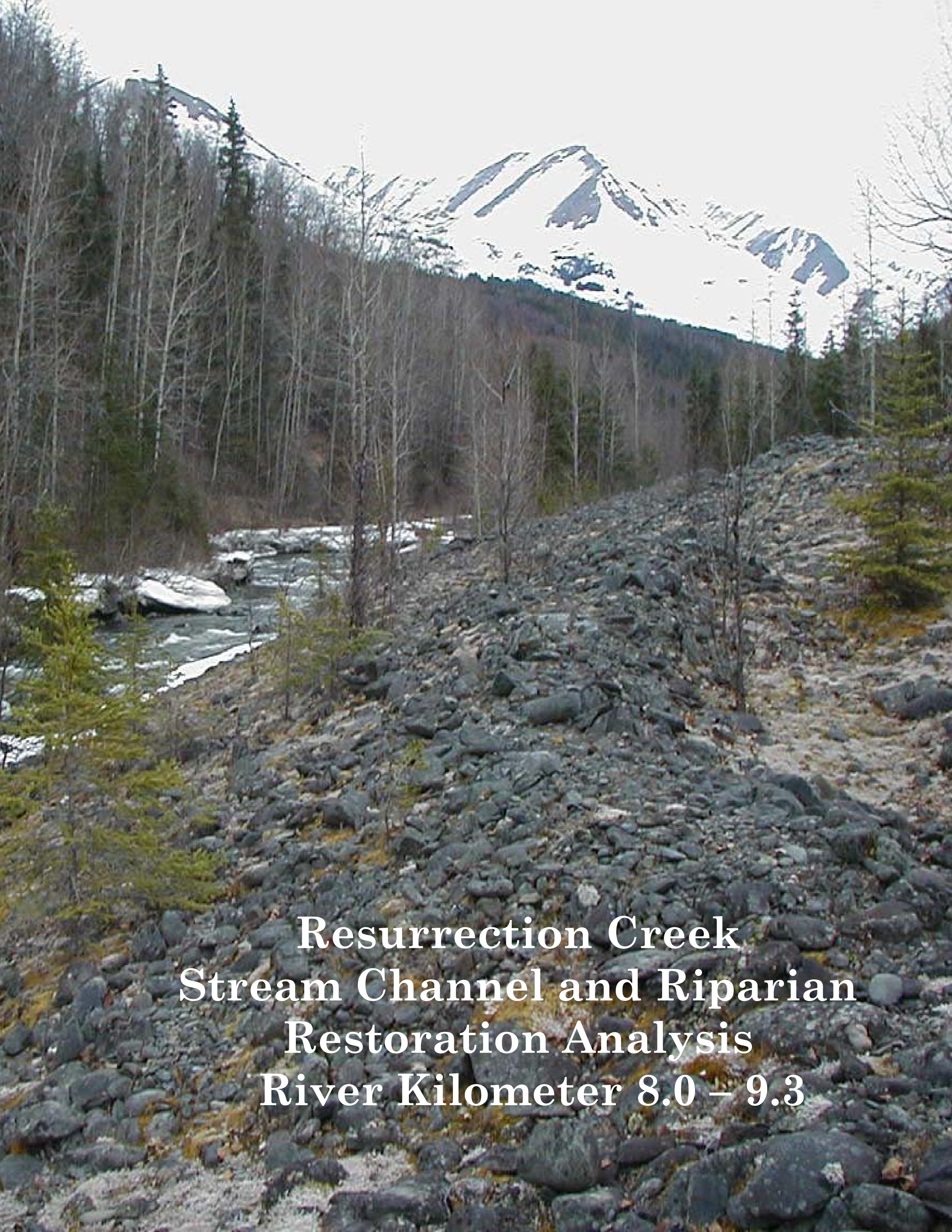

Resurrection Creek
Stream Channel and Riparian Restoration Analysis
River Kilometer 8.0 – 9.3

Resurrection Creek
Stream Channel and Riparian Restoration Analysis
River Kilometer 8.0-9.*3*
October 1, 2002

A product of the

Wind River

Watershed Restoration Team

Brian Bair, Paul Powers, Anthony Olegario

Table of Contents

EXECUTIVE SUMMARY……………………………………………………………………………….. 1
SUMMARY OF FINDINGS………………………………………………………………………. 1
GOALS…………………………………………………………………….………………….. 2
SHORT TERM OBJECTIVES……………………………………………………………….. 2
LONG TERM OBJECTIVES…………………………………………………………………… 2
PROPOSED ACTIONS TO ACCOMPLISH OBJECTIVES…………………………………………… 2
INTRODUCTION……………………………………………………………………………………… 4
PROJECT AREA………………………………………………..……………………………………… 4
PURPOSE AND NEED………………………………………………………………………………… 4
METHODS……………………………………………………………………………………………… 4
ANALYSIS APPROACH…………………………………………………….….……………….… 4
Reference Reach - Relic Analogs ……………………………………………………………… 5
Disturbed Reference Reaches - Disturbed Analogs……………………………………………… 5
Channel Geometry l Equations………………………………………………………………... 6
Quantitative Objectives……………………………………………………………………….. 8
Confluence of the Data…………………………………………………………………….. 9
TOTAL STATION MAPPING………………………………………………………………………… 9
RIPARIAN VEGETATION…………………………………………………………………………… 9
FLOOD FREQUENCY ANALYSIS……………………………………………………………….. 10
GEOMETRY……………………………………………………………………………………………… 10
BANKFULL CROSS-SECTIONS………………………………………………………………... 10
SEDIMENT ANALYSIS……………………………………………………………………………… 10
RESULTS & DISCUSSION…………………………………………………………………………… 11
REFERENCE REACH…………………………………………………………………………………. 11
FLOW FREQUENCY ANALYSIS………………………………………………………………. 11
GEOMETRY ANALYSIS……………………………………………………………………………. 12
SEDIMENT ANALYSIS……………………………………………………………………………… 15
RIPARIAN VEGETATION…………………………………………………………………………… 16
PROJECT AREA……………………………………………………………………………………….. 21
FLOW FREQUENCY ANALYSIS………………………………………………………………………. 23
GEOMETRY ANALYSIS……………………………………………………………………………. 23
SEDIMENT ANALYSIS……………………………………………………………………………… 28
RIPARIAN VEGETATION…………………………………………………………………………… 29
CONCLUSION………………………………………………………………………………………………. 33
GOALS & OBJECTIVES……………………………………………………………………………… 34
GOALS…………………………………………………………………………………………… 34
SORT TERM OBJECTIVES ~ 2-3 YEARS…………………………………………………….. 34
LONG TERM OBJECTIVES >50 YEARS…………………………………………………….. 34
PROPOSED ACTIONS TO ACCOMPLISH OBJECTIVES…………………………………………….. 34
ALTERNATIVES…………………………………………………………….………………………… 35
ALTERNATIVE A………………………………………………………………………………………... 35
ALTERNATIVE B……………………………………………………………………………………….. 35
ALTERNATIVE B COST ESITMATES………………………………………………………….. 39
ALTERNATIVE C……………………………………………………………………………………….. 42
ALTERNATIVE C COST ESITMATES………………………………………………………….. 46
ALTERNATIVES CONSIDERED……………………………………………………………………… 49
ALTERNATIVES D & E THE "OUT HAUL" ALTERNATIVE…………………………………….. 49
ALTERNATIVE F THE "PULL BACK" ALTERNATIVE…………………………………………….. 49
EFFECTS TO AQUATIC RESOURCES……………………………………………………………….. 50
ACKNOWLEDGEMENTS………………………………………………………………………………56
REFERENCES………………………………………………………………………………………………. 57
GLOSSARY OF TECHNICAL TERMS…………………………………………………………….. 62

LIST OF FIGURES

Figure 1. Locator maps for the Resurrection Creek project and reference reaches.

Figure 2. Example of a relic analog: the "Mining Reach" river mile 25 Wind River, Skamania County, Washington.

Figure 3. Stream geometry evaluated in a disturbed analog: Layout Creek, Skamania County, Washington

Figure 4. Comparison of empirical equations and observed analog data in the "Mining Reach", Wind River, Skamania County, Washington.

Figure 5. Aerial photo and contour site map overlay for 2002 reference reach survey, Resurrection Creek, Kenai Peninsula, Alaska.

Figure 6. Number and species of in-stream woody material per river kilometer within Resurrection Creek reference reach bankfull channel, Kenai Peninsula, Alaska.

Figure 7. Tree densities by species observed within the Resurrection Creek reference reach riparian vegetation plots, May, 2002 survey, Kenai Peninsula, Alaska.

Figure 8. Riparian tree species composition within the 2002 Resurrection Creek reference reach riparian vegetation plots, Kenai Peninsula, Alaska.

Figure 9. Riparian tree diameter class structure within the 2002 Resurrection Creek reference reach riparian vegetation plots, Kenai Peninsula, Alaska.

Figure 10. Snag and coarse downed woody material densities within the Resurrection Creek reference reach riparian vegetation plots, Kenai Peninsula, Alaska.

Figure 11. Resurrection Creek project reach area map Rkm 8.0-9.3.

Figure 12. Aerial photo and contour site map overlay for 2002 project reach survey, Resurrection Creek, Kenai Peninsula, Alaska.

Figure 13. Flood prone and bankfull widths for the disturbed project area and reference reaches of Resurrection Creek, Kenai Peninsula, Alaska.

Figure 14. Average existing and historic entrenchment ratios for the project area of Resurrection Creek, Kenai Peninsula, Alaska.

Figure 15. Number of in-stream woody material per river kilometer within the bankfull channel of Resurrection Creek reference and project reaches, Kenai Peninsula, Alaska.

Figure 16. Location of spawning gravel and flood plains of Resurrection Creek disturbed reference reach (~Rkm 9), Kenai Peninsula, Alaska.

Figure 17. Square meters of spawning gravel per kilometer for the Resurrection Creek project and reference reaches, Kenai Peninsula, Alaska.

Figure 18. Tree densities by species observed within the Resurrection Creek project reach riparian vegetation plots, May, 2002 survey, Kenai Peninsula, Alaska.

Figure 19. Riparian tree species composition within the Resurrection Creek project reach riparian vegetation plots, Kenai Peninsula, Alaska.

Figure 20. Riparian tree diameter class structure within the Resurrection Creek project reach riparian vegetation plots, Kenai Peninsula, Alaska.

Figure 21. Snag and coarse downed woody material densities within the reference and project reaches of Resurrection Creek riparian vegetation plots, Kenai Peninsula, Alaska

Figure 22. Alternative B conceptual design and comparison of existing conditions for Resurrection Creek project area, Kenai Peninsula, AK.

Figure 23. Mine tailing volumes, existing and designed stream channel for Alternative B, Resurrection Creek, Kenai Peninsula Alaska.

Figure 24. Alternative C conceptual design and comparison of existing conditions for Resurrection Creek project area, Kenai Peninsula, AK.

Figure 25. Mine tailing volumes, existing and designed stream channel for Alternative C, Resurrection Creek, Kenai Peninsula Alaska.

Figure 26. Maximum, minimum and average daily stream flows relative to salmonid life history and project implementation timeline for Resurrection Creek, near Hope, Alaska.

Figure 27. Trout Creek Restoration project site map, T.4N., R.6E. Section 13, Skamania County Washington.

LIST OF TABLES

Table 1. Layout Creek cross-sections applied to three mean radius of bend curvature (Rc) empirical equations (Williams, 1986).

Table 2. Calculated return intervals and flood frequency.

Table 3. Channel morphometry for the Resurrection Creek reference reach, Kenai Peninsula, Alaska.

Table 4. Pebble count data for the reference reach of Resurrection Creek, Rkm 13.2-14.0, Kenai Peninsula Alaska.

Table 5. Under-story composition of the reference reach, Resurrection Creek, Kenai Peninsula, Alaska. (Species are listed in relative order of abundance).

Table 6. Calculated return intervals and flood frequency for the Resurrection Creek project reach, Kenai Peninsula, Alaska.

Table 7. Channel morphometry for the Resurrection Creek project reach, Kenai Peninsula, Alaska.

Table 8. Pebble Count data for the project reach of Resurrection Creek, Rkm 8.3-9.0, Kenai Peninsula Alaska.

Table 9. Under-story composition of the project reach, Resurrection Creek, Kenai Peninsula, Alaska. (Species are listed in relative order of abundance).

Table 10. Alternative B channel morphometry for the Resurrection Creek project reach, Kenai Peninsula, Alaska.

Table 11. Project Cost Estimate Summary for Rehabilitation Alternative B, Resurrection Creek, Kenai Peninsula, Alaska.

Table 12. Alternative C channel morphometry for the Resurrection Creek project reach, Kenai Peninsula, Alaska

Table 13. Project Cost Estimate Summary for Rehabilitation Alternative C, Resurrection Creek, Kenai Peninsula, Alaska.

Table 14. Comparison of Restoration variables for the project reach, reference reach and action alternatives B & C, Resurrection Creek, Kenai Peninsula, Alaska.

LIST OF PHOTOS

Photo 1. Aerial ortho-photo of the reference reach, river kilometer 13.2 Resurrection Creek, Kenai Peninsula, Alaska.

Photo 2. Photo of typical in-stream woody material within the Resurrection Creek reference reach bankfull channel, river km 13.4 Kenai Peninsula, Alaska. *Photo Olegario*

Photo 3. Photo of mine tailings and stream channel confinement in Resurrection Creek project area, river km ~10, Kenai Peninsula, Alaska. *Photo Olegario*

Photo 4. Resurrection Creek river kilometer ~8.1-8.6, Kenai Peninsula Alaska.

Photo 5. 1995 Photo of the entrance to the Trout Creek old growth channel, Skamania County, WA. A logjam that was thought to be a migration barrier was removed in 1981. The removal of the logjam initiated the channel to "down-cut" or degrade approximately five feet below the original bed elevation. As the channel degraded the connectivity with the flood plain and the last remaining old growth reach in Trout Creek was abandoned. Wind River watershed, Skamania County Washington.

Photo 6. 1999 Photo of the entrance to the Trout Creek old growth channel after restoration of logjams. Stream bed was aggraded over four feet to regain connectivity with flood plain and reactivate 0.8 of a river mile of pristine habitat. Wind River Watershed, Skamania County Washington.

Photo 7. Desired future condition for Resurrection Creek in the year 2065. (Quartz Creek, Kenai Peninsula Alaska)

LIST OF REVIEWERS

Robert Develice, ***Vegetation Ecologist, U.S.D.A. Forest Service, Chugach National Forest***

Dean Davidson, ***Soil Scientist, U.S.D.A. Forest Service, Chugach National Forest***

David Blanchet, ***Hydrologist, U.S.D.A. Forest Service, Chugach National Forest***

Janine M. Castro, PhD, ***Geomorphologist, U.S. Fish and Wildlife Service, Oregon Fish and Wildlife Office.***

Eric Johansen, ***Fisheries Biologist, U.S.D.A. Forest Service, Seward Ranger District, Chugach National Forest***

Elizabeth Bella***, Botanist, U.S.D.A. Forest Service, Seward Ranger District, Chugach National Forest***

David Heller***, Regional Fisheries Program Manager, U.S.D.A. Forest Service, Pacific Northwest Region***

Susan Maiyo***, District Fisheries Biologist, Asland Ranger District, Siskyou National Forest, U.S.D.A. Forest Service, Pacific Northwest Region***

Lori Richter***, Design Engineer, U.S.D.A. Natural Resources Conservation Service, Anchorage, Alaska.***

EXECUTIVE SUMMARY

This document analyzes the existing riparian and stream channel conditions and investigates the potential restoration alternatives of a mined reach of Resurrection Creek, Kenai Peninsula, Alaska. The Resurrection Creek analysis area is located in the Western Kenai Mountains ecosection at the northern end of the Kenai Peninsula on the Chugach National Forest (figure 1). Resurrection Creek was home to Alaska's first gold rush nearly a century ago. Hydraulic and shovel mining within the watershed have reduced the quality and quantity of fish and wildlife habitat within the watershed. The most severe impacts from mining are located in the lower 10 river kilometers. The lower reaches within this area were identified as critical habitat for spawning and rearing habitat for coho, chum, pink and chinook salmon [U.S.D.A. Resurrection Creek Landscape Analysis (RCLA), 2002].

In May of 2002, members of the United States Forest Service, Pacific Northwest Region River Restoration Team surveyed a disturbed reach located at river kilometer (Rkm) 8.3 to 9.7. A relatively undisturbed reference reach located upstream, at Rkm 13.2 to 14 was also surveyed. The existing riparian and channel conditions of both reaches are analyzed and compared in this report to assess the state of successional recovery, habitat potential and to formulate restoration alternatives. The following presents a brief summary of findings and recommendations of the subsequent analysis:

SUMMARY OF FINDINGS

Without mechanical intervention, fish and wildlife habitat will limit biological production within the project area conceivably for centuries. Mine tailings generated nearly a century ago, are essentially functioning as dikes, and confining all flood flows to a single channel.

1) Flood-prone to bankfull channel width ratios within the disturbed project reach have been reduced from historic levels of 7:1 to the current condition of 1:1. The confinement of the stream channel has severely impacted both fish and wildlife habitat.

2) The mine tailings occupy approximately 54% of the historic floodplain and are composed of coarse sediment, which is preventing natural recovery of riparian vegetation composition and structure.
3) The elevations and orientation of mine tailings prevent fine sediment and organics carried by floods from being deposited on the floodplain. This detachment of the stream channel from the historic floodplain prevents the natural fertilization and soil augmentation mechanisms needed to reestablish vigorous riparian communities.
4) Poor habitat conditions for bears, bald eagles, moose and salmon will be persistent without regeneration of riparian vegetation. Although the disturbance occurred nearly a century ago, riparian vegetation and wildlife habitat have not recovered at a natural rate of succession; 86% of all riparian trees within the disturbed reach are <15cm in diameter, and snags and coarse downed wood are nearly nonexistent.
5) The mine tailings have confined and straightened the stream, which has increased the channel slope by 27%, from 0.12 to0.15. The increase in channel slope has homogenized the reach, creating a nearly continuous riffle that has severely impacted salmonid habitat. Compared to reference conditions, the project area per river kilometer contained:
    a. 76% fewer pools with >1 meter residual pool depth
    b. 92% less m^2/Rkm of spawning substrate
    c. 96% fewer side channels
    d. 95% fewer pieces of in-stream large woody material

Based on the data analyzed in this report, goals and restoration objectives were developed for Resurrection Creek Rkm 8.0-9.3.

GOALS

***The restoration goals for Resurrection Creek are to restore and reconnect the historic floodplain, stream channels and riparian areas to recover the natural range of aquatic and riparian habitat conditions, which fish and wildlife adapted to*.**

SHORT TERM OBJECTIVES
~ 2-3 YEARS

1) Increase flood prone width to bankfull width ratio (entrenchment ratio) from 1:1 to $\geq$6:1.
2) Decrease channel thalweg slope from 0.015 to 0.011 (1.5% - 1.1%).
3) Increase channel length by 15% (200m) and sinuosity from 1.01 to 1.4.
4) Increase pools with residual pool depths >1 meter from 3 pools per km to 14.
5) Increase perennial side channel flow from <1% to 5-20%.
6) Increase spawning gravel from 160m^2 to 2,000m^2.
7) Increase large in-stream woody material (>31cm in diameter, >20m in length) from 10 pieces/river km to ~200/river km.
8) Restore topsoil and fines to > 80% of the active floodplain and Increase floodplain coarse woody material from 40 to ~300/hectare.
9) Decrease over stocked riparian tree densities from 1,800 trees per hectare to (500-600) live trees/hectare.
10) Restore riparian tree species composition to 50% spruce, 40% cottonwood, 10% poplar and hemlock with a calamagrostis under-story.
11) Increase snags from 5 to ~100 snags/hectare.

LONG TERM OBJECTIVES
>50 YEARS

Restore riparian stand structure to 20% large trees (>41cm in diameter), 15% small trees (31-41cm in diameter), 20% poles (15-31cm in diameter), 45% seedling/saplings (0-15cm in diameter)

PROPOSED ACTIONS TO ACCOMPLISH OBJECTIVES

1) Mechanically manipulate mine tailings to recover floodplain width and elevations.
2) Reconstruct meander pattern, channel profile, pools and spawning habitat.
3) Develop multiple relief channels and off channel ponds within the floodplain.
4) Extract beetle killed spruce trees in high risk fire hazard areas and utilize as a source of in-stream and terrestrial woody material and snag enhancement.
5) Augment soils in reclaimed riparian areas to provide soil/landform and drainage conditions which can support native plant communities.
6) Thin existing overstocked riparian sapling spruce and cottonwood stands.
7) Use natural vegetation where seed source and site conditions are favorable towards achieving re-vegetation objectives.
8) Use native plant species in re-vegetation/restoration projects when natural re-vegetation conditions are not favorable

Resurrection Creek Project Area Locator Maps

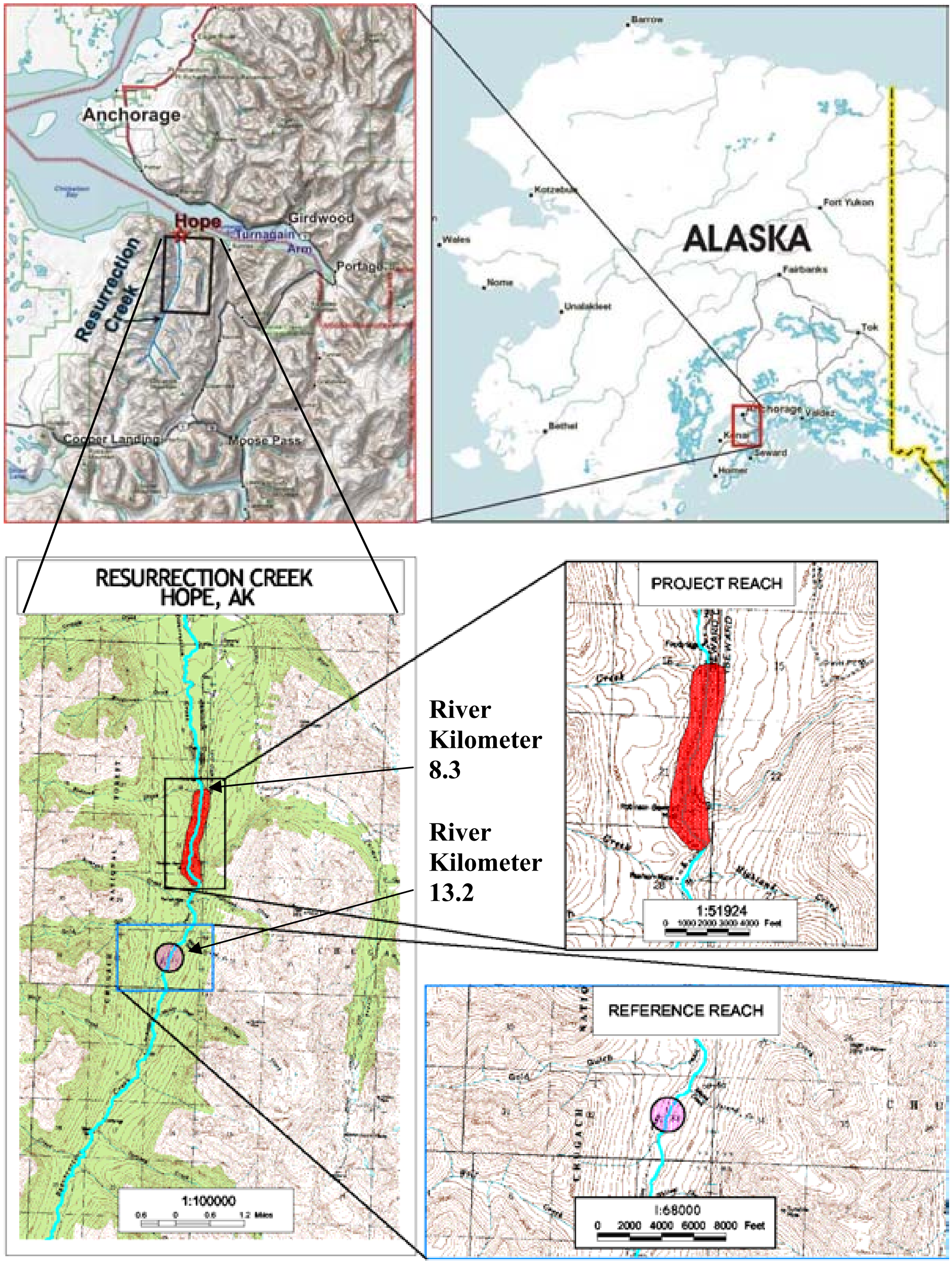

Figure 1. Locator maps for the Resurrection Creek project and reference reaches.

INTRODUCTION

The USFS Wind River Restoration Team based out of Carson, WA surveyed and analyzed stream channel conditions in Resurrection Creek to assist the Chugach National Forest with the development of a stream channel restoration strategy, rehabilitation alternatives and recommendations. This cooperative trans-regional effort is part of the Forest Services restoration strategy to utilize available skills and efficiently address water quality, fish and wildlife habitat issues in key sub-basins.

PROJECT AREA

The analysis area is located in the Western Kenai Mountains ecosection at the northern end of the Kenai Peninsula on the Chugach National Forest. Resurrection Creek begins in the Kenai Mountains at an elevation of over 1,539 meters (5,000') above sea level. The stream flows northwardly into the Turnagain Arm of Cook Inlet. The town of Hope, Alaska lies adjacent to the mouth of the stream on Turnagain Arm (see Figure 1). Resurrection Creek Watershed has an area of 103,230 acres (161 square miles). The project area begins at river kilometer 8.3 (upstream from tidewater) and extends upstream to river kilometer 9.7. A reference reach at about river km 13.2 to 14 was also surveyed and evaluated as part of this analysis (Kalli and Blanchet, 2001).

PURPOSE AND NEED

Resurrection Creek was home to Alaska's first gold rush. Portions of Resurrection Creek's main stem and tributaries have been mined for gold using various techniques. The majority of impacts to the stream channels and riparian areas in the project reach arose from hydraulic placer mining, which occurred mostly in the first two decades of the 1900's. Tailings generated from hydraulic mining, some of which are nearly 12 meters high, bisect and or occupy the majority of the alluvial valley bottom within the project area. These tailings have disconnected or buried the historic complex of stream channels and wetlands that provided high quality habitat for salmon, bears, bald eagles, moose and other fish and wildlife species. Resurrection Creek flows have done little to alter these tailing piles over the last century.

Fish distribution has been identified up to RM 19.0 of Resurrection Creek, with the lower 10 kilometers identified as critical habitat for spawning and rearing habitat for coho, chum, pink and chinook salmon [U.S.D.A. Resurrection Creek Landscape Analysis (RCLA), 2002]. The project area exists within this critical habitat, between river kilometers 8.0-9.3. In addition, this area has been withdrawn from mineral entry and was therefore identified as a potential pilot reach for restoration in the Landscape Analysis. The three main restoration and management components outlined in the Landscape Analysis document were: 1) aquatic habitat restoration, 2) vegetation restoration and 3) management, and heritage resources/human uses management. A major element of the Landscape Analysis was completion of several surveys deemed necessary to make decisions about restoration alternatives. The recommended surveys included channel, riparian, and fisheries surveys. This report addresses the first two management components of the report and explores restoration options.

METHODS

ANALYSIS APPROACH

The following provides a brief summary of the methodologies employed to analyze, design and develop a restoration strategy for this project. The meander geometry methods described below are appropriate for low gradient (<2%), unconfined alluvial stream channels similar to the Resurrection Creek project area (Williams, 1981).

Restoration Philosophy: The goal of restoration is to accelerate the recovery of watershed processes in which the fish and other riparian dependent species adapted.

Methodology: Channel geometry equations, stream flow patterns, fit relic, and disturbed analogous or reference reaches of stream have been used to develop restoration designs and implementation templates. Rosgen (1994), Montgomery (1993) and others provide channel classification methods that assist with the evaluation of channel conditions. The material presented in this section of the document is a *brief* summary of methods applied to channels similar to Resurrection Creek. An excellent reference for more detailed restoration strategies and design can be found at: http://www.usda.gov/stream_restoration.

Reference Reach - Relic Analogs

The definition of a reference reach or relic analog used for this analysis is: *an undisturbed reach of stream that possess similar channel morphology, hydrology, sediment regime and biota relative to the disturbed site to be analyzed, rehabilitated or restored* (Figure 2). The goal is to find a reference reach that contains the same riparian eco-class, slope, discharge, and sediment budget and channel confinement or entrenchment up-stream of the disturbed reach. The riparian vegetation composition and structure, thalweg slope, bank full width, average depth, belt width, entrenchment and large woody debris (LWD) within the reference reach are measured to compare and contrast the existing conditions within the disturbed reach and to develop restoration templates, goals and objectives (Figure 3).

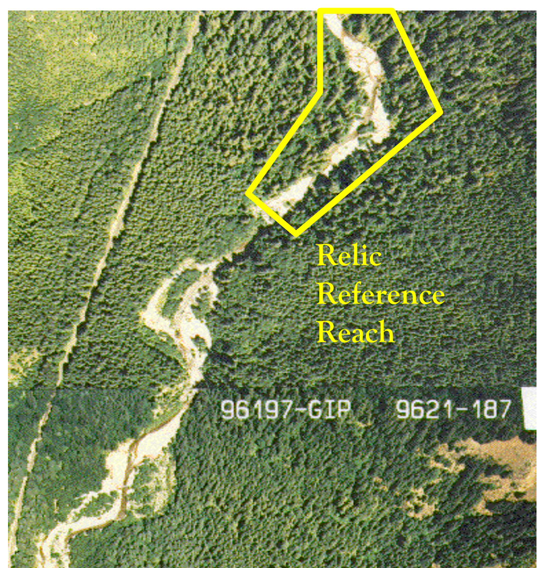

Figure 2. Example of a relic analog; the "Mining Reach" river mile 25 Wind River, Skamania County, Washington.

Other attributes such as bank stability, stream shade, biomass, etc. can also be used to develop templates and objectives. If relic reference reaches do not exist on the particular stream in need, adjacent undisturbed watersheds and stream channels can be used in part for reference. However adjacent watersheds cannot completely take the place of an adjoining relic analog due to differences in sediment load, hydrology and watershed conditions.

Disturbed Reference Reaches - Disturbed Analogs

Unfortunately, most streams in need of rehabilitation do not have relic reference reaches on the same stream. Disturbed references reaches or analogs can serve as surrogates. Disturbed analogs are portions of the channel within an impacted area that have been stable over time. They are capable of routing current and past sediment loads, and possess the habitat characteristics capable of supporting the aquatic species that evolved within (figure 3).

Disturbed analogs are usually found in small segments within the reach in need of treatment. Typically they are formed by remnant debris, cohesive soils and or recovering riparian areas with good root structure. Figure 3 depicts derived values in a potential disturbed analog.

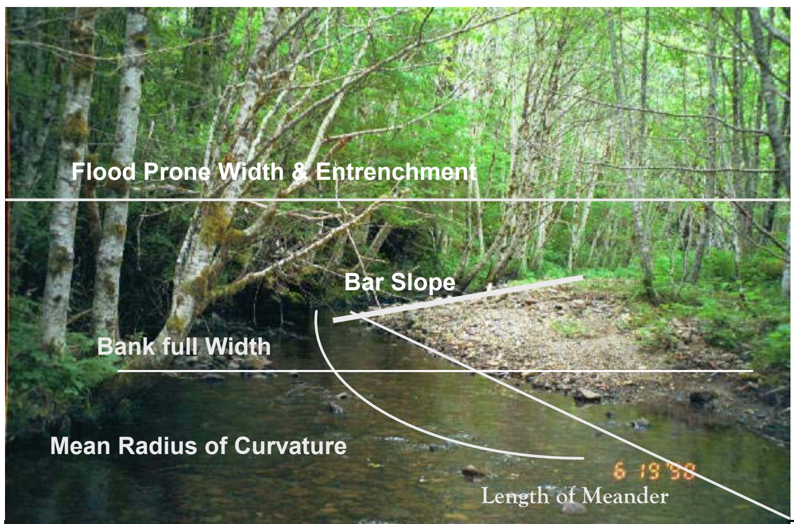

Figure 3. Stream geometry evaluated in a disturbed analog: Layout Creek, Skamania County, Washington

Disturbed analogs provide an extremely valuable clue as to how the channel can cope with the altered sediment budget, hydrology and riparian biota. In addition, they provide an excellent time reference for recovery. As in the case with relic analogs, data from disturbed analogs are used to develop restoration templates. Data was collected within a disturbed reference reach located within the Resurrection Creek project area and will be discussed in this analysis.

Channel geometry equations

Stream channel cross sections and meander geometry can be used to (1) evaluate analogs, (2) determine the health of a stream and (3) develop templates for restoration. In 1966 Langbein and Leopold evaluated low gradient alluvial stream channels (<2% slope and sinuosity >1.2) and developed channel geometry equations to predict stream channel geometry. In 1986 Williams expanded the data set and developed an additional 40 equations. More recently others have developed additional stream geometry equations to reflect regional variations in morphometry.

The equations are extremely useful in analyzing relic/disturbed analogs and designing restoration templates. In figure 4, an analog relic reach in Washington State was evaluated against the Leopold/Langbein and Williams equations. Although large amounts of wood chaotically complicate the meander geometry within this particular reach, the average analog of measured geometric values follows the predicted values of the channel geometry equations.

In table 1, five disturbed cross-sections in Washington State were evaluated for templates using the Williams equations. In this case bankfull width, area and mean depth data from each cross-section was entered into the equations. In this scenario the objective was not to use the equations to predict the radius of bend curvature, but to evaluate the fitness of the cross-sections. Data from cross-section LO2 predicted the same radius of curvature for all three equations and was in fact the most stable cross-section measured due to a remnant logjam. This and other similar cross-sections were used as templates rehabilitation design on three kilometers of stream in Southwest Washington. Cross-section L04 had an extreme width to depth ratio generated by poor lateral stability.

The poor health of this cross-section is evidenced by the bank full width (Wbnk) equation predicting a radius of curvature of 104m and the mean depth (D) equation predicting a radius of curvature of 24m. The equations confirmed that LO4 was in need of restoration and that morphometry from LO2 could be used to rehabilitate it.

The example of LO4 also illustrates the need to use caution and avoid using cookbook methods such as "pool spacing = 12 times bankfull width". If care is not taken in selecting cross-sections for design the risk of generating some potentially serious problems up or down stream significantly increases. For example, if channel designs are "over designed"; i.e., cross section area, length of meander and pool spacing intervals are too large and channel slope is too low, channel stability could be significantly affected by stream bed aggradation.

Channel geometry equations and methods described above were applied to Resurrection Creek to evaluate reference conditions and assist with the development of design templates.

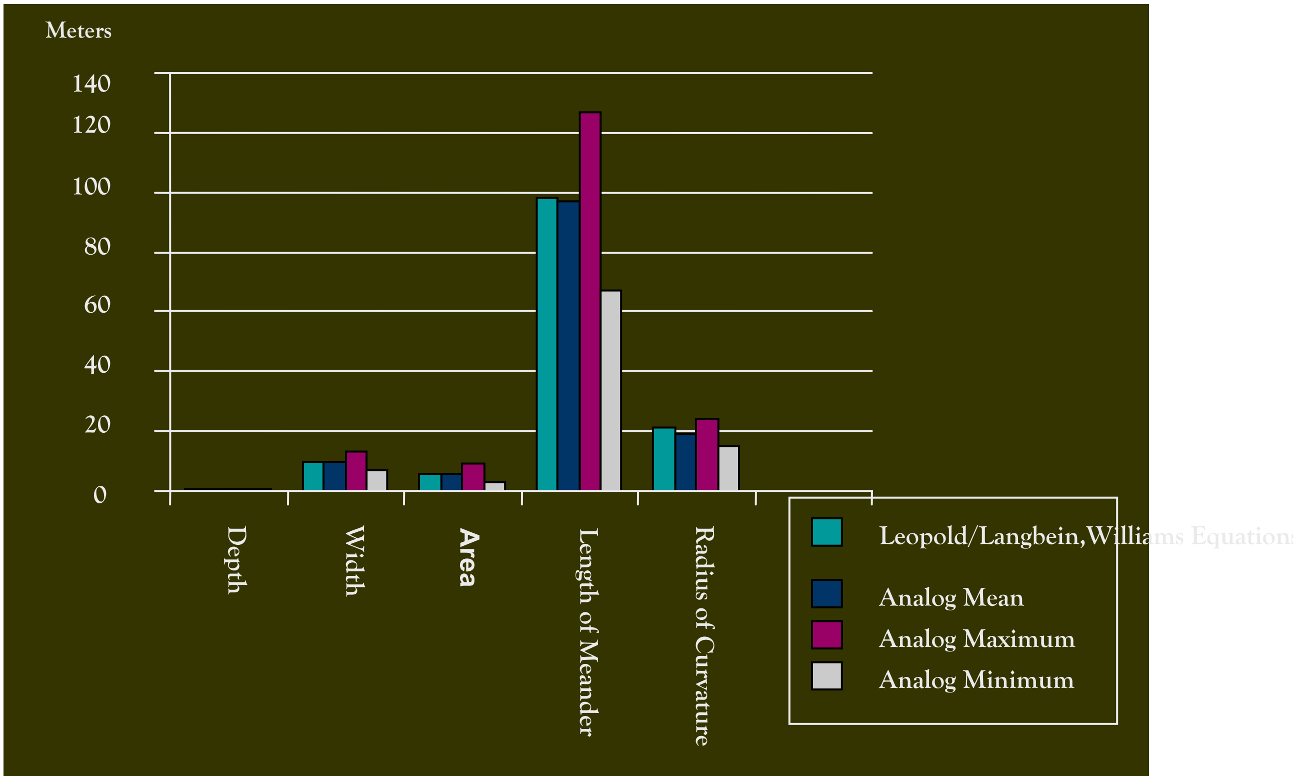

Figure 4. Comparison of channel geometry equations and observed analog data in the "Mining Reach", Wind River, Skamania County Washington.

Table 1. Layout Creek cross-sections applied to three mean radius of bend curvature (Rc) channel geometry equations (Williams, 1986).

Cross section 1.53 .66

.89

Cross section	Wbnk =0.71Rc	A = 0.067Rc	D = 0.085Rc
LO1	Rc = 60m	Rc = 47m	Rc = 34m
LO2	**Rc = 45m**	**Rc = 44m**	**Rc = 46m**
LO3	Rc = 53m	Rc = 38m	Rc = 26m
LO4	**Rc = 104m**	**Rc = 55m**	**Rc = 24m**
LO5	Rc = 43m	Rc = 31m	Rc = 21m

Quantitative Objectives
Quantitative project objectives for Resurrection Creek were formulated with template data. The template objectives provide the base for monitoring and measuring the success of the project. Two examples of quantitative monitoring relative to objectives in Southwest Washington State are presented below:

Layout Creek Monitoring Report (Powers, 1998) documented the following:

- Objective: Restore riparian conifers to densities of 61 trees per hectare, >79cm in diameter.
  - 53,000 western red cedar, grand fir and hemlock trees were planted along 6.4 river kilometers of Trout and Layout Creek.
- Objective: Increase LWD to 150 pieces/km, >31cm in diameter.
  - Large woody debris (>31cm in diameter) was increased 333%, from 50 to 168 pieces per km (along 3.1 km).
- Objective: Increase bank stability to >80% and reduce coarse and fine sediment input from banks.
  - Bank stability was increased from 60% to 93%, from 1.3 km unstable to <100 m.
  - Coarse and fine sediment input from eroding banks was decreased by an estimated 73%, from 133m^3 to 36m^3.
- Objective: Reconnect 900 meters of off channel habitat.
  - Two hundred meters of off channel habitat were reconnected to the main channel.
- Objective: Restore perennial flow.
  - Subterranean flow was reduced by 93%, from 0.7km to <40m.

Water year 2000 monitoring of the Mining Reach Restoration Project (Bair, 2000, Unpublished Data) evaluated 700 meters of stream for physical changes after restoration. Preliminary results are as follows:

- Objective: Restore riparian conifers to densities of 61 trees per hectare, >79cm in diameter.
  - 46,000 western red cedar and grand fir trees were planted along three river miles of the Upper Wind River.
- Large woody debris (>30cm in diameter) was increased 497%, from 106 to 529 pieces per km.
- Increased bank stability by 58% (420 meters of stable bank to 660m).
- Increased bank full channel length by 48% by restoring meanders, reconnecting floodplains and side channels (700 m to 1,036 m).
- Increased bank full pool volume by 520% (429m^3 - 2234m^3).

Confluence of the Data
The restoration analysis and design of Resurrection Creek stream channel, floodplain and riparian areas will use data from relic and disturbed reference sites and will be evaluated against channel geometry equations. The three together provide an excellent cross check and will reduce cost, risk of resource damage, and will accelerate the recovery of Resurrection Creek riparian areas, water quality and the animals that depend upon them.

TOTAL STATION MAPPING

A total station survey was conducted on river kilometers 8.0 to 9.3 and 13.2 to 14.0 to map topographic and hydraulic features from valley wall to valley wall. The survey included previously monumented, surveyed cross-sections established by Montana State University Graduate student Matt Blank. Survey data were used to create high-resolution AutoCAD contour maps of both the project area and reference reach. Data generated from these maps were then used for analysis of channel geometry and restoration alternative development. If action is taken, these maps will be used to develop detailed construction plans and provide the baseline for long term monitoring.

FLOOD FREQUENCY ANALYSIS

Discharge relationships were developed from stream gage data collected at the old USGS gaging station located downstream of the project area. PeakFQ 4.0 flood frequency analysis based on the guidelines delineated in bulletin 17B, published by the Interagency Committee on Water Data (1982), was used to calculate bankfull discharge and return intervals. PeakFQ fits the Pearson Type III distribution to the logarithms of annual flood peaks.

GEOMETRY

Channel geometry measurements within Resurrection Creek were taken on the ground, from aerial photos and AutoCAD generated maps. Measured values were compared against calculated values derived from channel geometry equations Leopold and Wolman (1957, 1960) Williams (1984), Leopold (1964, 1994), Hey and Thorne (1986), Allen (1970), Dury (1956) and Castro and Jackson (2001). The Castro and Jackson, Leopold, Wolman and Williams equations approximated the observed conditions found in the Reference Reach of Resurrection Creek and were therefore applied to this analysis.

BANKFULL CROSS-SECTIONS

Montana State University graduate student Matt Blank established and surveyed 47 permanent cross-sections on Resurrection Creek. Eight of these are located within the project area; two more are located within the established reference reach. Additional cross section data was obtained from generated AutoCAD maps.

SEDIMENT ANALYSIS

A total of 12 Wolman (1954) riffle pebble counts, three gravel bar samples and five tailings pile samples were taken within the project and reference reaches. A total of seven riffles, two gravel bars, and one pool tail crest (spawning sites) and five tailings piles were sampled in the project reach. Two riffles, one side channel riffle, one bar sample and one pool tail crest was sampled in the reference reach. Sediment movement and channel stability for both the reference and project reach were evaluated by methodologies developed by Shields, Andrews and Rosgen (1936,1983,1996).

RIPARIAN VEGETATION

Riparian vegetation was surveyed along seven established channel cross sections (Blank, 2001) within the project reach to evaluate species composition and stand structure. The project reach vegetation transects were labeled in association with Matt Blanks nomenclature i.e.; Resurrection Creek cross-section number 21, West bank = rc21w. Transects were extended from the bankfull width to the valley wall for a total area surveyed of 3,225 m^2. All trees were counted within five meters on either side of the transect line. Four transects and two circular plots were measured in the reference reach with a total area of 2,220 m^2. The linear transects again spurred off of Matt Blanks monumented cross-sections and were labeled as such. All tree species were identified and counted within the two, ten-meter radius circular plots. The circular plots were labeled cg1 and cg2 (circular groves 1 & 2). On 8/22/2002, Elizabeth Bella, Eric Johansen and Julianna Prosperi completed a follow up vegetation survey of the reference and project reaches to identify and characterize riparian composition including components of the under story.

RESULTS & DISCUSSION

REFERENCE REACH

The reference reach is located at river kilometer 13.2-14.0, approximately 3.5 kilometers upstream of the project area (photo 1). The reference reach drains approximately 31,433 hectares and is predominantly a C channel under the Rosgen classification system (Rosgen, 1994). Chugach National Forest personnel selected this site as a reference reach due to the mature riparian vegetation, existing floodplain and associated off channel characteristics. Morphometry values in this report differ from those presented in Blank's 2002 draft report. The differences in values are largely attributed to the scale and degree of resolution within the surveyed area. This survey focused on the upper meander bend and side channel due to vegetation maturity and stable channel characteristics. Forest archaeologists have documented mining in the reference reach in the early part of the century. However the tailings were not piled and did not alter floodplain elevations nor restrict the channel from its original floodplain. Therefore we considered this reach a relic reference reach.

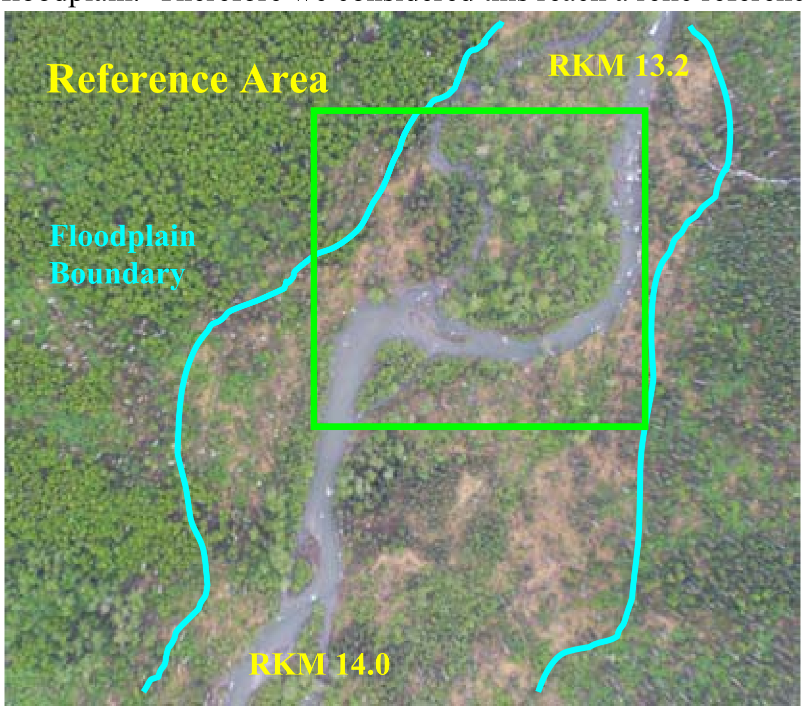

Photo 1. Aerial ortho-photo of the reference reach, river kilometer 13.2 Resurrection Creek, Kenai Peninsula, Alaska.

FLOW FREQUENCY ANLAYSIS

The reference site discharge relationships were extrapolated from stream gage data collected at the old USGS gaging station downstream of the project area. Watershed area to discharge relationships was used to adjust gage data. PEAKFQ 4.0 was used to calculate bank return intervals. Table 2 presents return intervals and flood frequency for the reference reach.

Table 2. Calculated return intervals and flood frequency for the reference reach.

Q	1.25	2	5	10	25	50	100	200	500
Cfs (ft^3/s)	**758**	**992**	**1,399**	**1,800**	**2,407**	**2,942**	**3,560**	**4,269**	**5,371**
Cms (m^3/s)	**22**	**28**	**40**	**51**	**68**	**83**	**101**	**121**	**152**

GEOMETRY ANALYSIS

The reference reach is located in an unconfined alluvial valley, which is evidenced by the floodplain width/bankfull width or entrenchment ratio of 8:1. The bankfull width to depth ratios ranged from 35-40 in the reference reach and was on the high end of the spectrum for Rosgen C channels. This may be partially due to the relatively high amount of large woody material found within the bankfull channel or high sediment loads. Large in-stream woody material >31cm in diameter totaled 214 pieces per river kilometer in the reference reach which formed numerous braids and maintained perennial side channels characteristic of alluvial fans or Rosgen D channels. The wood within this reach created and maintained an extremely diverse array of aquatic and terrestrial habitat (see photo 2). One large logjam moderated flow into a perennial side channel that contained the majority of pink, chinook and coho salmon spawning habitat within the reach. Pebble counts, ocular estimates and contour maps were used to estimate the quantity of spawning gravel within the reference reach. Approximately 1,100 m^2 was estimated in 0.42 river kilometers of the reference reach. This is thought to be a relatively conservative estimate due to the fact that a significant portion of the relief channel, which possessed the most of the spawning gravel, was covered by ice at the time of the survey. Other dispersed concentrations of in-stream wood protected islands of vegetation, dissipated flow and initiated fine sediment deposition on the floodplain. Photo 2 and figure 6 depicts the character, number and species of in-stream woody material per river kilometer within Resurrection Creek reference reach bankfull channel.

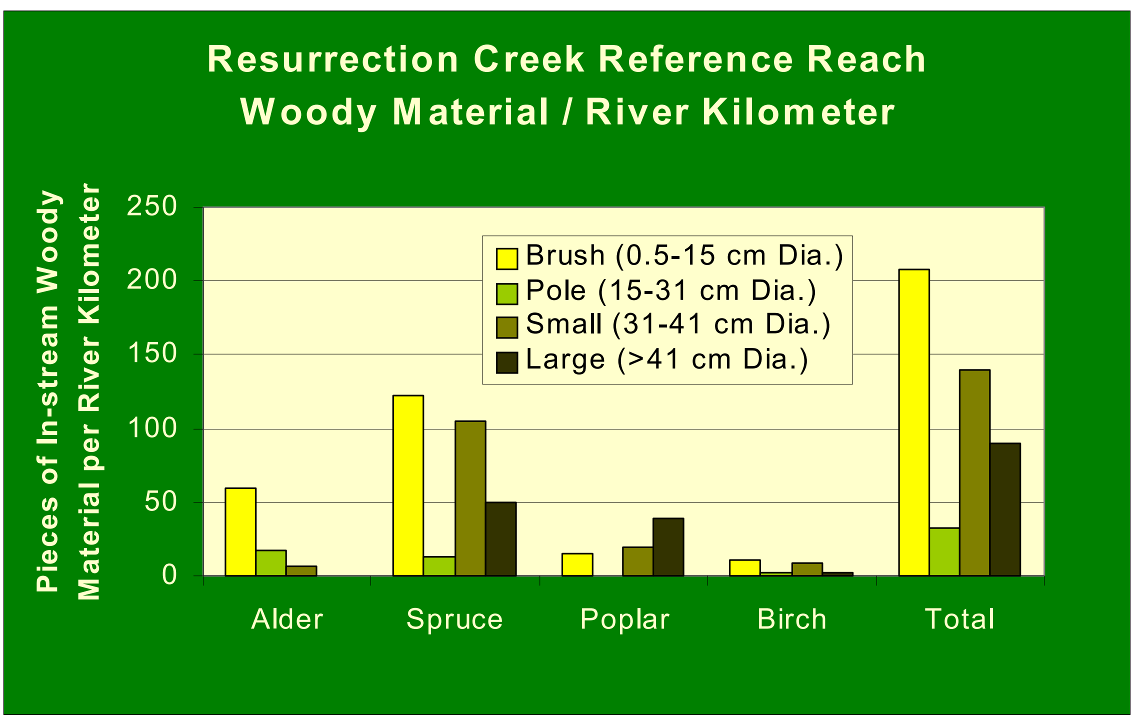

Figure 6. Number and species of in-stream woody material per river kilometer within Resurrection Creek reference reach bankfull channel, Kenai Peninsula, Alaska.

Photo 2. Photo of typical in-stream woody material within the Resurrection Creek reference reach bankfull channel, river km 13.4 (looking up-stream) Kenai Peninsula, Alaska.
Photo Olegario

Meander lengths were measured in the field, taken off of AutoCAD contour maps and low elevation aerial ortho-photos (Figure 5).

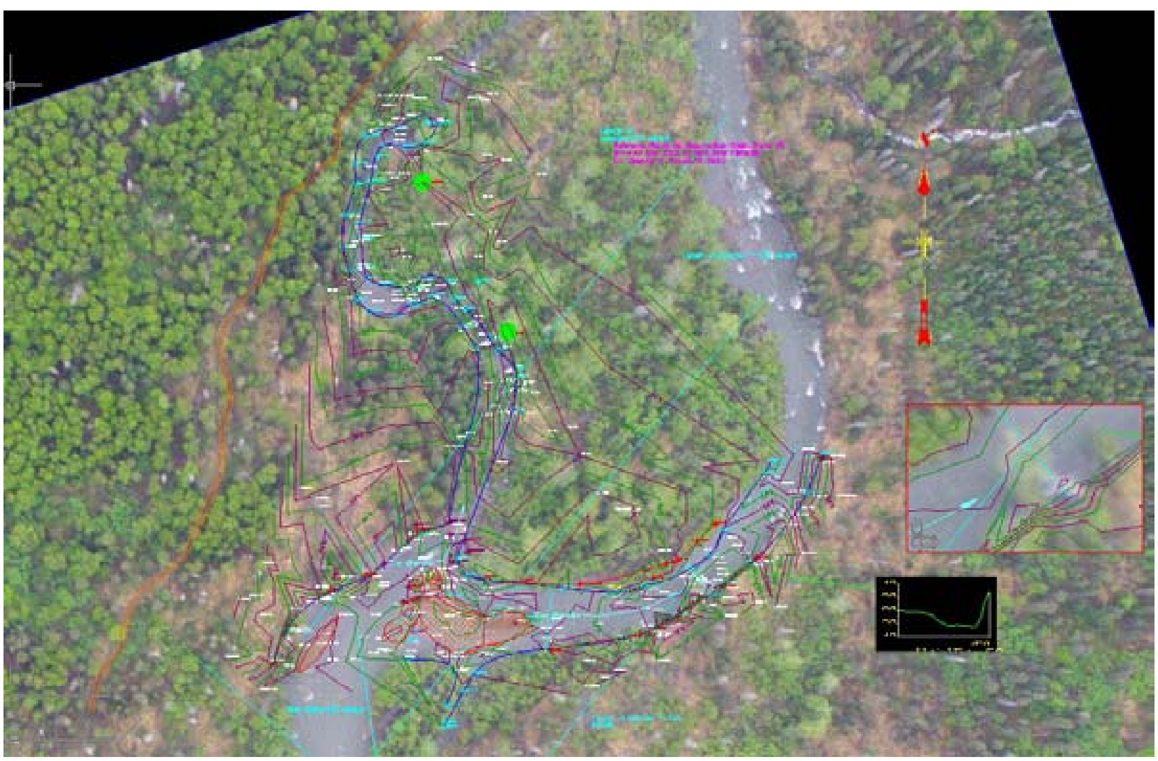

Figure 5. Aerial photo and contour site map overlay for 2002 reference reach survey, Resurrection Creek, Kenai Peninsula, Alaska.

Six meander lengths were measured in the reference reach. Length of meander values ranged from 116 – 146 meters and averaged 131 meters. These measured values were evaluated against calculated values generated from cross-sectional data and then applied to Williams (1984) channel geometry equations. The equation selected for this evaluation is based on stream channel cross-sectional area:

$$\text{Length of Meander (Lm)} = 30\text{Area (A)}^{0.65}$$

This particular equation is the most reliable due to the variability of widths and average depths within a reach, i.e., equations based on width and depth are subject to over and under estimating geometry respectively. Cross-sectional areas were taken from four cross-sections within or in close proximity to the reference reach. Values generated from hydraulic equations predicted an averaged length of meander of 136 meters (range 113-168 meters), which is relatively consistent with the measured values presented above.

Five pools with >1m residual pool depth were also counted within this reach, which was approximately 12 pools/river kilometer. Assuming two pools per meander length (average calculated Lm=136m) estimates 14.7 pools per river kilometer, which is also consistent with observed values.

Meander belt widths within the reference reach were also measured in four places and evaluated against William's equations. Measured belt widths ranged from 60-91 meters with an average belt width of 77 meters. The previous lengths of meander (six measured) taken in the reference reach were applied to the following equation to predict and evaluate the observed belt width values:

$$\text{Belt width (B)} = 0.61(\text{Lm})$$

Calculated values generated from measured lengths of meander predicted belt widths would range from 71 to 89 meters with an average belt width of 80 meters. Again the William's equations closely approximated the measured values, which increase the confidence in the utility of the William's equations for this area and this site as a reference reach. This data will also serve and play a critical role in development of restoration templates. Table 3 provides key geomorphic features for the reference reach.

Bankfull widths measured in the Reference Reach were also evaluated against discharge recurrence interval and hydraulic geometry relationships developed for the Pacific Northwest (Castro and Jackson, 2001). The hydraulic regression equations used for this analysis were:

Pacific Northwest Streams (N = 76)

$$\text{Bankfull Width (w)} = 2.34\text{Bankfull Discharge (Q)}^{0.49}$$

Pacific Maritime Mountain Streams (N = 22)

$$\text{Bankfull Width (w)} = 2.37\text{Bankfull Discharge (Q)}^{0.50}$$

West Interior Basin and Range Streams (N = 22)

$$\text{Bankfull Width (w)} = 0.96\text{Bankfull Discharge (Q)}^{0.60}$$

West Interior Basin and Range Streams (N = 22)

$$\text{Bankfull Width (w)} = 0.96\text{Bankfull Discharge (Q)}^{0.60}$$

Based on discharge, the Castro and Jackson equations predicted that bankfull widths would range from 15.8 – 20.1 meters. The average of all bankfull widths measured in the Reference Reach was 16.8 m which falls within that range.

Table 3. Channel morphometry for the Resurrection Creek reference reach, Kenai Peninsula, Alaska.

Valley Length	248 meters
Valley Slope	0.02 (2%)
Valley Width	215 meters
Channel Length	428 meters
Elevation Drop	5.0 meters
Thalweg Slope	0.0117 (1.17%)
Riffle Slope	0.015 (1.5%)
Rosgen Channel Type	C3-4
Bankfull Width Ave.	16.75 m
Bankfull Ave. Depth	0.56 m
Sinuosity	1.7
Large In-stream Wood/Kilometer	214 (>31cm in diameter)
Entrenchment ratio	7.9
Pools/Kilometer	12
D50	98mm
Length of Meander	113-168 meters
Belt Width	60-90 meters
Ave. Bed Shear Stress	0.64-0.85 Newtons/m^2

SEDIMENT ANALYSIS

Four pebble counts were conducted within the main-stem and side channel of the reference reach to evaluate stability, bed load movement and spawning substrate for salmonids. Table 4 shows the size percentage of substrate less than D16, D35, D50, D84 and D95, i.e., a D16 value of 36 is translated to 16% of the substrate in the sample is less than 36mm in diameter.

Table 4. Pebble Count data for the reference reach of Resurrection Creek, Rkm 13.2-14.0, Kenai Peninsula Alaska.

Samples	Size percent less than (mm)				
	D16	D35	D50	D84	D95
Reference RC3 #1 & 2	36	73	98	211	287
Reference Bar sample RC3	0	18	26	94	193
Spawning Substrate w/n Side channel Ref. Reach	10	20	28	73	135
Side Channel Riffle	29	41	52	86	137

Channel geometry equations originally derived from Shields (1936) for bed shear stress along with dimensionless shear stress equations further developed by Andrews, Rosgen and Leopold et al. (1983) were used to evaluate channel stability using the average particle sizes for the stream bed (D50) and sub pavement (Ds50). Time and funding constraints prevented additional sediment sampling that would further refine, calibrate and verify a sediment transport model with increased accuracy. The difficulties and limitations associated with bed-load transport have not been ameliorated due to complex mechanisms surrounding bed movement, lack of accurate field data to validate equations, and the limited value of channel geometry equations derived from uniform bed materials (Thorne et. al. 1996). The methods selected for this analysis required an iterative process where checks and crosschecks provided an acceptable level of confidence with the understanding of the variable nature of sediment transport from one location to the next or even within reaches.

Using values for D50 and Ds50 (98mm and 25.6mm respectively) for the reference reach, critical dimensionless shear stress was calculated as 0.0375. This value along with the largest particle diameter from the bar sample was then used to determine the bankfull mean depth required to entrain the largest particle in the bar sample. A ratio between the existing bankfull depth and calculated mean depth was then used to determine stream stability. With the criteria being stable if de/d =1, aggrading if de/d<1, and degrading if de>1 (where de-existing bankfull mean depth). The following presents the calculations and discusses the results of this analysis:

REFERENCE REACH CALCULATIONS

1.)

Independent variables:

D50 = 98 mm
Ds50 =25.6 mm (bar sample)
D_i = 200 mm
S = .015
d_e = 1.93-2.14 (range of values taken from field survey, May 2002)

Calculated variables:

τ_{ci}= .0259
d = 1.87ft

Comparison to existing bankfull depth:
d_e/d = (1.93-2.14)/1.87 = (1.03-1.1) This range of values suggests a stable reach; ie. Stream bed is not aggrading or degrading (de/d=1).

2.)

Independent variables:

D50 = 98 mm
Ds50 =34 mm (approximated as D50/2.5)
D_i = 200 mm
S = .015
d_e = 1.93-2.14ft (range of values taken from field survey, May 2002)

Calculated variables:

τ_{ci}= .0375
d = 2.71ft

Comparison to existing bankfull depth:
$d_e/d = 2.14/2.71 = .8$

Dimensionless shear stress values for the reference reach were calculated to be 0.0259 and the bankfull mean depth required to entrain the largest particle in the bar sample was calculated to be 1.87ft. Comparing this value to the measured bankfull mean depth range of 1.93-2.14 (AutoCAD survey & Matt Blank data) gave a ratio between 1.0-1.1. The results of the calculated values suggest that sediment transport mechanisms appear to be in equilibrium ($d_e/d \sim 1$) and that the channel is stable. This analysis increases the confidence in this reach as a suitable analog and reference site. However final project designs will require additional pavement and sub-pavement samples and data analysis due to the limited sample size.

RIPARIAN VEGETATION
Three linear and two circular vegetation plots totaling 3,225m² were surveyed to provide a representative characterization of vegetation structure and density. The tree species found within the riparian area were: Lutz spruce *Picea X lutzii,* paper birch *Betula papyrifera*, black cottonwood *Populus trichocarpa*, and mountain hemlock *Tsuga mertensiana*. The spruce beetle *Dendroctonus rufipennis* has had a significant effect on the vegetation within the Resurrection Creek watershed. Holsten, Werner and DeVelice (1995) found that 10 years after the 1974 infestation tree species remained approximately the same, but forest structure changed as tree density and species richness decreased in the Resurrection Creek watershed. Tree densities in the measured plots of the reference reach averaged 511 live trees per hectare (range 162-904, figure 7). Densities were similar to what Holsten, Werner and DeVelice found in the prescribed burn area (563 live trees per hectare) of their study in 1995. They postulated that the lower density growth rates may be attributed to the increased occurrence and ground cover of bluejoint grass *Calamagrostis canadensis.* A recent study by Schulz (2000) showed decreases in *Calamagrostis* cover to levels not significantly different than those occurring near the beginning of the spruce beetle infestation. Bluejoint grass was the dominant ground cover in the reference area and appears to be pervasive in alluvial riparian areas throughout the Kenai Peninsula. The dominance of bluejoint grass within riparian areas is probably related to the relatively high frequency of disturbance and/or sediment and organic deposition characteristic of flood prone areas.

There were observed differences in stand structure between the 1995 study and the 2002 riparian surveys. The 2002 riparian stands surveyed contained 51% Lutz spruce, 37% black cottonwood, 10% paper birch and 2% hemlock (figure 8). The 1995 study documented that Lutz spruce was the dominant tree species and comprised 93% of the stands. This difference in species composition may be partially attributed to the differences in upland and riparian vegetation composition. The differences in species composition may also be partially responsible for the differences in diameter structure between the 1995 report and the 2002 riparian survey. Fifty-one percent of the trees in both the burned and unburned areas of the 1995 study were composed of saplings 0-22 cm in diameter at breast height (dbh). In the 2002 survey 50% of the trees were also in the Seedling/Sapling class (0-15 cm dbh), which closely approximates what was found in the 1995 study (figure 9). However the riparian stands surveyed in 2002 contained higher densities of larger diameter trees (>31 cm dbh). Thirty-four percent of the trees measured in the 2002 riparian survey were in the small and large tree classes (>31cm dbh), the majority of which were black cottonwood. Whereas only 18% of the trees observed in the 1995 study were found to be >31 cm dbh, the majority of which were Lutz spruce. Snags and coarse woody debris levels within the 2002 reference reach plots ranged from 0-79 and 51-469 pieces per hectare respectively (figure 10). Due to the extent of beetle kill within the reference area these values may represent the extremes in natural variability.

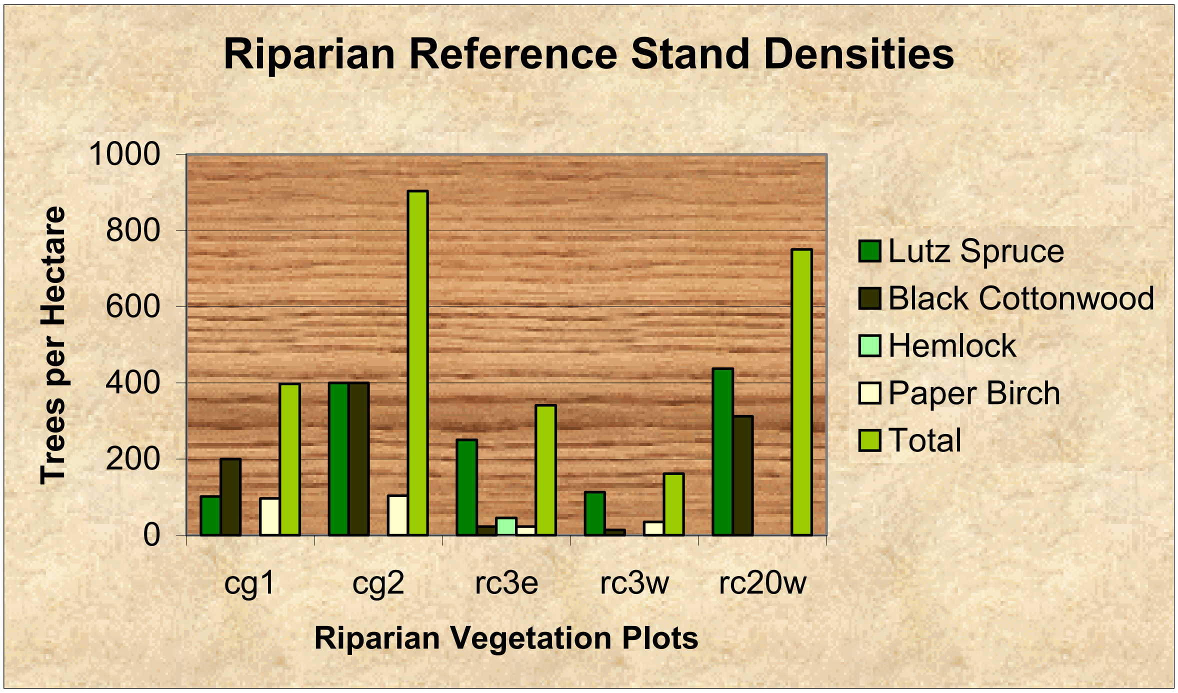

Figure 7. Tree densities by species observed within the Resurrection Creek reference reach riparian vegetation plots, May, 2002 survey, Kenai Peninsula, Alaska.

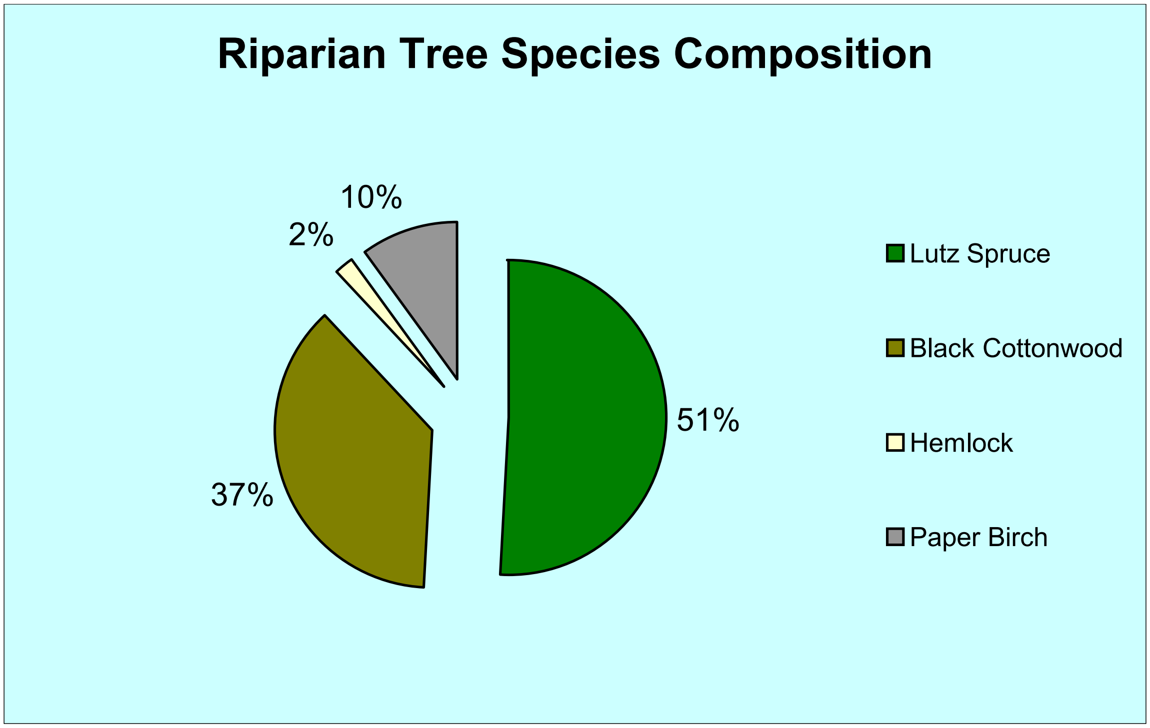

Figure 8. Riparian tree species composition within the 2002 Resurrection Creek reference reach riparian vegetation plots, Kenai Peninsula, Alaska.

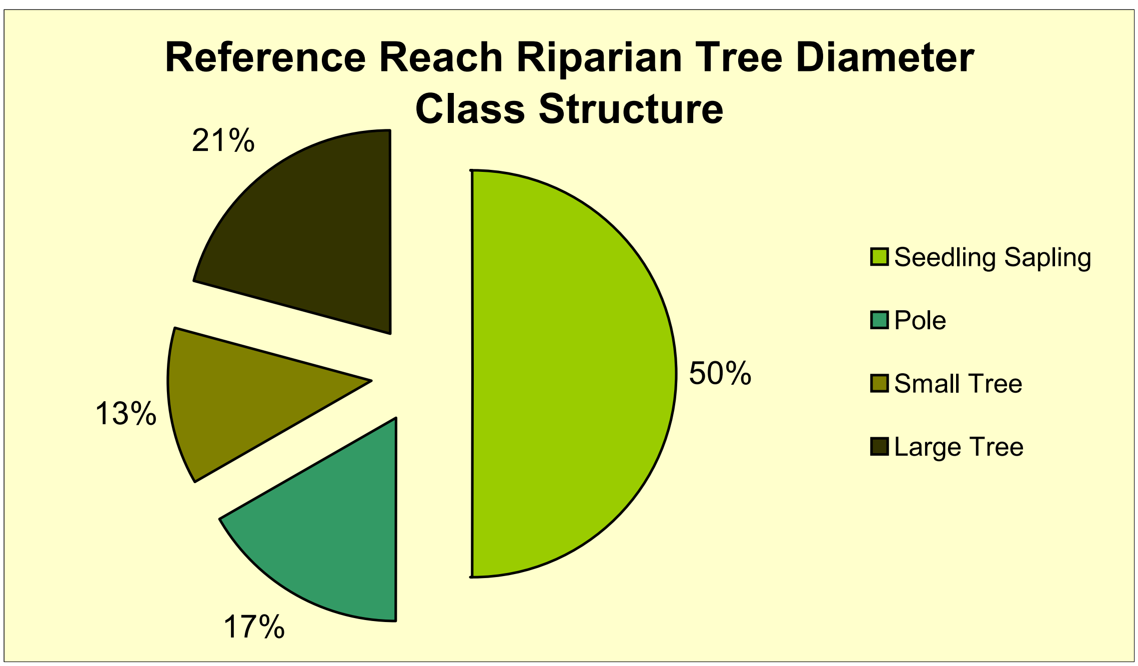

Figure 9. Riparian tree diameter class structure within the 2002 Resurrection Creek reference reach riparian vegetation plots, Kenai Peninsula, Alaska.
*** Seedling/Sapling = 0-15 cm diameter, Pole = 15-31 cm diameter, Small Tree = 31-41 cm diameter and Large Tree >41cm diameter.**

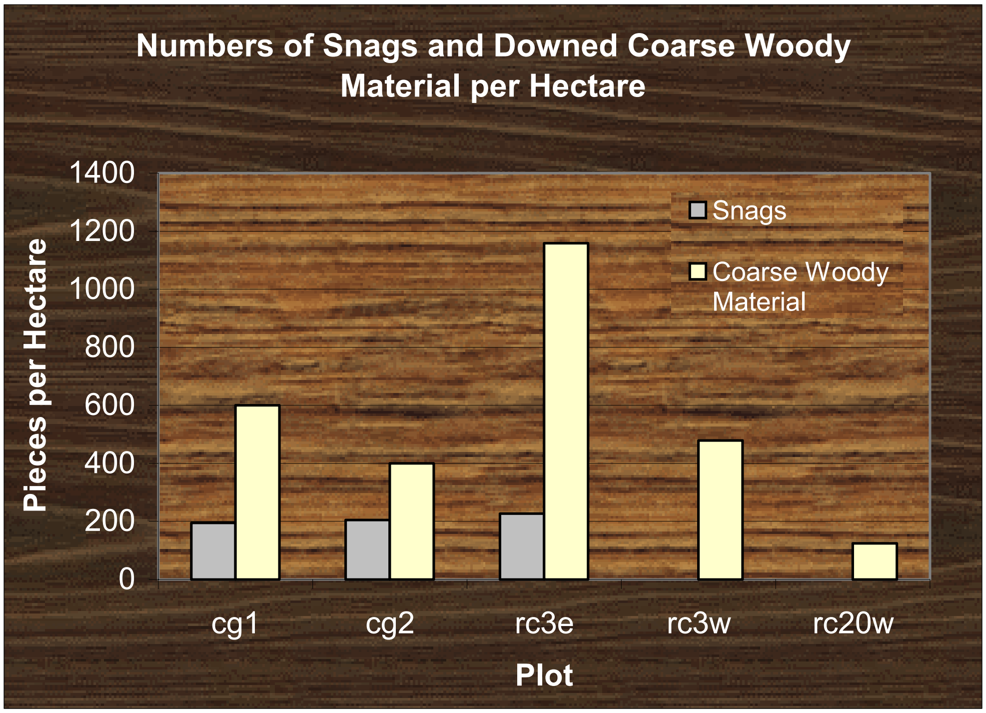

Figure 10. Snag and coarse downed woody material densities within the 2002 Resurrection Creek reference reach riparian vegetation plots, Kenai Peninsula, Alaska.

On 8/22/2002, Elizabeth Bella, Eric Johansen and Julianna Prosperi completed a follow up vegetation survey of the reference reach which included a characterization of the under story. The following is a paraphrased excerpt from their notes: The reference area is composed of a network of braided channels with thick patches of blue joint reedgrass and oak fern. There are large patches of open, fireweed-filled areas and patches of advanced willow and alder thickets. Forested cover influences the immediate stream edge areas; damp areas with cottonwood over-story with heavy horsetail cover. Table 5 provides the species and under-story composition of the reference reach in relative order of abundance.

Table 5. Under-story composition of the reference reach, Resurrection Creek, Kenai Peninsula, Alaska. (Species are listed in relative order of abundance).

Shrub	
Alnus crispa ssp. tenuifolia	Sitka alder
Salix scouleriana	Scouler's willow
Salix barclayi	Barclay's willow
Salix alaxensis	felt-leaved willow
Viburnum edule	highbush cranberry
Oplopanax horridus	devil's club
Ribes triste	northern red currant
Rubus spectabilis	salmonberry
Forb	
Epilobium ciliatum	purple willow-herb
Geum macrophyllum	large-leaved avens
Sangiusorba sitchensis	Sitka burnet
Polemonium acutiflorum	tall Jacob's ladder
Thalictrum sparsiflorum	few-flowered meadowrue
Heracleum lanatum	cow parsnip
Streptopus amplexifolius	twisted stalk
Trientalis europaea	arctic starflower
Viola spp.	violet
Fragaria virginiana	strawberry
Artemisia tilesia	wormwood
Galium aparine	sweet-scented bedstraw
Ferns/Allies	
Equisetum arvense	common horsetail
Gymnocarpium dryopteris	oak fern
Athyrium felix-femina	lady fern
Graminoids	
Calamagrosis canadensis	bluejoint reedgrass
Juncus ensifolius	common rush
Carex mertensiana	Merten's sedge
Carex canescens	grey sedge
Agrostis spp.	bentgrass

PROJECT AREA

The project area is located at river kilometer 8.0-9.3 and drains approximately 41,776 hectares (16,913 acres). This channel was classified as a Rosgen B2 to B3 stream. Historically the project area appears to have been a Rosgen C3 to C4. However, mine tailings left from placer and shovel mining in the early part of the century bisect the stream corridor. The mine tailings resulted in entrenchment of the stream and cutoff access from the historic floodplain (photo 3, figure 11). The direct impact of disturbance and loss of the stream's ability to access the floodplain have severely altered aquatic habitat and riparian vegetation composition.

Photo 3. Photo of mine tailings and stream channel confinement in Resurrection Creek project area, river km ~10, Kenai Peninsula, Alaska. ***Photo Olegario***

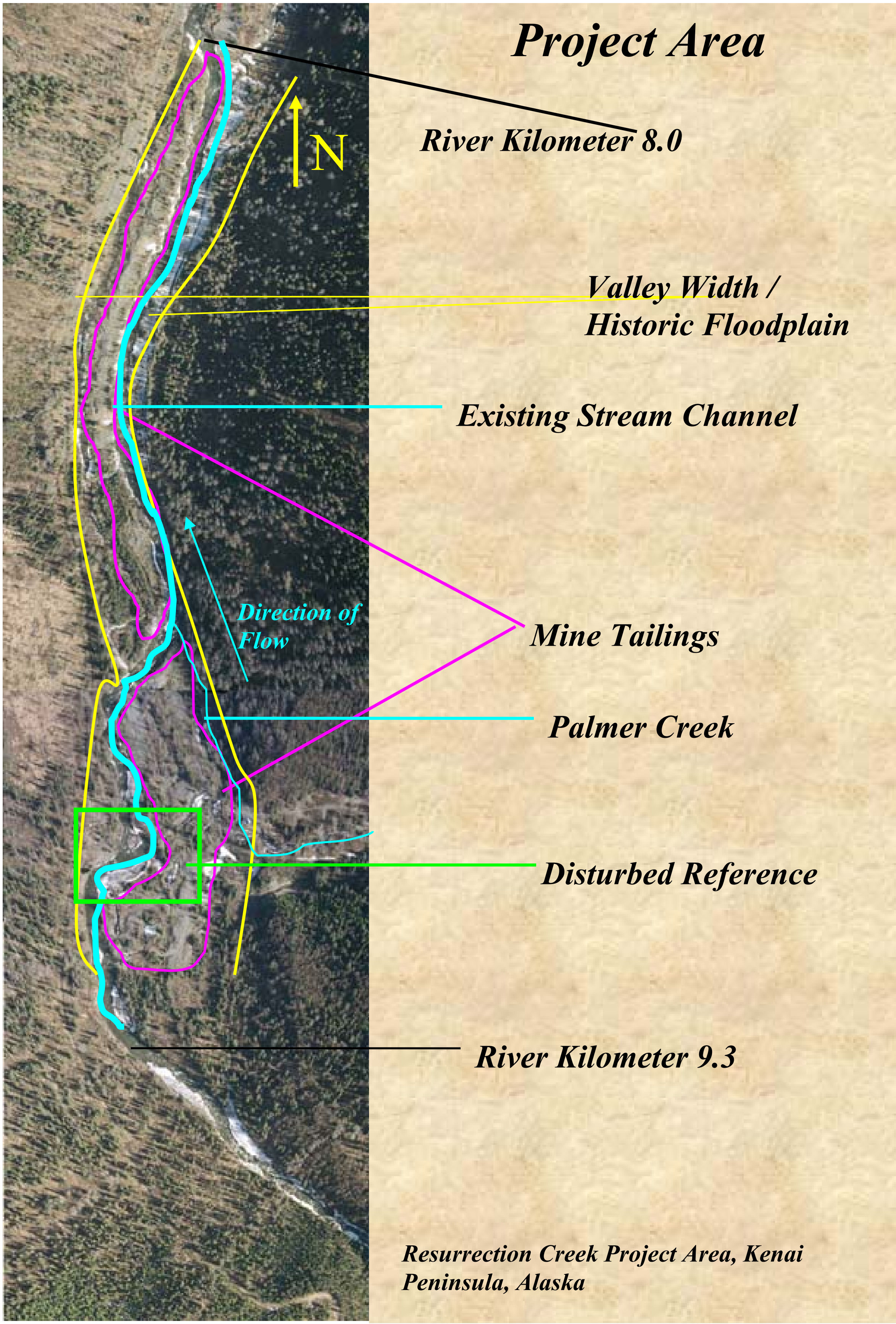

Figure 11. Resurrection Creek project reach area map Rkm 8.0-9.3.

FLOW FREQUENCY ANALYSIS

Discharge relationships were developed from stream gage data collected at the old USGS gaging station downstream of the project area. PEAKFQ 4.0 was used to calculate bankfull discharge and return intervals (table 6).

Table 6. Calculated return intervals and flood frequency for the project reach.

Q	1.25	2	5	10	25	50	100	200	500
Cfs (ft^3/s)	**1,011**	**1,323**	**1,865**	**2,400**	**3,210**	**3,923**	**4,747**	**5,692**	**7,162**
Cms (m^3/s)	**29**	**38**	**53**	**68**	**91**	**111**	**134**	**161**	**202**

GEOMETRY ANALYSIS

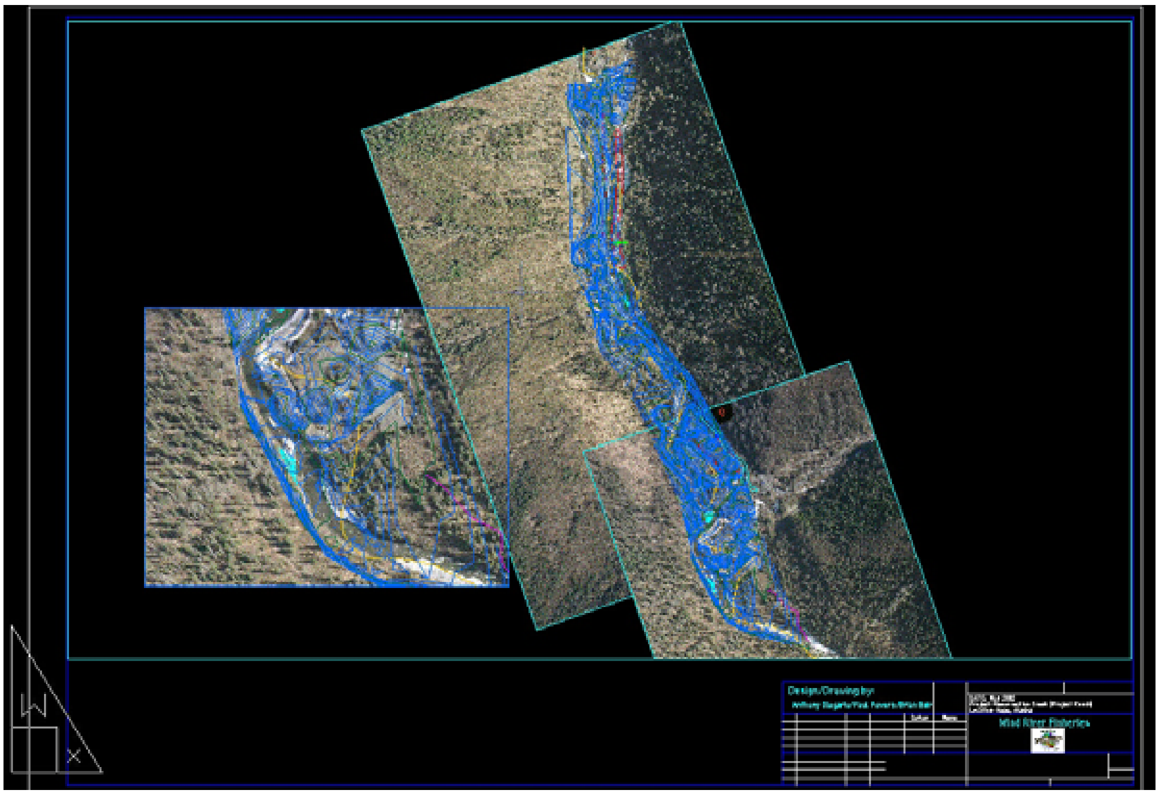

Figure 12. Aerial photo and contour site map overlay for 2002 project reach survey, Resurrection Creek, Kenai Peninsula, Alaska.

The project area and reference reach have similar valley slopes and widths. However the two reaches are vastly different systems in both form and function. The differences in bankfull width/floodplain width graphically illustrate the constriction of the stream channel and loss of floodplain due to the mine tailings (figures 13 & 14). The reference reach has a floodplain width eight times the normal bankfull width of the stream channel during flood flows >Q3. When floods occur they spread out over the floodplain, which allows the stream to disperse, dissipate and reduce stream power. Inundation of the floodplain also augments and fertilizes riparian areas by depositing fine sediment and organics. Sheet flow across the floodplain also creates a complex of side channels and off channel habitat that are critical for salmonid spawning and rearing.

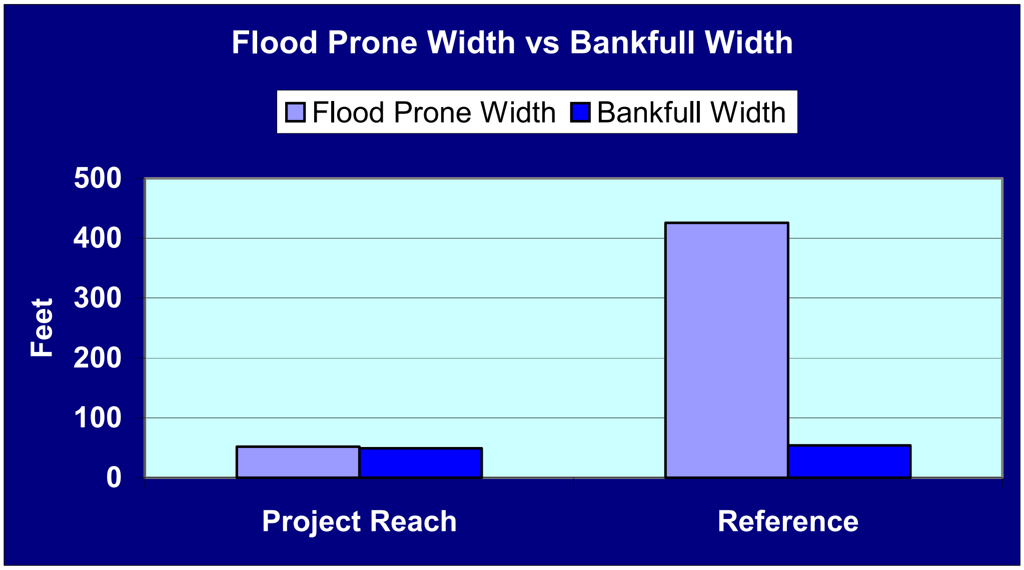

Figure 13. Flood prone and bankfull widths for the disturbed project area and reference reaches of Resurrection Creek, Kenai Peninsula, Alaska.

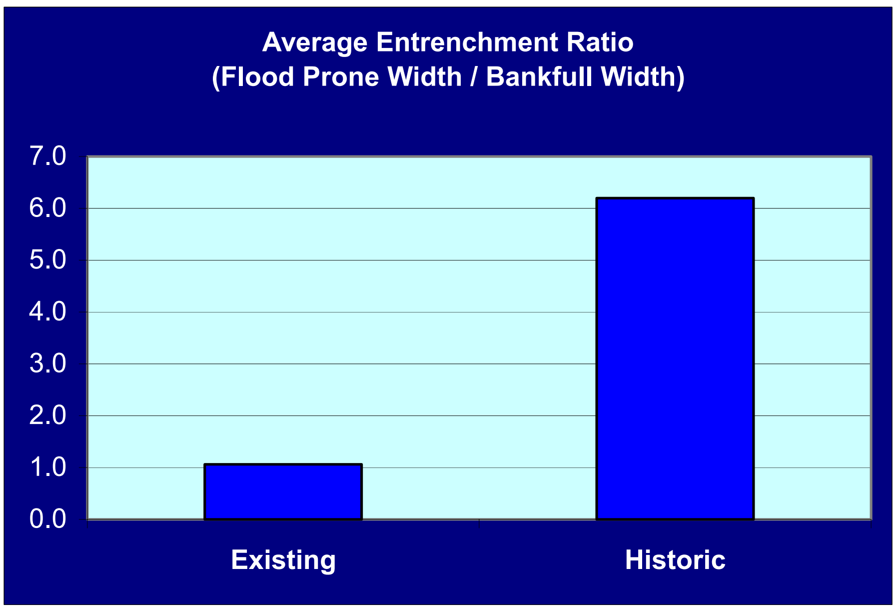

Figure 14. Average existing and historic entrenchment ratios for the project area of Resurrection Creek, Kenai Peninsula, Alaska.

In contrast to the reference reach, the tailings piles within the project area confine all flood flows into a single thread channel roughly the same size as the normal bankfull channel. The tailings piles are essentially functioning as dikes that cutoff the flood flows from the original floodplain. Water velocities accelerate as they are compressed through the constricted channel concentrating the stream's energy on the streambed, simplifying substrate and degrading the channel. Sediment and nutrients are transported through the project area depriving riparian areas of soil and nutrients, which in turn retards disturbance recovery and natural succession. Recent restoration work has reconnected a fraction of the historic salmonid off channel rearing habitat but the vast network of side channels has been either buried by the tailings or cutoff from the main channel.

The loss of organic input and nutrients within the project area is apparent when the quantities of large in-stream woody material within the reference reach are compared to that of the project reach. Ten pieces of large wood greater than 31 cm in diameter per river kilometer were found within the bankfull channel of the project reach whereas 214 pieces per river kilometer observed in the reference reach (figure 15). Chugach National Forest and Seward Ranger District personnel installed the majority of wood observed in the project reach for fish habitat enhancement. The effect of channel constriction by the mine tailings route large woody material and other organics such as salmon carcasses through the project reach during peak flow events much like a log flume.

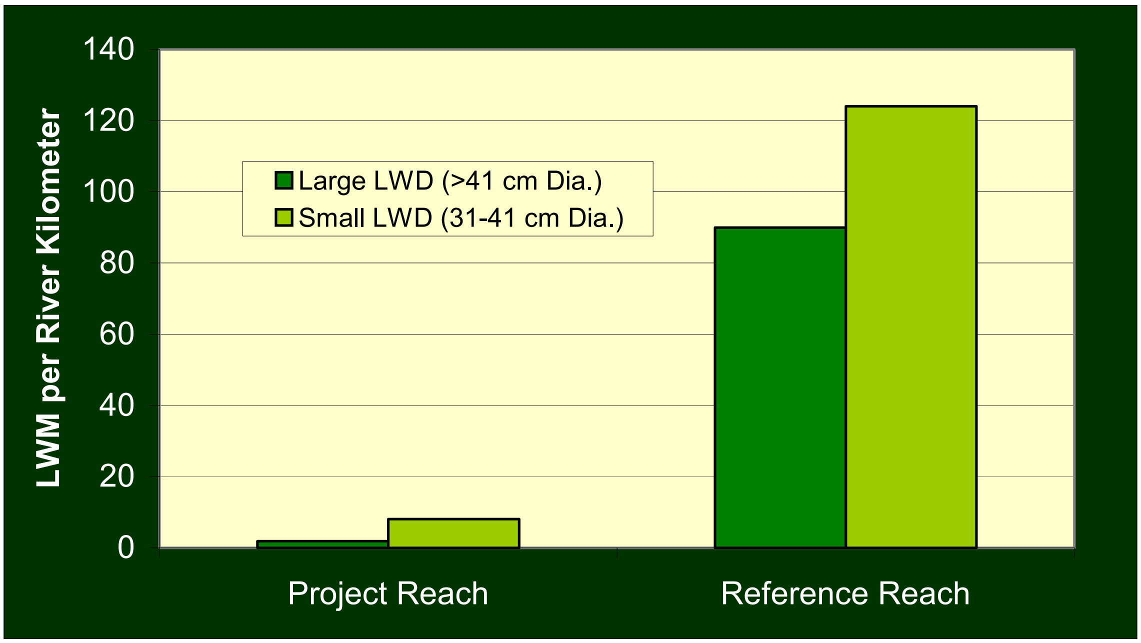

Figure 15. Number of in-stream woody material per river kilometer within the bankfull channel of Resurrection Creek reference and project reaches, Kenai Peninsula, Alaska.

Evidence of the historic meander geometry within the project reach was virtually non-existent due to the confinement of the stream channel and degree of channel straightening. Two reasonable meander lengths were measured (187m and 163m) within a disturbed reference area located at approximately river kilometer 9. The channel within this area was less confined and deposition and scour intervals appeared to be stable. These meander lengths were evaluated against the reference values to estimate pre-disturbance geometry. Cross-sectional areas derived from the project reach were again applied to the previously referenced Williams (1984) equations to evaluate meander lengths. Derived values predicted an average length of meander of 185m with a range of 141m – 221m. Measured length of meander values from the disturbed reference area fall within this range and appear to be remnants of the historic plan form geometry.

The entrenchment and increase in channel slope in the project reach has created a nearly continuous riffle with very few pools. Four pools with residual pool depths > 1m were measured in 1.4 kilometers of stream (approximately 3 pools per kilometer). In contrast, the reference reach contained 12 pools/ river kilometer. Most of the pools observed in the reference reach were associated with large woody material and or mature riparian vegetation. The lack of pools within the project area limits resting and rearing habitat for juvenile and adult salmonids.

Pebble counts and ocular estimates were used to estimate the quantity of spawning gravel within the project reach. Approximately 160 m^2 was estimated in 1.3 river kilometers of the project reach. The spawning gravel was isolated to one small patch in the disturbed reference area at approximately river kilometer 9. The spawning gravel existed in the only section of the project area where the stream was not entrenched and had access to a defined floodplain (figure 16). The reference reach contained 85% more spawning gravel per kilometer than the project area (figure 17).

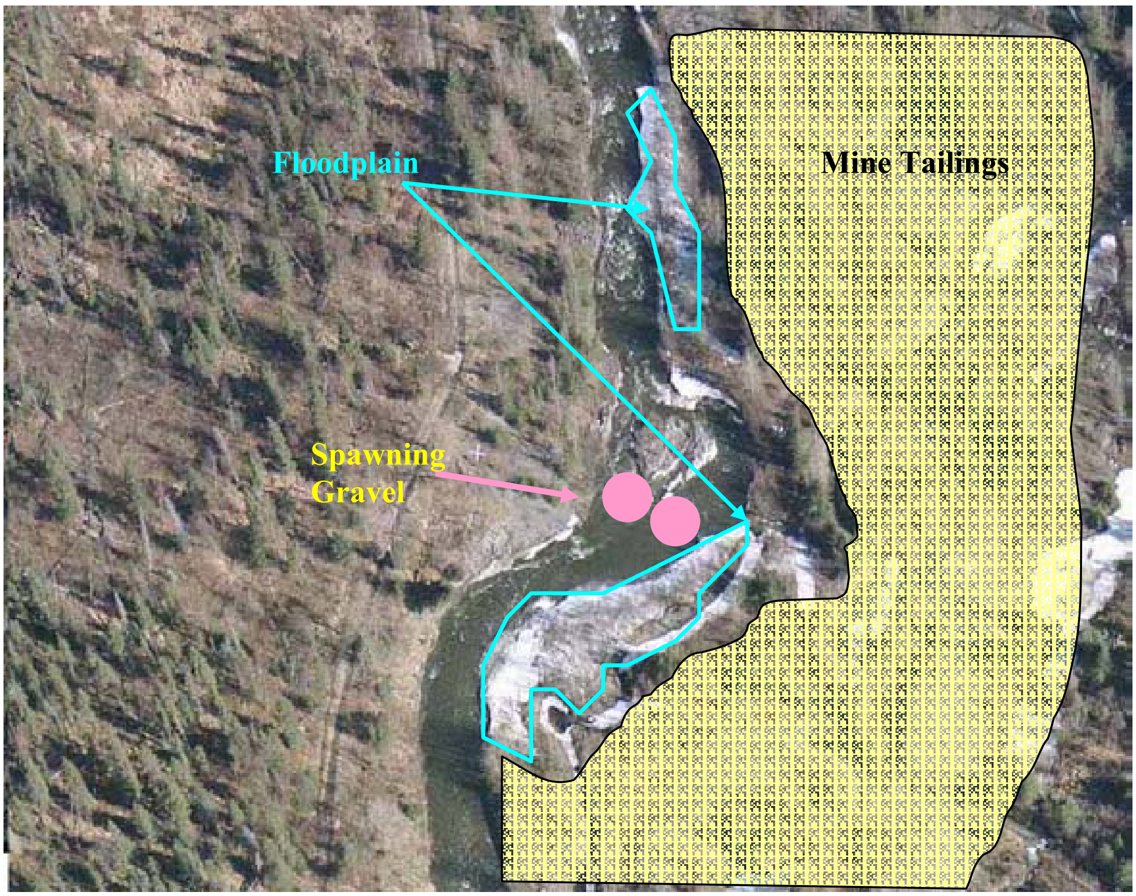

Figure 16. Location of spawning gravel and floodplains Resurrection Creek disturbed reference reach (~Rkm 9), Kenai Peninsula, Alaska.

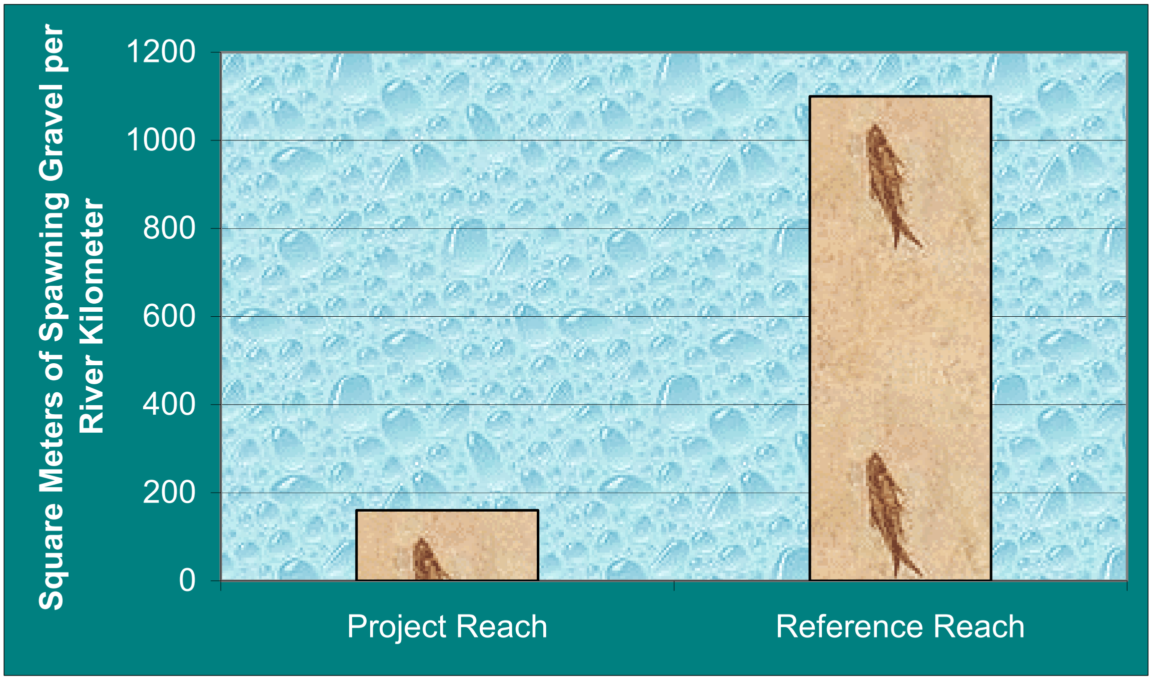

Figure 17. Square meters of spawning gravel per kilometer for the Resurrection Creek project and reference reaches, Kenai Peninsula, Alaska.

Table 7 provides key geomorphic features for the project reach.

Table 7. Channel morphometry for the Resurrection Creek project reach, Kenai Peninsula, Alaska.

Valley Length	1,305 meters
Valley Slope	(0.017) 1.7%
Valley Width	115-145 m
Channel Length	1495 m
Elevation Drop	22.34 m
Thalweg Slope	0.0152(1.52%)
Bankfull Width	15.7 m
Bankfull Ave. Depth	0.8 m
Riffle Slope	0.017 (1.7%)
Rosgen Channel Type	B3
Sinuosity	1.1
Large Wood/Kilometer	5 (>31 cm in dia.)
Entrenchment ratio	1.1
Pools/Kilometer	5
D35	66mm
D50	111mm
D84	258mm
Length of Meander	165-225m
Belt Width	101-138m
Ave. Bed Shear Stress	1.24-1.40 Newtons/m^2

SEDIMENT ANALYSIS

Fifteen pebble counts were conducted within riffles, gravel bars, pool tail crest (spawning gravel) and tailings piles of the project reach to evaluate stability, bed load movement, historic bed composition, potential restoration material and spawning substrate for salmonids (Table 8).

Table 8. Pebble Count data for the project reach of Resurrection Creek, Rkm 8.3-9.0, Kenai Peninsula Alaska.

Sample	Size percent less than (mm)				
	D16	D35	D50	D84	D95
#1 Mine Tailings	33	45	65	324	457
#2 Mine Tailings	30	48	59	156	234
#1 Boulder Tailings	304	382	450	782	967
#2 Boulder Tailings	323	438	555	873	1010
#3 Boulder Tailings	292	358	391	469	498
#1 Riffle abv. ST.Louis claim	13	46	85	250	342
#2 Riffle abv. ST.Louis claim	29	74	116	269	353
#3 Riffle abv. ST.Louis claim	24	66	111	250	469
#4 Riffle abv. ST.Louis claim	29	75	133	263	338
Riffle abv. conflu. Palmer Cr.	19	74	131	303	519
#1 Riffle abv dist. Ref.	40	95	148	238	344
#2 Riffle below dist. Ref.	56	86	126	232	336
Bar Sample Near St Louis claim	4	10	41	55	77
Bar Sample abv. conflu. Palmer Cr.	0	24	51	111	198
Spawning gravel in dist. Ref.	0	18	43	99	175

The mine tailings are composed of substrate from the historic streambed and floodplain. The average D84 for all riffle pebble counts (n=692) was 258mm which was slightly higher than the average D84 for the mine tailings 240mm (n=212). The D84 found within spawning substrate in the disturbed reference area was roughly half (127mm) of what was observed in the riffles above and below the site. The boulder piles located throughout the project reach were apparently a by-product of hydraulic and shovel mining. The average D16 of the boulder piles exceeded the average contained D84 for the substrate found in riffles.

The channel stability methods described in the reference reach section of this report were also used to analyze the project reach. The ratios of measured depths over calculated depths ranged between 3.3-4.4 in the project area. This range of calculated values are significantly greater than 1, which are 3-4 orders of magnitude greater than what was observed in the reference reach. This analysis indicates that the streambed in the project reach has degraded as a result of confinement and is fine grain substrate limited. The streambed does however appear to be vertically static. There are two possibilities why the streambed has not degraded further: 1) Fine grain particles were winnowed from the streambed during hydraulic mining and or after channel confinement leaving a coarser, immobile armor layer. 2) The cohesive marine deposited clays that underlie the bed and are functioning as hardpan or bedrock, and preventing erosion (Personal Communication with Dave Blanchet, April 2002).

RIPARIAN VEGETATION

The mine tailings occupy 54% of the floodplain and riparian area. The tailings are composed of coarse substrate, which holds little moisture, nutrients or fine soils to support the historic riparian vegetation. Hence riparian vegetation in the project area differed dramatically from both the reference reach and the Holsten, Werner and Develice (1995) study. Total tree densities averaged 1,786 trees per hectare with a range of 615-5,461 (figure 18). Tree densities within the 2002 reference reach surveys and the 1995 study found 511 and 563 trees per hectare. Survey transects RC 21 W contained extremely high tree densities (5,461/hectare) and was composed primarily of "dog hair" stands of cottonwood. Stocking levels were evaluated without RC 21, however densities were still double (1,174 trees/hectare) of what was observed in the reference area. Riparian tree species composition in the project area also differed radically from the reference reach vegetation. The reference reach riparian stands surveyed contained 51% Lutz spruce, 37% black cottonwood, 10% paper birch and 2% hemlock (figure 19). Whereas the project area was composed of 74% cottonwood and 26% Lutz spruce with birch and hemlock making up only a fraction of a percent of the various stands composition. Stand structure was also extremely different within the project reach with 86% of the trees surveyed were in the seedling sapling class and no large trees observed (figure 20). With the relatively young age of existing stands within the project area it was not surprising to see that snags and downed wood were virtually absent (figure 21).

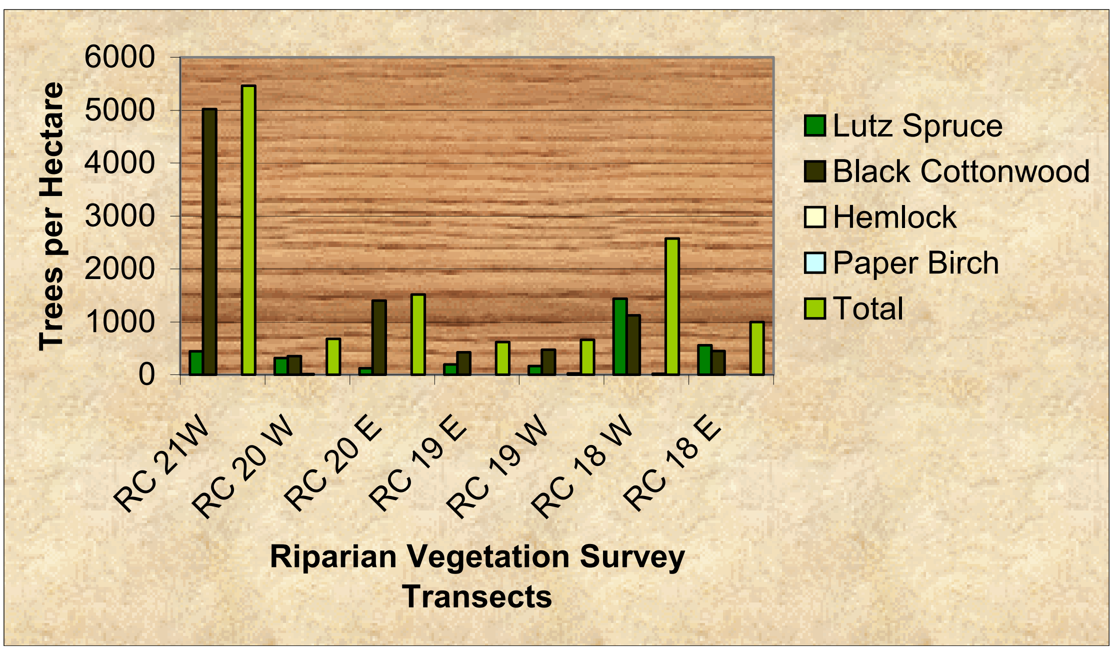

Figure 18. Tree densities by species observed within the Resurrection Creek project reach riparian vegetation plots, May, 2002 survey, Kenai Peninsula, Alaska.

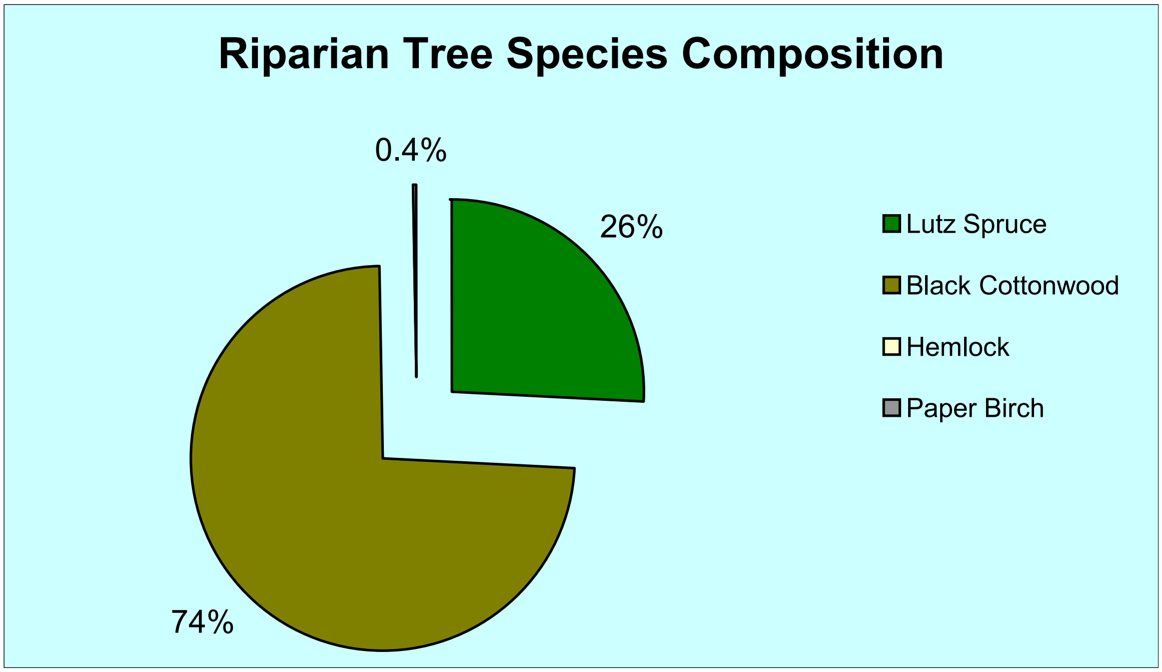

Figure 19. Riparian tree species composition within the Resurrection Creek project reach riparian vegetation plots, Kenai Peninsula, Alaska.

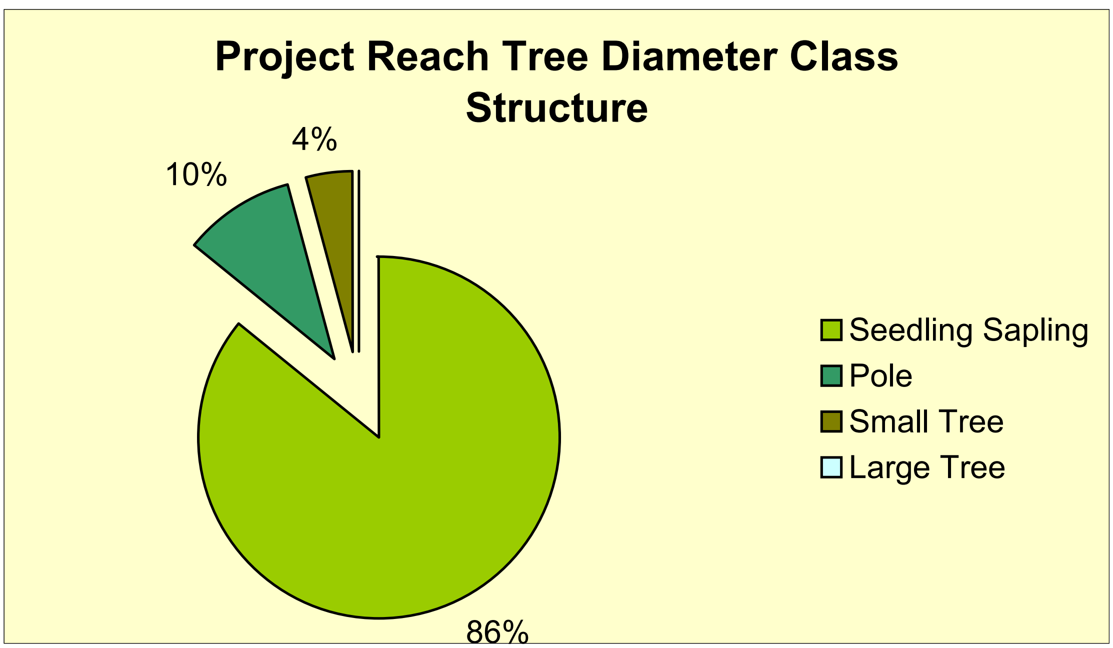

Figure 20. Riparian tree diameter class structure within the Resurrection Creek project reach riparian vegetation plots, Kenai Peninsula, Alaska.
*** Seedling/Sapling = 0-15 cm diameter, Pole = 15-31 cm diameter, Small Tree = 31-41 cm diameter and Large Tree >41cm diameter.**

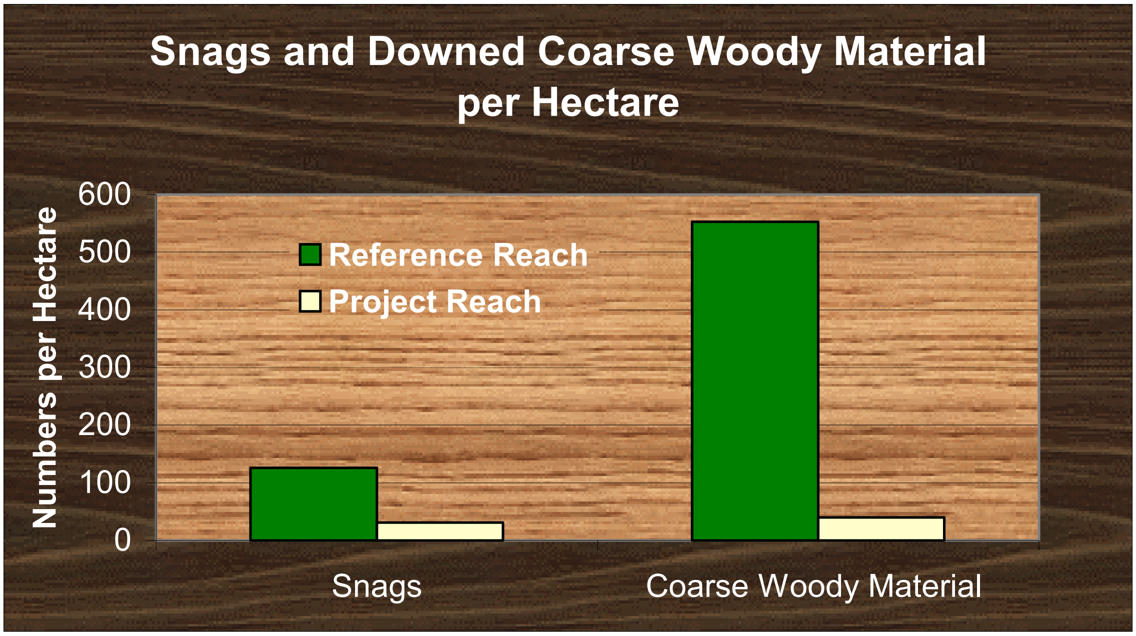

Figure 21. Snag and coarse downed woody material densities within the reference and project reaches of Resurrection Creek riparian vegetation plots, Kenai Peninsula, Alaska

On 8/22/2002, Elizabeth Bella, Eric Johansen and Julianna Prosperi completed a follow up vegetation survey of the project reach which included a characterization of the under story. The following are paraphrased excerpts from their notes: Overall, there were fewer species of plants and higher densities of early successional/disturbance species present within the project area than was observed in the reference reach. Salmonberry, wormwood, sweet-scented bedstraw was observed in very low densities and fireweed was conspicuously absent. Vegetation age, diversity and cover complexity development decreased from the valley wall to the bankfull channel. Table 9 provides the species and under-story composition of the project reach in relative order of abundance.

Table 9. Under-story composition of the project reach, Resurrection Creek, Kenai Peninsula, Alaska. (Species are listed in relative order of abundance).

Shrub	
Alnus crispa ssp. tenuifolia	Sitka alder
Salix scouleriana	Scouler's willow
Salix alaxensis	felt-leaved willow
Viburnum edule	highbush cranberry
Salix barclayi	Barclay's willow
Rosa acicularis	prickly rose
Ribes triste	northern red currant
Ribes laxiflorum	trailing black currant
Sambucus racemosa	red elderberry
Rubus idaeus	red raspberry
Linnaea borealis	twinflower

Forb	
Epilobium angustifolium	common fireweed
Sangiusorba sitchensis	Sitka burnet
Aconitum delphinifolium	monkshood
Thalictrum sparsiflorum	few-flowered meadowrue
Polemonium acutiflorum	tall Jacob's ladder
Trientalis europaea	arctic starflower
Mertensia paniculata	bluebells
Epilobium ciliatum	purple willow-herb
Geum macrophyllum	large-leaved avens
Viola spp.	violet
Actaea rubra	baneberry
Heracleum lanatum	cow parsnip
Fragaria virginiana	strawberry
Streptopus amplexifolius	twisted stalk
Claytonia spp.	miner's lettuce
Stelleria calycantha	northern starwort
Rubus pedatus	five-leaf bramble
Cornus canadensis	bunchberry dogwood

Ferns/Allies	
Equisetum arvense	common horsetail
Gymnocarpium dryopteris	oak fern
Athyrium felix-femina	lady fern
Equisetum hyemale	scouring-rush

Graminoids	
Calamagrosis canadensis	bluejoint reedgrass
Carex canescens	grey sedge
Poa pratensis	Kentucky bluegrass
Phleum pratense	timothy
Agrostis spp.	bentgrass
Carex laeviculmis	smooth sedge

CONCLUSION

The project area exist within the upper 10 kilometers identified as critical habitat for spawning and rearing habitat for coho, chum, pink and chinook salmon (RCLA, 2002). Mine tailings produced by placer mining nearly a century ago have significantly altered fish and wildlife habitat within the project reach (photo 4). The mine tailings have confined and straightened the stream, which has increased channel slope by 27%. The increase in channel slope has homogenized the reach creating a nearly continuous riffle with few pools or spawning gravel for fish. The mine tailings occupy 54% of the historic floodplain and are composed of coarse sediment unable to recover the natural riparian vegetation structure or composition. Flood-prone widths to bankfull channel width ratios within the disturbed project reach have been reduced from 7:1 to1:1. The dikes created by the mine tailings prevent fine sediment and organics carried by floods from being deposited on the floodplain. This detachment of the stream channel from the historic floodplain prevents the natural fertilization and soil augmentation mechanisms needed to reestablish vigorous riparian communities. Although the disturbance occurred nearly a century ago riparian vegetation and wildlife habitat have not recovered at a natural rate of succession; 86% of all riparian trees within the disturbed reach are <15cm in diameter with snags and coarse downed wood nearly nonexistent. Without regeneration of riparian vegetation habitat conditions for bears, bald eagles, moose and salmon will be extremely limited within the project reach for generations to come.

Photo 4. Resurrection Creek river kilometer ~8.1-8.6, Kenai Peninsula Alaska.

GOALS & OBJECTIVES

Based on the data analyzed in this report, goals and restoration objectives were developed for Resurrection Creek Rkm 8.0-9.3.

GOALS

The restoration goals for Resurrection Creek are to restore and reconnect the historic floodplain, stream channels and riparian areas to recover the natural range of aquatic and riparian habitat conditions, which fish and wildlife adapted to.

SHORT TERM OBJECTIVES
~ 2-3 YEARS

12) Increase flood prone width to bankfull width ratio (entrenchment ratio) from 1:1 to ≥6:1.
13) Decrease channel thalweg slope from 0.015 to 0.011 (1.5% - 1.1%).
14) Increase channel length by 15% (200m) and sinuosity from 1.01 to 1.4.
15) Increase pools with residual pool depths >1 meter from 3 pools per km to 14.
16) Increase perennial side channel flow from <1% to 5-20%.
17) Increase spawning gravel from 160m² to 2,000m².
18) Increase large in-stream woody material (>31cm in diameter, >20m in length) from 10 pieces/river km to ~200/river km.
19) Restore topsoil and fines to > 80% of the active floodplain and Increase floodplain coarse woody material from 40 to ~300/hectare.
20) Decrease over stocked riparian tree densities from 1,800 trees per hectare to (500-600) live trees/hectare.
21) Restore riparian tree species composition to 50% spruce, 40% cottonwood, 10% poplar and hemlock with a calamagrostis under-story.
22) Increase snags from 5 to ~100 snags/hectare.

LONG TERM OBJECTIVES
>50 YEARS

Restore riparian stand structure to 20% large trees (>41cm in diameter), 15% small trees (31-41cm in diameter), 20% poles (15-31cm in diameter), 45% seedling/saplings (0-15cm in diameter)

PROPOSED ACTIONS TO ACCOMPLISH OBJECTIVES

9) Mechanically manipulate mine tailings to recover floodplain width and elevations.
10) Reconstruct meander pattern, channel profile, pools and spawning habitat.
11) Develop multiple relief channels and off channel ponds within the floodplain.
12) Extract beetle killed spruce trees in high risk fire hazard areas and utilize as a source of in-stream and terrestrial woody material and snag enhancement.
13) Augment soils in reclaimed riparian areas to provide soil/landform and drainage conditions which can support native plant communities.
14) Thin existing overstocked riparian sapling spruce and cottonwood stands.
15) Use natural vegetation where seed source and site conditions are favorable towards achieving re-vegetation objectives.
16) Use native plant species in re-vegetation/restoration projects when natural re-vegetation conditions are not favorable

Alternatives presented below portray a wide array of approaches in the recovery of Resurrection Creek.

ALTERNATIVE A

Alternative A is the no action alternative. Barring a stochastic geologic or hydraulic event, the stream channel, riparian vegetation, fish and wildlife habitat would remain in its current condition indefinitely. The mine tailings will continue to confine the stream restricting flood prone width ratios to 1:1. Due to the confinement and resulting increase stream channel slope, pools, side channels, over-wintering and spawning habitat for fish will continue to be extremely limited within the project reach. Mine tailings that are composed of coarse substrate occupy approximately 50% of the historic floodplain. This coarse substrate is unable to support the historic riparian vegetation composition and stand structure. The mine tailings prevent flood flows and the fine sediment they deliver from being delivered to the floodplain. Therefore riparian vegetation will be perpetually sparse and continue to limit wildlife forage and habitat within the reach. No federal or private funds would be expended on this alternative. This alternative would not address the goals and quantitative objectives established in this report in the long or short term.

The following action alternatives are designed to achieve the previously discussed goals and objectives generated by this analysis.

ALTERNATIVE B

Alternative B proposes to utilize the mine tailings, which are composed of the historic streambed substrate to reconstruct the stream channel and floodplain network (figure 22). The road on the eastern bank of the project area would be improved for equipment and material access. There would be three designated stream crossing spurs from the access road. At the end of construction this road would be decommissioned and replaced with a new access road located upslope and out of the floodplain.

Tracked excavators and bulldozers would be used to manipulate tailings to reconstruct stream channels, gravel bars, wetlands and floodplains. Equipment would be spray washed to remove grease, oil and soil before entering the project area to prevent petroleum products from entering watercourses and prevent the spread of noxious weeds. An estimated 81,576 cubic meters of material from the existing tailings would be manipulated (figure 23). Substrate within the mine tailings would be graded and contoured to increase average bankfull width to flood prone width ratios from 1:1 to 7:1 to allow flood flows access to the historic floodplain.

Channel thalweg slope would be decreased from 1.5% to 1.3% by increasing channel length by 200 meters and sinuosity from 1.01 to 1.3. Side channels and wetland complexes and off channel rearing ponds would be designed and constructed to maintain 5-20% of the perennial flow. Recently constructed off channel rearing ponds and side channels would be modified and or incorporated into the network. Boulder tailing piles, which are found through out the project area possessed D16 values larger than the average substrate D84 found within the riffles of the project reach. These boulders will provide an excellent source of native material which would be used for grade controls within pool head breaks, side channel entrances and river bend apexes.

Work would begin at the downstream end of the project area and proceed up the channel. Channel excavation, meanders, side channels, and ponds, woody structure placement and gravel bar construction would be conducted out of flowing water where practical. After new channel segments are completed, the bulldozer and excavator would be used to construct "push-up" dams composed of native substrate to divert water into the newly constructed channels.

The majority of fish stranded in the dewatered sections would be rescued and transported above the project area. During push up dam construction turbidities are expected to exceed 25 NTU's from the diversion site to approximately 4 kilometers downstream for approximately one hour after construction. Five high turbidity events are anticipated for the construction of this alternative. There will be additional incidental increases in turbidity (<25 NTU's) generated from equipment crossing wetted channels and habitat structure placement.

A source of large trees (>41cm in diameter) would need to be identified for in-stream and terrestrial large woody material. Approximately 5,000 whole trees would be extracted (½ with roots attached), hauled to the project area and stockpiled at designated locations along the project reach. During channel construction, trees would be incorporated into structures, distributed throughout the reclaimed floodplain and replanted for snag habitat.

Site-specific areas such as islands above the 50-year floodplain would be mulched or have bluejoint sod mats applied. Overstocked sapling stands of spruce and cottonwood growing in areas of adequate soils would be thinned. Thinned material would be used as coarse mulch throughout the new floodplain. Natural vegetation of mechanically disturbed areas will be promoted where seed source and site conditions are favorable. Native plant species originating from local genetic stocks would be planted in areas where natural re-vegetation conditions are not favorable.

Due to hydraulic permitting constraints and the complexity of this alternative it is estimated to take approximately two field seasons to complete. This alternative would meet the all restoration goals and objectives described above. Table 10 presents the proposed channel morphometry for alternative B.

Table 10. Alternative B channel morphometry for the Resurrection Creek project reach, Kenai Peninsula, Alaska.

Project Valley Length	1,305 meters
Valley Slope	1.7%
Restored Valley Width	115-145 meters
Proposed Channel Thalweg Length	1,743 meters
Elevation Drop	22.3 meters
Proposed Channel Thalweg Slope	1.3%
Rosgen Channel Type	C3
Bankfull Width	17 meters
Bankfull Ave. Depth	0.8 meters
Width/Depth	22
Riffle Slope	1.5%
Proposed Sinuosity	1.3
Large Wood/km	90-125
Restored Entrenchment ratio	6-7
Pools/Kilometer	13
D84	260mm
Length of Meander	160-220 meters
Belt Width	100-140 meters
Ave. Bed Shear Stress	10.3-12.2Kg/m^2

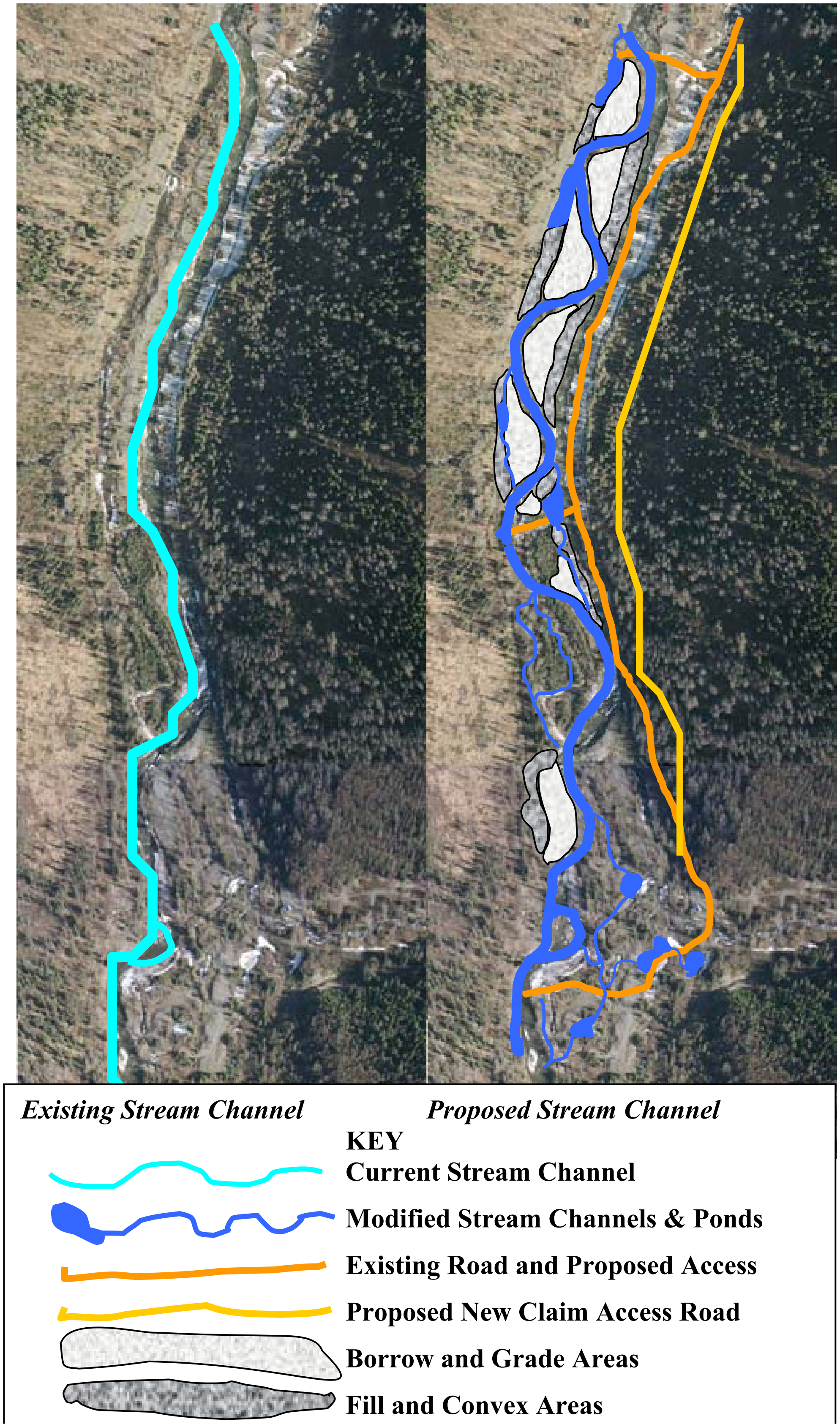

Figure 22. Alternative B conceptual design and comparison of existing conditions for Resurrection Creek project area, Kenai Peninsula, AK.

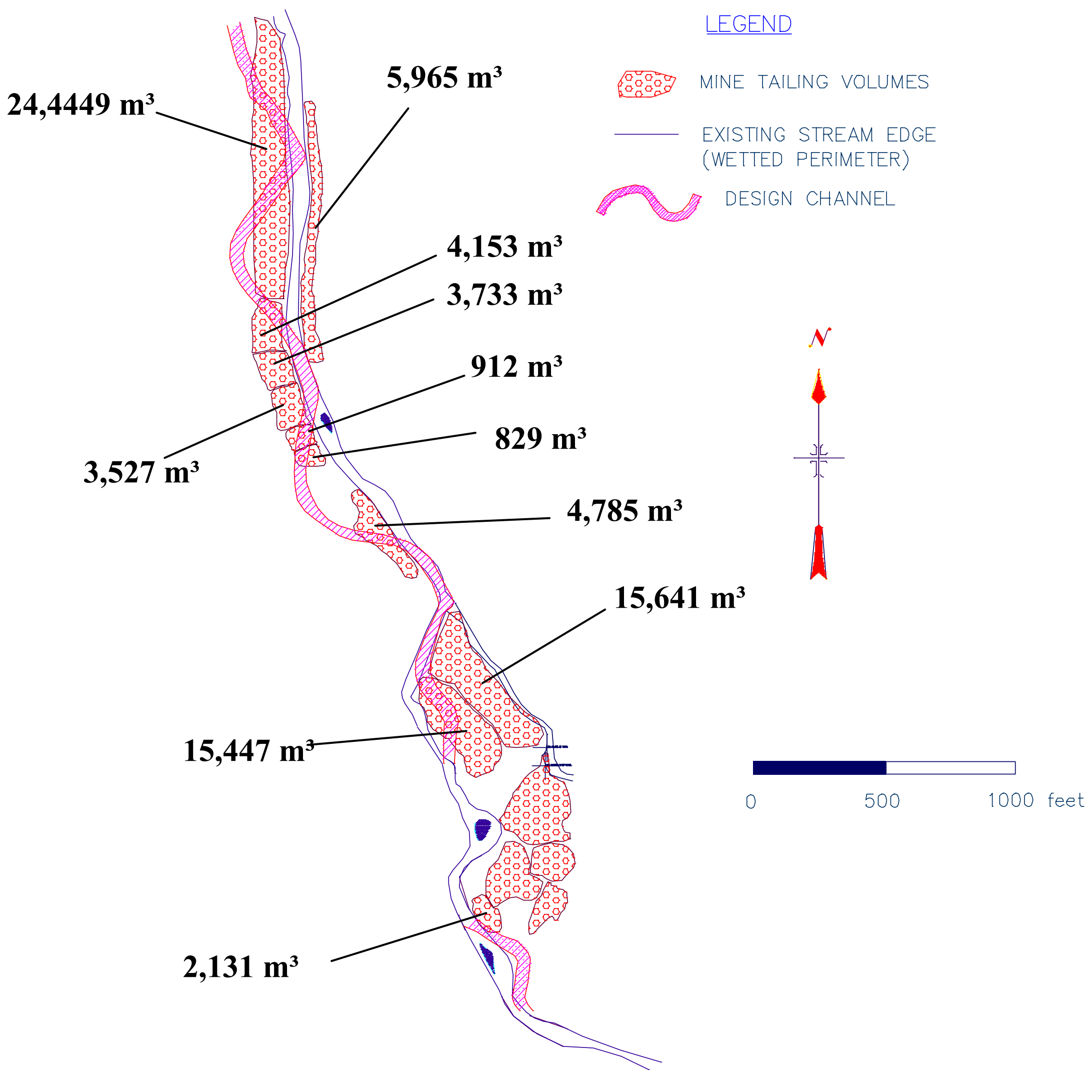

Figure 23. Mine tailing volumes, existing and designed stream channel for Alternative B, Resurrection Creek, Kenai Peninsula Alaska.

COST ESTIMATES

The cost estimates presented below and in the following alternative are intended to give line officers and program managers a gross estimate of potential implementation cost. Cost estimates would be refined as part of the final project design. Unit cost estimates are based on USDA Forest Service cost to government for completed stream channel and riparian restoration projects (1992-2001 adjusted for inflation) within the Wind River and White Salmon River watersheds, Skamania and Klickatat Counties, Washington. In addition the engineering cost implementation guide and professional experience was also used to estimate excavator and bulldozer time.

For a project of this complexity it is recommended that time and equipment contracts be utilized for stream channel and floodplain construction (excavator and bulldozer). Construction contracts would be applied to other aspects of the project such as material acquisition (tree extraction, haul and stockpile). At this time a specific source of trees for in-stream and floodplain woody material has not been identified. For the purpose of this exercise it was assumed that a local source of beetle killed trees within 40 kilometers could be located, extracted and hauled to the site.

ALTERNATIVE B COST ESITMATES

Table 11. Project Cost Estimate Summary for Rehabilitation Alternative B, Resurrection Creek, Kenai Peninsula, Alaska.

Line Item	Unit	Unit Cost	Days/ hectares/ logs…..	Cost
NEPA	Per River Km	**$55,740**	1	**$46,450**
Design	Per River Km	**$38,820**	1	**$31,350**
Contract Preparation	Per Day	**$260**	5	**$1,300**
Implementation Personnel	Per Day	**$255**	150	**$33,800**
Contract Admin. & Personnel	Per Day	**$260**	40	**$10,400**
Construction	Bulk	**NA**	NA	**$370,900**
Labor Crew	Per Day	**$600**	15	**$9,000**
Planting	Per Hectare	**$990**	48	**$47,520**
Materials	Bulk	**$5,000**	1	**$5,000**
Rig	Per Month	**$248**	2	**$496**
Overhead	25%			**$139,054**
Total Cost				**$695,270**
Cost/River Kilometer	River Km	1.1		**$632,064**

ALTERNATIVE C

Alternative C is similar to alternative B, though C proposes to increase channel length by 260 meters, by constructing an additional upstream meander, adjacent to Palmer Creek (figure 24). This alternative has four stream-crossing spurs from the access road. As in alternative B the access road would be decommissioned and replaced with a new access road located upslope and out of the floodplain.

This alternative would manipulate an estimated 103,886 cubic meters of material from the existing the tailings (figure 25). Flood prone width ratios would be increased from 1:1 to 8:1, channel thalweg slope would be decreased from 1.5% to 1.1% by increasing channel length by 260 meters and sinuosity from 1.01 to 1.5. As discussed in alternative B, side channels and wetland complexes and off channel rearing ponds would be designed and constructed to maintain 5-20% of the perennial flow. Recently constructed off channel rearing ponds and side channels would be modified and or incorporated into the network. Boulder tailing piles throughout the project area would be used for in-stream structure.

Work would begin at the downstream end of the project area and proceed up the channel. Channel excavation, meanders, side channels, and ponds, woody structure placement and gravel bar construction would be conducted out of flowing water where practical. After new channel segments are completed, the bulldozer and excavator would be used to construct "push-up" dams composed of native substrate to divert water into the new channels.

Fish stranded in the dewatered sections would be rescued and transported above the project area. During push up dam construction turbidities are expected to exceed 25 NTU's from the diversion site to approximately 4 kilometers downstream for approximately one hour after construction. Seven high turbidity events are anticipated for the construction of this alternative. There will be additional incidental increases in turbidity (<25 NTU's) generated from equipment crossing wetted channels and habitat structure placement.

A source of large trees (>41cm in diameter) would need to be identified for in-stream and terrestrial large woody material. Approximately 6,000 whole trees would be extracted (½ with roots attached), hauled to the project area and stockpiled at designated locations along the project reach. During channel construction, trees would be incorporated into structures, distributed throughout the reclaimed floodplain and replanted for snag habitat.

Site-specific areas such as islands above the 50-year floodplain would be mulched or have bluejoint sod mats applied. Overstocked sapling stands of spruce and cottonwood growing in adequate soils would be thinned. Thinned material would be used as coarse mulch throughout the new floodplain. Natural vegetation of mechanically disturbed areas will be promoted where seed source and site conditions are favorable. Native plant species originating from local genetic stocks would be planted in areas where natural re-vegetation conditions are not favorable. This alternative would meet or exceed all of the restoration objectives.

Table 16 provides the proposed morphometry for alternative C.

Table 12. Alternative C channel morphometry for the Resurrection Creek project reach, Kenai Peninsula, Alaska

Project Valley Length	1,305 meters
Valley Slope	1.7%
Restored Valley Width	115-145 meters
Proposed Channel Thalweg Length	2,015 meters
Elevation Drop	22.3 meters
Proposed Channel Thalweg Slope	1.1%
Rosgen Channel Type	C3
Bankfull Width	17 meters
Bankfull Ave. Depth	0.8
Width/Depth	22
Riffle Slope	1.5%
Proposed Sinuosity	1.5
Large Wood/km	90-125
Restored Entrenchment ratio	7-9
Pools/Kilometer	14
D84	260mm
Length of Meander	160-220 meters
Belt Width	100-140 meters
Ave. Bed Shear Stress	8.8-12.2Kg/m^2

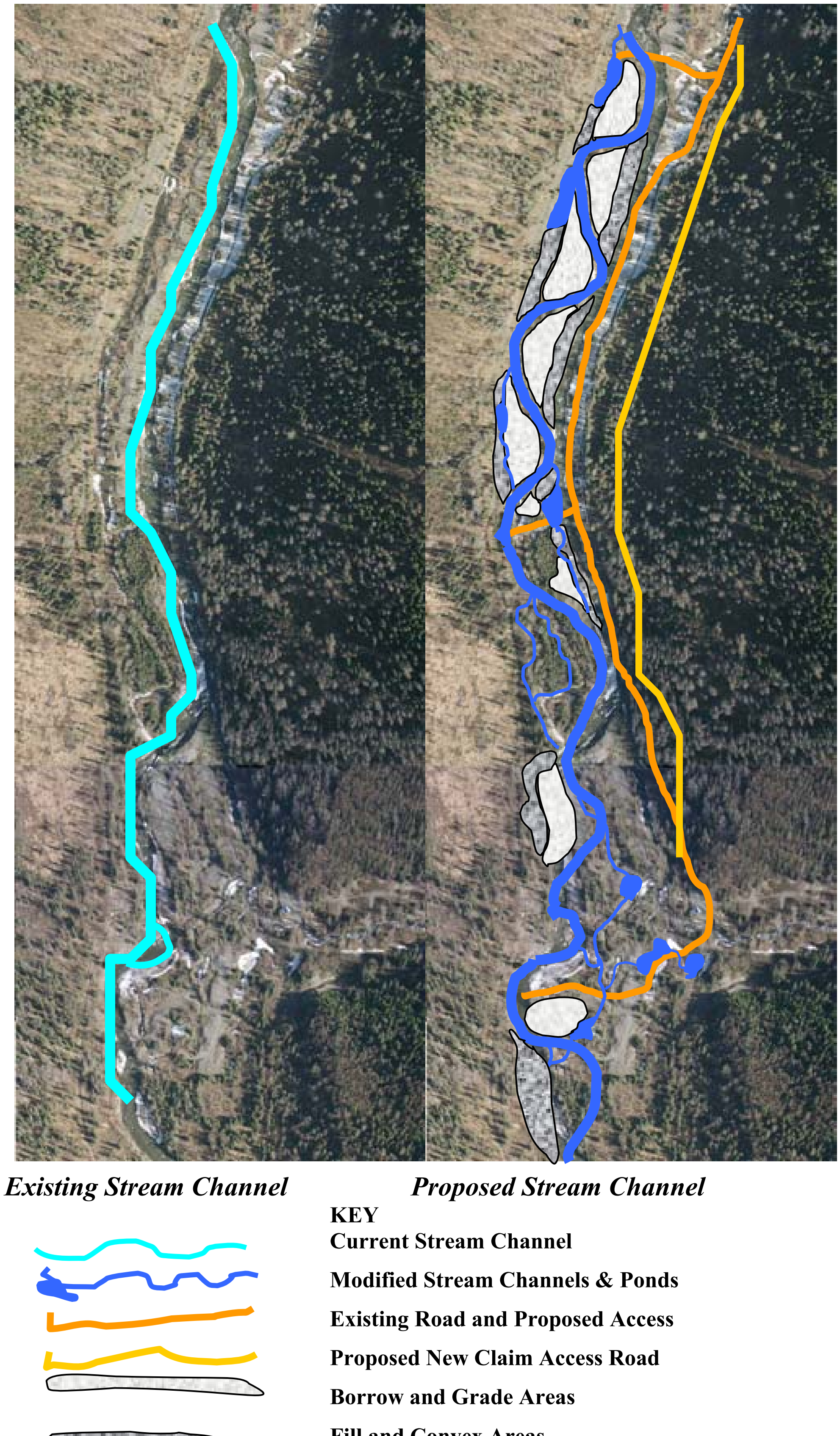

Figure 24. Alternative C conceptual design and comparison of existing conditions for Resurrection Creek project area, Kenai Peninsula, AK.

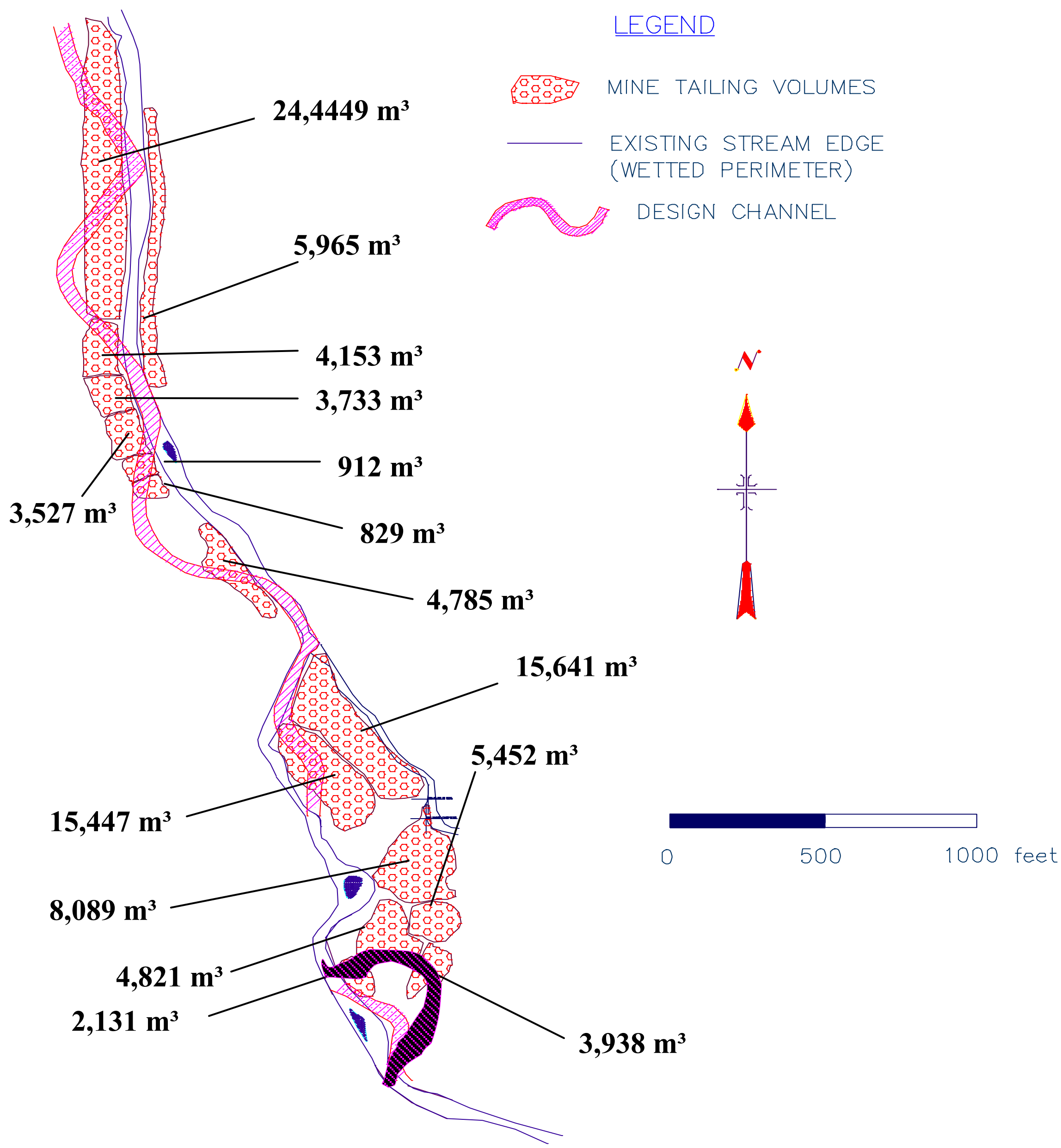

Figure 25. Mine tailing volumes, existing and designed stream channel for Alternative C, Resurrection Creek, Kenai Peninsula Alaska.

ALTERNATIVE C COST ESITMATES

Table 13. Project Cost Estimate Summary for Rehabilitation Alternative C, Resurrection Creek, Kenai Peninsula, Alaska.

Line Item	Unit	Unit Cost	Days/ hectares/ logs…..	Cost
NEPA	Per River Km	**$55,740**	1	**$50,890**
Design	Per River Km	**$38,820**	1	**$33,190**
Contract Preparation	Per Day	**$260**	6	**$1,560**
Implementation Personnel	Per Day	**$255**	150	**$43,550**
Contract Admin. & Personnel	Per Day	**$260**	50	**$13,000**
Construction	Bulk	**NA**	NA	**$438,050**
Labor Crew	Per Day	**$600**	15	**$9,000**
Planting	Per Hectare	**$990**	48	**$47,520**
Materials	Bulk	**$5,000**	1	**$5,000**
Rig	Per Month	**$248**	2	**$496**
Overhead	25%			**$160,564**
Total Cost				**$802,820**
Cost/River Kilometer	River Km	1.1		**$729,836**

ALTERNATIVES CONSIDERED

ALTERNATIVES D & E
THE "OUT HAUL" ALTERNATIVES

The Out Haul alternatives proposed to remove portions of the mine tailings and reconstruct the stream channel and floodplain network as proposed in alternatives B and C respectively. The logic behind these alternatives was to maximize flood prone width and reduce impacts to water quality. However after further evaluation, these alternatives increased the cost by $425,0000-$510,000, (approximately 65%) and only increased flood prone area by <15%. In addition, these alternatives would only have incremental effects on reducing high turbidity events during construction and therefore were dropped from consideration.

ALTERNATIVE F
THE "PULL BACK" ALTERNATIVE

The Pull Back alternative proposed to grade or pull back the tailings piles away from the existing stream channel and allow the stream to reoccupy a portion of its historic floodplain. This alternative would have little positive effects on channel length, slope or sinuosity in the short or long term. Nor would this alternative increase side channel habitat or spawning habitat for fish from the existing condition. This alternative would increase the floodplain to bankfull width ratio to approximately 4:1, which would provide an incremental increase in riparian vegetation and wildlife habitat. However, the cost benefits to fish, wildlife and water quality were minimal and therefore, the "Pull Back" alternative was dropped from further consideration.

Table 14 summarizes and compares key attributes of the existing conditions within the project reach (alternative A), reference reach and action alternatives B & C.

Table 14. Comparison of Restoration variables for the project reach, reference reach and action alternatives B & C, Resurrection Creek, Kenai Peninsula, Alaska.

	Alternative A Existing Condition	**Reference Reach**	**Alternative B**	**Alternative C**
Valley Slope	(0.017) 1.7%	(0.02) 2%	1.70%	1.70%
Valley Width	115-145 m	215 meters	115-145 meters	115-145 meters
Thalweg Channel Length	1,495 meters	428 meters	1,745 meters	2,015 meters
Channel Thalweg Slope	0.0152(1.52%)	0.0117 (1.17%)	1.30%	1.10%
Rosgen Channel Type	B3	C4	C4	C4
Bankfull Width	15.7 m	16.75 m	17 meters	17 meters
Bankfull Ave. Depth	0.8 m	0.56 m	0.8	0.8
Width/Depth	20	29	22	22
Riffle Slope	0.017 (1.7%)	0.015 (1.5%)	1.50%	1.50%
Sinuosity	1.1	1.7	1.3	1.5
Large Wood/km (>31 cm in dia.)	5	214	200	200
Entrenchment ratio (Floodprone width/bankfull width)	1.1	7.9	6-7	6-8
Pools/Kilometer	5	12	13	14
D84	258mm	211mm	250mm	250mm
Spawning Gravel m^2/River Kilometer	123m^2	1,100m^2	1,100m^2	1,100m^2
Length of Meander	165-225m	113-168 meters	160-220 meters	160-220 meters
Belt Width	18-42m	60-90 meters	100-140 meters	100-140 meters
Ave. Bed Shear Stress	12.2-13.7Kg/m^2	6.3-8.3 Kg/m^2	10.3-12.2Kg/m^2	8.8-12.2Kg/m^2
Live Trees per Hectare	1,800	537	550	550
Coarse Woody Debris per Hectare	40	554	300	300
Snags per Hectare	5	120	100	100

Effects to Aquatic Resources

Sediment and sediment transport are natural processes that provide streams with a source of substrate and nutrients. Sediment is naturally delivered to streams by a variety of mechanisms such as landslides and banks erosion. All streams and their associated aquatic organisms evolved to a natural "sediment load" or regime. The sediment load is the quantity and size of the material a stream typically transports. The sediment regime and composition determines the quantity and quality of aquatic habitat. When streams or watersheds are disturbed by fire, mining, logging, or road construction, excess sediment can be delivered to the stream altering both the quantity and composition of the substrate. This shift in the sediment composition can directly and indirectly affect aquatic organisms by altering water quality, incubation, larval development, juvenile rearing and spawning habitat.

Turbidity is the visible suspension of smaller particles of sediment typically carried by all streams. Turbidity meters measure the clarity of the water and assign a NTU (nephelometric turbidity units) value the turbidity level. Turbidity levels are typically tied to stream flow levels. At higher flow levels, sediment inputs are usually greater, and streams are better able to entrain and maintain finer sediments in suspension. High turbidities/suspended sediment can kill aquatic organisms by reducing growth rates and resistance to disease, by preventing successful development of eggs or larvae, by modifying natural movement or migration patterns, or by reducing the natural availability of food (EPA, 1986).

Channel excavation, meanders, side channels, and ponds, woody structure placement and gravel bar construction would be conducted out of flowing water where practical. For instance, construction of restored stream segments would begin on the west side of the tailings piles, which are isolated from the stream. This phase would be conducted in May-June. After new channel segments are completed, the bulldozer and excavator would be used to construct "push-up" dams composed of native substrate to divert water into the newly constructed channels. These segments would be connected to the main-stem of the stream in June, through mid July when stream flow peaks and natural turbidities are typically high (see figure 26). Short-term increases in turbidity would be expected during the connection phase. Based on water quality monitoring conducted during a similar type restoration project (Hatchery Reach Water Quality Monitoring, 1997), short-term increases exceeding the State of Alaska's water quality turbidity standards of 25 NTUs are expected. The duration of turbidity would be short-lived; approximately one hour after push-up dam construction. (Hatchery Reach Water Quality Monitoring, 1997). Turbidity levels would substantially dissipate downstream with fine silt and clay particles remaining in suspension for approximately one kilometer or ½ mile. Total duration of in-channel work is expected to be approximately 30-40 days per water year. Five to seven turbidity events greater than 25 NTU's are expected during this period.

Direct mortality of native fishes may occur during the implementation of action alternatives. Direct mortality could occur as a result of heavy equipment crossing the stream, excavation of streambed and push up dam construction. The turbidity generating phases of the project would be implemented during mid June through July to minimize the impacts to pink salmon, coho salmon, chinook salmon and resident dolly varden char, mountain whitefish and scuplin in their susceptible early life stages (egg to fry). In addition, the in-stream implementation phases of this project would occur post fry and smolt emigration and prior to adult salmon immigration and spawning. During implementation (4-5 weeks), de-watered sites would be electro-shocked after push up dam construction to remove any fish stranded behind the impoundment. The majority of fish would be removed from the dewatered area and moved up river before fill and grade. Direct impacts within the project reach would be limited to age 0 and 1+ chinook salmon and coho salmon, resident dolly varden and sculpin.

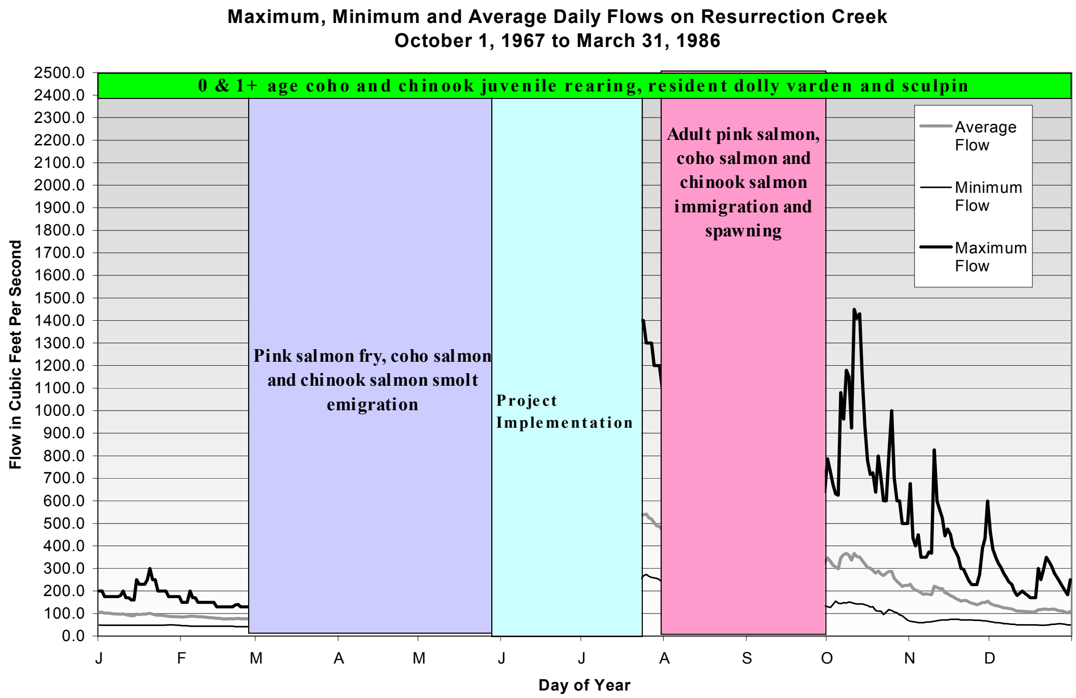

Figure 26. Maximum, minimum and average daily stream flows relative to salmonid life history and project implementation timeline for Resurrection Creek, near Hope, Alaska.

Direct mortality of aquatic macro invertebrates within the project area are also expected. This impact would be brief (12 hours) after disturbance and will be limited to the restored reaches and approximately 1 kilometer down stream. Based on research by Novotny and Faler (1982), re-colonization of aquatic invertebrates from upriver reaches could occur rapidly due to species dispersal from in river drift. Gersich and Brusven (1981) estimated that full aquatic insect colonization of rock substrates within disturbed areas would take 47 days.

Indirect mortality of fish could also occur as a result of increased turbidity. High turbidities have been shown to cause gill abrasion and reduce the feeding ability of salmonids which could indirectly kill juvenile coho and chinook salmon, resident dolly varden char and sculpin within and downstream of the project area (Lloyd, et al., 1987) (Sigler, 1980; Sigler et al., 1984).

All action alternatives would follow the Best Management Practices established in the Forest Service Manual (FSM) 2522 section 12.3. In addition, the following mitigation measures are proposed to minimize sedimentation, turbidity, and accidental petroleum spills:

The use of mechanized equipment within the ordinary high-water mark would be held to a minimum. District or Forest personnel would direct in-stream work and designate stream crossings. Approved equipment would be limited to tracked excavator and dozer GVW 120,000 lbs., portable winch, power saws and hand tools.

Ability to implement: High
Effectiveness: High

3. A spill containment plan would be prepared and approved before operations could start. The plan would require designated refueling sites and absorbent booms and diapers to be available on-site in case of petroleum leaks or spills.

Ability to implement: High
Effectiveness: High

4. Control methods such as diversion of water away from excavation sites, temporary settling ponds, and check dams would be required in order to minimize downstream sedimentation and turbidity.

Ability to implement: High
Effectiveness: High

5. Access roads would be rehabilitated upon completion of the project.

Ability to implement: High
Effectiveness: High

6. In stream work would be limited to the time period designated by the State on the Hydraulic Permit. In stream work is proposed for and would be limited to June through mid July.

These measures are anticipated to be effective in reducing the magnitude of turbidity events generated by this project.

The long-term indirect and cumulative effects of implementing this project would be the increase in spawning substrate, pools and perennial side channel flows and associated over-wintering habitat, which would improve aquatic habitat quantity and quality, fish populations and aquatic invertebrates. Aquatic vertebrate and invertebrate populations are expected to respond positively to the stream channel and riparian rehabilitation. Increased spawning and rearing habitat created by the action alternatives are expected to provide a long-term, net positive benefit to the project reach, the aquatic ecosystem, and fisheries resources for the foreseeable future.

The 1996 Trout Creek Old Growth Reach Restoration project in Washington State is similar in nature to what is proposed for Resurrection Creek. This project involved reconnecting 1.2 kilometers of an Old Growth stream channel to the main stem of the stream. This project entailed reconstructing stream channels, constructing large rock and log complexes to aggrade the streambed and reconnect the floodplain network and old growth channel (see figure 27 and photos 5 & 6).

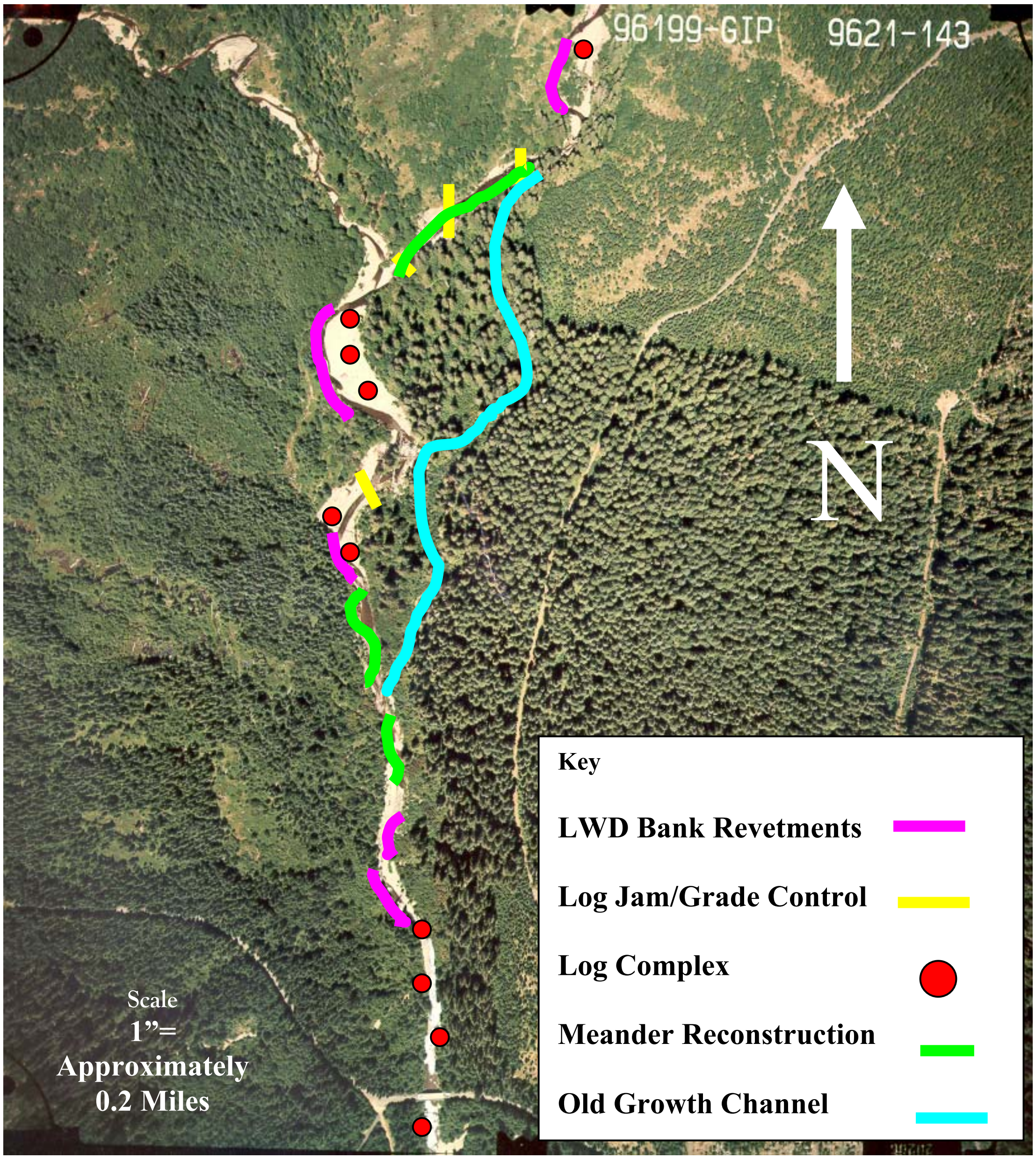

Figure 27. Trout Creek Restoration project site map, T.4N., R.6E. Section 13, Skamania County Washington.

The year following restoration of the old growth channel (1997) steelhead spawned in the restored reaches. More recently (2002), the majority of spawning within the Trout Creek watershed occurs within the old growth reach and upper project area. In addition, the reconstructed and re-watered channels contain a greater diversity of macro invertebrates and greater densities of 0 to 2 age juvenile steelhead than control or un-treated reaches (Bair, unpublished data).

Photo 5. 1995 Photo of the entrance to the Trout Creek old growth channel, Skamania County, WA. A logjam that was thought to be a migration barrier was removed in 1981. The removal of the logjam initiated the channel to "down-cut" or degrade approximately five feet below the original bed elevation. As the channel degraded the connectivity with the flood plain and the last remaining old growth reach in Trout Creek was abandoned. (Photos Bair)

Photo 6. 1999 Photo of the entrance to the Trout Creek old growth channel after restoration of logjams. Stream bed was aggraded over four feet to regain connectivity with flood plain and reactivate 0.8 of a river mile of pristine habitat.

The action alternatives would add approximately 1,600 pieces of large woody material (LWM), which, would be incorporated into structures, along the margins of the stream and floodplain. The addition of LWM would dramatically increase channel complexity, protect riparian conifers and increase pool quality. Benefits to adult and juvenile salmonids from the addition of LWM include the addition of cover, increased pool depths and retention of carcasses and other organics. Implementation of this project would in the long-term indirectly benefit both juvenile and adult salmonids by creating large lateral pools for rearing and resting during migrations and over-wintering habitat for coho. Monitoring in the "Mining Reach" of the Wind River in Washington State documented increases in bank full pool volume by 520% ($429m^3$ - $2234m^3$) (Bair, 2002).

In the long term, salmonids would also benefit from restored and self-maintained levels of channel complexity. LWM would also provide roughness elements that would help regulate bed load movement of the stream channel and fine sediment deposition on the flood plain through time. Log complexes would also assist in the regulation of water velocity and volume within side channels.

The Wind River, Trout Creek and Layout Creek in Washington State underwent major in-stream LWM restoration similar to that which is proposed for Resurrection Creek. In 1997 just under two river miles of Layout Creek, were treated with 1,200 pieces of LWM to reconnect stream channels, flood plains and increase bank and channel stability. Monitoring (USFS 1999 Layout Creek Monitoring report) showed that spawning and habitat utilization dramatically increased after rehabilitation. Layout Creek had no observed steelhead spawning for over two years; there were no documented steelhead redds in 1995 or 1996. As the monitoring report documents, steelhead spawning resumed dramatically the year following treatment. Layout Creek contains about 3% of the available spawning area within the Wind River Basin. In the year following extensive rehabilitation, 23% of all observed spawning within the entire Wind River Watershed occurred in Layout Creek. That is, within one year the number of documented steelhead redds increased from zero to 23% of all redds within the entire watershed (USFS, 1998).

Under the action alternatives, it is anticipated that the habitat utilization within the project reach would dramatically increase. Implementation would significantly upgrade spawning habitat within the project reach. The area of spawning gravel is estimated to increase from $123m^2$ to approximately $1,100m^2$ as a result of this project.

In conclusion, the long-term beneficial effects of implementing the action alternatives will out weigh the short-term negative effects to aquatic resources. The short-term negative effects will be localized; within the immediate project area to approximately one kilometer downstream. The long term effects are expected to have significant beneficial effects to coho salmon, chinook salmon, pink salmon and dolly varden char. The project will also indirectly benefit aquatic macro invertebrates and riparian dependent species such as bears and bald eagles.


Photo 7. Desired future condition for Resurrection Creek in the year 2065. (Quartz Creek looking up-stream, Kenai Peninsula Alaska)

AKNOWLEDGEMENTS

I would like to give a special thanks to Dave Blanchet and William Shuster for their coordination of the survey and logistical support. I would also like to give a very special and sincere THANK YOU to Eric Johansen and Larry Winter from the Seward Ranger District who assisted with the surveys and provided logistical support, local and biological knowledge; safety and peace of mind from bear malice. We would also like to thank Matt Blank for his work on channel cross sections and observations on Resurrection Creek and the Chugach Engineering Technicians for sharing their equipment and time and providing detailed and thorough monumented bank pins. I would also like to recognize the dedication and commitment of Wind River Crew: Emily Weinheimer, Greg Robertson, Paul Powers and Anthony Olegario. And last but certainly not least we would like to thank the citizens of Hope who graciously welcomed us and provided us with invaluable knowledge of the area's history.

REFERENCES

Allen, J.R.L. 1970. A quantitative model of grain size and sedimentary structure in lateral deposits. Geological Journal, in Thorne, C.R., Hey, R.D. and Newson, M.D.. 2001. Applied Fluvial Geomorphology for River Engineering and Management.

Andrews, E.D. 1983. Entrainment of gravel from naturally sorted riverbed material. Geological Society of America Bulletin, 94, 1225-1231.

Andrews, E.D. 1984. Bed-material entrainment and hydraulic geometry of gravel-bed rivers in Colorado. Geological Society of America Bulletin, 95, 371-378.

Bair, B. 1997. Trout Creek Restoration. U.S. Forest Service, Wind River Ranger District, Carson, Washington.

Bair, T.B., 1994-2002. Wind River Riparian and Stream channel Restoration Monitoring. Unpublished data.

Bair, T.B., 2002. Bonneville Power Administration Fish and Wildlife Habitat Enhancement Report, 2002. Wind River Restoration 2000-2001 Annual Report http://www.efw.bpa.gov/cgibin/ws.exe/websql.dir/FW/PUBLICATIONS/QueryCustom.pl?Category=H&SortOrder=DOEBPNum

Blank, M. 2002. DRAFT Resurrection Creek Hydraulic Data Collection and Water Surface Profile Model Development Summary Report.

Castro, J.M. and P.L. Jackson, 2001. Bankfull Discharge Recurrence Intervals and Regional Hydraulic Geometry Relationships: Patterns in the Pacific Northwest, USA. Journal of the American Water Resources Association. Volume 37, No. 5, October 2001.

Chow, V., 1959. Open-Channel Hydraulics. McGraw-Hill Book Company, New York.

Dury, G.H. 1955. Bed width and weave-length in meandering valleys. Nature, in Thorne, C.R., Hey, R.D. and Newson, M.D. 2001. Applied Fluvial Geomorphology for River Engineering and Management.

Environmental Protection Agency. 1986. Quality Criteria for water 1986. EPA 440/5-86-001. U.S. Environmental Protection Agency, Office of water regulations and Standards, Washington DC.235 pp.

Gersich, F.M. and M.A. Brusven. 1981. Insect colonization rates in near-shore regions subjected to hydroelectric power peaking flows. J. Freshw. Ecol. 1: 231-236.

Hey, R.D. and Thorne, C.R. 1986. Stable channels with mobile gravel beds. Journal of Hydraulic Engineering, American Society of civil Engineers in Thorne, C.R., Hey, R.D. and Newson, M.D. 2001. Applied Fluvial Geomorphology for River Engineering and Management.

Holsten, E.H., R A. Werner and R.L. Develice. 1995. Effects of a Spruce Beetle (Coleopetera: Scolytidae) Outbreak and Fire on Lutz Spruce in Alaska. State and Private Forestry, Forest Service, U.S. Department of Agriculture, Anchorage, AK. Environmental Entomology 24(6): 1539-1547.

Jonas, M., 2001. The hydraulic engineer's role in stream restoration projects. Proceedings of the Seventh Federal Interagency Sedimentation Conference, March 25 to 29, 2001.

Kalli, G and D. Blanchet, USDA Forest Service, Chugach National Forest, Resurrection Creek Watershed Association Hydrologic Condition Assessment.

Kirby, W.H., 1981, Annual flood frequency analysis using U.S. Water Resources Council Guidelines (program J407): U.S. Geological Survey Open File Report 79-1336I, WATERSTORE 2000. Statistical Approach to Surface Water Hydrologic Analysis – peakFQ 4.0

Leopold, L.B., Wolman M.G. 1957. River Channel Patterns-Braided, Meandering and Straight. United States Geological Survey, Professional Paper 282B.

Leopold, L.B., Wolman M.G. 1960. River meanders. Bulleting of the Geological Society of America, 71, 769-794.

Leopold, L.B., Wolman, M.G. and Miller, J.P., 1964. Fluvial processes in geomorphology. Freeman, San Francisco, CA.

Lloyd, D.S., J.P. Koenings, and LaPerriere, 1987. Effects of turbidity in fresh waters of Alaska. N. Am. J. Fish. Mgmt. 7(1):18-33.

Montgomery, D.R. and J.M. Buffington, 1993. Channel classification, prediction of channel response, and assessment of channel conditions. Washington State Dept. of Natural Resources, Timber/Fish/Wildlife Agreement, Rpt. TFW-SH10-93-002, 84 p.

Novotny, J.F. & M.P. Faler, 1982. Diurnal characteristics of zoolplankton and macroinvertebrates in the tailwater below a Kentucky flood control reservoir. Journal of Freshwater Ecology, Vol. 1, No. 4.

Powers, P and T. Bair., 1999. Layout Creek Rehabilitation Monitoring Report. USDA Forest Service monitoring.

Rosgen, D. L., 1994, A classification of natural rivers. Catena 22:169-199

Rosgen, D. L., 1996, Applied river morphology. Wildland Hydrology. Pagosa Springs, Colorado.

Schulz, B. 2000. Resurrection Creek permanent plots revisited. USDA Forest Service, Alaska Region, Technical Report R10-TP-89. 14 pp.

Shields, A. 1936, Application of similarity principles and turbulence research to bedload movement. Mitt. Preuss. Verschsanst., Berlin. Wasserbau Schiffbau. In W.P. Ptt and J.C. Uchelen (translators), California Institute of Technology, Pasadena, CA. Report No. 167: 43pp.

Sigler, J.W., 1980. Effects of chronic turbidity on feeding, growth and social behavior o steelhead trout and coho salmon. Ph.D. dissertation, University of Idaho. Moscow, ID. 158.p

Sigler, J.W., T.C. Bjornn, and F.H. Everest, 1984. Effects of chronic turbidity on density and growth of steelhead and coho salmon. Trans. Am. Fish. Soc. 113:142-150.

Thorne, C.R., Hey, R.D. and Newson, M.D. 1997. Applied Fluvial Geomorphology for River Engineering and Management. Wiley & Sons Ltd.

Williams, G. P., 1986, River meanders and channel size. Journal of Hydrology, 88: 147-164.

Wolman, M.G., 1954, A method of sampling coarse river-bed material. Transactions of American Geophysical Union 35: 951-956.

U.S.D.A. Forest Service, 1997. Hatchery Reach Project Implementation Water Quality Monitoring, Unpublished Data.

U.S.D.A. Forest Service, August 1992. FSM 2522; Ecosystem Analysis at the Watershed Scale, Version 2.2,; 11 AAC 95.330.

Hart Crowser Inc. for U.S.D.A. Forest Service, Chugach National Forest, January 31, 2002. Resurrection Creek Landscape Analysis, Hope Alaska. 12556-01

Glossary of Technical Terms

Bankfull Channel — The stream channel that is formed by the dominant discharge, also referred to as the active channel, which meanders across the floodplain as it forms pools, riffles, and point bars.

Bankfull Width / Depth Ratio — The ratio of bankfull width divided by average bankfull depth.

Bar or Gravel Bar — (1) A sand or gravel deposit found on the bed of a stream that is often exposed during low-water periods. (2) An elongated landform generated by waves and currents, usually running parallel to the shore, composed predominantly of unconsolidated sand, gravel, stones, cobbles, or rubble and with water on two sides.

Bed Load — (1) Sediment particles up to rock, which slide and roll along the bottom of the streambed. (2) Material in movement along a stream bottom, or, if wind is the moving agent, along the surface. (3) The sediment that is transported in a stream by rolling, sliding, or skipping along or very close to the bed. In USGS reports, bed load is considered to consist of particles in transit from the bed to an elevation equal to the top of the bed-load sample nozzle (usually within 0.25 feet of the streambed). Contrast with material carried in *Suspension* or *Solution*.

Bed Shear Stress — The force per unit area exerted by water as it shears over a surface.

Channel Stabilization — Erosion prevention and stabilization of velocity distribution in a channel using jetties, drops, revetments, vegetation, and other measures.

Cross Section — A graph or plot of ground elevation across a stream valley or a portion of it, usually along a line perpendicular to the stream or direction of flow.

D50 — Median particle/grain size of sediment.

Disturbed Reference — A disturbed reach of stream that possesses similar channel morphology, hydrology, sediment regime and biota relative to the reach of stream to be analyzed, rehabilitated or restored.

Entrenchment Ratio — Flood-prone width divided by bankfull width; a measure of floodplain accessibility and inundation.

Floodplain — (1) (FEMA) Any normally dry land area that is susceptible to being inundated by water from any natural source. This area is usually low land adjacent to a river, stream, watercourse, ocean or lake. (2) A strip of relatively smooth land bordering a stream, built of sediment carried by the stream and dropped in the slack water beyond the influence of the swiftest current. It is called a *Living Flood Plain* if it is overflowed in times of high water but a *Fossil Flood Plain* if it is beyond the reach of the highest flood. (3) The lowland that borders a stream or river, usually dry but subject to flooding. (4) The transversely level floor of the axial-stream drainage way of a semi-bolson or of a major desert stream valley that is occasionally or regularly alluviated by the stream overflowing its channel during flood. (5) The land adjacent to a channel at the elevation of the bankfull discharge, which is inundated on the average of about 2 out of 3 years. The floor of stream valleys, which can be inundated by small to very large floods. The one-in-100-year floodplain has a probability of 0.01 chance per year of being covered with water. (6) That land outside of a stream channel described by the perimeter of the *Maximum Probable Flood*. Also referred to as a *Flood-Prone Area*.

Flood-prone Width — Width or extent of floodwaters within a valley.

Graminoid — A grass or grass-like plant.

In-stream Large Woody Material — Coarse wood material such as twigs, branches, logs, trees, and roots that fall into streams.

Length of Meander — One full sine wave of a stream meander.

Mainstem — (1) The major reach of a river or stream formed by the smaller tributaries which flow into it. (2) The principal watercourse of a river, excluding any tributaries

Meander — (1) The turn of a stream, either live or cut off. The winding of a stream channel in the shape of a series of loop-like bends. (2) A sinuous channel form in flatter river grades formed by the erosion on one side of the channel (pools) and deposition on the other side (point bars).

Meander Belt Width — Amplitude or width containing the meander.

Mine tailings — Rock spoils from mining activity.

Morphology — (1) The science of the structure of organisms. (2) The external structure form and arrangement of rocks in relation to the development of landforms. River morphology deals with the science of analyzing the structural make-up of rivers and streams. *Geomorphology* deals with the shape of the Earth's surface.

Organic — Matter derived from living organisms.

Plots — A map or plan; a measured piece of land. To mark or note on or as if on a map or chart.

Pool — (1) A location in an active stream channel, usually located on the outside bends of meanders, where the water is deepest and has reduced current velocities. (2) A deep reach of a stream; a part of the stream with depth greater than the surrounding areas frequented by fish. The reach of a stream between two riffles; a small and relatively deep body of quiet water in a stream or river. Natural streams often consist of a succession of pools and riffles.

Reference Reach — Undisturbed reach of stream that possesses similar channel morphology, hydrology, sediment regime and biota relative to the disturbed site to be analyzed, rehabilitated or restored.

Return Period (or Recurrence Interval) — In statistical analysis of hydrologic data, based on the assumption that observations are equally spaced in time with the interval between two successive observations as a unit of time, the return period is the reciprocal of 1 minus the probability of a value equal to or less than a certain value; it is the mean number of such time units necessary to obtain a value equal to or greater than a certain value one time. For example, with a one-year interval between observations, a return period of 100 years means that, on the average, an event of this magnitude, or greater, is not expected to occur more often than once in 100 years. Also see *Exceedence Interval, Recurrence Interval, Flood Frequency, Frequency Curve*.

Redd — A depression in gravel created by salmon and trout to deposit and incubate their eggs.

Riffle — (1) A shallow rapids, usually located at the crossover in a meander of the active channel. (2) Shallow rapids in an open stream, where the water surface is broken into waves by obstructions such as shoals or sandbars wholly or partly submerged beneath the water surface. (3) Also, a stretch of choppy water caused by such a shoal or sandbar; a rapid; a shallow part of the stream.

Riparian Areas (Habitat) — (1) Land areas directly influenced by a body of water. Usually such areas have visible vegetation or physical characteristics showing this water influence. Stream sides, lake borders, and marshes are typical riparian areas. Generally refers to such areas along flowing bodies of water. The term *Littoral* is generally used to denote such areas along non-flowing bodies of water. (2) (USFWS) Plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent *Lotic* and *Lentic* water bodies (rivers, streams, lakes, or drainage ways). Riparian areas have one or both of the following characteristics: (a) distinctively different vegetative species than adjacent areas, and

(b) species similar to adjacent areas but exhibiting more vigorous or robust growth forms. Riparian areas are usually transitional between *Wetlands* and *Uplands*.

Sediment — (1) Soil particles that have been transported from their natural location by wind or water action; particles of sand, soil, and minerals that are washed from the land and settle on the bottoms of wetlands and other aquatic habitats. (2) The soil material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by erosion (by air, water, gravity, or ice) and has come to rest on the earth's surface. (3) Solid material that is transported by, suspended in, or deposited from water. It originates mostly from disintegrated rocks; it also includes chemical and biochemical precipitates and decomposed organic material, such as humus. The quantity, characteristics, and cause of the occurrence of sediment in streams are influenced by environmental factors. Some major factors are degree of slope, length of slope, soil characteristics, land usage, and quantity and intensity of precipitation. (4) In the singular, the word is usually applied to material in suspension in water or recently deposited from suspension. In the plural the word is applied to all kinds of deposits from the waters of streams, lakes, or seas, and in a more general sense to deposits of wind and ice. Such deposits that have been consolidated are generally called sedimentary rocks. (5) Fragmental or clastic mineral particles derived from soil, alluvial, and rock materials by processes of erosion, and transported by water, wind, ice, and gravity. A special kind of sediment is generated by precipitation of solids from solution (i.e., calcium carbonate, iron oxides). Excluded from the definition are vegetation, wood, bacterial and algal slimes, extraneous lightweight artificially made substances such as trash, plastics, flue ash, dyes, and semisolids.

Side Channels — Typically small stream channels which branch off of the mainstream channel.

Snag — A tree or branch embedded in a lake or streambed. A stub or stump remaining after a branch has been lopped or torn off.

Smolt — A juvenile, silvery salmon up to 15cm long, which has lost its parr marks and has attained the silverly coloration of the adult. This coloration signifies the readiness of the young fish to migrate to the seas and its ability to adapt to the water environment.

Spawning Gravel — Streambed substrate suitable for salmonid spawning.

Succession — (Biology) (1) The ecological process of sequential replacement by plant communities on a given site as a result of differential reproduction and competition. (2) Directional, orderly process of change in a living community in which the community modifies the physical environment to eventually establish an ecosystem which is as stable as possible at the site in question.

Thalweg — (1) The line connecting the deepest points along a stream. (2) The lowest thread along the axial part of a valley or stream channel. (3) A subsurface, ground-water stream percolating beneath and in the general direction of a surface stream course or valley. (4) The middle, chief, or deepest part of a navigable channel or waterway.

Turbidity — A measure of light obscuration by water. Turbidity increases as the amount of suspended sediments in the water column increase.

Woody Debris — Coarse wood material such as twigs, branches, logs, trees, and roots that fall into streams.