Lake and the stage controlled by the Corra Lynn Dam and the Grohman Narrows associated with Kootenay Lake. The effect of backwater is to deposit sediment within the backwater zone and to fine the bed material due to the reduced shear stress and stream power. The seasonal influence of the backwater is shown for streamflows of 6,000 cfs, 20,000 cfs, 40,000 cfs and 60,000 for high and low lake levels (**Figure 43a** and **Figure 43b**). The corresponding elevations using linear interpolation for the 30,000 cfs backwater for the low and high lake stage are shown in **Figure 44**. The basic data and elevations were provided by Berenbrock (2005). The elevations of the backwater for the low lake level for 30,000 cfs and both the low and high lake level at Klockman Ranch gage cross-section for 65,000 cfs are shown in **Figure 45**.

The presence of backwater significantly decreases the stream power required to transport sediment and leads to aggradation of the bed and fining of bed-material size. Unit stream power is the product of shear stress and velocity; thus, backwater flattens the slope and decreases mean velocity of the water column and directly decreases the energy to transport sediment. Sediment transport relations (capacity and competence) are presented for both existing and proposed conditions in this plan.

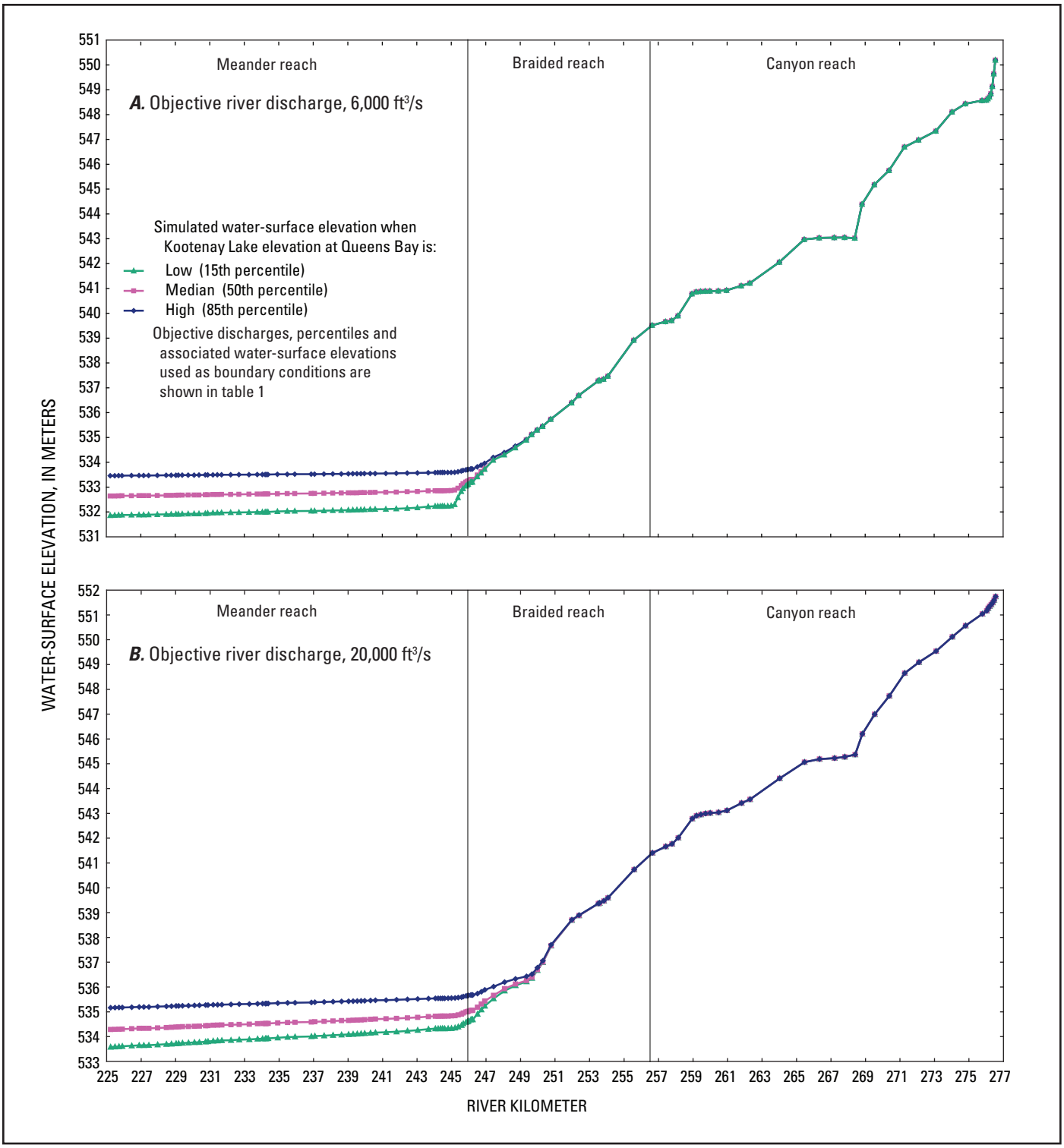


Figure 43a. Extent of backwater elevations for various flows and stages of Kootenay Lake levels for flows of 6,000 cfs and 20,000 cfs (extracted from Berenbrock, 2006).

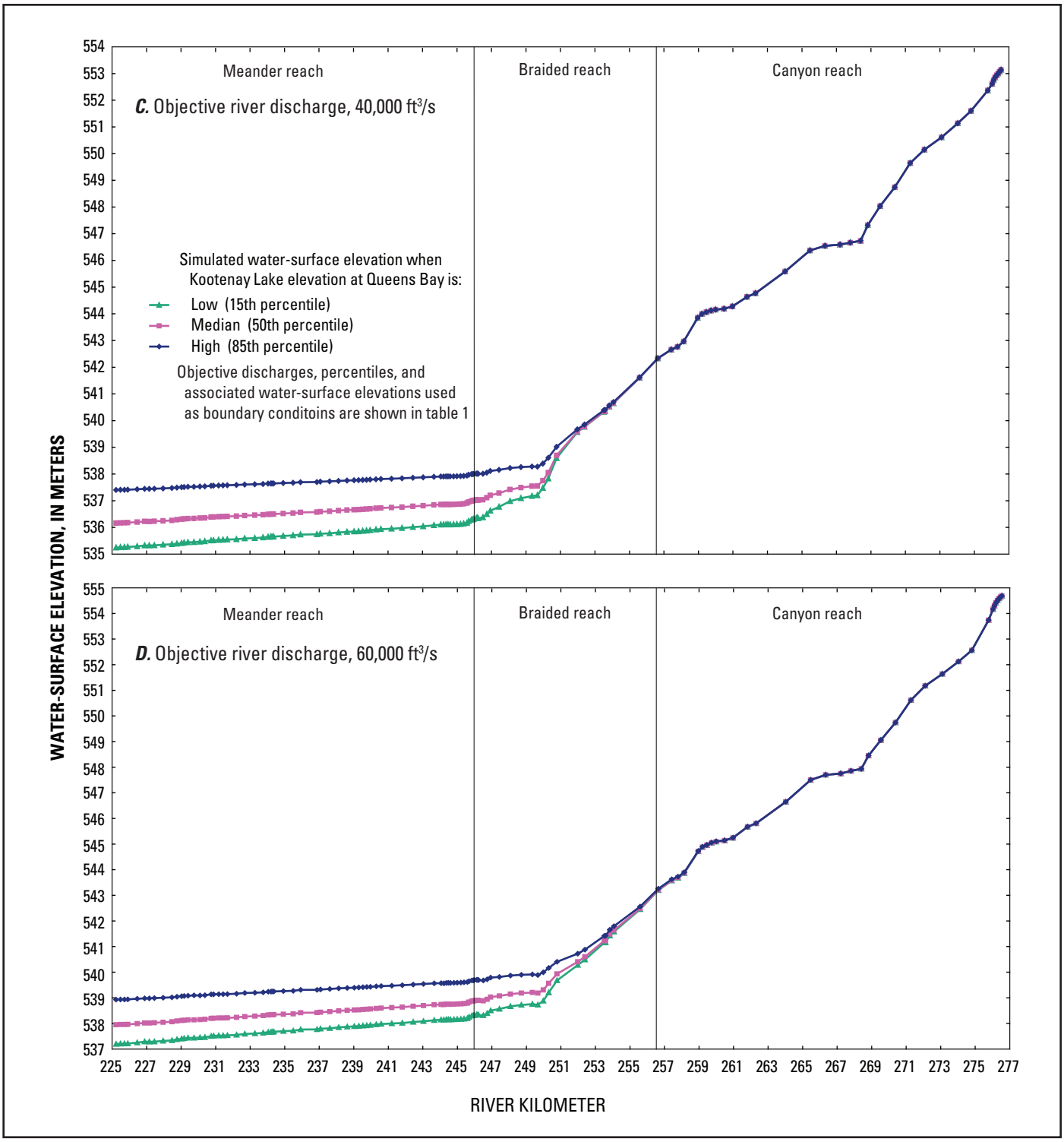


Figure 43b. Continuation of backwater, discharge and Lake levels for flows 40,000 and 60,000 cfs (extracted from Berenbrock, 2006).

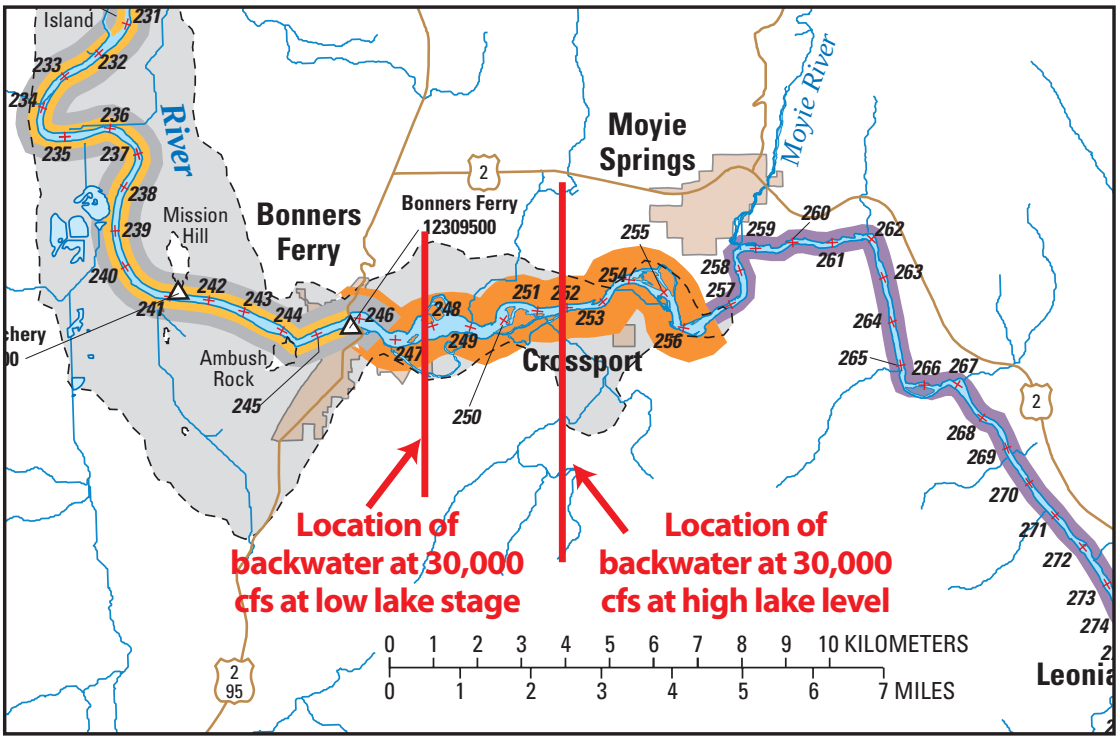


Figure 44. Location map of the extent of the backwater based on a linear interpolation from **Figure 40a** and **Figure 40b** for a flow of 30,000 cfs for low and for high Kootenay Lake elevations (image extracted from Berenbrock, 2006).

Hydrology (Comparison of Pre- and Post-Dam Hydrograph, Flood Peaks and Flow-Duration)

Since 1972, the streamflow magnitude associated with the bankfull discharge or "normal high flow" has been reduced from 70,000 cfs to 32,500 cfs at the Porthill USGS gage for a 1.5 year return period discharge, (USACE, 1984). This reduction in bankfull discharge represents approximately a 5% change. Streamflow peaks and timing of flows comparing pre- and post-dam data are shown at the Leonia gage (**Figure 46**). The flow-duration curve at the same gage is shown in **Figure 47**. It is obvious that significant reductions of stream flow will lead to river instability. Because the stream channel that was formed and maintained over time before 1972 is now an over-fit or oversized channel, changes in the morphological, sedimentological, hydraulic character and biological function will all change. Due to being an over-fit channel, the width/depth ratio is much too high to be efficient because the roughness is greater, the sediment transport capacity is less and the stream channels are prone to aggradation. The oversized channel is more susceptible to the development of extensive central bars. Even though the river has experienced major floods in recent years, the braided reach has not "flushed out the sediment with the increased peak flow, but rather has extended its bars, enlarged its width and accelerated streambank erosion" (Barton, 2007). The 100-year flood has been reduced by 54% from 124,000 cfs to 67,400 cfs (USACE, 1984). The change in flow duration is also significant in that it reflects a greatly reduced magnitude and frequency of high flows and also an increase in winter baseflows (**Figure 48**).

The effects of such reduced high flows not only affect the sediment transport and overall stability, but also lead to channel entrenchment. In other words, it takes over 50% more discharge to get out of previous banks. What used to be a normal high flow to be associated with the incipient point of flooding as the river accesses its floodplain is now comparable to a major, large magnitude flood. The result of such entrenchment, even without levees, will accelerate streambank erosion due to the increase in bank-height ratio. A previous floodplain in essence becomes a terrace because it requires twice as much flow to reach the surface that previously flooded. That flow that would frequently overtop the previous bank is now associated with a 100-year magnitude flood based on the flood frequency analysis from the USGS stream gage. To correct this problem, because it is unlikely that the dam will be removed, it will be necessary to match a stable channel morphology and dimensions to the new flow regime.

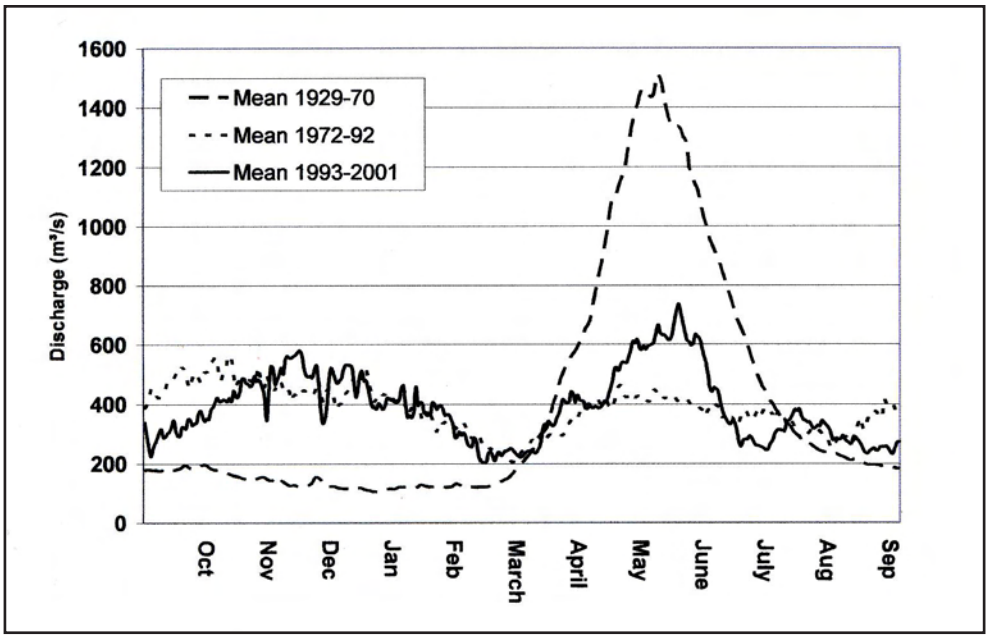


Figure 46. Location map of the extent of the backwater based on a linear interpolation from **Figure 40a** and **Figure 40b** for a flow of 30,000 cfs for low and for high Kootenay Lake elevations (image extracted from Berenbrock, 2006).

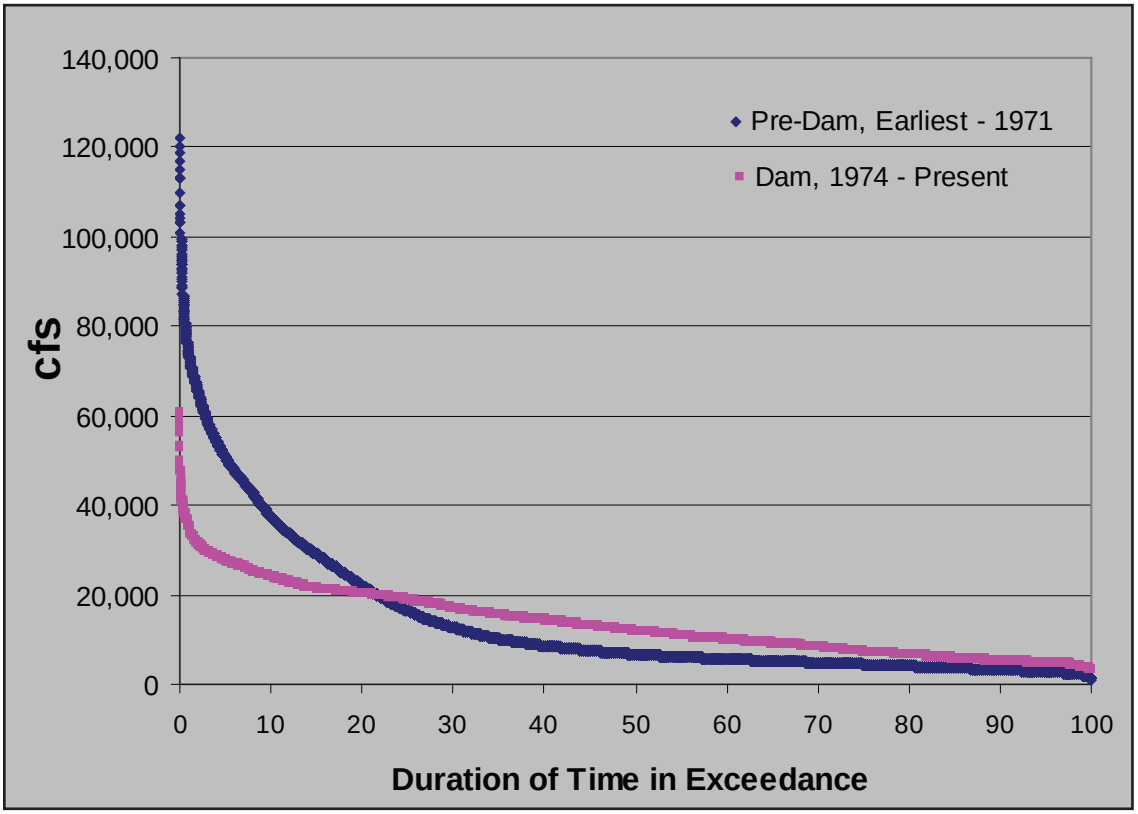


Figure 47. Duration curve based on the Leonia gage.

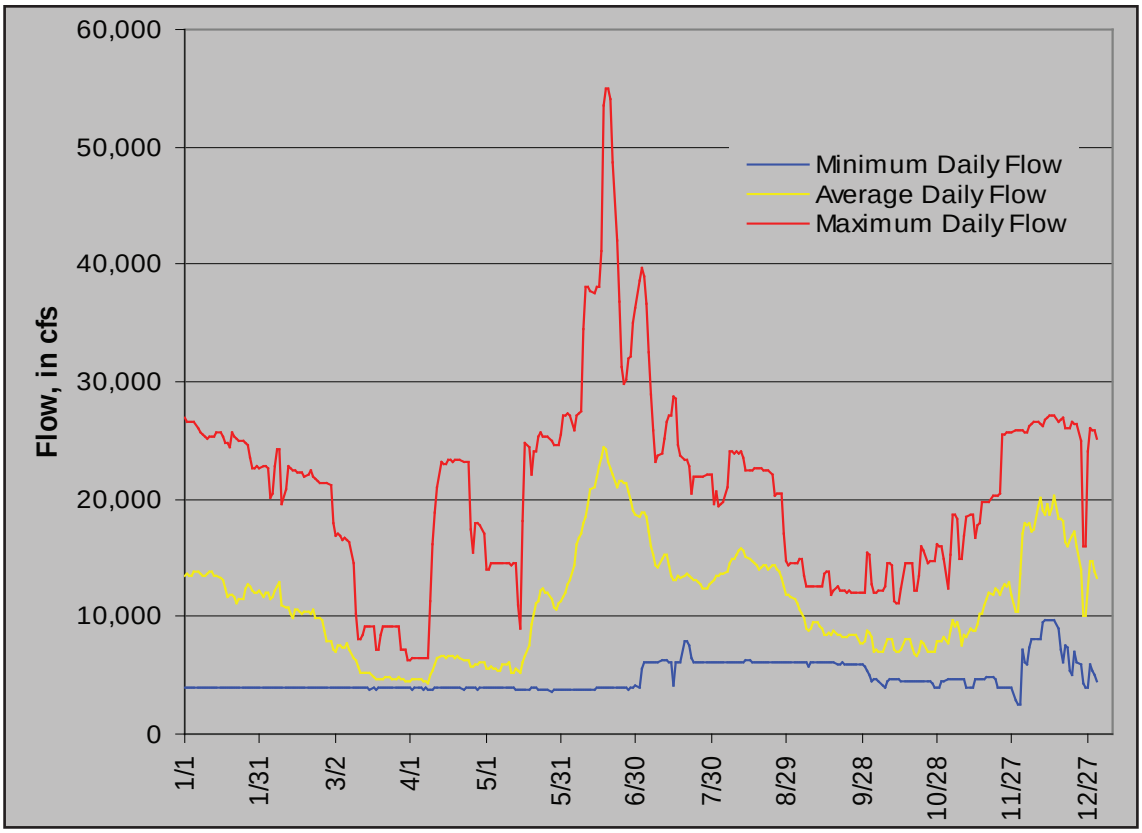


Figure 48. Daily flow below Libby Dam, 1996 to present.

Sedimentology

Because 70% of the drainage area of the Kootenai River basin drains into Libby Dam, the sediment regime has drastically changed. According to the Corps of Engineers, 1,481,000 tons/yr of suspended sediment was predicted to drain into Libby Dam and 401,000 tons/yr of bedload (USACOE, 1970-1974). The total sediment yield would be approximately 1,882,000 tons/yr. The significant reduction of the measured suspended sediment rating curve at Copeland, Idaho at the USGS gage comparing pre- and post-dam conditions are shown in **Figure 49** ((Tetra Tech, Inc. and Perkins Geosciences, 2004). With the corresponding change in grade as the Kootenai leaves the inter-gorge canyon into the terraced/alluvial valley, with the corresponding slope reduction, one would expect to observe the natural morphology of a braided river due to the excess sediment deposition. The longitudinal profile of the Kootenai River developed by the USGS below Libby Dam is shown in **Figure 50** (Tetra Tech, Inc. and Perkins Geosciences, 2004). The slope change associated with the braided channel is shown clearly on this profile. The sediment supply of post-Libby Dam, however is a marked contrast to pre-dam sediment supply and river character (**Figure 49**). Estimates have been made by the USGS that the present Kootenai River at Copeland is only 15% of its pre-Libby Dam sediment yield or 299,000 tons/yr of suspended sediment (Tetra Tech, Inc. and Perkins Geosciences, 2004). The controlling variables and boundary conditions that are related to the braided channel have now changed and are related to the instability of the present channel.

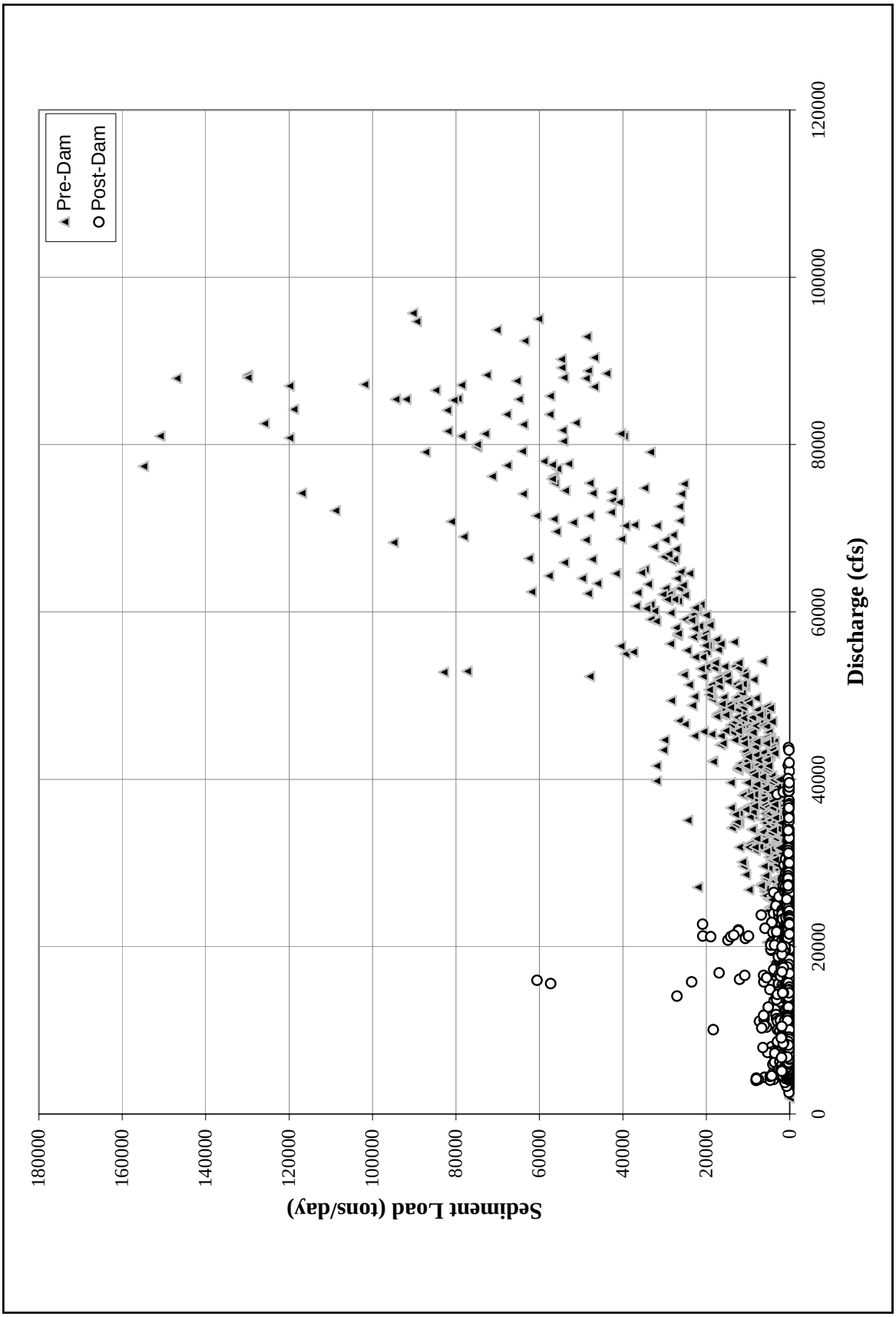


Figure 49. Plot of suspended load comparing pre- and post-Libby Dam conditions for the Kootenai River near Copeland, ID (USGS gage #12318500) (extracted from Tetra Tech, Inc, 2004).

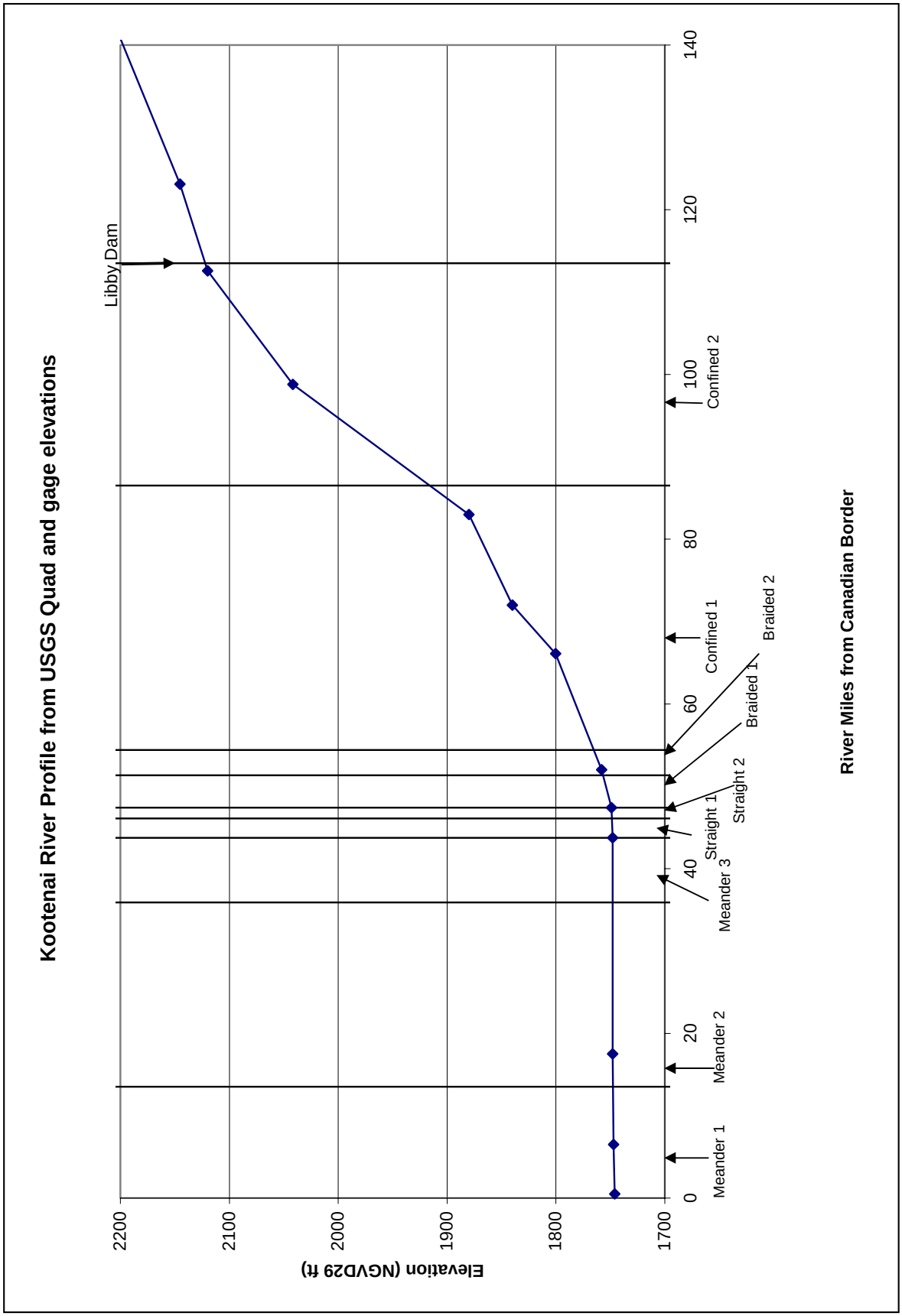


Figure 50. Kootenai River longitudinal profile from Libby Dam to the Canadian border showing variation in slope for the meandering, straight and braided reaches (extracted from Tetra Tech, Inc, 2004).

Sediment Transport Capacity

Even with the reduced sediment supply, the predicted sediment load of suspended sand sediment and bedload being delivered to the upper end of the braided reach using USGS data for high supply source was estimated at 400,634 tons/yr and 111,109 tons/yr, respectively, for lake backwater levels (**Table 5**). The values for low sediment supply from USGS data resulted in 70,689 tons/yr of suspended sand and 28,842 tons/yr of bedload (**Table 5**). These estimates were determined using the FLOWESED and POWERSED models (Rosgen, 2006a, 2006b, 2007). *Appendix IV* includes flowcharts depicting the general overview of the FLOWSED and POWERSED models and also includes additional model runs and detailed data summaries. Furthermore, the FLOWSED and POWERSED prediction methods and model tests are included in *Appendix V* (Rosgen, 2006a).

The sediment transport change under low lake levels and the change in sediment transport as influenced by the change in width/depth ratio from 28 (station 159) to 315 (station 155.8) resulted in a significant reduction in the suspended sand sediment of 74% and 83% for bedload sediment. This significant reduction in transport results in an obvious deposit in the stream bed or aggradation (**Table 5**). For the deposition rate for the same stations under high lake levels, the comparable location reduction was 92% for bedload. The suspended didn't materially change from the low lake level until station 152.4 when the suspended sand transport was reduced by 96%. The sediment deposition is strongly influenced by both width/depth ratio and backwater (energy slope).

The results of the FLOWSED and POWERSED runs as summarized in *Appendix IV* show the dramatic sediment deposition in the braided reach due to width/depth ratio and backwater. These issues are addressed in the proposed stream restoration design. It is interesting to note the sediment budget showing the contributions of streambank erosion by station (**Table 5**). The tons per year of potential sediment supply (primarily sand) is extensive. The photographs of the braided reach show the excess sediment deposition consistent with the sediment capacity analysis. The high width/depth ratio, oversized channel and eroding banks leading to channel enlargement, as well as lateral and down valley meander migration, are reflected in **Figures 51**, **52** and **53**.

One of the proposed limiting factors associated with the white sturgeon recruitment problem is associated with shallow river depths from the bridge upstream of Bonners Ferry in the braided reach (**Figure 52** and **Figure 53**). Upstream migration of sturgeon is discouraged by these shallow depths, and thus, their historic spawning reaches in coarse, more suitable substrate are not available. The majority of the sturgeon return downstream to spawn in unsuitable habitat of sand rather than to proceed upstream. The sediment deposition/aggradation problem of the braided reach is one of the issues that may preclude successful sturgeon recruitment.

The sand sediment supply from the streambanks makes up for the majority of the sediment being deposited in the river bed as stream length increases below the upper reach and is being transported as suspended sediment downstream. The amount of sand from the BANCS streambank erosion model for the braided reach was estimated at 77,800 tons/yr (some of which is deposited in the channel bed before being routed downstream). One of the major problems in the straight reach below the bridges is the sand invasion over a coarse substrate. One objective would be to reduce the sand load of sediment that currently overwhelms the coarse substrate. Coarse substrate is a key to egg survival in the recruitment issue with the white sturgeon. Reducing the sand supply from streambank erosion will also help reduce the extensive land loss in this reach.

	Existing Conditions; Low Lake Level; Low Bedload Transport Rate (8.6lb/s)	Existing Conditions; Low Lake Level; High Bedload Transport Rate (33lb/s)	Existing Conditions; Low Lake Level; Low Suspended Transport Rate (15mg/l)*	Existing Conditions; Low Lake Level; High Suspended Transport Rate (85mg/l)*	Existing Conditions; High Lake Level; Low Bedload Transport Rate (8.6lb/s)	Existing Conditions; High Lake Level; High Bedload Transport Rate (33lb/s)	Existing Conditions; High Lake Level; Low Suspended Transport Rate (15mg/l)*	Existing Conditions; High Lake Level; High Suspended Transport Rate (85mg/l)*	Existing Conditions; Bank Erosion Total Annual Erosion Yield = 152,500 Tons/YR
159.505	28,842	111,109	70,689	400,634	28,842	111,109	70,689	400,634	228
159.5									
158.80									3,432
156.70	5,061	19,476	18,297	103,680	2,527	9,725	14,614	82,805	15,255
155.86									10,402
154.03	843	5,621	7,229	25,530	-	-	3,938	15,133	28,897
152.42									21,493
150.03	7	386	1,569	15,562	-		1,678	-	8,772
143.99									38,945
140.00									25,064

*** Suspended Sediment Values Exclude the Washload (Sediment Smaller than 0.062 mm)**

Table 5. Results of existing total annual sediment yield for suspended sand and bedload for low and high supply and for low and high backwater stage for various locations.

Figure 51. Example of extensive bar deposition and accelerated bank erosion on the upper braided reach (USGS photo).

Figure 52. The lower braided reach adjacent to Hwy 95 showing fining of bed material, high width/depth ratio and excessive sediment deposition.

Figure 53. The lower braided reach looking upstream showing excess sediment deposition, high width/depth ratio and shallow depths (width/depth ratio = 186).

Sediment Competence/Entrainment

To determine if the stream has the competence or ability to transport the largest size made available from immediately upstream, a sediment competence computation was initiated (Rosgen, 2006b). This calculation is also required to determine bed stability; i.e., does the stream have sufficient shear stress (depth and slope) to transport the largest size of sediment made available. The use of a bar sample to substitute for a sub-pavement sample to determine the largest size made available (D_{100}) and the median size is shown in **Figure 54**. The grain-size distribution of the bar is a surrogate for the size distribution of bedload at the bankfull stage. A bar sample was obtained and a pebble count of an active riffle was collected in the upper portion of the braided reach of the Kootenai River at RM 153.5 (RKM 247) (**Figure 4**, **Figure 55**). The resultant analysis is shown in **Table 6** and in **Figure 56**.

The results indicate that the stream does not have sufficient depth, slope or corresponding shear stress to move an 80 mm particle made available to the river from the C4 stream type immediately upstream. The existing mean depth for the bankfull discharge of 30,000 cfs is 9 ft with a slope of 0.00032. The required depth to move the 80 mm particle on the bar is 21 ft for the same slope. The two methods provided very similar results. The use of dimensionless bankfull shear stress generated a value of 0.016, which requires a value of 21 ft to move an 80 mm particle on the existing slope (**Table 6**). The dimensional shear stress of 0.4 lbs/ft^2 needed to transport the 80 mm particle is 20 ft (using the Colorado curve as shown in **Figure 56** and **Table 6**). The interpretation from both methods predicted stream aggradation.

An additional bar sample and riffle particle size analysis (pebble count) was conducted at location RM 156 (RKM 251) (**Figure 4** and **Figure 57**). The results of the sediment competence analysis are shown in **Table 7**. At this location, the stream also indicated aggradation. The largest size on this bar was 105 mm, requiring 30 ft of depth for the existing slope of 0.00035 compared to the existing depth of 9.1 ft. The dimensionless shear stress was 0.019 compared to 0.016 for the previous bar location. The dimensional shear stress computation was 0.2 lbs/ft^2 and predicted 22.9 ft of depth and 0.5 lbs/ ft^2 for the existing slope to move the largest particle of 105 mm (**Figure 58**, **Table 7**).

This data is used in the design phase to ensure that the proposed design for the dimension, pattern and profile of the river is sufficient to entrain and transport 80–105 mm particles in this reach.

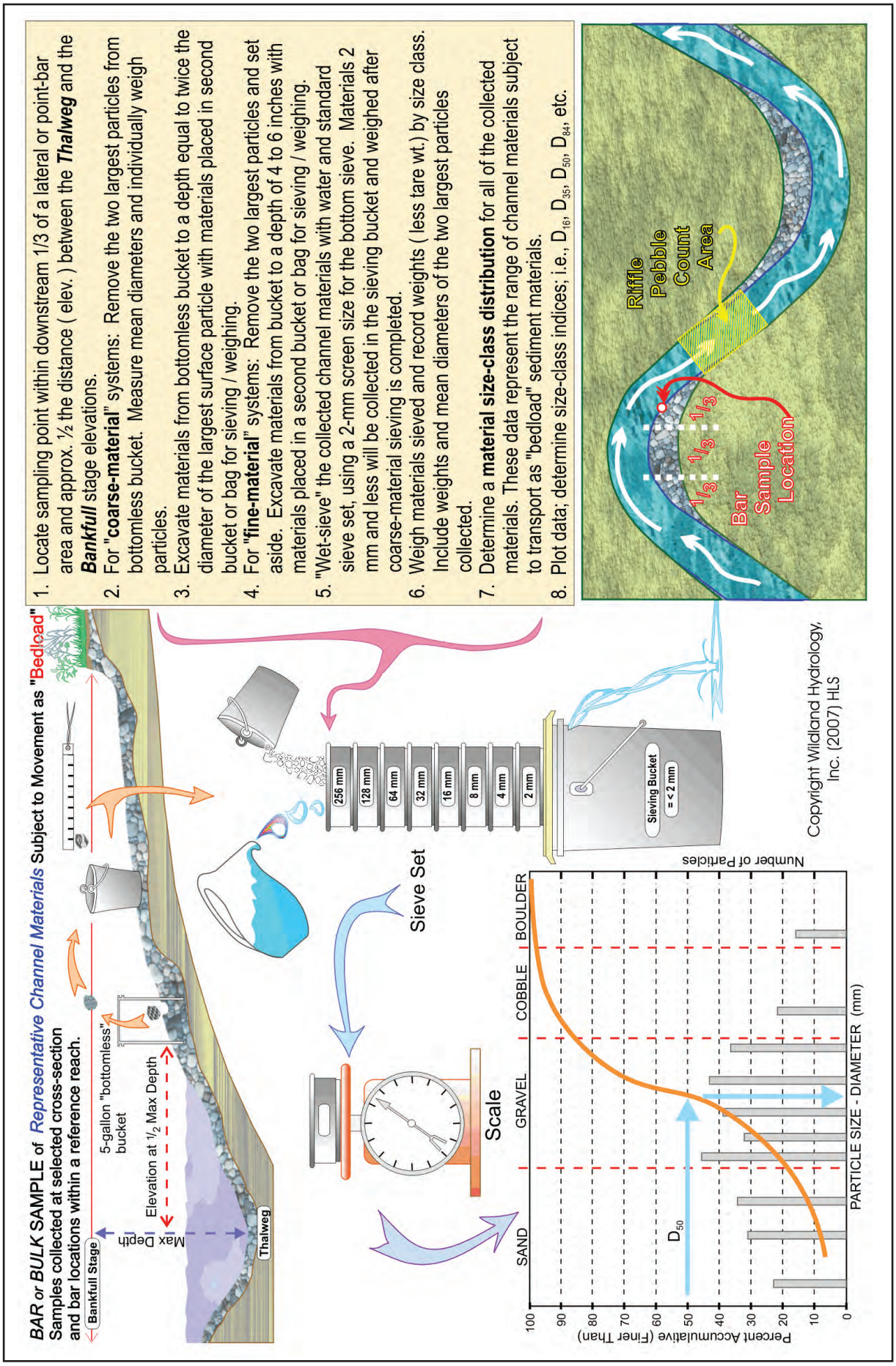


Figure 54. Diagram of bar sample location and the field method to wet-sieve bar samples.

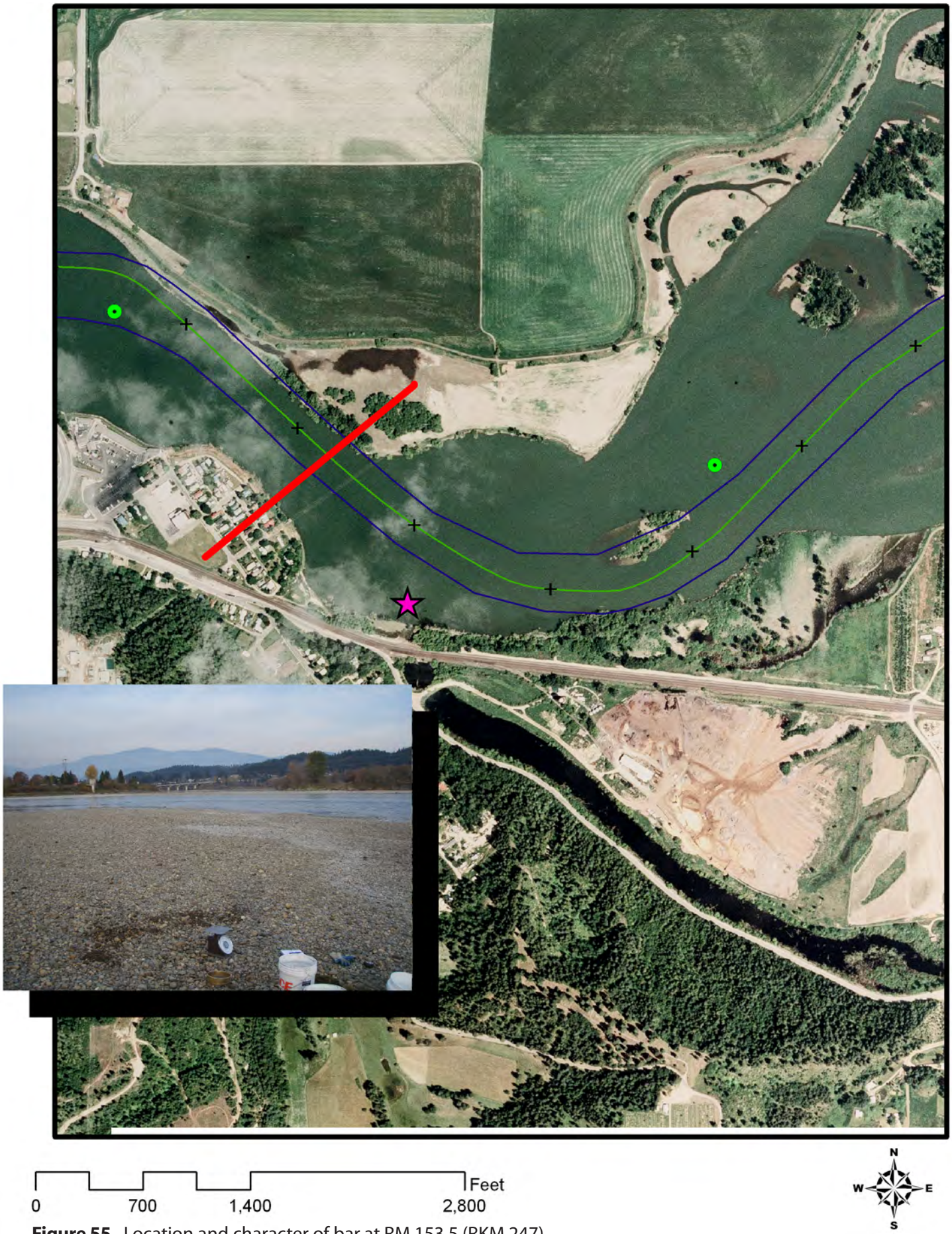
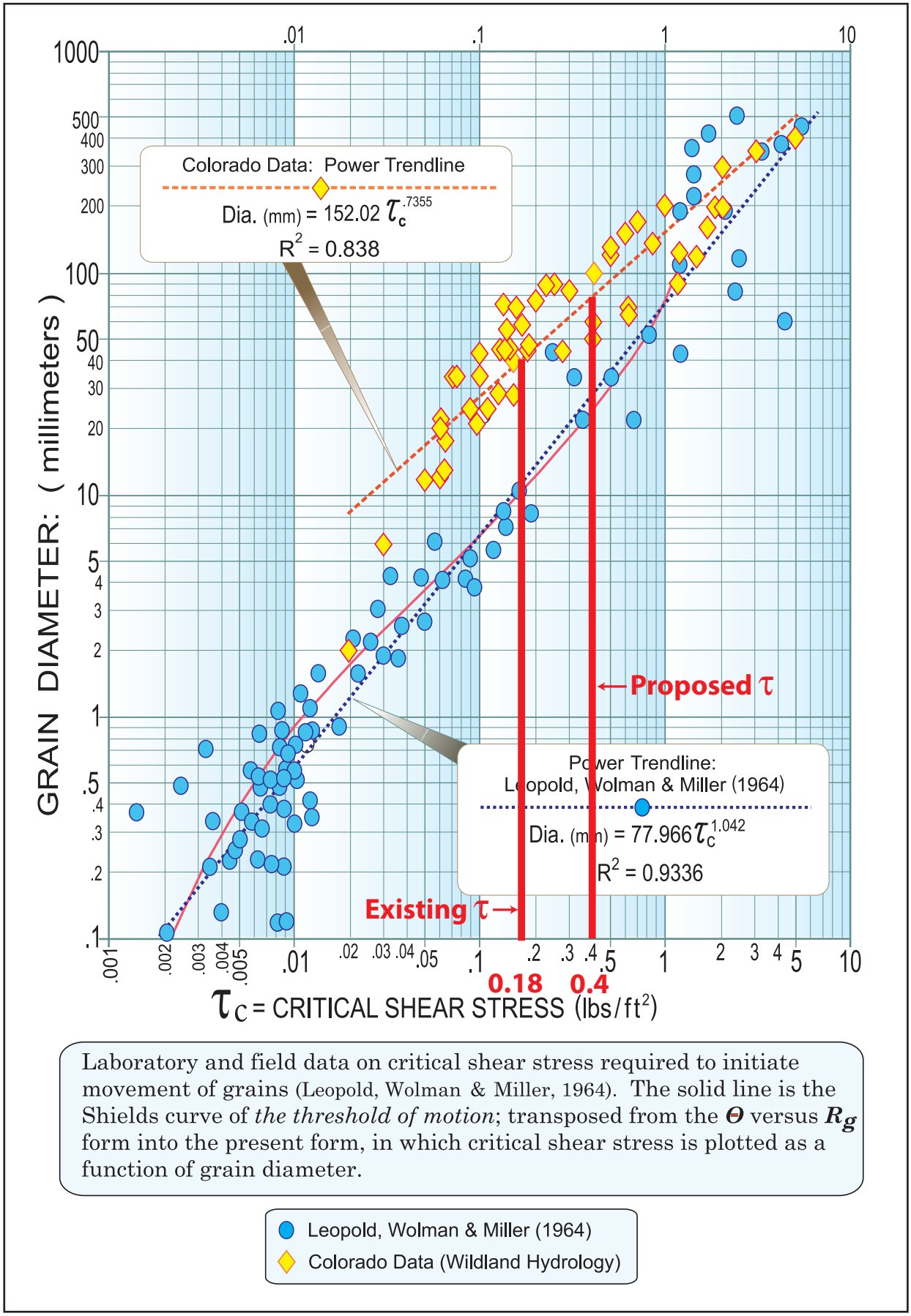


Figure 55. Location and character of bar at RM 153.5 (RKM 247).

Table 6. Sediment competence calculation form to assess bed stability and determine depth and slope requirements at RM 153.5 (RKM 247) (Rosgen, 2006b).

Stream: **Kootenai River**			Stream Type: **D4**		
Location: **RM 153.5 (RKM 247)**			Valley Type: **VIII**		
Observers: **Bidelspach and Kasun**			Date: **10/29/07**		
Enter Required Information for Existing Condition					
29.8	D_{50}	Riffle bed material D_{50} (mm)			
17.5	$D_{50}^{\wedge}$	Bar sample D_{50} (mm)			
0.26	D_{max}	Largest particle from bar sample (ft)	**80**	**(mm)**	304.8 mm/ft
.00032	**S**	Existing bankfull water surface slope (ft/ft)			
9	**d**	Existing bankfull mean depth (ft)			
1.65	γ_s	Submerged specific weight of sediment			
Select Appropriate Equation; Calculate Critical Dimensionless Shear Stress					
1.7	$D_{50}/D_{50}^{\wedge}$	Range: 3 – 7	Use EQUATION 1: $\tau^* = 0.0834\,(D_{50}/D_{50}^{\wedge})^{-0.872}$		
2.7	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2: $\tau^* = 0.0384\,(D_{max}/D_{50})^{-0.887}$		
0.016	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:		**2**
Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample					
21	**d**	Required bankfull mean depth (ft)	$d = \frac{\tau^* \gamma_s D_{max}}{S}$ (use D_{max} in ft)		
Check ✓: ☐ Stable ☑ Aggrading ☐ Degrading					
Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample					
0.0009	**S**	Required bankfull water surface slope (ft/ft)	$S = \frac{\tau^* \gamma_s D_{max}}{d}$ (use D_{max} in ft)		
Check ✓: ☐ Stable ☑ Aggrading ☐ Degrading					
Sediment Competence Using Dimensional Shear Stress					
0.18	Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = existing depth, S = existing slope				
40	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 56)**				
0.4	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 56)**				
20	Predicted mean depth required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, S = existing slope		$d = \frac{\tau}{\gamma S}$		
0.0007	Predicted slope required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, d = existing depth		$S = \frac{\tau}{\gamma d}$		



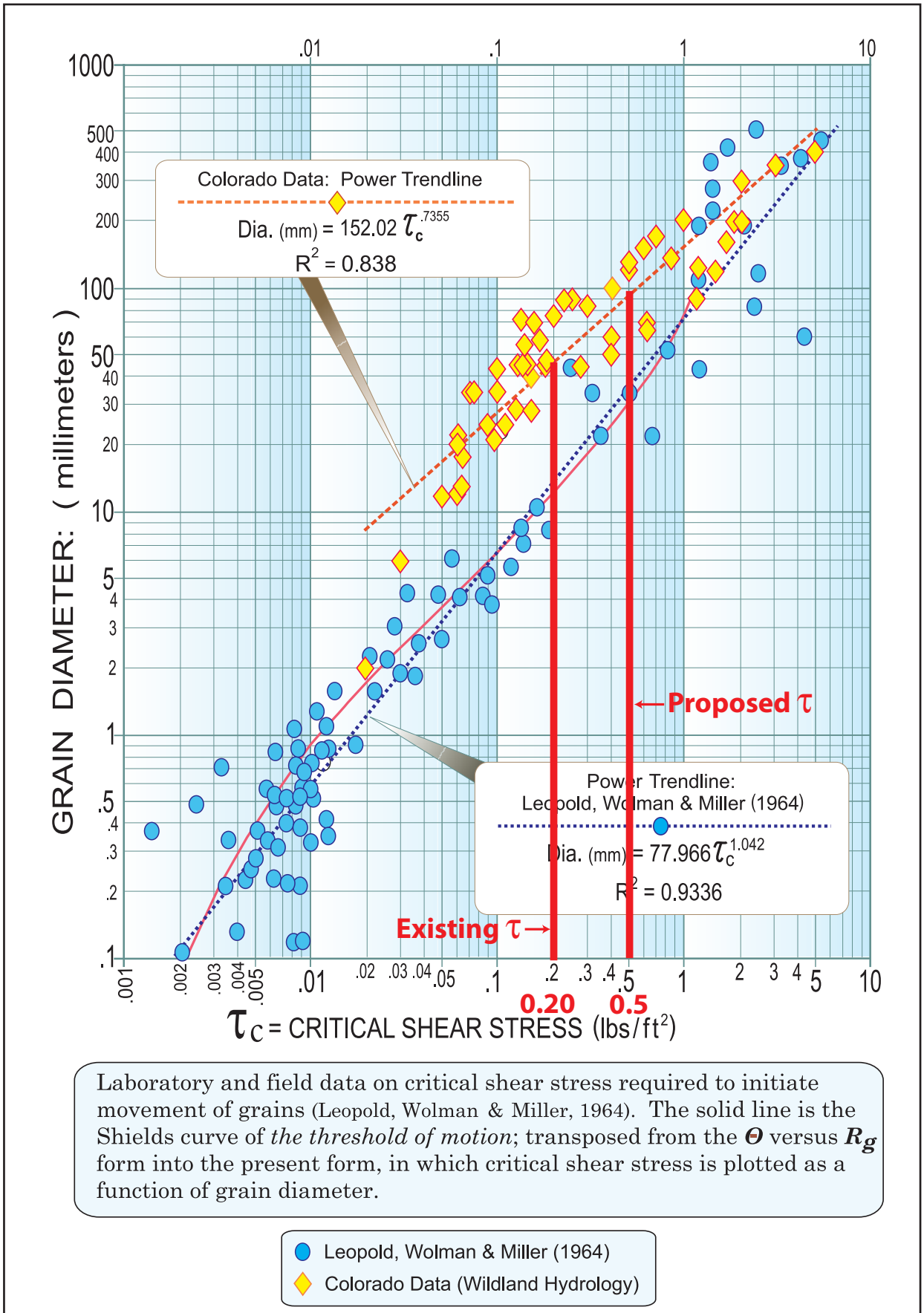
Laboratory and field data on critical shear stress required to initiate movement of grains (Leopold, Wolman & Miller, 1964). The solid line is the Shields curve of *the threshold of motion*; transposed from the Θ versus R_g form into the present form, in which critical shear stress is plotted as a function of grain diameter.

Figure 56. Relation of existing versus proposed dimensional shear stress and grain size for stream competence for RM 153.5 (RKM 247) (Rosgen, 2006b).

Figure 57. Location and character of bar at RM 156 (RKM 251).

Table 7. Sediment competence calculation form to assess bed stability and determine depth and slope requirements at RM 156 (RKM 251) (Rosgen, 2006b).

Stream: **Kootenai River**			Stream Type: **D4**		
Location: **RM 156 (RKM 251)**			Valley Type: **VIII**		
Observers: **Bidelspach and Kasun**			Date: **10/29/07**		
Enter Required Information for Existing Condition					
47	D_{50}	Riffle bed material D_{50} (mm)			
16	$D_{50}^{\wedge}$	Bar sample D_{50} (mm)			
0.34	D_{max}	Largest particle from bar sample (ft)	**105**	**(mm)**	304.8 mm/ft
.00035	**S**	Existing bankfull water surface slope (ft/ft)			
9.1	**d**	Existing bankfull mean depth (ft)			
1.65	γ_s	Submerged specific weight of sediment			
Select Appropriate Equation; Calculate Critical Dimensionless Shear Stress					
2.9	$D_{50}/D_{50}^{\wedge}$	Range: 3 – 7	Use EQUATION 1: $\tau^* = 0.0834\ (D_{50}/D_{50}^{\wedge})^{-0.872}$		
2.2	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2: $\tau^* = 0.0384\ (D_{max}/D_{50})^{-0.887}$		
0.019	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:		**2**
Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample					
30	**d**	Required bankfull mean depth (ft)	$d = \frac{\tau^* \gamma_s D_{max}}{S}$ (use D_{max} in ft)		
Check ✓: ☐ Stable ☑ Aggrading ☐ Degrading					
Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample					
0.0012	**S**	Required bankfull water surface slope (ft/ft)	$S = \frac{\tau^* \gamma_s D_{max}}{d}$ (use D_{max} in ft)		
Check ✓: ☐ Stable ☑ Aggrading ☐ Degrading					
Sediment Competence Using Dimensional Shear Stress					
0.20	Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = existing depth, S = existing slope				
50	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 58)**				
0.50	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 58)**				
22.9	Predicted mean depth required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, S = existing slope		$d = \frac{\tau}{\gamma S}$		
0.0009	Predicted slope required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, d = existing depth		$S = \frac{\tau}{\gamma d}$		



Laboratory and field data on critical shear stress required to initiate movement of grains (Leopold, Wolman & Miller, 1964). The solid line is the Shields curve of *the threshold of motion*; transposed from the Θ versus R_g form into the present form, in which critical shear stress is plotted as a function of grain diameter.

Figure 58. Relation of existing versus proposed dimensional shear stress and grain size for stream competence for RM 156 (RKM 251) (Rosgen, 2006b).

Stream Channel Adjustment/Stability

The results of the cumulative effects of land uses, flood control, riparian vegetation loss, floodplain loss, changes in flow and sediment regime and operational hydrology of Libby and Kootenay Lake have translated their effects on the loss of ecological functioning of the Kootenai River below the confluence of the Moyie River to the Canadian border. The combined effects on the observed physical and biological functioning on 50 plus miles of river are documented to prescribe a solution to the cause and consequence of river impairment. Each of the study reaches is described separately as some of the recommendations will vary by different valley and stream types.

Loss of Ecological Function and River Stability

Braided Reach

The reach being summarized is in the delineation area shown in **Figure 4**. Several studies have looked at time-trends of channel change, such as the Kootenai flats erosion study (USACOE, 1983) and the USGS study (Barton, 2005). Both of these studies confirmed that the stream channel has shifted its position over the years prior to and following Kootenai Dam. It must be remembered that the backwater from Kootenay Lake has extended into the braided reach and influenced excess deposition and corresponding channel shifts. To help recruitment for the sturgeon, two ideas were offered: 1) to raise the stage of Kootenay Lake to increase flow depth for sturgeon, and 2) restore historic high flows below Libby Dam. Although these ideas were intended to be helpful, neither will restore the stability and ecological functioning. Any increase in Kootenay Lake stage will accelerate sediment deposition/aggradation and streambank instability and will further decrease stream depth. It would also increase flood stage at conditions less than flood flows. The increase in peak flows in the presence of high width/depth ratios, high streambanks and poor riparian vegetation would accelerate bank erosion and bar development and would not decrease streamflow depth in this reach. The accelerated streambank erosion would increase supply of sand to the downstream reaches, adding to the sediment problem.

The USGS study by Barton (2005) in the braided reach indicated that the stream channel between 1928 and 1958 shifted as the stream channel geometry had a major migration with lateral migration of approximately 1,968 ft (600 meters). From 1958 to the closure of Libby Dam in 1972, the river was relatively stable without notable aggradation or degradation. Between 1979 and 1982, however, the channel underwent some major channel migration. The likely cause was the reduced sediment transport capacity due to the major reduction in the bankfull discharge leading to deposition/aggradation. The lateral migration and enlargement caused over 931 ft (84 meters) of erosion. The flood of 2005 continued the accelerated streambank erosion without "flushing" the sediment out and deepening the channel to help sturgeon migration. The contrast of the aerial photographs and evident channel changes between 1978 and 1998 for the same flows are shown in **Figure 59**. The increase in the width of the inundated channel is shown in **Figure 60**, during relatively low flows. The hydrologic events prior to and following the active channel widening and migration are shown in **Figure 61** (Barton, 2005).

The high flow from the 2005 flood did little to help stabilize the channel, balance sediment or restore the ecological function. As discussed in the sediment section, an "over-fit" or oversized

channel continues to deposit sediment until eventually its size matches the controlling variables and boundary conditions of its watershed. In this case, the stream flow of over 70,000 cfs has been reduced to near 30,000 cfs. The competence calculations and the sediment transport capacity calculations of both processes indicated that the stream reach is aggrading. The accelerated streambank erosion of over 2.1 tons/ft/yr is an extremely high erosion rate.

Any restoration plan for this reach must match the morphological parameters that are compatible with the controlling variables (valley slope, valley width, size of substrate, size and concentration and nature of sediment, streamflow and vegetative boundary condition). The morphological parameters and the stability analysis indicate an extensive "makeover": the width, depth, slope, sinuosity and other dimension, pattern and profile relations need to be put back into an equilibrium state with the existing independent, controlling variables. This is discussed in more detail in the proposed design for this reach.

A major concern continues related to the adverse effects of the backwater, depending on the various lake levels of Kootenay Lake during spring snowmelt runoff conditions or mid-winter, rain-on-snow events. The backwater effects are highly significant in affecting the energy slope to transport sediment and maintain a defined thalweg depth for migrating sturgeon during late spring conditions. The sediment transport capacity model indicates zero transport of sediment at the highest Kootenay Lake stage. To reduce some of the major impacts in the presence of backwater and reduced energy slope, it is advisable to reduce the sediment supply from upstream sources, such as the Fisher River tributary– a notoriously high sediment supply producer, and/or the very high streambank erosion in this reach. Because this reach produces approximately 77,800 tons of sediment per year (primarily sand), it is advisable to reduce such rates to protect private property from evident losses.

Figure 59. Contrast of channel change between 1978 and 1998, post-Libby Dam response (extracted from Barton, 2005).

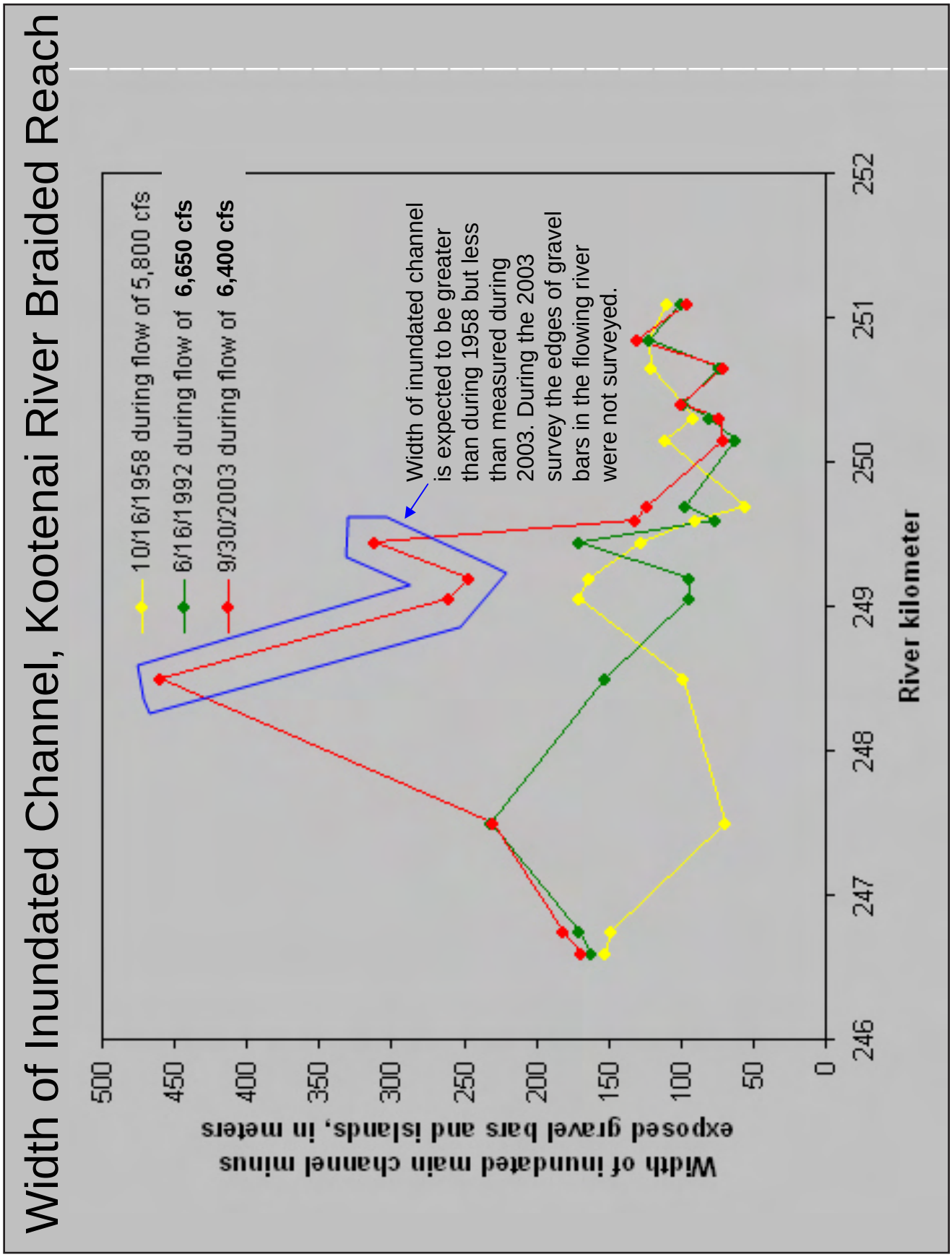


Figure 60. The width increase in the braided reach from 1958 to 1992 to 2003 (extracted from Barton, 2005).

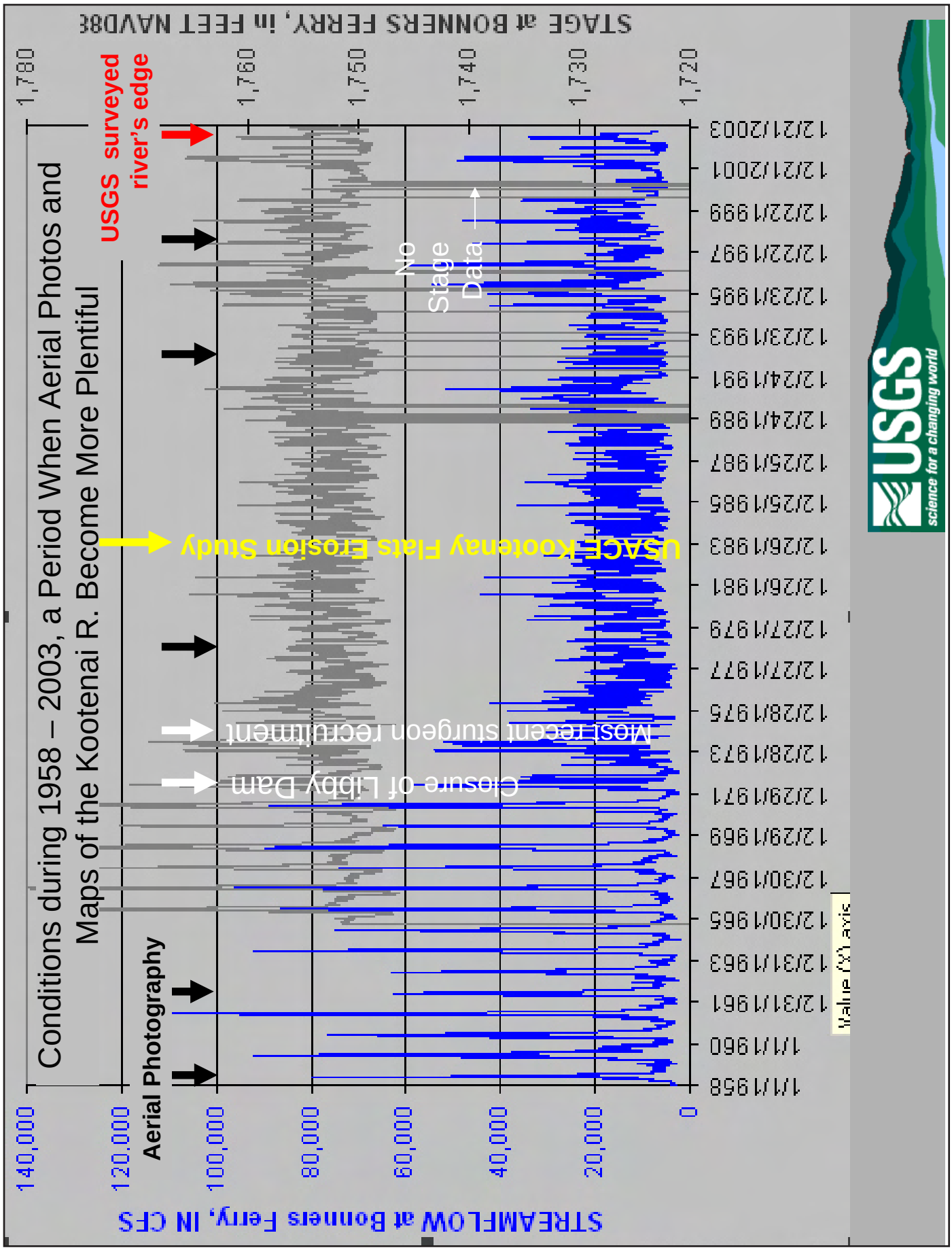


Figure 61. Streamflow pre- and post-Libby Dam related to flood stage by year indicating period of channel change (extracted from Barton, 2005).

Straight Reach

This reach, as shown in **Figure 5**, is an F4/5/1 stream type– an entrenched, sand-invaded, gravel-bed channel with bedrock control. This is a critical reach due to the shallow, high width/depth ratio at the upper reach that transitions into the braided reach below the U.S. 95 Bridge. The obvious plume of sand has fined the surficial particles creating a sand-dominated substrate. Under the sands, however, are gravel and small cobble overlaying bedrock in certain portions. There have been some direct observations of sturgeons' presence in this reach for short periods. To many biologists, the upper portion of this reach and immediately upstream of the bridges presents a migration deterrent to sturgeon due to the shallowing of the depth. Any spawning in this reach would have limited success due to the surficial sand deposits. The sediment transport capacity in this reach also indicates aggradation of sand due to the high width/depth ratios, lower energy slope and backwater from Kootenay Lake.

The streambank erosion rate in this reach is the lowest of any of the three reaches studied. This is due to the various rock outcrops on the channel margin and the extensive rip-rap on the right bank. The lower portion of the reach, however, starts to transition from the bedrock-controlled reach into a glacio-lacustrine valley and the streambank erosion increases an order of magnitude. Both banks of this reach are leveed to prevent any flooding in Bonners Ferry.

Meandering Reach

This reach is shown in **Figure 6** and is an F5, entrenched, sand bed stream that extends into British Columbia through a Valley Type X or glacio-lacustrine valley. This reach has major lateral instability due to excessive streambank erosion (1.61 tons/ft/yr). The accelerated erosion as summarized in the BANCS model is due to the loss of woody riparian vegetation and very high banks on both sides causing stream entrenchment. The high levees for flood control ensure that no access to a floodplain can be gained to relieve shear stress during flood periods. There is also a uniform bed and bank material, which does not provide a great diversity of habitat such as instream cover. Surprisingly, near Shorty's Island, there is critical habitat for white sturgeon due to observations of spawning attempts over the years. The substrate, being sand, is unsuitable for success and recruitment has been nonexistent for many years. The stream has been actively migrating and even with the rip-rap protection on the levee banks there is extensive erosion throughout the reach.

Because the Kootenai River now has half of its pre-Kootenai Dam bankfull discharge, it now takes a flow greater than the 100-year flow to overtop many locations. Another problem with this reach is that over 17 pumping stations have to pump water from the interior of the levees into the river through the existing levees at and in fields to reduce the water table. This drainage problem is aggravated by the levees as flood stages increase in stage instead of spreading onto a floodplain at lower stages than contained in the levee system.

This reach, as discussed earlier, used to be a riparian forest and wetland complex prior to development around the 1920s. Flooding was common; thus lowering of the Grohman Narrows in the same period was necessary to reduce backwater flooding in Idaho. Maintenance of the levees has been identified by the Corps of Engineers as being needed in many locations.

Conceptual Restoration Strategy

The initial assessment of the causes and consequences of river impairment has led the restoration in a direction that can be self-sustaining and meet multiple objectives. The general strategy for this particular restoration alternative is to:

a) Establish stable stream types so that their dimension, pattern and profile match the new bankfull discharge of 30,000 cfs.

b) Establish floodplains by removing levees where feasible and excavate new floodplains at a level to accommodate the incipient point of flooding on this surface at 30,000 cfs.

c) The new floodplain will be established to recruit cottonwoods and willows to reestablish floodplain function.

d) Create habitat to offset limiting factors for sturgeon and other key species.

e) Reduce streambank erosion and sediment supply of sand.

f) Protect land from accelerated erosion by reducing bank heights and incorporating woody debris and woody vegetation transplants for streambank stabilization and habitat enhancement.

g) Reduce flood levels by establishing a lowered floodplain under the levees.

h) Create habitat diversity and instream cover for various age classes and fish species.

i) Create a C4 stream type in the braided reach that will transport sediment and increase river depth to induce sturgeon to migrate up river to suitable spawning habitat.

j) Create the hydraulics and substrate to help spawning success in the straight reach by installing a three stage channel with submerged rock structures to keep sand cleaned off of suitable substrate for sturgeon.

k) In the new floodplains, create depressional wetlands, oxbow channels, oxbow lakes and side channel features for habitat diversity and off-channel sediment storage.

Specific Restoration Objectives (Emphasized Elements)

1. Increase depth of flow in the braided reach for sturgeon migration and access to suitable spawning habitat. This will be accomplished by changing the braided reach into a single-thread, riffle/pool, meandering channel with a low width/depth ratio and floodplain access (C4 stream type). The dimension, pattern and profile will match the post-Libby Dam bankfull discharge of 30,000 cfs.
2. Gradually deposit sediment from the upper watershed along 6.5 miles of newly created meandering C4 stream type both in the channel and in side channels and oxbow lakes. Approximately 5–10% of the bases flow and bankfull will be diverted into side channels and oxbows for each diversion point. This will be accomplished by gradually decreasing the width/depth ratio from the upper to lower end of the reach and lowering the inner berm to allow for sediment storage. The oxbows in the floodplain will be over-deepened in locations to also allow for sediment storage.

The sediment deposition in the floodplain and on inner berms will reduce the potential of a sediment splay or fan/delta at the transition to the straight reach due to a change in energy slope and backwater. It is essential to maintain the channel depth in this reach for sturgeon migration.

3. Reduce sediment supply by a) reducing the high sand supply from streambank erosion, and b) identifying disproportionate sediment supply and the causes from tributaries such as the Fisher River.
4. Reconnect the Kootenai River floodplain for the entire reach to a) reduce flood stage by providing more flood capacity below the river terrace, b) provide a source of cottonwood recruitment by allowing overbank flows, c) reduce streambank heights for streambank erosion reduction, d) reduce maintenance costs for levee repair and streambank rip-rap, and e) reduce water table in agricultural fields.
5. Coarsen substrate in critical habitat locations with the use of a defined inner-berm channel and alternating rock vanes in the straight reach and in the meandering reach near the mouth of myrtle creek and Shorty's Island spawning sites.
6. Increase turbulence, shear stress, stream power and local velocity and hydraulic conditions to encourage spawning by the use of rock vanes and channel re-shaping.
7. Introduce woody debris (logs, root wads, tops) into the toe of banks and willow/cottonwood cuttings to reestablish a riparian corridor, stabilize streambanks with native materials and add habitat and nutrients to the river.
8. Increase instream cover for fish.
9. Increase habitat diversity by creating side channels, wetlands and oxbows in both the existing and constructed floodplain.
10. Offset limiting factors related to physical habitat and water quality established for various fish species.
11. Provide habitat to help sturgeon recruitment by opportunity for eggs to disperse into inundated habitat to adhere to coarse substrate, woody debris or wetland surfaces for incubation. Submerged toe wood (large woody debris) and submerged riparian vegetation cuttings will be established throughout entire river area for multiple functions, including potential assistance with sturgeon recruitment.
12. Provide habitat for yolk-sac larvae to move into riparian crevices for pre-feeding development.
13. Provide habitat for feeding larvae to have food-rich flooded habitat for early growth by creating submerged wetlands, side channels, roughness with LWD and oxbow lake habitat interconnected to the river.
14. Provide habitat diversity that will allow larvae to transition to juveniles as the water recedes to permanent channels. Provide refugia to reduce predation loss.
15. Improve nutrient base with riparian vegetation and submerged woody debris to improve biological productivity.
16. Reduce flood stage for same magnitude streamflow in the braided, straight and meandering reaches by reshaping channel, decreasing width/depth ratio, increasing sediment transport capacity, decreasing sediment supply (to prevent aggradation and loss of channel capacity) and creating a floodplain at a lower level.
17. Reduce the existing high streambank erosion rates, high sediment supply and land loss.

18. Eliminate stream adjacent levees to establish floodplain elevations to match new bankfull discharge. Setback levees may be established only if final flood studies dictate such. The initial analysis indicates that set-back levees for flood control to contain the 100-year flood will not be necessary. If set-back levees are deemed necessary, pumping costs will not be reduced.
19. Reduce water table levels in agricultural fields (river terrace). Reduce pumping costs by eliminating most levees to allow natural drainage from tributaries, overland flow and flow diversions.
20. Homes constructed on levees and permanent surfaced roads will be retained, relying on the floodplain construction and levee removal on the opposite bank.
21. Stabilize tributary stream headcut channels and provide structures to encourage fish migration and use.
22. Change stream type on the meandering reach from an F5 to C5 by reducing the entrenchment ratio by constructing a new floodplain at a lower elevation (30,000 cfs bankfull). Convert F5 to C5 stream types.
23. Model sediment transport to accommodate the effects of backwater, existing sediment budget versus new design dimension, pattern and profile. Evaluate USGS 3-D model when finished. Modify design dimension, pattern and profile to satisfy sediment transport and hydraulic requirements.
24. Make recommendations to the Canadian government on critical lake levels of Kootenay Lake to reduce flood impacts and sediment deposition problems leading to shallow depths that are adversely affecting sturgeon migration.
25. Design and construct structures in the Kootenai River to prevent bridge pier scour for both the Highway 95 and railroad bridges.
26. Recommend grazing practices to minimize riparian vegetation and habitat damage.
27. Recommend a sequence strategy for construction staging.

Proposed Design Recommendations for the Kootenai River

Upon the initial completion of the stability assessment, an in-depth review of the intensive detailed biological assessments, reports of the Federal and State agencies and various consultants, a proposed design is outlined to help offset the adverse cumulative effects of past land use and the causes of river impairment.

A natural channel design approach is used to implement this geomorphic procedure, as shown in **Figure 62** (Rosgen, 2007). The proposed design will need field validation for some of the model assumptions and empirical relations used in the various design steps shown in **Figure 62**. A particularly important component of this design is the sediment assessment for both existing and proposed conditions. The flowchart in **Figure 63** outlines the steps required for this assessment. The results of the proposed design on sediment supply, channel stability and competence are described in this design phase. Field measurements obtained in 2008 by the U.S. Geological Survey will assist in calibrating and validating various sediment prediction methods used for the design. Modifications may be made to this design based on peer review comments, changes in objectives and assumptions, and most importantly, the measured data to improve prediction values. The basic outline using analog, analytical and empirical methodologies used for the Kootenai River design is shown in **Figure 64** (Rosgen, 2007).

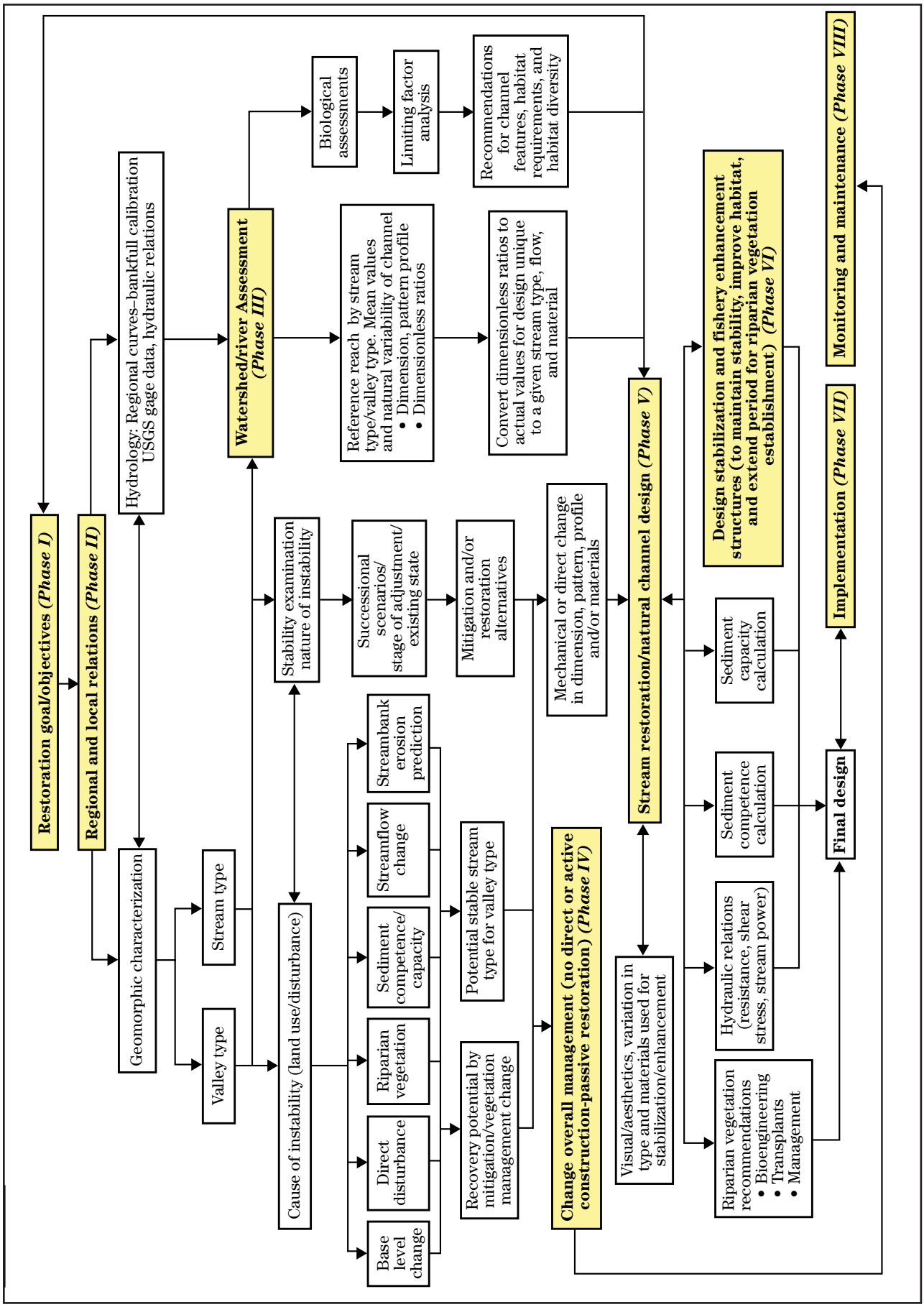


Figure 62. River restoration approach implemented for the Kootenai River design using a geomorphic channel design approach (Rosgen, 2007).

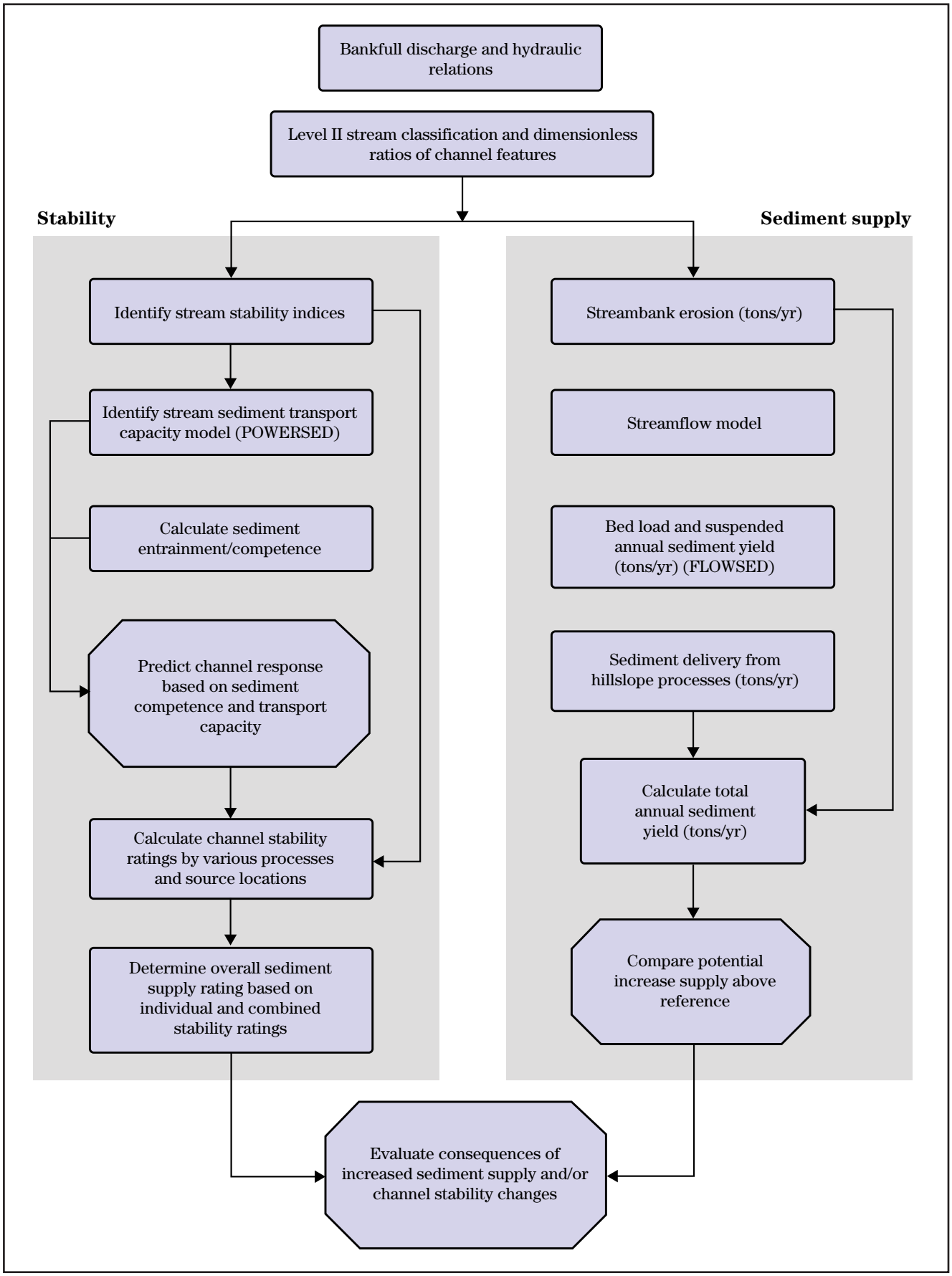


Figure 63. Flowchart for determining sediment supply and stability consequences for river assessment and design (Rosgen, 2006b, 2007).

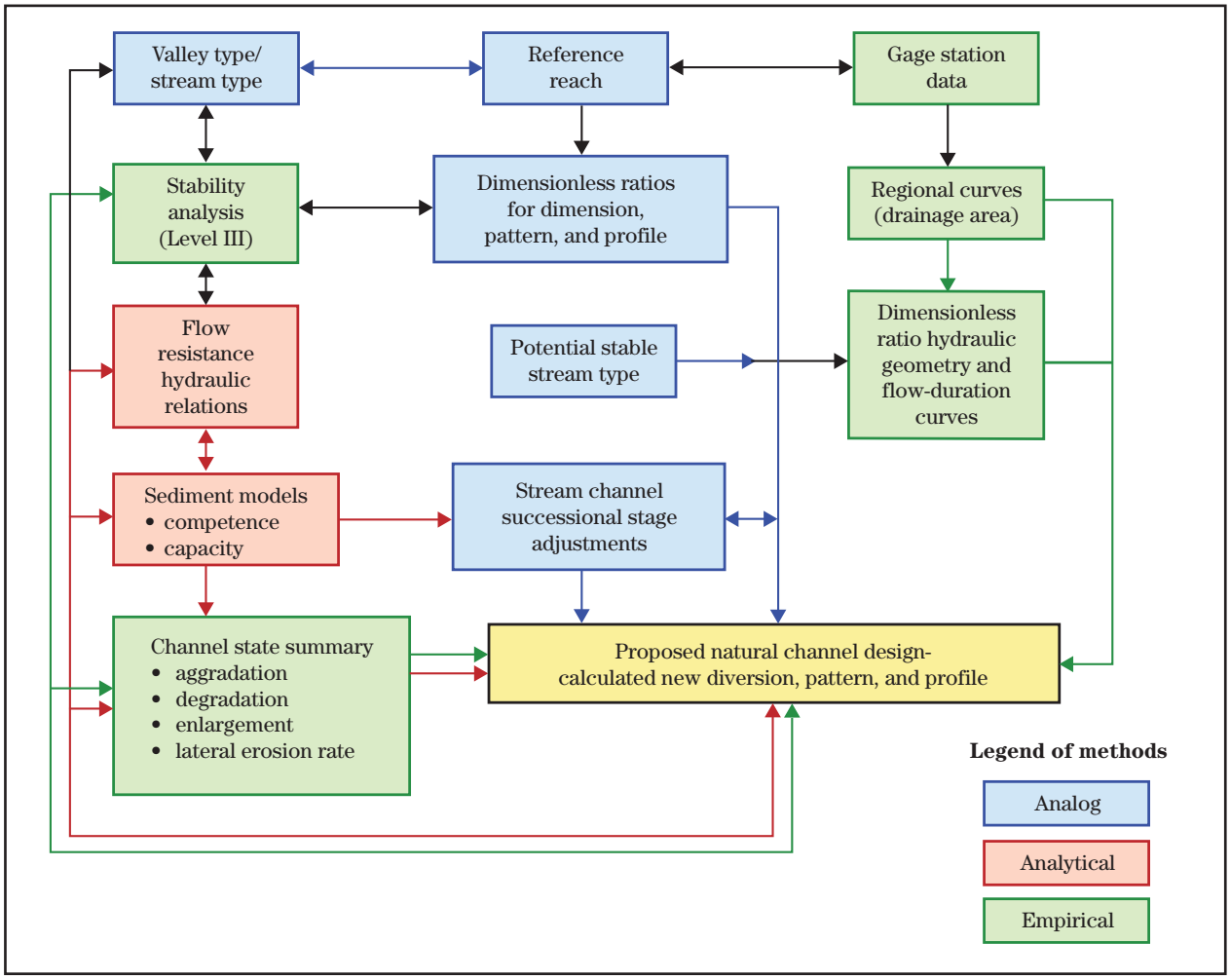


Figure 64. Generalized flowchart representing the geomorphic channel design utilizing analog, analytical and empirical methodologies used in the Kootenai River restoration design (Rosgen, 2007).

Reference Reach Relations

Morphological data from the Priest River (Idaho) and the Bull River (Northwestern Montana) collected by River Design Group, Montana, are summarized in **Tables 8**, **9** and **10**. These data are used to compare dimension, pattern, profile and materials for similar valley types and boundary conditions to impaired (existing) conditions and are used to assist in developing values for design variables. These reaches were selected as they represent rivers that have stabilized over time below reservoirs in similar valley types and geologic provinces. Additional data from other rivers of similar morphological type and valley types are also used to develop dimensionless ratios for scaling to allow extrapolation to the Kootenai River.

Stream Channel Dimension, Pattern, Profile and Materials

The morphological, hydraulic and sedimentological relations as determined from this approach are summarized in the following proposed design plan. The summarized values for the three different reaches (braided, straight and meandering) for existing condition, reference reach and proposed design variables are included in **Table 8** for the braided reach, **Table 9** for the straight reach and **Table 10** for the meandering reach. These values are used for the design pattern (meander length, radius of curvature, belt width and sinuosity), for the cross-section dimensions of riffles, runs, glides and pools of width, depth, cross-sectional area, maximum depths, point bar slopes, etc., and profile data of their slopes and unique bed features. An example of the use of this data is the schematic design showing the plan and profile views of a typical layout of a C4 stream type showing the appropriate depth and slope and position of riffles, runs, pools and glides (**Figure 65**). The dimensionless ratios from **Table 8**, **9** and **10** for each reach are converted to actual values for design purposes. The typical plan, profile and section views of riffles, pools, runs and glides for each of the proposed restoration reaches are shown in **Figure 66** for the braided reach, **Figure 67** for the straight reach and in **Figure 68** for the meander reach.

The proposed plan-view layout for the 6.5 miles of braided reach is shown in **Figure 69a** and **Figure 69b**. The proposed plan-view layout for the straight reach is shown in **Figure 70**. The proposed plan-view layout for the meandering reach is depicted in **Figure 71a**, **Figure 71b**, **Figure 71c** and **Figure 71d**. Details of the plan, profile and section view are shown in the multiple design sheets for each reach presented in *Appendix VI*.

Table 8. Morphological characteristics of the existing and proposed braided reach with reference reach data.

Restoration Site: **Kootenai River, Braided Reach Design Station 0 to 365+00** Reference Reaches: **Upper Priest River**							
Variables	**Existing Channel**		**Proposed Reach**		**Upper Priest River Reference Reach**		
1 Stream Type	**D4**		**C4**		**C4**		
2 Drainage Area, mi^2	**11,740**		**11,740**		**n/a**		
3 Mean Riffle Depth, ft (d_{bkf})	Mean:	**9.0**	Mean:	**14.9**	Mean:	**5.8**	
	Range:	**7.5 - 13.1**	Range:	**14.1 - 15.5**	Range:	**5.3 - 6.2**	
4 Riffle Width, ft (W_{bkf})	Mean:	**1170**	Mean:	**402**	Mean:	**170**	
	Range:	**620 - 2500**	Range:	**371 - 424**	Range:	**157 - 184**	
5 Width/Depth Ratio (W_{bkf}/d_{bkf})	Mean:	**130**	Mean:	**27.0**	Mean:	**29**	
	Range:	**59 - 212**	Range:	**25.0 - 30.0**	Range:	**27.4 - 32**	
6 Riffle Cross-Sectional Area, ft^2 (A_{bkf})	Mean:	**10530**	Mean:	**6000**	Mean:	**978**	
	Range:	**7400 - 18500**	Range:		Range:	**973 - 983**	
7 Max Riffle Depth (d_{mbkf})	Mean:	**10.9**	Mean:	**20.0**	Mean:	**7.3**	
	Range:	**9.8 - 13.2**	Range:	**18.7 - 20.5**	Range:	**6.2 - 8.1**	
8 Max Riffle Depth/Mean Riffle Depth (d_{mbkf}/d_{bkf})	Mean:	**1.21**	Mean:	**1.34**	Mean:	**1.26**	
	Range:	**1.09 - 1.47**	Range:	**1.30 - 1.60**	Range:	**1.07 - 1.40**	
9 Mean Pool Depth, ft (d_{bkfp})	Mean:	**13.5**	Mean:	**20.8**	Mean:	**7.9**	
	Range:	**12.8 - 14.2**	Range:	**18.0 - 24.0**	Range:	**7.2 - 9.3**	
10 Mean Pool Depth/Mean Riffle Depth	Mean:	**1.5**	Mean:	**1.4**	Mean:	**1.4**	
	Range:	**1.4 - 1.6**	Range:	**1.2 - 1.6**	Range:	**1.2 - 1.6**	
11 Pool Width, ft (W_{bkfp})	Mean:	**1170**	Mean:	**442**	Mean:	**191**	
	Range:	**800 - 18500**	Range:	**402 - 523**	Range:	**175 - 220**	
12 Pool Width/Riffle Width	Mean:	**1.0**	Mean:	**1.1**	Mean:	**1.1**	
	Range:	**1.0 - 1.3**	Range:	**1.0 - 1.3**	Range:	**1.0 - 1.3**	
13 Pool Cross-Sectional Area, ft^2 (A_{bkfp})	Mean:	**15795**	Mean:	**9233**	Mean:	**1503**	
	Range:	**9500 - 19500**	Range:	**8000 - 10200**	Range:	**1301 - 1628**	
14 Pool Area/Riffle Area	Mean:	**1.1**	Mean:	**1.5**	Mean:	**1.5**	
	Range:	**0.9 - 1.9**	Range:	**1.3 - 1.7**	Range:	**1.3 - 1.7**	
15 Max Pool Depth (d_{mbkfp})	Mean:	**27**	Mean:	**45.0**	Mean:	**14.9**	
	Range:	**22 - 34**	Range:	**35.0 - 49.0**	Range:	**12.6 - 17.6**	
16 Max Pool Depth/Mean Riffle Depth (d_{mbkfp}/d_{bkf})	Mean:	**3.0**	Mean:	**2.8**	Mean:	**2.6**	
	Range:	**2.4 - 3.8**	Range:	**2.3 - 3.3**	Range:	**2.2 - 3.0**	
17 Inner Berm Width, ft (W_{ib})	Mean:	**n/a**	Mean:	**240**	Mean:	**145**	
	Range:		Range:		Range:	**136 151**	

Table 8 (Braided Reach Data) Page 2/5

	Variables	Existing Channel	Proposed Reach	Upper Priest River Reference Reach
18	Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	Mean: **n/a** Range:	Mean: **0.60** Range:	Mean: **0.85** Range: **0.80 0.89**
19	Inner Berm Depth, ft (d_{ib})	Mean: **n/a** Range:	Mean: **8.42** Range:	Mean: **3.80** Range: **3.65 4.05**
20	Inner Berm Depth to Mean Riffle Depth (d_{ib}/d_{bkf})	Mean: **n/a** Range:	Mean: **0.57** Range:	Mean: **0.66** Range: **0.63 0.70**
21	Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	Mean: **n/a** Range:	Mean: **28.5** Range:	Mean: **38.2** Range: **33.6 41.4**
22	Inner Berm Cross-Sectional Area (A_{ib})	Mean: **n/a** Range:	Mean: **2000** Range:	Mean: **551** Range: **540 564**
23	Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	Mean: **n/a** Range:	Mean: **0.33** Range:	Mean: **0.56** Range: **0.55 0.58**
24	Low Bank Height (LBH)	Mean: **23** Range: **19 - 34**	Mean: **20.0** Range: **18.7 - 20.5**	Mean: **8.03** Range: **6.2 - 9.72**
25	Low Bank Height to Max Riffle Depth (LBH/d_{mbkf})	Mean: **2.1** Range: **1.7 - 3.1**	Mean: **1.0** Range:	Mean: **1.1** Range: **1.0 - 1.2**
26	Width of Floodprone Area, ft (W_{fpa})	Mean: **1250** Range: **800 - 1950**	Mean: **1250** Range: **950 - 1950**	Mean: **833** Range: **650 - 950**
27	Entrenchment Ratio (W_{fpa}/W_{bkf})	Mean: **1.07** Range: **1.05 - 1.14**	Mean: **3.1** Range: **2.4 - 4.9**	Mean: **4.90** Range: **4.14 - 5.16**
28	Point Bar Slope	Mean: **3%** Range:	Mean: **10%** Range:	Mean: **6-12%** Range:
29	Bankfull Discharge, ft^3/s (Q_{bkf})	**30000**	**30000**	**3715**
30a	Bankfull Mean Velocity, ft/s (u_{bkf})	**2.85**	**5.00**	**3.80**
30b	Low Flow Mean Velocity, ft/s (u_{bkf})	**2.93**	**3.00**	**~2.7**
30c	1/2 BKF Mean Velocity, ft/s (u_{bkf})	**2.87**	**3.80**	**~3.1**
31	Meander Length, ft (L_m)	Mean: **7294** Range: **4632 - 11078**	Mean: **5200** Range: **4632 - 5784**	Mean: **1883** Range: **1250 - 2300**
32	Meander Length Ratio (L_m/W_{bkf})	Mean: **6.2** Range: **4.0 - 9.5**	Mean: **12.9** Range: **11.5 - 14.4**	Mean: **11.1** Range: **7.4 - 13.5**

Variables	Existing Channel	Proposed Reach	Upper Priest River Reference Reach
33 Radius of Curvature, ft (R_c)	Mean: **1380** Range: **1245 - 1981**	Mean: **1380** Range: **1245 - 1550**	Mean: **510** Range: **438 - 656**
34 Ratio of Radius of Curvature to Bankfull Width (R_c/W_{bkf})	Mean: **1.2** Range: **1.1 - 1.7**	Mean: **3.4** Range: **3.1 - 3.9**	Mean: **3.0** Range: **2.6 - 3.9**
35 Belt Width, ft (W_{blt})	Mean: **2232** Range: **1415 - 2957**	Mean: **2232** Range: **1850 - 2957**	Mean: **1300** Range: **1100 - 1400**
36 Meander Width Ratio (W_{blt}/W_{bkf})	Mean: **1.9** Range: **1.2 - 2.5**	Mean: **5.6** Range: **4.6 - 7.4**	Mean: **7.6** Range: **6.5 - 8.2**
37 Individual Pool Length, ft	Mean: **950** Range: **650 - 1154**	Mean: **1350** Range: **825 - 1650**	Mean: **535** Range: **458 - 612**
38 Pool Length to Riffle Width	Mean: **0.8** Range: **0.6 - 1.0**	Mean: **3.4** Range: **2.1 - 4.1**	Mean: **3.1** Range: **2.7 - 3.6**
39 Pool to Pool Spacing (based on pattern), ft (p-p)	Mean: **6500** Range: **3600 - 9800**	Mean: **3500** Range: **3200 - 3700**	Mean: **1510** Range: **1499 - 1521**
40 Ratio of p-p Spacing to Bankfull Width (p-p/W_{bkf})	Mean: **5.6** Range: **3.1 - 8.4**	Mean: **8.7** Range: **8.0 - 9.2**	Mean: **8.9** Range: **8.8 - 8.9**
41 Riffle Length, ft	Mean: **3696** Range: **2112 - 4752**	Mean: **1230** Range: **650 - 2100**	Mean: **242** Range: **117 423**
42 Riffle Length to Riffle Width (W_{bkf})	Mean: **3.2** Range: **1.8 - 4.1**	Mean: **3.1** Range: **1.6 - 5.2**	Mean: **1.4** Range: **0.7 2.5**
43 Stream Length (SL)	**31200**	**36500**	**40500**
44 Valley Length (VL)	**29169**	**29169**	**22500**
45 Valley Slope (VS)	**0.00066**	**0.00066**	**0.0016**
46a Average Water Surface Slope (S)	**0.00061**	**0.00052**	**0.00095**
46b Low Flow Average Water Surface Slope (S)	**0.00067**	**0.00060**	**n/a**
46c 1/2 BKF Average Water Surface Slope (S)	**0.00058**	**0.00055**	**n/a**
47 Sinuosity (k)	SL/VL: **1.05** VS/S: **1.08**	SL/VL: **1.25** VS/S: **1.27**	SL/VL: **1.80** VS/S: **1.68**

Table 8 (Braided Reach Data) Page 4/5

	Variables	Existing Channel		Proposed Reach		Upper Priest River Reference Reach	
48	Riffle Slope (water surface facet slope) (S_{rif})	Mean:	**0.00064**	Mean:	**0.0012**	Mean:	**0.00222**
		Range:	**0.0004 - 0.002**	Range:	**0.001 - 0.0014**	Range:	**0.00191 - 0.00255**
49	Ratio Riffle Slope to Average Water Surface Slope (S_{rif}/S)	Mean:	**1.05**	Mean:	**2.34**	Mean:	**2.34**
		Range:	**0.66 - 2.5**	Range:	**2.01 - 2.7**	Range:	**2.01 - 2.7**
50	Run Slope (water surface facet slope) (S_{run})	Mean:	**n/a**	Mean:	**0.00036**	Mean:	**0.00063**
		Range:		Range:	**0.0003 - 0.0004**	Range:	**0.00055 - 0.00071**
51	Ratio Run Slope/Average Water Surface Slope (S_{run}/S)	Mean:	**n/a**	Mean:	**0.7**	Mean:	**0.66**
		Range:		Range:	**0.6 - 0.75**	Range:	**0.58 - 0.75**
52	Pool Slope (water surface facet slope) (S_p)	Mean:	**0.0009**	Mean:	**0.00005**	Mean:	**0.00016**
		Range:	**0.0000005 - 0.0004**	Range:		Range:	**0.00014 - 0.00017**
53	Ratio of Pool Slope/Average Water Surface Slope (S_p/S)	Mean:	**1.5**	Mean:	**0.1**	Mean:	**0.2**
		Range:	**0.00 - 0.6**	Range:		Range:	**0.15 - 0.2**
54	Glide Slope (water surface facet slope) (S_g)	Mean:	**n/a**	Mean:	**0.00021**	Mean:	**0.0004**
		Range:		Range:	**0.0002 - 0.0002**	Range:	**0.00038 - 0.00041**
55	Ratio Glide Slope/Average Water Surface Slope (S_g/S)	Mean:	**n/a**	Mean:	**0.4**	Mean:	**0.42**
		Range:		Range:	**0.4 - 0.43**	Range:	**0.40 - 0.43**
56	Max Run Depth, ft (d_{run})	Mean:	**n/a**	Mean:	**25.3**	Mean:	**11.1**
		Range:		Range:	**23.8 - 28.3**	Range:	**11.1 - 11.2**
57	Ratio Max Run Depth/ Bankfull Mean Depth (d_{run}/d_{bkf})	Mean:	**n/a**	Mean:	**1.7**	Mean:	**1.91**
		Range:		Range:	**1.6 - 1.9**	Range:	**1.91 – 1.93**
58	Max Glide Depth, ft (d_g)	Mean:	**n/a**	Mean:	**22.4**	Mean:	**10.5**
		Range:		Range:	**17.9 - 25.3**	Range:	**9.7 – 11.2**
59	Ratio Max Glide Depth/ Bankfull Mean Depth (d_g/d_{bkf})	Mean:	**n/a**	Mean:	**1.5**	Mean:	**1.81**
		Range:		Range:	**1.2 – 1.7**	Range:	**1.67 – 1.93**
MATERIALS							
60	Particle Size Distribution of Channel Material (active bed)						
	D_{16} (mm)	**9.4**		**n/a**		**14**	
	D_{35} (mm)	**14.6**		**n/a**		**34**	
	D_{50} (mm)	**30.3**		**n/a**		**46**	
	D_{84} (mm)	**40**		**n/a**		**91**	
	D_{95} (mm)	**64**		**n/a**		**136**	

MATERIALS				
61	Particle Size Distribution of Bar Material			
	D_{50} (mm)	**17**	**n/a**	**22**
	D_{84} (mm)	**64**	**n/a**	**60**
	D_{max}: Largest size particle at the toe (lower third) of bar (mm)	**93**	**n/a**	**85**

SEDIMENT TRANSPORT VALIDATION (Based on Bankfull Shear Stress)		Proposed
62	Calculated shear stress value, lb/ft^2, (τ)	**0.48**
63	Moveable particle size from Shields Curve at bankfull shear stress - (mm)	**25**
64	Moveable particle size from Shields Curve at bankfull shear stress - Colorado Data (mm)	**100**
65	Largest particle size (mm) to be moved (D_{max}) (see #61: Particle Size Distribution of Bar Material)	**80-105**
66	Predicted shear stress required to initiate movement of D_{max} (mm) (Shields curve)	**0.45-0.80**
67	Predicted mean depth required to initiate movement of D_{max} (mm), $d = \tau/\gamma S$	**13.9-24.6**
68	Predicted slope required to initiate movement of D_{max} (mm) $S=\tau/\gamma d$	**0.00041**
69	Dimensionless shear stress (τ^*) (see competence form)	**.016-.019**
70	Required mean depth d_{bkf} (ft) calculated using dimensionless shear stress equation for a given slope	**17.3**
71	Required slope S (ft) calculated using dimensionless shear stress equation for a given depth	**0.0006**
72	Bankfull Unit Stream Power (lbs/ft/sec), $\omega = \tau\ u_{bkf}$	**2.42**
73	Bankfull Froude Number	**0.23**
74a	Mannings "n" @ Low Flow	**0.046**
74b	Mannings "n" @ 1/2 BKF	**0.042**
74c	Mannings "n" @ Bankfull	**0.041**

Remarks:

Table 9. Morphological characteristics of the existing and proposed straight reach with reference reach data.

Restoration Site: Kootenai River, Straight Reach Design Station 365+00 to 462+00
Reference Reaches: Upper Priest River, & Bull River

Variables	Existing Channel	Proposed Reach	Upper Priest River Reference Reach	Bull River Reference Reach
1 Stream Type	F4/5/1	C4/B4c	C4	E4
2 Drainage Area, mi^2	11,740	11,740	n/a	n/a
3 Mean Riffle Depth, ft (d_{bkf})	Mean: 11.2 Range: 10.2 - 14.1	Mean: 18.3 Range: 17.5 - 18.3	Mean: 5.8 Range: 5.3 - 6.2	Mean: 5.7 Range: 5 - 6.4
4 Riffle Width, ft (W_{bkf})	Mean: 574 Range: 550 - 680	Mean: 328 Range: 328 - 342	Mean: 170 Range: 157 - 184	Mean: 52 Range: 49 - 57
5 Width/Depth Ratio (W_{bkf}/d_{bkf})	Mean: 51.3 Range: 48 - 59	Mean: 18 Range: 20 - 20	Mean: 29 Range: 27.4 - 32	Mean: 9 Range: 8.1 - 10
6 Riffle Cross-Sectional Area, ft^2 (A_{bkf})	Mean: 6314 Range: 5900 - 7100	Mean: 6000 Range:	Mean: 978 Range: 973 - 983	Mean: 295 Range: 283 - 323
7 Max Riffle Depth (d_{mbkf})	Mean: 18.9 Range: 18.0 - 19.3	Mean: 25.0 Range: 24 - 25	Mean: 7.3 Range: 6.2 - 8.1	Mean: 8.1 Range: 7.5 - 8.8
8 Max Riffle Depth/Mean Riffle Depth (d_{mbkf}/d_{bkf})	Mean: 1.7 Range: 1.6 - 1.7	Mean: 1.37 Range: 1.31 - 1.37	Mean: 1.26 Range: 1.07 - 1.40	Mean: 1.42 Range: 1.32 - 1.54
9 Mean Pool Depth, ft (d_{bkfp})	Mean: 42.6 Range:	Mean: 32.9 Range: 29.3 - 43.9	Mean: 7.9 Range: 7.2 - 9.3	Mean: 13.4 Range: 12.2 - 15.0
10 Mean Pool Depth/Mean Riffle Depth	Mean: 3.8 Range:	Mean: 1.8 Range: 1.6 - 2.4	Mean: 1.4 Range: 1.2 - 1.6	Mean: 2.4 Range: 2.1 - 2.6
11 Pool Width, ft (W_{bkfp})	Mean: 428 Range: -	Mean: 361 Range: 262 - 393	Mean: 191 Range: 175 - 220	Mean: 56 Range: 44 - 62
12 Pool Width/Riffle Width	Mean: 0.7 Range:	Mean: 1.1 Range: 0.8 - 1.2	Mean: 1.1 Range: 1.0 - 1.3	Mean: 1.1 Range: 0.8 - 1.2
13 Pool Cross-Sectional Area, ft^2 (A_{bkfp})	Mean: 18239 Range:	Mean: 9300 Range: 8400 - 10800	Mean: 1503 Range: 1301 - 1628	Mean: 471 Range: 310 - 580
14 Pool Area/Riffle Area	Mean: 2.9 Range:	Mean: 1.6 Range: 1.4 - 1.8	Mean: 1.5 Range: 1.3 - 1.7	Mean: 1.60 Range: 1.1 - 2.0
15 Max Pool Depth (d_{mbkfp})	Mean: 77 Range:	Mean: 45.8 Range: 40.3 - 54.9	Mean: 14.9 Range: 12.6 - 17.6	Mean: 13.4 Range: 12.2 - 15
16 Max Pool Depth/Mean Riffle Depth (d_{mbkfp}/d_{bkf})	Mean: 6.9 Range:	Mean: 2.5 Range: 2.2 - 3.0	Mean: 2.6 Range: 2.2 - 3.0	Mean: 2.4 Range: 2.1 - 2.6
17 Inner Berm Width, ft (W_{ib})	Mean: n/a Range:	Mean: 192 Range:	Mean: 145 Range: 136 151	Mean: 42 Range: 37 44

Table 9 (Straight Reach Data) Page 2/5

	Variables	Existing Channel	Proposed Reach	Upper Priest River Reference Reach	Bull River Reference Reach
18	Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	Mean: **n/a** Range:	Mean: **0.59** Range:	Mean: **0.85** Range: **0.80 0.89**	Mean: **0.81** Range: **0.71 0.85**
19	Inner Berm Depth, ft (d_{ib})	Mean: **n/a** Range:	Mean: **10.3** Range:	Mean: **3.80** Range: **3.65 4.05**	Mean: **11** Range: **9.1 13.18**
20	Inner Berm Depth to Mean Riffle Depth (d_{ib}/d_{bkf})	Mean: **n/a** Range:	Mean: **0.56** Range:	Mean: **0.66** Range: **0.63 0.70**	Mean: **1.93** Range: **1.60 2.31**
21	Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	Mean: **n/a** Range:	Mean: **0.59** Range:	Mean: **38.2** Range: **33.6 41.4**	Mean: **12** Range: **11 17**
22	Inner Berm Cross-Sectional Area (A_{ib})	Mean: **n/a** Range:	Mean: **1978** Range:	Mean: **551** Range: **540 564**	Mean: **132** Range: **100 145**
23	Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	Mean: **n/a** Range:	Mean: **0.33** Range:	Mean: **0.56** Range: **0.55 0.58**	Mean: **0.45** Range: **0.34 0.49**
24	Low Bank Height (LBH)	Mean: **44** Range: **40 - 50**	Mean: **25.0** Range:	Mean: **8.03** Range: **6.2 - 9.72**	Mean: **8.91** Range: **7.5 - 10.56**
25	Low Bank Height to Max Riffle Depth (LBH/d_{mbkf})	Mean: **2.3** Range: **2.1 - 2.6**	Mean: **1.0** Range:	Mean: **1.1** Range: **1.0 - 1.2**	Mean: **1.1** Range: **1.0 - 1.2**
26	Width of Floodprone Area, ft (W_{fpa})	Mean: **650** Range: **600 - 750**	Mean: **650** Range: **600 - 750**	Mean: **833** Range: **650 - 950**	Mean: **276** Range: **231 - 353**
27	Entrenchment Ratio (W_{fpa}/W_{bkf})	Mean: **1.1** Range: **1.05 - 1.14**	Mean: **2.0** Range: **1.8 - 2.0**	Mean: **4.90** Range: **4.14 - 5.16**	Mean: **5.31** Range: **4.71 - 6.19**
28	Point Bar Slope	Mean: **25%** Range:	Mean: **15%** Range:	Mean: **6-12%** Range:	Mean: **20-25%** Range:
29	Bankfull Discharge, ft^3/s (Q_{bkf})	**30000**	**30000**	**3715**	**~3.33**
30a	Bankfull Mean Velocity, ft/s (u_{bkf})	**4.75**	**5.00**	**3.80**	**~1000**
30b	Low Flow Mean Velocity, ft/s (u_{bkf})	**3.34**	**3.03**	**~2.7**	**n/a**
30c	1/2 BKF Mean Velocity, ft/s (u_{bkf})	**4.1**	**4.3**	**~3.1**	**n/a**
31	Meander Length, ft (L_m)	Mean: **9355** Range: **7400 - 11310**	Mean: **2500** Range: **1990 - 4460**	Mean: **1883** Range: **1250 - 2300**	Mean: **460** Range: **341 - 580**
32	Meander Length Ratio (L_m/W_{bkf})	Mean: **16.3** Range: **12.9 - 19.7**	Mean: **7.6** Range: **6.1 - 13.6**	Mean: **11.1** Range: **7.4 - 13.5**	Mean: **8.8** Range: **6.6 - 11.2**

Table 9 (Straight Reach Data) Page 3/5

Variables	Existing Channel	Proposed Reach	Upper Priest River Reference Reach	Bull River Reference Reach
33 Radius of Curvature, ft (R_c)	Mean: **1352** Range:	Mean: **1077** Range: **950 - 1352**	Mean: **510** Range: **438 - 656**	Mean: **96** Range: **61 - 131**
34 Ratio of Radius of Curvature to Bankfull Width (R_c/W_{bkf})	Mean: **2.4** Range:	Mean: **6.3** Range: **5.6 - 8.0**	Mean: **3.0** Range: **2.6 - 3.9**	Mean: **1.8** Range: **1.2 - 2.5**
35 Belt Width, ft (W_{blt})	Mean: **800** Range:	Mean: **750** Range: **600 - 800**	Mean: **1300** Range: **1100 - 1400**	Mean: **317** Range: **273 - 409**
36 Meander Width Ratio (W_{blt}/W_{bkf})	Mean: **1.4** Range:	Mean: **2.3** Range: **1.8 - 2.4**	Mean: **7.6** Range: **6.5 - 8.2**	Mean: **6.1** Range: **5.3 - 7.9**
37 Individual Pool Length, ft	Mean: **3722** Range:	Mean: **3722** Range:	Mean: **535** Range: **458 - 612**	Mean: **136** Range: **106 - 162**
38 Pool Length to Riffle Width	Mean: **6.5** Range:	Mean: **11.4** Range:	Mean: **3.1** Range: **2.7 - 3.6**	Mean: **2.6** Range: **2.0 - 3.1**
39 Pool to Pool Spacing (based on pattern), ft (p-p)	Mean: **10032** Range:	Mean: **10032** Range:	Mean: **1510** Range: **1499 - 1521**	Mean: **320** Range: **199 - 482**
40 Ratio of p-p Spacing to Bankfull Width ($p\text{-}p/W_{bkf}$)	Mean: **17.5** Range:	Mean: **59.0** Range:	Mean: **8.9** Range: **8.8 - 8.9**	Mean: **6.2** Range: **3.8 - 9.3**
41 Riffle Length, ft	Mean: **2112** Range:	Mean: **2080** Range:	Mean: **242** Range: **117 423**	Mean: **75** Range: **54.2 82**
42 Riffle Length to Riffle Width (W_{bkf})	Mean: **3.7** Range:	Mean: **6.3** Range:	Mean: **1.4** Range: **0.7 2.5**	Mean: **1.4** Range: **1.0 1.6**
43 Stream Length (SL)	**9300**	**9700**	**40500**	**2100**
44 Valley Length (VL)	**9200**	**9200**	**22500**	**1235**
45 Valley Slope (VS)	**0.00022**	**0.00022**	**0.0016**	**0.0016**
46a Average Water Surface Slope (S)	**0.00021**	**0.00022**	**0.00095**	**0.00013**
46b Low Flow Average Water Surface Slope (S)	**0.00042**	**0.00042**	**n/a**	**n/a**
46c 1/2 BKF Average Water Surface Slope (S)	**0.00030**	**0.00032**	**n/a**	**n/a**
47 Sinuosity (k)	SL/VL: **1.01** VS/S: **n/a**	SL/VL: **1.05** VS/S: **1.00**	SL/VL: **1.80** VS/S: **1.68**	SL/VL: **1.70** VS/S: **12.31**

	Variables	Existing Channel	Proposed Reach	Upper Priest River Reference Reach	Bull River Reference Reach
48	Riffle Slope (water surface facet slope) (S_{rif})	Mean: **0.00052** Range:	Mean: **0.00067** Range:	Mean: **0.00222** Range: **0.002 - 0.003**	Mean: **0.00016** Range: **0.0001 - 0.0002**
49	Ratio Riffle Slope to Average Water Surface Slope (S_{rif}/S)	Mean: **2.36** Range:	Mean: **3.05** Range:	Mean: **2.34** Range: **2.01 - 2.7**	Mean: **1.23** Range: **1.00 - 1.5**
50	Run Slope (water surface facet slope) (S_{run})	Mean: **n/a** Range:	Mean: **0.0001** Range:	Mean: **0.00063** Range: **0.0006 - 0.0007**	Mean: **n/a** Range:
51	Ratio Run Slope/Average Water Surface Slope (S_{run}/S)	Mean: **n/a** Range:	Mean: **0.7** Range: **0.6 - 0.75**	Mean: **0.66** Range: **0.58 - 0.75**	Mean: **n/a** Range:
52	Pool Slope (water surface facet slope) (S_p)	Mean: **0.000005** Range:	Mean: **0.00002** Range:	Mean: **0.00016** Range: **0.0001 - 0.0002**	Mean: **0.00007** Range: **.00003 - .00009**
53	Ratio of Pool Slope/Average Water Surface Slope (S_p/S)	Mean: **0.0** Range:	Mean: **0.1** Range:	Mean: **0.2** Range: **0.15 - 0.2**	Mean: **0.5** Range: **0.23 - 0.7**
54	Glide Slope (water surface facet slope) (S_g)	Mean: **n/a** Range:	Mean: **0.00009** Range:	Mean: **0.0004** Range: **4E-04 - 4E-04**	Mean: **n/a** Range:
55	Ratio Glide Slope/Average Water Surface Slope (S_g/S)	Mean: **n/a** Range:	Mean: **0.4** Range:	Mean: **0.42** Range: **0.40 - 0.43**	Mean: **n/a** Range:
56	Max Run Depth, ft (d_{run})	Mean: **n/a** Range:	Mean: **32.9** Range: **31.1 - 34.8**	Mean: **11.1** Range: **11.1 - 11.2**	Mean: **9.9** Range: **8.4 - 11.7**
57	Ratio Max Run Depth/ Bankfull Mean Depth (d_{run}/d_{bkf})	Mean: **n/a** Range:	Mean: **1.8** Range: **1.7 - 1.9**	Mean: **1.91** Range: **1.91 – 1.93**	Mean: **1.74** Range: **1.47 – 2.05**
58	Max Glide Depth, ft (d_g)	Mean: **n/a** Range:	Mean: **27.5** Range: **22.0 - 32.9**	Mean: **10.5** Range: **9.7 – 11.2**	Mean: **10** Range: **6.9 – 12.5**
59	Ratio Max Glide Depth/ Bankfull Mean Depth (d_g/d_{bkf})	Mean: **n/a** Range:	Mean: **1.5** Range: **1.2 – 1.8**	Mean: **1.81** Range: **1.67 – 1.93**	Mean: **1.75** Range: **1.21 – 2.19**
MATERIALS					
60	Particle Size Distribution of Channel Material (active bed)				
	D_{16} (mm)	**0.05**	**n/a**	**14**	**0.05**
	D_{35} (mm)	**0.12**	**n/a**	**34**	**0.88**
	D_{50} (mm)	**2.2**	**n/a**	**46**	**1.4**
	D_{84} (mm)	**4.0**	**n/a**	**91**	**4.68**
	D_{95} (mm)	**6.5**	**n/a**	**136**	**8**

Table 9 (Straight Reach Data) Page 5/5

MATERIALS				
61	Particle Size Distribution of Bar Material			
	D_{50} (mm)	**n/a**	**n/a**	**n/a**
	D_{84} (mm)	**n/a**	**n/a**	**n/a**
	D_{max}: Largest size particle at the toe (lower third) of bar (mm)	**n/a**	**n/a**	**n/a**

SEDIMENT TRANSPORT VALIDATION (Based on Bankfull Shear Stress)		**Proposed**
62	Calculated shear stress value, lb/ft^2, (τ)	**0.07**
63	Moveable particle size from Shields Curve at bankfull shear stress - Original Data (mm)	**0.4**
64	Moveable particle size from Shields Curve at bankfull shear stress - Colorado Data (mm)	**0.5**
65	Largest particle size (mm) to be moved (D_{max}) (see #61: Particle Size Distribution of Bar Material)	**n/a**
66	Predicted shear stress required to initiate movement of D_{max} (mm) (Shields curve)	**n/a**
67	Predicted mean depth required to initiate movement of D_{max} (mm), $d = \tau/\gamma S$	**n/a**
68	Predicted slope required to initiate movement of D_{max} (mm) $S=\tau/\gamma d$	**n/a**
69	Dimensionless shear stress (τ^*) (see competence form)	**n/a**
70	Required mean depth d_{bkf} (ft) calculated using dimensionless shear stress equation for a given slope	**n/a**
71	Required slope S (ft) calculated using dimensionless shear stress equation for a given depth	**n/a**
72	Bankfull Unit Stream Power (lbs/ft/sec), $\omega = \tau\ u_{bkf}$	**0.20**
73	Bankfull Froude Number	**0.11**
74a	Mannings "n" @ Low Flow	**0.045**
74b	Mannings "n" @ 1/2 BKF	**0.032**
74c	Mannings "n" @ Bankfull	**0.030**

Remarks:

Table 10. Morphological characteristics of the existing and proposed meandering reach with reference reach data.

Restoration Site: **Kootenai River, Meandering Reach Design Station 462+00 to 2609+56** Reference Reaches: **Upper Priest River, & Bull River**						
Variables	**Existing Channel**		**Proposed Reach**		**Bull River Reference Reach**	
1 Stream Type	**F5**		**C4**		**E4**	
2 Drainage Area, mi^2	**11,740**		**11,740**		**n/a**	
3 Mean Riffle Depth, ft (d_{bkf})	Mean:	**19.5**	Mean:	**19.5**	Mean:	**5.7**
	Range:	**18 - 22**	Range:	**18 - 22**	Range:	**5 - 6.4**
4 Riffle Width, ft (W_{bkf})	Mean:	**550**	Mean:	**550**	Mean:	**52**
	Range:	**475 - 605**	Range:	**475 - 605**	Range:	**49 - 57**
5 Width/Depth Ratio (W_{bkf}/d_{bkf})	Mean:	**28.0**	Mean:	**28**	Mean:	**9**
	Range:	**23.0 - 34**	Range:	**23.0 - 34**	Range:	**8.1 - 10**
6 Riffle Cross-Sectional Area, ft^2 (A_{bkf})	Mean:	**10700**	Mean:	**10700**	Mean:	**295**
	Range:	**9500 - 13500**	Range:	**9500 - 13500**	Range:	**283 - 323**
7 Max Riffle Depth (d_{mbkf})	Mean:	**27.5**	Mean:	**27.5**	Mean:	**8.1**
	Range:	**24.5 - 31**	Range:	**24.5 - 31**	Range:	**7.5 - 8.8**
8 Max Riffle Depth/Mean Riffle Depth (d_{mbkf}/d_{bkf})	Mean:	**1.4**	Mean:	**1.41**	Mean:	**1.42**
	Range:	**1.3 - 1.6**	Range:	**1.30 - 1.60**	Range:	**1.32 - 1.54**
9 Mean Pool Depth, ft (d_{bkfp})	Mean:	**31.2**	Mean:	**31.2**	Mean:	**13.4**
	Range:	**28.3 - 35.1**	Range:	**28.3 - 35.1**	Range:	**12.2 - 15.0**
10 Mean Pool Depth/Mean Riffle Depth	Mean:	**1.6**	Mean:	**1.8**	Mean:	**2.4**
	Range:	**1.5 - 1.8**	Range:	**1.6 - 2.4**	Range:	**2.1 - 2.6**
11 Pool Width, ft (W_{bkfp})	Mean:	**585**	Mean:	**620**	Mean:	**56**
	Range:	**470 - 600**	Range:	**550 - 715**	Range:	**44 - 62**
12 Pool Width/Riffle Width	Mean:	**1.1**	Mean:	**1.1**	Mean:	**1.1**
	Range:	**0.9 - 1.1**	Range:	**1.0 - 1.3**	Range:	**0.8 - 1.2**
13 Pool Cross-Sectional Area, ft^2 (A_{bkfp})	Mean:	**16540**	Mean:	**16540**	Mean:	**471**
	Range:	**11500 - 18239**	Range:	**11500 - 18239**	Range:	**310 - 580**
14 Pool Area/Riffle Area	Mean:	**1.5**	Mean:	**1.5**	Mean:	**1.60**
	Range:	**1.1 - 1.7**	Range:	**1.1 - 1.7**	Range:	**1.1 - 2.0**
15 Max Pool Depth (d_{mbkfp})	Mean:	**55**	Mean:	**54.6**	Mean:	**13.4**
	Range:	**45 - 65**	Range:	**44.9 - 64.4**	Range:	**12.2 - 15**
16 Max Pool Depth/Mean Riffle Depth (d_{mbkfp}/d_{bkf})	Mean:	**2.8**	Mean:	**2.8**	Mean:	**2.4**
	Range:	**2.3 - 3.3**	Range:	**2.3 - 3.3**	Range:	**2.1 - 2.6**
17 Inner Berm Width, ft (W_{ib})	Mean:	**n/a**	Mean:	**200**	Mean:	**42**
	Range:	**-**	Range:	**-**	Range:	**37 44**

Table 10 (Meandering Reach Data) Page 2/5

	Variables	Existing Channel	Proposed Reach	Bull River Reference Reach
18	Inner Berm Width to Riffle Width (W_{ib}/W_{bkf})	Mean: **n/a** Range: **-**	Mean: **0.36** Range: **-**	Mean: **0.81** Range: **0.71 0.85**
19	Inner Berm Depth, ft (d_{ib})	Mean: **n/a** Range: **-**	Mean: **10.3** Range: **-**	Mean: **11** Range: **9.1 13.18**
20	Inner Berm Depth to Mean Riffle Depth (d_{ib}/d_{bkf})	Mean: **n/a** Range: **-**	Mean: **0.53** Range: **-**	Mean: **1.93** Range: **1.60 2.31**
21	Inner Berm Width/Depth Ratio (W_{ib}/d_{ib})	Mean: **n/a** Range: **-**	Mean: **0.36** Range: **-**	Mean: **12** Range: **11 17**
22	Inner Berm Cross-Sectional Area (A_{ib})	Mean: **n/a** Range: **-**	Mean: **3500** Range: **-**	Mean: **132** Range: **100 145**
23	Inner Berm Cross-Sectional Area to Riffle Cross-Sectional Area (A_{ib}/A_{bkf})	Mean: **n/a** Range: **-**	Mean: **0.33** Range: **-**	Mean: **0.45** Range: **0.34 0.49**
24	Low Bank Height (LBH)	Mean: **55** Range: **50 - 65**	Mean: **27.5** Range: **24.5 - 31**	Mean: **8.91** Range: **7.5 - 10.56**
25	Low Bank Height to Max Riffle Depth (LBH/d_{mbkf})	Mean: **2.0** Range: **1.8 - 2.4**	Mean: **1.0** Range: **-**	Mean: **1.1** Range: **1.0 - 1.2**
26	Width of Floodprone Area, ft (W_{fpa})	Mean: **650** Range: **600 - 750**	Mean: **1150** Range: **1050 - 1250**	Mean: **276** Range: **231 - 353**
27	Entrenchment Ratio (W_{fpa}/W_{bkf})	Mean: **1.2** Range: **1.05 - 1.14**	Mean: **2.1** Range: **2.0 - 2.3**	Mean: **5.31** Range: **4.71 - 6.19**
28	Point Bar Slope	Mean: **25%** Range:	Mean: **15%** Range:	Mean: **20-25%** Range:
29a	Bankfull Mean Velocity, ft/s (u_{bkf})	**2.80**	**2.80**	**~ 3.3**
30	Bankfull Discharge, ft^3/s (Q_{bkf})	**30000**	**30000**	**~ 1000**
29b	Low Flow Mean Velocity, ft/s (u_{bkf})	**1.19**	**1.19**	**n/a**
29c	1/2 BKF Mean Velocity, ft/s (u_{bkf})	**2.05**	**2.05**	**n/a**
31	Meander Length, ft (L_m)	Mean: **6500** Range: **1750 - 10954**	Mean: **6500** Range: **2750 - 10954**	Mean: **460** Range: **341 - 580**
32	Meander Length Ratio (L_m/W_{bkf})	Mean: **11.8** Range: **3.2 - 19.9**	Mean: **11.8** Range: **5.0 - 19.9**	Mean: **8.8** Range: **6.6 - 11.2**

Variables	Existing Channel	Proposed Reach	Bull River Reference Reach
33 Radius of Curvature, ft (R_c)	Mean: **1515** Range: **850 - 3103**	Mean: **1515** Range: **1140 - 3103**	Mean: **96** Range: **61 - 131**
34 Ratio of Radius of Curvature to Bankfull Width (R_c/W_{bkf})	Mean: **2.8** Range: **1.5 - 5.6**	Mean: **2.8** Range: **2.1 - 5.6**	Mean: **1.8** Range: **1.2 - 2.5**
35 Belt Width, ft (W_{blt})	Mean: **6500** Range: **3851 - 8520**	Mean: **6500** Range: **3851 - 7500**	Mean: **317** Range: **273 - 409**
36 Meander Width Ratio (W_{blt}/W_{bkf})	Mean: **11.8** Range: **7.0 - 15.5**	Mean: **11.8** Range: **7.0 - 13.6**	Mean: **6.1** Range: **5.3 - 7.9**
37 Individual Pool Length, ft	Mean: **3600** Range: **3000 - 6400**	Mean: **3600** Range: **3000 - 6400**	Mean: **136** Range: **106 - 162**
38 Pool Length to Riffle Width	Mean: **6.5** Range: **5.5 - 11.6**	Mean: **6.5** Range: **5.5 - 11.6**	Mean: **2.6** Range: **2.0 - 3.1**
39 Pool to Pool Spacing (based on pattern), ft (p-p)	Mean: **11500** Range: **6000 - 12672**	Mean: **11500** Range: **6000 - 12672**	Mean: **320** Range: **199 - 482**
40 Ratio of p-p Spacing to Bankfull Width (p-p/W_{bkf})	Mean: **20.9** Range: **10.9 - 23.0**	Mean: **20.9** Range: **10.9 - 23.0**	Mean: **6.2** Range: **3.8 - 9.3**
41 Riffle Length, ft	Mean: **n/a** Range:	Mean: **2680** Range: **2000 - 3500**	Mean: **75** Range: **54.2 82**
42 Riffle Length to Riffle Width (W_{bkf})	Mean: **n/a** Range:	Mean: **4.9** Range: **3.6 - 6.4**	Mean: **1.4** Range: **1.0 1.6**
43 Stream Length (SL)	**225000**	**214756**	**2100**
44 Valley Length (VL)	**119000**	**119000**	**1235**
45 Valley Slope (VS)	**0.0001**	**0.0001**	**0.0016**
46 Average Water Surface Slope (S)	**0.000058**	**0.000059**	**0.00013**
46b Low Flow Average Water Surface Slope (S)	**0.000060**	**0.000061**	**n/a**
46c 1/2 BKF Average Water Surface Slope (S)	**0.000059**	**0.000060**	**n/a**
47 Sinuosity (k)	SL/VL: **1.89** VS/S: **1.72**	SL/VL: **1.80** VS/S: **1.69**	SL/VL: **1.70** VS/S: **12.31**

Table 10 (Meandering Reach Data) Page 4/5

	Variables	Existing Channel	Proposed Reach	Bull River Reference Reach
48	Riffle Slope (water surface facet slope) (S_{rif})	Mean: **n/a** Range:	Mean: **0.0000708** Range: **0.000059 - 0.0000885**	Mean: **0.00016** Range: **0.0001 - 0.0002**
49	Ratio Riffle Slope to Average Water Surface Slope (S_{rif}/S)	Mean: **n/a** Range:	Mean: **1.20** Range: **1.00 - 1.5**	Mean: **1.23** Range: **1.00 - 1.5**
50	Run Slope (water surface facet slope) (S_{run})	Mean: **n/a** Range:	Mean: **0.00003894** Range: **0.0000354 - 0.00004425**	Mean: **n/a** Range:
51	Ratio Run Slope/Average Water Surface Slope (S_{run}/S)	Mean: **n/a** Range:	Mean: **0.7** Range: **0.6 - 0.75**	Mean: **n/a** Range:
52	Pool Slope (water surface facet slope) (S_p)	Mean: **0.00001** Range:	Mean: **0.00001** Range:	Mean: **0.00007** Range: **.00003 - .00009**
53	Ratio of Pool Slope/Average Water Surface Slope (S_p/S)	Mean: **0.1** Range:	Mean: **0.1** Range:	Mean: **0.5** Range: **0.23 - 0.7**
54	Glide Slope (water surface facet slope) (S_g)	Mean: **n/a** Range:	Mean: **0.00002** Range: **0.0000236 - 0.00002537**	Mean: **n/a** Range:
55	Ratio Glide Slope/Average Water Surface Slope (S_g/S)	Mean: **n/a** Range:	Mean: **0.4** Range: **0.4 - 0.43**	Mean: **n/a** Range:
56	Max Run Depth, ft (d_{run})	Mean: **n/a** Range:	Mean: **35.1** Range: **33.2 - 37.1**	Mean: **9.9** Range: **8.4 - 11.7**
57	Ratio Max Run Depth/ Bankfull Mean Depth (d_{run}/d_{bkf})	Mean: **n/a** Range:	Mean: **1.8** Range: **1.7 - 1.9**	Mean: **1.74** Range: **1.47 – 2.05**
58	Max Glide Depth, ft (d_g)	Mean: **n/a** Range:	Mean: **29.3** Range: **23.4 - 35.1**	Mean: **10** Range: **6.9 – 12.5**
59	Ratio Max Glide Depth/ Bankfull Mean Depth (d_g/d_{bkf})	Mean: **n/a** Range:	Mean: **1.5** Range: **1.2 – 1.8**	Mean: **1.75** Range: **1.21 – 2.19**
MATERIALS				
60	Particle Size Distribution of Channel Material (active bed)			
	D_{16} (mm)	**Sand < 2**	**n/a**	**0.05**
	D_{35} (mm)	**Sand < 2**	**n/a**	**0.88**
	D_{50} (mm)	**Sand < 2**	**n/a**	**1.4**
	D_{84} (mm)	**Sand < 2**	**n/a**	**4.68**
	D_{95} (mm)	**Sand < 2**	**n/a**	**8**

MATERIALS				
61	Particle Size Distribution of Bar Material			
	D_{50} (mm)	**n/a**	**n/a**	**n/a**
	D_{84} (mm)	**n/a**	**n/a**	**n/a**
	D_{max}: Largest size particle at the toe (lower third) of bar (mm)	**n/a**	**n/a**	**n/a**

SEDIMENT TRANSPORT VALIDATION (Based on Bankfull Shear Stress)		Proposed
62	Calculated shear stress value, lb/ft^2, (τ)	**0.07**
63	Moveable particle size from Shields Curve at bankfull shear stress - Original Data (mm)	**0.4**
64	Moveable particle size from Shields Curve at bankfull shear stress - Colorado Data (mm)	**0.5**
65	Largest particle size (mm) to be moved (D_{max}) (see #61: Particle Size Distribution of Bar Material)	**n/a**
66	Predicted shear stress required to initiate movement of D_{max} (mm) (Shields curve)	**n/a**
67	Predicted mean depth required to initiate movement of D_{max} (mm), $d = \tau/\gamma S$	**n/a**
68	Predicted slope required to initiate movement of D_{max} (mm) $S=\tau/\gamma d$	**n/a**
69	Dimensionless shear stress (τ^*) (see competence form)	**n/a**
70	Required mean depth d_{bkf} (ft) calculated using dimensionless shear stress equation for a given slope	**n/a**
71	Required slope S (ft) calculated using dimensionless shear stress equation for a given depth	**n/a**
72	Bankfull Unit Stream Power (lbs/ft/sec), $\omega = \tau\ u_{bkf}$	**0.20**
73	Bankfull Froude Number	**0.11**
74a	Mannings "n" @ Low Flow	**0.045**
74b	Mannings "n" @ 1/2 BKF	**0.032**
74c	Mannings "n" @ Bankfull	**0.030**

Remarks:

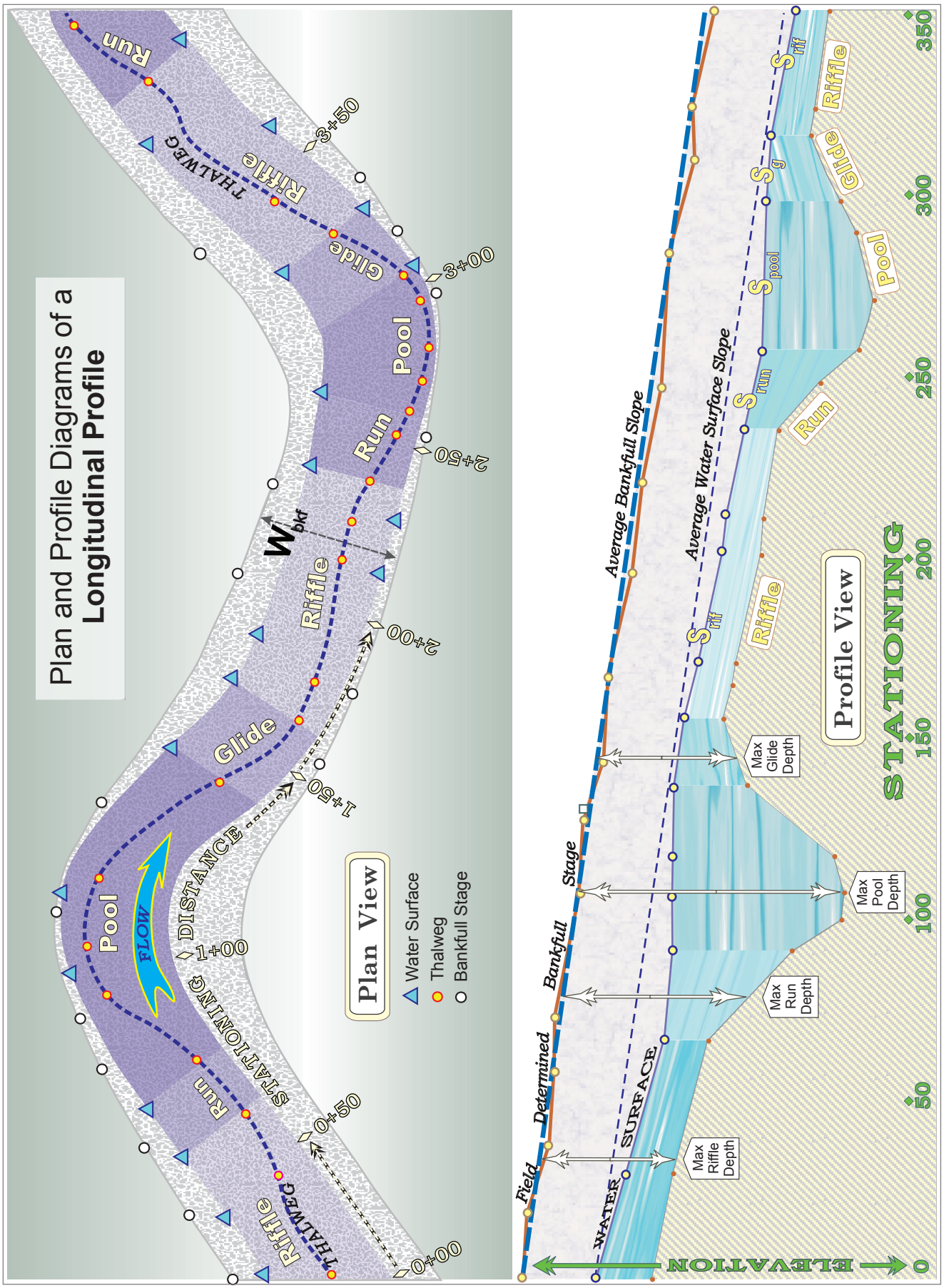


Figure 65. Schematic example of plan and profile views for a C4 stream type depicting the location, depth and slope of riffles, pools, runs and glides.

Sediment Analysis of Proposed Design (Capacity and Competence)

The FLOWSED and POWERSED models (Rosgen, 2006a, 2006b, 2007) were run for the proposed design under different sediment supply and Kootenay Lake backwater conditions. The design concept and variation in width/depth ratio for subsequent cross-sections trending down valley was to gradually deposit sediment in the inner berm surface of the channel and by side channels depositing sediment into the floodplain areas in oxbows and in wetlands that would naturally occur. The lower width/depth ratios and defined thalweg bounded by the inner berm feature should create high velocity gradients and strong secondary circulation (down-welling, which provides a high boundary shear stress to help maintain the maximum depth). The reduction in streambank erosion will also create a significant reduction in sediment supply. The 77,800 tons of sediment contributed from streambank erosion in the total reach length needs to be considered comparing existing versus proposed sediment budgets and the source of sediment supply. The goal is to prevent a major deposition fan or delta where the valley and channel slope reduces and/or is in the presence of backwater. In order to deepen the channel to encourage white sturgeon to migrate headward, it is imperative that the channel bed does not aggrade.

The existing sediment transport capacity reflects an exceptionally high sediment deposition rate in the braided reach (**Figure 72**). The factors that appear to have a significant effect are width/depth ratio and high versus low lake backwater (energy slope). For example, as the stream reach changed its width/depth ratio from 27 to 62 and the stream was influenced by high lake stage, 92% of the bedload sediment was deposited between station 159.5 and 156.7. When comparing how much bedload was deposited at the same station at low lake stage, 83% was deposited, which shows the sensitivity of width/depth ratio. It is difficult to prevent aggradation under either of these conditions.

The results of the sediment analysis based on this proposed design of a lower width/depth ratio showed a more gradual reduction in supply but not the same rate of deposition over a short distance (**Figure 73**). The low stage compared to the high stage for the same sediment supply and width/depth ratio is very sensitive (**Figure 72** and **Figure 73**). The data indicates that there is a feasible solution of sediment transport at low stage but not at the high stage of lake levels.

The encouraging results of this design approach is to gradually ***reduce the sediment supply*** (used to develop the sediment rating curves by location), but ***increase the sediment transport capacity*** in a single-thread meandering channel that has a high potential of maintaining its depth without a base-level change through aggradation. The procedure used in the model was to proportionately reduce the sediment supply from the higher width/depth ratio furthest upstream (**Figure 73**). As the stream distance increases, the width/depth ratio decreases to maintain a high sediment transport but with proportionately less sediment supply. The supply reduction for the design is primarily from streambank erosion and side channel/oxbow lake deposition. The sediment yield values are summarized in **Table 11**. The results of this analysis indicate that the proposed design at low lake stages, can prevent a sediment wedge at the lower end of the braided reach. The design appears feasible for both sediment capacity and competence.

The increase in streambank erosion through the reach is very significant but can be greatly reduced with the proposed design. A significant problem occurs, however, when due to high lake backwater levels occurring from Kootenay Lake, a major drop of both bedload and suspended sand load for high sediment supply occurs between stations 156.7 and 154 (**Figure 73**).

	Existing Conditions; Low Lake Level; Low Bedload Transport Rate (8.6lb/s)	Existing Conditions; Low Lake Level; High Bedload Transport Rate (33lb/s)	Existing Conditions; Low Lake Level; Low Suspended Transport Rate (15mg/l)*	Existing Conditions; Low Lake Level; High Suspended Transport Rate (85mg/l)*	Existing Conditions; High Lake Level; Low Bedload Transport Rate (8.6lb/s)	Existing Conditions; High Lake Level; High Bedload Transport Rate (33lb/s)	Existing Conditions; High Lake Level; Low Suspended Transport Rate (15mg/l)*	Existing Conditions; High Lake Level; High Suspended Transport Rate (85mg/l)*	Design Conditions; Low Lake Level; Low Bedload Transport Rate (8.6lb/s)	Design Conditions; Low Lake Level; High Bedload Transport Rate (33lb/s)	Design Conditions; Low Lake Level; Low Suspended Transport Rate (15mg/l)*	Design Conditions; Low Lake Level; High Suspended Transport Rate (85mg/l)*	Design Conditions; High Lake Level; Low Bedload Transport Rate (8.6lb/s)	Design Conditions; High Lake Level; High Bedload Transport Rate (33lb/s)	Design Conditions; High Lake Level; Low Suspended Transport Rate (15mg/l)*	Design Conditions; High Lake Level; High Suspended Transport Rate (85mg/l)*	Existing Conditions; Bank Erosion Total Annual Erosion Yield = 152,500 Tons/YR
159.505	28,842	111,109	70,689	400,634	28,842	111,109	70,689	400,634	28,842	111,109	71,226	403,671	28,842	111,109	71,226	403,671	228
159.5																	
158.80									13,125	50,512	49,092	278,173	13,125	50,512	49,092	278,173	3,432
156.70	5,061	19,476	18,297	103,680	2,527	9,725	14,614	82,805	8,281	31,860	45,373	256,887	8,281	31,860	45,373	256,887	15,255
155.86									2,817	10,847	22,385	126,709	580	2,222	11,811	67,024	10,402
154.03	843	5,621	7,229	25,530	-	-	3,938	15,133	1,843	6,876	17,647	99,780	149	627	5,412	30,827	28,897
152.42									478	2,033	9,479	53,603	7	149	2,609	14,928	21,493
150.03	7	386	1,569	15,562	-		1,678	-	-	292	3,332	18,969	-	-	959	5,329	8,772
143.99									-	-	357	2,890	-	-	-	496	38,945
140.00																	25,064

* Suspended Sediment Values Exclude the Washload (Sediment Smaller than 0.062 mm)

Table 11. Summary of annual sediment yields by location for high and low sediment supply and lake levels.

River Structures

Objectives of Structures

River structures are designed and recommended for the following specific objectives for the Kootenai River restoration project:

1. Provide instream cover for fish
2. Provide a food and nutrient base
3. Decrease near-bank stress for streambank erosion reduction
4. Provide for off-channel diversion of flow into floodplains and oxbow lakes
5. Create hydraulics to keep sand in transport and to clean off sand to expose coarser substrate
6. Provide roughness to reduce streambank erosion
7. Hold streambanks intact to buy time for riparian vegetation establishment for improved rooting depth and density
8. Grade control

The types of structures designed for this project include:

- Toe wood/sod mats
- Rock vanes
- J-hook vanes
- W-weirs
- Cross vanes (for tributary grade control– not for main river)
- Root wad/log vane J-Hook (for tributaries)
- Step pool structures (located at outflow of oxbow lakes)

Toe Wood/Sod Mats

Toe wood/sod mats are designed to add roughness for preventing fluvial entrainment of bank material, instream cover for fish, a nutrient base, benthic habitat, survival of eggs, larvae, juveniles, protection from predation, high and low flow refugia, aesthetic appeal and a natural solution that occurs on many riparian forested ecosystems. The plan-view and side-view drawings are shown in **Figure 74** and **Figures 75a**, **75b** and **75c**.

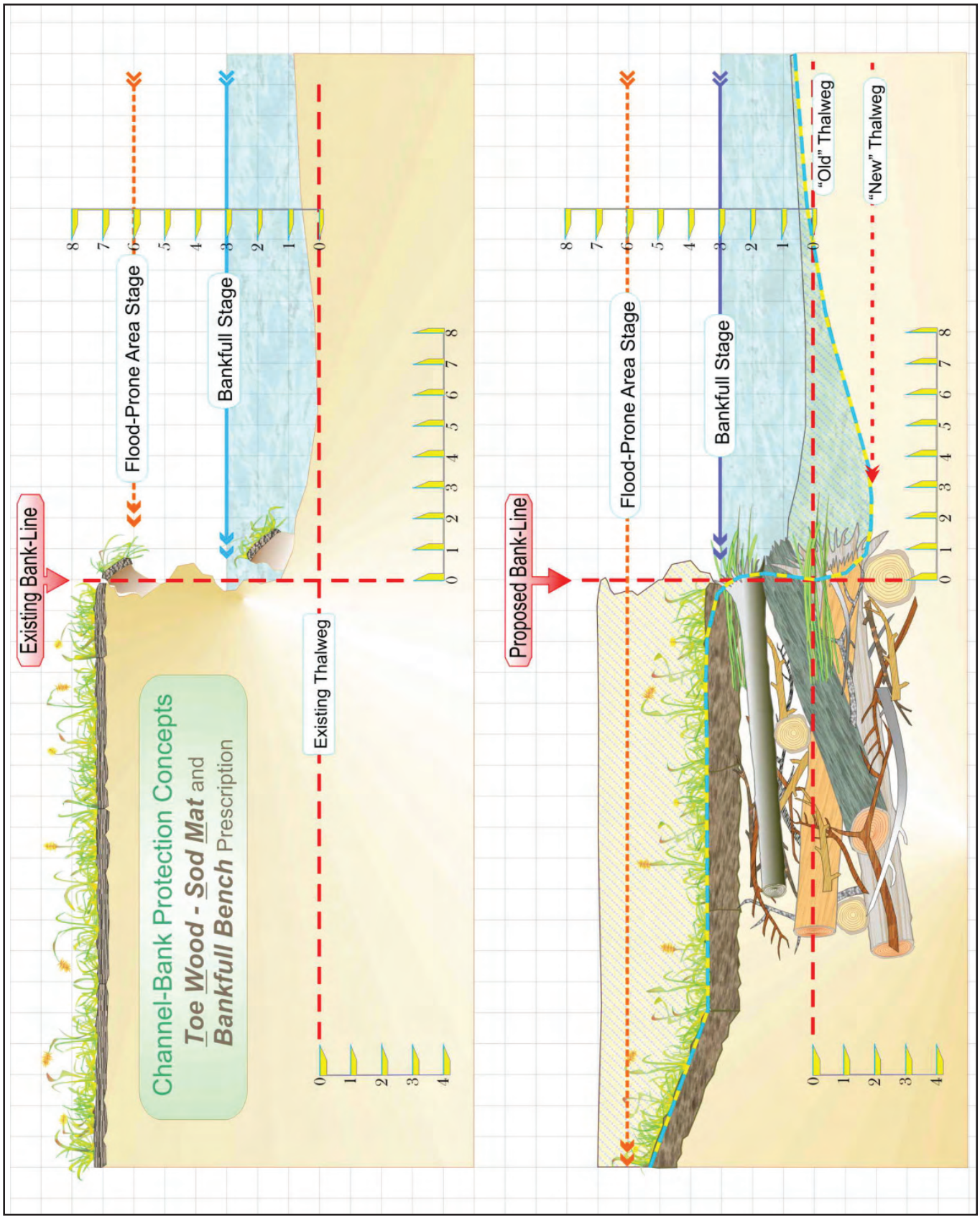


Figure 74. Section view of the toe wood/sod mat river structure.

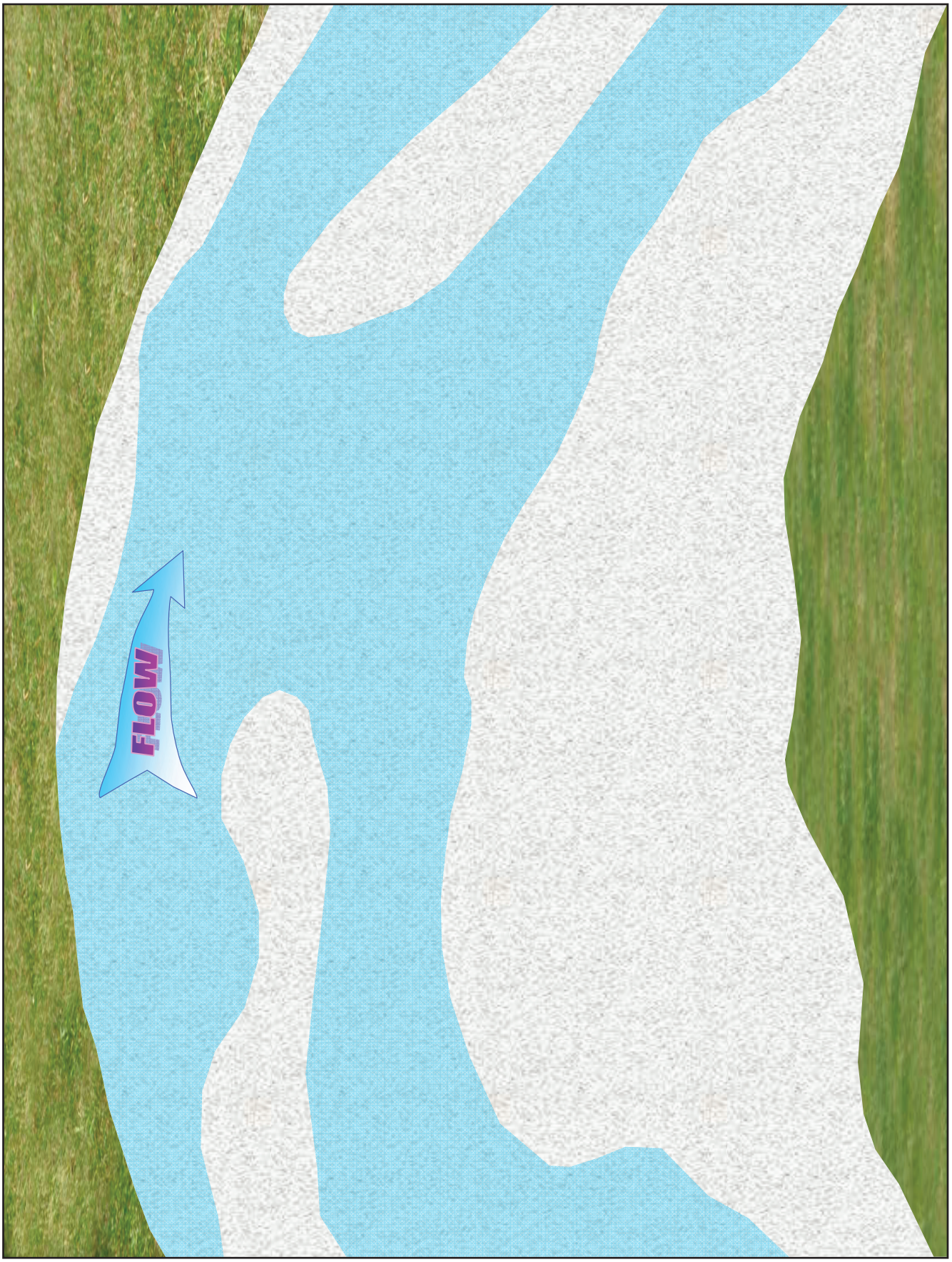


Figure 75a. A plan view example of installation of the toe wood/sod mat river structure with willow cuttings; current view shows river before installation.

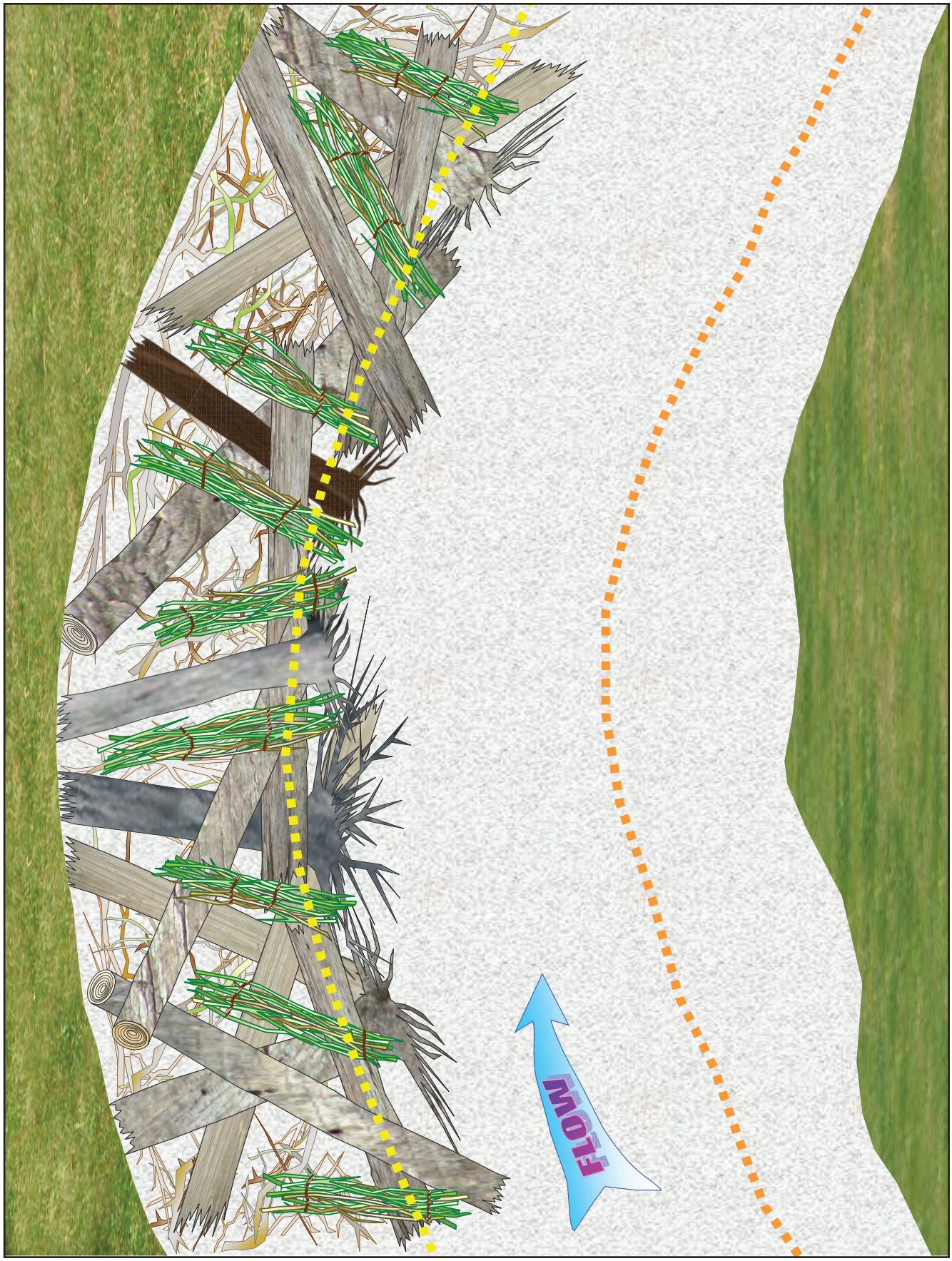


Figure 75b. Continuation of toe wood/sod mat river structure showing bedding of submerged large wood on outside of bend.

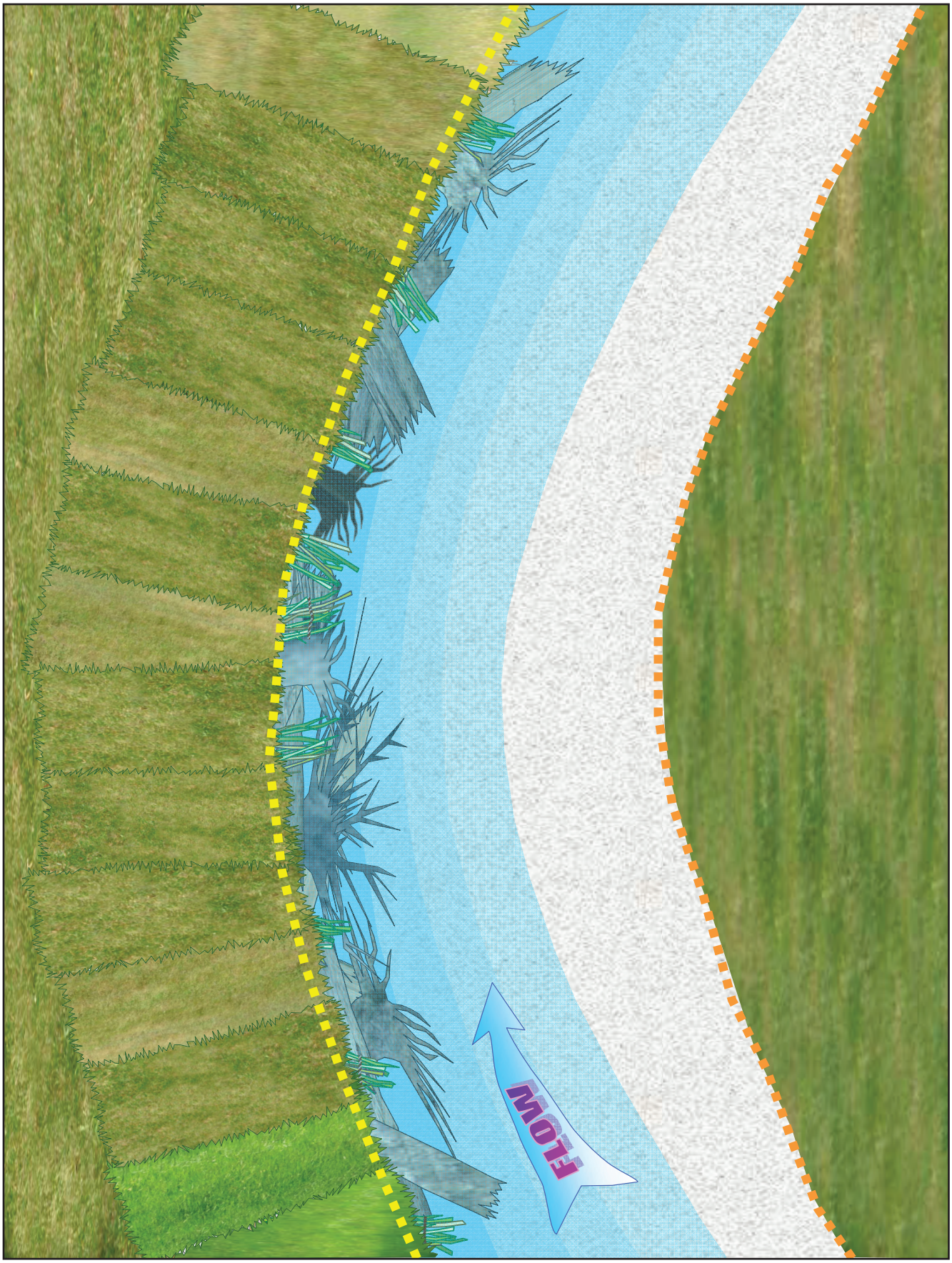


Figure 75c. Finished toe wood/sod mat river structure with submerged, exposed wood overlain with willow cuttings and sod mats.

Rock Vanes

Rock vanes are designed to decrease near-bank shear stress and high velocity gradient to reduce streambank erosion. This structure protects the bank up to 2.5 to 3 times its vane length. The rock vanes substitute for rip-rap, gabions, longitudinal toe rock and other hard control bank revetments. An example of a rock vane is shown in **Figure 76**. A combination of alternating rock vanes is designed for the thalweg channel bounded by inner berm banks as shown in **Figure 77**. This figure also shows the bankfull banks being stabilized with woody debris. In conjunction with toe wood, this is similar to what is being proposed in the straight reach where no floodplain can be created due to development. The alternating rock vanes are designed to create a shear force to clean the sand off of gravel, cobble and the rocks making up the structure.

J-Hook Vanes

J-hook vanes are modified from a standard design for the Kootenai for the purpose of diverting water into side channels and into oxbow lakes (**Figure 78**). The structure creates a differential head so as to present water to the diversion channel at lower flows. The width and elevation of the thalweg of the side channel determines the amount of free-flowing water that will be diverted. Plan sheets show exact locations of the use of the J-hook vane for diversion.

W-Weirs

W-weirs are recommended for use on the Kootenai River for bridge pier scour reduction protection. The structure would be placed upstream of the bridge piers with the vane arms tying into the bankfull stage on a newly created floodplain. The use of this structure directs the high shear stress and stream power in the center of the channel in between center piers. The center of the structure builds a bar in front of the pier to reduce high shear stress (**Figure 79** shows a plan view sketch of a W-wier and a double W-weir in front of the Hwy 95 and railroad bridge in the straight reach). Details of this structure are shown in **Figures 80**. These structures have been successfully implemented on many bridges on large rivers over the last 12 years, performing as designed through many large floods (e.g., on the San Juan and Little Snake Rivers in Colorado). The W-weir will also have several deep and well-defined thalwegs, which will encourage sturgeon migration. Research on the use of W-weirs was conducted by Johnson *et al*. (2002) at Penn State University for bridge pier scour protection.

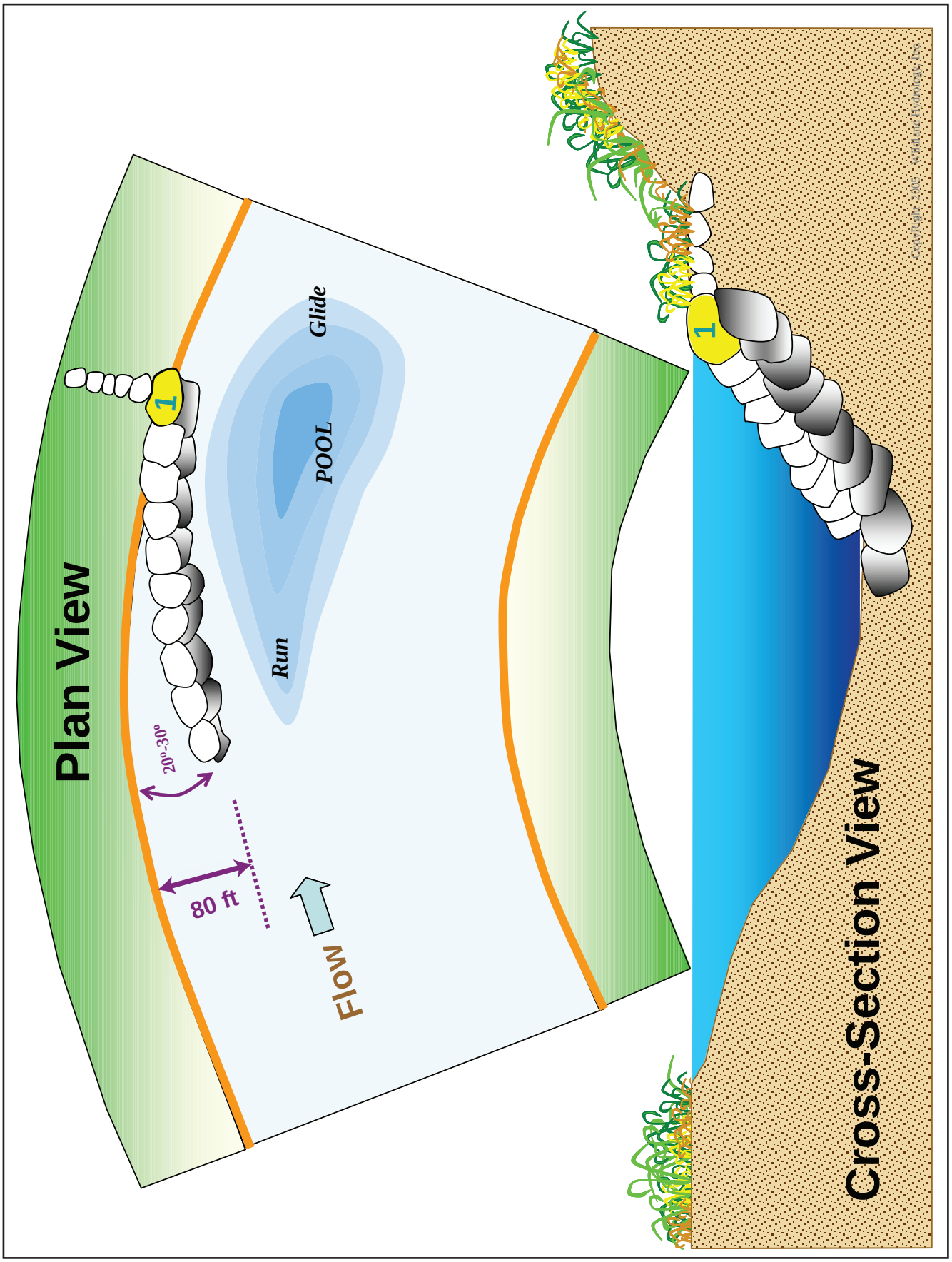


Figure 76. Plan and section view of a rock vane used on the Kootenai River to protect new fill on the outside of a bend. The structure decreases near-bank stress and buys time for vegetation establishment.

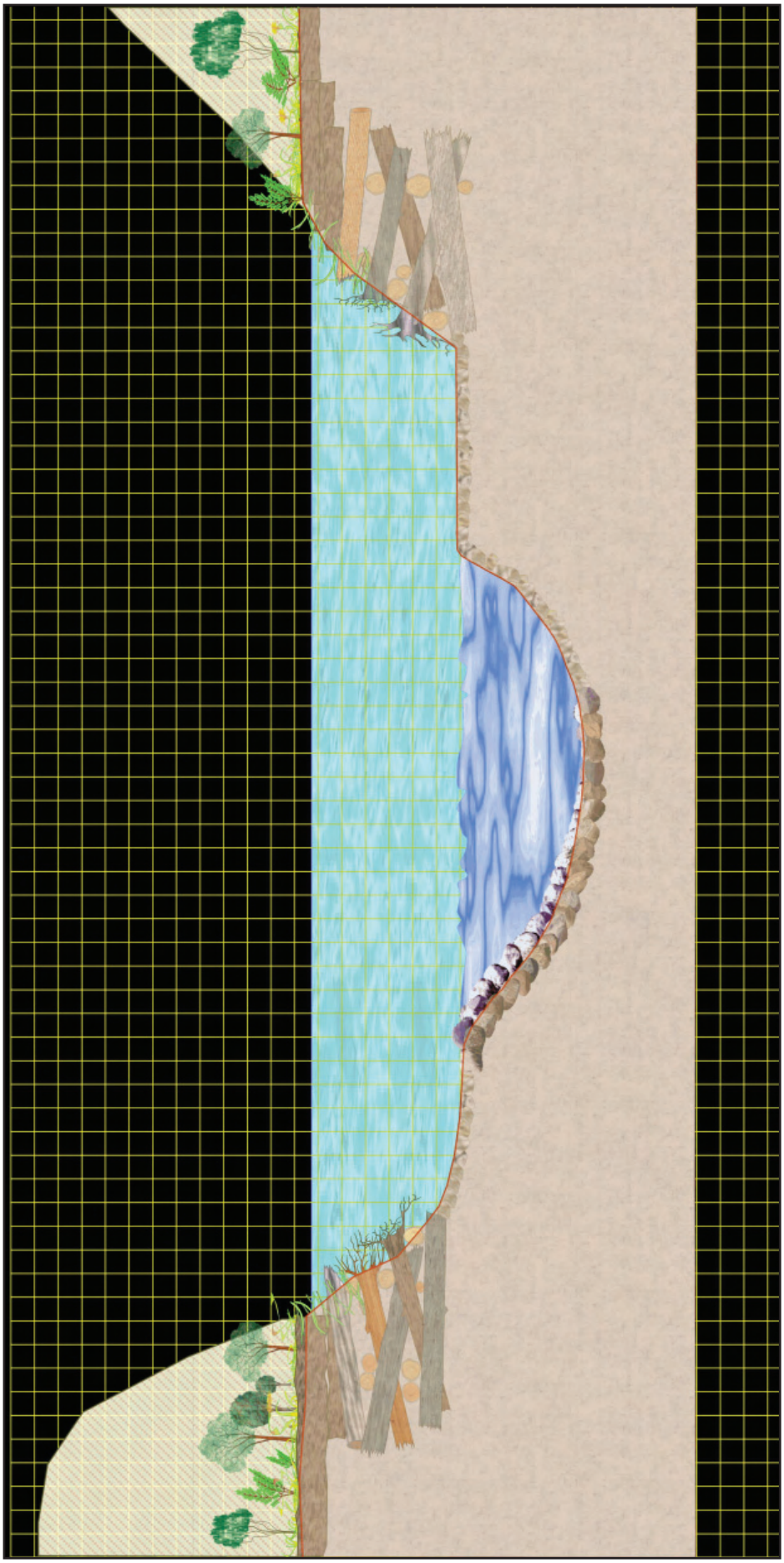


Figure 77. Use of alternative rock vanes inside inner berm (low flow) channel to be used in the straight reach on the F4/5/1 stream type.

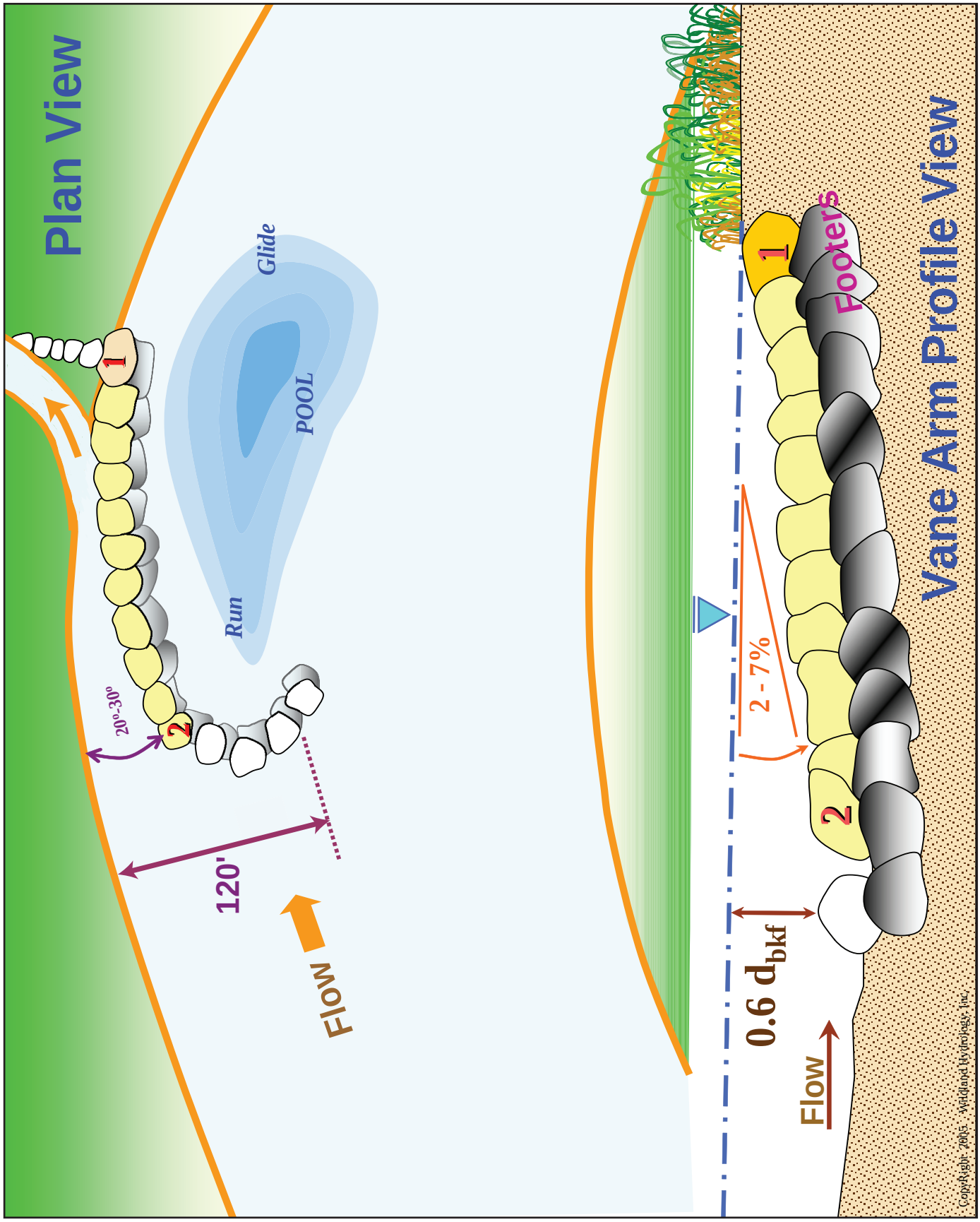


Figure 78. Plan and profile view of a J-hook vane used on the Kootenai River for flow diversion onto floodplains.

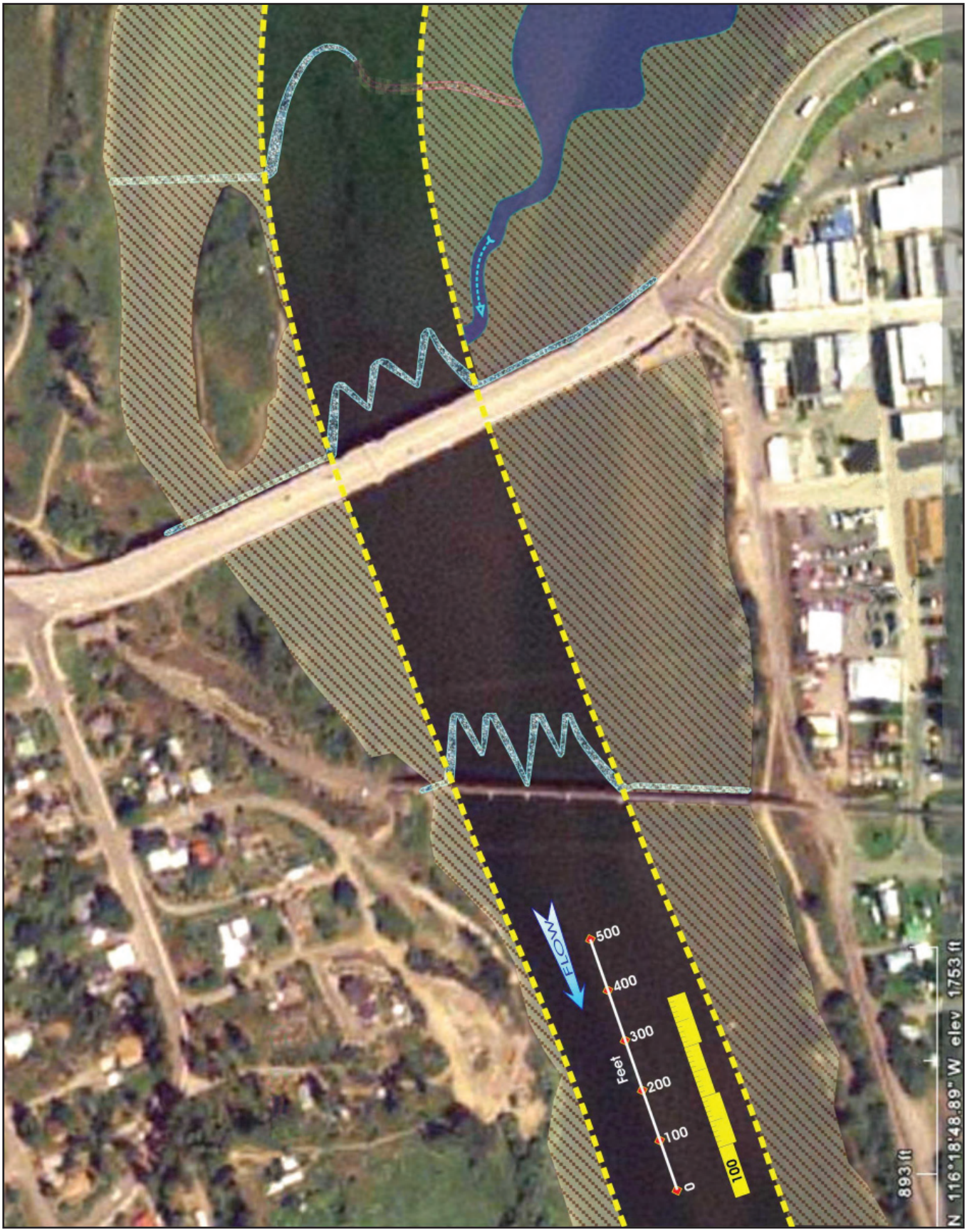


Figure 79. Adaptation of a double W-weir (Hwy 95) and a series of two W-weirs (railroad bridge).

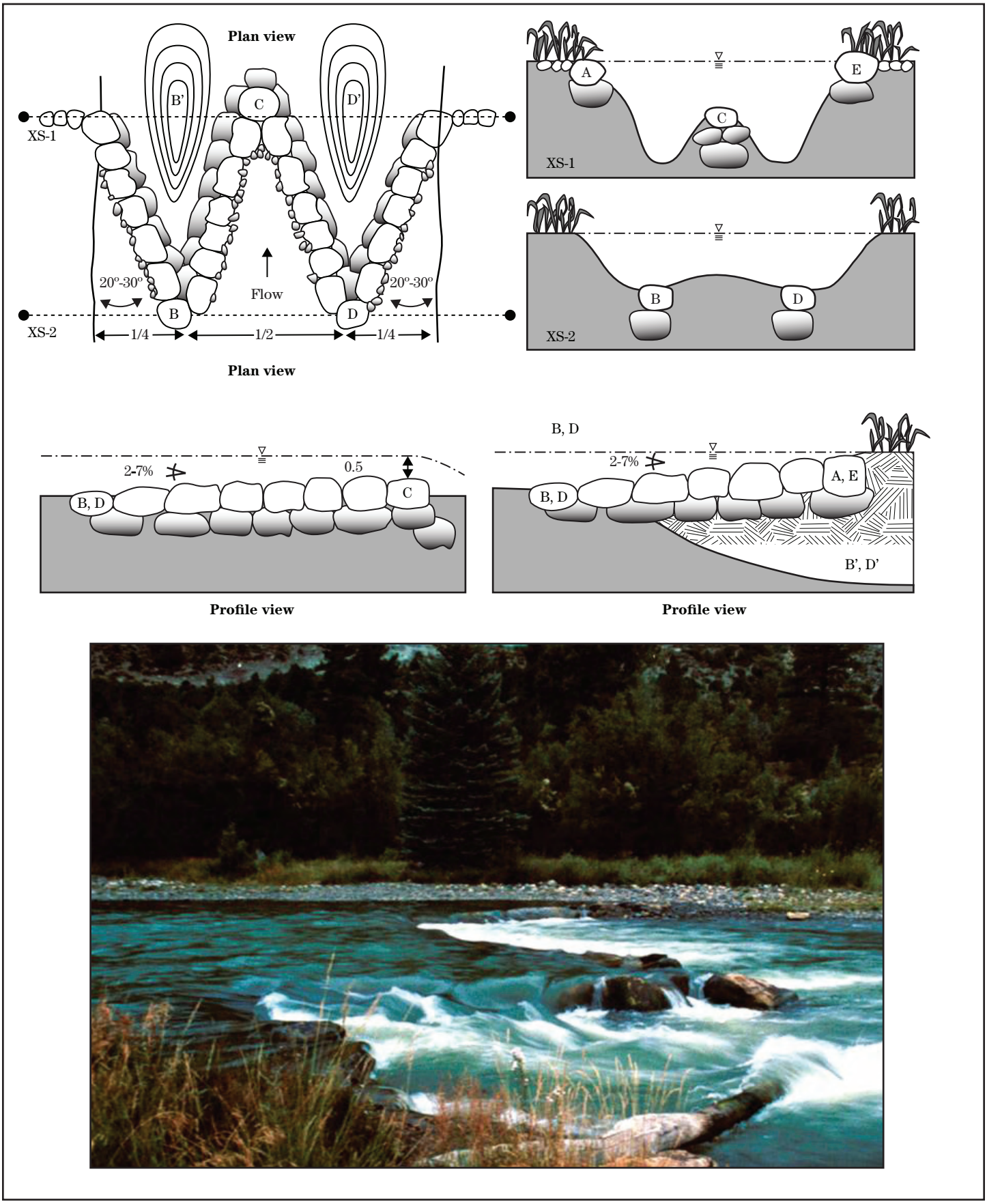


Figure 80. Details of a W-weir including plan, cross-section and profile views and a photograph of an installed W-weir (Rosgen, 2007).

Cross Vanes

Cross vane structures are used for grade control on tributary streams to the Kootenai River. Examples of cross vane details are shown in **Figure 81**. Photographs of various adaptations of cross vanes are shown in **Figures 82a**, **83b**, **82c** and **82d**.

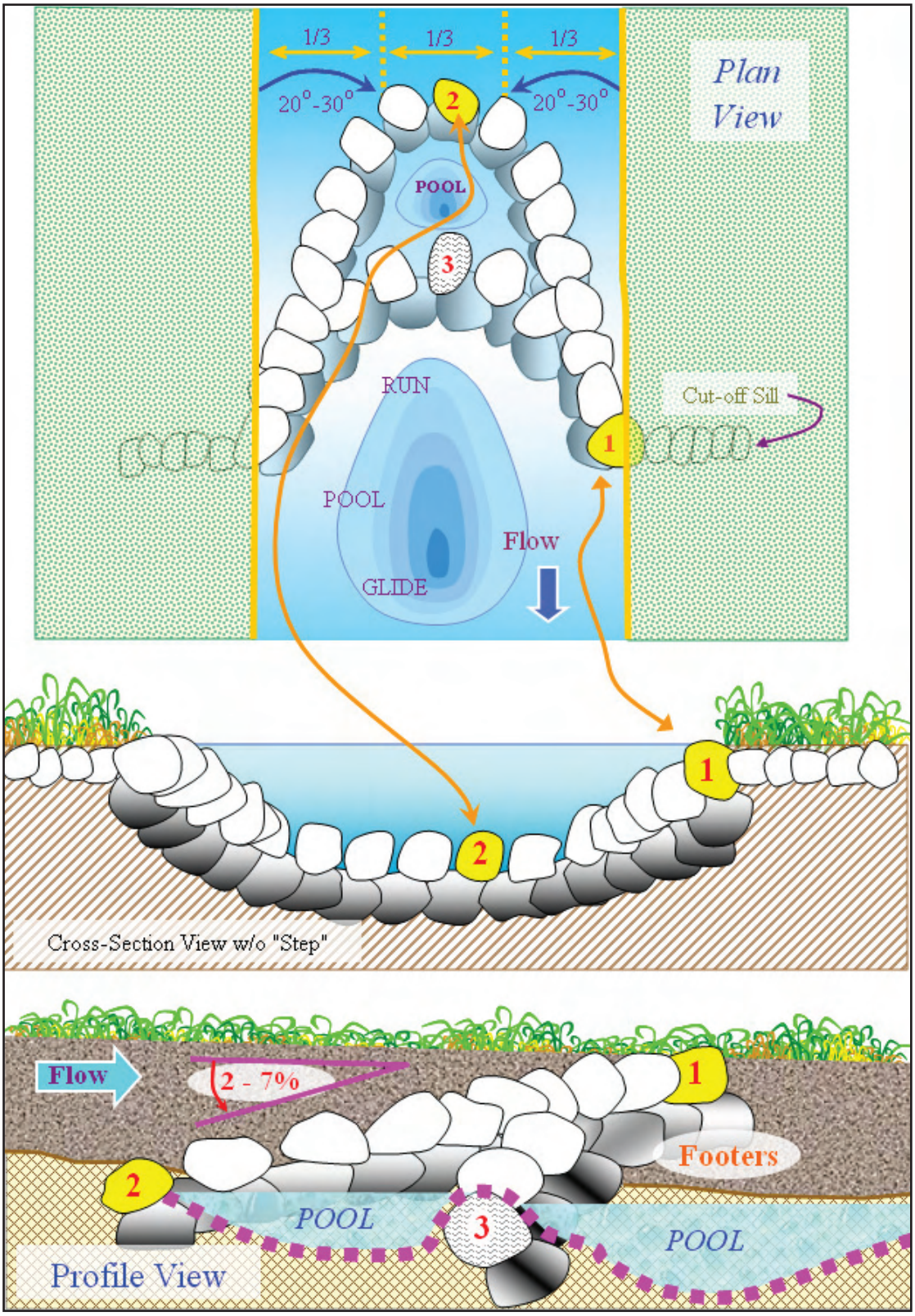


Figure 81. Plan, cross-section and profile views of the cross-vane structure for use on tributary streams for grade control (Rosgen, 2007).

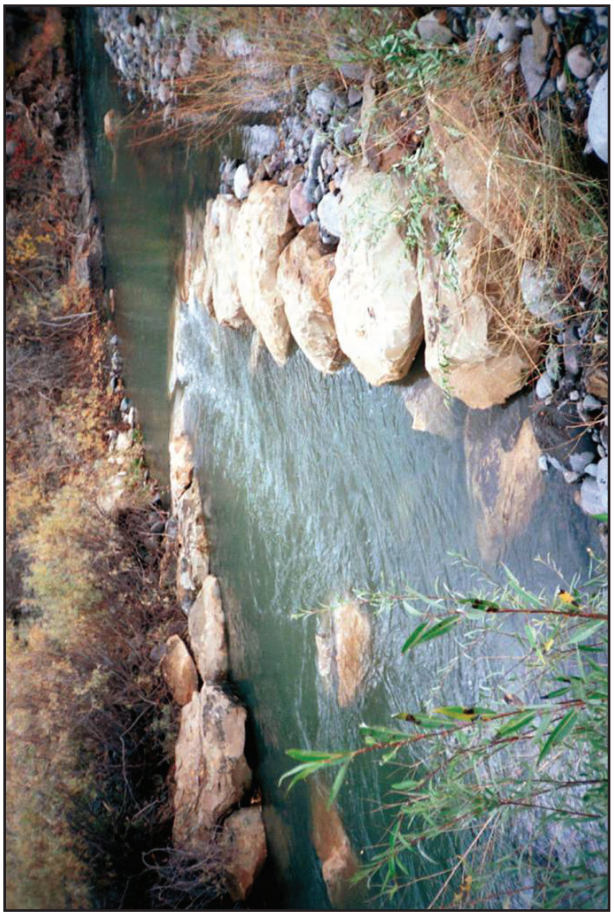


Figure 82a. Cross-vane installed on the lower Blanco River, Colorado.

Figure 82b. Cross-vane/step-pool on the East Fork Piedra River, Colorado.

Figure 82c. Cross-vane structure with step on the East Fork Piedra River, Colorado.

Figure 82d. Cross-vane/root wad/log vane step-pool converting a braided D4 to C4 stream type on the East Fork Piedra River, Colorado.

Root Wad/J-Hook Log Vane

This structure is appropriate for streambank stability and habitat improvement for application on the tributaries to the Kootenai River (**Figure 83**).

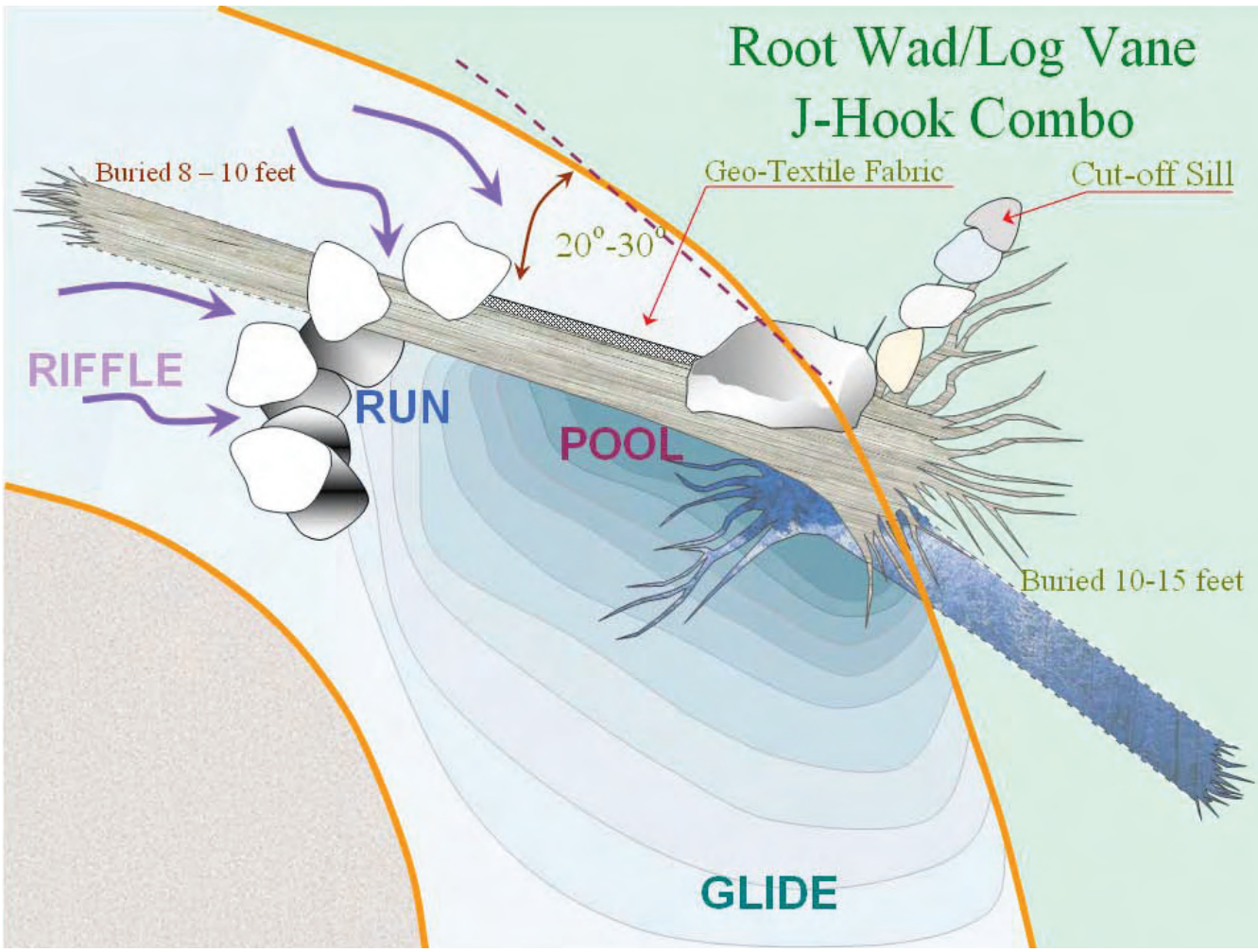


Figure 83. Example of rood wad/log vane, J-hook combo for tributaries to the Kootenai River (Rosgen, 2007).

Step/Pool Structures

These are grade control structures to be used with culverts and for the G and steeper F stream types for the tributary streams that are prone to headcutting (incision). Examples are provided in the photographs in **Figure 84a** and **Figure 84b**.

Figure 84a. Example of a constructed step/pool channel.

Figure 84b. Example of a grade control step/pool structure.

Discussion of the Design Recommendations for Each Unique Reach Morphology

The Braided Reach

This reach of the Kootenai River would normally or historically be a braided (D4) stream type. However, due to the reduced sediment supply and peak flows, a C4 stream type may be a more compatible morphology for this terraced/alluvial valley type that can support either stream type. A single-thread, meandering (C4) stream type would also be best suited to meet the fisheries objective and to reduce streambank erosion. The high width/depth ratio of the braided reach that is associated with a low mean depth and velocity and corresponding unit stream power will continue to deposit sediment and maintain bed features of convergence/divergence. This morphology will continue to have excess sediment deposition as shown in the POWERSED runs and field evidence, corresponding with accelerated bank erosion as shown in the USGS time-trend study of the post-Libby Dam conditions (Barton, 2005). The change in the controlling variables and boundary conditions of sediment and streamflow that has maintained the braided morphology would best support a C4 stream type. The sediment regime change from both the Libby Dam and the Moyie River has significantly reduced the historic sediment loads. The stream is over-sized for the new flows and as such, lateral erosion, meander migration and channel enlargement have and will continue be the dominant processes unless restored. The planned restoration is designed to reduce sediment supply from the very high streambank erosion and other obvious, treatable sediment sources. The lower width/depth ratio would allow for some natural sediment deposition in the channel and in the floodplain channels and oxbow lakes.

The habitat diversity created by the single-thread channel and floodplain features would be beneficial for the Sturgeon and other emphasized species. The key to this D4 to C4 conversion is the created increased depth, higher turbulence, increased velocity and coarser substrate that would potentially meet the suitable habitat and migration criteria for the white sturgeon.

The planned toe wood, willow cuttings and transplants along specified locations on the banks of the C4 stream type would provide good habitat and a food base and would also help reduce the bank erosion until the vegetation becomes established for the long term stability and function. The established floodplain would provide for overbank flooding for cottonwood recruitment and fine sediment deposition. The author has conducted major river restoration projects of converting D4 braided channels to C4 meandering types. One of these projects on the South Fork of the Little Snake River, Colorado, that converted a D4 to a C4 for 10 miles, involved total reconstruction of the channel. This project was monitored for 5 years by the Engineering and Fisheries Departments of Colorado State University (Bledsoe and Meyer, 2005). This restoration project was a very successful braided river to meandering conversion, as documented by the five-year monitoring program. The Blanco River restoration was also a successful D4 to C4 conversion project although the upstream sediment supply was kept at very high levels (Berger, 1992). These projects, though completed on smaller rivers than the Kootenai River, are sustainable, natural channel design projects similar to the proposed design on the Kootenai River. All of these D4 to C4 conversion projects have improved fishery habitat and floodplain function. The proposed layout of the new C4 stream type is shown in **Figures 69a** and **69b** and is shown in detail in the plan and profile sheets in *Appendix VI*.

Straight Reach

This reach is entrenched with a high width/depth ratio that promotes sediment deposition. The POWERSED model indicates excess deposition of suspended sand. The sand plumes obvious in this reach have overlain a gravel and cobble sub-surface bed material. Sturgeon have been observed in this reach but do not appear to advance upstream into the shallower upstream end. The proposed design is to construct an inner berm channel of approximately 180 ft to accommodate approximately 5,000–6,000 cfs. The cobble/gravel material will be imported from the oxbow lake excavation of the braided reach. This will help to transport fine sands through the reach and to scour sands from the coarse gravel underlying the sand. Alternating rock vanes are planned to create turbulence, great depth and the hydraulics to keep the rocks, cobble and gravel exposed for potentially more suitable substrate as well as instream cover. The alternating rock vanes will also help protect the banks of the inner berm channel from erosion by decreasing near-bank shear stress. Toe wood logs and root wads will also be placed in between the vanes for instream cover and on upper bankfull banks where needed for additional function as previously described.

The shaping of this channel is shown in **Figure 77** in conjunction with alternating rock vanes within the inner berm channel. The plan view of the proposed channel work is shown in **Figure 70** and in the plan and profile sheets in *Appendix VI*. An example of the proposed shaping of the channel and floodplain under the bridges is shown in **Figure 85** where a constructed floodplain as designed is depicted in this enhanced photograph. The W-weir or pier stabilization structures would be added to reduce any potential pier scour. The piers that would be buried in the floodplain would not be at any risk. The persistent backwater may preclude the need for pier stabilization.

Figure 85. A simulation of a new floodplain constructed under the bridges in the straight reach.

Meandering Reach

The meandering reach is an entrenched F5 stream type that is designed to be converted to a C5 stream type. This involves converting an entrenched, meandering channel to one with a floodplain. At the stage associated with 30,000 cfs (new post-Libby Dam bankfull), the terrace and/or levee is planned to be lowered to construct a floodplain. This will reduce flood stage by several feet as will be demonstrated in the flood-level studies. This will also allow the tributaries, overland flow and other natural drains to operate without pumping behind existing levees. The bank heights will be reduced and revegetation is planned for the streambank and riparian zone. Toe wood/sod mats with willow cuttings are planned to be installed in regions of high near-bank stress and high erodibility. **Figure 86** shows the typical conversion from the F5 to C4 stream type and newly constructed floodplain. Some of the floodplains will be shaped to created depressional wetlands and some will have side channels and oxbows with flow through structure.

The extent of the proposed channel alignment is shown in **Figure 71a** through **Figure 71d**. Some of the radius of curvatures are too tight to be stable (with R_c / W ratios less than one bankfull width). The details on the alignment and structure location and design details are shown in the plan and profile sheets in *Appendix VI*.

Shorty's Island (within the meandering reach) is a critical habitat location for spawning sturgeon. In this location only is a design that involves the construction of an inner berm low flow channel with alternating rock vanes (as in the straight reach). The use of toe wood in conjunction with the rock vanes hopes to provide more suitable coarse substrate and wood debris that may help in the recruitment issues. It is not advisable to make a gravel/cobble and boulder channel in a glacio-lacustrine valley in a sand-dominated system. This is being done only due to the possibility that the sturgeon are fingerprinted to spawn at this site and they may not choose to migrate further upstream into more suitable habitat in steeper gradient gravel/cobble substrate reaches (C3, C4, B2 and B3 stream types that occur upstream). Typical shaping and instream structures are shown in **Figure 77** and **Figure 87**. Design details are shown in the plan and profile sheets in *Appendix VI*.

The tributaries in the meandering reach are incised at their confluence with the Kootenai River. It is recommended to install step/pool structures to encourage fish to use these tributaries and to reduce the erosion from the bed and banks. Some of the incision is developed from a lowered base level from dredging, while other reasons have to do with channelization, straightening, over grazing or direct disturbance to stream channels.

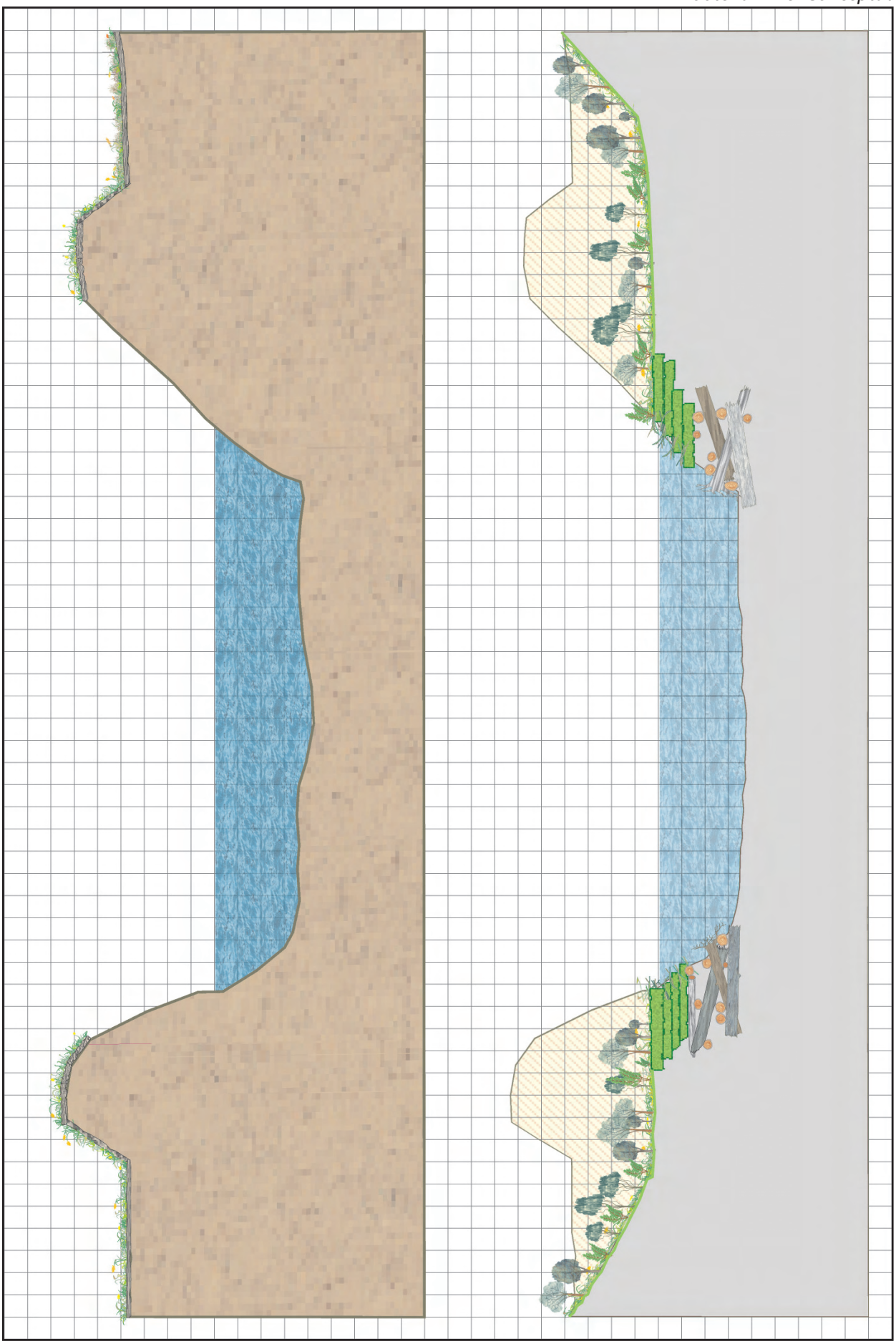


Figure 86. Contrast of existing vs. proposed example of typical cross-section to convert the F5 stream type to C5 stream type. Note the toe wood and levee removal with new floodplain.

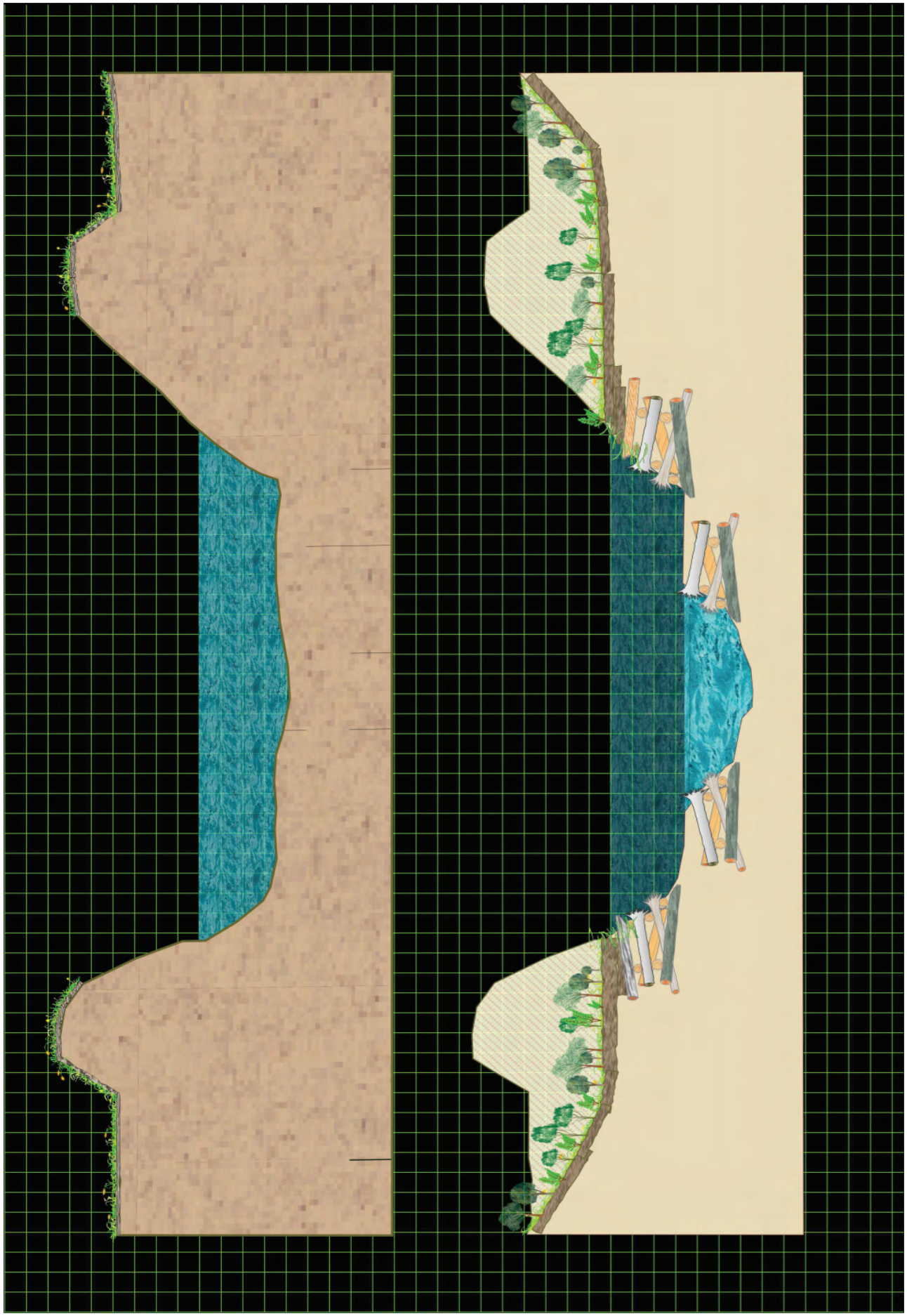


Figure 87. Typical channel shaping at Shorty's Island constructing an inner berm with the toe wood and alternating rock vanes.

Flood Level Analysis for Proposed Design

A flood level study using HEC-RAS was done to compare the proposed design conditions to the existing conditions for a variety of discharges and downstream lake levels. Flooding on this river is controlled by the operational regulation and management of both the upstream and downstream dams. The existing USGS HEC-RAS model (Berenbrock, 2006) was used as a basis for the comparison of concept design to existing conditions.

Upstream, the flow is controlled by Libby Dam and is managed so that hundred year stage is not exceeded in Bonners Ferry as well as various other locations on the Kootenai flats. Downstream, Corralynn Dam controls the lake level of Kootenay Lake in the Canadian providence of British Columbia.

The combination of the lake level and the flow will produce various stages that are unique to this back water system. Refer to the back water summary of the Klockman Ranch, USGS gauge (**Figure 46**). The design of this restoration relates to flooding in two ways: first by increasing the riparian floodplain to try to reduce stage and possibly remove the levies and pumps. Also, the design would increase the conveyance of the channel to reduce flood stage.

The proposed reaches are discussed from downstream to upstream due to the nature of the backwater analysis used in the HEC-RAS model.

Meandering Reach

The proposed restoration of the meandering reach includes creation of a 500+ foot floodplain at the existing 30,000 cfs bank full stage. This flow corresponds with a lake level of 1745 ft at the Porthill USGS gauge. The 500 foot floodplain was decided upon based on the existing bankfull width of the channel, the desired entrenchment ratio and the resulting reduction of flood stage at Ambush Rock. The existing thalwag elevation and bankfull dimensions of the meandering reach are comparable to the existing conditions.

Floodplain size was varied and HEC-RAS model runs were completed to analyze the existing energy grade line from river mile 106 to mile 151.5. **Figure 88** shows the flood stage reduction at Ambush Rock, river mile 151.5, based on a design width of a newly graded floodplain at the existing bankfull elevation.

Various HEC-RAS runs, with a newly created floodplain from 100-800 feet of new floodplain width, were modeled at high lake level stage. This was determined from the Porthill gauge, which was 1,760 feet and a corresponding flow of 65,000 cfs flowing through the system. This flow of 65,000 cfs is greater than the one hundred year flow reported by Army Corp of Engineers at Bonners Ferry, which is approximately 58,000 cfs. Due to the nature of the downstream backwater, the Army Corp of Engineers does not have a typical 100-year flow calculated for these reaches of the Kootenai River, but they do have 100-year stages for various locations on the river. Based on the analysis downstream HEC-RAS runs and the bank full width of 450 to 550 feet, the proposed floodplain design uses as newly graded floodplain width 500 feet to reduce the stage at Bonners Ferry by 3.5 feet.

This design will allow for the removal of all of the levies in the meandering reach without allowing the flood flows to reach the former flood plain or the terrace, which includes homes and agricultural land. **Figure 89** shows the existing versus designed floodplain stages at high

and low lake level for both 30,000 and 65,000 cfs. Due to the dimension of the channel below bankfull being nearly constant, there is no reduction of stage at 30,000 and low lake level in the meandering reach. As the downstream stage increases for the flood flows, water will flow onto the newly created floodplain with a higher resistance to flow than the existing channel. At lower lake level flows below 65,000 cfs, a smaller reduction of flood stage is shown compared to the high lake levels with the same flow. At the 65,000 cfs with a high lake level, the reduction in stage, based on the conceptual design, will be 0 to 3.5 feet.

Straight Reach

The straight reach from river mile 151.5 to 153.2 is laterally confined by bedrock and the town of Bonners Ferry. Based on the confinement of the reach, it will not allow for the creation of a new 500 foot floodplain. The resulting design will convert an F stream type into a B little C stream type with a varying entrenchment ratio less than 1.9. The thalwag is graded at a lower elevation and the slope of this reach has been made steeper to increase conveyance and decrease stage. **Figures 90** and **91** show the flood level profiles of the conceptual design for the meandering reach, which is river design stationing 365.00 to 450.00. Through this reach the flood stages for all flows including the high lake level of 65,000 cfs will be reduced with the proposed design.

Braided Reach

The proposed design of the braided reach includes channel realignment and an adjustment of the dimension, pattern and profile of the river. **Figures 90** and **91** show the floodplain reduction based on the 65,000 cfs with high lake level compared to existing conditions. The width/depth ratio of this reach was significantly decreased, which increases conveyance and sediment transport capacity. The resulting flood stage will allow for the removal of all levies throughout this reach with a flood stage reduction varying from 2 to 3.5 feet below the existing flood stage for 65,000 cfs.

Summary

In summary, the conceptual design will create a large floodplain downstream that will reduce the stage at Ambush Rock. This will also reduce the backwater effect and increase the energy grade line through the upstream straight and braided reaches. The newly designed narrow width/depth ratio channel upstream of Ambush Rock will efficiently convey the water through the system. The narrow width/depth ratio and increase of energy grade line with also increase the sediment transport through the system as displayed in Figure 73. Based on the HEC-RAS analysis of the conceptual design, all flood levies and pumps could be removed from the Kootenai River below the confluence of the Moyie River and the Canadian-United States border. The reduction of these levies and pump stations would save millions of dollars in recurring maintenance cost and would increase drainage from the agricultural lands on the Kootenai flats. The final design stage will include discussions of desired flood stage below former flood plains relating property loss to reduction of stage through the project.

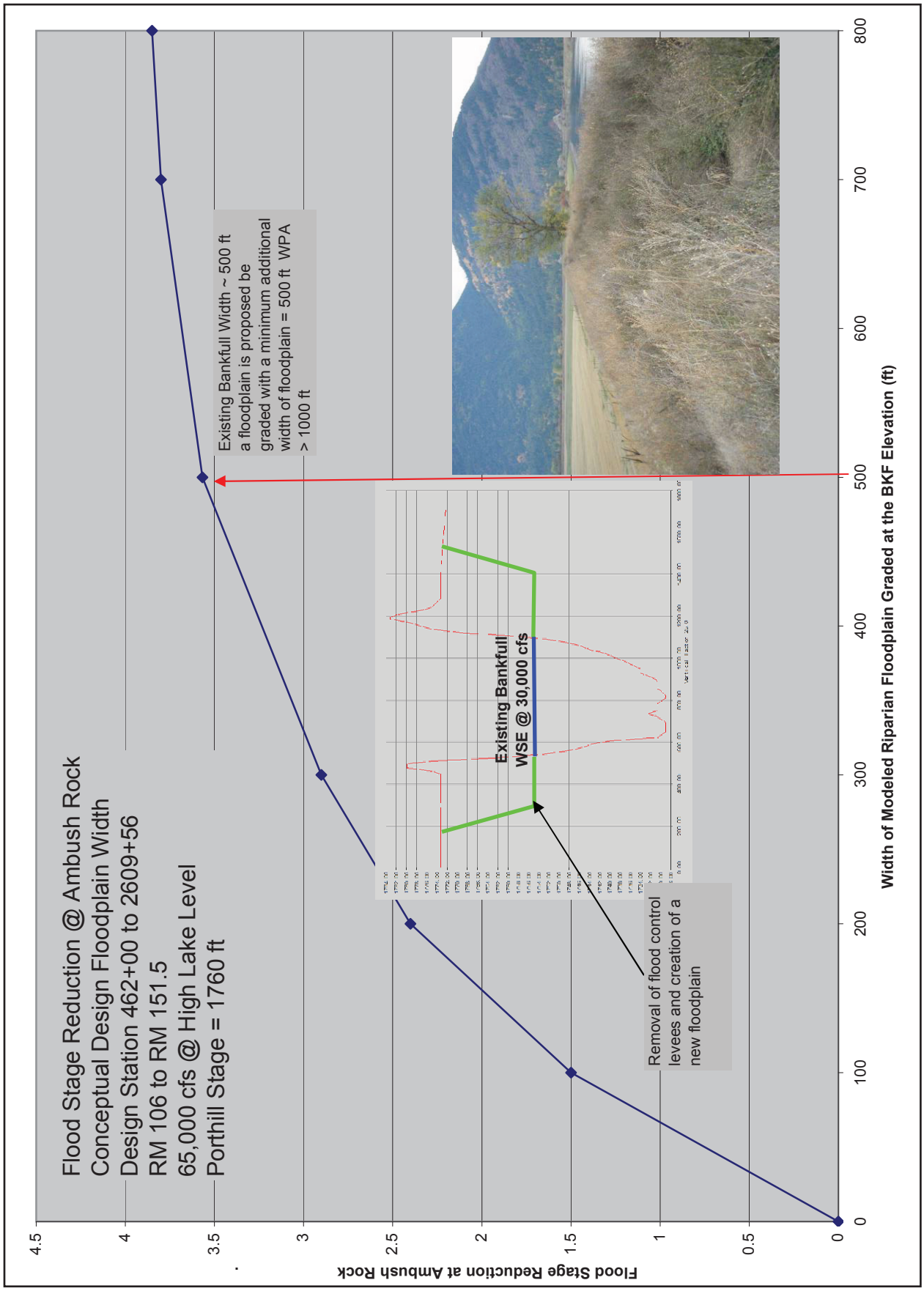
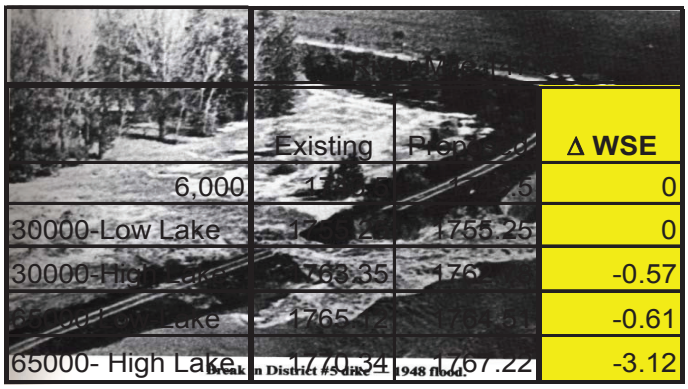


Figure 88. HEC-RAS downstream cross-sections.

Kootenai River Restoration - Grading a Riparian Floodplain
Meandering F5 Channel
Prepared by DAB
Checked by DLR
5/13/2008

Bankfull Flow =	**30000 cfs**
Bankfull Width =	**498.6 ft**
Bankfull Depth =	**21.5 ft**
Width to Depth Ratio =	**23.2 ft**
USGS River Mile =	**147.7 Miles**
USGS River KM =	**237.7 KM**
Design Station =	**62,550 FT**



	Existing	Plan	Δ WSE
6,000	[illegible]	[illegible]	0
30000-Low Lake	[illegible]	1755.25	0
30000-High Lake	1768.35	1768	-0.57
65000-Low Lake	1765	[illegible]	-0.61
65000- High Lake	1770.34	1767.22	-3.12

Cross-Section - Meandering Existing F5 Conversion to a C5

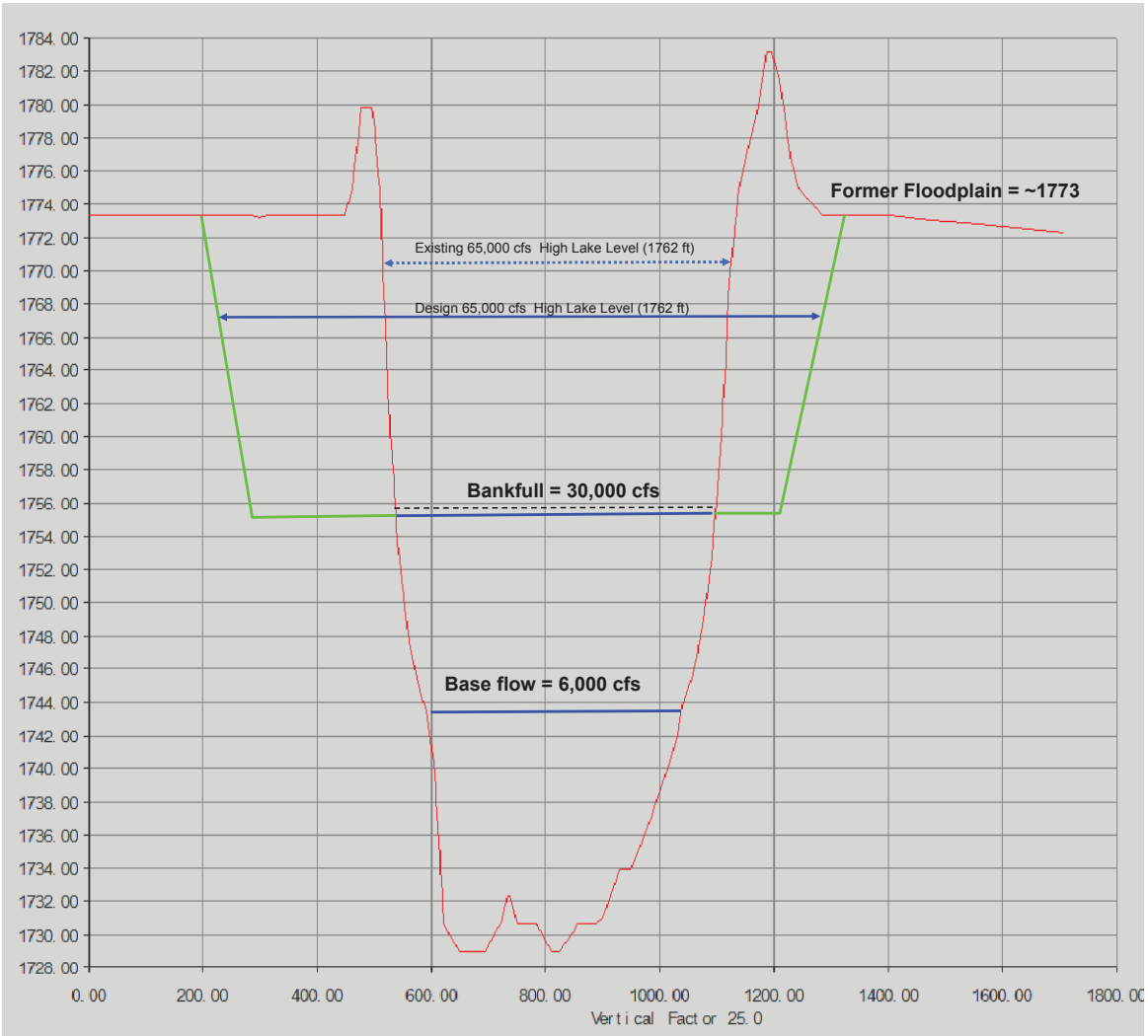


Figure 89. Flood level typical cross-section for the meandering reach.

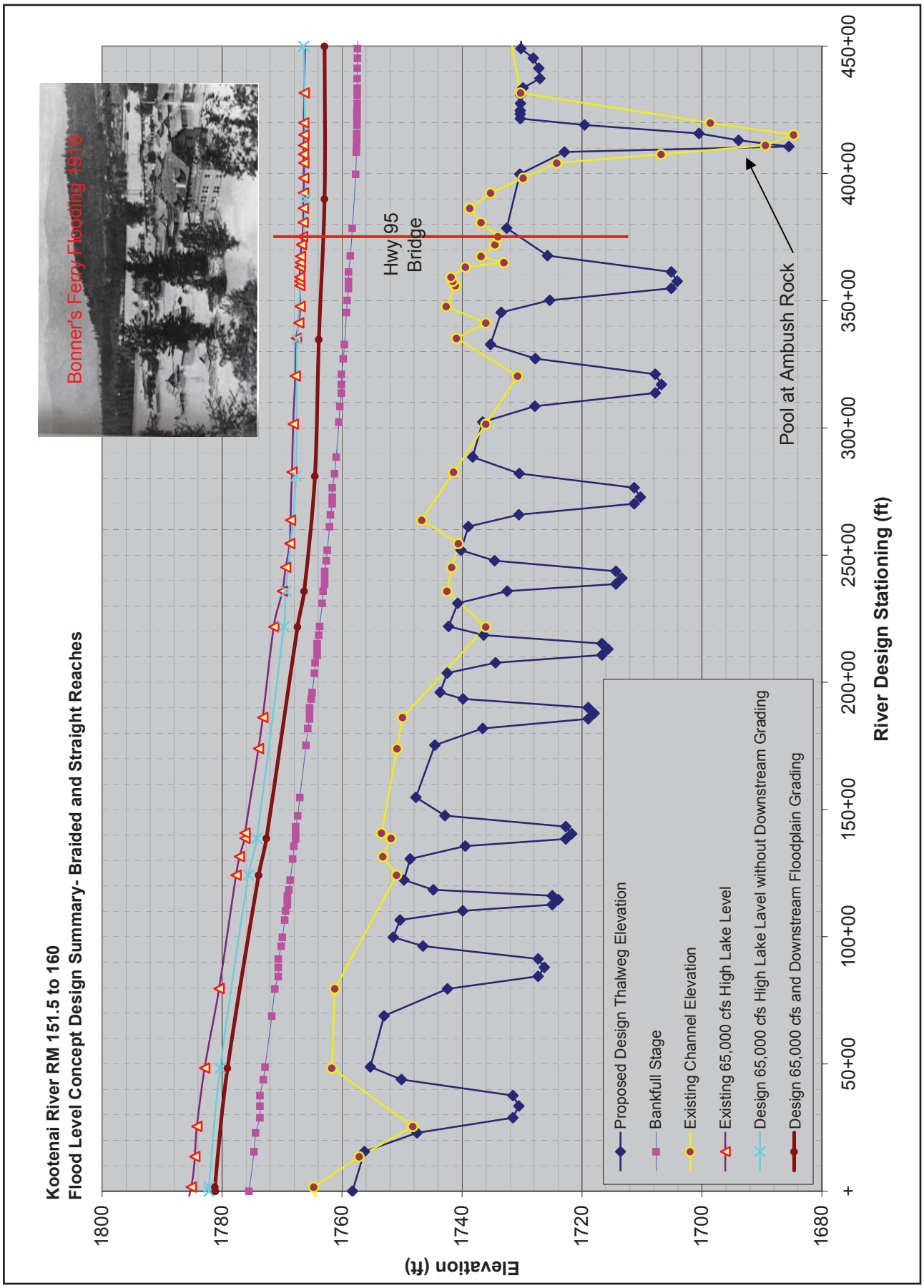
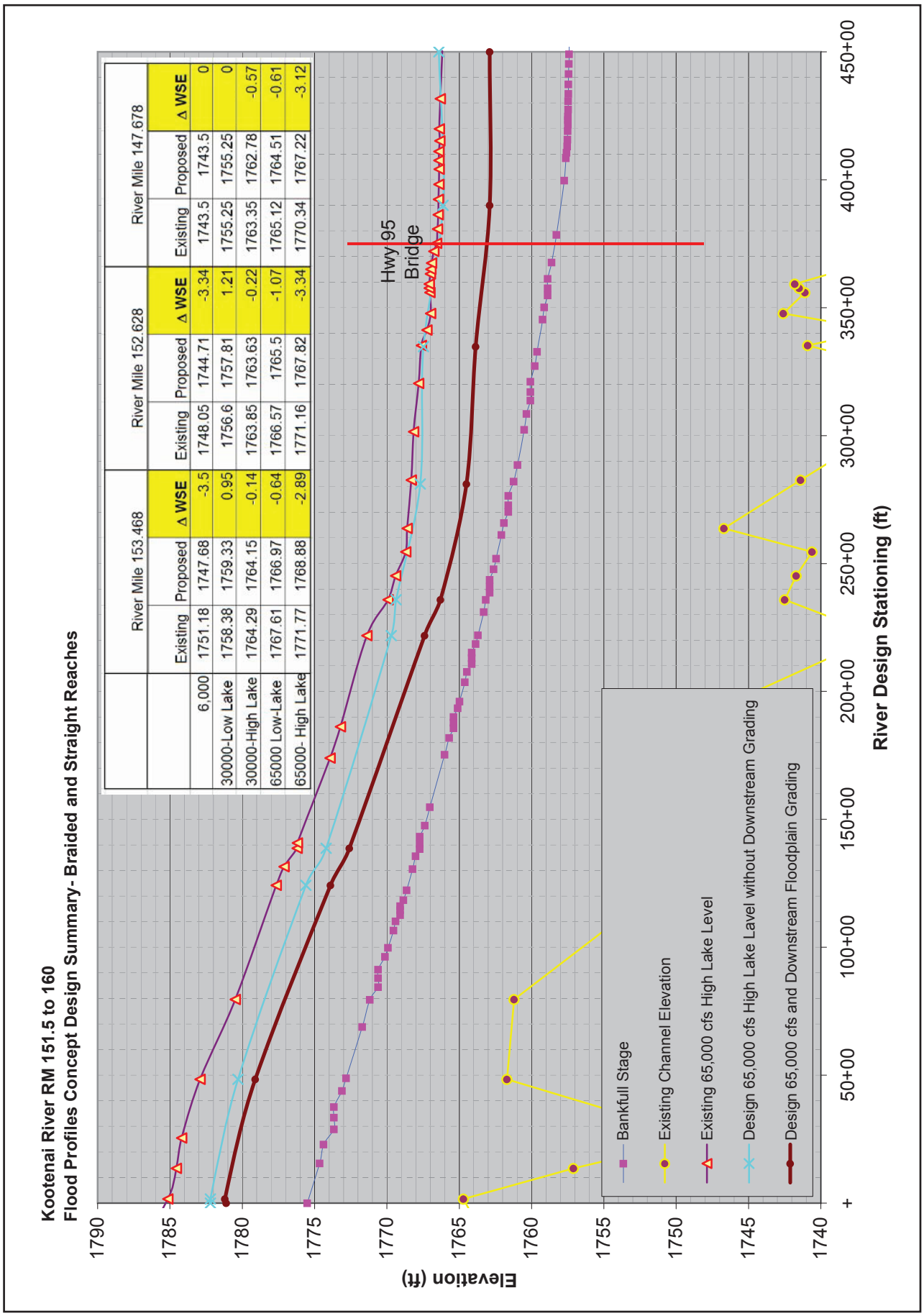


Figure 90. Flood level Concept design summary for the braided and straight reaches.



	River Mile 153.468			River Mile 152.628			River Mile 147.678		
	Existing	Proposed	Δ WSE	Existing	Proposed	Δ WSE	Existing	Proposed	Δ WSE
6,000	1751.18	1747.68	-3.5	1748.05	1744.71	-3.34	1743.5	1743.5	0
30000-Low Lake	1758.38	1759.33	0.95	1756.6	1757.81	1.21	1755.25	1755.25	0
30000-High Lake	1764.29	1764.15	-0.14	1763.85	1763.63	-0.22	1763.35	1762.78	-0.57
65000 Low-Lake	1767.61	1766.97	-0.64	1766.57	1765.5	-1.07	1765.12	1764.51	-0.61
65000- High Lake	1771.77	1768.88	-2.89	1771.16	1767.82	-3.34	1770.34	1767.22	-3.12

Figure 91. Flood profiles Concept design summary for the braided and straight reaches.

Assumptions Inherent in Design Proposal

- Secondary circulation with inner berm shape will keep sand routed in the presence of backwater using alternating rock vanes.
- Flow regime will not materially change.
- Need to negotiate with Canada on high lake levels backwater problems. It is not very probable to prevent river aggradation associated with the high lake stage backwater.
- Need to gain the support of the local landowners for cooperation, CRP, conservation easements, riparian grazing incentives, off-channel watering and corridor fencing assistance with new Farm bill.
- That the sediment transport model accurately portrays the potential for sediment transport.
- That the relations in the streambank erosion BANCS model are reasonable and fit the conditions of the Kootenai.
- Field validation can be accomplished to verify the model outputs for sediment and bank erosion.
- The existing resistance (Manning's n) of the meandering reach will be the same as the designed resistance of the braided reach.
- The designed resistance (Manning's n) of the braided reach will be less than the existing resistance of the braided reach.
- Access will be granted by the property owners to grade the new floodplain, thus taking it out of agricultural production.
- The existing USGS HEC-RAS model for the Kootenai River had proper spacing of cross-sections and appropriate cross-sectional elevations.
- The increase of velocities and the increase of depth will encourage sturgeon to migrate and spawn upstream in the braided reach.
- Access of tributaries and floodplains to the river will encourage productions of numerous species at various life stages.
- Downstream boundary conditions at Corralynn Dam are appropriate in the HEC-RAS model provided by USGS.
- The morphological conditions of the river will not deposit sediment in channel that will reduce local energy grade slopes and conveyance.

Recommended Sequence Strategy for Implementation/ Construction Staging

It is recommended that the year prior to implementing construction that materials (trees and boulders) are gathered, hauled and stockpiled on site in close proximity for their use. Willow cuttings should be collected the year prior to planting, then placed into water or in cold storage. It is advisable that the agencies, local community or various farmers start to grow the plant materials for transplanting, such as cottonwood saplings and sod mats with willow seedlings planted with a rhizomatous grass sod foundation. This could develop into a new local industry for native materials.

1. Start at the top of the reach at the head of the braided reach. Convert D4 to C4 stream type. Divert water into various existing channels to construct in the semi-dry condition. Save excess excavated gravel/cobble sizes from channel and oxbow to be used for the inner berm in the straight reach. The braided reach construction needs to be constructed first so that the river can be "cleaned" from top to bottom of construction. The duration of construction should be 7–9 months.

2. The first phase of work needs to include bridge pier stabilization structures. The year prior to construction, the gathering of materials and stockpile of trees and boulders needs to be located on site.
3. The straight reach should be staged next. This work needs to be done at low flows. Need cooperation from BPA to hold flow releases to a minimum during this construction since no by-pass of flow is possible.
4. Because the critical habitat near Shorty's Island has been identified, the improvement may need to be implemented first. The disadvantage, however, of initiating this work before the work is completed upstream is the fine sediment invasion that can occur due to construction activities. Disturbance from upstream, in-channel construction will often generate fine sediment that can deposit in critical habitat and the coarse substrate that is planned to be placed in the inner berm and bed along with the submerged alternating rock vanes. If possible, it would be preferable to complete the upstream F5/C5 conversion, bank revetment with the toe wood and willow cuttings prior to starting Shorty's Island reach enhancement. The duration of this work may take 0.5 to 1.0 mile/month to complete.
5. The work below Shorty's Island can proceed as follow: 1) remove the levees, 2) construct the floodplain, 3) implement channel alignment if required, 4) install the toe wood and willow cuttings, and 5) create wetlands and other floodplain features, reseeding and planting.

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