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Evaluation of Bioengineered Stream Bank Stabilization in Alaska

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STABILIZATION IN ALASKA

FINAL REPORT

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Abstract

This report documents and presents the results of a study of the use of bioengineered erosion control structures on Alaskan streams and rivers. Field investigations of hydraulic and vegetation conditions at eleven study sites around the State of Alaska were conducted to determine the performance of these structures. Root wads, live staking, brush layering, and coir logs were the primary bioengineering methods used for erosion control at the study sites. A one-dimensional numerical computer model was applied at each site to estimate the magnitude of average bed and bank shear stresses (tractive force) apparent to the erosion control structures at the 50-year and 100-year design flood levels. Discharge records and field flood indicators were checked to correlate structure condition to flow history. Damage at existing structures was attributed to flowing ice, undermining of toe protection, buoyancy effects, and failure of construction fabrics. Root wad structures in good condition were located in areas with high boat wake occurrence, but low channel tractive forces. The findings of the study suggest the types of bioengineered erosion control structures studied have not been proven to offer reliable bank erosion protection during flooding conditions on channels with high tractive forces.

Summary of Findings

The main objective of this study was to gain an understanding of the factors and conditions that govern successful implementation of bioengineered erosion control structures (BECS) in Alaska. A key component to accomplishing these objectives involved the quantitative evaluation of existing bioengineered erosion control structures to assess the design, construction, and expected performance of such structures. A comprehensive analysis, using field data from both successful projects and those that have suffered some failure, was conducted to identify the overall vegetative and hydraulic performance of the study structures.

Eleven sites were chosen for analysis to determine vegetative and hydraulic characteristics, and engineering performance since construction. Hydraulic characteristics at each site, particularly the potential for bed and bank erosion, were determined by conducting a shear stress analysis. The level of performance was based upon two criteria:

1. how well the structure holds up in flooding conditions, when water velocities are high and maximum protection is required at the bank
2. how well the structure holds up in the harsh Alaska environment, where it might be exposed to such factors as river ice, cold soils, aufeis, and other aspects of a northern climate.

A summary table of the sites, type and condition of the BECSs, and a brief narrative describing the performance of the site, is found in Table 1. Results from the shear stress analysis are found in Table 10.

Table 1. Summary table of eleven BECS study sites.

Site	Type of BECS	Condition of BECS	Comments
Anchor River-Steelhead CG	Root wad, brushlayer	Destroyed during flooding	Shear stress analysis indicated severe toe erosion potential. Project failed after extreme flooding due to toe erosion.
Anchor River-Silverking CG	Brushlayer, coir log, spruce tree revetment	Damaged at lower brushlayer during flooding	Shear stress analysis indicated toe erosion potential. Project incurred downstream damage after extreme flooding due to toe erosion.
Campbell Creek near Taku Park	Root wad	Bank collapse	Shear stress analysis indicated toe erosion potential. Progressive toe erosion and erosion of inner bank material resulted in bank collapse.
Chena River at Doyon Estates	Willow brushlayer	Soil lift damage	Soil lift fabric wrap damage from ice, boat wakes. Toe rock erosion, thin willow root development.
Deep Creek	Willow brushlayer, brush mattress	Downstream end destroyed, mid-stream damage from flooding	Severe hydraulic conditions and improper soil lift fabric material led to downstream failure during extreme flooding events. Upstream willow brush layers and brush mattresses performed well.
Kenai River-Centennial Park	Root wad, willow brushlayer	Good condition	Good protection from boat wakes. Shear stress analysis indicates low bank toe erosion potential at site.
Kenai River-Riddle	Root wad, willow	Good condition	Good protection from boat wakes. Shear stress analysis indicates low bank toe erosion potential at

	brushlayer		site.
Ship Creek at Cottonwood Park	Root wad, willow brushlayer	Good condition	Hydraulic analysis indicates high potential for bank toe erosion during Q_{50}, Q_{100}. Site has not yet been subjected to flood larger than Q_2.
Theodore River	Root wad	Severe damage	Root wads displaced due to buoyancy forces during flood.
Willow Creek-Lapham	root wad, willow brushlayer	Good condition	Shear stress analysis indicates high potential for bank toe erosion at high stages. New site has not yet been subjected to flood larger than Q_2.
Willow Creek-Pioneer Lodge	Root wad, willow brushlayer	Good condition	Shear stress analysis indicates high potential for bank toe erosion at high stages. New site has not yet been subjected to flood larger than Q_2.

Vegetation Performance

The analysis of the vegetation used in the bioengineering projects focused on the use of appropriate plant species and site conditions. Alaska has several native willows that root readily and are tolerant of soils which are periodically saturated throughout the growing season. These are important characteristics for plants used in streambank bioengineering techniques, and are well understood by botanists. Appropriate plant species were used at most of the study sites. Site conditions appeared adequate for most projects; this includes aspect, soil chemistry, and depth to water table. One site, which was the sole Interior Alaska site, exhibited marginal rooting conditions. Failed soil lifts exposed roots which were thin and low in density.

Hydraulic Performance

A shear stress analysis conducted as part of this study was designed to analyze the potential for bed and bank erosion at each BECS installation. The average shear stress apparent to the bed or bank for a given discharge was compared to the critical shear stress, which is the tractive force per unit area required to initiate particle motion and begin the erosion process. This analysis provides a mechanism to assess the potential for failure of a BECS because of scour of the bed upon which the BECS sits, or scour of the bank into which the BECS is constructed.

Two root wad/brush layer sites on the Kenai River are located in areas of heavy boat traffic, and experience constant boat wake action during the summer months. No new significant bank erosion has been observed at these sites since installation (1996 and 1997). The hydraulic analysis of these locations indicates that average shear stresses are low compared to critical shear stresses. The potential for erosion at these sites is relatively low for conditions less than the 50-year flood magnitude. These structures appear to perform well in protecting the bank from boat wakes, river ice, and other environmental wear. To date, flooding at these sites has not exceeded the 5-year flood. Larger flows are needed to test their effectiveness at preventing bank toe erosion.

Root wad/brush layer sites on Ship Creek and Willow Creek are relatively new, and have not yet been subjected to flooding. Though the Willow Creek-Pioneer Lodge is subjected to occasional boat wakes, the other sites are not. The shear stress analysis of these sites indicates that a high potential for bank erosion exists, due mainly to the steepness of the bank.

Flooding on the Kenai Peninsula in October and November 2002 provided important data and forensic evidence as to structural integrity and modes of failure for three sites. An Anchor River brush layering site suffered some damage during the October flood when tractive forces scoured away the channel and bank toe material, causing a section of the treatment to collapse. The majority of the project remained intact. A downstream root wad/brush layer site suffered severe damage when tractive forces during the October flood event scoured away the channel and bank toe material, effectively removing the foundation for the root wad structure. Within a few days of the flood, the upper third of the root wad structure had been pulled away from the bank and into the channel. The remainder of the project failed during the November flood. The shear stress analysis indicated a high potential for bed and bank erosion at the two Anchor River sites.

A brush layer/brush mattress/live staking structure located on Deep Creek suffered severe damage at the very downstream end of the project, but held up well in the upstream two thirds of the project. Channel and toe erosion did not appear to be a factor in the failed section; the use of riprap along the toe of the structure was probably instrumental in reducing toe erosion. Silt was deposited in the mid- and upstream sections of the structure, up to a foot in depth, indicating that the willows played some role in reducing water velocity. Though willows appeared damaged, with stripped leaves and branches, a quick recovery of the remaining plants is expected. The removal of bank material through the geogrid soil wrap material, combined with overtopping of the structure and erosion from strong backeddy currents, resulted in the downstream failure of the section.

The magnitudes of the floods on the Anchor River and Deep Creek were estimated at well over the 100-year flood level, and greatly exceeded the standard design discharges for many erosion control structures (50-year flood). However, by observing conditions and surveying cross-sections before and after, the floods were valuable for confirming the shear stress analyses of those sites. Additionally, they provided direct and important insight into the mechanisms that lead to failure at various flood magnitudes. These shear stress values may be used with data from future projects and studies on other streams and rivers to construct quantitative relationships between channel hydraulic conditions and performance limits or design requirements for BECSs.

Recommendations

Recommendations are presented both for immediate implementation of BECSs, and for design improvements for future consideration.

Implementation

- Until current designs of BECSs are improved to provide substantial bank toe erosion protection, the use of vegetation as a structural component in an erosion control project should occur only in areas of low erosion potential, or for areas where failure results in insignificant consequences.

- Details of design, construction, and maintenance of BECSs should be compiled and reviewed. Recommendations for limits of use should be refined. Designs should be reviewed and approved by a licensed professional engineer. Following construction of a BECS, as-built drawings should be completed and archived.

- A comprehensive shear stress analysis of the reach where a BECS is being considered for use should be conducted by an experienced hydraulic engineer. In addition to the shear stress analysis, a bed scour depth analysis of the site should be conducted. The scour depth analysis should include the three major additive components of scour: long-term bed elevation change, general scour and contraction scour, and local scour.

- The selection of willow species in BECS design is dependent on the desired function and expected frequency of inundation of the willow. Though the proper use and selection of vegetation is well understood in Alaska, care must be taken to correctly identify those species during harvesting and installation.

- Successful implementation of BECSs will require that periodic inspection and maintenance be conducted. Schedules should be established that will allow for inspection of the structure and bank toe during low water periods. In addition to annual maintenance, sites should be inspected after major floods. Maintenance and repairs should be conducted as needed. Personnel should be trained to identify the signs that indicate the need for repair or maintenance. Documentation of repairs and maintenance is a crucial factor for improving future designs.

Design Improvements

- Design improvements are needed to protect the foundations of BECSs from large tractive forces. In particular, techniques should be developed for root wad structures. Current methodology relies on an embedded root fan to provide toe scour protection. New techniques should focus on providing flexible, self-healing, seamless, and substantial toe protection capabilities, based on design flood criteria.

- Current design methodology for BECSs does not provide any self-healing features for such structures in the event of severe toe erosion. Techniques should be developed to provide flexible self-healing capabilities. For example, such techniques may include either a stone toe trench placed beneath the expected depth of maximum scour, or a self-launching stone toe, which will launch stone into the eroded area as scour occurs.

- Improvements to the methods and materials used in fabric encapsulated soil lifts should be considered. Rates of degradation of the inner burlap fabric need to be assessed and correlated to rates of adequate root mass development in brush layering applications. Outer fabrics with greater tensile strength and abrasion resistance, or other techniques, should be evaluated for use on streams where ice damage may occur.

- Design guidance should be developed to assist designers with determining the extent of longitudinal protection required to adequately protect the channel bank. Site-specific factors which have a bearing on the actual length of protection required should be identified.

- Hydrologic guidance is needed to identify the range of water surface elevations at which the various components of a BECS are to be installed. Current designs often rely on the use of the term ‘ordinary high water’ (OHW) to establish the construction elevation of a root wad or toe rock layer. Guidelines should be developed that would provide design elevations for all components of a BECS. Hydrologic guidance should also be developed to determine the vertical extent of protection required at a site, and the probability of an overtopping event.

CHAPTER 1 - INTRODUCTION AND RESEARCH APPROACH

Problem Statement and Research Objective

The Alaska Department of Transportation & Public Facilities (AKDOT&PF) is responsible for designing, installing and maintaining stream bank stabilization structures for projects across Alaska. These structures serve to protect Alaska's transportation infrastructure from the forces of water erosion along streams, rivers, lakes, and coastal areas. The AKDOT&PF typically employs traditional 'hard' stream bank protection methods, such as riprap and rock gabions. Engineers have used this approach to stream bank stabilization because of the available engineering guidance and performance criteria that have been developed and used for years.

Due to a recent surge of interest, the use of bioengineered stream bank stabilization methods, popular in Europe for years, is becoming more common in the United States. Bioengineering techniques generally involve using a combination of materials to armor and protect stream banks, including vegetation (willow), root wads, toe rock, coconut fiber bio-logs (coir logs), and coir blankets. Instructional courses in the theory, design, and installation of such methods are available at several locations in the lower 48 states, and regulatory agencies and consulting firms are enrolling their personnel in these courses in ever-increasing numbers. However, instructors for these courses generally present qualitative methods for 'typical' conditions, with little or no design criteria. Additionally, instructors often ignore the special situations and requirements for unique locations and harsh climates.

The subarctic and arctic climates in Alaska present special design challenges for the engineer. The revegetation of barren and disturbed areas in colder climates, often a critical element of bioengineered bank protection, is very slow compared with similar situations in warmer climates. Contributing to slow re-establishment of natural conditions are such factors as: short cool growing seasons, permafrost, aufeis deposits, lack of annual plant species, and the resulting dependency on asexual vegetation reproduction. As a result, structures are often designed improperly and may fail prematurely, or not function properly from the start.

Another challenge to the successful implementation of alternative stream bank protection methods is the need to understand the many complex processes associated with river behavior. Many of the structures that have been installed throughout the U.S. and Alaska in the past ten years have essentially changed the dimension, pattern, and the profile of the host river. Designers may not focus on understanding the morphological variables that determine the river's natural stability, and may attempt to apply standardized techniques to a wide variety of conditions. Other common problems include a design that has been developed only for a particular reach, ignoring upstream and downstream considerations.

Comprehensive engineering guidelines for the selection, design, and installation of natural channel and stream bank stabilization structures are inadequate nationwide, and virtually non-existent for Alaska. Charged with constructing and maintaining Alaska's transportation facilities and infrastructure in a safe and efficient manner, AKDOT&PF often chooses to rely on traditional stream bank protection measures, for which industry-accepted design standards and performance data are readily available.

Scope of Study

The objectives of this study were to:

1. gather quantitative field data and other relevant information necessary to supplement existing knowledge and ongoing national research;
2. gain an understanding of the factors and conditions that govern successful implementation of bioengineered structures in Alaska to satisfy both engineering and environmental goals;
3. increase the understanding and confidence necessary to design and construct bioengineered stream bank stabilization projects.

A key component to accomplishing these objectives involved the evaluation of existing bioengineered erosion control structures to assess the design, construction parameters, and expected performance of such structures. A comprehensive analysis, using field data from both successful projects and those that have suffered some failure, was conducted to identify the parameters necessary to meet both engineering and environmental requirements. By integrating information from the national and state reviews of existing projects with results from Alaskan projects, the identification and description of the influence of Alaska's unique climate, hydrology, and vegetation on bioengineered bank protection projects will be possible.

The scope of this study was expanded when heavy rainfall occurred on the Kenai Peninsula and created flooding conditions in October and November 2002 for a number of streams and rivers in the area. Flooding occurred at four of the project sites which had already been field-analyzed during the summer months. Additionally, the flooding affected a number of other bioengineered erosion control structures (BECSs) scattered around the Kenai Peninsula which had not been included in the original site study list.

In response to the flooding, additional field activities were conducted at the four flooded project sites during the first week in November 2002. Field surveys were conducted to extend the existing cross-sections to the high water indicators from the flood, so that estimates of flood magnitude and other hydraulic parameters could be made. At three sites, other surveys were conducted to help establish the cause and extent of damage incurred as a result of the flood. In addition to the project sites, conditions were analyzed at several other BECSs which were subjected to flood flows.

Research Approach

An assessment of the condition and performance of existing BECSs was accomplished by conducting extensive field investigations at eleven sites around the state of Alaska. Site-specific field surveys were conducted following preliminary efforts to interview project owners, designers, and regulators, and to obtain design or as-built documents. Site descriptions, techniques, photographs, and design documents are found in Appendix C.

Site surveys were conducted to collect specific hydrologic and hydraulic data necessary to conduct an analysis of the hydraulic performance of the BECSs. The analyses were conducted to assess either 1) how well the structures performed in high water/high velocity conditions which occurred during the project life, or 2) predict how they would perform in simulated high water conditions using numerical hydraulic modeling techniques.

Fieldwork was conducted throughout the 2002 summer; each site was visited three to five times. The stream channel fieldwork focused on obtaining stream and floodplain geometry data and channel hydraulic information. The fieldwork conducted at each site included extensive cross-section and longitudinal surveys of the channel, channel bed material gradation measurements, discharge and velocity measurements, and other related measurements. A description of the fieldwork conducted is found in Appendix B.

A key objective in the research approach was to conduct a hydraulic analysis of each of the sites. The objective of the hydraulic analysis was to identify the upper end of hydraulic conditions in which a BECS may be subjected to while retaining structural integrity, and to identify modes of failure when those values are exceeded. The performance of bioengineered structures found in the literature was generally reported in terms of either shear stress (tractive force) or flow velocities. The project sites were analyzed using both techniques.

Because of the difficulty in obtaining hydraulic measurements during high river stage, the hydraulic analysis involves the use of the HEC-RAS hydraulic modeling system (USACE, 1998), which is a water-surface profile computational model for one-dimensional, gradually varied flow. The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion. The momentum equation is utilized in situations where the water surface profile is rapidly varied, such as at bridges (USACE, 1998). Numeric models of each study site were created using stream geometric data. Once the models were constructed and calibrated, estimations of channel velocities, stage, and average shear stress were calculated for each BECS for a range of discharges. A technical discussion of the shear stress analysis is found in Appendix B.

Another important component of the assessment of BECSs is an analysis of the vegetation used as an element of the bioengineered structure. At each site, extensive data from the bioengineering structure and bank vegetation were collected. Vegetation was assessed for the use of appropriate plant species in the design. Site conditions were assessed for their impact on plant vigor. Site conditions were assessed for aspect, depth to water, and soil chemistry. Additionally, soil samples were collected from several sites and analyzed for soil chemistry and nutrients.

CHAPTER 2 - FINDINGS

Literature Review

Early in this study, a literature review was conducted to examine peer-reviewed and grey literature related to the design, construction, and performance of bioengineered streambank stabilization structures. In general, the literature is replete with many papers describing the general results of individual projects, conducted on streams and rivers throughout the lower 48 states and Europe. Additionally, many reports, guidance manuals, web sites, and popular articles are available which describe a wide range of bioengineering techniques, methods, and demonstration projects. Most of these papers, though of relevance to the general science of stream restoration, were not included in this literature review unless they contained specific engineering design information or described projects in Alaska and other subarctic climates. Reviewers noted a dearth of papers and reports specifically presenting comprehensive engineering data from past projects, design data gathered from laboratory or flume experiments, or in-field measurements of hydraulic data at bioengineered sites. The complete literature review is found in Appendix A. Examples of bioengineering techniques are found in the Appendix and are taken from Muhlberg and Moore (1998).

Vegetative Observations

Three criteria for the success of the vegetated portion of a soil bioengineering project are: 1) the use of appropriate plant species; 2) proper plant handling, and 3) site conditions. It was impossible for study personnel to determine how plants were handled during harvesting, storage, and planting for each of the study sites, due to lack of archived project data. However, it was much easier to ascertain whether or not appropriate plant species were used at each of the study sites. Alaska has several native willows that root readily and are tolerant of periodically saturated soils. These are important characteristics for plants used in streambank bioengineering techniques and are found in Salix alaxensis, S. barclayi, S. lasiandra, S. stichensis and Populus sp. Site conditions were assessed for aspect, soil conditions, and depth to water table.

Two species of Poplar, Populus balsamnifera and P. trichocarpa, occur in southcentral Alaska; their ranges overlap (Viereck and Little, 1972). Since it is difficult to differentiate between the two species at these project sites, they are referred to as Populus sp. in the following discussions. A listing of the vegetation data is found in Appendix D.

Anchor River-Silverking Campground

This site contains two discontinuous sections of brush layering and approximately 100 feet of a spruce tree revetment. Sedges were growing at the toe of the upstream brush layer. The vegetated toe protection appeared to be adequate since the thalweg was on the other side of the river at the time of installation.

The overall plant cover of the brush layer was close to 100 percent, and the growth appeared to be vigorous, indicating good site conditions and appropriate plant species. Willow, grasses, Epilobium angustifolium, Equisetum sp. and Heracleum lanatum were growing within the brush layers. A downstream willow bundle provided 85 percent cover. The current season's growth averaged 18 inches, indicating good site conditions. Portions of the spruce tree revetment had trapped silt which was being colonized by sedges.

Plant growth appeared vigorous and soil bioengineering treatments appeared to be stabilizing the bank. Debris such as grasses and small branches were caught in the tops of the branches of the top brush layer. The brush layer also provided overhanging vegetation.

This site was inundated by the fall 2002 floods. Inspection after the October flood showed some damage to the project vegetation. Damage included the loss of 25 feet of willow brush layering treatment at the downstream end of the project and associated bank collapse. At the upper end of the structure, most of the willow remained intact and anchored to the bank, though branches were bent and stripped of leaves from the impact of the flood. The spruce tree revetment also survived the fall floods and remained intact.

Anchor River-Steelhead Campground

This site, which was constructed in early summer 2002, was not initially part of the study. However, cross-sections were surveyed and other field data were collected here in July 2002 to provide interested parties with data for long-term monitoring purposes. This BECS was subsequently added as a study site after being subjected to the large fall 2002 floods. Because of the late addition, and the fact that the site had suffered severe damage in the flood, a complete vegetation analysis was not conducted at this site. Willow brush layering was used in two layers above a root wad base. Vegetation mats were used on the top of the bank.

This site was inundated by the fall 2002 floods. Though the structure appeared intact for the first few days following the October flood peak, severe damage was noted 8 days later. The upstream third of the root wad structure underneath this section had been pulled out away from the bank and into the channel. The section of the willow brush layering above the damaged root wads had been destroyed. The majority of the vegetative mat on top of the bank was still intact. The remaining root wad/brush layer structure failed following the second flood in November 2002.

Campbell Creek-Taku Park

Overall plant cover, including grasses, was 95 percent and plant growth was vigorous. Woody plants provided approximately 80 percent cover at the central portion of the project and only 35 percent cover at the upstream and downstream ends of the project. Salix alaxensis, S. scouleriana, Alnus sp., Picea glauca, grasses and clover were the primary plant taxa found at the site. The Alnus sp. seeded onto the site from shrubs growing nearby. The original planting density may have been lower at the ends of the project which would explain the lower plant cover for that area.

The root wads were installed so that their roots overlapped, but they were not adequately trenched into the creek bed. Water was flowing behind the root wads and undercutting the bank. The toe of the bank above and behind the root wad lacked additional protection such as a coir log, live siltation, or brush layer.

Two small trails extended from the bike path to the creek at the upstream and downstream ends of the project. A third trail intersects the stream slightly downstream from the project center where, in July, the undercut bank was beginning to fail. The bank collapsed after high water in October.

Chena River-Doyon Estates

Overall plant cover was 75-80 percent and plant vigor was moderate. In early summer, approximately 10-15 feet of the brush layer was missing from an upstream section of the project. Additional lengths of brush layering failed later in the summer. An alder and willow clump may have slid down the bank into the river, though some local residents reported that the slide was created by beavers that are known to be in the area.

Many willows have been pruned or browsed by moose. The shrubby growth form noted on moose-pruned willows at one other site was not observed here. Erosion was occurring behind the upper brush layer and within the brush layers.

The wrapped soil lifts between the brush layers have been damaged by ice, high water, boat wakes, or a combination of all three. The outer material on the wrap has ripped and since the inner liner has decomposed, the contents of the wrap (soil/gravel mix) were washing out. The wraps were dwindling in size and pulling away from the branches, allowing roots to be exposed. Exposed roots appeared to be thin, and low in density.

Deep Creek

Five soil bioengineering techniques were installed at Deep Creek for a multiple technique demonstration planting. The live stakes were planted on the banks in the upstream section. The brush mattress was planted on the banks downstream of the live stakes. The live siltation technique and willow bundle were placed at the toe of brush mattress. Brush layers were created on the stream banks downstream of the brush mattress. A layer of large diameter armor stone was used to protect the toe of the structure.

Overall plant cover was high, and plant vigor was moderate to vigorous, depending on the location. This indicated good site and aspect conditions. Site conditions here include the presence of moose, which browsed on the live stakes the previous winter, limiting their shoot growth.

The branches in the live siltation were dead but the technique continued to protect the toe of the brush mattress. Siltation has occurred behind the dead branches and covered the bundle that was planted there. The bundle was placed too low, below OHW, and was silted over before it had a chance to grow. Small paths to the stream were found at a few locations throughout the project, but did not to have a negative impact on the stability of the streambank.

The specific brush layers were difficult to distinguish. The geogrid used to wrap the soil layers was exposed in some areas, particularly where paths have been created.
Salix barclayi was the primary willow installed immediately above the rock toe protection on the downstream end of the brush layers. Salix alaxensis would have been the preferred willow for installation near the water because it is more tolerant of flooding and ice scouring, grows quickly, and provides overhanging branches more readily than S. barclayi.

The most vigorous plants occurred midway up the streambank. The face of the brush layers, especially at the downstream end of the project, was nearly vertical. The top of the bank was sloping down towards the creek. The toe of the brush layer was slowly eroding, probably from a gradual removal of fines. Prior to the fall floods, erosion had also begun at the downstream end of the project where the geogrid wrap is exposed.

This site was inundated by the fall 2002 floods. Inspection after the October flood showed some damage to the project vegetation. Damage included the loss of 10 feet of the geogrid brush layering treatment at the downstream end of the project, and associated severe erosion and collapse of the untreated downstream bank adjacent to this section. Upstream of this failure, most of the willow remained intact and anchored to the bank, though branches were bent and stripped of leaves from the impact of the flood. Significant deposition of silt was found at the toe of the brush layering, up to a foot in some locations.

Kenai River-Centennial Park

As part of the bank stabilization project at this location, four elevated stairways were installed from the top of bank to the river at the endpoints and the middle of the project. The stairs provided access to the river. Despite the stairs, a few people climbed the fence, cut the vegetation along the river and created new fishing sites. Approximately ten percent of the vegetation was damaged over the entire site, but the damaged branches appeared to be viable and capable of recovering. On the largest disturbed section (approximately 15 feet long), new growth was occurring from basal buds.

Despite the minor damage to the project caused by fishing activities, the project appeared to be protecting the riverbank from erosion. The first brush layer (closest to the water) was constructed entirely with S. alaxensis. S. barclayi and P. sp. were mixed into the second brush layer. The willows have been browsed by moose. The tops of the branches were broken and bent over, and new shoot growth was occurring below the breaks. Despite trampling, moose browse, and periodic high water, the willow growth appears vigorous. Grasses were growing on the coir log and willows were providing overhanging branches. A healthy stand of hairgrass was growing on the slope above the brush layers.

The slope above the brush layers was seeded with grasses and a netted erosion control fabric covered the slope. A sparse cover of red fescue appeared to be the dominant forb growing on the slopes behind two downstream sections of the project. Hairgrass was growing on the slope behind the upstream section of the project; it provided more cover than the fescue. The erosion control fabric appeared to be inhibiting native plant colonization. Few native plants have colonized the slope. Once the erosion control fabric decomposes, the rate of plant colonization will probably increase. The fabric may not have been needed; the plants at the toe of the slope would tolerate being buried by eroding soil if it occurred and there was no sign that surface erosion was a problem.

High water in late October and early November 2002 inundated the root wad boles and lower willow brush layering. Water velocity between the willow and root fans was low, and no damage was noted to the vegetation from the flooding conditions.

Kenai River-Riddle Property

This project is located in an intertidal reach of the lower Kenai River. Willows were planted above two tiers of root wads. Behind the willows is a retaining wall, 8 to 10 feet tall. The entire project has been fertilized with Miracle Gro. Additionally, selected areas were fertilized with fish cleaning water, fish blood, and fish waste.

Plant cover varied from 50 to 100 percent. The highest plant cover occurred where two layers of willow were present, one growing along the water's edge and the other close to the retaining wall. The lowest plant cover occurred when the plants were not growing close to the retaining wall. This area may not have been planted.

A fish cleaning table was located on top of the retaining wall and fish waste was dumped onto the willows. The willows had been cut and the leaves had been damaged thus reducing plant cover to 60 percent. A depression in the soil has occurred in the plantings near the access to the dock. Plant cover was 50 percent in this area. The property owners have indicated that they plan to plant more willows, fill in the depression, and generally maintain the site.

Ship Creek-Cottonwood Park

Plant cover varied along sections of the bank. Generally the lower brush layers had a smaller plant cover than the upper layers. Plant cover on the lower brush varied from 40-60 percent. One small section, approximately 4 feet long, had no cover at all. The best plant cover occurred behind a large root wad, suggesting that protection provided by the root wad aided plant growth. Plant cover for the upper brush layer varied from 50-95 percent and averaged around 90 percent. The brush layers were providing some overhanging vegetation.

Theodore River

The downstream 30 feet of root wads were still in place, though badly damaged. An upper section of the project root wads appeared to be missing. A large slump was occurring along the entire length of the bank. The bank was almost vertical from erosion, and the slump was exposing the root wad boles which had been extended into the bank. Brush layering was not used at this site, and live staking was not apparent. The upper bank was composed mainly of alder and grasses, with a low percentage of willow.

Willow Creek-Lapham Property

Plant cover was nearly 100 percent in both brush layers. Branches from the lower brush layer were overhanging the root wads. The willows in the upper brush layer had been pruned by the property owner in 2001. The pruning created a shrubby growth form. Vicia cracca, Bird vetch, has invaded the site and was growing in the top brush layer to the height of the willows in two locations within the project area.

Overall plant vigor was high but it may be compromised if the V. cracca becomes established in the brush layer. V. cracca was observed in several other locations on the property. The brush layers/root wads have apparently stabilized the site for the present.

Willow Creek-Pioneer Lodge

Stream restoration crews installed an elevated light penetrating walkway along the entire treated bank. Grasses and willows were growing up through the walkway and are pruned by foot traffic. Overall plant cover was 95 percent, however the plant cover near the stairs to the creek was 80-90 percent. Some trampling was noted in the brush layers, however it does not appear to have reduced the effectiveness of the technique.

Grasses and branches from the brush layers provided some overhanging vegetation. Willow growth was vigorous despite the rust colored fungus on the leaves. This fungus is often observed on willows later in the growing season and does not seem to compromise the general vigor of the plant.

Soil Samples

Soil samples were collected from four of the study sites, and results are found in Appendix D. Soil samples were not collected at the other sites primarily because vegetated mats prevented access to the soil that may have been used in construction. The value of the soil test is questionable because it is unclear whether the soil sample truly represented the soils used in construction.

The results of the soil tests show that the pH of the soils generally is mildly acidic (pH 5.9-6.3), with the exception of the Campbell Creek-Taku Park mid and lower project samples. These samples are approaching the strongly acidic range (pH 5.2-5.5) but are still within the range allowing for maximum absorption of soil nutrients. The soil tests also show that nutrient levels for total nitrogen (NH_4 and NO_3), phosphorus (P) and potassium (K) are very low. A plant tissue analysis would have provided more useful information. Alaska native plants are adapted to nutrient poor soils so a tissue analysis would reflect more accurately the nutrient status of the plant. The plants at the various projects did not show signs of nutritional stress such as chlorosis of the leaves.

Flow Velocity

Water velocities may generally be expected to increase as discharge increases. Therefore, the ability to withstand high water velocities implies an ability to withstand high discharge rates. Water velocity profiles were constructed based on measurements taken adjacent to the BECS at most sites. Measurements were taken in an area along the BECS which had the fastest current flow, based on visual observation and preliminary measurements. Measurements were taken at both incremental depths starting from the surface, and incremental distances from the BECS, starting at 0.5 feet from the leading edge of the structure.

A generally dry summer resulted in lower stage levels for most velocity profile measurements. Conversely, extreme flooding conditions during October 2002 physically prevented velocity profile measurements at the Deep Creek and Anchor River sites. As such, most measurements were made during typical low summer discharges; measurements for the Chena River and Kenai River sites occurred at higher stages.

Velocity profiles from these measurements were graphed onto cross-sections which intersected the BECSs, using isovels. An example of these measurements is found in Figure 1. All of the site velocity profile measurements are found in Appendix E.

In addition to the measured velocity profiles, estimated average velocities were computed using HEC-RAS. Based on models calibrated at low flow conditions, average channel velocities were estimated for the 50-year flood, 100-year flood, and the largest flood during the project life. An example of the average velocity estimate for the largest flood during the project life at the Chena River site is found in Figure 2. All of the modeled velocities are listed in Appendix F.

Shear Stress Analysis

For this study, the concept of shear stress is used to illustrate the potential of bed and bank erosion at each of the study sites. Tractive force is defined as a force exerted by moving water on bed and bank material. When this force is less than some critical value, the bed material remains motionless. However, when the tractive force over the bed reaches or exceeds a critical value, particle motion begins (Simons and Senturk, 1976). Shear stress is defined as the tractive force per unit area of the bed.

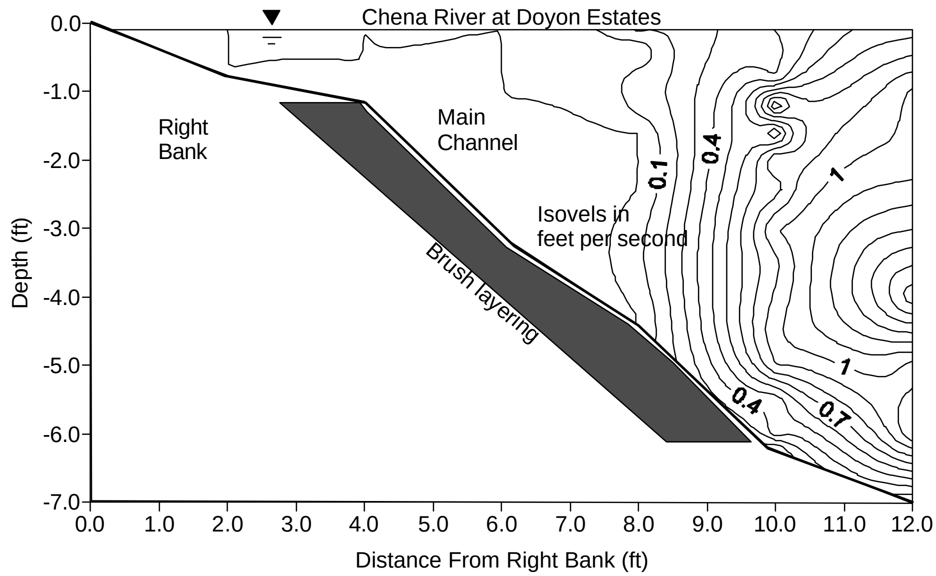

Figure 1. Velocity profile for Chena River BECS; Q = 8870 cfs.

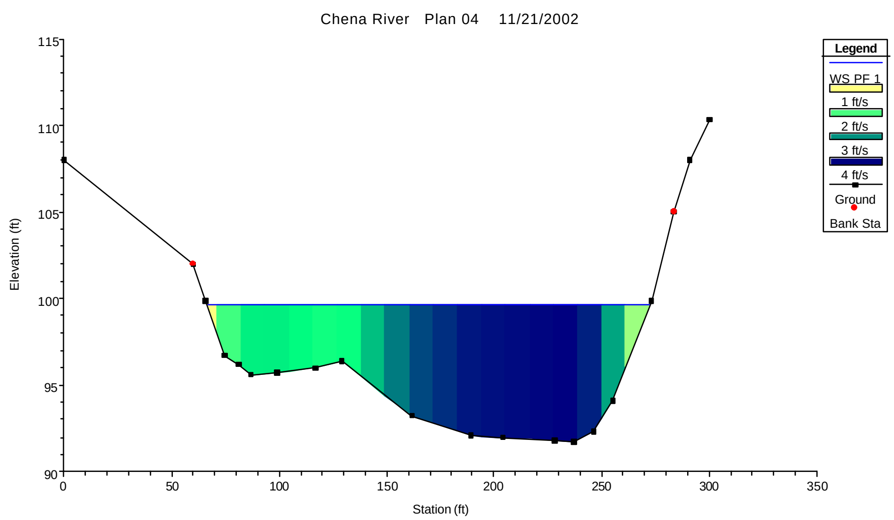

Figure 2. Average velocity model for Chena River BECS; Q = 8870 cfs.

Estimates of shear stress and critical shear stress were developed using analytical methods described in Appendix B. At each site, average channel shear stresses were estimated for the 2-year, 50-year flood, 100-year flood, and the largest flood during the project life. The critical bed shear stress was also calculated for each site, based on bank and channel characteristics. The critical shear stress was then compared to the average shear stresses apparent to a channel at the different flood magnitudes. If the average shear stress for a given discharge exceeded the critical shear stress, this would indicate the potential of particle movement and subsequent bed or bank erosion. Comparisons were made by computing ratios of average and critical shear stresses. A ratio of 1 or less indicates a stable channel geometry; a ratio of greater than 1 indicates the potential for either bed or bank erosion from shear stress during high water events. Appendix G shows the computed average and critical shear stresses for all study sites. Also found in Appendix G are ratios of average to critical shear stress for each of the design flows for bed and bank shear stresses.

Anchor River-Silverking Campground

At Anchor River-Silverking Campground, the BECS, installed during the fall of 2000, is located on the left bank just downstream from the old Sterling Highway bridge. The structure is of coir log willow layering construction, with a section of spruce revetment in the middle. Damage to the structure from the fall 2002 floods included loss of 25 feet of the coir log/brush layering treatment at the downstream end of the project and associated bank collapse.

The HEC-RAS analysis was conducted for this site, using modeled flood discharges of the 2-year flood, 50-year flood, 100-year flood, and estimates of the October 2002 discharge. In the shear stress analysis, the calculated average to critical bed shear stress ratio for the 2-year flood magnitude is 0.44, indicating a low potential for particle movement. However, the average to critical bank shear stress ratio for the 2-year flood is 1.62, and increases to 3.71 for the 50-year flood. The analysis indicates a potential for bed erosion at the 50-year flood and greater, and a high potential for bed erosion at all large flood magnitudes.

A cross-section was surveyed through the BECS at this site, before and after the late October flood (Figure 3). The cross-section indicates significant scour at the toe of the bank and adjacent channel.

The high bed and bank erosion potential indicated by the shear stress analysis is corroborated by the pre- and post-flood cross-section survey. The mechanism for failure at this site appeared to be the erosion of the channel bed and bank toe at the BECS location, leading to the loss of support and collapse of the BECS.

Anchor River-Steelhead Campground

The Anchor River-Steelhead Campground site is 1800 feet downstream from the Anchor River-Silverking Campground site, and was added to the project after the October 2002 flood event. This site was constructed using root wads with willow brush layering, and was installed in July 2002. The top end of the structure was tied into a 15-year old gabion structure at the mouth of an abandoned channel. Damage to the structure from the October flood was significant, and included the removal of 40 feet of the upper end of the root wad treatment, which is 33% of the entire structure (Figure 4). Of note is the fact that this structure did not fail during the peak of the flood, but at some point between 3 and 8 days after the October flood peak. The remaining portion of the structure was destroyed by the November flood.

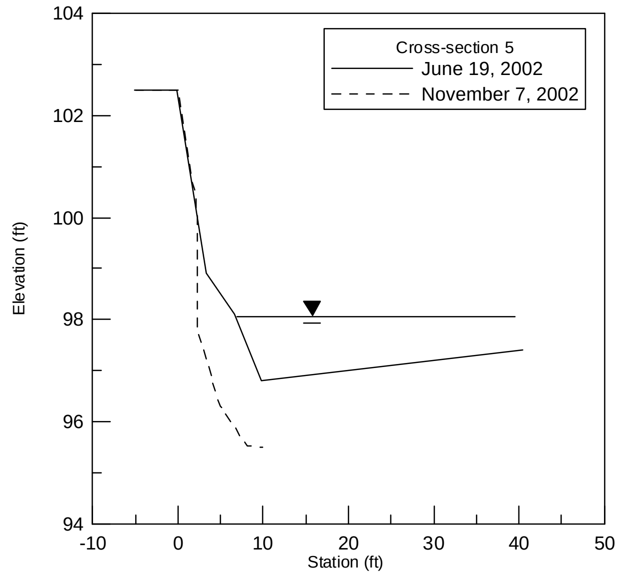

Figure 3. Left bank at Anchor River-Silverking Campground BECS, before and after passage of the October 2002 flood event.

Figure 4. Looking upstream at the failed root wad/brush layering section at Anchor River-Steelhead Campground.

The shear stress analysis for this site indicates a potential for bed and bank erosion at the 2-year flood magnitude, which increases significantly with increasing discharge. For example, the bed and bank average to critical shear stress ratios for the 50-year flood are 1.53 and 2.15 respectively.

A cross-section was surveyed through the BECS at this site, before and after the late October flood (Figure 5). The cross-section indicates significant scour at the toe of the bank and adjacent channel. The shear stress analysis is corroborated by the pre- and post-flood cross-section survey. The mechanism for failure of the BECS at this site appeared to be the erosion of the channel bed and bank toe at the BECS location.

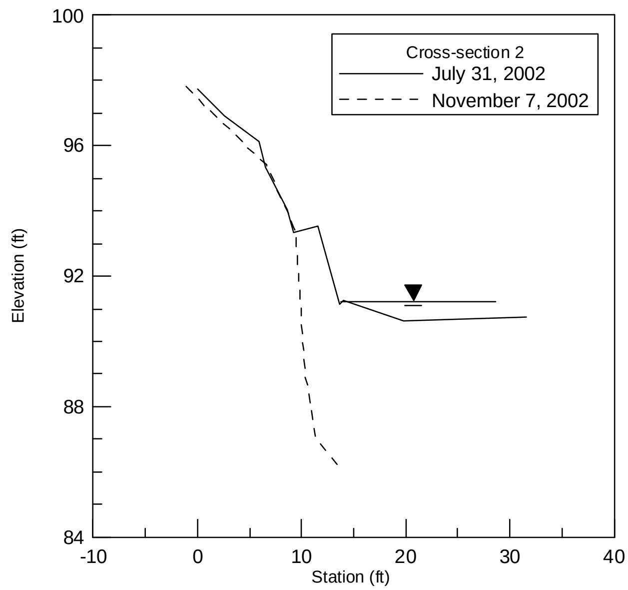

Figure 5. Left bank at Anchor River-Steelhead Campground BECS, before and after passage of the October 2002 flood event.

Campbell Creek-Taku Park

The shear stress analysis for Campbell Creek shows an average/critical shear stress ratio of 1.0 for the channel bed at the 2-year flood, indicating the threshold of particle incipient motion. This increases to 2.2 for the 50-year flood, and 2.9 for the 100-year flood.

The critical bank shear stress could not be calculated for this site. On a channel bank, the shear stress acting to move a particle has two components: water forces move the sediment particle down the channel in the direction of flow, and the gravity force causes the sediment particle to move down the sloping side of the channel (Lane, 1955). As the bank angle increases toward the angle of repose of the particles, the critical shear stress required to initiate particle motion becomes smaller, due to the increasing influence of gravity. When the bank angle meets or exceeds the angle of repose, the critical shear stress is essentially zero.

The estimated lower bank angle at Campbell Creek exceeds the average angle of repose for the bank material. This situation, in which the critical shear stress is at or close to zero, significantly increases the potential for erosion, and places the entire burden of bank stability on the BECS structure.

Some bank failure was noticed and recorded at the Campbell Creek BECS in late summer. The extent of the failure extended appreciably after high water from precipitation events in Anchorage during October 2002. On November 7, the bank collapse started 25 feet from the downstream end of the project, and extended 32 feet upstream. Cross-sections surveyed during the summer field work were located upstream and downstream of this failed section, preventing a comparative measurement of channel change. However, toe scour was noted under the root wads; well over a foot of water was measured between the bottom of the footer log and the channel bottom. Additionally, bank material from behind the root wad fans had been removed. In fact, so much material had been removed from the lower portion of the root wad structure that a survey rod could be extended up to 7 feet into the structure between the root wad fans. The upper bank collapsed due to the lower bank erosion, and water flow between the root wad boles was apparent from above.

Chena River

The Chena River site suffers from partial failure of the fabric encapsulated soil lifts (FESLs) along a substantial portion of the project. As noted in the vegetation section above, the outer wrap has been ripped, probably by bank ice or spring ice floes. The inner burlap filter wrap has deteriorated, and material has been transported out of the FESLs. This has resulted in partial collapse of the FESLs, up to 20’ or more in length in some areas (Figure 6). Other damage was noted along the bottom FESL, which was slumping in several locations into the channel. In these areas, the toe rock had apparently been eroded out from beneath the FESL. Shear forces from tangential ice flows may have been responsible for moving the placed toe rock. Additionally, wave action from boat traffic may have caused non-cohesive bank material to be removed if an adequate filter was not used with the toe rock, leading to toe rock erosion.

Flow in the Chena River is affected by regulation from the Chena River Lakes Flood Control Project, which was completed in 1980. The Moose Creek Dam is a flood-control structure on the Chena River that impounds water only during high flows in the Chena River. The dam was designed to reduce maximum flows to 12,000 cubic feet per second in downtown Fairbanks (Burrows et al., 2000).

The HEC-RAS analysis estimates that the average shear stresses for the Chena River are low for all modeled flows. This is due to the low energy slope through the study reach. However, the estimated critical bed and bank shear stresses are extremely low, and result in average to critical shear stress ratios of greater than 1. The low critical shear stress estimate is the result of an artificially low value of bed material size, which was obtained from the silt layer found across the channel bed. The shape of the channel and the potential for erosion is most likely controlled by a coarser material underneath the silt layer, rather than the silt layer itself (Robert Burrows, USGS hydrologist, oral commun., 2003). As such, the critical shear stress estimation may not be valid.

Figure 6. Failed FESL at Chena River-Doyon Estates.

Though damage to the soil lifts was observed in early summer, substantially more damage was noted after passage of the August 2002 high water event when the BECS was submerged. The velocity profile measured at the peak of the August event shows very low velocities within the willow section of the BECS. Boat wakes may also be responsible for some of the bank erosion, as they are severe and constant in this area.

Deep Creek

Deep Creek was one the project sites inundated by the October and November 2002 floods. The lower end of the BECS (approximately 10 feet in length) failed substantially as a result of the October 2002 flood; the failure migrated upstream during the November flood. The FESLs were completely destroyed, and up to 20 feet of material was eroded out from the bank (Figure 7). Much of the geogrid material used as the outer wrap for the FESLs was still evident, as it trailed out from the remaining soil lifts. One of the project cross-sections surveyed during the summer field work was located just upstream of the failed section. A resurvey of that cross-section after the October flood showed little change in channel elevation from pre-flood surveys, and seemed to indicate that toe erosion and failure was not the cause of the failure, such as was evident for the Anchor River sites.

Upstream of the failed section, the remainder of the project appeared to be in good condition following the October flood. Up to a foot of silt deposition was found at the toe of the brush layering. The willow layering, which was inundated during the flooding, suffered minor damage, and leaves and small branches were stripped off. However, the

FESLs appeared to be in good condition, along with the brush mattress section. Some additional failure of the FESLs was reported after the November flood.

The HEC-RAS analysis was conducted for three cross-sections at the Deep Creek site. Cross-section 6 was located near the lower end of the BECS, just upstream of the failed section. Cross-section 7 was located 185 feet upstream from Cross-section 6, in the upper section of the BECS. Cross-section 5 was located about 90 feet downstream of the BECS. For cross-section locations, see the design drawings in Appendix C

The HEC-RAS analysis at Cross-section 7 computed low ratios of average to critical shear stress for both the bed and bank, indicating good stability. The shallow angle of the bank at this point, and the bed material gradation were responsible for relatively large values of critical bed and bank shear stress. Little damage to the bank or BECS was noted from the October flood in this section.

Figure 7. Failed bank at downstream end of Deep Creek BECS.

The HEC-RAS analysis at Cross-section 6 also computed low ratios of average to critical shear stress for the bed. Bank critical shear stress could not be calculated because of the steep bank angle. The analysis indicated good bed stability at this section, but high potential for bank erosion. Severe damage occurred to the BECS just adjacent and downstream from Cross-section 6. The channel geometry of Deep Creek changes significantly just downstream of Cross-section 6 and the BECS. The left floodplain disappears, and is replaced by a steep bedrock outcrop which narrows the channel considerably. Additionally, the channel takes a 90° turn to the right. This channel geometry may have resulted in major hydraulic effects during the flood, including strong flow separation and back eddies. The HEC-RAS analysis at Cross-section 5, located downstream from the end of the BECS at the 90° turn, shows large values of average shear stress for flows above Q_2. The ratios of average to critical bed shear stress for the

Q_{50}, Q_{100}, and Q_{flood} at Cross-section 5 are estimated at 1.03, 1.12, and 3.23 lb/ft^2 respectively.

As mentioned, the mode of failure at the lower section was most likely not related to toe failure from channel erosion. A layer of large diameter armor stone was used to protect the toe of the structure. The entire bank was overtopped by the October flood, to a depth of several feet, and the downstream structure was probably subject to erosion from a strong back eddy. This section of bank was almost vertical, and was much steeper than adjacent sections upstream. In addition, gravel and soil in the lifts were most likely removed from the front of the structure through the holes in the wrap material. The material used for the soil lifts on this project differed from other projects, which commonly use 2 layers of biodegradable fabric wrap. The brush layering soil wraps were constructed using a geosynthetic grid material, rather than a traditional ‘coir fiber’ material (Figure 8). Geogrids are net-shaped synthetic polymer-coated fibers that are normally used to reinforce earth-fill slope, wall and base layer construction. Geogrid is not a filter material, and will not retain soil particles smaller than the open gridding spaces. A burlap fabric used inside the geogrid at the front face to contain the fines had deteriorated completely, which most likely allowed material to be eroded out from the soil lifts.

Figure 8. Geogrid used at Deep Creek.

Kenai River-Centennial Park

The Kenai River-Centennial Park site is located near River Mile 21, just downstream of the Sterling Highway Bridge in Soldotna. A USGS report describes this section of river as having a low rate of bank erosion and low relative sensitivity to streamside development, due to channel characteristics such as armoring and an underfit channel

(Dorava and Moore, 1997). Dorava and Moore noted that this reach was relatively undamaged by a 100-year flood in September 1995.

The HEC-RAS analysis for this site shows low to moderate ratios of average to critical shear stress, indicating good stability at the bed and bank. For example, the average to critical ratios for bed and bank shear stress for the October 31, 2002 discharge of 23,100 cfs (largest flood of project life) are 0.92 and 0.97. Ratios of average to critical shear stress for the 50-year and 100-year flood levels are 1.04 and 1.10 respectively. A wide channel, shallow slope, large average bed material, and channel geometry combine to result in low to moderate average shear stress for this site. This site is subjected to frequent boat wakes during the summer months. The BECS is in good condition.

Kenai River-Riddle Property

The Kenai River-Riddle property site is located near River Mile 10, near the confluence of Beaver Creek. A 100-year flood event on the Kenai River caused substantial alterations in this reach in September 1995 (Dorava and Moore, 1997). A USGS report describes channel characteristics for this section of river which are indicative of a high relative sensitivity to streamside development (Dorava and Moore, 1997). The Riddle site was constructed in May 1996 as part of a larger project which included four properties.

The HEC-RAS analysis for this site shows low to moderate ratios of average to critical shear stress. For example, the average to critical ratios for bed and bank shear stress for the October 31, 2002 discharge of 23,100 cfs are 0.55 and 0.80, indicating low potential for bed or bank channel erosion. Hydraulic modeling at this BECS is complicated by the fact that the structure is located within the intertidal zone. However, velocity profile measurements made during the first two hours of the outflow of a 24-foot high tide show low water velocities within the willow plants extending from the top of the root wad structure. The BECS is in good condition, and appears to be structurally intact after 7 years of operation (Figure 9).

Ship Creek-Cottonwood Park

The HEC-RAS analysis for the Cottonwood Park site shows low potential for bed erosion, and slightly higher potential for bank erosion. The average to critical shear stress ratios for bed and bank for the largest flood of project life (826 cfs) are 0.60 and 0.98. However, the average to critical bank shear stress ratios for the 50-year and 100-year flood events are 1.30 and 1.35, indicating some potential for bank erosion at larger flows. The structure is in good condition (Figure 10). The structure is only a few years old and has not been subjected to flows above the 2-year flood to date.

Theodore River

The Theodore River root wad site was recommended for inclusion in this study by the designing engineer. The project is located in a remote area away from the Alaska highway system, and is one of the earliest root wad projects to be installed in Alaska (Dan Billman, HDR Inc. engineer, oral commun, 2002). The site was designed as a

Figure 9. Root wads at Kenai River-Riddles.

Figure 10. Root wads/brush layering at Ship Creek-Cottonwood Park.

temporary structure to protect a bridge abutment for several years. The structure performed well as designed; however, the design life has expired, and the structure is currently in poor condition. The project was approximately 40 feet long. The lower section was still in place, though badly damaged. A short upstream section of the project has completely failed. Much of the bank above and behind the root wads has failed also, and is slumping into the channel.

The HEC-RAS analysis for this project shows a low potential for bed and bank erosion at the 2-year flood magnitude, and a moderate potential for larger floods. A low energy gradient through this reach results in low values for average shear stress. The average to critical bed shear stress ratios for the Q_2, Q_{50}, Q_{100}, and Q_{flood} are 0.44, 0.92, 1.04, and 0.80 respectively.

Channel elevations from the July 2002 survey at Cross-section 5 show little change from the design drawing dated March 1994. Channels often scour during flood events, and gradually return to pre-flood elevations from continual redeposition of material, with little residual evidence. Bed and bank erosion may have occurred during a flood event at this site, which could have damaged the root wad structure.

Another possible explanation for the root wad failure may be buoyant force. Because wood weighs less than water, an upward buoyant force is exerted on wood when submerged. A significant volume of wood was used in the construction of this project; root wad logs were 20 feet long and 2 feet in diameter, and were spaced every 6.6 feet. Approximately 120 feet of footer logs were placed underneath the root wads in rows of 3 or 4. A considerable upward buoyant force would have been developed if this structure was inundated. High water marks found at the Theodore site indicate that the BECS has probably been inundated sometime in the past nine years.

Due to its remote location and lack of available materials, the root wads were anchored using large tree boles driven into the bank through the structure. Fabric encapsulated soil lifts were not used, though native fill material was placed over the structure. If flooding conditions eroded the fill and compromised the anchoring system, the buoyant force may have been large enough to float the root wads and initiate failure of the structure.

Willow Creek-Lapham Property

This structure is a root wad/soil lift/willow brush layering combination. The HEC-RAS analysis for the Willow Creek-Lapham site shows low potential for bed erosion, but high potential for bank erosion. The average to critical shear stress ratios for the bed for the 50-year and 100-year flood events are 0.84 and 0.88, indicating moderately low potential for bank erosion at larger flows. The average to critical bank shear stress ratio for the largest flood of project life (826 cfs) is 2.51. The recurrence interval for that flood is less than 2 years (Q_2). The structure is only a few years old, and is in good condition.

The owner reported that the channel has been subjected to extreme bank erosion and lateral channel migration in the past. In fact, an abandoned well casing currently located in the channel near the left bank used to be within the boundaries of the Lapham backyard, on the right side of the channel.

Willow Creek-Pioneer Lodge

At Willow Creek-Pioneer Lodge, the BECS, installed during the spring of 2000, is located on the left bank just downstream from the Parks Highway bridge. The structure is a root wad/soil lift/willow brush layering combination, with an elevated walkway to reduce impacts from trampling

The HEC-RAS analysis for the Willow Creek-Pioneer site shows low potential for bed erosion, but high potential for bank erosion. The average to critical shear stress ratios for the bed for the estimated 100-year flood is 0.54. However, the bank shear stress could not be calculated, because the bank angle exceeds the average angle of repose for the bank material. The structure, only a few years old, has not been subjected to flows above the 2-year flood to date, and is in good condition.

Fall 2002 Floods

In addition to four of the eleven project sites already discussed, a number of BECSs were subjected to flooding conditions during the October and November 2002 flooding events. Though these sites were not analyzed using the comprehensive techniques for the original project sites, visual inspections were performed during the first week in November, and results are reported here.

The BECS at the Sportsman's Landing on the Kenai River was inspected on October 31, 2002. This structure was installed as part of a jetty replacement at the viewing deck upstream of the boat launch. A 12" coir fiber log, willow bundles, and other plantings were placed over a section of placed riprap for a length of 54 feet. Discharge at the nearby Kenai River at Cooper Landing station was 12,500 cfs on October 31. The top of the coir log was just submerged at the time of inspection, and recent high water marks indicated that the coir log had been inundated by 1.5 feet of water during the flood peak of 15,300 on October 26.

Velocity measurements were made adjacent to the coir log, along the upper section of the jetty, where water velocity appeared to be highest (Table 2).

Table 2. Velocity measurements at Sportsman's Landing.

Distance From Bank (feet)	Depth (feet)	Average Velocity (feet per second)
0.5	1.0	1.31
1.0	1.1	1.95
2.0	1.2	3.35

The structure appeared to be in good condition, and no bank erosion was apparent at the time of inspection. Not enough information was collected at this site to calculate shear stresses.

The BECS at the Pillars State Park on the lower Kenai River was also inspected. This structure was installed as part of a boat launch improvement, and utilizes coir logs and brush layering. The structure is in the intertidal zone of the Kenai River. Because of channel geometry, water velocities near the bank and coir logs are generally low. The structure appeared to be in excellent condition, and no bank erosion was apparent at the time of inspection (Figure 11).

Other sites inspected included a root wad-protected culvert road crossing on Slikok Creek in Soldotna, and a coir log/grass roll site on the Kasilof River at the Crooked Creek State Recreation Site. High water had receded somewhat at both sites. Flow velocities were not measured, though they appeared to be slow. Both structures were in excellent condition.

Figure 11. Pillars State Park BECS.

CHAPTER 3 - INTERPRETATION, APPRAISAL, AND APPLICATIONS

One of the objectives of this study was to assess the factors and conditions that govern successful implementation of bioengineered erosion control structures in Alaska. Such an assessment requires the analysis and understanding of a number of different parameters. These parameters are related directly to the design and performance of such structures; the goal of this analysis is to increase the understanding and confidence necessary to design and construct bioengineered stream bank stabilization projects.

Velocity Influence on BECS Performance

Velocity has been used as an indicator of BECS performance, as described in the literature review (Appendix A). Velocity profiles show that water velocities at the study sites were, for the most part, low in range. Some of the values may be attributed to the hydraulic roughness of the structure itself. For example, measurements made during August 2002 flooding at the Chena River site show velocities at or near 0 feet per second in and near the brush layer section, which was submerged by high water. This section has an extremely thick growth of willows rising vertically from the bank, and the willows were probably effective in slowing water velocities at this location. Similarly, water velocities between 0-1 feet per second were measured in and near submerged willows at the Kenai River-Riddle property during the receding limb of a spring high tide cycle.

Most measurements within 2 perpendicular feet of the root wad structures were within 1-2 feet per second. The highest recorded velocities were recorded at Deep Creek, where a velocity of 7 feet per second was recorded 1 foot from the bank adjacent to large toe rock. Stage was low at the time of this measurement, and the water was not running through the project willow growth.

Velocity measurements made at the project BECSs were substantially less than the maximum measured velocities listed for various types of structures in the literature review (Table 3). This may be attributed to generally low flow conditions at the time of most measurements, with the exception of the Chena River and Kenai River sites. Leopold et al. (1964) report that the mean velocity of rivers in flood varies from about 6 to 10 feet per second. Field velocity measurements were impossible to obtain during the extreme October and November floods, because of the difficulty and danger of making such measurements. Estimations of flood velocities were obtained by conducting numerical modeling with the HEC-RAS computer program. Water velocities were modeled for the flood discharge which damaged the root wad structure at the Anchor River-Steelhead Campground site. Those modeled velocities were in the lower end of the range of maximum velocities measured at various root wad sites and reported in the literature review (Biendenharn et al., 1997).

Velocity is one of several properties used to describe the habitat value of a site along a river. However, velocity may not be the best indicator of engineering performance for BECS applications because of inherent problems with measurement procedures. Velocity variations across a channel may make it difficult to determine where to measure the representative velocity. For example, the hydraulic roughness of a streamside structure creates friction or shear stress. Through energy transfer, this friction force will generally result in lower water velocities at the structure. Some papers in the literature specifically reported average velocities. However, others did not, and it was often not obvious if the reported upper velocity values were measured directly adjacent to the structure, or were measured farther out in the channel.

An additional complication arises from the fact that in turbulent conditions, velocities may vary in magnitude up to two times the mean. As shear stress is proportional to the velocity squared, conditions may be such that shear stress is increased four times greater than what point velocity measurements indicate (Leopold et al., 1964).

Finally, the use of velocity as a performance benchmark or criteria provides an incomplete picture about other hydraulic conditions that may have a direct effect on the engineering performance of a BECS. Reported maximum values of velocity do not provide any information on such hydraulic features as the depth or shape of a channel, or the bed material gradation. These features and others are important variables in the inherent stability of a channel, and the potential for bed and bank erosion. For example, a root wad project installed on a stream with an average bed material size of 100 millimeters will have a higher resistance to toe erosion than a similar project located on a stream with an average bed material size of 10 millimeters, all other factors being equal.

Shear Stress and BECS Performance

A shear stress analysis can provide important information for assessing the engineering performance of a BECS, and the bank and channel conditions at a BECS site. Such an analysis may focus on either the structural integrity of the construction materials, or the ability of the channel material to resist erosion. Schiechtl and Stern (1997) presented values of maximum permissible mechanical stresses. Though not explicitly stated in the study, it appears that those values represent limits that, if exceeded, might result in the deformation or failure of the actual structure components. As an example, exceeding shear stress values may result in the tearing of jute fabric, the separation or breaking of plant roots, or the shearing off or separation of a root wad from a footer log from the failure of an anchor.

The damage to the Deep Creek BECS was probably the result of shear stresses acting directly on, and causing failure to the BECS components. Study personnel speculated that bank material was washed through the open gridding spaces in the geogrid, which led to the failure of the soil lifts. As the material from the soil lifts was eroded away, the willow plants in the brush layering were probably pulled out from the bank, hastening the bank failure. Erosion also took place from behind the structure because of the overtopping water. Severe toe erosion did not seem to be a factor in the structural failure. The substantial toe rock used at this site undoubtedly was responsible for limiting bank toe erosion during the fall floods. Shear stress values that were estimated for the Deep Creek October 2002 flood by the HEC-RAS modeling effort were substantially less than those reported in the literature for willow brush layers or willow mats after three to four seasons.

The shear stress analysis conducted as part of this study was not designed to analyze forces on structural components, but to analyze the potential for bed and bank erosion at each BECS installation. The average shear stress apparent to the bed or bank for a given discharge was compared to the critical shear stress, which is the hydraulic stress required to initiate particle motion and begin the erosion process. This analysis provides a mechanism to assess the potential for failure of a BECS because of scour of the bed upon which the BECS sits, or scour of the bank into which the BECS is constructed.

During the course of this study, three study sites suffered partial or complete failure from erosion of the bank toe which supported the BECS. These three sites were identified in the shear stress analysis as having a high potential for erosion from bed and bank shear stresses. The two Anchor River sites were subjected to extremely large flooding conditions in October and November 2002. Cross-sections surveyed before and after the October flood showed extensive toe erosion which led to the failure of the BECSs. The Campbell Creek-Taku Park site suffered not only from bank toe erosion, but from removal of bank material behind the root wad fans (Figure 12). The inner bank material erosion was most likely due to the lack of a liner material or coir log behind the root fans. Once toe erosion removed the material around the root wad fans, the inner bank material was easily eroded by the flowing water. Techniques utilized on more recent root wad installations are designed to alleviate this type of erosion; such techniques include embedding root wads in large gravel and cobble base, and using fabric encapsulated soil lifts constructed on top of the root wad base.

Figure 12. Failed bank at Campbell Creek-Taku Park.

Vegetation Performance

The analysis of the vegetation used in the bioengineering projects focused on: 1) the use of appropriate plant species, and 2) site conditions. The care of plant material during harvesting, storage, and planting is also important to the successful use of vegetation. However, it was impossible for study personnel to determine how plants were handled during these early stages of the projects, due to lack of archived project data.

The determination of whether or not appropriate plant species were used at each of the study sites was much easier to make. Alaska has several native willows that root readily and are tolerant of soils which are saturated periodically throughout the growing season. These are important characteristics for plants used in streambank bioengineering techniques and are found in Salix alaxensis, S. barclayi, S. lasiandra, S. stichensis and Populus sp. The use of appropriate plant species in Alaska is well understood by practitioners of bioengineering techniques, and most of the study sites exhibited proper species use and placement. The sole exception was at the Deep Creek site, where S. barclayi was the primary willow installed immediately above the rock toe protection on the downstream end of the brush layers. Salix alaxensis would have been the preferred willow for installation near the water because it is more tolerant of flooding and ice scouring, grows quickly and provides overhanging branches more readily than S. barclayi.

Additionally, site conditions also appeared adequate for most projects; this includes aspect, soil chemistry, and depth to water table. The Chena River-Doyon Estates site, which was the sole Interior Alaska site, exhibited marginal rooting conditions. Failed soil lifts exposed roots which were thin and low in density. It was difficult to ascertain whether root development was low, or roots had broken off and washed away due to flooding and boat wakes. No sign of water stress was noted at most sites. Plant stress observed at the Ship Creek-Cottonwood Park site may have been due to lack of adequate moisture.

A variety of vegetation techniques have been developed for bioengineering projects; however, the BECSs in this study were constructed primarily with brush layers. Brush mattressing and live siltation techniques were used at Deep Creek, and live siltation was also used at Kenai River-Centennial Park. Brush layers are commonly used because they are easy to construct and are effective at stabilizing banks. Although brush mattresses require more plant material than brush layers, they also provide effective vegetative and physical protection to the streambank. The brush mattress at Deep Creek also appeared to allow more native plants to become established within the boundaries of the technique.

Climatic Influence on BECS Performance

Concern has been noted in the past that the effect of factors unique to Alaska on the performance of BECSs has not been adequately described by investigators. These factors include permafrost, aufeis, cold soil temperatures, ice floes, and other hydrologic conditions common to arctic and subarctic climates. The scope of this study included the identification and description of the influence of Alaska's unique climate and hydrology on the performance of BECSs.

Damage from spring ice floes to the coir or jute fabric wraps used on soil lifts was noted at two locations. In several short sections of the Anchor River-Silverking site, ice damage was noted on the soil lifts. Ice damage was also noted on longer sections of the Chena River-Doyon site. Damage from flowing ice left a distinctive mark; the fabric had been ripped out and pulled downstream, where it was found in a compacted bundle. A failed outer wrap was noted in numerous locations at the Chena River-Doyon site. The failed outer wrap, combined with a deteriorated inner wrap, led to the spillage of bank material used in the soil lifts, and subsequent failure of those lifts.

Damage at the Chena River site may also be related to floating ice which attaches to the bank during the winter. Ice covers tend to follow the water level. As the winter progresses and discharge drops, the bank ice falls into the channel, and exerts a shear force on the bank material. Nearby residents reported that annual bank erosion results from bank ice action each spring. Additional problems may occur at sites with fixed structures which extend into the channel, such as root wads. River ice may attach to such structures; a buoyant force is then exerted on the structure if the water level rises.

In this study, no impacts to the study BECSs were noted from the presence of aufeis deposits. One possible scenario where damage might occur is when aufeis deposits fill stream channels. Such a deposit may force spring runoff out of the channel and into a BECS. No reports of such damage by aufeis were noted in the literature review.

Similarly, no specific impacts to the study BECSs were noted from the presence of permafrost. Permafrost is likely not present for most of the study watersheds in the Anchorage area and in the Kenai Peninsula region (Johnson and Hartman, 1971). Discontinuous permafrost may be present in the Willow Creek and Chena River watersheds. The presence of permafrost in a watershed should be a consideration when designing BECSs. In such a watershed, storm runoff can be relatively rapid as the result of the presence of an impermeable layer at shallow depths (Slaughter and Kane, 1979).

Cold soils and slow revegetation rates appear to have some impact on the use and importance of vegetation in BECSs in Alaska and other northern climates. In many of the various BECS designs, the vegetation increases bank stability through a root system which reinforces and strengthens the soil. Stability and erosion protection will increase in time as the vegetation grows.

At high latitudes, low annual solar insolation and seasonally eccentric solar insolation influence the climate. The effects of cold on terrestrial plant productivity are determined on a latitudinal gradient, from the temperate regions to the polar tundra (Milner and Oswood, 1997). For example, researchers have shown that inputs of riparian leaf litter are low in Alaskan waters compared with temperate regions of the United States (Oswood et al., 1995). Within Alaska, leaf litter input is almost negligible in Arctic streams, and increases significantly as latitude decreases and the thermal regime increases.

Almost all subarctic plants are perennials with slow growing seedlings. On disturbed ground, colonizing trees such as willow, alder, aspen and birch usually grow quite slowly for several years, before growing more rapidly as the plant matures. Densmore et al. (2000) report that for revegetation in the subarctic, natural revegetation from seed or assisted revegetation with direct seeding of native plants will not provide surface erosion control for 1 to 10 years.

Plants in northern climates require a much longer time to develop an adequate root mass for protecting and reinforcing soil, especially when compared to conditions in the temperate regions of the United States. The implications for reduced plant productivity, especially in Interior Alaska, point to a longer establishment period for vegetation, and a smaller factor of safety until full bank protection is achieved.

Engineering Design Considerations

Root Wads

Seven of the eleven sites which were subjected to a hydraulic analysis for this study were constructed in part or completely using root wads. Three sites, including two on Willow Creek and one on Ship Creek, have only been in place for a few years, and have not been subjected to flooding conditions. These sites were found to be in excellent condition.

Two sites on the Kenai River have been in place for at least five years, and remain in good condition. The shear stress analysis shows low average to critical shear stress ratios at these sites, and large floods have not occurred on the Kenai River since either of these structures was built. Boat wakes are a constant occurrence on the Kenai River, especially during the busy summer months, and these root wad structures appear to protect banks against boat wake erosion. However, modes of bank erosion are different for boat wakes and flooding conditions.

Three root wad sites in the study suffered partial or complete failure. Two of the sites were analyzed and determined to have high average to critical shear stress ratios at the bed and bank, thereby indicating a high potential for bed and bank erosion at the BECS site. A third root wad site may have suffered some failure from buoyant forces which acted to float the wooden structure during flood inundation.

Root wads are normally designed to protect against channel scour by trenching or embedding the bottom part of the root fan into the channel during construction. To protect against bank erosion below water level, root wads are designed to be overlapped to provide continuous cover. In some designs, large rocks placed between the fans, and coir logs are placed above or below the boles lengthwise along the channel to provide additional protection against erosion.

In high shear stress channels, these design features appear to be insufficient protection against erosion. Root fans, by their nature, are non-geometric in shape, which results in large gaps between the root masses after placement. Such gaps were readily apparent in several of the root wad structures in the study. Either bank material or a face of the sorted rocks used as bedding for the root boles was visible along much of the root fan face (Figure 13). In a channel reach with high tractive forces, unprotected bank material will be subject to transport forces.

Figure 13. Poorly embedded root fans with large gaps in lateral coverage at Willow Creek-Lapham.

Scour

The undermining of revetment toe protection has been identified as one of the primary mechanisms of revetment failure (Federal Highway Administration, 2000). Modern engineering practice dictates that depth of scour estimates must be calculated during the design of traditional revetment structures so that a protective layer is placed at a sufficient depth with a sufficient volume in the streambed to prevent undermining. Depth of scour equations are generally based on empirical data, and various agencies have produced such equations, including the Federal Highway Administration and the U.S. Corps of Engineers. Depth of scour calculations must take into consideration channel degradation as well as natural scour and fill processes (Federal Highway Administration, 2000). Root wads are designed to be embedded such that the root fan protects against bed erosion; however scour calculations must be conducted to determine the depth of protection required. Scour depths were calculated by project designers for the Campbell Creek and Theodore River sites. No mention of scour calculations was made by other study site designers or owners.

Current designs for root wad construction result in a rigid structure which is often pinned or cabled together. Additionally, there are generally no design features incorporated to 'self-heal' the structure in the event of toe erosion. Structural rigidity and a lack of self-healing ability combine to create a potential for damage or failure in the event of toe scour.

Channel Geometry

Other considerations for revetment design are mentioned in engineering manuals, but were not readily apparent in BECS design procedures. For example, bank stabilization will often cause a channel to deepen, especially at a channel bend. Additionally, flow velocities and tractive forces often increase in channel bends, due to non-uniform and non-symmetrical flow conditions (Graf, 1971). These factors must be evaluated, along with channel geometries and hydraulic conditions, when designing revetments on a curved reach.

Extent of Bank Protection

Another important consideration which was not observed in the design for many of the study sites is the longitudinal extent required to adequately protect the channel bank. One criterion established by the Federal Highway Administration (2000) requires that the minimum upstream distance of the revetment should be 1.0 channel width, and that the downstream distance should be at least 1.5 channel widths, from the tangents to the bend at the bend entrance or exit. However, the authors note that many site-specific factors will have a bearing on the actual length of protection required. Downstream erosion was noted at several of the BECSs during the study, especially at the Anchor River sites. In practice, other considerations often have bearing on the length and limits of bank protection projects, including property ownership and budgets.

Filters

The use of granular or fabric filters to prevent the migration of fine soil particles and permit the relief of hydrostatic pressures within the soils is an additional design factor for traditional revetments. The necessity for such filters is the same for BECSs; however, information for the design of such filters is sketchy. For example, McCullah (2002), in describing a combination root wad/riprap treatment, mentions the use of a filter layer, either graded aggregate or filter fabric, placed under the riprap to prevent the washout (piping) of fines through the armor layer, but provides no details on construction techniques or materials.

Application of Study Results

The analysis of data from eleven study sites has provided important information about the engineering performance of existing BECSs in Alaska. Combined with the review of existing literature, this analysis can be used to provide recommendations to AKDOT&PF for the design and implementation of bioengineered bank stabilization structures. Recommendations are made for three areas of concern: hydraulic conditions, design improvements, and maintenance and inspection.

Hydraulic Conditions For Successful Applications

- Identification of the potential for channel bank erosion is essential for the design of any structure in the river environment (Brown and Clyde, 1989). The primary method for identifying erosion potential is observation. Data should include observations of current site conditions, and historic information, such as aerial photography, river survey data, and interviews with long-time residents.

- If little or no observed long-term data is available, a shear stress analysis should be conducted by an experienced hydraulic engineer of the reach where a BECS is being considered for use. Until design improvements are made to BECSs to protect against toe erosion, BECSs should not be used in channels where the average shear stress of the bed or bank approaches or exceeds the critical shear stress at or below the design flood magnitude.

- In addition to a shear stress analysis, a bed scour analysis of the site should be conducted. The scour analysis should include the three major additive components of scour: long-term bed elevation change, general scour and contraction scour, and local scour. If the predicted scour depth for the design flood exceeds the protected depth of the foundation of a BECS design, the BECS should not be used.

- Installations on rivers that experience ice floes during spring breakup or heavy boat wake occurrence should consider the use of root wads or other mechanical structures to protect willow plants and fabric soil wraps.

Design Improvements

- The largest problem for BECS installation noted during the study was the inadequate toe protection and subsequent inability of the structures to withstand large tractive forces during flooding. Design improvements are needed to protect the foundation of the structure from such forces. In particular, techniques should be developed for root wad structures. Current methodology relies on an embedded root fan to provide toe scour protection. New techniques should focus on providing a seamless and substantial toe protection capability.

- Current design methodology for such structures does not provide any self-healing features for such structures in the event of severe toe erosion. Techniques should be developed to provide self-healing capabilities. For example, such techniques may include either a stone toe trench placed beneath the expected depth of maximum scour, or a self-launching stone toe, which will launch stone into the eroded area as scour occurs.

- Improvements to the methods and materials used in fabric encapsulated soil lifts should be considered. Along with other factors, deterioration of an inner burlap filter wrap contributed to the failure of some soil lifts at two sites, Chena River-Doyon Estates and Deep Creek. Rates of degradation need to be assessed and correlated to rates of adequate root mass development in brush layering applications. Outer fabrics with greater tensile strength and abrasion resistance should be evaluated for use on streams where ice damage may occur.

- Design guidance should be developed to assist designers in determining the extent of longitudinal protection required to adequately protect the channel bank. Site-specific factors which have a bearing on the actual length of protection required should be identified.

- Hydrologic guidance is needed to identify the range of water surface elevations at which the various components of a BECS are to be installed. Current designs often rely on the use of the term 'ordinary high water' (OHW) to establish the construction elevation of a root wad or toe rock layer. Disparities between estimates of the OHW during project construction have been noted in the past. Other BECS projects around the state, such as the Cunningham Park root wad project near Soldotna, may not perform as designed because of improper vertical placement of the structure (Technical Advisory Committee meeting, May 2002). Guidelines should be developed that would provide an easily quantifiable hydrologic parameter to design elevations. Hydrologic guidance should also be developed to determine the vertical extent of protection required at a site, and the probability of an overtopping event.

Maintenance and Inspection

- Successful implementation of BECS will require that periodic inspection and maintenance be conducted. Schedules should be established that will allow for inspection of the structure and bank toe during low water periods.

- In addition to annual maintenance, sites should be inspected after major floods. Maintenance and repairs should be conducted as needed. As a general rule, missing structural components should be replaced with larger and heavier components. Personnel should be trained to identify the signs which indicate the need for repair or maintenance. Rigorous documentation of repairs and maintenance is crucial for improving future designs.

CHAPTER 4 - CONCLUSIONS AND SUGGESTED RESEARCH

Conclusions

Several conclusions may be made based on a study of eleven bioengineered erosion control structures. The conclusions are based on field investigations, a hydraulic shear stress analysis, and the results of several large floods which inundated some of the study sites and provided confirmation of the shear stress analysis.

On streams where large tractive forces during flooding conditions will initiate bed and bank particle movement, current designs and techniques for BECSs do not provide adequate protection from toe erosion in flooding conditions. This can result in erosion of the bank toe upon which the structure is located. Such erosion may lead to partial or total failure of the BECS.

Current design methodology for such structures does not provide any self-healing features for such structures in the event of severe toe erosion. In contrast, a properly designed riprap structure will include either a stone toe trench placed beneath the expected depth of maximum scour, or a self-launching stone toe, which will launch stone into the eroded area as scour occurs.

Other operational problems related to types of materials used and environmental factors unique to northern climates exist for BECSs in Alaska. For example, damage from moving channel ice to the outer soil lift fabric wrap was noted at several sites.

Root wads do appear to offer significant protection to banks from damage inflicted by boat wakes. Willow cuttings appear to work well at brush layering sites. The willows root and grow quickly, and the soil lift/willow brush layering technique appears to be effective at quickly restoring vegetative growth to denuded or eroded banks.

Until current designs of BECSs are improved, the use of such structures should occur only in areas of low erosion potential, or for areas where failure results in insignificant consequences.

Suggested Research

Additional research is needed to continue the evaluation of bioengineered erosion control structures on rivers and streams, and to investigate new designs and methods which will improve the hydraulic performance of those structures. Specific research topics are outlined below.

- Review and compilation of design and construction techniques and procedures. Development of installation guidelines, describing where and when BECSs may be implemented.

- Development and testing of a hybrid structure, which incorporates both a properly design riprap toe up to ordinary high water, and a BECS above the rock base.

- Review and assessment of the use of instream structures such as rock vanes, cross vanes, and W-weirs to convey flood flows and reduce channel and bank erosion for Alaskan streams and rivers.

- Quantification of below-ground biomass of root development for brush layering techniques, with a comparison of such for different climate conditions (Interior and Southcentral Alaska), aspect, and soil conditions.

- Determination of environmental differences (habitat value) between new soft revetments and traditional revetments.

The ultimate goal of this research is to develop comprehensive engineering guidelines for the selection, design, and installation of natural channel and stream bank stabilization for Alaska and other northern areas.

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APPENDIX A-LITERATURE REVIEW

Design Manuals

Biendenharn et al. (1997) described the stabilization of eroding banks as one of the most challenging problems of environmental hazard management in the United States. A 1997 handbook published by the U.S. Army Waterways Experiment Station described in detail a wide range of techniques and design guidance for parties undertaking bank erosion projects. The handbook described the use of vegetation as typically used in conjunction with structural methods, or for areas of low erosion potential, or for areas where failure results in insignificant consequences. A short chapter in the handbook provides an overview to the use of vegetation, both as armor and as indirect protection. Grassy vegetation and the roots of brushy and woody vegetation act as armor, while brushy and woody vegetation may act as indirect protection (Biendenharn et al., 1997).

Gray and Leiser (1982) combined the perspectives of an engineer and a horticulturist to describe how vegetation and structures can be used individually or together to stabilize slopes. The book discusses the general principles and advantages of biotechnical slope and streambank protection. Schiechtl (1980) described revegetation and stabilization techniques for treating difficult erosion control problems. Descriptions of the techniques include procedure, materials, time, ecological and technical effectiveness, cost, advantages and disadvantages and maintenance. Appendices provide extensive information on plant materials for temperate, arid, semi arid and tropical regions.

Schiechtl and Stern (1997) listed four reasons for the use of hard materials to assist with a vegetative erosion control structure: Tractive forces and flow velocities exceed the resistance of bed materials, newly established vegetative measures need added protection until full rooting takes place, increasing groundwater pressures displace fine grained materials of the bed and lower bank, and insufficient space for vegetative measures.

Vegetation

Biendenharn et al. (1997) listed several advantages and disadvantages of the use of vegetation in erosion control structures. For example, the authors listed environmental attractions and lower relative costs as advantages. Disadvantages included lower factor of safety for extreme hydraulic conditions, and limited quantitative guidance. Comparative data was not provided.

Vegetation can control erosion through five mechanisms: reinforce soil through roots; dissipate wave energy; intercept water; enhance water infiltration; and deplete soil water by uptake and transpiration (Biendenharn et al., 1997). Vegetation specifically protects streambanks by one or more of four actions: root system holds the soil together; vegetation stalks increase flow resistance; vegetation acts as a buffer against abrasive sediment transport; and vegetation can induce sediment deposition by reducing shear stresses (Klingman and Bradley, 1976).

Hoitsma and Payson (1998) summarized, from a number of referenced studies, the parameters that affect vegetal resistance to stream flow; these include density, stem lengths, root penetration, rooting habits, uniformity of vegetation, soil erodability, and the physical and chemical soil characteristics that affect the growth and establishment of plants.

Vegetation increases bank stability by two factors: roots stabilize and reinforce the soil, and vegetation helps reduce soil moisture, increasing soil strength (Simon and Collision, 2001). By conducting field studies to quantify root reinforcement in streambanks, the authors determined that soil strength is mechanically increased by the tensile strength and spatial density of root fibers. Four tree species were assessed for their contribution to soil strength; black willow had the poorest root reinforcing properties. In a companion study, Collision and Simon (2001) determined that the hydrologic effects of vegetation on bank stability include rainfall interception, moisture removal through transpiration, and tree canopy interception and stemflow. The authors' study showed that the hydrologic effects of bank vegetation on stability are as important as the mechanical effects, and can be either beneficial or detrimental, depending on antecedent rainfall (Collision and Simon, 2001).

Darby (1999) developed a hydraulic model capable of simulating stage-discharge curves in channels with a range of riparian vegetation types. Though the purpose of Darby's study was to investigate the risk of flooding by researching the effects of vegetation on flow resistance and subsequent stage increases, the model could also be used as a design tool for channel design using vegetated bioengineering structures. Four vegetation categories are included in the model, including: flexible vegetation that is growing, flexible vegetation that is dead or dormant, nonflexible vegetation stems that are spaced close together; and nonflexible vegetation stems that are spaced further apart. The model may be used to determine the specific types of riparian vegetation to be used for a given design discharge.

Performance Data

Of the literature that did provide direct performance data, the performance of vegetation in bioengineered structures was generally reported in terms of either shear stress (tractive force) or flow velocities (Hoitsma and Payson, 1998). Shear stress includes several hydraulic variables in one parameter, including depth, the wetted channel perimeter, and flow velocities. For example, the maximum permissible mechanical stresses, in terms of base load pressures, are given for various types of bioengineered construction materials, both immediately following construction and after 3 to 4 seasons (Schiechtl and Stern, 1997). See Table 3.

Table 3. Maximum permissible mechanical stresses for structures.

Construction material	Stress (lb/ft^2) immediately after completion	after 3-4 seasons
Turf	0.20	2.01
Reed plantings	0.10	0.60
Reed roll	0.60	1.21
Wattle fence	0.20	1.00
Live fascine	1.21	1.61
Willow brush layer	0.40	2.82
Willow mat	1.00	6.04
Deciduous tree plantings	0.40	2.42
Branch layer	2.01	6.04
Coarse gravel and stone cover with live cuttings	1.00	5.03
Rip-rap with live branches	4.03	6.04
Rip-rap large quarry stone	-	5.04
Dry stone wall, stone pitching	-	12.09

Schiechtl and Stern (1997) also note that maximum tractive shear stress levels should not exceed 2.01-2.82 lb/ft^2 for the use of shrub or brush willows.

Biendenharn et al. (1997) list velocity information from a number of projects throughout the country, with a note that velocities listed are probably much less than the maximum threshold values that were sustained by the installed structures, due to measurements made on the fall of the hydrograph after flood events (Table 4). The authors also describe velocity measurements of 12.0 feet per second on a root wad structure in Colorado.

Table 4. Local flow velocities sustained by bioengineering treatments.

Type of Bioengineering Treatment	Maximum Velocity Recorded (ft/sec)	Notes
Log revetment with coir geotextile roll and grass seeding above roll	10.0	Logs anchored in the bank with heavy duty cables. Rock jetties used for hard points at strategic points.
Root wads with large root pads of willow	8.7	Lack of maintenance during spring. 1994 (additional root wads at scour points) caused partial washout of the upper meander during spring flood of 1995.
Root wads with large clumps of willow	4.0	Lower velocities measured in and around bioengineering treatment than further out into channel; this can be attributed to larger roughness

		coefficient.
Dormant willow posts with rock toe	3.1	4 rolls of willow posts on 4-ft centers; 10-15 feet long cedar trees between 1st 2 rows of willow; coir geotextile roll and riprap placed at toe along meander apex.

Though some engineering design criteria, such as limits of water velocities and shear stress for various types structures were available, such criteria combined with repeated loading information was essentially non-existent.

Hoitsma and Payson (1998) compiled summaries from studies on the shear stress resistance of grass-lined channels for the past 50 years. They recommended that future studies include the study of performance data on constructed bioengineered structures, including the associated vegetal resistance of native herbaceous and woody plant species used in streambank engineering.

Hydraulic Characteristics

Causes of bank erosion and erosion structure failure are many, and are briefly described in Brown and Clyde (1989). They include abrasion, debris flows, water flow, eddy action, flow acceleration, unsteady flow, freeze/thaw, bank trampling by humans, ice, precipitation, waves, toe erosion, and subsurface flows.

Six variables are considered to control the dimensions of natural channels (Hey, 1978). They include discharge, bed load discharge, bed material size, bank material characteristics, valley slope, and bank vegetation. Karle and Densmore (2001) used these variables to provide a basis for investigating early channel failure on a stream channel design project using bioengineering techniques on a project in Denali National Park in Alaska. The authors concluded that alder bundles placed laterally to the channel at one channel width apart did not provide enough protection along a non-cohesive, unvegetated gravel bank, due to low critical shear stresses.

Freeman et al. (1998) describe a method for the determination of Manning's n roughness values for shrubs and woody vegetation. Though developed for the estimation of roughness values for vegetated channels, this method might be useful for estimating roughness values of bioengineered structures using vegetation. Plant variables in the equations include the frontal area of an individual plant blocking flow, net submerged frontal area of a partially submerged plant, total cross-sectional area of the stems of an individual plant, and the relative plant density.

Additionally, values of vegetated materials are found in many published tables for Manning's n, and may be adapted for use in determining 'n' values for BECSs. For example, the value for brushy growth is 0.010-0.025, the value for young trees is 0.025-0.050, and the value for brushy growth on bank or tress with full foliage is 0.050-0.100 (Jarrett, 1985; Cowan, 1956). No other values specifically linked to BECSs were found in the literature.

Design Considerations

The flow characteristics and capacity of a stream channel will be affected by erosion control measures utilizing vegetative cover. Structures which slow near-bank velocities will reduce the capacity of a channel. The Manning-Strickler roughness equation was modified by Felkel (DVWK, 1984) to include the retarding effect of vegetation roughness on velocities and discharge, by changing the wetted perimeter parameter P to Po/P, where Po is the wetted perimeter free of vegetation, and P is the wetted perimeter. The effect is more pronounced in narrow rivers where the proportion of bank to bed is greater, rather than in wide rivers.

Dorava (1999) evaluated three techniques commonly in use along the Kenai River for their effectiveness at attenuating boatwakes and retarding streambank erosion; the three techniques included spruce tree revetments, bio-logs, and an engineered bank-stabilization structure using bio-logs, cabled spruce logs and willow plantings. However, Dorava noted that his study could not be used to identify which technique was more effective at reducing flood-induced erosion for the 10- to 100-year flood events. Dorava (1999) determined that detailed measurements of water velocity can only be used for qualitative comparisons of habitat value for erosion control structures.

Biendenharn et al. (1997) described differences in costs for vegetative erosion control treatments, and listed issues to consider when comparing costs for bioengineering to costs for structural hard methods. The authors stated that, in general, bioengineered treatments are much less expensive than traditional methods of streambank erosion control such as riprap; however, they noted that local conditions, available materials, hauling distances, and prevailing labor rates are some of the factors which may result in greater costs for bioengineering methods.

Schiechtl and Stern (1997) describe three categories of constraints when considering the application of vegetative materials for erosion control structures. Biological constraints result when project areas are unsuitable for certain plants, or are outside the limits of distribution. Technical constraints restrict the feasibility of slope stabilization based on the substratum’s ability to support root growth. Time limit constraints generally require implementation or planting only during certain seasonal conditions (Schiechtl and Stern, 1997).

Johnson et al. (2002) described the differences in design parameters for stream restoration projects and bridge foundation protection. Generally, bridges are protected for up to the 100-year storm; this design is based on all overbank flow being directed through the bridge structure. However, the basis of most channel restoration and erosion control structure design is the bankfull flow; higher flood flows are considered to flow out of bank onto the floodplain. The authors presented adaptations of methods of natural in-stream structures to provide a transition that will convey design flood flows for a bridge, convey sediment flows without causing pier and abutment scour, and do not produce aggradation beneath bridge. Methods included vanes, cross vanes, and W-weirs.

Woven coir fabric is widely used in bioengineered stream bank stabilization projects; it is used to minimize surface erosion and increase the shear resistance of reconstructed stream banks during the period of vegetative establishment (Miller et al., 1998). The material is biodegradable, and is designed to biodegrade only after providing enough bank protection to allow vegetation to mature and strengthen. Miller et al. (1998) studied the longevity of two strengths of woven coir fabric by using the tested tensile strengths of various samples of different ages as an indication of degradation. Fabric samples in this study showed a significant loss of tensile strength over time, especially after the first one to three years after installation. The authors theorized that factors affecting rates of degradation include exposure to ultraviolet radiation and microbial action (Miller et al., 1998).

Engineering drawings of specifications of bioengineered erosion control structures are available from the Natural Resources Conservation Service on the World Wide Web at the URL address www.wcc.nrcs.usda.gov/wtec/wtec.html. (Bernard and Tuttle, 1998). Another source for technical information is an interactive CD marketed by Salix Applied Earthcare (McCullah, 2002). This CD provides information on 38 biotechnical soil stabilization techniques and drawings for 39 soil bioengineering techniques in an AutoCad format. All of the techniques have been implemented and photos documenting the before and after conditions of the sites are included. Additionally a directory of erosion control product manufacturer websites can be found on the CD.

Northern Studies

Specific information relating to projects in Alaska and other northern climates was difficult to find, though some was available. Papers and reports describing general design conditions and results for projects in Fairbanks, Anchorage, and along the Kenai River were reported. Some design and performance information for a project within Denali National Park was reported. However, information which related northern climatic conditions such as permafrost, aufeis, or ice flow bank damage to bioengineered structure performance, was difficult to find in the literature.

Ice damage to riprap has been described in a number of publications. The forces of moving ice are assumed to be the same for both riprap and bioengineered structures. Moving surface ice can cause crushing and bending forces, large impact loadings, and excessive shearing forces from tangential contact (Brown and Clyde, 1989). Though detailed quantitative analyses were not performed, observers in New England noted that riprap sized to resist design flows were successful in resisting ice forces (Brown and Clyde, 1989).

Butera and Billman (1998) described the need, design, and construction of stream bank erosion control projects in Anchorage, Alaska, using bioengineering techniques. The paper emphasizes the need to understand basin hydraulics and hydrology before attempting a design, but does not describe any characteristics of the project watersheds that are directly related to Alaskan conditions. Similarly, Tose et al. (1998) described four bioengineering treatments constructed on the Chena River in Fairbanks, Alaska to alleviate bank erosion from boat wakes, but did not describe site specific conditions unique to Alaska or northern climates.

Muhlberg and Moore (1998) presented several soil bioengineering techniques that have been used successfully in Alaska. This guide is meant to assist the process of selecting techniques for a streambank stabilization project. However, detailed design information or technical criteria for selecting techniques is not presented. A section describes the selection of the appropriate plant species for use in soil bioengineering projects by region.

An annotated bibliography of literature published prior to 1981 comprises over 500 bibliographic citations relating to erosion control principles and practices (Slaughter and Aldrich, 1989). The bibliography includes a short section of references specific to Alaska, the Arctic and subarctic, and similar high-latitude settings. The editors noted that available knowledge concerning erosion control may be generally applied to high-latitude conditions, though they also noted that more research is needed to investigate the influence of human activities on the thermal and physical stability of permafrost-dominated terrain.

A best management practices manual, written to guide the design and construction of Alaska Power Authority projects, described ‘state-of-the-art’ techniques for bank stabilization using vegetation (APA, 1985). The manual discussed the use of vegetative bank stabilization for small streams and low gradient streams, and mentioned that mechanical techniques, such as revetments and gabions, may be used to supplement vegetation in streams with higher flows or poor soil conditions.

The Corps of Engineers, in describing a project to prevent bank erosion on the Talkeetna River, proposed a grass cover on a section of riverbank graded to a slope of one vertical to three horizontal (Corps of Engineers, 1974). The graded and seeded bank was designed to withstand flow velocities up to 5 feet per second during overtopping, though no references were given for that performance standard.

Factor Of Safety/Risk Assessment

Several papers included in the review discuss the uncertainty in hydrology and hydrologic-based design, and the risks that engineers face when designing stream restoration projects. Schwar and Bernard (1998) described two risks that engineers face when designing stream restoration projects: structural failure and restoration failure. They also discuss the appropriateness of risk assessment; the group discussion panel stated that risk should not be tied to flood recurrence intervals, as that implies a level of assurance which does not exist. McCuen (2001) discussed the uncertainty in hydrology and hydrologic-based design, and described the bias for overestimation of discharge rates because of such uncertainty. He argued that comprehensive methods of risk assessment may not be appropriate or economical for small water resource projects, and suggested that factors of safety be developed for small projects that account for sources of hydrologic uncertainty.

Johnson and Brown (2001) described sources of uncertainty when assessing the risk of failure of stream channel modification and restoration. The authors presented the FMEA (Failure Modes and Effects Analysis) method for incorporating uncertainty during the design phase of a channel rehabilitation project. The FMEA model considers risk in term of likelihood of a failure, the consequences of failure, and the level of difficulty required to detect failure (Johnson and Brown, 2001).

APPENDIX B-DATA COLLECTION AND ANALYSIS METHODS

Data Collection

Fieldwork was conducted throughout the 2002 summer; each site was visited three to five times. The fieldwork conducted at each site includes the following:

- survey of longitudinal profile
- survey of cross-sections upstream, through, and downstream of the bioengineered structure (average 10 cross-sections per site)
- two water discharge measurements at each site, or use of operating USGS gage data
- water surface elevation data for each discharge measurement
- near-bank velocity profile at bioengineered structure
- channel material gradation, using pebble count
- elevation survey of typical structure composition at each site
- river morphology information
- photographs
- high water indicators, where available

All profile surveys and cross-section surveys were conducted using a Pentax PTS V3 three-second total station. Most sites were wadable, and cross-sections were surveyed by shooting to a wader carrying a reflecting prism. The Chena River and both Kenai River sites were not wadable, due to deep water. In those three cases, cross-section endpoints, from the edge of water to the floodplain, were surveyed using typical methods described above. In-channel measurements were made by boat, using a sonar depth finder (Garmin Fishfinder 100), calibrated to <0.1 ft to determine depth, and an electronic range finder (Bushnell Yardage Pro) to determine stationing from the left bank. All discharge and velocity measurements were made using a Price AA current meter.

A generally dry summer resulted in lower stage levels for most velocity profile measurements. However, velocity profile measurements were made during high water for the Chena River and Kenai River sites.

To characterize the composition of the stream bed, a Wolman pebble count was conducted at each study site (Wolman, 1954). Bed particles were randomly selected via a step-toe procedure, and the intermediate axis (neither the longest nor shortest of the three mutually perpendicular sides of each particle picked up) was measured and recorded. One hundred particles were measured per count. Pebble counts were conducted between the bankfull limits of the channel, unless the section was not wadable. Counts were conducted between the downstream and upstream limits of the BECS. The sampler began at the downstream end of the BECS, and worked his way upstream in a zigzag fashion while continuing to sample. Efforts were made to avoid sampling material which may have been used as fill in the BECS construction and spilled out. The particles are tallied and reported by using Wentworth size classes in which the size doubles with each class (2, 4, 8, 16, 32, etc.).

In response to the October flooding in the Kenai Peninsula, additional field activities were conducted at the flooded project sites during the first week in November 2002. Field surveys were conducted to extend the existing cross-sections to the high water indicators from the flood, so that estimates of flood magnitude and other hydraulic parameters could be made. At two sites, other surveys were conducted to help establish the cause and extent of damage incurred as a result of the flood. In addition to the project sites, workers analyzed conditions at several other BECSs which were subjected to flood flows. At most sites, an inspection of the structure was made to determine if any damage had occurred; velocity measurements were made, if appropriate, and photographs were taken. At one site, more extensive measurements, typical of those used for the original project BECSs, were made.

Vegetation Analysis

An important component of the assessment of BECSs is an analysis of the vegetation used as the key component of a bioengineered structure. Considerable effort was made to determine the most effective method for evaluating the vegetation at the study sites. Discussions with numerous plant ecologists were held before field work began. The consensus was that, to determine the level of protection and stability that vegetation is providing to a streambank, sites should be inspected for plant health, plant cover, and signs of potential failure. As there are no standards to indicate how many live stems are needed for a properly functioning project, measurements of willow stem density were not made.

Each site was visited from late July through August, 2002. Qualitative and limited quantitative observations were made. Plant species, vigor, overall plant height, diameter breast height and existing shoot growth were measured for each species. The diameter breast height was measured for shoots greater than six feet. The number of shoots measured varied depending upon the number of plants of each species present in the project. Twenty shoots were measured on the dominant species, Salix alaxensis. Fewer shoots were measured on the species that were less common. Percent cover was determined visually by looking at the amount of ground surface covered by leaves, branches, and stems of willow along the length of the project. In many cases, plant cover was relatively consistent. Variations in plant cover were combined to determine an overall plant cover. When large variations in plant cover occurred, they were described. Measurements of elevation differences between the willow layers or soil lifts and the water surface elevation were made for most sites. Attempts to identify ordinary high water were not made; rather, water surface elevations were noted in reference to the discharge at the time of the measurement. These measurements were made during typical summer low flows, which were all substantially less than bankfull flow.

Three soil samples were collected from four sites. Most of the projects used the brush layer technique which contains fabric wrapped soil layers. The soil within the wrapped soil layer could not be sampled without compromising the material holding the soil. As a result soil samples were collected immediately behind the top brush layer. This collection location provided the best opportunity to sample soil that may have been representative of the soil used throughout the project. At many of the sites it was not possible to collect soil because a vegetated mat had been placed adjacent to or on top of the top brush layer.

Approximately a quart of soil was removed for each soil sample. Leaf litter and moss was scraped from the soil surface and roots were removed. The samples were analyzed by the University of Alaska Plant and Soils Lab for nitrogen (N), phosphorous (P), potassium (K), organic matter (OM), acidity (pH) and particle size.

Shear Stress Analysis

Shear stress is defined as the frictional force per unit area which causes flow resistance along a channel boundary. An equal and opposite force caused by the shearing of water is exerted on bed and bank material, and is often referred to as tractive force. Average shear stress is expressed as:

$$t_O bed = gDS$$

where *D* is depth, *S* is energy gradient, and ? is the unit weight of water. A more general shear stress equation represents the average value of the tractive force per unit wetted area, and is represented by:

$$t_O bed = gRS$$

where *R* is the hydraulic radius. Note that the fluid stress acting on the bed is expressed as a function of the product of water depth and energy grade line, and not mean velocity. However, velocity is partly dependent on depth and slope, and as such is correlated with applied shear stress (Leopold et al, 1964).

As the applied stress is increased, a point is reached where grains of bed material begin to move. This is commonly referred to as critical stress or critical tractive force (Leopold et al, 1964). The object of the study analysis is to estimate average shear stress in both the main channel and bank shear stress where the BECS is located, for varying discharge magnitudes. Critical shear stress is then calculated for each site, based on bed material and bank structure. If the average shear stress exceeds the critical shear stress, the potential exists for channel and bank toe erosion at the BECS site. Such bed and bank erosion is identified as a cause for failure for BECSs. For example, if the toe of a bank upon which a root wad structure or brush layering structure is constructed scours away, the structure has essentially lost its foundation, and will collapse. Similarly, if shear stress forces are large enough to remove the gravel material that is used to construct the fabric-encapsulated soil lifts, then the structure will likewise collapse.

Many investigators have studied the shear stress required to initiate particle motion. The Shields diagram for initial motion of particles is widely recognized. Leopold, Wolman, and Miller (1964) presented a threshold curve of initial motion where shear stress is plotted against grain size D, which is based on both laboratory and field data. Leopold warns that this figure should be used only as a first approximation, as individual river channels may not be similar to the conditions used to develop the curve (Leopold, 1994). Critical bed shear stress may also be determined from Lane (1955) for coarse noncohesive material:

$$t_C bed = 0.08 D_{75}$$

where D_{75} is the diameter in millimeters at which 75% of the bed particles are finer by size.

On a channel bank, the critical shear stress results not only from the water force which moves particles downstream, but from the gravity force moving particles down the bank slope. Critical bank shear stress is calculated using an estimated angle of repose f for coarse bank materials, and an estimated bank angle q (Graff, 1971). The ratio of critical shear stress of the bank to the bed is:

$$\frac{t_c bank}{t_c bed} = \cos q \sqrt{1 - \frac{\tan^2 q}{\tan^2 f}}$$

For this study, estimates of shear stress and critical shear stress were developed in the following manner. Estimates of the average bed shear stress at the BECS location were developed for each of the modeled design and flood flows using the HEC-RAS computer code and numerical models of each study site, constructed with channel geometry and related hydraulic data. Based on calibrated models, average channel shear stresses were estimated for the 2-year, 50-year flood, 100-year flood, and the largest flood during the project life. Average shear stresses were calculated using the hydraulic radius, rather than attempting to determine shear stress distributions across a channel without field measurements of velocity profiles in flood. Readers are referred to Graf (1971) and Simons and Senturk (1976) for additional explanation

Critical bed shear stress was calculated, using the Lane equation (Lane, 1955) and the D_{75} bed material size for each study site. The bank angles at each BECS were estimated from survey data. Angle of repose values for noncohesive material were obtained from Lane (1955). The critical shear stresses for both bed and bank were developed as described above. Table 10 shows the computed average and critical shear stresses for all study sites. Also found in Table 10 are ratios of average to critical shear stress for each of the design flows for bed and bank shear stresses. A ratio of 1 or less indicates a stable channel geometry; a ratio of greater than 1 indicates the potential for either bed or bank erosion from shear stress during high water events.

Note that the shear stress analysis is not intended to provide an absolute prediction of stability or erosion. Nor is it intended as a design tool. It is used as an analytical method to assist with the examination of channel conditions, and is based on established shear stress and sediment transport science.

Estimations of Flood Magnitude

Discharge magnitudes used for modeling and analysis purposes include the 2-year flood (Q_2), the 50-year flood (Q_{50}), the 100-year flood (Q_{100}), and the largest flood occurring on the study reach since construction of the BECS. Magnitudes for the largest project flood were obtained either through USGS gaging records if available, or through analysis of high water mark field indicators at the BECS site. Estimations for the extreme October floods on Anchor River and Deep Creek were made by applying the extended cross-sections surveyed after the flood to the HEC-RAS computer model. Modeled discharges were increased until model results matched observed water surface elevations. Limited time and budget prevented a thorough analysis of flood magnitudes; the USGS Water Resource Division in Anchorage is currently conducting a study of flooding conditions on Anchor River and Deep Creek, and estimates of flood magnitudes are due to be completed in summer 2003 (David Meyer, USGS hydrologist, oral commun., 2003). However, discharge calculations made for this study are sufficient to provide reasonable estimations of shear stress and velocity.

For sites with a sufficient stream-gaging record (Chena River, Kenai River, Willow Creek), regional regression flood estimates were used to estimate the flood magnitudes (Jones and Fahl, 1994). For ungaged sites, the 2-year, 50-year, and 100-year floods were computed by using regional regression equations, which required drainage basin characteristics as described by Jones and Fahl (1994). Statistically significant basin characteristics that vary by region throughout the State include basin area size, mean basin elevation, mean annual precipitation, mean minimum January temperature, and percentage of basin covered by forest or covered by lakes and ponds. Estimations for flood magnitudes for all sites are found in Table 5.

Table 5 also contains the estimated discharge of the largest flood to occur at the site since construction of the BECS (Q_{flood}). Estimates were obtained from USGS gaging records or from analysis of field indicators.

Table 5. Estimated flood magnitudes for study sites.

Project Site	**Q_2**	**Q_5**	**Q10**	**Q25**	**Q50**	**Q100**	**Q_{flood}**
Anchor River	2310	3610	4720	6480	8170	10000	13000
Campbell Creek	400	610	760	950	1090	1230	-
Chena River*	9270	-	-	-	-	-	8870
Deep Creek	491	718	900	1100	1266	1429	9600
Kenai River at Riddle	19400	24500	28300	32900	36300	40000	27600
Kenai River at Centennial	19400	24500	28300	32900	36300	40000	27600
Ship Creek	850	1140	1370	1660	1900	2150	826
Theodore River	940	1340	1640	2040	2340	2650	2020
Willow Creek at Lapham	1610	2280	2780	3320	3740	4150	1521
Willow Creek at Pioneer	2100	2970	3590	4280	4800	5300	1950

*Regulated stream. Maximum discharge through downtown Fairbanks from upstream escapement is 12,000 cfs.

APPENDIX C-STUDY SITES

The selection of sites appropriate for this study was accomplished with the input and assistance from the project Technical Advisory Committee (TAC). The TAC originally selected ten sites for inclusion in the fieldwork portion of this study. An eleventh site was added after flooding in October 2002.

Numerous bioengineered erosion control structures have been constructed in projects around Alaska, and many were considered for inclusion in this study. Several criteria were established to guide the selection process. One criterion for site selection was that the structure should be located in a high-energy reach (steep slope). Sites that have not performed as expected had high priority, along with examples of sites which did perform well. Additionally, the TAC was interested in looking at a number of different erosion control techniques.

The priority list agreed upon by the TAC exceeded the total number of sites selected for inclusion in the study. In that manner, several alternate sites were available for study in the event that some 'priority sites' were found upon inspection to be not suitable for the purposes of this study. The original design drawings and/or plans for many of the sites were supplied by the engineering consultants and contractors involved in the projects. Additional design information was supplied by the Alaska Department of Natural Resources. The Alaska Department of Fish and Game, which was responsible for approving designs and issuing fish habitat permits for each of the study sites, supplied copies of the permits for a few of the sites; additional information on site conditions and construction methods may be available from that agency. A summary table is found on the next page (Table 6).

Table 6. Project site names and descriptions.

Site Name	Year Built	Length (feet)	Techniques Used †	Designed by	Constructed By	Aspect
Anchor River at Silverking Campground	1999	200	BL, STR, CL	AKDNR	Contractor	N10ºW
Anchor River at Steelhead Campground	2002	120	BL, RW, VM	ADF&G	Contractor	N35ºE
Campbell Creek at Taku Park	1995	120	RW, LSt	HDR, Inc.	Contractor	N49ºW at center
Chena River at Doyon Estates	1998	546	BL, RR	Resource agencies	Great Northwest, Inc.	S35ºE at center
Deep Creek	1994	350	BL, BM, LSi, RR, WF	AKDNR	Cook Inlet Construction	S32ºE at center
Kenai River at Centennial Park	1997	500	BL, CL, LSi, LSt, VM, RW	Wm J. Nelson and Asscts	Contractor	N35ºE
Kenai River at Riddle	1996	200	RW, BL	Wm J. Nelson and Assts	Foster Construction	S74ºE
Ship Creek	2000	425	RW, BL, VM	ADF&G	Moore's Landscaping	S40ºW
Theodore River	1994	55	RW	HDR, Inc.	Unocal	N51ºW
Willow Creek at Pioneer Lodge	2001	425	RW, BL	ADF&G	Contractor	N05ºE
Willow Creek at Lapham Property	2000	121	RW, BL	ADF&G	Contractor	S10ºE

†RW-root wads
BL-brush layering
VM-vegetative mat
RR-riprap toe
LSt-live staking
LSi-live siltation
CL-coir logs
STR-spruce tree revetment
WF-willow fascine
BM-brush matting

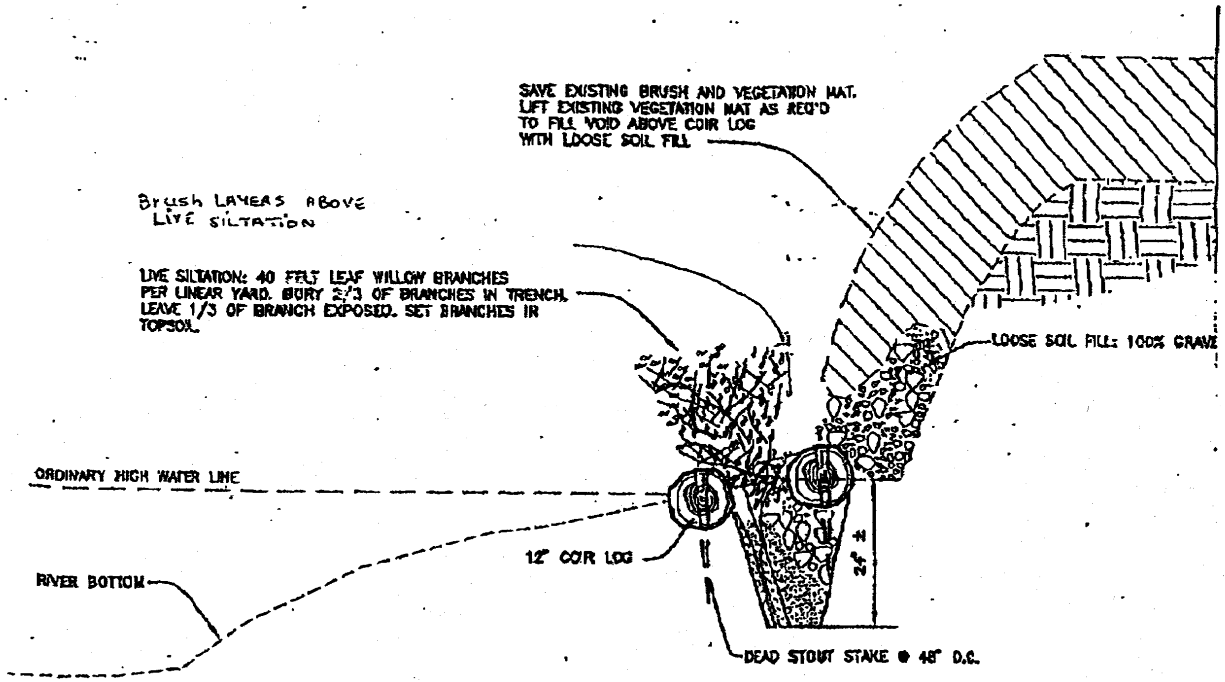
Anchor River at Silverking Campground

This project is located on the left bank of the Anchor River at the Silverking State Campground, just downstream from the bridge. The project was constructed in the fall of 1999. The project consists of two layers of coir logs with willow layers, and two fabric encapsulated soil lifts with coir fabric and willow layers. The design and bid documents called for a willow density in the brush layering of 12 cuttings per foot. Additionally, a 100-foot long section of spruce tree revetment (STR) was installed, beginning downstream of the brush layering installation. The STR protected the toe of a relatively undisturbed naturally vegetated section. Design documents call for the installation of a coir log/live siltation section; no evidence of this feature was found at the site during field inspections. Of note for this project was the collection and installation of willows in the autumn dormancy period.

This site was completely inundated by flooding conditions during fall 2002.

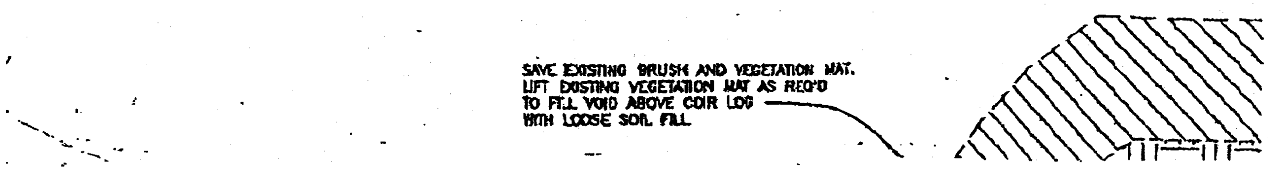
AKDNR and ADF&G were asked to provide copies of the design and bid document for this project. Design drawings appear to be missing from the supplied document; the only project design drawing provided is found on the following page, and shows the coir log/live siltation feature that was not observed at the site.

Figure 14. Anchor River at Silverking Campground, looking upstream (06/20/2003).



(B) **COIR LOG/ LIVE SILTATION**

NOT TO SCALE



Anchor River at Steelhead Campground

This site was located on the left bank of the Anchor River at the Steelhead State Campground, approximately 1800 feet downstream from the Anchor River-Silverking Campground site. This site was added to the project after the October 2002 flood event.

At Anchor River-Steelhead Campground, a base layer of root wads and two layers of willow brush layering structure were installed in July 2002. The upstream end of the structure abuts the end of a 15-year old gabion revetment at the mouth of an abandoned channel. The project was constructed in mid-summer of 2002. The design and bid documents called for a willow density in the brush layering of 25 cuttings per foot.

According to design documents, root wads were spaced at roughly 4.5 feet apart. Trunk lengths for the root wads were 10 feet in length, and root fan diameters were a minimum of 6 feet. The root wads were secured by rebar to a header log placed immediately behind the root fan. An additional note in the design documents specified that the upstream root wad shall abut the gabion revetment such that the fan overlaps the end of the gabion revetment by at least two feet.

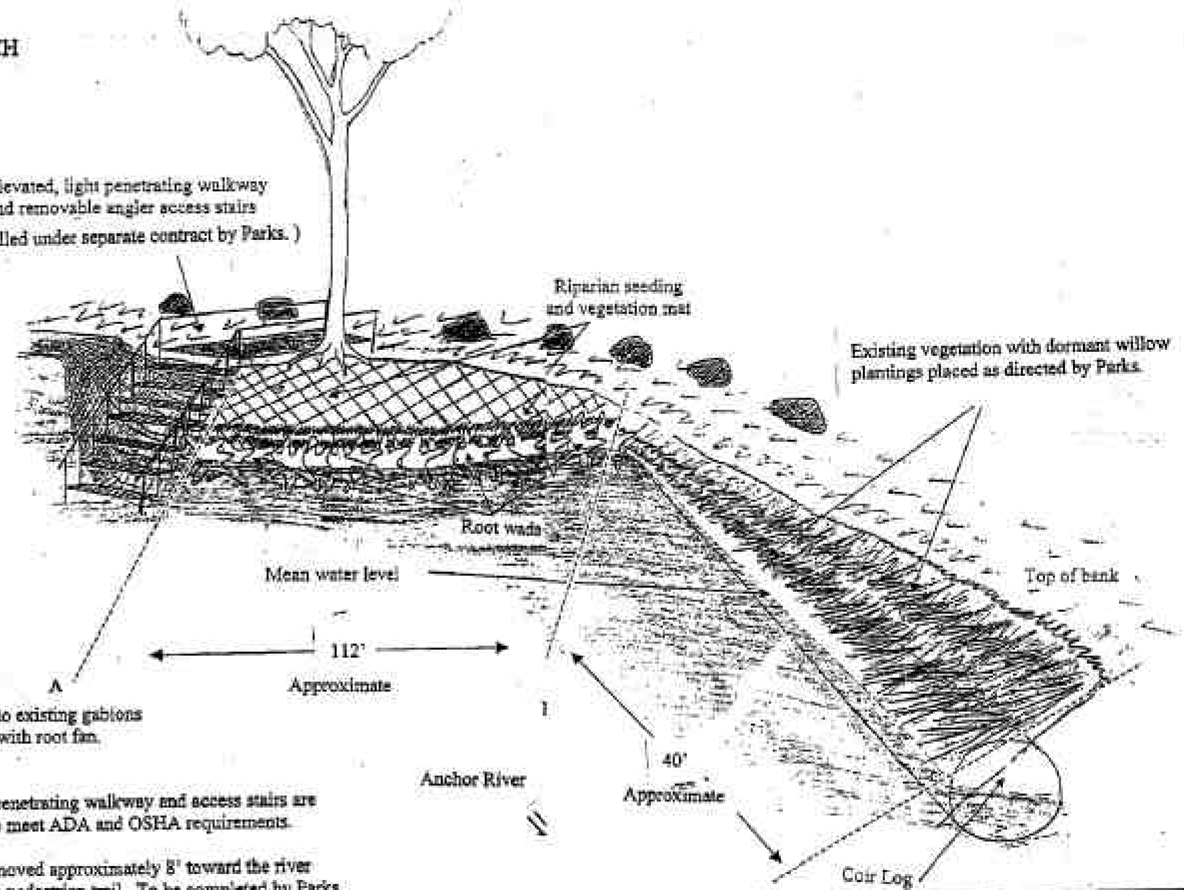
This site was completely inundated by flooding conditions during fall 2002.

The design drawings are found on the following pages.

Figure 15. Anchor River at Steelhead Campground, looking downstream (07/31/2003).

CONCEPTUAL SKETCH

Not to Scale



Notes: Abut root wads to existing gabions
By overlapping with root fan.

Elevated, light-penetrating walkway and access stairs are
to be installed to meet ADA and OSHA requirements.

Boulders to be moved approximately 8' toward the river
to accommodate pedestrian trail. To be completed by Parks.

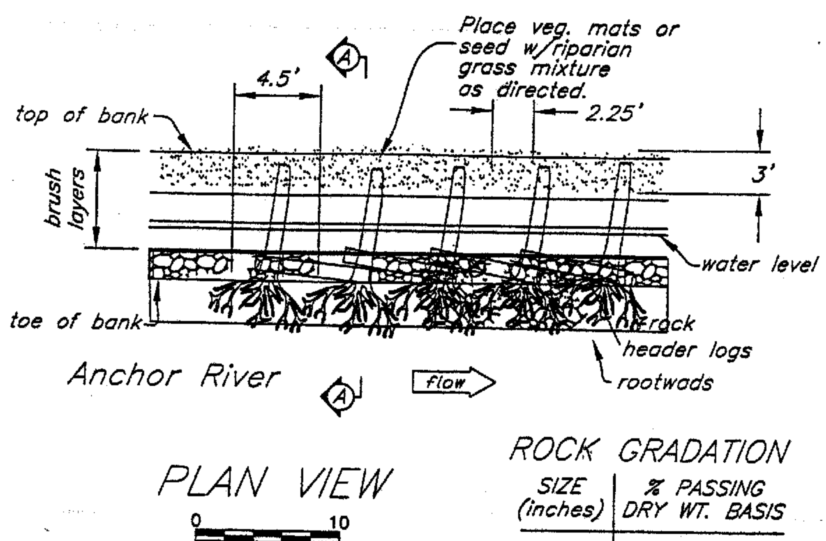
Elevation of root wad installation
to be staked in field.

WILDLIFE HABITAT INCENTIVES PROGRAM
ANCHOR RIVER STATE PARK
STREAMBANK STABILIZATION

U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE

Designed	GM / SMT	Date	8/99	Approved by	
Drawn	KLS		3/00	Title	
Traced				Sheet No. 3	Drawing No.
Checked	LWR		3/00	of 4	AK-40-00-001

SCS-ENG-312A REV 8-75

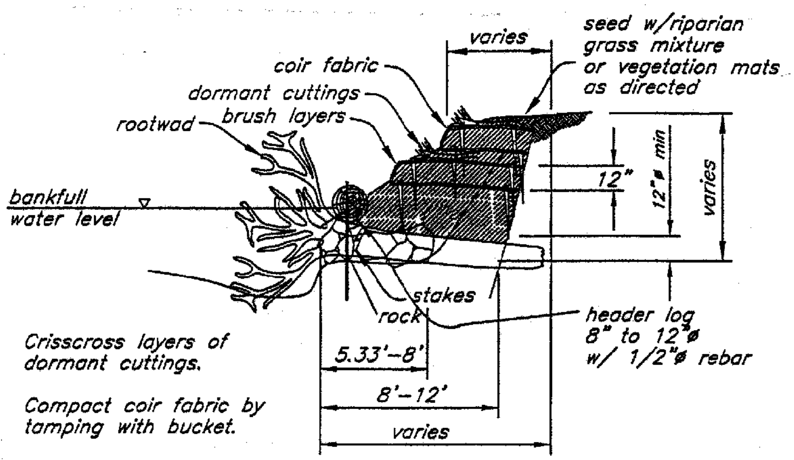


PLAN VIEW

Scale in feet (approximate)

ROCK GRADATION

SIZE (inches)	% PASSING DRY WT. BASIS
12	100
6	35–70
4	20–45
2	0–20



Crisscross layers of dormant cuttings.

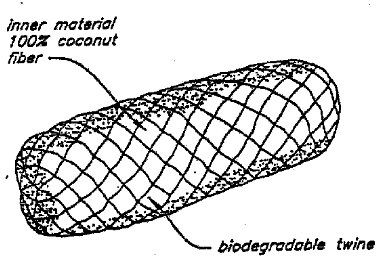
Compact coir fabric by tamping with bucket.

Backfill between rootwads w/rock as specified.

Slope trench for trunk of rootwad at 6H:1V.

SECTION A–A

0 5
SCALE IN FEET
(approximate)



COIR LOG DETAIL

WILDLIFE HABITAT INCENTIVES PROGRAM
ANCHOR RIVER STATE PARK
STREAMBANK STABILIZATION

U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE

Designed GM/SMT	Date 3/99	Approved by	
Drawn KLS/RWR	3/99	Title	
Traced		Sheet No. 4	Drawing No.
Checked TWK	3/00	of 4	AK-HD-00-46

SCS-ENG-313A REV 8-75

Campbell Creek near Taku Park

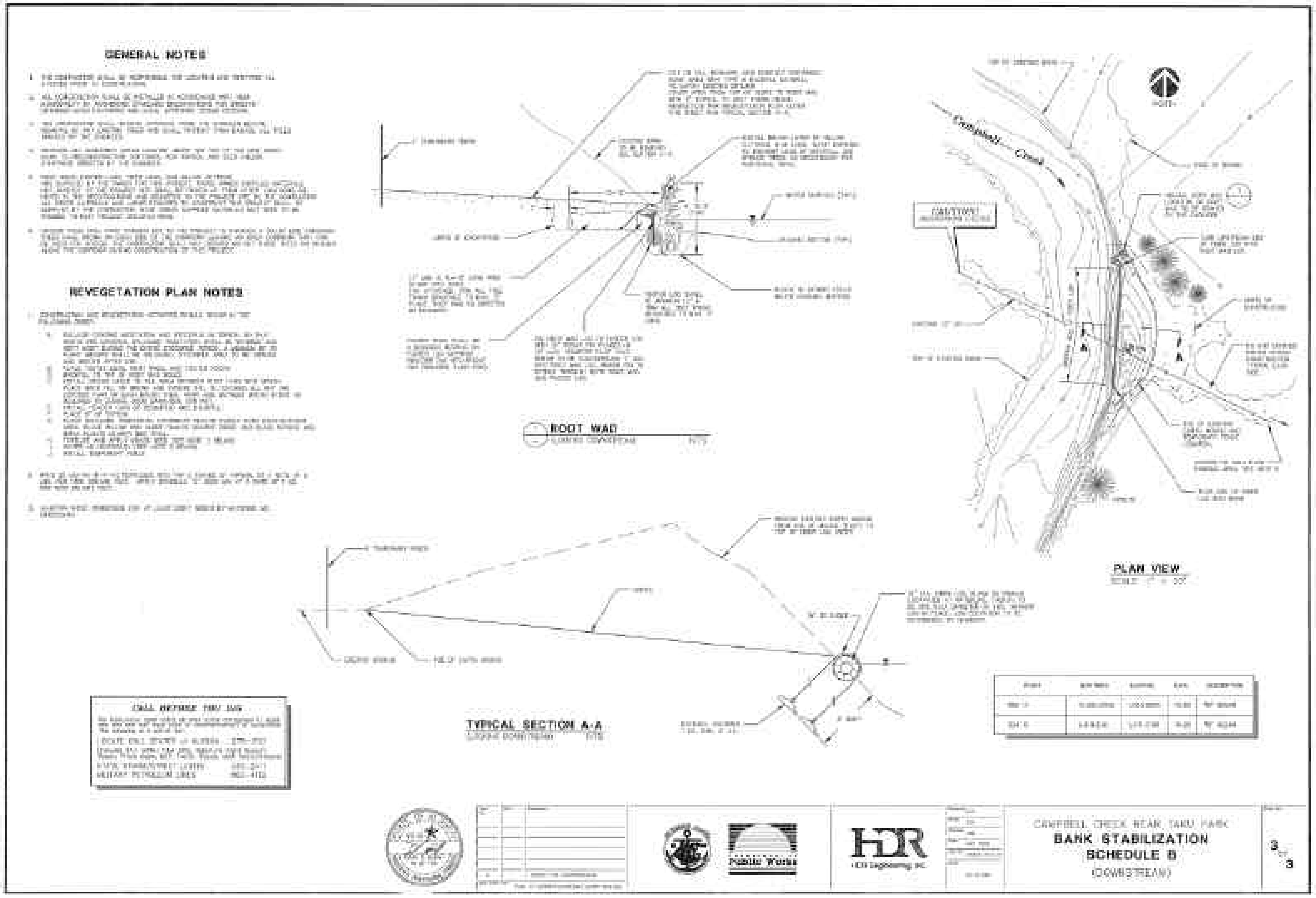
The original Campbell Creek site selected by the TAC was located at the Sourdough Mining Company. However, an ongoing major project involving the construction of an elevated bike path directly over the erosion control structure at the site would have resulted in data collection difficulties. Because of this, an alternative site at Campbell Creek near Taku Park was selected. This project was constructed using root wads, and was designed by HDR Engineering, Inc. It was installed in 1995. The project is located on the left bank, adjacent to a bike path, and receives a substantial amount of use from pedestrians, bike riders, and park visitors.

According to the design engineer, installation of this structure occurred according to the design documents, with some exceptions (Dan Billman, oral commun., 2002). The constructed elevation of root wads is 6" to 12" higher than the design called for. The reason for this is that the timing of the installation was restricted by permit. The permitted installation time period coincided with high water, which led to installation difficulties. The design was based on raw materials available at the time (root wads, footer logs, and boulders), which were collected and provided by ADF&G. The wood structure was bedded in a silty gravel mix. No fabric was used in the construction, and other than some live staking on the bank, no brush layering was used on the lower bank.

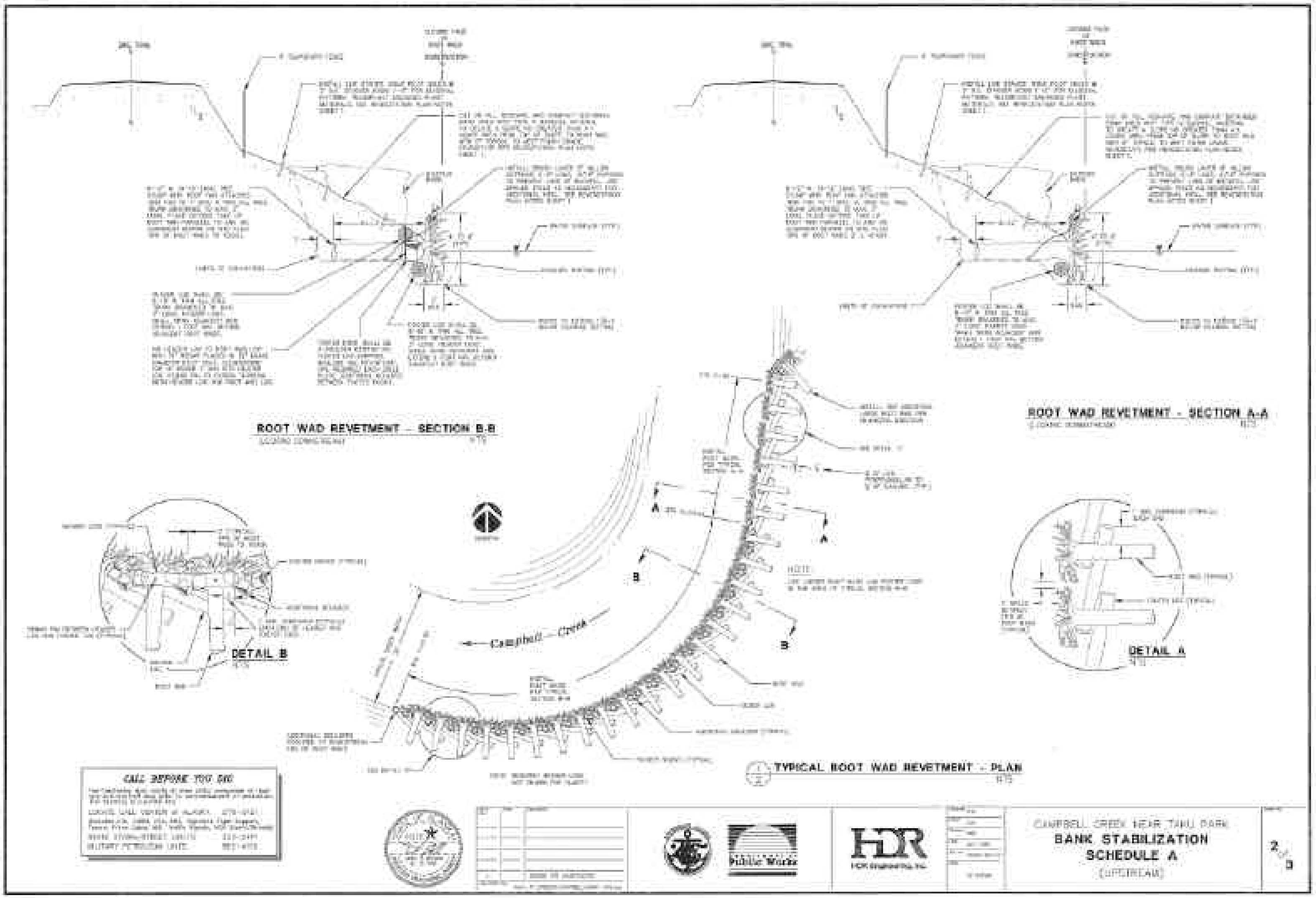
The design engineer also noted that the longitudinal extent of the BECS was an important design consideration, and noted that the beginning of the project extended upstream of the tangent to the bend at the bend entrance, and ended downstream of the tangent to the bend at the bend exit.

Additional construction information is found on the attached engineering design drawings.

Figure 16. Campbell Creek near Taku Park (07/13/2003).



GENERAL NOTES
REVEGETATION PLAN NOTES
ROOT WAD
TYPICAL SECTION A-A
PLAN VIEW
Campbell Creek
CAUTION!
CALL BEFORE YOU DIG
HDR
Public Works
CAMPBELL CREEK NEAR TAKU PARK
BANK STABILIZATION
SCHEDULE B
(DOWNSTREAM)

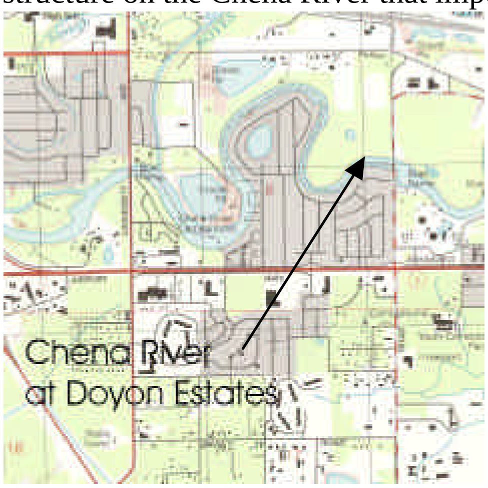


ROOT WAD REVETMENT - SECTION B-B
ROOT WAD REVETMENT - SECTION A-A
DETAIL B
DETAIL A
Campbell Creek
B
A
TYPICAL ROOT WAD REVETMENT - PLAN
CALL BEFORE YOU DIG
Public Works
HDR
CAMPBELL CREEK NEAR TAKU PARK
BANK STABILIZATION
SCHEDULE A
(UPSTREAM)

Chena River at Doyon Estates

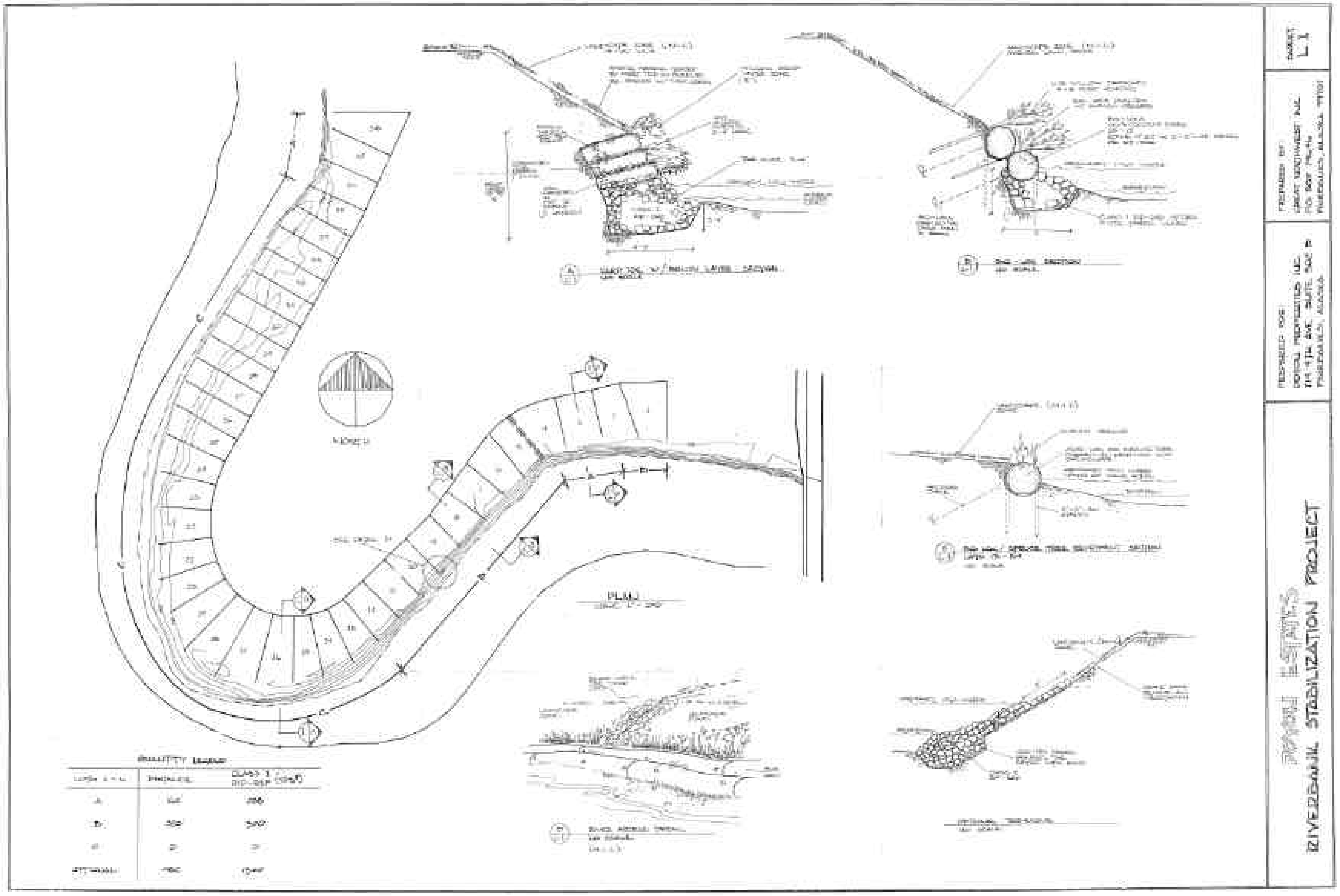
The Chena River site at Doyon Estates was selected for inclusion in the project because it represented the only good data collection site north of Southcentral Alaska. This site is located on private property along the right bank of the Chena River, just downstream from the Peger Road bridge. The erosion control structure was constructed using brush layering with soil wraps, with a Class 1 riprap foundation, and was installed in 1998. The brush layering consists of two fabric encapsulated soil lifts, which were each constructed with two fabric layers. An outer coir netting is coupled with a biodegradable inner burlap blanket to contain the soil/gravel fill. Live willow cuttings 3-4 feet in length were placed in between the two soil lifts, and at the top of the upper soil lift.

Flow in the Chena River is affected by regulation from the Chena River Lakes Flood Control Project, which was completed in 1980. The Moose Creek Dam is a flood-control structure on the Chena River that impounds water only during high flows in the Chena River. The dam was designed to reduce maximum flows to 12,000 cubic feet per second in downtown Fairbanks (Burrows et al., 2000). Though Chena River does not have a steep energy gradient through the project site, it does receive heavy boat traffic during the summer, resulting in severe wake erosive forces along the banks. Additionally, residents report that ice floes during spring breakup are also responsible for bank erosion.



Additional construction information is found on the attached design drawing.

Figure 17. Chena River at Doyon Estates (06/04/2003).


RIVERBANK STABILIZATION PROJECT
PLAN
L1

Deep Creek

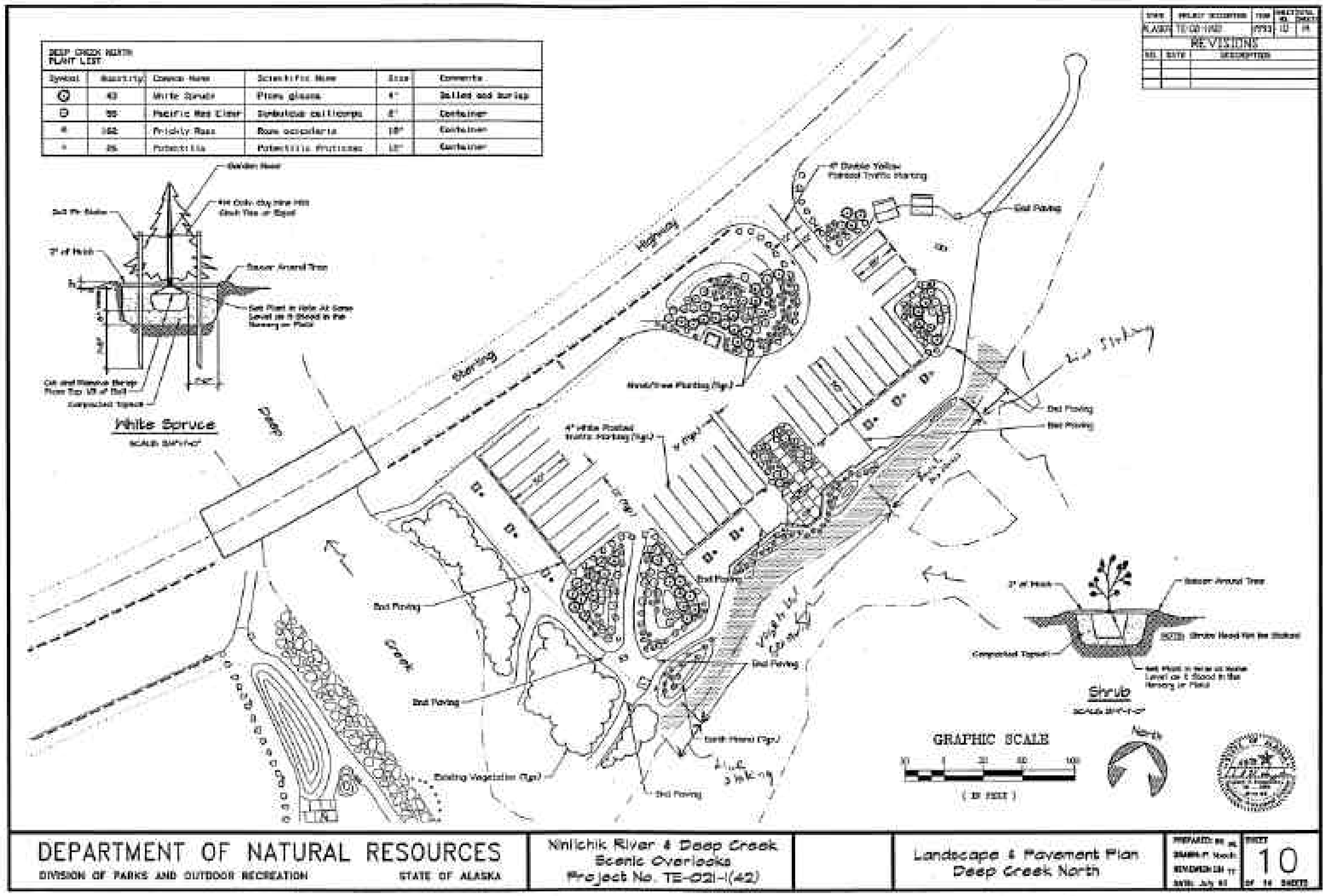
This site is located at the Deep Creek State Campground, adjacent to the Sterling Highway. Five soil bioengineering techniques were installed at Deep Creek for a multiple technique demonstration planting. ADF&G reports that the project used 225 feet each of live siltation, willow fascines and brush matting and brush layering. Design documents indicate that three 18 inch thick wrapped rock lifts were to be constructed as a base for the full length of the excavated project area. A layer of large diameter armor stone was used to protect the toe of the structure.

The brush layering soil wraps were constructed using a geosynthetic grid material, rather than a traditional coir fiber material. Geogrids are net-shaped synthetic polymer-coated fibers that are normally used to reinforce earth-fill slope, wall and base layer construction. Incorporated in the base layers of paved or finished surfaces, or in surface layers of walls and slopes, they provide a stabilizing force within the soil structure itself. Geogrid is not a filter material, and will not retain soil particles smaller than the open gridding spaces. A burlap fabric was used inside the geogrid at the front face to contain the fines; however, no evidence of the burlap fabric could be seen during field inspections, indicating that the fabric had decomposed entirely since construction.

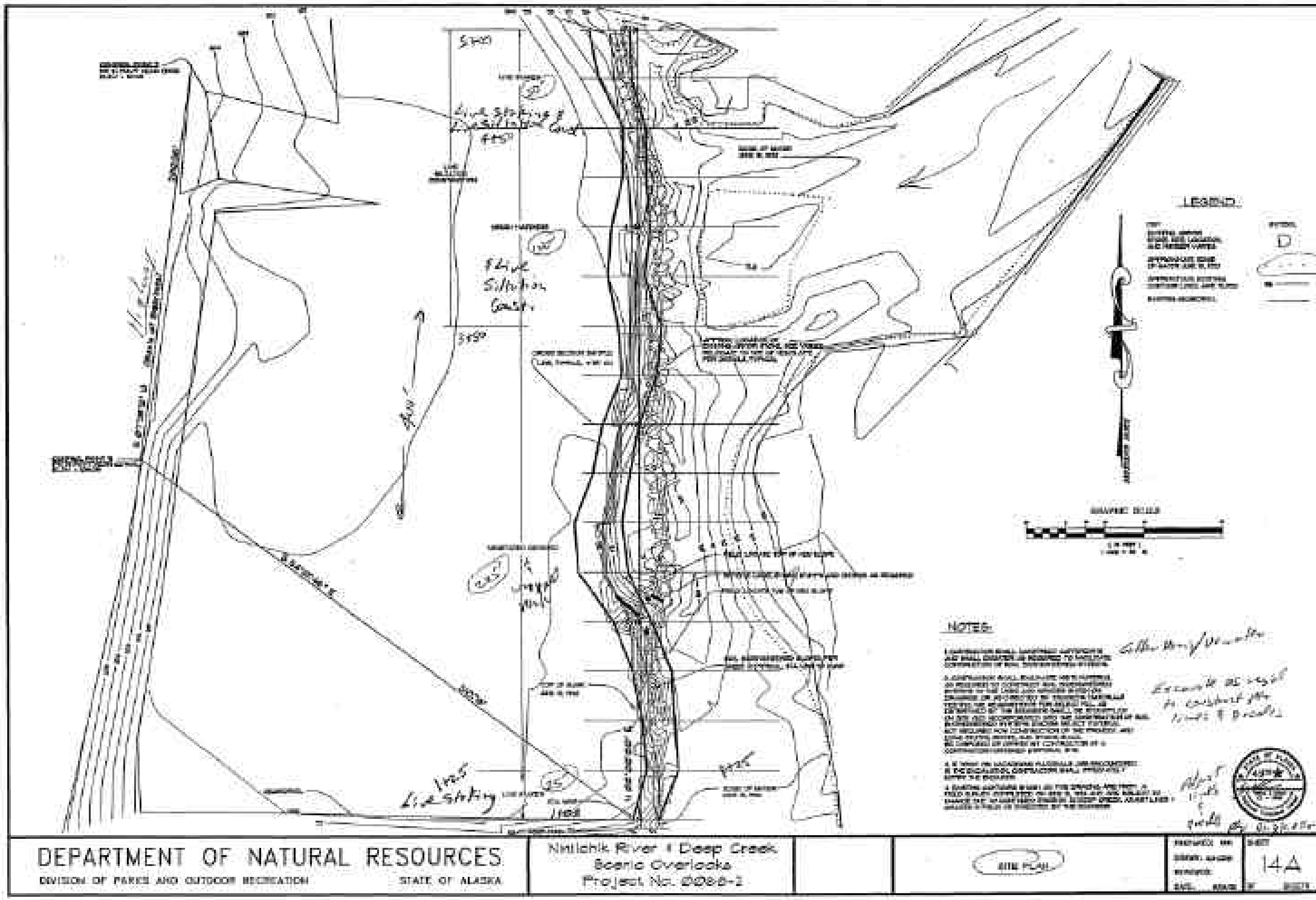
The BECS project was originally installed to provide protection for directly impinging flow from the main channel. Shortly after the project was finished, a large channel change occurred, and a previously minor channel became the new main channel. This changed the flow pattern from directly impinging on the BECS to parallel flow and a much smaller angle of impinging on the lower section.

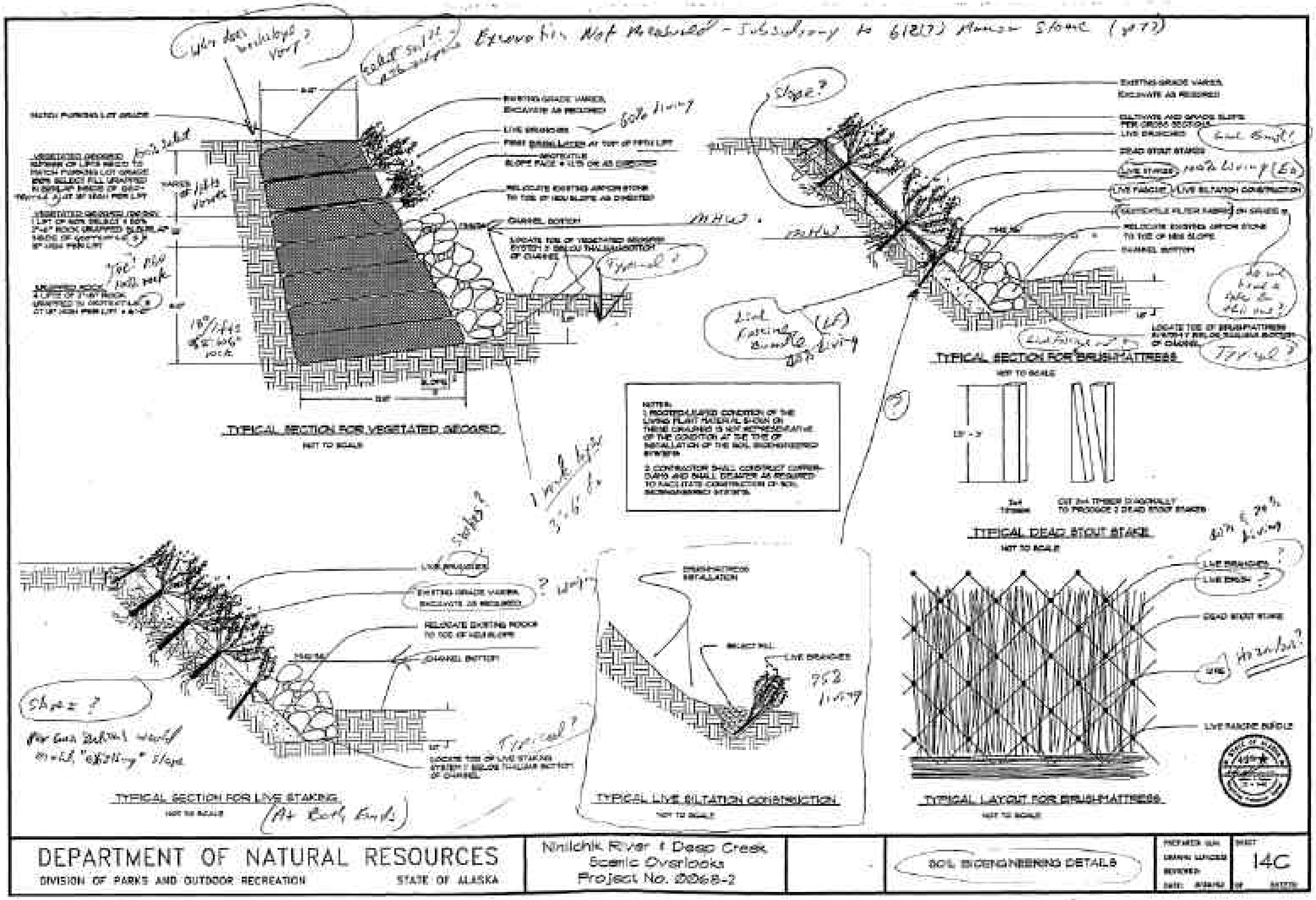
Additional construction information is found on the attached design drawings.

Figure 18. Deep Creek, looking upstream (06/23/2003).



DEEP CREEK NORTH
PLANT LIST
Symbol
Common Name
Scientific Name
Size
Comments
White Spruce
Pacific Red Elder
Prickly Rose
Potentilla
Potentilla fruticosa
Balled and burlap
Container
White Spruce
Highway
Sterling
Deep
Creek
End Paving
Existing Vegetation (Typ.)
Shrub
GRAPHIC SCALE
(IN FEET)
North
REVISIONS
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF PARKS AND OUTDOOR RECREATION
STATE OF ALASKA
Ninilchik River & Deep Creek
Scenic Overlooks
Project No. TE-021-1(42)
Landscape & Pavement Plan
Deep Creek North
10


LEGEND
NOTES:
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF PARKS AND OUTDOOR RECREATION
STATE OF ALASKA
Ninilchik River & Deep Creek
Scenic Overlooks
Project No. 0088-2
SITE PLAN
14A

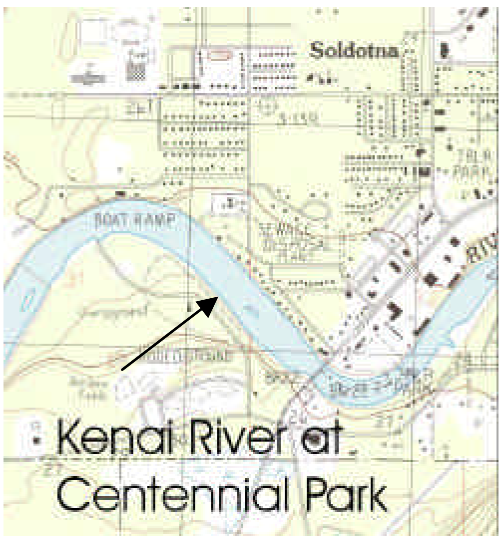

TYPICAL SECTION FOR VEGETATED GEOGRID
NOT TO SCALE
TYPICAL SECTION FOR BRUSHMATTRESS
NOT TO SCALE
TYPICAL DEAD STOUT STAKE
NOT TO SCALE
TYPICAL SECTION FOR LIVE STAKING
NOT TO SCALE
TYPICAL LIVE SILTATION CONSTRUCTION
NOT TO SCALE
TYPICAL LAYOUT FOR BRUSHMATTRESS
NOT TO SCALE
LIVE BRANCHES
DEAD STOUT STAKE
CHANNEL BOTTOM
LIVE FASCINE BUNDLE
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF PARKS AND OUTDOOR RECREATION
STATE OF ALASKA
Ninilchik River & Deep Creek
Scenic Overlooks
Project No. 0068-2
SOIL BIOENGINEERING DETAILS
14C

Kenai River at Centennial Park

The project was designed by William J. Nelson and Associates in Kenai, Alaska, and was constructed in 1997. This site was included in the study because of the large discharges which occur every summer in the glacially fed river, and the large ice floes which also cause substantial bank erosion on the Kenai. Design drawings show a total project length of 600 feet, though workers could only identify a 500 foot length during field inspections.

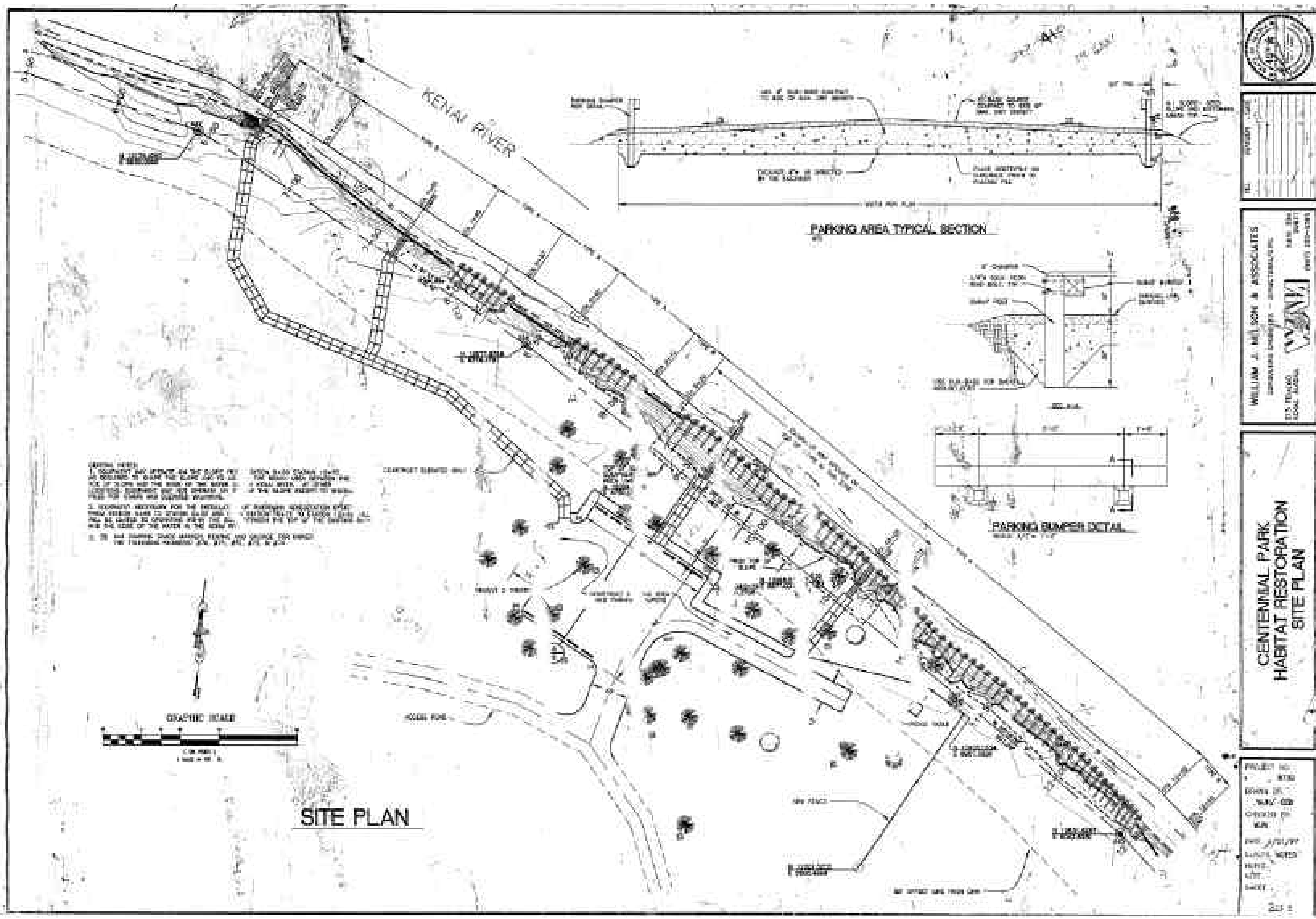
The project was constructed using root wads, coir logs, brush layering, live siltation, and live willow staking. Design documents show the root wads trunks to be 8 feet long, 12 inches in diameter, and a root fan diameter of 5 to 12 feet. Root wads were spaced every 5 feet. Root wad centers were to be installed at an elevation of ordinary high water. Fill rock of between 3 to 6 inches was used to fill in voids between the root wads. Header or footer logs were not noted on the design drawings or during project inspections.

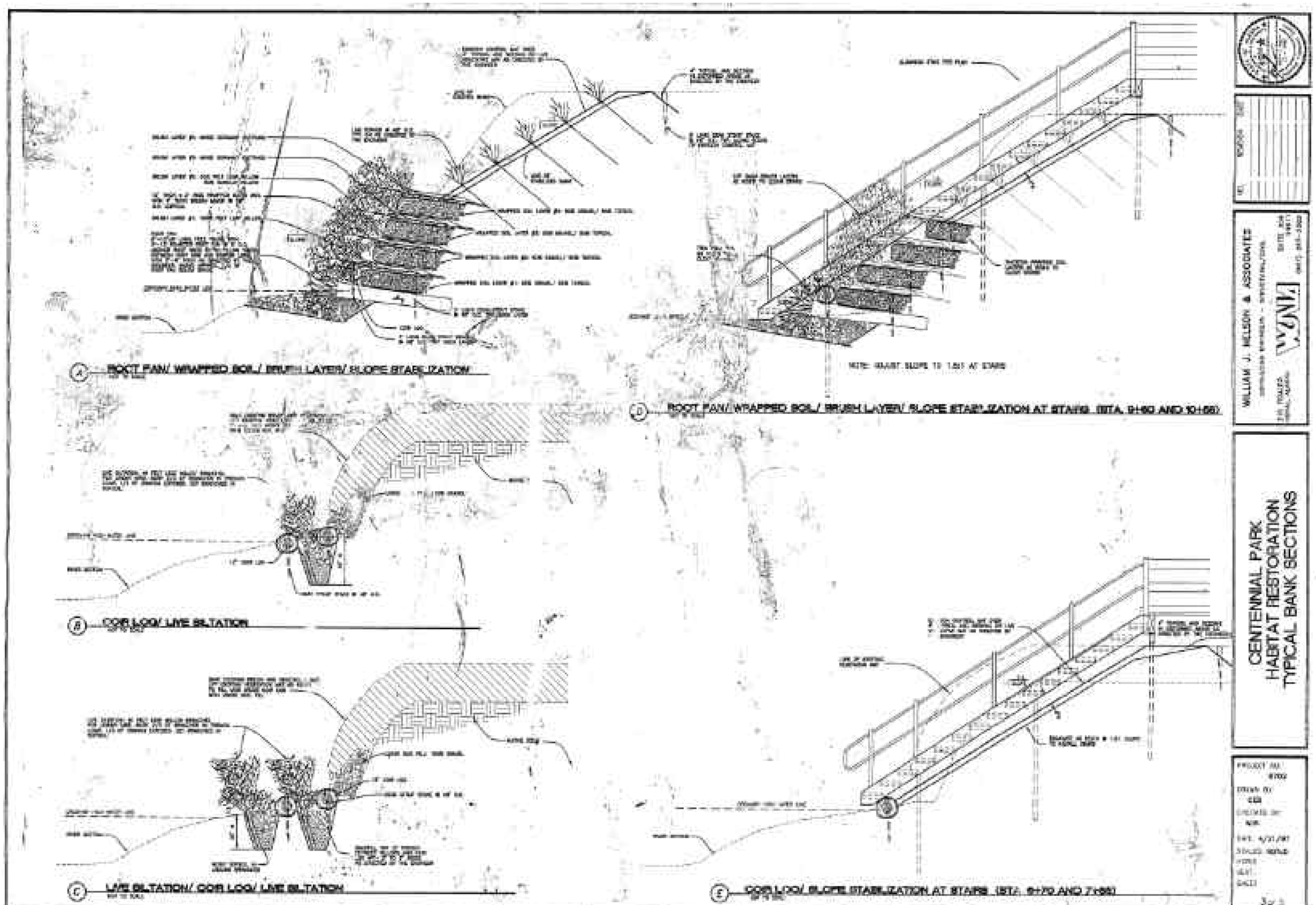
Though four fabric-encapsulated soil lifts layered with willow were shown on the design document, only two or three were observed. The lifts were constructed using a wrap mat, made of woven coir fiber twine, and an inner liner mat, made of biodegradable natural coconut coir fiber. Live cut willow stalks, at least 4 feet long, were placed on top of the soil lifts; the design documents specified a density of 25 branches per linear yard.



Live siltation was also used on this project. Coir logs were used in conjunction with live siltation plantings, which were planted near the ordinary high water elevation. Additional construction information is found on the attached design drawings.

Figure 19. Kenai River at Centennial Park (08/18/2003)


KENAI RIVER
PARKING AREA TYPICAL SECTION
PARKING BUMPER DETAIL
GRAPHIC SCALE
SITE PLAN
WILLIAM J. NELSON & ASSOCIATES
CENTENNIAL PARK
HABITAT RESTORATION
SITE PLAN

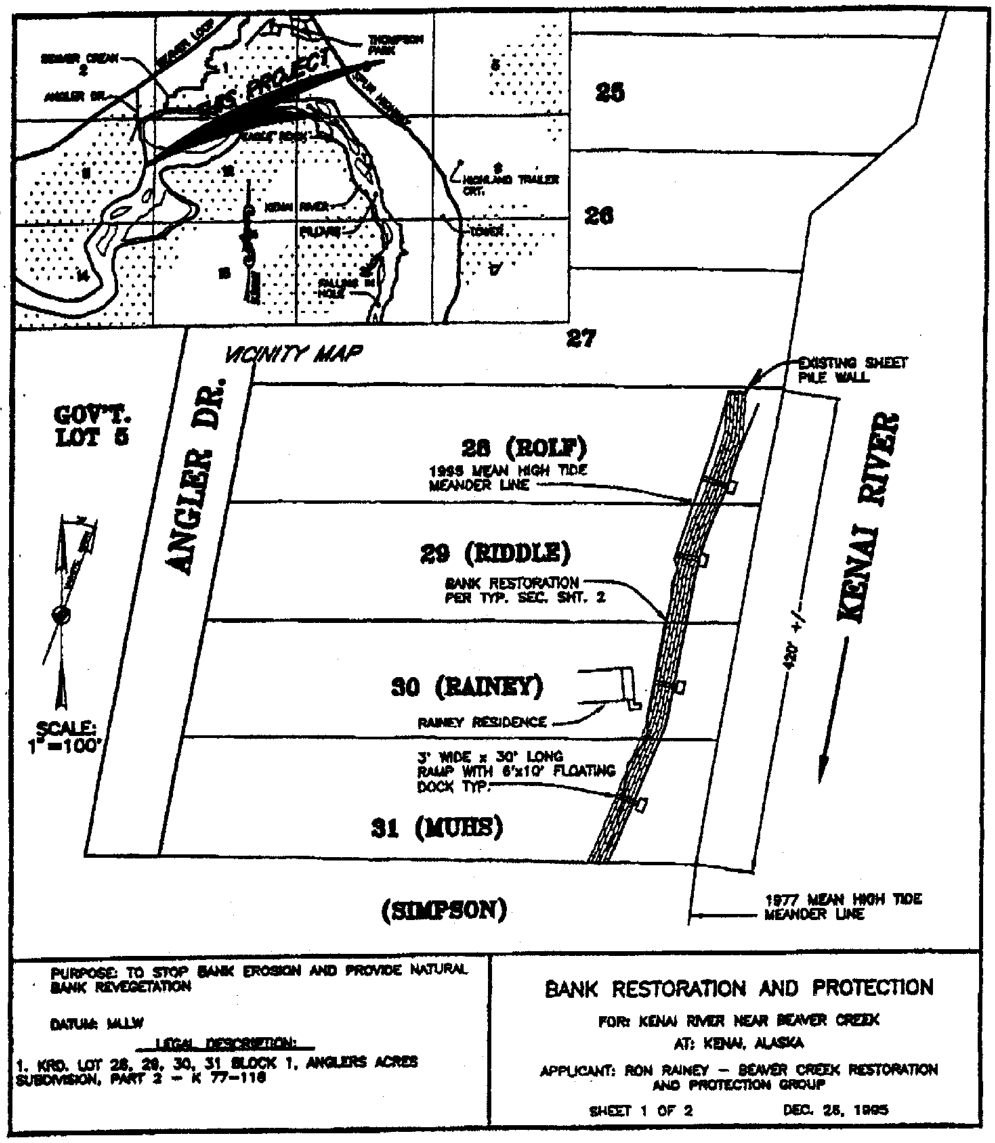

ROOT FAN/ WRAPPED SOIL/ BRUSH LAYER/ SLOPE STABILIZATION
ROOT FAN/ WRAPPED SOIL/ BRUSH LAYER/ SLOPE STABILIZATION AT STAIRS
COIR LOG/ LIVE SILTATION
LIVE SILTATION/ COIR LOG/ LIVE SILTATION
COIR LOG/ SLOPE STABILIZATION AT STAIRS
WILLIAM J. NELSON & ASSOCIATES
CENTENNIAL PARK
HABITAT RESTORATION
TYPICAL BANK SECTIONS

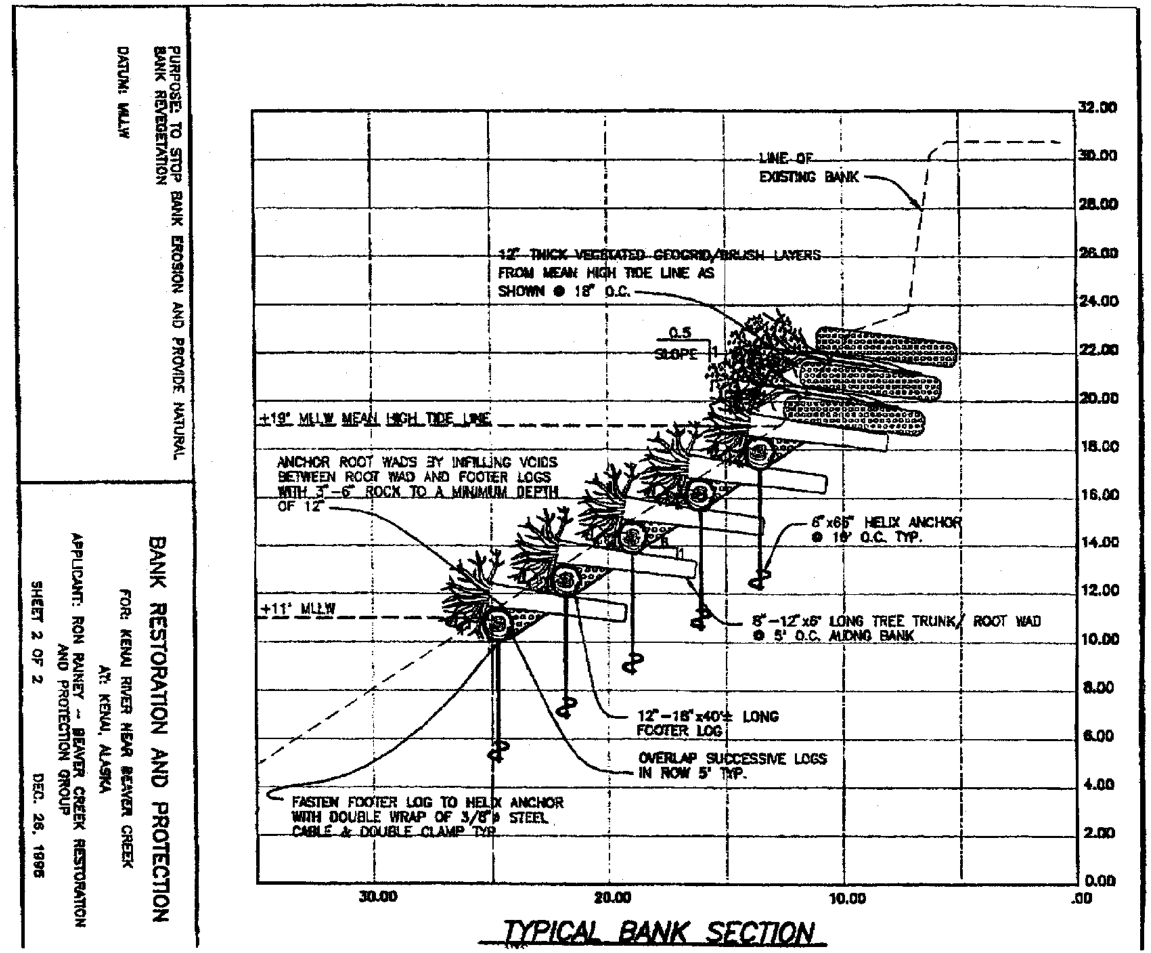
Kenai River at Riddles Property

This site was constructed in 1996, and is within the inter-tidal zone of the Kenai River. This results in the site being subjected to high velocities and erosive forces in two directions twice a day, in addition to boat wakes. The site was constructed on several adjacent private properties, using root wads, brush layering, live staking, and cabled spruce trees. The site is located on the right bank, on the lower end of a large sweeping left hand turn, just downstream from the confluence with Beaver Creek.

Five rows of root wads were used for the base of the structure. Root wad trunks were 6 feet long, and spaced 5 feet on center. Footer logs were used beneath each row of root wads, and were anchored to the bank using helix anchors. The lowest footer log was placed at an elevation of mean low low water, and the center of the top root wad was placed at an elevation of mean high tide line. Fabric encapsulated soil lifts 12" thick, layered with willow branches, were used above the root wads to protect the bank. A timber crib wall extended from the brush layering to the top of the bank. Some of the willows in the brush layering are pruned during the summer months to enhance visibility. Cabled spruce tree revetments were also installed along the root wads. Additional construction information is found on the attached design drawings.

Figure 20. Kenai River at Riddles property (06/22/2003).


25
26
27
VICINITY MAP
GOV'T. LOT 5
ANGLER DR.
28 (ROLF)
1995 MEAN HIGH TIDE MEANDER LINE
29 (RIDDLE)
BANK RESTORATION PER TYP. SEC. SHT. 2
30 (RAINEY)
RAINEY RESIDENCE
3' WIDE x 30' LONG RAMP WITH 6'x10' FLOATING DOCK TYP.
31 (MUHS)
(SIMPSON)
EXISTING SHEET PILE WALL
KENAI RIVER
420' +/-
1977 MEAN HIGH TIDE MEANDER LINE
SCALE: 1"=100'
PURPOSE: TO STOP BANK EROSION AND PROVIDE NATURAL BANK REVEGETATION
DATUM: MLLW
LEGAL DESCRIPTION:
1. KRD. LOT 28, 29, 30, 31 BLOCK 1, ANGLERS ACRES SUBDIVISION, PART 2 – K 77-116
BANK RESTORATION AND PROTECTION
FOR: KENAI RIVER NEAR BEAVER CREEK
AT: KENAI, ALASKA
APPLICANT: RON RAINEY – BEAVER CREEK RESTORATION AND PROTECTION GROUP
SHEET 1 OF 2
DEC. 26, 1995



PURPOSE: TO STOP BANK EROSION AND PROVIDE NATURAL BANK REVEGETATION
DATUM: MLLW
BANK RESTORATION AND PROTECTION
FOR: KENAI RIVER NEAR BEAVER CREEK
AT: KENAI, ALASKA
APPLICANT: RON RAINEY - BEAVER CREEK RESTORATION AND PROTECTION GROUP
SHEET 2 OF 2
DEC. 26, 1996
LINE OF EXISTING BANK
12" THICK VEGETATED GEOGRID/BRUSH LAYERS FROM MEAN HIGH TIDE LINE AS SHOWN @ 18" O.C.
0.5
SLOPE
1
±19' MLLW MEAN HIGH TIDE LINE
ANCHOR ROOT WADS BY INFILLING VOIDS BETWEEN ROOT WAD AND FOOTER LOGS WITH 3"-6" ROCK TO A MINIMUM DEPTH OF 12"
8"x66" HELIX ANCHOR @ 10' O.C. TYP.
+11' MLLW
8"-12"x6' LONG TREE TRUNK/ ROOT WAD @ 5' O.C. ALONG BANK
12"-18"x40'± LONG FOOTER LOG
OVERLAP SUCCESSIVE LOGS IN ROW 5' TYP.
FASTEN FOOTER LOG TO HELIX ANCHOR WITH DOUBLE WRAP OF 3/8"ϕ STEEL CABLE & DOUBLE CLAMP TYP.
32.00
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
30.00
20.00
10.00
.00
TYPICAL BANK SECTION

Ship Creek

This site is located on the Fort Richardson Army Post in Anchorage, just downstream from the Glenn Highway bridge. A riprap project was originally constructed on this site to arrest bank erosion, and was eventually removed as part of this project, and replaced by the existing structure. In an unrelated project, a short adjoining section was constructed using a coir log just upstream of the main structure.

At Ship Creek-Cottonwood Park, a base layer of root wads and two layers of willow brush layering structure were installed in early 2000. According to design documents, root wads were spaced at roughly 5 feet apart. Trunk lengths for the root wads were 8 feet in length, and root fan diameters were a minimum of 5 feet. The root wads were secured to a header log placed immediately behind the root fan. Design documents specify the use of a footer log, though no indication of a footer log was discovered during field inspections. Backfill, consisting of 3-6 inch rock, was used to fill in the voids between the root wads. Design documents also specified the use of a coir log, placed on the subgrade immediately above and behind the header log construction and above the first brush layer; however, the coir log was not observed during field visits.

The brush layering consists of two fabric encapsulated soil lifts, which were each constructed with two fabric layers. An outer coir netting is coupled with a biodegradable inner blanket to contain the soil/gravel fill. Live willow cuttings 4 feet in length were placed in between the two soil lifts, and at the top of the upper soil lift. Finally, a vegetative mat was transplanted onto the upper portions of the slope on the project site, from the edge back approximately 6 feet. Additional construction information is found on the attached design drawings.

Figure 21. Ship Creek at Cottonwood Park (06/28/2003).

FIGURE 4 Rootwad techniques

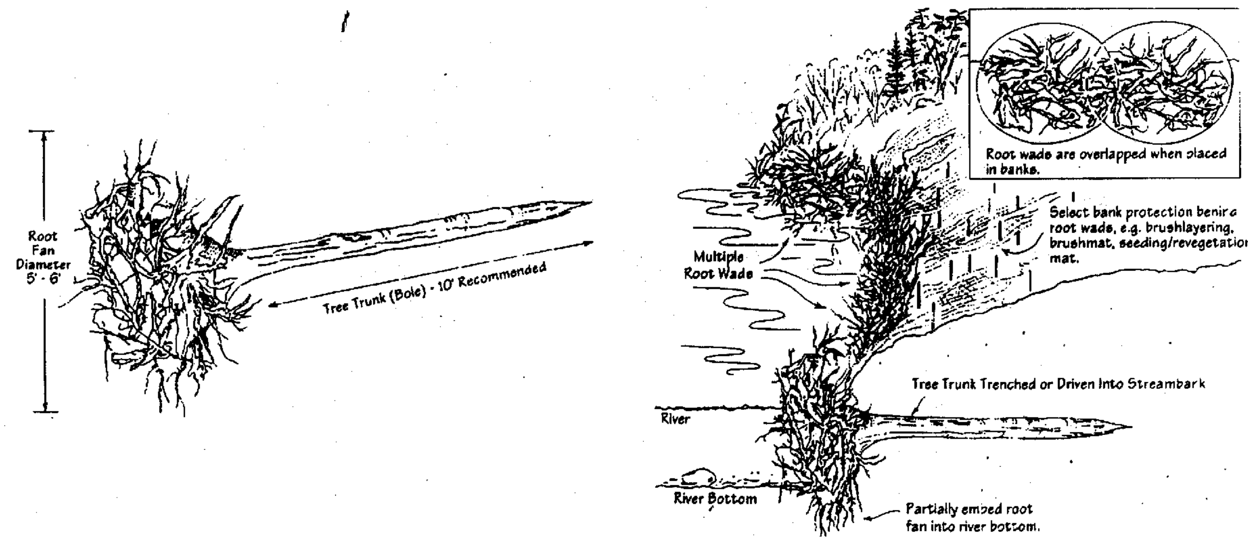
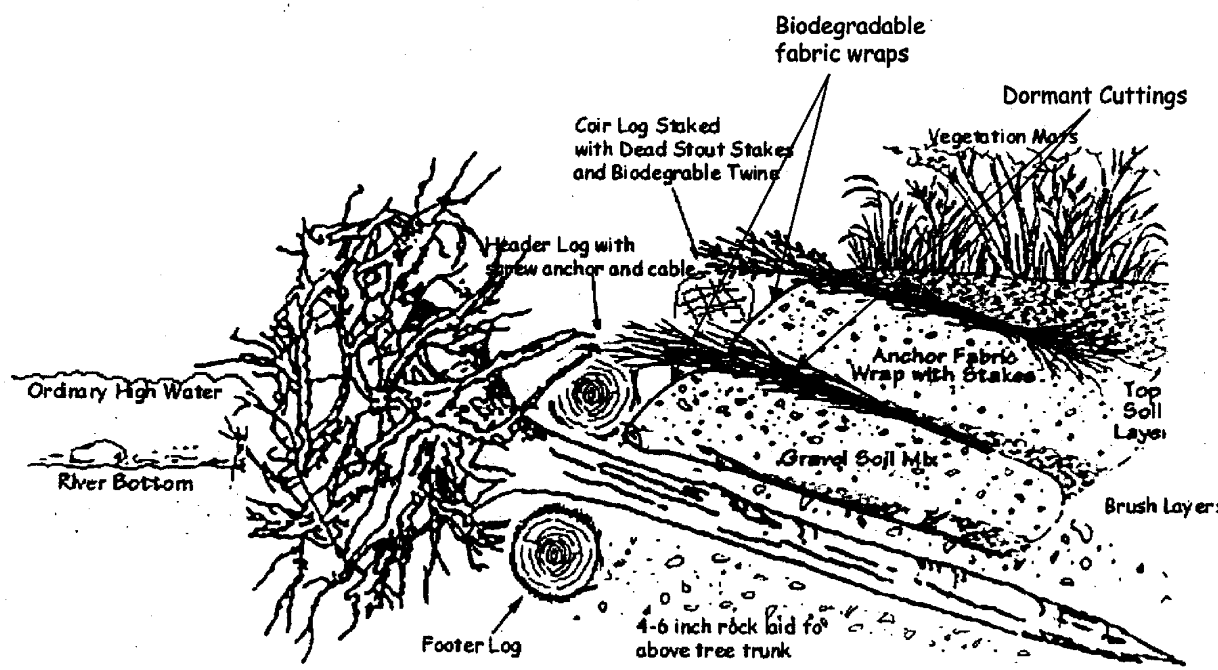
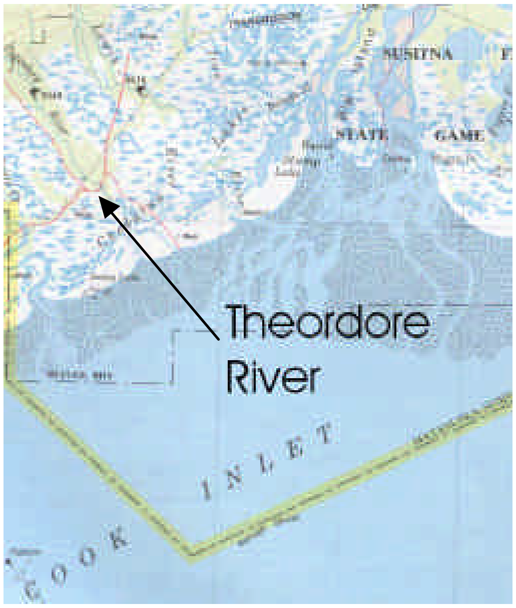


FIGURE 5 Side view of streambank restoration. (not to scale)



Theodore River

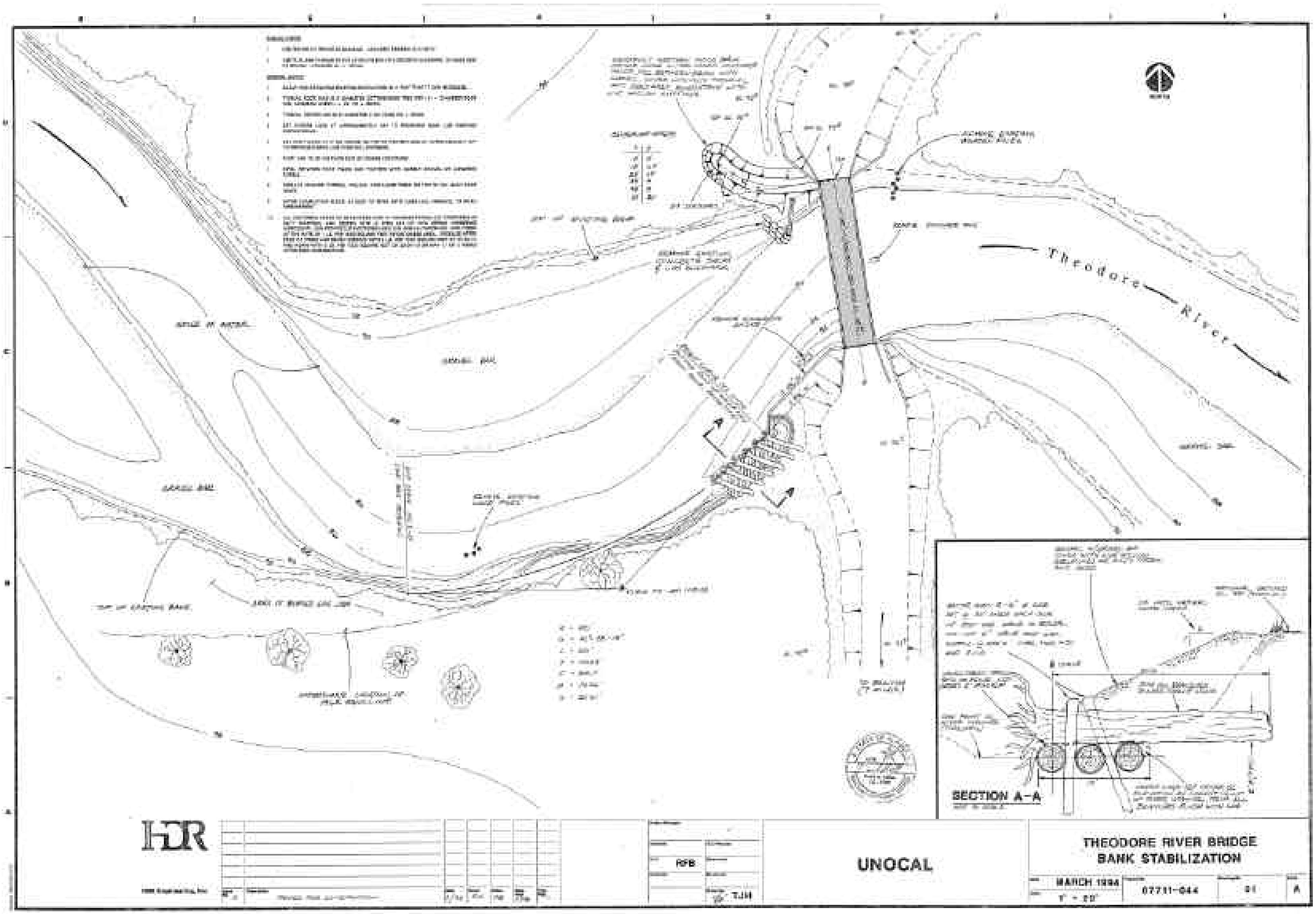
The Theodore River site is one of the earliest root wad sites to be constructed in the State of Alaska. This site is located just upstream of a small bridge on the Theodore River, approximately 35 air miles west of Anchorage across the Cook Inlet.



Installation of this structure occurred according to the design drawings, with a few variations (Dan Billman, oral commun., 2003). The horizontal length was a bit shorter than 40 feet, due to lack of materials. Multiple footer logs were used beneath the root wads. Root wad boles were 20' in length and 18" to 24" in diameter. The structure was installed approximately 6" to 12" higher in elevation than designed, due to difficulties with high water during installation. No fabric or rocks were used for this installation.

Additional construction information is found on the attached design drawing.

Figure 22. Theodore River (07/27/2003).


Theodore River
SECTION A-A
HDR
UNOCAL
THEODORE RIVER BRIDGE
BANK STABILIZATION
MARCH 1994
1" = 20'
07711-044
A
RFB
TJH

Willow Creek at Lapham Property

This site is located just off the Hatcher Pass road, east of the Parks Highway, in Southcentral Alaska, and is just downstream from the USGS gaging station on Willow Creek. This project was constructed on private property, in the backyard of a house along a bank which was suffering from extensive erosion. The structure was built using root wads, brush layering and willow cuttings. Though the original design called for additional revegetation efforts with woody plants to extend several feet back from the bank, the homeowner modified those plans and extended grass up to the bank's edge.

This project was installed in early 2000. According to design documents, 25 root wads were installed in the 120 foot project length. Trunk lengths for the root wads were 10 feet in length, and root fan diameters were a minimum of 6 feet. The root wads were secured to a header log placed immediately behind the root fan. Additionally, footer logs were noticed in some areas of the project, though not specifically mentioned in the design documents. Backfill was used to fill in the voids between the root wads. Design documents also specified the use of a coir log, placed on the subgrade immediately above and behind the header log construction and above the first brush layer; however, the coir log was not observed during field visits.

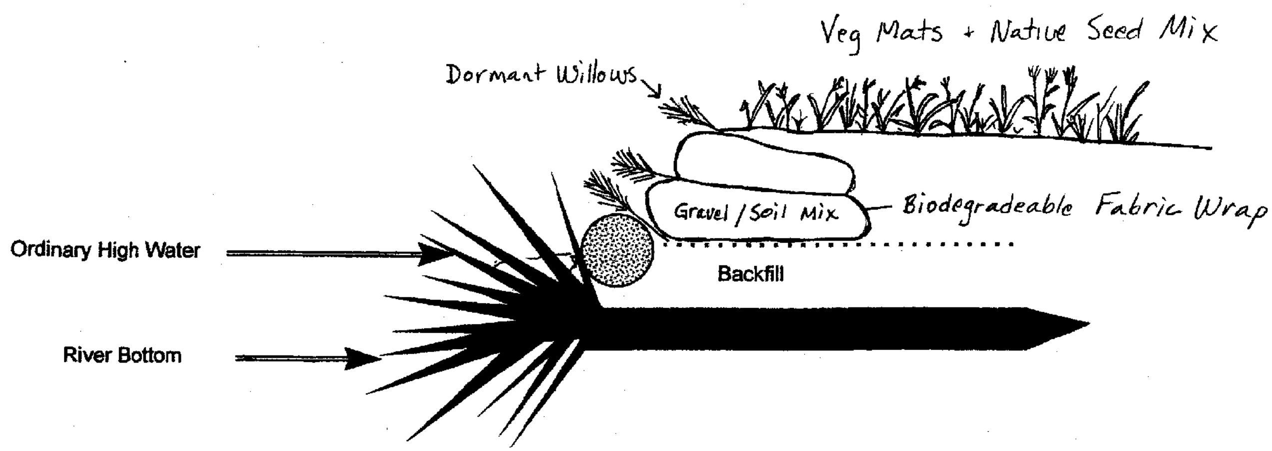
The brush layering consists of two fabric encapsulated soil lifts, which were each constructed with two fabric layers. An outer coir netting is coupled with a biodegradable inner blanket to contain the soil/gravel fill. Live willow cuttings were placed in between the two soil lifts, and at the top of the upper soil lift. The design drawing for this site is found on the following page.

Figure 23. Willow Creek at Lapham property (07/12/2003).

Proposed Design Features: Lapham Streambank Restoration, Willow Creek

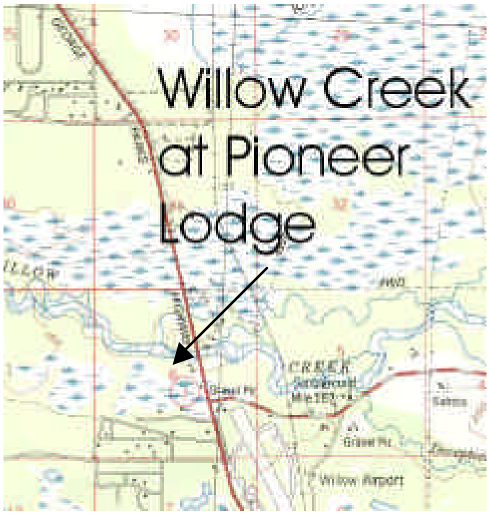
- **ROOTWADS:** 25 rootwads, minimum diameter 6 ft, with at least 10 feet of bole attached will be installed in a trench below the river bottom and backfilled. Rootwads will be overlapped when placed in bank and will match existing undulations of bank.
- **COIR LOG:** installed immediately behind rootwad, partially buried and staked for retention.
- **BRUSH LAYERING:** Horizontal benches will be excavated immediately behind coir log. Excavated fill will be replaced and wrapped in biodegradable fabric for retention. Dormant willow cuttings (feltleaf and blueberry) will be installed in 4" of saturated topsoil between each layer at a density of 13-15 per foot.
- **REVEGETATION OF UPPER BANK:** Vegetative mats consisting of diverse local plant communities will be installed in topsil at top of project. Areas surrounding veg mats will be planted with a native seed mix and a variety of native shrubs and trees.

Side View of Poposed Design



Willow Creek at Pioneer Lodge

This site is located just downstream from the Parks Highway bridge in Southcentral Alaska, along the left bank. The 425 foot structure was constructed using root wads and brush layering. Header logs and backfill were used to anchor the root wad boles. Three brush layers were used. The brush layering consists of fabric encapsulated soil lifts, which were each constructed with two fabric layers. An outer coir netting is coupled with a biodegradable inner blanket to contain the soil/gravel fill. Live willow cuttings were placed in between the soil lifts, and at the top of the upper soil lift. A light penetrating walkway was also installed to decrease impacts from human trampling.



Design drawings could not be obtained from the owner or from the resource agencies involved in the project construction or permitting.

Figure 24. Willow Creek at Pioneer Lodge, looking upstream (06/27/2003).

APPENDIX D-VEGETATION DATA

Table 7. Vegetation descriptions for study site BECSs.

Site Name	Treatment Section	Species	Height (feet)	Shoot Growth Height (inches)	Diameter Breast Height (inches)	Comments
Anchor River-Silverking	upstream brush layering	Salix alaxensis	= 5.0	6 to 26	nd	
		S. sitchensis	= 3.5	8	nd	
Anchor River-Silverking	downstream brush layering	Salix alaxensis	35 to 66	8 to 30	nd	.
		S. sitchensis	32 to 40	16 to 28	nd	
Campbell Creek-Taku Park	root wad	Salix alaxensis	6 to 12	16 to 36	< 2.5	
		S. scouleriana	4 to 5	4 to 12	nd	
		Alnus sp.	0.5 to 6	4 to 30	0.5	
		Picea glauca	4 to 8	nd	1.0	
Chena River-Doyon	brush layering	Salix alaxensis	2 to 7	9 to 56	0.5	pruned
		S. arbusculoides	4	10	nd	
		S. lasiandra	5	12	nd	
		Alnus sp.	= 3	nd	nd	
Deep Creek	brush mattress	Salix alaxensis	7.5	24 to 56	1.25	
		S. barclayi	= 3.5	8 to 14	nd	
		Populus sp.	7.5	10 to 20	0.75 to 1.9	
		Alnus sp.	10	11 to 14	0.5 to 2.25	
Deep Creek	brush layer	Salix alaxensis	= 9	30	0.5 to 3.5	
		S. barclayi	= 5	16	0.25	
		S. scouleriana	= 7	30	1.5	
		S. sitchensis	= 6.5	23	1.0	
		Populus sp.	4.5 to 12	24	0.5 to 2	
		Alnus sp.	= 3	nd	nd	

Table 7. Vegetation descriptions for study site BECSs-Continued.

Site Name	Treatment Section	Species	Height (feet)	Shoot Growth Height (inches)	Diameter Breast Height (inches)	Comments
Kenai River-Centennial	downstream section	Salix alaxensis	8 to 12	18 to 32	2	
		S. barclayi	3	14 to 22	nd	
		Populus sp.	5 to 8	21 to 36	0.75	
Kenai River-Centennial	between stairway 2 and 3	Salix alaxensis	= 8	30 to 36	1 to 2	
		S. barclayi	=3.5	10 to 22	nd	
		S. scouleriana	= 7	12 to 26	1	
		S. sitchensis	3.5	10 to 26	nd	
		Populus sp.	= 6	8 to 29	nd	
Kenai River-Centennial	upstream of stairway 3 to end	Salix alaxensis	= 6	15 to 28	0.5	
		S. barclayi	= 3	10 to 17	nd	
		S. scouleriana	= 4	13 to 24	nd	
Kenai River-Riddle	rootwad	Salix alaxensis	13+	24 to 56	2 to 2.5	pruned
		S. barclayi	4	6 to 12	nd	
		Alnus sp.	3 to 10	6 to 20	2	
Ship Creek-Cottonwood	rootwad	Salix alaxensis	3 to 6	6 to 38	0.5	
		S. barclayi	3	5 to 12	nd	
		S. scouleriana	4	18	nd	
		S. stichensis	4	9	nd	
		Populus	4 to 5	10 to 34	nd	
Theodore River	rootwad	Salix alaxensis	10 to 12	24 to 56	2 to 2.5	
		Populus sp.	10	nd	nd	
		Alnus sp.	10	6 to 20	2	
Willow Creek-Lapham	rootwad	Salix alaxensis	3 to 4	40	nd	pruned
Willow Creek-Pioneer	rootwad	Salix alaxensis	5 to 6	6 to 44	0.5	
		S. sitchensis	5	15 to 24	nd	

Table 8. Depth to water surface elevation (WSEL) from treatment layers.

Site Name	Treatment Layer	Distance to WSEL (feet)	Discharge (cfs)
Anchor River-Silverking	bottom of coir layer	0.8	504
	bottom of 1st willow layer	1.6	
	bottom of coir layer	1.8	
	bottom of 2nd willow layer	2.2	
	bottom of 3rd willow layer	3.0	
	top of bank	4.1	
Anchor River-Steelhead	center of root wad	0.1	129
	center of root wad	2.4	
	top of header log	2.2	
	top of lower coir layer	2.9	
	top of upper layer	4.2	
	edge of sod	5.0	
	top of bank	6.6	
Campbell Creek-Taku Park	bottom of channel	-3.4	69
	bottom of footer log	-1.7	
	center of root wad	1.3	
	bottom of header log	2.0	
	top of bank	3.6	
Chena River-Doyon	bottom of 1st soil lift	0.0	3240
	1st willow layer	1.2	
	2nd willow layer	2.5	
Deep Creek-xsec 6	bottom of 1st soil lift	0.0	220
	top of bank, all soil lifts	6.5	
Kenai River-Centennial	center of root wad	0.4	15,500
	top of coir fabric, willow layers	3.7	
Ship Creek-Cottonwood	center of root wad	0.4	155
	1st soil lift	0.9	
	1st willow layer	1.5	
	2nd soil lift	1.9	
	2nd willow layer	2.7	
	top of bank	3.1	
Willow Creek-Lapham	center of root wad	1.2	696
	top of header log	2.6	
	willow layer, top of FESL	3.5	
	top of bank	4.1	
Willow Creek-Pioneer Lodge	center of root wad	2.1	710
	1st willow layer	3.7	
	2nd willow layer	4.3	
	3rd willow layer	4.8	
	top of bank	5.5	

Soil Samples

Soil samples were collected from four of the study sites (Table 9). The results of the soil tests show that the pH of the soils generally are mildly acidic, with the exception of the Taku mid and lower project samples. These samples are approaching the strongly acidic range but are still within the range allowing for maximum absorption of soil nutrients. These soil samples also contained a high percentage of organic matter (LIO), more indicative of forest soils or mineral soils containing an organic layer. For comparison the farm soils in the Matanuska Valley typically range from 3-4 percent organic matter.

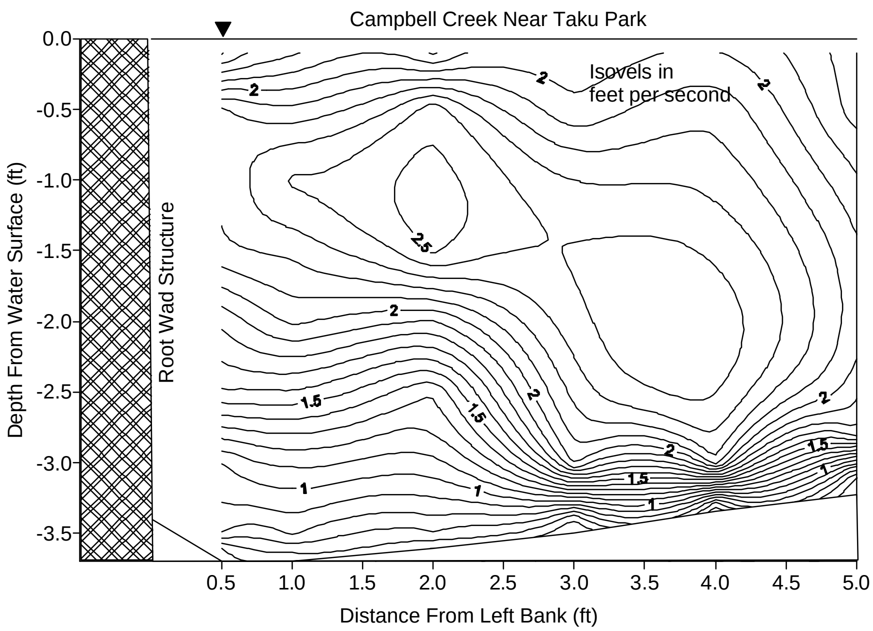
The soil tests also show that nutrient levels for total nitrogen (NH_4 and NO_3), Phosphorus (P) and potassium (K) are very low. A plant tissue analysis would have provided more useful information. Alaska native plants are adapted to nutrient poor soils so a tissue analysis would reflect more accurately the nutrient status of the plant. The plants at the various projects did not show signs of nutritional stress such as chlorosis of the leaves.

Table 9. Soil test results.

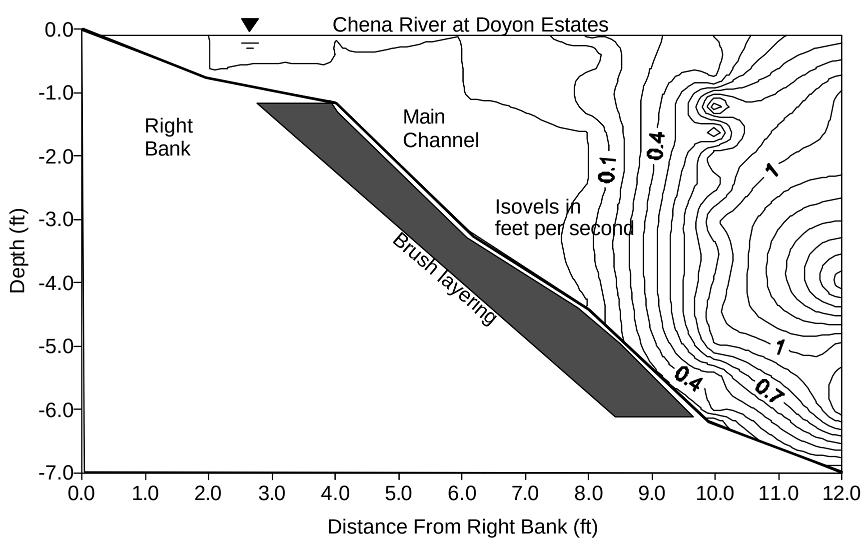
Description	pH	NH_4 (ppm)	NO_3 (ppm)	P (ppm)	K (ppm)	% Gravel >2mm	% L01	% Sand	% Silt	% Clay
Deep Ck 1 Brush Mat	6.20	1	<1	32	268	49.6	5.74	65.2	25.2	9.6
Deep Ck 2 Brush Layer	6.08	<1	<1	24	136	13.8	4.53	57.6	32.8	9.6
Deep Ck 3 Brush Layer	5.90	<1	<1	25	154	48.5	3.96	61.6	26.8	11.6
Centennial 1	6.20	<1	1	28	98	34.0	2.30	73.6	20.8	5.6
Centennial 2	6.01	<1	<1	50	66	49.1	2.17	77.6	16.8	5.6
Centennial 3	5.86	<1	<1	10	44	7.0	5.96	45.6	44.8	9.6
Anchor River 1	6.34	<1	<1	42	122	65.3	3.44	85.6	10.8	3.6
Anchor River 2	5.94	1	<1	6	102	45.0	5.63	69.6	20.8	9.6
Anchor River 3	6.14	1	<1	34	109	72.1	2.29	85.6	8.8	5.6
Taku N end of project	5.43	4	1	<1	110	0	17.84	70.4	22.8	6.8
Taku mid project	5.27	3	<1	<1	107	0	20.63	74.4	22.8	2.8
Taku S end of project	5.26	6	<1	<1	74	0	23.80	74.4	20.8	4.8

APPENDIX E-MEASURED VELOCITY PROFILES

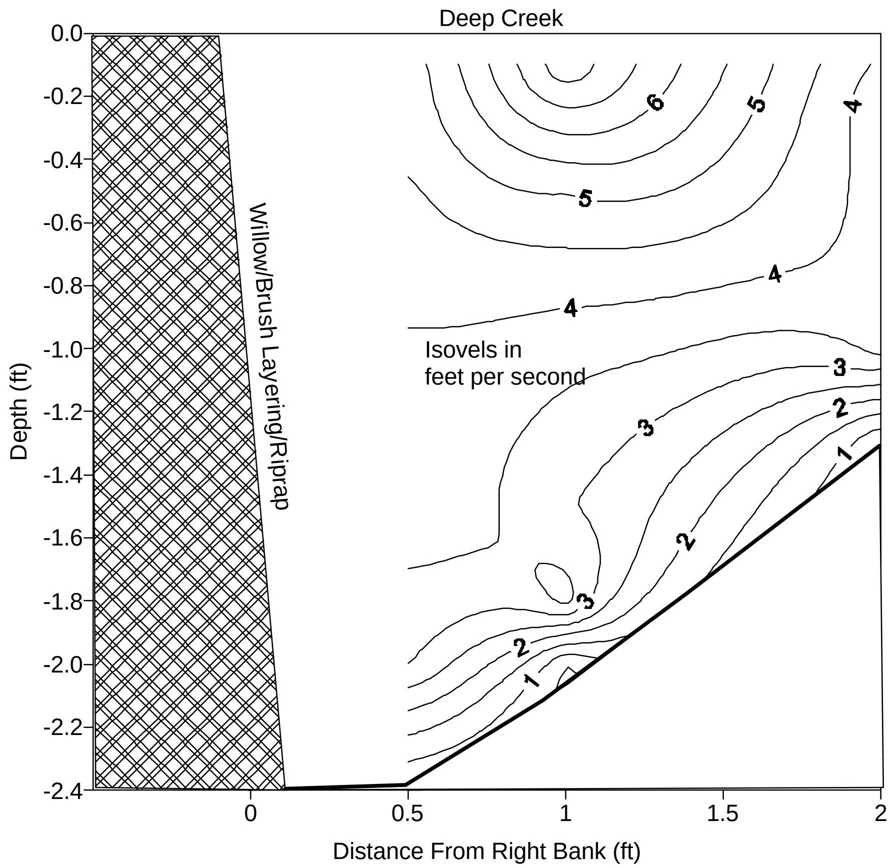
Velocity profiles at most sites were developed by making a series of water velocity measurements in the channel immediately adjacent to the BECS, using a Price AA current meter. Measurements were made in a grid pattern, at varying distances from the structure, and varying depths from the water surface. The following profile plots were created using three-dimensional graphing software, which interpolates between data points to create the isovels (lines of constant velocity). The velocity measurement data are found in Appendix H.



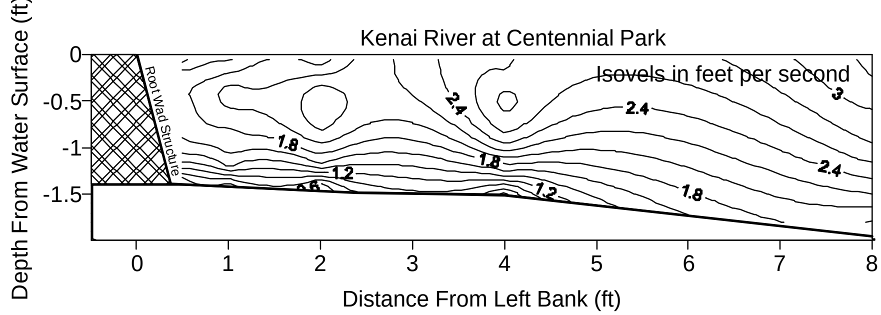
Campbell Creek at Taku Park-Q = 69.15 cfs



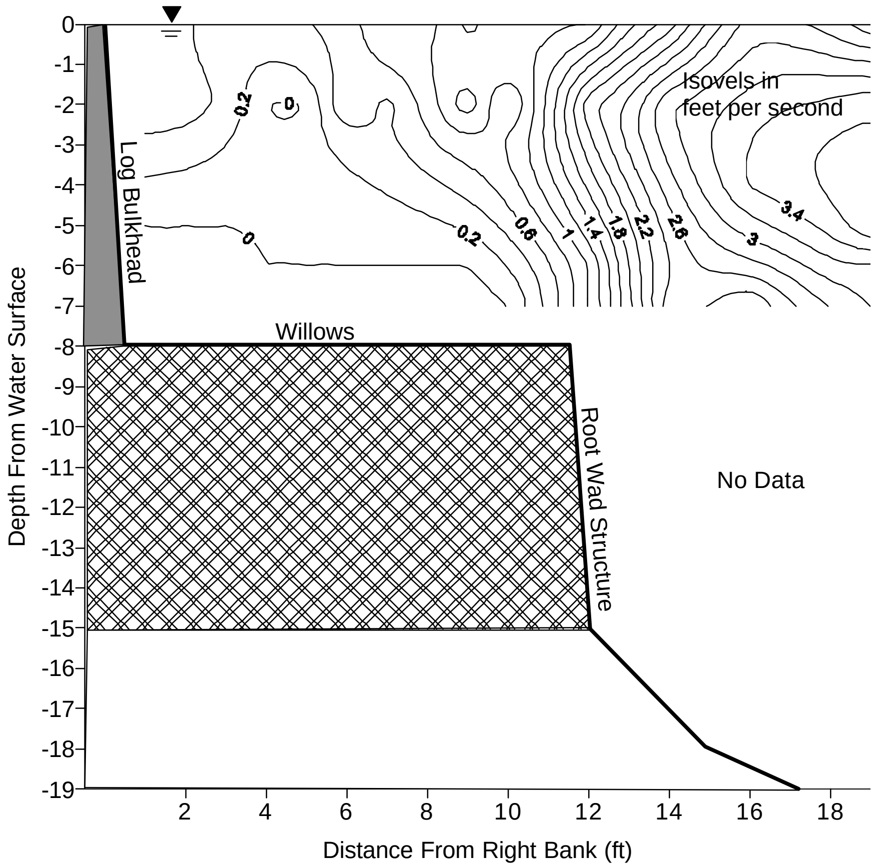
Chena River at Doyon Estates; Q = 8,870 cfs



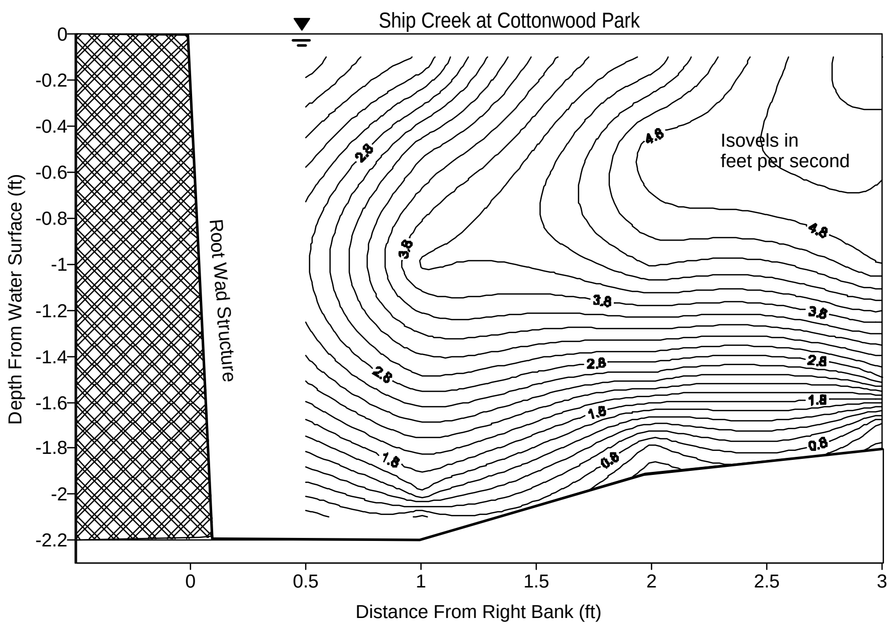
Deep Creek; Q = 176.46 cfs.



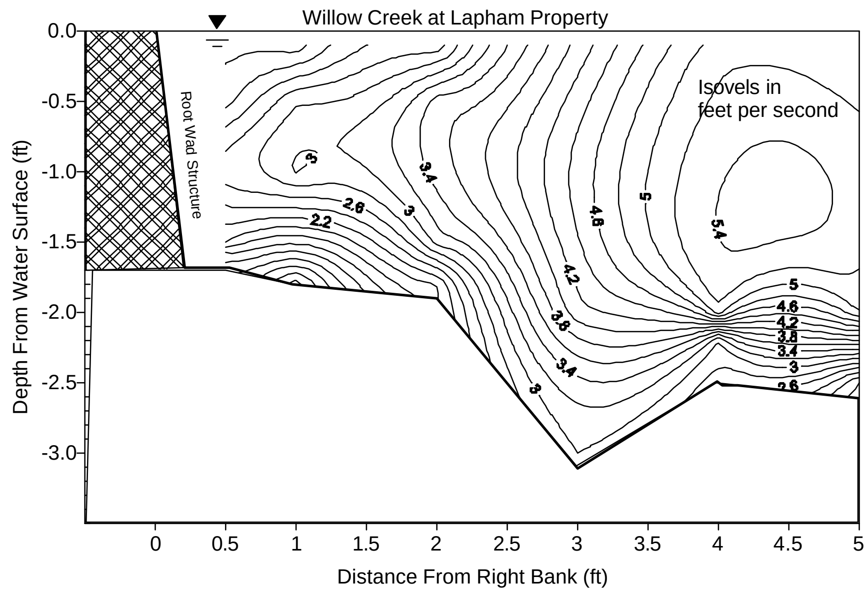
Kenai River at Centennial Park, Q = 15,500 cfs.



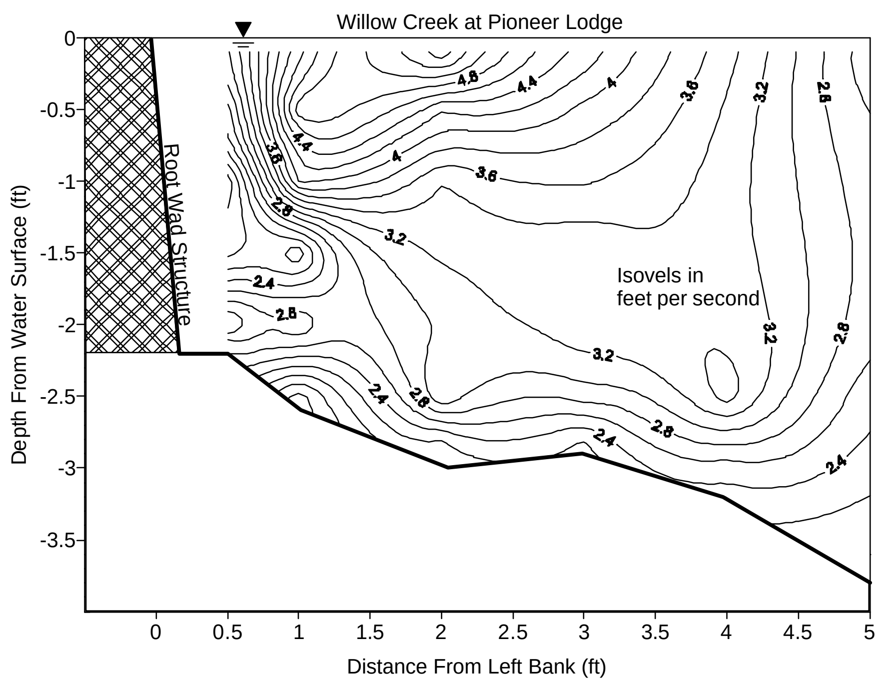
Kenai River at Riddle Property; Q = 11,500 cfs, 24 foot ebb tide.



Ship Creek at Cottonwood Park; Q = 155.06 cfs.



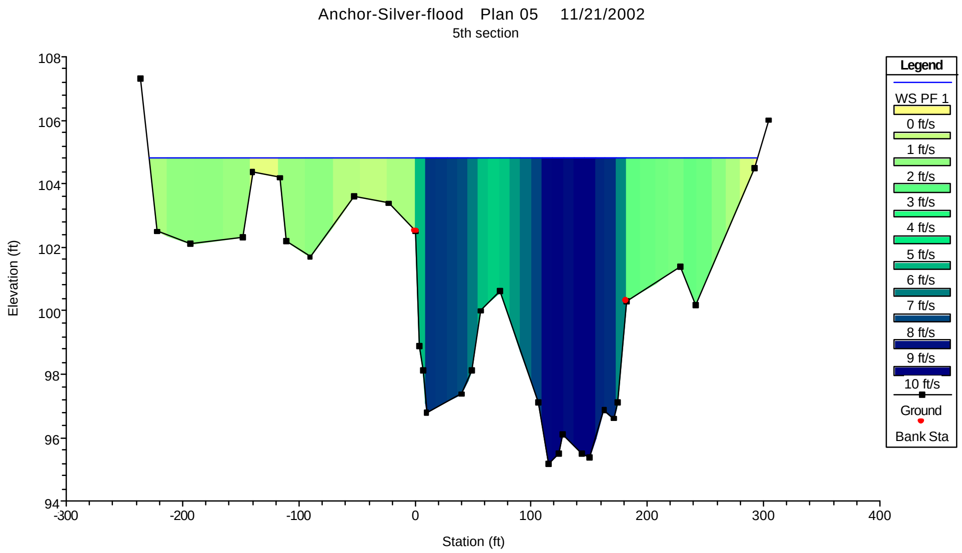
Willow Creek at Lapham Property, Q = 696.00 cfs.



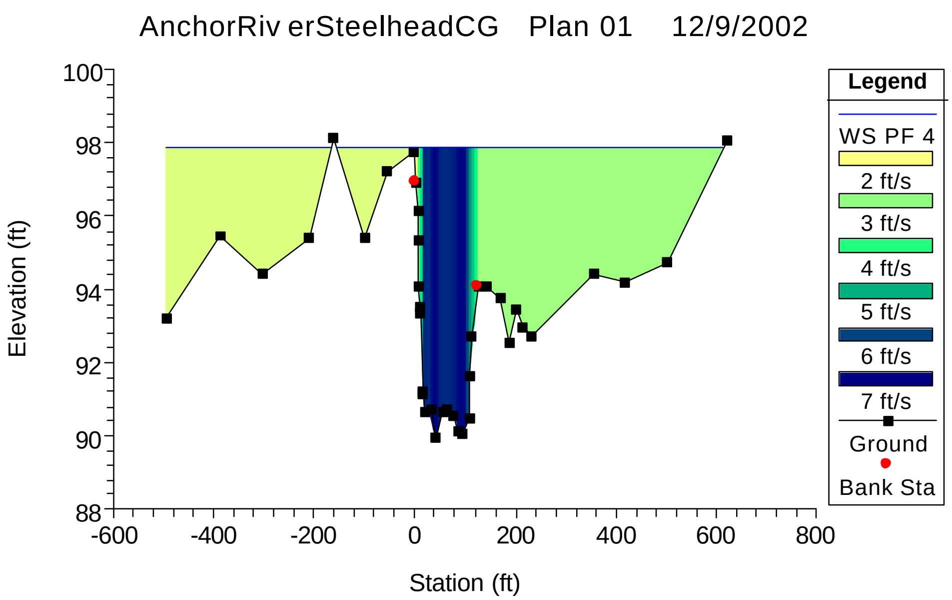
Willow Creek at Pioneer Lodge, Q = 696 cfs.

APPENDIX F-HEC-RAS MODELING RESULTS: CHANNEL VELOCITY

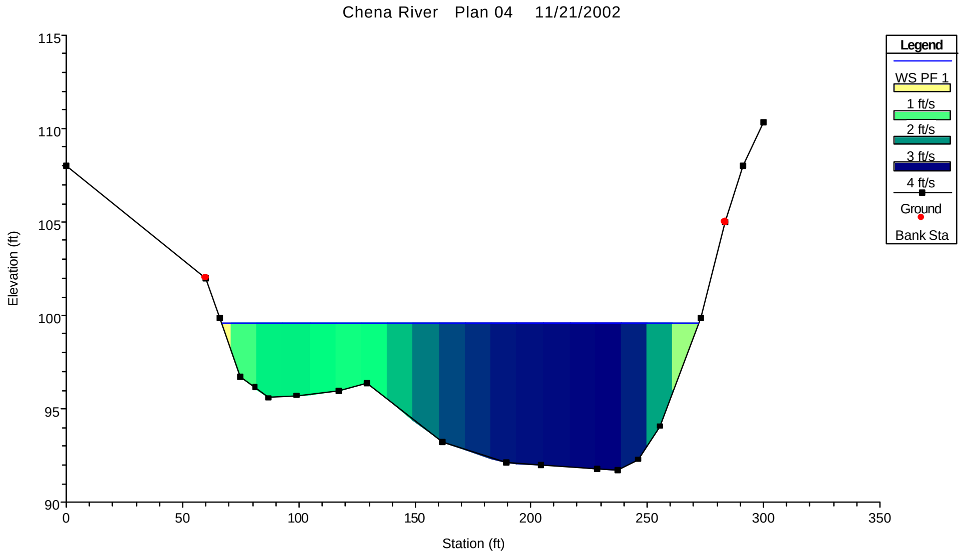
Anchor River at Silverking Campground, Q_{flood} = 13,000 cfs



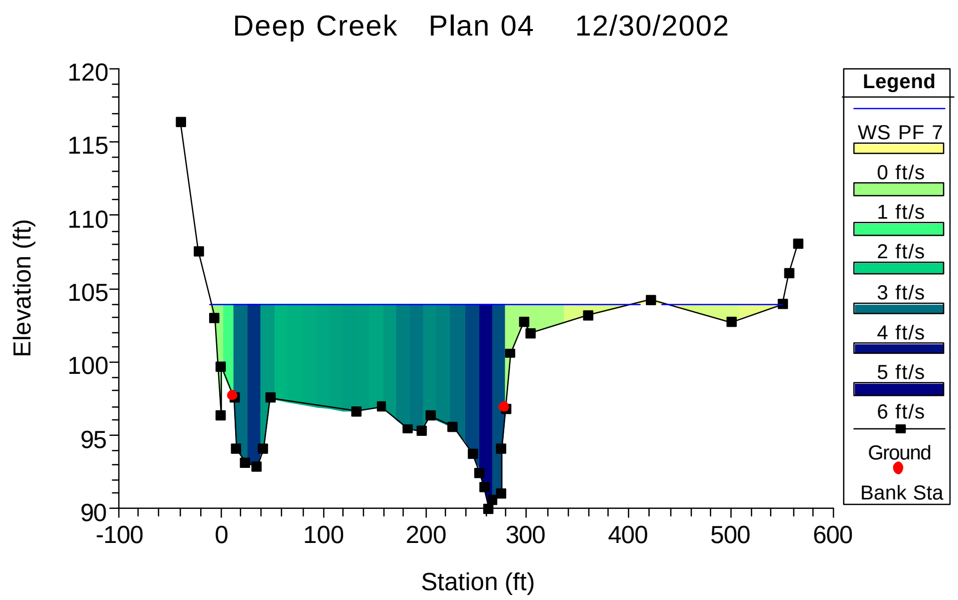
Anchor River at Steelhead Campground, Q_{flood} = 13,000 cfs



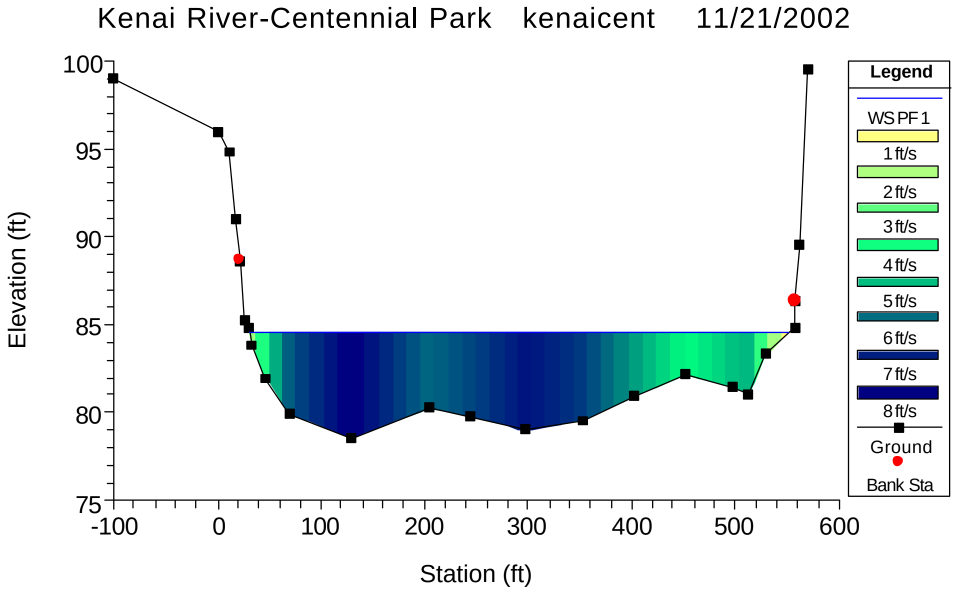
Chena River, Q_{flood} = 8,870 cfs



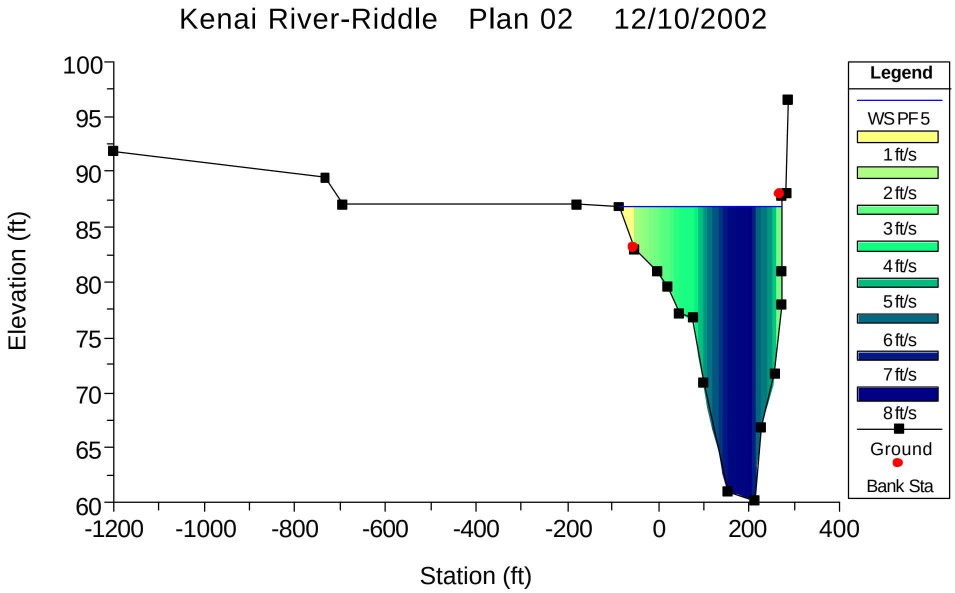
Deep Creek, Qflood = 9,600 cfs



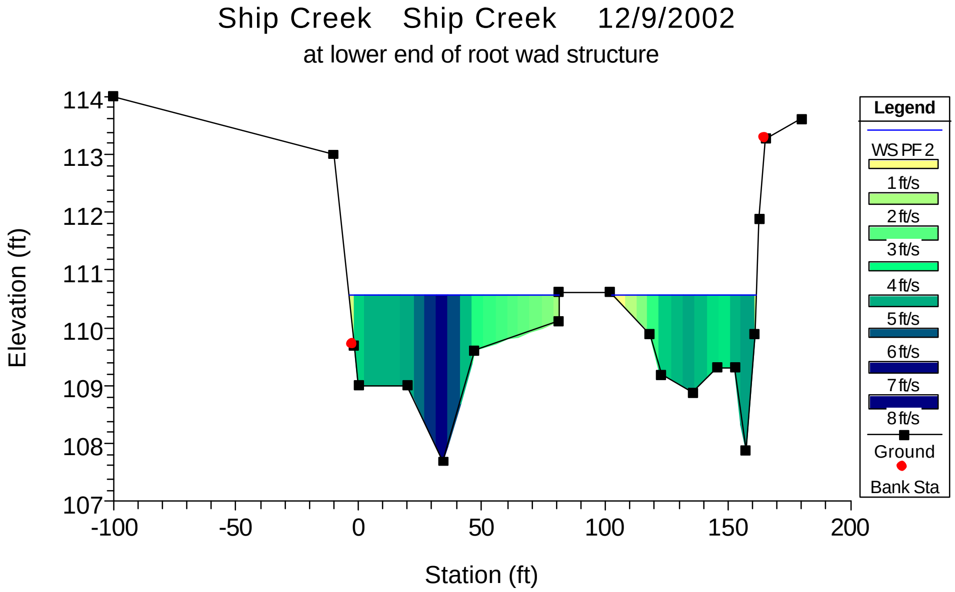
Kenai River-Centennial Park, Q_{flood} = 27,600 cfs



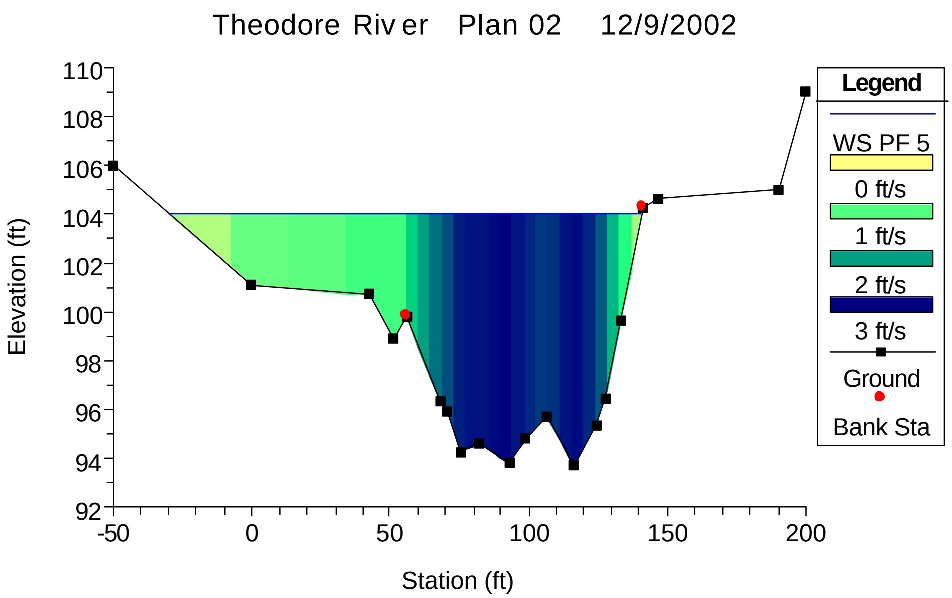
Kenai River at Riddle Property, Q_{flood} = 27,600 cfs



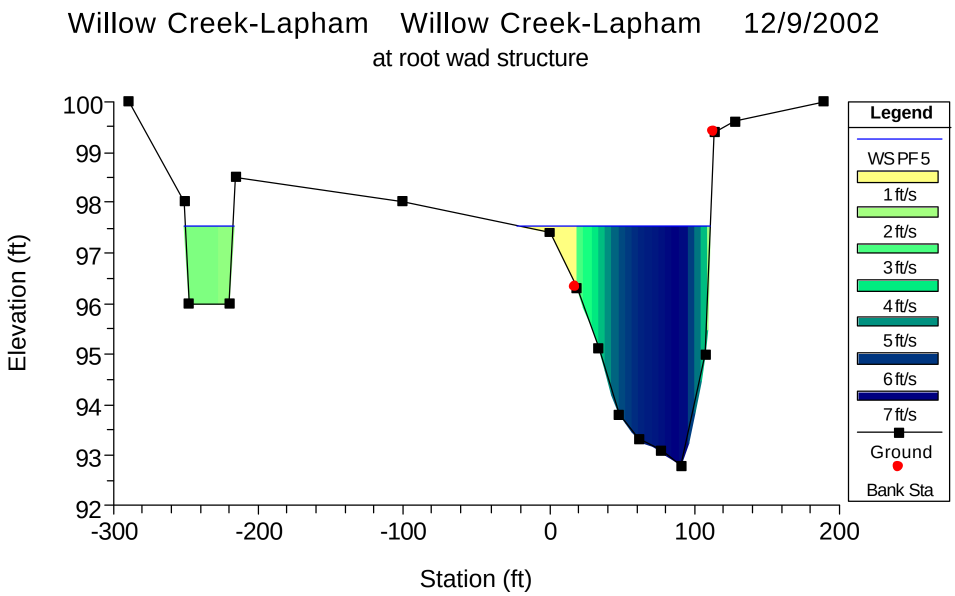
Ship Creek at Cottonwood Park, Q_{flood} = 826 cfs



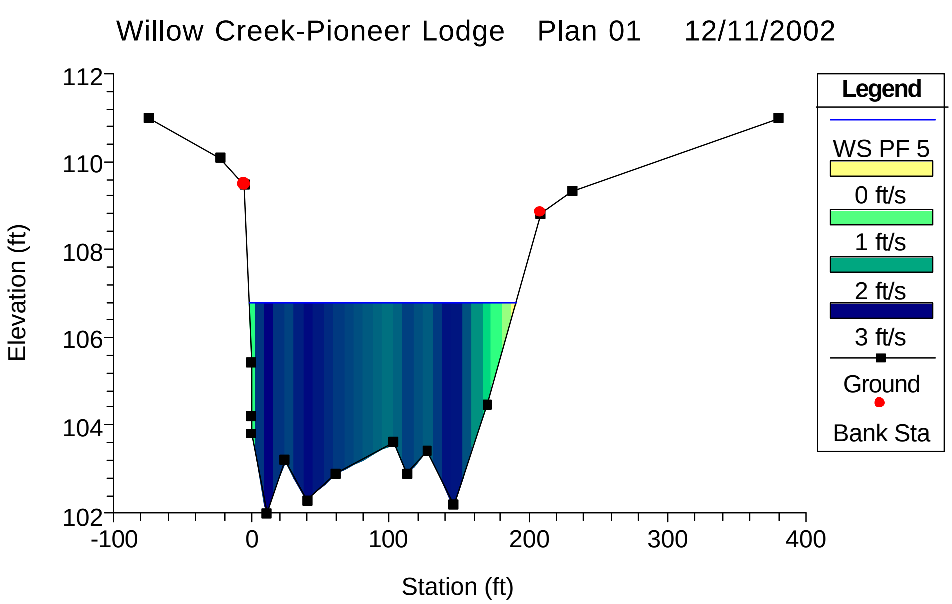
Theodore River, Q_{flood} = 2020 cfs



Willow Creek at Lapham Property, Q_{flood} = 1950 cfs



Willow Creek at Pioneer Lodge, Q_{flood} = 1950 cfs



APPENDIX G-HEC-RAS MODELING RESULTS: SHEAR STRESS

Table 10. Computed critical and average shear stress values for study site BECSs.

Site Name (*Bed Shear Stress*) (*Bank Shear Stress*)		Shear Stress (lbs/ft^2) Critical	Shear Stress (lbs/ft^2) Average Q_2	Q_{50}	Q_{100}	Q_{flood}	Ratio Average/Critical Shear Stress Q_2	Q_{50}	Q_{100}	Q_{fld}	Comments
Anchor River-Silverking	*bed*	1.00	0.44	1.01	1.17	1.26	0.44	1.01	1.17	1.26	
	bank	0.21	0.34	0.78	0.90	0.97	1.62	3.71	4.29	4.62	
Anchor River-Steelhead	*bed*	1.00	1.08	1.53	1.62	1.74	1.08	1.53	1.62	1.74	
	bank	0.55	0.83	1.18	1.25	1.34	1.51	2.15	2.27	2.43	
Campbell Creek-Taku Park	*bed*	0.49	0.49	1.06	1.42	ND	1.00	2.16	2.90	ND	bank angle exceeds
	bank	NA	0.38	0.82	1.09	ND	NA	NA	NA	NA	angle of repose
Chena River-Doyon	*bed*	0.16	0.20	0.20*	*	0.25	1.25	1.25*	*	1.56	*maximum regulated Q
	bank	0.12	0.15	0.15*	*	0.19	1.25	1.25*	*	1.58	is 12,000 cfs
Deep Creek-xsec 5	*bed*	1.18	0.61	1.21	1.32	3.81	0.52	1.03	1.12	3.23	
	bank	1.17	0.47	0.93	1.01	2.93	0.40	0.79	0.86	2.50	
Deep Creek-xsec 6	*bed*	1.18	0.67	0.49	0.47	0.48	0.57	0.42	0.40	0.41	
	bank	NA	0.52	0.38	0.36	0.37	NA	NA	NA	NA	
Deep Creek-xsec 7	*bed*	1.18	0.53	0.60	0.62	0.46	0.45	0.51	0.53	0.39	
	bank	1.18	0.41	0.46	0.48	0.35	0.35	0.39	0.41	0.30	
Kenai River-Centennial	*bed*	0.84	0.67	0.87	0.92	0.77	0.80	1.04	1.10	0.92	
	bank	0.61	0.52	0.67	0.71	0.59	0.85	1.10	1.16	0.97	

Table 10. Computed critical and average shear stress values for study site BECSs-Continued

Site Name (*Bed Shear Stress*) (*Bank Shear Stress*)		Shear Stress (lbs/ft^2) Critical	Average Q2	Average Q50	Average Q100	Average Qfld	Ratio Average/Critical Shear Stress Q2	Q50	Q100	Qfld	Comments
Kenai River-Riddle	*bed*	0.82	0.30	0.59	0.65	0.45	0.37	0.72	0.79	0.55	
	bank	0.44	0.23	0.45	0.50	0.35	0.52	1.02	1.14	0.80	
Ship Creek-Cottonwood	*bed*	1.15	0.70	0.91	0.95	0.69	0.61	0.79	0.82	0.60	
	bank	0.54	0.54	0.70	0.73	0.53	1.00	1.30	1.35	0.98	
Theodore River	*bed*	0.25	0.11	0.23	0.26	0.20	0.44	0.92	1.04	0.80	
	bank	0.20	0.09	0.18	0.20	0.15	0.45	0.90	1.00	0.75	
Willow Creek-Lapham	*bed*	1.80	1.08	1.52	1.58	1.21	0.60	0.84	0.88	0.67	
	bank	0.37	0.83	1.17	1.22	0.93	2.24	3.16	3.30	2.51	
Willow Creek-Pioneer	*bed*	0.74	0.20	0.37	0.40	0.19	0.27	0.50	0.54	0.26	bank angle exceeds
	bank	NA	0.15	0.28	0.31	0.15	NA	NA	NA	NA	angle of repose

NA-Not applicable. Bank angle exceeds estimated angle of repose for bank material, and indicates high potential for bank erosion during high water events.

ND-No data. No high water marks were found to indicate highest discharge during project life.

* Chena River is regulated. The maximum permissible flow of 12,000 cfs is listed in the Q50 column for convenience, but no recurrence interval is assigned.

Anchor River at Silverking Campground

Q_2-2310 cfs

: Plan 03 River: Anchor River Reach:Silverking Campg Riv Sta: 5.0 Profile: PF 1 E.G. Elev (ft)	100.82	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.28	Wt. n-Val.		0.035	0.060
W.S. Elev (ft)	100.54	Reach Len. (ft)	121.00	116.00	104.00
Crit W.S. (ft)		Flow Area (sq ft)		541.72	2.54
E.G. Slope (ft/ft)	0.002333	Area (sq ft)		541.72	2.54
Q Total (cfs)	2310.00	Flow (cfs)		2309.16	0.84
Top Width (ft)	196.01	Top Width (ft)		178.17	17.85
Vel Total (ft/s)	4.24	Avg. Vel. (ft/s)		4.26	0.33
Max Chl Dpth (ft)	5.34	Hydr. Depth (ft)		3.04	0.14
Conv. Total (cfs)	47828.1	Conv. (cfs)		47810.7	17.4
Length Wtd. (ft)	115.98	Wetted Per. (ft)		180.74	17.88
Min Ch El (ft)	95.20	Shear (lb/sq ft)		0.44	0.02
Alpha	1.01	Stream Power (lb/ft s)		1.86	0.01
Frctn Loss (ft)	0.34	Cum Volume (acre-ft)	0.00	6.12	0.30
C & E Loss (ft)	0.01	Cum SA (acres)	0.01	2.29	0.48

Q_{50}-8170 cfs

: Plan 03 River: Anchor River Reach:Silverking Campg Riv Sta: 5.0 Profile: PF 1 E.G. Elev (ft)	104.06	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.75	Wt. n-Val.	0.060	0.035	0.060
W.S. Elev (ft)	103.31	Reach Len. (ft)	121.00	116.00	104.00
Crit W.S. (ft)		Flow Area (sq ft)	146.73	1045.14	203.56
E.G. Slope (ft/ft)	0.002879	Area (sq ft)	146.73	1045.14	203.56
Q Total (cfs)	8170.00	Flow (cfs)	190.93	7532.88	446.18
Top Width (ft)	435.65	Top Width (ft)	157.45	182.30	95.90
Vel Total (ft/s)	5.85	Avg. Vel. (ft/s)	1.30	7.21	2.19
Max Chl Dpth (ft)	8.11	Hydr. Depth (ft)	0.93	5.73	2.12
Conv. Total (cfs)	152256.9	Conv. (cfs)	3558.2	140383.5	8315.1
Length Wtd. (ft)	115.28	Wetted Per. (ft)	157.96	185.72	96.10
Min Ch El (ft)	95.20	Shear (lb/sq ft)	0.17	1.01	0.38
Alpha	1.41	Stream Power (lb/ft s)	0.22	7.29	0.83
Frctn Loss (ft)	0.31	Cum Volume (acre-ft)	1.83	12.96	4.13
C & E Loss (ft)	0.05	Cum SA (acres)	1.90	2.32	2.83

Q_{100}-10,000 cfs

: Plan 03 River: Anchor River Reach:Silverking Campg Riv Sta: 5.0 Profile: PF 1 E.G. Elev (ft)	104.71	Element	Left OB	Channel	Right OB

Vel Head (ft)	0.87	Wt. n-Val.	0.060	0.035	0.060
W.S. Elev (ft)	103.84	Reach Len. (ft)	121.00	116.00	104.00
Crit W.S. (ft)		Flow Area (sq ft)	244.94	1141.81	256.07
E.G. Slope (ft/ft)	0.003038	Area (sq ft)	244.94	1141.81	256.07
Q Total (cfs)	10000.00	Flow (cfs)	389.73	8966.21	644.06
Top Width (ft)	484.33	Top Width (ft)	199.88	182.30	102.15
Vel Total (ft/s)	6.09	Avg. Vel. (ft/s)	1.59	7.85	2.52
Max Chl Dpth (ft)	8.64	Hydr. Depth (ft)	1.23	6.26	2.51
Conv. Total (cfs)	181442.7	Conv. (cfs)	7071.3	162685.3	11686.0
Length Wtd. (ft)	115.24	Wetted Per. (ft)	200.65	185.72	102.37
Min Ch El (ft)	95.20	Shear (lb/sq ft)	0.23	1.17	0.47
Alpha	1.51	Stream Power (lb/ft s)	0.37	9.16	1.19
Frctn Loss (ft)	0.32	Cum Volume (acre-ft)	3.07	14.10	5.57
C & E Loss (ft)	0.07	Cum SA (acres)	2.59	2.32	3.12

Q_{flood}-13,000 cfs

: Plan 03 River: Anchor River Reach:Silverking Campg Riv Sta: 5.0 Profile: PF 1 E.G. Elev (ft)	105.75	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.94	Wt. n-Val.	0.060	0.035	0.060
W.S. Elev (ft)	104.81	Reach Len. (ft)	121.00	116.00	104.00
Crit W.S. (ft)		Flow Area (sq ft)	453.53	1318.06	360.17
E.G. Slope (ft/ft)	0.002846	Area (sq ft)	453.53	1318.06	360.17
Q Total (cfs)	13000.00	Flow (cfs)	942.74	11024.64	1032.62
Top Width (ft)	523.45	Top Width (ft)	228.75	182.30	112.40
Vel Total (ft/s)	6.10	Avg. Vel. (ft/s)	2.08	8.36	2.87
Max Chl Dpth (ft)	9.61	Hydr. Depth (ft)	1.98	7.23	3.20
Conv. Total (cfs)	243685.7	Conv. (cfs)	17671.8	206657.5	19356.5
Length Wtd. (ft)	115.22	Wetted Per. (ft)	229.81	185.72	112.67
Min Ch El (ft)	95.20	Shear (lb/sq ft)	0.35	1.26	0.57
Alpha	1.62	Stream Power (lb/ft s)	0.73	10.55	1.63
Frctn Loss (ft)	0.29	Cum Volume (acre-ft)	5.51	16.04	7.95
C & E Loss (ft)	0.08	Cum SA (acres)	3.20	2.32	3.23

Anchor River at Steelhead Campground

Q_2-2310 cfs

: Plan 01 River: AnchorRiver Reach:Steelhead Campgr Riv Sta: 2.0 Profile: PF 1 E.G. Elev (ft)	94.87	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.25	Wt. n-Val.	0.075	0.055	0.075
W.S. Elev (ft)	94.62	Reach Len. (ft)	323.00	240.00	154.00
Crit W.S. (ft)		Flow Area (sq ft)	51.34	433.31	294.81

E.G. Slope (ft/ft)	0.004830	Area (sq ft)	51.34	433.31	294.81
Q Total (cfs)	2310.00	Flow (cfs)	52.28	1904.74	352.98
Top Width (ft)	586.67	Top Width (ft)	104.32	118.89	363.46
Vel Total (ft/s)	2.96	Avg. Vel. (ft/s)	1.02	4.40	1.20
Max Chl Dpth (ft)	4.68	Hydr. Depth (ft)	0.49	3.64	0.81
Conv. Total (cfs)	33239.1	Conv. (cfs)	752.3	27407.7	5079.1
Length Wtd. (ft)	242.04	Wetted Per. (ft)	105.75	120.96	363.55
Min Ch El (ft)	89.94	Shear (lb/sq ft)	0.15	1.08	0.24
Alpha	1.84	Stream Power (lb/ft s)	0.15	4.75	0.29
Frctn Loss (ft)	1.32	Cum Volume (acre-ft)	2.07	2.12	0.71
C & E Loss (ft)	0.00	Cum SA (acres)	1.67	0.59	0.96

Q_{50}-8170 cfs

: Plan 01 River: AnchorRiver Reach:Steelhead Campgr Riv Sta: 2.0 Profile: PF 2 E.G. Elev (ft)	97.05	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.28	Wt. n-Val.	0.075	0.055	0.075
W.S. Elev (ft)	96.77	Reach Len. (ft)	323.00	240.00	154.00
Crit W.S. (ft)		Flow Area (sq ft)	649.79	693.03	1181.76
E.G. Slope (ft/ft)	0.004468	Area (sq ft)	649.79	693.03	1181.76
Q Total (cfs)	8170.00	Flow (cfs)	1294.09	3896.06	2979.85
Top Width (ft)	946.77	Top Width (ft)	373.66	123.45	449.66
Vel Total (ft/s)	3.24	Avg. Vel. (ft/s)	1.99	5.62	2.52
Max Chl Dpth (ft)	6.83	Hydr. Depth (ft)	1.74	5.61	2.63
Conv. Total (cfs)	122230.2	Conv. (cfs)	19360.7	58288.4	44581.2
Length Wtd. (ft)	238.99	Wetted Per. (ft)	377.36	126.17	449.78
Min Ch El (ft)	89.94	Shear (lb/sq ft)	0.48	1.53	0.73
Alpha	1.72	Stream Power (lb/ft s)	0.96	8.61	1.85
Frctn Loss (ft)	1.25	Cum Volume (acre-ft)	7.83	3.40	2.98
C & E Loss (ft)	0.01	Cum SA (acres)	3.22	0.60	1.14

Q_{100}-10,000 cfs

: Plan 01 River: AnchorRiver Reach:Steelhead Campgr Riv Sta: 2.0 Profile: PF 3 E.G. Elev (ft)	97.52	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.29	Wt. n-Val.	0.075	0.055	0.075
W.S. Elev (ft)	97.23	Reach Len. (ft)	323.00	240.00	154.00
Crit W.S. (ft)		Flow Area (sq ft)	828.35	749.85	1391.64
E.G. Slope (ft/ft)	0.004384	Area (sq ft)	828.35	749.85	1391.64
Q Total (cfs)	10000.00	Flow (cfs)	1825.60	4387.92	3786.48
Top Width (ft)	997.37	Top Width (ft)	407.64	124.00	465.73
Vel Total (ft/s)	3.37	Avg. Vel. (ft/s)	2.20	5.85	2.72
Max Chl Dpth (ft)	7.29	Hydr. Depth (ft)	2.03	6.05	2.99
Conv. Total (cfs)	151033.3	Conv. (cfs)	27572.6	66272.2	57188.5
Length Wtd. (ft)	239.96	Wetted Per. (ft)	411.88	126.73	465.86
Min Ch El (ft)	89.94	Shear (lb/sq ft)	0.55	1.62	0.82
Alpha	1.65	Stream Power (lb/ft	1.21	9.48	2.22

		s)			
Frctn Loss (ft)	1.24	Cum Volume (acre-ft)	9.31	3.67	3.51
C & E Loss (ft)	0.01	Cum SA (acres)	3.35	0.60	1.18

Q_{flood}-13,000 cfs

: Plan 01 River: AnchorRiver Reach:Steelhead Campgr Riv Sta: 2.0 Profile: PF 4 E.G. Elev (ft)	98.21	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.31	Wt. n-Val.	0.075	0.055	0.075
W.S. Elev (ft)	97.90	Reach Len. (ft)	323.00	240.00	154.00
Crit W.S. (ft)		Flow Area (sq ft)	1132.65	833.01	1711.86
E.G. Slope (ft/ft)	0.004250	Area (sq ft)	1132.65	833.01	1711.86
Q Total (cfs)	13000.00	Flow (cfs)	2756.52	5148.29	5095.20
Top Width (ft)	1100.57	Top Width (ft)	487.34	124.00	489.23
Vel Total (ft/s)	3.53	Avg. Vel. (ft/s)	2.43	6.18	2.98
Max Chl Dpth (ft)	7.96	Hydr. Depth (ft)	2.32	6.72	3.50
Conv. Total (cfs)	199406.5	Conv. (cfs)	42282.1	78969.4	78155.0
Length Wtd. (ft)	241.10	Wetted Per. (ft)	492.37	126.73	489.37
Min Ch El (ft)	89.94	Shear (lb/sq ft)	0.61	1.74	0.93
Alpha	1.59	Stream Power (lb/ft s)	1.49	10.78	2.76
Frctn Loss (ft)	1.23	Cum Volume (acre-ft)	11.64	4.07	4.31
C & E Loss (ft)	0.01	Cum SA (acres)	3.64	0.60	1.23

Campbell Creek

Q_2-400 cfs

: campfloods River: Campbell Creek Reach:Root Wads Riv Sta: 4.0 Profile: PF 3 E.G. Elev (ft)	99.83	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.30	Wt. n-Val.	0.060	0.035	0.060
W.S. Elev (ft)	99.53	Reach Len. (ft)	81.00	70.00	63.00
Crit W.S. (ft)		Flow Area (sq ft)	0.62	77.80	39.89
E.G. Slope (ft/ft)	0.002337	Area (sq ft)	0.62	77.80	39.89
Q Total (cfs)	400.00	Flow (cfs)	0.32	359.20	40.49
Top Width (ft)	72.05	Top Width (ft)	0.58	20.50	50.97
Vel Total (ft/s)	3.38	Avg. Vel. (ft/s)	0.51	4.62	1.02
Max Chl Dpth (ft)	5.23	Hydr. Depth (ft)	1.06	3.80	0.78
Conv. Total (cfs)	8274.2	Conv. (cfs)	6.6	7430.1	837.5
Length Wtd. (ft)	69.63	Wetted Per. (ft)	2.21	23.06	51.09
Min Ch El (ft)	94.30	Shear (lb/sq ft)	0.04	0.49	0.11
Alpha	1.68	Stream Power (lb/ft s)	0.02	2.27	0.12
Frctn Loss (ft)	0.14	Cum Volume (acre-ft)	0.02	0.90	0.07
C & E Loss (ft)	0.04	Cum SA (acres)	0.05	0.37	0.25

Q_{50}-950 cfs

: campfloods River: Campbell Creek Reach:Root Wads Riv Sta: 4.0 Profile: PF 4 E.G. Elev (ft)	101.28	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.61	Wt. n-Val.	0.060	0.035	0.060
W.S. Elev (ft)	100.68	Reach Len. (ft)	81.00	70.00	63.00
Crit W.S. (ft)	99.97	Flow Area (sq ft)	3.32	101.34	104.58
E.G. Slope (ft/ft)	0.003870	Area (sq ft)	3.32	101.34	104.58
Q Total (cfs)	950.00	Flow (cfs)	3.38	718.09	228.54
Top Width (ft)	86.56	Top Width (ft)	4.33	20.50	61.73
Vel Total (ft/s)	4.54	Avg. Vel. (ft/s)	1.02	7.09	2.19
Max Chl Dpth (ft)	6.38	Hydr. Depth (ft)	0.77	4.94	1.69
Conv. Total (cfs)	15270.5	Conv. (cfs)	54.3	11542.7	3673.5
Length Wtd. (ft)	69.12	Wetted Per. (ft)	6.16	23.06	61.91
Min Ch El (ft)	94.30	Shear (lb/sq ft)	0.13	1.06	0.41
Alpha	1.90	Stream Power (lb/ft s)	0.13	7.52	0.89
Frctn Loss (ft)	0.23	Cum Volume (acre-ft)	0.10	1.34	1.95
C & E Loss (ft)	0.06	Cum SA (acres)	0.08	0.37	2.22

Q_{100}-1230 cfs

: campfloods River: Campbell Creek Reach:Root Wads Riv Sta: 4.0 Profile: PF 5 E.G. Elev (ft)	101.79	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.80	Wt. n-Val.	0.060	0.035	0.060
W.S. Elev (ft)	100.99	Reach Len. (ft)	81.00	70.00	63.00
Crit W.S. (ft)	100.45	Flow Area (sq ft)	4.85	107.80	124.51
E.G. Slope (ft/ft)	0.004857	Area (sq ft)	4.85	107.80	124.51
Q Total (cfs)	1230.00	Flow (cfs)	6.38	891.76	331.86
Top Width (ft)	90.61	Top Width (ft)	5.42	20.50	64.68
Vel Total (ft/s)	5.19	Avg. Vel. (ft/s)	1.31	8.27	2.67
Max Chl Dpth (ft)	6.69	Hydr. Depth (ft)	0.89	5.26	1.92
Conv. Total (cfs)	17648.9	Conv. (cfs)	91.5	12795.7	4761.7
Length Wtd. (ft)	69.02	Wetted Per. (ft)	7.30	23.06	64.88
Min Ch El (ft)	94.30	Shear (lb/sq ft)	0.20	1.42	0.58
Alpha	1.92	Stream Power (lb/ft s)	0.26	11.73	1.55
Frctn Loss (ft)	0.29	Cum Volume (acre-ft)	0.13	1.46	2.72
C & E Loss (ft)	0.06	Cum SA (acres)	0.08	0.37	2.24

Chena River

Q_2-9270 cfs

: 03-all flood River: Chena River Reach:brush layering Riv Sta: 4.0 Profile: PF 3 E.G. Elev (ft)	106.55	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.20	Wt. n-Val.	0.060	0.035	0.060
W.S. Elev (ft)	106.36	Reach Len. (ft)	185.00	252.00	328.00
Crit W.S. (ft)		Flow Area (sq ft)	94.85	2567.50	2.39

E.G. Slope (ft/ft)	0.000281	Area (sq ft)	94.85	2567.50	2.39
Q Total (cfs)	9270.00	Flow (cfs)	65.88	9203.38	0.73
Top Width (ft)	270.48	Top Width (ft)	43.56	223.40	3.52
Vel Total (ft/s)	3.48	Avg. Vel. (ft/s)	0.69	3.58	0.31
Max Chl Dpth (ft)	14.66	Hydr. Depth (ft)	2.18	11.49	0.68
Conv. Total (cfs)	553472.4	Conv. (cfs)	3933.7	549495.1	43.6
Length Wtd. (ft)	251.55	Wetted Per. (ft)	43.77	226.84	3.78
Min Ch El (ft)	91.70	Shear (lb/sq ft)	0.04	0.20	0.01
Alpha	1.05	Stream Power (lb/ft s)	0.03	0.71	0.00
Frctn Loss (ft)	0.06	Cum Volume (acre-ft)	0.80	58.55	0.03
C & E Loss (ft)	0.01	Cum SA (acres)	0.25	4.86	0.05

Q-12,000 cfs

: 03-all flood River: Chena River Reach:brush layering Riv Sta: 4.0 Profile: PF 5 E.G. Elev (ft)	109.13	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.21	Wt. n-Val.	0.060	0.035	0.060
W.S. Elev (ft)	108.91	Reach Len. (ft)	185.00	252.00	328.00
Crit W.S. (ft)		Flow Area (sq ft)	234.88	3139.22	20.45
E.G. Slope (ft/ft)	0.000235	Area (sq ft)	234.88	3139.22	20.45
Q Total (cfs)	12000.00	Flow (cfs)	218.44	11770.49	11.07
Top Width (ft)	294.74	Top Width (ft)	60.00	223.40	11.34
Vel Total (ft/s)	3.54	Avg. Vel. (ft/s)	0.93	3.75	0.54
Max Chl Dpth (ft)	17.21	Hydr. Depth (ft)	3.91	14.05	1.80
Conv. Total (cfs)	783191.9	Conv. (cfs)	14257.0	768212.6	722.3
Length Wtd. (ft)	251.09	Wetted Per. (ft)	61.21	226.84	12.01
Min Ch El (ft)	91.70	Shear (lb/sq ft)	0.06	0.20	0.02
Alpha	1.10	Stream Power (lb/ft s)	0.05	0.76	0.01
Frctn Loss (ft)	0.05	Cum Volume (acre-ft)	1.52	71.11	0.40
C & E Loss (ft)	0.00	Cum SA (acres)	0.30	4.91	0.23

Q_{flood}-8870 cfs

: 03-all flood River: Chena River Reach:brush layering Riv Sta: 4.0 Profile: PF 2 E.G. Elev (ft)	105.19	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.24	Wt. n-Val.	0.060	0.035	
W.S. Elev (ft)	104.95	Reach Len. (ft)	185.00	252.00	328.00
Crit W.S. (ft)		Flow Area (sq ft)	43.57	2253.92	
E.G. Slope (ft/ft)	0.000399	Area (sq ft)	43.57	2253.92	
Q Total (cfs)	8870.00	Flow (cfs)	27.86	8842.14	
Top Width (ft)	252.82	Top Width (ft)	29.52	223.30	
Vel Total (ft/s)	3.86	Avg. Vel. (ft/s)	0.64	3.92	
Max Chl Dpth (ft)	13.25	Hydr. Depth (ft)	1.48	10.09	

Conv. Total (cfs)	443794.4	Conv. (cfs)	1394.0	442400.3	
Length Wtd. (ft)	251.77	Wetted Per. (ft)	29.67	226.73	
Min Ch El (ft)	91.70	Shear (lb/sq ft)	0.04	0.25	
Alpha	1.03	Stream Power (lb/ft s)	0.02	0.97	
Frctn Loss (ft)	0.09	Cum Volume (acre-ft)	0.47	51.51	
C & E Loss (ft)	0.01	Cum SA (acres)	0.22	4.82	

Deep Creek-xsec 5

Q_2-745 cfs

: 1 River: Deep Creek Reach:brushlayer Riv Sta: 5.0 Profile: PF 2 E.G. Elev (ft)	95.24	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.23	Wt. n-Val.		0.045	
W.S. Elev (ft)	95.01	Reach Len. (ft)	269.00	179.00	32.00
Crit W.S. (ft)		Flow Area (sq ft)		192.42	
E.G. Slope (ft/ft)	0.003398	Area (sq ft)		192.42	
Q Total (cfs)	745.00	Flow (cfs)		745.00	
Top Width (ft)	64.95	Top Width (ft)		64.95	
Vel Total (ft/s)	3.87	Avg. Vel. (ft/s)		3.87	
Max Chl Dpth (ft)	6.61	Hydr. Depth (ft)		2.96	
Conv. Total (cfs)	12780.6	Conv. (cfs)		12780.6	
Length Wtd. (ft)	179.00	Wetted Per. (ft)		67.45	
Min Ch El (ft)	88.40	Shear (lb/sq ft)		0.61	
Alpha	1.00	Stream Power (lb/ft s)		2.34	
Frctn Loss (ft)	0.97	Cum Volume (acre-ft)		2.84	
C & E Loss (ft)	0.02	Cum SA (acres)		1.29	

Q_{50}-1868 cfs

: 1 River: Deep Creek Reach:brushlayer Riv Sta: 5.0 Profile: PF 3 E.G. Elev (ft)	97.26	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.51	Wt. n-Val.		0.045	0.060
W.S. Elev (ft)	96.75	Reach Len. (ft)	269.00	179.00	32.00
Crit W.S. (ft)		Flow Area (sq ft)		319.71	17.37
E.G. Slope (ft/ft)	0.004898	Area (sq ft)		319.71	17.37
Q Total (cfs)	1868.00	Flow (cfs)		1845.33	22.67
Top Width (ft)	103.24	Top Width (ft)		76.74	26.50
Vel Total (ft/s)	5.54	Avg. Vel. (ft/s)		5.77	1.31
Max Chl Dpth (ft)	8.35	Hydr. Depth (ft)		4.17	0.66
Conv. Total (cfs)	26689.9	Conv. (cfs)		26366.1	323.9
Length Wtd. (ft)	178.11	Wetted Per. (ft)		81.00	26.58
Min Ch El (ft)	88.40	Shear (lb/sq ft)		1.21	0.20
Alpha	1.07	Stream Power (lb/ft s)		6.97	0.26
Frctn Loss (ft)	1.24	Cum Volume (acre-ft)		5.11	0.01
C & E Loss (ft)	0.02	Cum SA (acres)		1.62	0.01

Q_{100}-2107 cfs

: 1 River: Deep Creek Reach:brushlayer Riv Sta: 5.0 Profile: PF 4 E.G. Elev (ft)	97.58	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.57	Wt. n-Val.		0.045	0.060
W.S. Elev (ft)	97.01	Reach Len. (ft)	269.00	179.00	32.00
Crit W.S. (ft)		Flow Area (sq ft)		339.39	24.33
E.G. Slope (ft/ft)	0.005062	Area (sq ft)		339.39	24.33
Q Total (cfs)	2107.00	Flow (cfs)		2067.86	39.14
Top Width (ft)	104.54	Top Width (ft)		76.74	27.80
Vel Total (ft/s)	5.79	Avg. Vel. (ft/s)		6.09	1.61
Max Chl Dpth (ft)	8.61	Hydr. Depth (ft)		4.42	0.88
Conv. Total (cfs)	29615.9	Conv. (cfs)		29065.8	550.1
Length Wtd. (ft)	177.65	Wetted Per. (ft)		81.26	27.90
Min Ch El (ft)	88.40	Shear (lb/sq ft)		1.32	0.28
Alpha	1.09	Stream Power (lb/ft s)		8.04	0.44
Frctn Loss (ft)	1.25	Cum Volume (acre-ft)		5.52	0.01
C & E Loss (ft)	0.02	Cum SA (acres)		1.67	0.02

Qflood-9600 cfs (estimated)

: 1 River: Deep Creek Reach:brushlayer Riv Sta: 5.0 Profile: PF 7 E.G. Elev (ft)	103.85	Element	Left OB	Channel	Right OB
Vel Head (ft)	1.89	Wt. n-Val.		0.045	0.060
W.S. Elev (ft)	101.96	Reach Len. (ft)	269.00	179.00	32.00
Crit W.S. (ft)		Flow Area (sq ft)		719.73	224.09
E.G. Slope (ft/ft)	0.007316	Area (sq ft)		719.73	224.09
Q Total (cfs)	9600.00	Flow (cfs)		8365.46	1234.54
Top Width (ft)	129.65	Top Width (ft)		76.80	52.84
Vel Total (ft/s)	10.17	Avg. Vel. (ft/s)		11.62	5.51
Max Chl Dpth (ft)	13.56	Hydr. Depth (ft)		9.37	4.24
Conv. Total (cfs)	112235.6	Conv. (cfs)		97802.3	14433.3
Length Wtd. (ft)	168.25	Wetted Per. (ft)		86.21	53.43
Min Ch El (ft)	88.40	Shear (lb/sq ft)		3.81	1.92
Alpha	1.18	Stream Power (lb/ft s)		44.32	10.55
Frctn Loss (ft)	1.11	Cum Volume (acre-ft)	0.75	14.23	1.18
C & E Loss (ft)	0.10	Cum SA (acres)	0.91	1.97	0.52

Deep Creek-xsec 6

Q_2-745 cfs

: 1 River: Deep Creek Reach:brushlayer Riv Sta: 6.0 Profile: PF 2 E.G. Elev (ft)	95.79	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.23	Wt. n-Val.		0.045	
W.S. Elev (ft)	95.57	Reach Len. (ft)	220.00	128.00	79.00
Crit W.S. (ft)		Flow Area (sq ft)		194.66	

E.G. Slope (ft/ft)	0.005618	Area (sq ft)		194.66	
Q Total (cfs)	745.00	Flow (cfs)		745.00	
Top Width (ft)	97.19	Top Width (ft)		97.19	
Vel Total (ft/s)	3.83	Avg. Vel. (ft/s)		3.83	
Max Chl Dpth (ft)	5.52	Hydr. Depth (ft)		2.00	
Conv. Total (cfs)	9939.7	Conv. (cfs)		9939.7	
Length Wtd. (ft)	128.00	Wetted Per. (ft)		101.22	
Min Ch El (ft)	90.05	Shear (lb/sq ft)		0.67	
Alpha	1.00	Stream Power (lb/ft s)		2.58	
Frctn Loss (ft)	0.55	Cum Volume (acre-ft)		3.41	
C & E Loss (ft)	0.00	Cum SA (acres)		1.53	

Q_{50}-1868 cfs

: 1 River: Deep Creek Reach:brushlayer Riv Sta: 6.0 Profile: PF 3 E.G. Elev (ft)	97.85	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.17	Wt. n-Val.	0.060	0.045	0.060
W.S. Elev (ft)	97.68	Reach Len. (ft)	220.00	128.00	79.00
Crit W.S. (ft)		Flow Area (sq ft)	1.01	564.55	0.41
E.G. Slope (ft/ft)	0.003777	Area (sq ft)	1.01	564.55	0.41
Q Total (cfs)	1868.00	Flow (cfs)	0.67	1867.04	0.29
Top Width (ft)	268.30	Top Width (ft)	1.94	265.40	0.96
Vel Total (ft/s)	3.30	Avg. Vel. (ft/s)	0.66	3.31	0.71
Max Chl Dpth (ft)	7.63	Hydr. Depth (ft)	0.52	2.13	0.43
Conv. Total (cfs)	30396.3	Conv. (cfs)	10.9	30380.7	4.8
Length Wtd. (ft)	127.72	Wetted Per. (ft)	3.87	271.36	1.29
Min Ch El (ft)	90.05	Shear (lb/sq ft)	0.06	0.49	0.08
Alpha	1.00	Stream Power (lb/ft s)	0.04	1.62	0.05
Frctn Loss (ft)	0.55	Cum Volume (acre-ft)	0.00	6.41	0.02
C & E Loss (ft)	0.03	Cum SA (acres)	0.00	2.12	0.04

Q_{100}-2107 cfs

: 1 River: Deep Creek Reach:brushlayer Riv Sta: 6.0 Profile: PF 4 E.G. Elev (ft)	98.12	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.17	Wt. n-Val.	0.060	0.045	0.060
W.S. Elev (ft)	97.95	Reach Len. (ft)	220.00	128.00	79.00
Crit W.S. (ft)		Flow Area (sq ft)	1.83	637.99	0.72
E.G. Slope (ft/ft)	0.003194	Area (sq ft)	1.83	637.99	0.72
Q Total (cfs)	2107.00	Flow (cfs)	1.18	2105.26	0.57
Top Width (ft)	270.69	Top Width (ft)	4.02	265.40	1.27
Vel Total (ft/s)	3.29	Avg. Vel. (ft/s)	0.64	3.30	0.79
Max Chl Dpth (ft)	7.90	Hydr. Depth (ft)	0.46	2.40	0.57
Conv. Total (cfs)	37279.7	Conv. (cfs)	20.8	37248.8	10.0
Length Wtd. (ft)	127.56	Wetted Per. (ft)	6.36	271.36	1.70
Min Ch El (ft)	90.05	Shear (lb/sq ft)	0.06	0.47	0.08
Alpha	1.01	Stream Power (lb/ft s)	0.04	1.55	0.07
Frctn Loss (ft)	0.51	Cum Volume (acre-ft)	0.00	6.96	0.03
C & E Loss (ft)	0.04	Cum SA (acres)	0.01	2.17	0.04

Qflood-9600 cfs (estimated)

: 1 River: Deep Creek Reach:brushlayer Riv Sta: 6.0 Profile: E.G. Elev (ft)	104.27	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.25	Wt. n-Val.	0.060	0.045	0.060
W.S. Elev (ft)	104.01	Reach Len. (ft)	220.00	128.00	79.00
Crit W.S. (ft)		Flow Area (sq ft)	105.06	2246.36	239.22
E.G. Slope (ft/ft)	0.000925	Area (sq ft)	105.06	2246.36	239.22
Q Total (cfs)	9600.00	Flow (cfs)	182.09	9232.22	185.69
Top Width (ft)	538.18	Top Width (ft)	23.69	265.40	249.10
Vel Total (ft/s)	3.71	Avg. Vel. (ft/s)	1.73	4.11	0.78
Max Chl Dpth (ft)	13.96	Hydr. Depth (ft)	4.44	8.46	0.96
Conv. Total (cfs)	315634.	Conv. (cfs)	5986.7	303542.	6105.3
Length Wtd. (ft)	125.25	Wetted Per. (ft)	30.10	271.36	250.82
Min Ch El (ft)	90.05	Shear (lb/sq ft)	0.20	0.48	0.06
Alpha	1.19	Stream Power (lb/ft s)	0.35	1.96	0.04
Frctn Loss (ft)	0.25	Cum Volume (acre-ft)	1.02	18.59	1.60
C & E Loss (ft)	0.16	Cum SA (acres)	0.97	2.48	0.79

Deep Creek-xsec 7

Q_2-745 cfs

: 1 River: Deep Creek Reach:brushlayer Riv Sta: 7.0 Profile: PF 2 E.G. Elev (ft)	96.75	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.18	Wt. n-Val.		0.045	
W.S. Elev (ft)	96.58	Reach Len. (ft)	255.00	186.00	176.00
Crit W.S. (ft)		Flow Area (sq ft)		221.32	
E.G. Slope (ft/ft)	0.004723	Area (sq ft)		221.32	
Q Total (cfs)	745.00	Flow (cfs)		745.00	
Top Width (ft)	119.62	Top Width (ft)		119.62	
Vel Total (ft/s)	3.37	Avg. Vel. (ft/s)		3.37	
Max Chl Dpth (ft)	3.63	Hydr. Depth (ft)		1.85	
Conv. Total (cfs)	10840.6	Conv. (cfs)		10840.6	
Length Wtd. (ft)	186.00	Wetted Per. (ft)		122.50	
Min Ch El (ft)	92.95	Shear (lb/sq ft)		0.53	
Alpha	1.00	Stream Power (lb/ft s)		1.79	
Frctn Loss (ft)	0.96	Cum Volume (acre-ft)		4.30	
C & E Loss (ft)	0.01	Cum SA (acres)		1.99	

Q_{50}-1868 cfs

: 1 River: Deep Creek Reach:brushlayer Riv Sta: 7.0 Profile: PF 3 E.G. Elev (ft)	98.67	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.20	Wt. n-Val.	0.060	0.045	
W.S. Elev (ft)	98.47	Reach Len. (ft)	255.00	186.00	176.0

					0
Crit W.S. (ft)		Flow Area (sq ft)	7.13	518.35	
E.G. Slope (ft/ft)	0.005111	Area (sq ft)	7.13	518.35	
Q Total (cfs)	1868.00	Flow (cfs)	8.34	1859.66	
Top Width (ft)	286.79	Top Width (ft)	14.45	272.34	
Vel Total (ft/s)	3.55	Avg. Vel. (ft/s)	1.17	3.59	
Max Chl Dpth (ft)	5.52	Hydr. Depth (ft)	0.49	1.90	
Conv. Total (cfs)	26129.4	Conv. (cfs)	116.7	26012.7	
Length Wtd. (ft)	186.17	Wetted Per. (ft)	14.72	276.66	
Min Ch El (ft)	92.95	Shear (lb/sq ft)	0.15	0.60	
Alpha	1.01	Stream Power (lb/ft s)	0.18	2.14	
Frctn Loss (ft)	0.81	Cum Volume (acre-ft)	0.03	8.72	0.02
C & E Loss (ft)	0.01	Cum SA (acres)	0.05	3.27	0.04

Q_{100}-2107 cfs

: 1 River: Deep Creek Reach:brushlayer Riv Sta: 7.0 Profile: PF 4 E.G. Elev (ft)	98.86	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.21	Wt. n-Val.	0.060	0.045	
W.S. Elev (ft)	98.65	Reach Len. (ft)	255.00	186.00	176.00
Crit W.S. (ft)		Flow Area (sq ft)	9.95	566.52	
E.G. Slope (ft/ft)	0.004829	Area (sq ft)	9.95	566.52	
Q Total (cfs)	2107.00	Flow (cfs)	12.26	2094.74	
Top Width (ft)	290.02	Top Width (ft)	17.43	272.59	
Vel Total (ft/s)	3.66	Avg. Vel. (ft/s)	1.23	3.70	
Max Chl Dpth (ft)	5.70	Hydr. Depth (ft)	0.57	2.08	
Conv. Total (cfs)	30319.7	Conv. (cfs)	176.4	30143.4	
Length Wtd. (ft)	186.22	Wetted Per. (ft)	17.75	276.96	
Min Ch El (ft)	92.95	Shear (lb/sq ft)	0.17	0.62	
Alpha	1.02	Stream Power (lb/ft s)	0.21	2.28	
Frctn Loss (ft)	0.72	Cum Volume (acre-ft)	0.04	9.53	0.03
C & E Loss (ft)	0.01	Cum SA (acres)	0.07	3.32	0.04

Qflood-9600 cfs (estimated)

: 1 River: Deep Creek Reach:brushlayer Riv Sta: 7.0 Profile: PF 7 E.G. Elev (ft)	104.45	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.22	Wt. n-Val.	0.060	0.045	0.060
W.S. Elev (ft)	104.23	Reach Len. (ft)	255.00	186.00	176.00
Crit W.S. (ft)		Flow Area (sq ft)	627.11	2103.53	134.63
E.G. Slope (ft/ft)	0.000989	Area (sq ft)	627.11	2103.53	134.63
Q Total (cfs)	9600.00	Flow (cfs)	1142.51	8361.78	95.71
Top Width (ft)	604.62	Top Width (ft)	174.47	275.80	154.35
Vel Total (ft/s)	3.35	Avg. Vel. (ft/s)	1.82	3.98	0.71
Max Chl Dpth (ft)	11.28	Hydr. Depth (ft)	3.59	7.63	0.87
Conv. Total (cfs)	305223.6	Conv. (cfs)	36325.2	265855.3	3043.0

Length Wtd. (ft)	190.61	Wetted Per. (ft)	175.31	280.92	154.86
Min Ch El (ft)	92.95	Shear (lb/sq ft)	0.22	0.46	0.05
Alpha	1.26	Stream Power (lb/ft s)	0.40	1.84	0.04
Frctn Loss (ft)	0.18	Cum Volume (acre-ft)	3.16	27.88	2.36
C & E Loss (ft)	0.00	Cum SA (acres)	1.55	3.63	1.61

Kenai River-Centennial Park

Q_2-19400 cfs

: kencent River: Kenai River Reach:root wads Riv Sta: 4.0 Profile: PF 4 E.G. Elev (ft)	86.64	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.71	Wt. n-Val.		0.030	
W.S. Elev (ft)	85.93	Reach Len. (ft)	566.00	701.00	839.00
Crit W.S. (ft)		Flow Area (sq ft)		2864.31	
E.G. Slope (ft/ft)	0.001982	Area (sq ft)		2864.31	
Q Total (cfs)	19400.00	Flow (cfs)		19400.00	
Top Width (ft)	530.47	Top Width (ft)		530.47	
Vel Total (ft/s)	6.77	Avg. Vel. (ft/s)		6.77	
Max Chl Dpth (ft)	7.35	Hydr. Depth (ft)		5.40	
Conv. Total (cfs)	435745.8	Conv. (cfs)		435745.8	
Length Wtd. (ft)	701.00	Wetted Per. (ft)		532.12	
Min Ch El (ft)	78.58	Shear (lb/sq ft)		0.67	
Alpha	1.00	Stream Power (lb/ft s)		4.51	
Frctn Loss (ft)	1.05	Cum Volume (acre-ft)		162.50	
C & E Loss (ft)	0.05	Cum SA (acres)		26.86	

Q_{50}-36,300 cfs

: kencent River: Kenai River Reach:root wads Riv Sta: 4.0 Profile: PF 5 E.G. Elev (ft)	89.83	Element	Left OB	Channel	Right OB
Vel Head (ft)	1.07	Wt. n-Val.	0.065	0.030	0.065
W.S. Elev (ft)	88.75	Reach Len. (ft)	566.00	701.00	839.00
Crit W.S. (ft)		Flow Area (sq ft)	0.02	4367.18	2.63
E.G. Slope (ft/ft)	0.001723	Area (sq ft)	0.02	4367.18	2.63
Q Total (cfs)	36300.00	Flow (cfs)	0.00	36297.82	2.17
Top Width (ft)	537.03	Top Width (ft)	0.31	534.50	2.22
Vel Total (ft/s)	8.31	Avg. Vel. (ft/s)	0.16	8.31	0.82
Max Chl Dpth (ft)	10.17	Hydr. Depth (ft)	0.08	8.17	1.19
Conv. Total (cfs)	874579.9	Conv. (cfs)	0.1	874527.5	52.3
Length Wtd. (ft)	701.03	Wetted Per. (ft)	0.35	537.22	3.25
Min Ch El (ft)	78.58	Shear (lb/sq ft)	0.01	0.87	0.09
Alpha	1.00	Stream Power (lb/ft s)	0.00	7.27	0.07
Frctn Loss (ft)	1.01	Cum Volume (acre-ft)	0.58	237.41	0.19
C & E Loss (ft)	0.05	Cum SA (acres)	0.74	27.08	0.10

Q_{100}-40,000 cfs

: kencent River: Kenai	90.44	Element	Left	Channel	Right

River Reach:rootwads Riv Sta: 4.0 Profile: PF 6 E.G. Elev (ft)			OB		OB
Vel Head (ft)	1.15	Wt. n-Val.	0.065	0.030	0.065
W.S. Elev (ft)	89.29	Reach Len. (ft)	566.00	701.00	839.00
Crit W.S. (ft)		Flow Area (sq ft)	0.46	4653.44	3.96
E.G. Slope (ft/ft)	0.001693	Area (sq ft)	0.46	4653.44	3.96
Q Total (cfs)	40000.00	Flow (cfs)	0.20	39996.10	3.70
Top Width (ft)	538.54	Top Width (ft)	1.32	534.50	2.72
Vel Total (ft/s)	8.59	Avg. Vel. (ft/s)	0.43	8.59	0.94
Max Chl Dpth (ft)	10.71	Hydr. Depth (ft)	0.35	8.71	1.45
Conv. Total (cfs)	972233.3	Conv. (cfs)	4.8	972138.4	90.0
Length Wtd. (ft)	701.03	Wetted Per. (ft)	1.49	537.22	3.98
Min Ch El (ft)	78.58	Shear (lb/sq ft)	0.03	0.92	0.10
Alpha	1.00	Stream Power (lb/ft s)	0.01	7.87	0.10
Frctn Loss (ft)	1.01	Cum Volume (acre-ft)	1.05	251.69	0.24
C & E Loss (ft)	0.05	Cum SA (acres)	1.09	27.10	0.11

Q_{flood}=27,600 cfs

: kencent River: Kenai River Reach:rootwads Riv Sta: 4.0 Profile: PF 7 E.G. Elev (ft)	88.28	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.89	Wt. n-Val.		0.030	0.065
W.S. Elev (ft)	87.39	Reach Len. (ft)	566.0	701.00	839.00
Crit W.S. (ft)		Flow Area (sq ft)		3639.50	0.48
E.G. Slope (ft/ft)	0.001819	Area (sq ft)		3639.50	0.48
Q Total (cfs)	27600.00	Flow (cfs)		27599.77	0.23
Top Width (ft)	533.81	Top Width (ft)		532.87	0.94
Vel Total (ft/s)	7.58	Avg. Vel. (ft/s)		7.58	0.48
Max Chl Dpth (ft)	8.81	Hydr. Depth (ft)		6.83	0.50
Conv. Total (cfs)	647049.9	Conv. (cfs)		647044.6	5.4
Length Wtd. (ft)	701.01	Wetted Per. (ft)		535.20	1.38
Min Ch El (ft)	78.58	Shear (lb/sq ft)		0.77	0.04
Alpha	1.00	Stream Power (lb/ft s)		5.86	0.02
Frctn Loss (ft)	1.03	Cum Volume (acre-ft)	0.03	201.20	0.07
C & E Loss (ft)	0.05	Cum SA (acres)	0.15	26.99	0.07

Kenai River at Riddle Property

Q_2-19,400 cfs

: Plan 01 River: KenaiRiver-Riddl Reach:rootwad Riv Sta: 2.0 Profile: PF 2 E.G. Elev (ft)	85.30	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.31	Wt. n-Val.	0.060	0.035	
W.S. Elev (ft)	84.99	Reach Len. (ft)	1292.00	1077.00	994.00
Crit W.S. (ft)		Flow Area (sq ft)	17.79	4312.41	
E.G. Slope (ft/ft)	0.000370	Area (sq ft)	17.79	4312.41	
Q Total (cfs)	19400.00	Flow (cfs)	8.39	19391.61	
Top Width (ft)	341.21	Top Width (ft)	17.92	323.29	

Vel Total (ft/s)	4.48	Avg. Vel. (ft/s)	0.47	4.50	
Max Chl Dpth (ft)	24.69	Hydr. Depth (ft)	0.99	13.34	
Conv. Total (cfs)	1009177.3	Conv. (cfs)	436.6	1008740.6	
Length Wtd. (ft)	1077.41	Wetted Per. (ft)	18.03	333.44	
Min Ch El (ft)	60.30	Shear (lb/sq ft)	0.02	0.30	
Alpha	1.01	Stream Power (lb/ft s)	0.01	1.34	
Frctn Loss (ft)	0.46	Cum Volume (acre-ft)	2.35	116.26	0.02
C & E Loss (ft)	0.03	Cum SA (acres)	2.89	11.83	0.02

Q_{50}-36,300 cfs

: Plan 01 River: KenaiRiver-Riddl Reach:rootwad Riv Sta: 2.0 Profile: PF 3 E.G. Elev (ft)	89.03	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.66	Wt. n-Val.	0.060	0.035	0.060
W.S. Elev (ft)	88.37	Reach Len. (ft)	1292.00	1077.00	994.00
Crit W.S. (ft)		Flow Area (sq ft)	940.94	5405.69	4.03
E.G. Slope (ft/ft)	0.000593	Area (sq ft)	940.94	5405.69	4.03
Q Total (cfs)	36300.00	Flow (cfs)	714.36	35584.42	1.22
Top Width (ft)	1000.37	Top Width (ft)	665.85	323.50	11.02
Vel Total (ft/s)	5.72	Avg. Vel. (ft/s)	0.76	6.58	0.30
Max Chl Dpth (ft)	28.07	Hydr. Depth (ft)	1.41	16.71	0.37
Conv. Total (cfs)	1490758.4	Conv. (cfs)	29337.2	1461371.1	50.1
Length Wtd. (ft)	1083.83	Wetted Per. (ft)	666.11	336.42	11.32
Min Ch El (ft)	60.30	Shear (lb/sq ft)	0.05	0.59	0.01
Alpha	1.30	Stream Power (lb/ft s)	0.04	3.92	0.00
Frctn Loss (ft)	0.59	Cum Volume (acre-ft)	43.08	156.87	0.18
C & E Loss (ft)	0.10	Cum SA (acres)	26.42	11.96	0.17

Q_{100}-40,000 cfs

: Plan 01 River: KenaiRiver-Riddl Reach:rootwad Riv Sta: 2.0 Profile: PF 4 E.G. Elev (ft)	89.64	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.72	Wt. n-Val.	0.060	0.035	0.060
W.S. Elev (ft)	88.92	Reach Len. (ft)	1292.00	1077.00	994.00
Crit W.S. (ft)		Flow Area (sq ft)	1309.49	5583.56	10.10
E.G. Slope (ft/ft)	0.000630	Area (sq ft)	1309.49	5583.56	10.10
Q Total (cfs)	40000.0	Flow (cfs)	1266.68	38727.68	5.64
Top Width (ft)	1009.20	Top Width (ft)	674.65	323.50	11.05
Vel Total (ft/s)	5.79	Avg. Vel. (ft/s)	0.97	6.94	0.56
Max Chl Dpth (ft)	28.62	Hydr. Depth (ft)	1.94	17.26	0.91
Conv. Total (cfs)	1593065.4	Conv. (cfs)	50447.8	1542393.	224.5
Length Wtd. (ft)	1086.64	Wetted Per. (ft)	674.93	336.42	11.87
Min Ch El (ft)	60.30	Shear (lb/sq ft)	0.08	0.65	0.03
Alpha	1.39	Stream Power (lb/ft s)	0.07	4.53	0.02
Frctn Loss (ft)	0.61	Cum Volume (acre-ft)	58.76	163.55	0.28
C & E Loss (ft)	0.11	Cum SA (acres)	29.76	11.96	0.18

Q_{flood}=27,600 cfs

: Plan 01 River:	87.32	Element	Left	Channel	Right

KenaiRiver-Riddl Reach:rootwad Riv Sta: 2.0 Profile: PF 5 E.G. Elev (ft)			OB		OB
Vel Head (ft)	0.49	Wt. n-Val.	0.060	0.035	
W.S. Elev (ft)	86.83	Reach Len. (ft)	1292.0	1077.00	994.00
Crit W.S. (ft)		Flow Area (sq ft)	66.33	4910.14	
E.G. Slope (ft/ft)	0.000487	Area (sq ft)	66.33	4910.14	
Q Total (cfs)	27600.00	Flow (cfs)	55.74	27544.27	
Top Width (ft)	358.02	Top Width (ft)	34.60	323.42	
Vel Total (ft/s)	5.55	Avg. Vel. (ft/s)	0.84	5.61	
Max Chl Dpth (ft)	26.53	Hydr. Depth (ft)	1.92	15.18	
Conv. Total (cfs)	1250282.1	Conv. (cfs)	2524.8	1247757.	
Length Wtd. (ft)	1079.11	Wetted Per. (ft)	34.82	335.30	
Min Ch El (ft)	60.30	Shear (lb/sq ft)	0.06	0.45	
Alpha	1.02	Stream Power (lb/ft s)	0.05	2.50	
Frctn Loss (ft)	0.53	Cum Volume (acre-ft)	11.25	138.33	0.07
C & E Loss (ft)	0.06	Cum SA (acres)	8.16	11.96	0.03

Ship Creek at Cottonwood Park

Q_2-850 cfs

: ship River: Ship Creek Reach:root wads Riv Sta: 5.0 Profile: PF 2 E.G. Elev (ft)	110.90	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.34	Wt. n-Val.	0.060	0.035	
W.S. Elev (ft)	110.56	Reach Len. (ft)	199.00	235.00	243.00
Crit W.S. (ft)		Flow Area (sq ft)	0.91	182.11	
E.G. Slope (ft/ft)	0.008786	Area (sq ft)	0.91	182.11	
Q Total (cfs)	850.00	Flow (cfs)	1.14	848.86	
Top Width (ft)	143.95	Top Width (ft)	2.10	141.86	
Vel Total (ft/s)	4.64	Avg. Vel. (ft/s)	1.26	4.66	
Max Chl Dpth (ft)	2.86	Hydr. Depth (ft)	0.43	1.28	
Conv. Total (cfs)	9068.2	Conv. (cfs)	12.2	9056.1	
Length Wtd. (ft)	234.98	Wetted Per. (ft)	2.27	143.65	
Min Ch El (ft)	107.70	Shear (lb/sq ft)	0.22	0.70	
Alpha	1.01	Stream Power (lb/ft s)	0.28	3.24	
Frctn Loss (ft)	1.63	Cum Volume (acre-ft)	0.00	3.93	0.05
C & E Loss (ft)	0.02	Cum SA (acres)	0.00	2.57	0.14

Q_{50}-1900 cfs

: ship River: Ship Creek Reach:root wads Riv Sta: 5.0 Profile: PF 3 E.G. Elev (ft)	111.98	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.51	Wt. n-Val.	0.060	0.035	
W.S. Elev (ft)	111.47	Reach Len. (ft)	199.00	235.00	243.00
Crit W.S. (ft)		Flow Area (sq ft)	3.80	329.89	
E.G. Slope (ft/ft)	0.007349	Area (sq ft)	3.80	329.89	
Q Total (cfs)	1900.00	Flow (cfs)	7.05	1892.95	
Top Width (ft)	168.74	Top Width (ft)	4.29	164.45	
Vel Total (ft/s)	5.69	Avg. Vel. (ft/s)	1.86	5.74	

Max Chl Dpth (ft)	3.77	Hydr. Depth (ft)	0.89	2.01	
Conv. Total (cfs)	22164.2	Conv. (cfs)	82.3	22081.9	
Length Wtd. (ft)	234.92	Wetted Per. (ft)	4.64	166.63	
Min Ch El (ft)	107.70	Shear (lb/sq ft)	0.38	0.91	
Alpha	1.01	Stream Power (lb/ft s)	0.70	5.21	
Frctn Loss (ft)	1.50	Cum Volume (acre-ft)	0.11	6.53	0.34
C & E Loss (ft)	0.00	Cum SA (acres)	0.23	2.69	0.35

Q_{100}-2150 cfs

: ship River: Ship Creek Reach:root wads Riv Sta: 5.0 Profile: PF 4 E.G. Elev (ft)	112.20	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.55	Wt. n-Val.	0.060	0.035	
W.S. Elev (ft)	111.65	Reach Len. (ft)	199.00	235.00	243.00
Crit W.S. (ft)		Flow Area (sq ft)	4.62	360.01	
E.G. Slope (ft/ft)	0.007041	Area (sq ft)	4.62	360.01	
Q Total (cfs)	2150.00	Flow (cfs)	8.98	2141.02	
Top Width (ft)	169.38	Top Width (ft)	4.73	164.64	
Vel Total (ft/s)	5.90	Avg. Vel. (ft/s)	1.94	5.95	
Max Chl Dpth (ft)	3.95	Hydr. Depth (ft)	0.98	2.19	
Conv. Total (cfs)	25623.3	Conv. (cfs)	107.0	25516.3	
Length Wtd. (ft)	234.91	Wetted Per. (ft)	5.12	166.90	
Min Ch El (ft)	107.70	Shear (lb/sq ft)	0.40	0.95	
Alpha	1.01	Stream Power (lb/ft s)	0.77	5.64	
Frctn Loss (ft)	1.48	Cum Volume (acre-ft)	0.18	7.05	0.44
C & E Loss (ft)	0.00	Cum SA (acres)	0.35	2.70	0.42

Q_{flood} = 826 cfs

: ship River: Ship Creek Reach:root wads Riv Sta: 5.0 Profile: PF 5 E.G. Elev (ft)	110.87	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.33	Wt. n-Val.	0.060	0.035	
W.S. Elev (ft)	110.54	Reach Len. (ft)	199.00	235.00	243.00
Crit W.S. (ft)		Flow Area (sq ft)	0.85	178.54	
E.G. Slope (ft/ft)	0.008811	Area (sq ft)	0.85	178.54	
Q Total (cfs)	826.00	Flow (cfs)	1.05	824.95	
Top Width (ft)	143.27	Top Width (ft)	2.03	141.24	
Vel Total (ft/s)	4.60	Avg. Vel. (ft/s)	1.24	4.62	
Max Chl Dpth (ft)	2.84	Hydr. Depth (ft)	0.42	1.26	
Conv. Total (cfs)	8799.8	Conv. (cfs)	11.2	8788.6	
Length Wtd. (ft)	234.98	Wetted Per. (ft)	2.20	143.00	
Min Ch El (ft)	107.70	Shear (lb/sq ft)	0.21	0.69	
Alpha	1.01	Stream Power (lb/ft s)	0.26	3.17	
Frctn Loss (ft)	1.63	Cum Volume (acre-ft)	0.00	3.86	0.04
C & E Loss (ft)	0.02	Cum SA (acres)	0.00	2.57	0.13

Theodore River

Q_2-940 cfs

: 1 River: Theodore River Reach:root wads Riv Sta: 5.0 Profile: PF 2 E.G. Elev (ft)	101.87	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.05	Wt. n-Val.	0.060	0.045	
W.S. Elev (ft)	101.82	Reach Len. (ft)	113.00	113.00	113.00
Crit W.S. (ft)	96.74	Flow Area (sq ft)	71.17	492.58	
E.G. Slope (ft/ft)	0.000295	Area (sq ft)	71.17	492.58	
Q Total (cfs)	940.00	Flow (cfs)	32.63	907.37	
Top Width (ft)	144.39	Top Width (ft)	63.25	81.13	
Vel Total (ft/s)	1.67	Avg. Vel. (ft/s)	0.46	1.84	
Max Chl Dpth (ft)	8.12	Hydr. Depth (ft)	1.13	6.07	
Conv. Total (cfs)	54752.7	Conv. (cfs)	1900.7	52852.0	
Length Wtd. (ft)	113.00	Wetted Per. (ft)	63.56	84.10	
Min Ch El (ft)	93.70	Shear (lb/sq ft)	0.02	0.11	
Alpha	1.18	Stream Power (lb/ft s)	0.01	0.20	
Frctn Loss (ft)	0.11	Cum Volume (acre-ft)	0.19	5.97	0.56
C & E Loss (ft)	0.15	Cum SA (acres)	0.28	1.30	0.53

Q_{50}-2340 cfs

: 1 River: Theodore River Reach:root wads Riv Sta: 5.0 Profile: PF 3 E.G. Elev (ft)	104.61	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.11	Wt. n-Val.	0.060	0.045	0.060
W.S. Elev (ft)	104.50	Reach Len. (ft)	113.00	113.00	113.00
Crit W.S. (ft)	98.40	Flow Area (sq ft)	276.94	715.64	0.39
E.G. Slope (ft/ft)	0.000458	Area (sq ft)	276.94	715.64	0.39
Q Total (cfs)	2340.00	Flow (cfs)	308.40	2031.56	0.04
Top Width (ft)	179.78	Top Width (ft)	90.56	85.30	3.93
Vel Total (ft/s)	2.36	Avg. Vel. (ft/s)	1.11	2.84	0.11
Max Chl Dpth (ft)	10.80	Hydr. Depth (ft)	3.06	8.39	0.10
Conv. Total (cfs)	109290.1	Conv. (cfs)	14403.9	94884.2	2.0
Length Wtd. (ft)	113.00	Wetted Per. (ft)	90.99	88.95	3.93
Min Ch El (ft)	93.70	Shear (lb/sq ft)	0.09	0.23	0.00
Alpha	1.29	Stream Power (lb/ft s)	0.10	0.65	0.00
Frctn Loss (ft)	0.15	Cum Volume (acre-ft)	1.61	8.83	2.22
C & E Loss (ft)	0.15	Cum SA (acres)	0.80	1.31	0.96

Q_{100}-2650 cfs

: 1 River: Theodore River Reach:root wads Riv Sta: 5.0 Profile: PF 4 E.G. Elev (ft)	105.04	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.12	Wt. n-Val.	0.060	0.045	0.060
W.S. Elev (ft)	104.92	Reach Len. (ft)	113.00	113.00	113.00
Crit W.S. (ft)	98.71	Flow Area (sq ft)	315.98	751.57	8.20
E.G. Slope (ft/ft)	0.000484	Area (sq ft)	315.98	751.57	8.20
Q Total (cfs)	2650.00	Flow (cfs)	382.87	2265.58	1.55
Top Width (ft)	220.12	Top Width (ft)	94.85	85.30	39.97
Vel Total (ft/s)	2.46	Avg. Vel. (ft/s)	1.21	3.01	0.19
Max Chl Dpth (ft)	11.22	Hydr. Depth (ft)	3.33	8.81	0.21
Conv. Total (cfs)	120423.8	Conv. (cfs)	17398.8	102954.	70.6

Length Wtd. (ft)	113.00	Wetted Per. (ft)	95.31	88.95	39.97
Min Ch El (ft)	93.70	Shear (lb/sq ft)	0.10	0.26	0.01
Alpha	1.32	Stream Power (lb/ft s)	0.12	0.77	0.00
Frctn Loss (ft)	0.16	Cum Volume (acre-ft)	1.88	9.28	2.56
C & E Loss (ft)	0.16	Cum SA (acres)	0.82	1.31	1.05

Q_{flood}-2020 cfs

: 1 River: Theodore River Reach:root wads Riv Sta: 5.0 Profile: PF 5 E.G. Elev (ft)	104.13	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.10	Wt. n-Val.	0.060	0.045	
W.S. Elev (ft)	104.03	Reach Len. (ft)	113.00	113.00	113.00
Crit W.S. (ft)	98.07	Flow Area (sq ft)	236.09	676.19	
E.G. Slope (ft/ft)	0.000424	Area (sq ft)	236.09	676.19	
Q Total (cfs)	2020.00	Flow (cfs)	235.57	1784.43	
Top Width (ft)	170.68	Top Width (ft)	85.83	84.85	
Vel Total (ft/s)	2.21	Avg. Vel. (ft/s)	1.00	2.64	
Max Chl Dpth (ft)	10.33	Hydr. Depth (ft)	2.75	7.97	
Conv. Total (cfs)	98107.8	Conv. (cfs)	11441.3	86666.5	
Length Wtd. (ft)	113.00	Wetted Per. (ft)	86.24	88.42	
Min Ch El (ft)	93.70	Shear (lb/sq ft)	0.07	0.20	
Alpha	1.28	Stream Power (lb/ft s)	0.07	0.53	
Frctn Loss (ft)	0.14	Cum Volume (acre-ft)	1.31	8.34	1.88
C & E Loss (ft)	0.14	Cum SA (acres)	0.79	1.31	0.91

Willow Creek at Lapham Property

Q_2-1610 cfs

: willowlapham River: Willow Creek-Lap Reach:root wad Riv Sta: 5.0 Profile: PF 2 E.G. Elev (ft)	97.60	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.41	Wt. n-Val.	0.060	0.045	
W.S. Elev (ft)	97.19	Reach Len. (ft)	146.00	286.00	360.00
Crit W.S. (ft)		Flow Area (sq ft)	41.97	292.03	
E.G. Slope (ft/ft)	0.005486	Area (sq ft)	41.97	292.03	
Q Total (cfs)	1610.00	Flow (cfs)	75.05	1534.95	
Top Width (ft)	139.15	Top Width (ft)	47.51	91.64	
Vel Total (ft/s)	4.82	Avg. Vel. (ft/s)	1.79	5.26	
Max Chl Dpth (ft)	4.39	Hydr. Depth (ft)	0.88	3.19	
Conv. Total (cfs)	21736.4	Conv. (cfs)	1013.2	20723.2	
Length Wtd. (ft)	271.28	Wetted Per. (ft)	48.13	92.70	
Min Ch El (ft)	92.80	Shear (lb/sq ft)	0.30	1.08	
Alpha	1.14	Stream Power (lb/ft s)	0.53	5.67	
Frctn Loss (ft)	1.53	Cum Volume (acre-ft)	0.51	8.46	0.20
C & E Loss (ft)	0.02	Cum SA (acres)	0.35	2.87	0.19

Q_{50}-3740 cfs

: willowlapham River: Willow Creek-Lap Reach:root wad Riv	99.52	Element	Left OB	Channel	Right OB

Sta: 5.0 Profile: PF 3 E.G. Elev (ft)					
Vel Head (ft)	0.57	Wt. n-Val.	0.060	0.045	
W.S. Elev (ft)	98.95	Reach Len. (ft)	146.00	286.00	360.00
Crit W.S. (ft)		Flow Area (sq ft)	350.58	454.96	
E.G. Slope (ft/ft)	0.005095	Area (sq ft)	350.58	454.96	
Q Total (cfs)	3740.00	Flow (cfs)	702.87	3037.13	
Top Width (ft)	382.84	Top Width (ft)	289.09	93.76	
Vel Total (ft/s)	4.64	Avg. Vel. (ft/s)	2.00	6.68	
Max Chl Dpth (ft)	6.15	Hydr. Depth (ft)	1.21	4.85	
Conv. Total (cfs)	52395.9	Conv. (cfs)	9846.9	42548.9	
Length Wtd. (ft)	257.65	Wetted Per. (ft)	290.25	95.45	
Min Ch El (ft)	92.80	Shear (lb/sq ft)	0.38	1.52	
Alpha	1.71	Stream Power (lb/ft s)	0.77	10.12	
Frctn Loss (ft)	1.32	Cum Volume (acre-ft)	2.35	14.10	1.48
C & E Loss (ft)	0.02	Cum SA (acres)	1.91	2.98	1.34

Q_{100}-4150 cfs

: willowlapham River: Willow Creek-Lap Reach:root wad Riv Sta: 5.0 Profile: PF 4 E.G. Elev (ft)	99.74	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.59	Wt. n-Val.	0.060	0.045	
W.S. Elev (ft)	99.15	Reach Len. (ft)	146.00	286.00	360.00
Crit W.S. (ft)		Flow Area (sq ft)	409.05	473.82	
E.G. Slope (ft/ft)	0.005111	Area (sq ft)	409.05	473.82	
Q Total (cfs)	4150.00	Flow (cfs)	902.22	3247.78	
Top Width (ft)	387.00	Top Width (ft)	293.00	94.00	
Vel Total (ft/s)	4.70	Avg. Vel. (ft/s)	2.21	6.85	
Max Chl Dpth (ft)	6.35	Hydr. Depth (ft)	1.40	5.04	
Conv. Total (cfs)	58049.4	Conv. (cfs)	12620.1	45429.3	
Length Wtd. (ft)	253.30	Wetted Per. (ft)	294.17	95.76	
Min Ch El (ft)	92.80	Shear (lb/sq ft)	0.44	1.58	
Alpha	1.71	Stream Power (lb/ft s)	0.98	10.82	
Frctn Loss (ft)	1.25	Cum Volume (acre-ft)	2.89	14.99	1.99
C & E Loss (ft)	0.03	Cum SA (acres)	2.04	2.99	1.83

Q_{flood}-1950 cfs

: willowlapham River: Willow Creek-Lap Reach:root wad Riv Sta: 5.0 Profile: PF 5 E.G. Elev (ft)	98.01	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.47	Wt. n-Val.	0.060	0.045	
W.S. Elev (ft)	97.54	Reach Len. (ft)	146.00	286.00	360.00
Crit W.S. (ft)		Flow Area (sq ft)	61.16	323.90	
E.G. Slope (ft/ft)	0.005571	Area (sq ft)	61.16	323.90	
Q Total (cfs)	1950.00	Flow (cfs)	118.85	1831.15	
Top Width (ft)	167.55	Top Width (ft)	75.49	92.06	
Vel Total (ft/s)	5.06	Avg. Vel. (ft/s)	1.94	5.65	
Max Chl Dpth (ft)	4.74	Hydr. Depth (ft)	0.81	3.52	
Conv. Total (cfs)	26124.8	Conv. (cfs)	1592.3	24532.5	

Length Wtd. (ft)	268.59	Wetted Per. (ft)	76.30	93.24	
Min Ch El (ft)	92.80	Shear (lb/sq ft)	0.28	1.21	
Alpha	1.18	Stream Power (lb/ft s)	0.54	6.83	
Frctn Loss (ft)	1.51	Cum Volume (acre-ft)	0.66	9.51	0.27
C & E Loss (ft)	0.03	Cum SA (acres)	0.43	2.92	0.22

Willow Creek at Pioneer Lodge

Q_2-2100 cfs

: Plan 01 River: Willow Creek Pio Reach:root wad Riv Sta: 5.0 Profile: PF 2 E.G. Elev (ft)	107.10	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.14	Wt. n-Val.		0.035	
W.S. Elev (ft)	106.96	Reach Len. (ft)	181.00	213.00	178.00
Crit W.S. (ft)		Flow Area (sq ft)		701.29	
E.G. Slope (ft/ft)	0.000914	Area (sq ft)		701.29	
Q Total (cfs)	2100.00	Flow (cfs)		2100.00	
Top Width (ft)	194.51	Top Width (ft)		194.51	
Vel Total (ft/s)	2.99	Avg. Vel. (ft/s)		2.99	
Max Chl Dpth (ft)	4.96	Hydr. Depth (ft)		3.61	
Conv. Total (cfs)	69458.0	Conv. (cfs)		69458.0	
Length Wtd. (ft)	211.30	Wetted Per. (ft)		196.81	
Min Ch El (ft)	102.00	Shear (lb/sq ft)		0.20	
Alpha	1.00	Stream Power (lb/ft s)		0.61	
Frctn Loss (ft)	0.33	Cum Volume (acre-ft)	0.01	9.83	0.73
C & E Loss (ft)	0.03	Cum SA (acres)	0.09	2.74	0.93

Q_{50}-4800 cfs

: Plan 01 River: Willow Creek Pio Reach:root wad Riv Sta: 5.0 Profile: PF 3 E.G. Elev (ft)	109.27	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.29	Wt. n-Val.		0.035	0.060
W.S. Elev (ft)	108.98	Reach Len. (ft)	181.00	213.00	178.00
Crit W.S. (ft)		Flow Area (sq ft)		1116.14	0.71
E.G. Slope (ft/ft)	0.001155	Area (sq ft)		1116.14	0.71
Q Total (cfs)	4800.00	Flow (cfs)		4799.88	0.12
Top Width (ft)	221.50	Top Width (ft)		213.74	7.76
Vel Total (ft/s)	4.30	Avg. Vel. (ft/s)		4.30	0.17
Max Chl Dpth (ft)	6.98	Hydr. Depth (ft)		5.22	0.09
Conv. Total (cfs)	141227.9	Conv. (cfs)		141224.	3.6
Length Wtd. (ft)	209.01	Wetted Per. (ft)		216.93	7.76
Min Ch El (ft)	102.00	Shear (lb/sq ft)		0.37	0.01
Alpha	1.00	Stream Power (lb/ft s)		1.60	0.00
Frctn Loss (ft)	0.37	Cum Volume (acre-ft)	1.63	15.45	5.03
C & E Loss (ft)	0.03	Cum SA (acres)	1.34	2.82	3.22

Q_{100}-5300 cfs

: Plan 01 River: Willow Creek Pio	109.59	Element	Left OB	Channel	Right OB

Reach:root wad Riv Sta: 5.0 Profile: PF 4 E.G. Elev (ft)					
Vel Head (ft)	0.31	Wt. n-Val.		0.035	0.060
W.S. Elev (ft)	109.28	Reach Len. (ft)	181.00	213.00	178.00
Crit W.S. (ft)		Flow Area (sq ft)		1179.71	4.89
E.G. Slope (ft/ft)	0.001173	Area (sq ft)		1179.71	4.89
Q Total (cfs)	5300.00	Flow (cfs)		5298.40	1.60
Top Width (ft)	234.42	Top Width (ft)		214.06	20.36
Vel Total (ft/s)	4.47	Avg. Vel. (ft/s)		4.49	0.33
Max Chl Dpth (ft)	7.28	Hydr. Depth (ft)		5.51	0.24
Conv. Total (cfs)	154721.6	Conv. (cfs)		154674.	46.8
Length Wtd. (ft)	209.05	Wetted Per. (ft)		217.37	20.37
Min Ch El (ft)	102.00	Shear (lb/sq ft)		0.40	0.02
Alpha	1.01	Stream Power (lb/ft s)		1.79	0.01
Frctn Loss (ft)	0.38	Cum Volume (acre-ft)	1.98	16.18	5.85
C & E Loss (ft)	0.04	Cum SA (acres)	1.39	2.82	3.37

Qflood=1950 cfs

: Plan 01 River: Willow Creek Pio Reach:root wad Riv Sta: 5.0 Profile: PF 5 E.G. Elev (ft)	106.94	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.13	Wt. n-Val.		0.035	
W.S. Elev (ft)	106.80	Reach Len. (ft)	181.00	213.00	178.00
Crit W.S. (ft)		Flow Area (sq ft)		671.42	
E.G. Slope (ft/ft)	0.000901	Area (sq ft)		671.42	
Q Total (cfs)	1950.00	Flow (cfs)		1950.00	
Top Width (ft)	192.92	Top Width (ft)		192.92	
Vel Total (ft/s)	2.90	Avg. Vel. (ft/s)		2.90	
Max Chl Dpth (ft)	4.80	Hydr. Depth (ft)		3.48	
Conv. Total (cfs)	64963.8	Conv. (cfs)		64963.8	
Length Wtd. (ft)	211.55	Wetted Per. (ft)		195.15	
Min Ch El (ft)	102.00	Shear (lb/sq ft)		0.19	
Alpha	1.00	Stream Power (lb/ft s)		0.56	
Frctn Loss (ft)	0.33	Cum Volume (acre-ft)	0.00	9.40	0.59
C & E Loss (ft)	0.03	Cum SA (acres)	0.00	2.73	0.80

APPENDIX H-CHANNEL SURVEY AND DISCHARGE DATA

DESCRIPTION OF DATA FILE

Fieldwork was conducted throughout the 2002 season. Each field study site was visited three to five times. This Excel file consists of the field survey data from that fieldwork. Data includes:

1. Station location (latitude, longitude).
2. Date of survey(s).
3. Channel slope through study reach.
4. Cross-section data. Cross-sections consist of station-elevation pairs, with stationing from left to right looking downstream, and elevations based on local benchmarks and arbitrary datums. Cross-sections are numbered from downstream to upstream sequentially, from 1.
5. Distances between the cross-sections, along the left and right overbanks, and center of channel.
6. Two water discharge measurements, or listing of USGS gage data if available.
7. Water surface elevation data for all cross-sections for first discharge measurement, and additional WSEL data for some cross-sections for second discharge measurement.
8. Near-bank velocity profile at bio-engineered structure. Due to low water at time of sampling, no profile data was collected at Anchor River and Theodore River.
9. Channel material gradation, using modified Wolman pebble count. Gradation is also described using Wentworth size classes.

Abbreviations used with the survey data include the following:

LEW-left edge of water
REW-right edge of water
LOB-left overbank
ROB-right overbank
hwm-high water mark
bnkfl-bankful

UNITS

Unless otherwise noted, all units of length are in feet (ft). All units of area are in square feet (ft2). All units of velocity are in feet per second (ft/sec). All units of discharge are in cubic feet per second (cfs).

SITE NAME, LOCATION, CROSS-SECTION SURVEY							
Anchor River at Silverking Campground					lat-long	N 59d46'16.5"	
Original Cross-section survey June 19, 2002						W 151d50'11.8"	
Cross-sections numbered from downstream to upstream							
All units in feet							
Discharge	228.87 cfs						
Slope =	0.0035 ft/ft						
Second cross-section survey Nov 04-05, 2002							
Survey based on local coordinate system							
Elevations shot to arbitrary benchmark.							
All cross-section stationing surveyed from Left Bank to Right Bank looking downstream							
Local elevation control, BM1, 103.70 ft-restroom concrete pad.							
Downstream Distance				Downstream Distance From 2-1			
LOB	Center	ROB		LOB	Center	ROB	
0.0	0	0		232.0	242	246	
Cross-section 1				Cross-section 2			
Station	Elevation			Station	Elevation		
-386.8	105.2	hvy veg		-174.0	102.7	hvy veg	
-358.7	100.7	HWM here 102.7		-141.3	102.6	edge of road-HWM	
-287.6	100	hvy veg		-116.7	102.8	edge of road	
-255.7	100.1	hvy veg		-79.2	100.8	hvy veg	
-246.8	98.8	hvy veg		-35.5	101.5	hvy veg	
-235.9	101.9	edge of road		0.0	102.3	hvy veg	
-211.9	101.7	edge of road		57.4	102.4	hvy veg	
-206.1	100.2	grass		67.6	99.3	hvy veg	
-104.8	100.5	grass		68.6	96.6	lew-rt chnl	
-82.2	101.7	gravel		68.9	96		
-12.0	102	gravel		76.1	94.9		
29.8	99.3	grass		100.6	96.5	rew	
51.2	96.5	bnkfl		118.7	97.6		
63.4	96.6			122.7	97.3		
65.3	95.3	lew		125.7	96	lew-main chnl	
66.1	94.4			131.8	94.4		
111.2	93.6			145.6	94.2		
141.5	94.4			148.8	94.4		
148.8	94.1			152.5	94.6		
163.5	95.3	rew		157.7	94.9		
164.1	96.1			161.1	95.7		
169.1	96.7	bnkfl		172.5	96.1		
174.5	100.1			191.7	95.8		
331.0	98.4	lt veg		197.6	96.7	rew-main chnl	
338.0	96.1	lt veg		216.8	98.4	bnkfl	
351.6	95.4	lt veg		253.3	98.9	hvy veg	
353.3	97.6	lt veg		259.7	96	hvy veg	
433.6	99.6	lt veg		266.3	98.2	hvy veg	
441.7	96.8	lt veg		285.5	102.2	hvy veg	HWM 102.6
463.3	101	HWM at right side 99.6'		292.2	101.7	hvy veg	
473.4	106.2	lt veg		387.5	101.3	hvy veg	
				411.5	102.2	hvy veg	
				424.6	100.3	hvy veg	
				464.2	101.2	hvy veg	
				474.1	104.7	hvy veg	
				483.7	108	hvy veg	
Downstream Distance From 3 to 2				Downstream Distance From 4-3			
LOB	Center	ROB		LOB	Center	ROB	
115.0	146	157		180.0	122	107	
Cross-section 3				Cross-section 4			
Station	Elevation			Station	Elevation	Notes	
-140.1	103.37	hvy veg		-167.9	105.4		
-115.5	103.27	HWM		-159.3	104.6	HWM	

-78.0	101.47	hvy veg		-124.5	101.1	hvy veg	
-34.3	102.17	hvy veg		-65.7	104.4	edge of road	
0.0	101.7	hvy veg		-49.9	101.2	hvy veg	
24.3	100.2	hvy veg		-22.4	101.5	hvy veg	
41.2	101.9	hvy veg		0.0	101.73		
53.3	100.3	hvy veg		50.8	102		
55.8	98.4	hvy veg		60.3	97.8	lew	
61.7	98.6	stream		61.4	96.7		
63.6	96.9	lew		72.5	96.7		
63.9	94.2			78.7	97		
67.4	94.2			101.4	97.7		
81.7	97	rew-rt chnl		110.4	97.8	rew	
124.8	99.4			113.0	100.3		
143.3	99.1			175.3	97.9		
154.9	97.5			188.3	97.2	lew	
155.7	97	lew-main chnl		197.7	95.2		
155.9	96.2			212.7	94.5		
160.7	95.7			222.2	95.4		
180.9	96.2			232.3	95.2		
220.8	95.1			233.5	97.2	rew	
224.5	96.8	rew		238.8	99.7		
231.2	99.2			251.5	100.2		
237.1	99.3			260.6	100.4		
242.6	99.9	hvy veg		303.7	99.6	hvy veg	
280.2	99.9	hvy veg		330.1	100.8	hvy veg	
286.6	97	hvy veg		358.2	102.5	hvy veg	HWM 104.0
293.2	99.2	hvy veg		378.2	105		
312.4	103.2	hvy veg					
319.1	102.7	hvy veg					
414.4	102.3	hvy veg					
438.4	103.2	hvy veg					
451.5	101.3	hvy veg					
491.1	102.2	hvy veg					
501.0	105.7	hvy veg					
510.6	109	hvy veg					
Downstream Distance From 5-4				Downstream Distance From 6-5			
LOB	Center	ROB		LOB	Center	ROB	
121.0	116	104		116.0	111	115	
Cross-section 5				Cross-section 6			
Station	Elevation	Notes		Station	Elevation	Notes	
-235.6	107.3			-116.6	105.7		
-222.4	102.5	HWM		-97.1	105.2	HWM	
-193.6	102.1			-81.4	102.2	hvy veg	
-147.7	102.3	hvy veg		-71.2	102.8	hvy veg	
-139.4	104.4	edge of road		-65.0	104.6	road edge	
-116.5	104.2	edge of road		-38.3	104.4	road edge	
-110.3	102.2	hvy veg		0.0	104.1		
-90.5	101.7	hvy veg		57.6	102.4		
-52.1	103.6	grass		62.0	99.4		
-22.9	103.4	HWM nr lft chl 105.0		81.9	98.3	lew	
0.0	102.5			102.5	96.8		
3.4	98.9			106.2	96.6		
6.7	98.1	lew		127.8	96.8		
9.8	96.8			127.8	98.2	rew	
40.5	97.4			128.9	99.7		
49.4	98.1	rew-rt chnl		152.6	101		
56.2	100			155.7	98.2	lew-rt chnl	
73.7	100.6			156.6	96.6		
106.3	97.1	lew		163.3	96.1		
115.0	95.2			170.4	96.1		
123.3	95.5			177.4	97.1		
127.1	96.1			191.8	98.2		
143.9	95.5			211.4	98.2	rew	
150.0	95.4			224.9	100.5	hvy veg	

162.7	96.9			248.7	99.3		
171.1	96.6			265.2	102.1	hvy veg	
174.3	97.1	rew		285.4	104.5	hwm	
182.3	100.3			300.6	109.6		
228.1	101.4						
241.5	100.2						
292.2	104.5	HWM					
304.3	106						
Downstream Distance From 7-6				Downstream Distance From 8-7			
LOB	Center	ROB		LOB	Center	ROB	
119.0	106	100		110.0	112	112	
Cross-section 7				Cross-section 8			
Station	Elevation	Notes		Station	Elevation	Notes	
-131.4	105.65			-132.3	105.9		
-104.9	105.15	HWM left side 105.45'		-105.8	105.4	HWM 105.7'	
-82.3	105.45	edge of road		-83.2	105.7	edge of road	
-56.1	104.85	gravel		-57.0	105.1	gravel	
-4.8	103.95	gravel		-5.7	104.2	gravel	
-2.3	103.35	grass		0.0	104.8	hwm	
0.0	103.8			37.9	102.5		
14.2	102.9			49.1	99.7		
36.2	99.1			53.2	100.8		
59.8	99.3			57.8	100.6		
64.3	98.6	LEW		58.9	99.4	lew-left chnl	
68.7	98			59.0	99		
74.3	98.6			80.9	99.6	rew-left chnl	
90.1	97.7			91.9	99.6		
101.3	98.2			98.9	99.2	lew-main chnl	
108.3	97.2			107.9	97.8		
130.6	97.3			117.3	97.1		
157.9	97.9			141.5	96.9		
161.6	98.8	REW		158.9	97.2		
180.5	101.2			166.6	99.2	rew-main chnl	
204.8	101.1			167.5	99.4		
217.4	103.3			168.6	101.4		
220.0	104.55	HWM		180.6	101.9	bnkfl	
227.0	106.7			199.6	104.65	HWM	
				206.6	106.8		
Downstream Distance From 9-8				Downstream Distance From 10-9			
LOB	Center	ROB		LOB	Center	ROB	
93.0	75	69		150.0	137	133	
Cross-section 9				Cross-section 10			
Station	Elevation			Station	Elevation	Notes	
-208.8	108.4	paved		-192.0	108.4	paved-hwm	
-179.3	107.9	paved-HWM		-162.5	107.9	paved	
-160.3	105.6	hvy veg		-143.5	105.6	hvy veg	
-96.2	105.8	hvy veg		-79.4	105.8	hvy veg	
-36.1	105.6	hvy veg		-19.3	105.6	hvy veg	
-16.8	105.4	hvy veg		0.0	103.4		
0.0	104.1			61.3	102.7		
18.3	102.5			65.9	100.3		
35.1	99.7	lew-left chnl		70.8	100.4		
37.1	99.3			71.0	99.9	lew	
39.1	99.1			71.6	99.1		
41.1	99.2			105.1	100.1		
43.1	99.4			118.9	99.3		
45.1	99.4			126.1	97.8		
47.1	99.4			150.7	97.2		
49.1	99.4			174.5	99.1		
51.1	99.4			174.9	99.6	rew	
53.1	99.5			177.6	104.5	lt veg	
55.1	99.5			192.0	108.6	hwm-lt veg	
57.1	99.6			194.0	109.8	lt veg	
59.1	99.7	rew-left chanl					

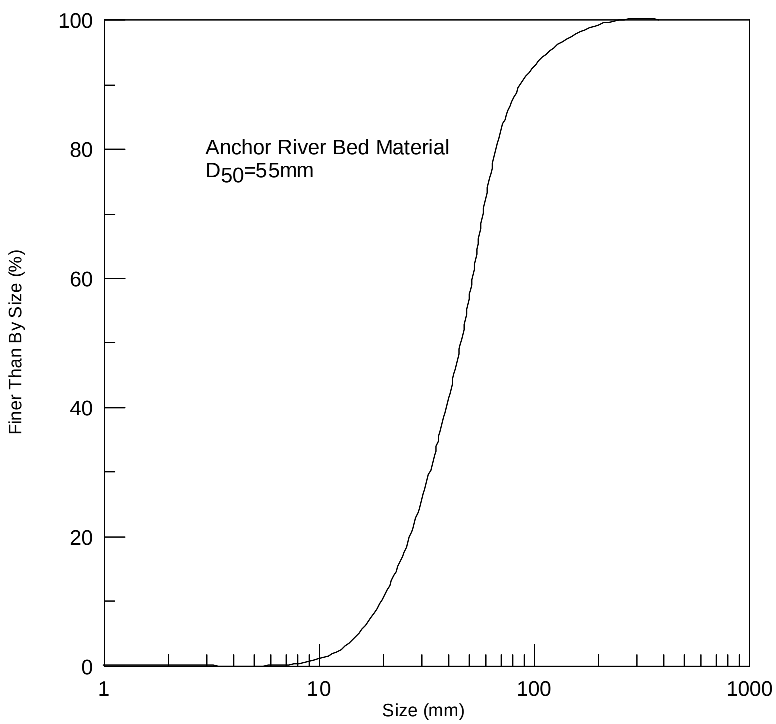
78.0	99.9						
85.4	99.4	lew-rght chnl					
88.4	99.1						
91.4	98.5						
94.4	97.9						
97.4	97.2						
100.4	97						
103.4	96.8						
106.4	96.5						
109.4	96.4						
112.4	96.6						
115.4	96.6						
118.4	96.5						
121.4	96.8						
124.4	96.9						
127.4	97.7						
130.4	98.5						
133.4	98.1						
136.4	98.2						
139.4	98.5						
141.4	99.4	rew-rght chnl					
142.9	101.9	bnkfl-lt veg					
155.6	107.5	HWM					
157.5	108.6						
165.3	113.6						
Downstream Distance From 11-10				Downstream Distance From 12-11			
LOB	Center	ROB		LOB	Center	ROB	
124.0	120	116		156.0	161	168	
Cross-section 11				Cross-section 12			
Station	Elevation	Notes		Station	Elevation	Notes	
0.0	103.5			0.0	103		
3.4	102.8			12.8	101.8		
5.3	101.5			17.2	102.3		
14.4	100.1	lew		48.8	100.4	LEW	
19.2	99.2			66.5	97.9		
25.8	99.3			70.0	97.6		
32.9	98.7			80.3	97.9		
37.4	98.7			85.3	98.4		
53.3	99.4			93.8	99.3		
78.8	97.1			101.7	100.4	REW	
84.2	97.2			107.0	101.5		
98.2	98.7			107.4	104.6		
109.1	99.9	rew					
113.8	101.2						
116.9	105.6						

DISCHARGE MEASUREMENTS								
Discharge Measurements at Anchor River								
All measurements with AA current meter								
all units in English (feet, cubic feet per second)								
Discharge Measurement June 19, 2002					Time Start	1835		
Left Channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
9.6	0	0	0	0	1	0	0	
11.6	0.45	10	40	0.569	2	0.9	0.5121	
13.6	0.6	15	42	0.805	2	1.2	0.966	
15.6	0.5	20	41	1.09	2	1	1.09	
17.6	0.35	25	44	1.27	2	0.7	0.889	
19.6	0.3	20	40	1.12	2	0.6	0.672	
21.6	0.3	20	54	0.834	2	0.6	0.5004	
23.6	0.3	20	49	0.918	2	0.6	0.5508	
25.6	0.3	15	50	0.679	2	0.6	0.4074	

27.6	0.2	5	40	0.293	2	0.4	0.1172	
29.6	0.2	10	48	0.477	2	0.4	0.1908	
31.6	0.1	0	0	0	4.7	0.47	0	
39	0	0	0	0	3.7	0	0	
						total	5.90	cfs
Right Channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
60	0	0	0	0	1.5	0	0	
63	0.35	15	50	0.679	3	1.05	0.71295	
66	0.9	20	41	1.09	3	2.7	2.943	
69	1.5	30	40	1.67	3	4.5	7.515	
72	2.2	40	50	1.78	3	6.6	11.748	
75	2.4	40	40	2.22	3	7.2	15.984	
78	2.6	40	40	2.22	3	7.8	17.316	
81	2.9	50	44	2.52	3	8.7	21.924	
84	3	40	44	2.02	3	9	18.18	
87	2.8	60	43	3.09	3	8.4	25.956	
90	2.8	50	45	2.47	3	8.4	20.748	
93	2.9	50	42	2.64	3	8.7	22.968	
96	2.6	50	40	2.77	3	7.8	21.606	
99	2.5	40	40	2.22	3	7.5	16.65	
102	1.7	40	42	2.12	3	5.1	10.812	
105	0.9	30	51	1.31	3	2.7	3.537	
108	1.3	20	59	0.765	3	3.9	2.9835	
111	1.2	10	60	0.385	3	3.6	1.386	
114	0.9	0	0	0	2.5	2.25	0	
116	0	0	0	0	1	0	0	
						total	222.97	cfs
						Total Q=	228.87	cfs
Discharge Measurement August 27, 2002					Time Start	1715		
Main channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
35	0	0	0	0	2.5	0	0	
40	0.25	15	58	0.588	5	1.25	0.735	
45	0.4	20	55	0.82	5	2	1.64	
50	0.75	40	47	1.89	5	3.75	7.0875	
55	0.9	50	45	2.47	5	4.5	11.115	
60	0.9	40	57	1.57	5	4.5	7.065	
65	0.65	40	41	2.17	5	3.25	7.0525	
70	0.45	40	54	1.65	5	2.25	3.7125	
75	0.7	50	40	2.77	5	3.5	9.695	
80	1.3	50	46	2.41	5	6.5	15.665	
85	1.3	40	40	2.22	5	6.5	14.43	
90	1.2	50	40	2.77	5	6	16.62	
95	1.5	40	48	1.86	5	7.5	13.95	
100	1.4	50	47	2.36	5	7	16.52	
105	1.3	40	44	2.02	5	6.5	13.13	
110	0.85	40	44	2.02	5	4.25	8.585	
115	1	40	50	1.78	5	5	8.9	
120	1	40	43	1.98	5	5	9.9	
125	0.6	20	53	0.85	5	3	2.55	
130	0.55	0	0	0	3.5	1.925	0	
132	0	0	0	0	1	0	0	
							168.35	
						Total Q=	168.35	cfs

BED MATERIAL PEBBLE COUNT-					
PARTICLE GRADATIONAL ANALYSIS					
Pebble Count at Anchor River					
19-Jun-02					
In mm					
60	118	43	80	73	
48	90	39	65	26	
21	135	110	61	81	

91	61	56	70	35	
18	85	46	21	47	
15	96	26	76	36	
68	153	41	10	27	
26	75	45	66	61	
68	170	68	68	27	
42	140	48	78	110	
59	61	53	53	122	
43	140	125	102	32	
73	98	70	50	66	
510	68	26	76	33	
22	123	68	26	38	
56	195	35	50	36	
50	78	53	210	39	
112	28	35	27	34	
35	62	62	16	85	
115	70	83	65	123	
Wentworth					
size class					
(mm)		cumulative			
<2	0	0			
2-4	0	0			
4-8	0	0			
8-16	2	2			
16-32	14	16			
32-64	37	53			
64-128	39	92			
128-256	7	99			
256-512	1	100			
Bed material composition-mostly very coarse gravel to medium					
cobbles, with occasional very large cobbles, small boulders, and sand.					
D50=55mm					
D75=61mm					



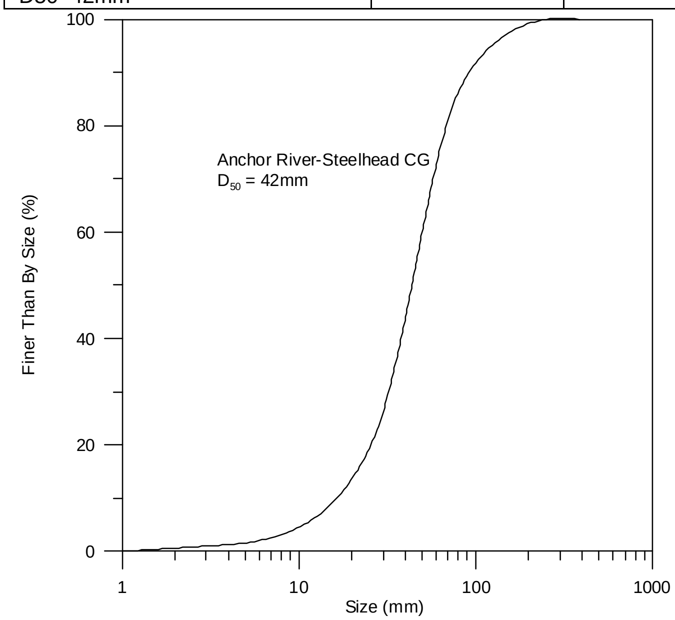
SECOND WATER SURFACE				
ELEVATION SURVEY				
Water Surface Elevations at Second Discharge				
27-Aug-02				
Discharge	168.35	cfs		
WSEL	at			
99.81	xsec 3			
100.83	xsec 4			
100.98	xsec 5			
Bank survey at BECS-typical section				
Bank angle from horizontal at toe 37°				
Q = 504 cfs				Depth to
dist	elevation			wsel
0.0	96.8	channel		-1.3
3.1	98.1	LEW		0
6.4	98.9	Bottom of coir lift		0.8
7.1	99.7	Bottom of first willow layer		1.6
7.7	99.9	Bottom of coir lift		1.8
7.8	100.3	Bottom of second willow layer		2.2
8.7	100.5	Bottom of coir lift		2.4
9.3	101.1	Bottom of third willow layer		3
10.8	102.2	Top of Bank		4.1

SITE NAME, LOCATION, CROSS-SECTION SURVEY						
Anchor River at Steelhead Campground					lat-long	N 59d46'17.3"
Cross-sections surveyed July 31, 2002						W 151d50'44.9"
Cross-sections numbered from downstream to upstream						
All units in feet						
Discharge	128.74	cfs				
Slope =	0.0062	ft/ft				
Cross-sections resurveyed November 5, 2002						
Survey based on local coordinate system						
Elevations shot to arbitrary benchmark.						
All cross-section stationing surveyed from Left Bank to Right Bank looking downstream						
Local elevation control, BM1, 103.70 ft-restroom concrete pad.						
Downstream Distance				Downstream Distance		
LOB	Center	ROB		LOB	Center	ROB
0	0	0		323	240	154
Cross-section 1				Cross-section 2		
Station	Elevation			Station	Elevation	
-495.6	90.1	trees		-493.0	93.2	
-390.1	92.35	hvy veg		-387.5	95.45	
-306.3	91.3	hvy veg		-303.7	94.4	
-213.6	92.3	hvy veg		-211.0	95.4	lite veg
-166.1	95	hvy veg		-163.5	98.1	
-100.6	92.3	hvy veg		-98.0	95.4	
-55.8	94.1			-53.2	97.2	cl road
0.0	93.74	TOB		0.0	97.74	
0.6	90.34	LB		2.6	96.9	lb at root wads
2.4	89.34	lew		5.9	96.14	edgeofsod
5.9	88.84			6.6	95.34	topof upper layer
12.8	88.14			8.6	94.04	top of lowercoirlayer
20.5	87.64			9.3	93.34	topofheaderlog
28.5	87.74			11.6	93.54	centerofupperrootwad
37.8	88.94			13.7	91.14	lew
46.1	89.34	rew		14.1	91.24	centeroflowerrootwad
62.4	90.64	gravl		19.7	90.64	
78.4	90.84			31.5	90.74	
94.6	93.04	trees		43.5	89.94	
108.5	93.04	trees		53.5	90.64	
114.5	92.24	trees		64.6	90.74	
131.2	92.74	trees		77.5	90.54	
143.4	92.24	trees		88.6	90.14	
161.7	93.04	trees		97.1	90.04	
183.1	92.64	trees		107.0	90.47	
201.8	93.14	trees		110.3	91.64	rew
227.4	92.94			115.3	92.74	
251.8	92.34			126.6	94.04	
266.5	91.14			142.1	94.04	
274.5	94.04			168.9	93.74	topofgravelbar
300.0	96.2	hwm-Octflood		188.8	92.54	
				203.8	93.44	
				214.0	92.94	
				232.9	92.74	
				356.0	94.4	
				420.0	94.2	
				503.6	94.7	
				621.0	98.05	hwm-Octflood
Downstream Distance						
LOB	Center	ROB				
460	320	204				
Cross-section 3						
Station	Elevation					
-559.6	106.2					
-541.3	98.3					

-422.3	96.9	99.8	hwm				
-386.0	93.3						
-355.4	98.9	edge of road					
-332.7	98.8	edge of road					
-305.5	96.4						
-282.4	96.7						
-267.4	90.3						
-258.4	92						
-252.4	93.7						
-210.6	95.3						
-135.0	97.6						
-70.6	96.25						
0.0	94.44						
5.8	93.94	LB					
10.5	92.94	lew					
24.6	90.64						
37.7	90.84						
51.8	91.44						
65.8	92.14						
75.8	92.14						
82.6	92.14						
86.2	92.64	rew					
96.1	93.24						
112.7	92.64	rb					
116.3	94.94						
127.7	95.24						
139.1	94.54						
140.3	96.1	grvl					
194.2	94.2	lt veg					
282.9	96.3						
391.7	94						
602.1	94.8						
742.8	106.85						
	98.05	hwm-Octflood					

DISCHARGE MEASUREMENTS								
Discharge Measurements at Anchor River								
All measurements with AA current meter								
all units in English (feet, cubic feet per second)								
Discharge Measurement June 19, 2002					Time Start	1835		
Left Channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
6	0	0	0	0	1.25	0	0	
8.5	0.55	24	40	1.34068	2.5	1.375	1.843435	
11	0.7	40	40	2.2226	2.5	1.75	3.88955	
13.5	0.9	40	40	2.2226	2.5	2.25	5.00085	
16	0.9	34	40	1.89188	2.5	2.25	4.25673	
18.5	1.1	44	40	2.44308	2.5	2.75	6.71847	
21	1.2	54	40	2.99428	2.5	3	8.98284	
23.5	1.1	68	40	3.76596	2.5	2.75	10.35639	
26	1.3	80	40	4.4274	2.5	3.25	14.38905	
28.5	1.3	78	40	4.31716	2.5	3.25	14.03077	
31	1.4	74	40	4.09668	2.5	3.5	14.33838	
33.5	1.3	62	40	3.43524	2.5	3.25	11.16453	
36	1.2	74	40	4.09668	2.5	3	12.29004	
38.5	1.1	76	40	4.20692	2.5	2.75	11.56903	
41	0.9	54	40	2.99428	2.5	2.25	6.73713	
43.5	0.5	32	40	1.78164	2.5	1.25	2.22705	
46	0.35	16	40	0.89972	3	1.05	0.944706	
49.5	0	0	0	0	1.75	0	0	
						Qtotal=	128.74	cfs

BED MATERIAL PEBBLE COUNT-				
Pebble Count at Anchor River Steelhead CG				
In mm				
85	140	125	102	3
73	98	35	50	51
510	68	13	43	61
76	123	33	26	38
56	195	115	50	36
27	78	66	210	39
112	12	35	27	34
46	62	22	16	85
26	70	83	65	68
41	118	43	80	35
45	90	39	65	53
50	135	110	61	45
48	61	56	70	26
53	50	48	21	50
47	96	21	100	36
26	153	120	10	22
26	75	5	175	35
67	170	15	68	41
42	140	68	78	110
59	61	81	53	122
Wentworth				
size class				
(mm)		cumulative		
<2	0	0		
2-4	1	1		
4-8	1	2		
8-16	4	6		
16-32	12	18		
32-64	39	57		
64-128	34	91		
128-256	8	99		
256-512	1	100		
Bed material composition-mostly coarse gravel to medium				
cobbles, with occasional very large cobbles, small boulders, and sand.				
D50=42mm				



SITE NAME, LOCATION, CROSS-SECTION SURVEY					
Campbell Creek near Taku Park				lat	N61d09'13.8"
Cross-sections surveyed July 13, 2002				long	W149d52'36.7"
Cross-sections numbered from downstream to upstream					
All units in feet					
Discharge	64.04	cfs			
Slope =	0.0023	ft/ft			
Survey based on local coordinate system					
Elevations shot to arbitrary benchmark.					
All cross-section stationing surveyed from Left Bank to Right Bank looking downstream					
Local elevation control, BM1, 104.00 ft-Top of pin (rebar) on left bank					
Downstream Distance to Lower cross-section			Downstream Distance From 2-1		
LOB	Center	ROB	LOB	Center	ROB
0	0	0	72	168	372
Cross-section 1			Cross-section 2		
Station	Elevation		Station	Elevation	
0.0	98.9	lb	-10.0	100	est
12.3	98.7	bnkfl	0.0	98.8	
26.0	96.9	lew	14.9	99	bnkfl
33.4	96.8		26.7	98	
37.4	96		27.6	97.3	lew
43.5	95		29.8	95.6	
46.7	94.8		32.9	95.6	
49.9	95.2		37.3	97	
54.6	95.7		50.5	96.9	
57.2	97.3	rew	59.1	96.3	
57.2	96.9		67.0	96.2	
57.3	98.1	rb	70.3	97.3	rew
67.4	99.5		72.7	98.9	
97.9	98.9		87.0	99.3	rb
297.9	100	est	287.0	100	
330.0	105	est			
Downstream Distance From 3-2			Downstream Distance From 4-3		
LOB	Center	ROB	LOB	Center	ROB
92	94	81	81	70	63
Cross-section 3			Cross-section 4		
Station	Elevation		Station	Elevation	Notes
-30.0	105	est	-20.0	105	est
-20.0	103	est	0.0	103.7	sidewalk
0.0	101.7		15.7	102.4	
9.9	100.6		25.4	99.6	
18.4	99		26.0	97.4	lew
21.6	97.6	lew	26.4	95	
26.0	96.3		28.0	94.3	
32.6	96.8		28.6	94.5	
42.0	96.7		31.8	94.5	
52.6	97		34.2	95.1	
57.6	96.6		38.0	96	
64.6	97.7	rew	42.8	96.9	
66.6	98.5		46.5	97.7	rew
80.1	100		54.3	98.8	bnkfl
100.0	102		89.7	99	rb
188.0	102.5	est	130.0	103	est
Downstream Distance From 5-4			Downstream Distance From 6-5		
LOB	Center	ROB	LOB	Center	ROB
109	75	29	92	77	67
Cross-section 5			Cross-section 6		
Station	Elevation	Notes	Station	Elevation	Notes
-20.0	105	est	0.0	105	lb sidewalk
0.0	104.4	sidewalk	16.2	99.8	
14.5	102.2		32.3	99.2	
26.0	99.9		40.7	98.4	

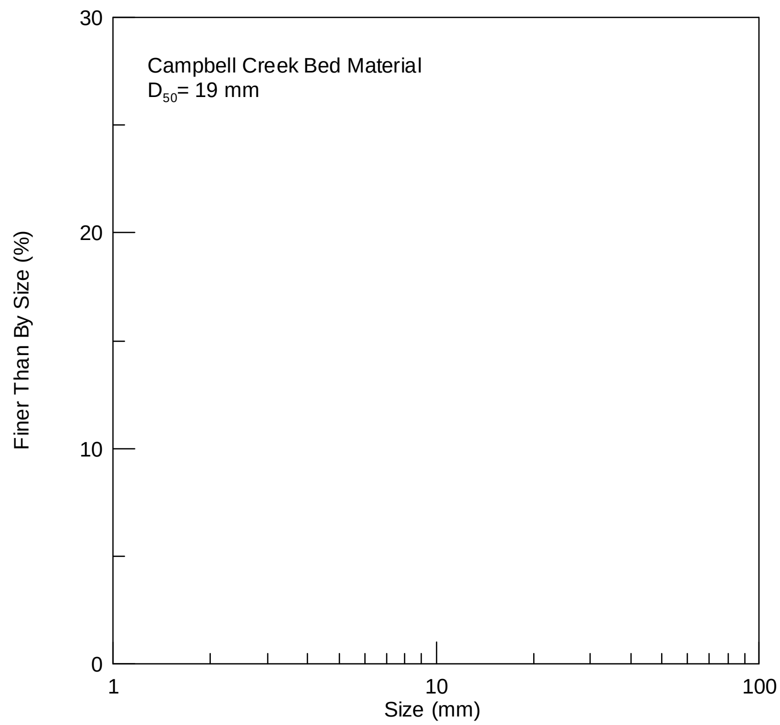
26.9	97.9	lew		41.7	98	lew	
26.9	97.1			44.0	97.2		
29.6	96			50.5	97.1		
33.5	95.6			59.6	97		
36.1	95.3			68.2	96.7		
41.0	95.5			74.5	96.7		
45.5	96.4			76.6	96.9		
51.7	96.9			76.9	98	rew	
53.6	97.6	rew		78.4	98.9		
56.3	99.3			81.3	99.97		
70.1	99.5			97.5	98.8		
83.2	99.5	rb		114.5	99.9		
120.0	103	est		164.0	103	est	
Downstream Distance From 7-6				Downstream Distance From 8-7			
LOB	Center	ROB		LOB	Center	ROB	
80	93	125		129	119	85	
Cross-section 7				Cross-section 8			
Station	Elevation	Notes		Station	Elevation	Notes	
-15.0	107	est		0.0	106.3		
0.0	101.3	lb		24.2	101.2		
4.5	99.8	bnkfl		30.7	100.1		
5.0	98.2			31.6	98.7	lew	
6.3	98.1	lew		31.6	98.2		
8.9	97.3			33.4	98.2		
14.2	96.9			37.5	98.5		
19.3	97.2			43.4	97.8		
29.7	97			58.3	97		
38.9	97.9			62.8	96.8		
39.5	98.2	rew		68.3	98.7	rew	
42.4	98.4			69.9	100.1		
43.7	100.3			83.7	101.1		
61.0	100.7			100.2	102.5	rb	
86.6	99.6			250.0	103	est	
230.0	103	est					
Downstream Distance From 9-8				Downstream Distance From 10-9			
LOB	Center	ROB		LOB	Center	ROB	
44	47	54		183	103	57	
Cross-section 9							
0.0	107.05	lb-edge of bike trail		Cross-section 10			
4.4	106.55			Station	Elevation	Notes	
7.5	103.85			-30.0	106	est	
14.0	101.55			0.0	100.15		
22.8	100.35			11.2	100.15		
23.1	98.85	lew		19.4	99.95		
23.1	98.15			30.2	99.35		
28.8	96.55			37.3	99.95		
34.6	96.55			47.2	99.45		
40.4	97.85			55.7	99.45		
48.3	97.95			56.0	98.95	lew	
57.4	98.85	rew		60.5	97.95		
62.0	99.25			64.6	96.95		
62.7	99.95			71.0	97.25		
74.7	100.55			77.8	96.45		
83.2	101.05			82.8	96.65		
200.0	103	est		85.7	98.95	rew	
				86.7	100.45		
				93.8	101.05		
				102.5	100.95		
				120.0	103	est	

DISCHARGE MEASUREMENTS								
Discharge Measurements at								
All measurements with AA current meter								
all units in English (feet, cubic feet per second)								
Discharge Measurement			7/13/2002		Time Start	1412		
Main Channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
8.5	0	0	0	0	0.75	0	0	
10	0.3	20	70	0.648	1.5	0.45	0.2916	
11.5	0.4	20	43	1.04	1.5	0.6	0.624	
13	0.55	20	46	0.976	1.5	0.825	0.8052	
14.5	0.6	30	50	1.34	1.5	0.9	1.206	
16	0.6	40	49	1.82	1.5	0.9	1.638	
17.5	0.7	40	45	1.98	1.5	1.05	2.079	
19	0.9	50	49	2.27	1.5	1.35	3.0645	
20.5	1.2	50	48	2.31	1.5	1.8	4.158	
22	1.5	50	47	2.36	1.5	2.25	5.31	
23.5	1.8	50	46	2.41	1.5	2.7	6.507	
25	2	50	47	2.36	1.5	3	7.08	
26.5	2.25	40	46	1.94	1.5	3.375	6.5475	
28	2.5	40	56	1.59	1.5	3.75	5.9625	
29.5	2.4	20	40	1.12	1.5	3.6	4.032	
31	2.4	20	45	0.998	1.5	3.6	3.5928	
32.5	2.3	20	40	1.12	1.5	3.45	3.864	
34	1.9	40	51	1.75	1.5	2.85	4.9875	
35.5	2	20	59	0.765	1.5	3	2.295	
37	1.7	0	0	0	1.25	2.125	0	
38	0	0	0	0	0.5	0	0	
						Total	64.04	cfs
Discharge Measurement			8/28/2002		Time Start	1042		
Main channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
16	0.2	0	0	0	0.75	0.15	0	
17.5	0.45	20	47	0.956	1.5	0.675	0.6453	
19	0.55	30	47	1.43	1.5	0.825	1.17975	
20.5	0.45	30	40	1.67	1.5	0.675	1.12725	
22	0.65	30	53	1.27	1.5	0.975	1.23825	
23.5	0.9	40	58	1.54	1.5	1.35	2.079	
25	1.2	40	49	1.82	1.5	1.8	3.276	
26.5	1.45	40	41	2.17	1.5	2.175	4.71975	
28	1.6	50	47	2.36	1.5	2.4	5.664	
29.5	1.7	50	45	2.47	1.5	2.55	6.2985	
31	1.8	50	45	2.47	1.5	2.7	6.669	
32.5	1.9	50	46	2.41	1.5	2.85	6.8685	
34	1.85	50	49	2.27	1.5	2.775	6.29925	
35.5	1.8	40	52	1.71	1.5	2.7	4.617	
37	1.5	30	47	1.43	1.5	2.25	3.2175	
38.5	1.35	30	53	1.27	1.5	2.025	2.57175	
40	1.4	30	48	1.4	1.5	2.1	2.94	
41.5	1.4	30	41	1.63	1.5	2.1	3.423	
43	1.35	30	42	1.59	1.5	2.025	3.21975	
44.5	1.4	30	46	1.46	1.5	2.1	3.066	
46	0.2	5	52	0.23	0.75	0.15	0.0345	
						Total	69.15	cfs

VELOCITY PROFILE					
Velocity Profile at		Campbell Creek			
Root wad structure		8/28/2002			
Distance	Total	Depth From			Velocity
From bank	Depth	Surface	Revs	Seconds	(feet/sec)
0.5	3.7	0.1	30	42	1.59
0.5	3.7	0.5	40	40	2.22
0.5	3.7	1	40	40	2.22
0.5	3.7	1.5	40	41	2.17
0.5	3.7	2	40	49	1.82
0.5	3.7	2.5	30	42	1.59
0.5	3.7	3	20	45	0.998
0.5	3.7	3.5	20	56	0.805
1	3.8	0.1	40	50	1.78
1	3.8	0.5	40	42	2.12
1	3.8	1	50	46	2.41
1	3.8	1.5	40	40	2.22
1	3.8	2	40	44	2.02
1	3.8	2.5	30	42	1.59
1	3.8	3	20	40	1.12
1	3.8	3.5	20	55	0.82
2	3.6	0.1	40	50	1.78
2	3.6	0.5	50	45	2.47
2	3.6	1	50	44	2.52
2	3.6	1.5	50	44	2.52
2	3.6	2	40	47	1.89
2	3.6	2.5	30	51	1.31
2	3.6	3	20	42	1.07
2	3.6	3.5	20	65	0.696
3	3.5	.6 depth	40	44	2.02
4	3.35	.6 depth	40	41	2.17
5	3.2	.6 depth	40	51	1.75

BED MATERIAL PEBBLE COUNT-						
PARTICLE GRADATIONAL ANALYSIS						
Pebble Count at		Campbell Creek				
date	7/13/2002					
In mm						
14	<2	9	24	7		
97	<2	13	21	57		
30	17	21	10	23		
3	16	22	5	8		
13	12	41	32	63		
10	11	26	41	28		
24	9	10	36	20		
58	7	34	72	22		
8	10	<2	37	47		
9	15	4	56	49		
20	7	80	64	24		
8	11	33	65	60		
26	18	19	28	63		
62	37	20	31	22		
34	31	35	43	50		
19	30	43	70	60		
48	300	47	40	34		
130	<2	30	14	55		
27	6	15	21	66		

28	12	54	3	21		
Wentworth						
size class						
(mm)		cumulative				
<2	4	4				
2-4	2	6				
4-8	6	12				
8-16	20	32				
16-32	30	62				
32-64	29	91				
64-128	7	98				
128-256	1	99				
256-512	1	100				
Bed material composition-mostly medium, coarse, and very coarse gravels,						
with some medium cobbles, very fine gravels, and occasional small boulder.						
D50=19mm		D75=30mm				



SECOND WATER SURFACE ELEVATION SURVEY						
Water Surface Elevations at Second Discharge						
28-Aug-02						
Discharge	69.15	cfs				
WSEL	at					
97.5	xsec 4					
97.83	xsec 5					
98.85	xsec 9					
98.95	xsec 10					

Bank survey at BECS-typical section						
Bank angle from horizontal at toe exceeds 45°						
Q = 69.2 cfs				Depth to		
dist	elevation			WSEL		
0.0	89.6	Bottom of channel		-3.4		
3.1	91.3	Bottom of footer log		-1.7		
2.1	92.9	Top of footer log		-0.1		
2.1	93.0	LEW		0.0		
2.2	94.3	Center of root wad		1.3		
1.1	95.0	Bottom of header log		2.0		
1.1	95.7	Top of header log		2.7		
6.4	96.6	Top of bank		3.6		

SITE NAME, LOCATION, CROSS-SECTION SURVEY							
Chena River at Doyon Estates						lat	N64d50'39.4"
Cross-sections surveyed June 23, 2002						long	W147d46'42"
Cross-sections numbered from downstream to upstream							
All units in feet							
Discharge	3240	cfs					
Slope =	0.0003	ft/ft					
Survey based on local coordinate system							
Elevations shot to arbitrary benchmark.							
All cross-section stationing surveyed from Left Bank to Right Bank looking downstream							
Local elevation control, BM1, 114.30 ft-at NE corner of bridge abutment, brass bm marked el-441.52.							

Downstream Distance From 1-0			Downstream Distance From 2-1		
LOB	Center	ROB	LOB	Center	ROB
0	0	0	203	250	293
Cross-section 1			Cross-section 2		
Station	Elevation		Station	Elevation	
0.0	107.6		0.0	109.7	
5.3	107.6		17.3	99.4	lew
12.0	99.2	lew	26.3	97.2	
21.0	91.1		32.3	95.8	
30.0	88.9		53.3	95	
39.0	88.5		62.3	94.7	
48.0	87.2		74.3	94.8	
60.0	86		89.3	94.9	
69.0	86.7		104.3	95.1	
78.0	88.7		119.3	94.9	
90.0	89.4		134.3	94.3	
102.0	90.2		149.3	92.5	
114.0	91.3		164.3	91.5	
123.0	92.4		182.3	92.7	
135.0	94.2		200.3	94.7	
138.0	95.4		209.3	94.8	
159.0	99.2	rew	218.3	95.9	
161.0	107.4		233.3	99.4	rew
171.0	107.6		241.0	105.9	
			250.0	108	est

Downstream Distance From 3-2			Downstream Distance From 4-3		
LOB	Center	ROB	LOB	Center	ROB
501	489	476	185	252	328
Cross-section 3			Cross-section 4		
Station	Elevation		Station	Elevation	Notes
0.0	110		0.0	108	
0.5	103		60.0	102	
20.5	102		66.0	99.9	lew
22.5	99.5	lew	75.0	96.7	
28.5	97.5		81.0	96.2	
52.5	94.1		87.0	95.6	
67.5	91.5		99.0	95.7	
91.5	92		117.0	96	
109.5	91.1		129.0	96.4	
124.5	90.9		162.0	93.2	
142.5	90.3		189.0	92.1	
163.5	90.6		204.0	92	
178.5	91		228.0	91.8	
193.5	92.4		237.0	91.7	
199.5	95.7		246.0	92.3	
220.5	99.5	rew	255.0	94.1	
230.0	105		273.0	99.9	rew
238.2	109		283.4	105	hwm
			291.2	108	
			300.1	110.3	tob

Downstream Distance From 5-4				Downstream Distance From 6-5		
LOB	Center	ROB		LOB	Center	ROB
181	185	179		230	240	251
Cross-section 5				Cross-section 6		
Station	Elevation	Notes		Station	Elevation	Notes
0.0	106.7			0.0	105	
10.0	101.5			10.0	102.8	
10.5	99.9	lew		15.0	102	
19.5	95.9			28.0	101.3	
37.5	92.4			30.0	99.9	lew
52.5	91			45.0	95.5	
70.5	90.3			57.0	90.6	
79.5	91.3			69.0	87.3	
103.5	94.1			84.0	86.4	
124.5	94.8			102.0	86	
139.5	94.9			114.0	84.9	
151.5	94.4			123.0	87.3	
166.5	94.8			132.0	90.4	
181.5	94.8			147.0	88.9	
199.5	95.9			165.0	88.9	
208.5	96.3			180.0	88.8	
223.5	99.9	rew		189.0	89.5	
233.0	105			195.0	90.1	
241.0	107.8	tob		201.0	93.9	
				216.0	99.9	rew
				224.0	103.9	
				250.0	105	est
Downstream Distance From 7-6				Downstream Distance From 8-7		
LOB	Center	ROB		LOB	Center	ROB
323	410	495		275	284	291
Cross-section 7				Cross-section 8		
Station	Elevation	Notes		Station	Elevation	Notes
0.0	105.9			0.0	108.7	lbtob
14.9	104.7			18.6	104.2	
44.1	100	lew		21.0	101.7	
80.1	96.7			26.2	99.9	lew
83.1	96.1			44.2	97.6	
95.1	95			65.2	88.4	
104.1	91.7			80.2	83.2	
119.1	87.5			113.2	77.5	
143.1	87.8			134.2	76.9	
164.1	87.4			149.2	79.6	
173.1	88.1			167.2	82.9	
194.1	92			179.2	83	
218.1	96.8			194.2	83.9	
236.1	93.6			203.2	84.1	
251.1	94.5			209.2	89.9	
266.1	97.1			227.2	95.2	
269.1	97.6			233.2	94.8	
302.1	99.9	rew		248.2	99.9	rew
315.6	101.4	bnkfl		254.1	101.2	bnkfl
327.8	105.9	tob		267.0	104.1	rbtob
				287.0	108	est
Downstream Distance From 9-8						
LOB	Center	ROB				
593	499	421				
Cross-section 9						
Station	Elevation	Notes				
0.0	109.6	tob				
4.7	104.1					
12.2	100	lew				
27.2	94.9					
30.2	92.8					
42.2	90.4					

57.2	90.5							
72.2	90.7							
93.2	92							
102.2	92.3							
117.2	92.5							
132.2	93							
147.2	93.9							
150.2	94.5							
162.2	95							
165.2	94.6							
186.2	100	rew						
192.0	101.5	bnkfl						
206.0	104.5							
250.0	108	est						

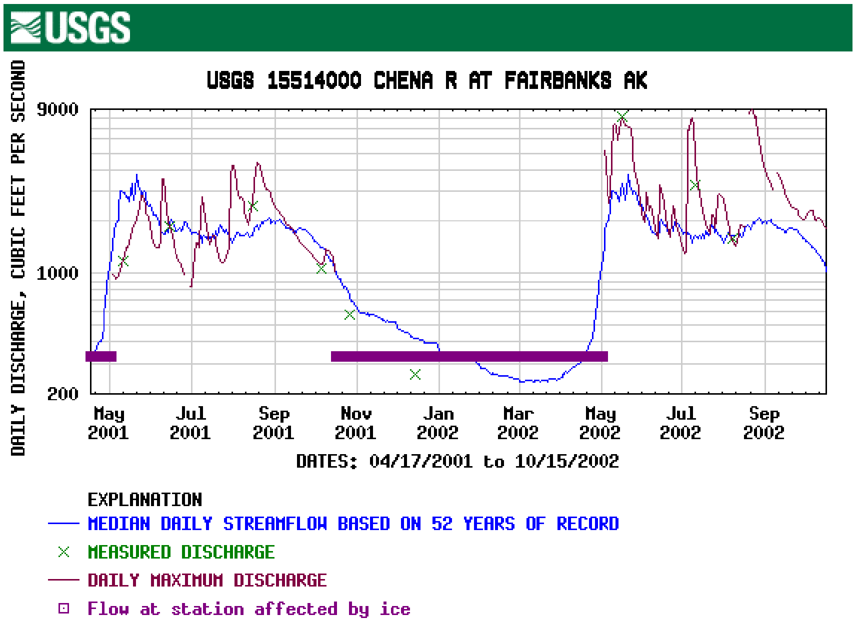
DISCHARGE MEASUREMENTS				
Discharge Measurements at			Chena River	
All measurements with AA current meter				
all units in English (feet, cubic feet per second)				
Discharge Measurement				
from USGS gaging station			Chena R at Fairbanks AK	
			15514000	
date:	time	discharge	stage	
8/20/2002	1800	8,870 cfs	8.52 ft	
9/5/2002	1600	3240 cfs	3.48 ft	

VELOCITY PROFILE						
Velocity Profile at		Chena River		date:	8/20/2002	
brush layering				time:	1800	
				discharge	8,870	cfs
Distance	Total	Depth From			Velocity	
From bank	Depth	Surface	Revs	Seconds	(feet/sec)	
2	0.7	0.1	0	40	0	
4	1.1	0.1	0	40	0	
4	1.1	0.4	0	40	0	
4	1.1	0.8	0	40	0	
6	3.2	0.1	0	40	0	
6	3.2	0.4	0	40	0	
6	3.2	0.8	0	40	0	
6	3.2	1.2	0	40	0	
6	3.2	1.6	0	40	0	
8	4.3	0.1	5	53	0.226	
8	4.3	0.4	0	40	0	
8	4.3	0.8	3	50	0.15	
8	4.3	1.2	3	50	0.15	
8	4.3	1.6	0	40	0	
8	4.3	2	0	40	0	
8	4.3	2.4	0	40	0	
10	6.2	0.1	10	57	0.405	
10	6.2	0.4	7	44	0.369	
10	6.2	0.8	10	58	0.398	
10	6.2	1.2	20	40	1.12	
10	6.2	1.6	10	60	0.385	
10	6.2	2	20	49	0.918	

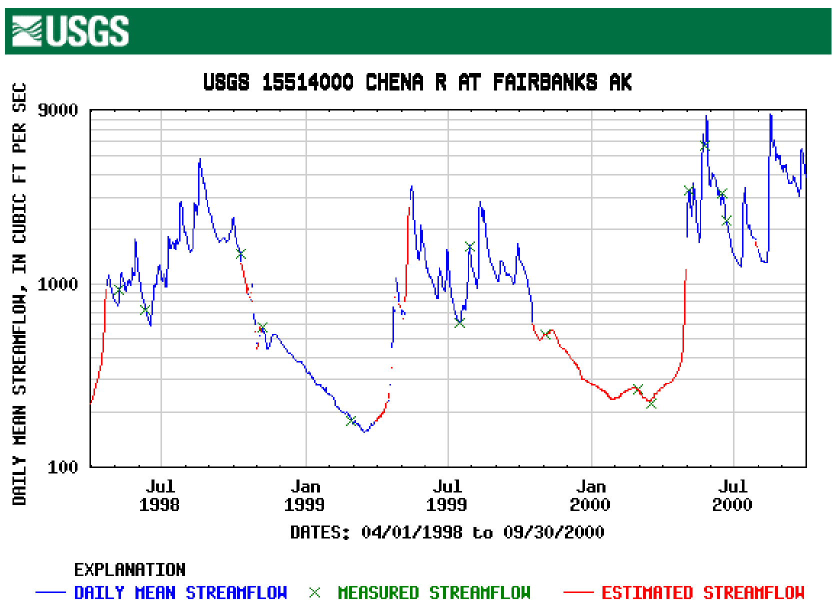
10	6.2	2.4	20	61	0.741	
10	6.2	3	20	45	0.998	
10	6.2	3.5	20	52	0.866	
10	6.2	4	20	49	0.918	
10	6.2	4.5	20	46	0.976	
10	6.2	5	20	50	0.9	
10	6.2	5.5	10	54	0.426	
10	6.2	6	10	50	0.459	
12	7	0.1	15	52	0.654	
12	7	1	20	44	1.02	
12	7	2	20	44	1.02	
12	7	3	30	52	1.29	
12	7	4	30	40	1.67	
12	7	5	20	47	0.956	
12	7	6	20	41	1.09	

BED MATERIAL PEBBLE COUNT-	
PARTICLE GRADATIONAL ANALYSIS	
Pebble Count at	Chena River
date	
In mm	
No pebble count conducted at Chena River, due to	
silt-sand bottom through most of study reach.	
Wentworth	
size class	
(mm)	cumulative
All material <2mm.	100
Bed material composition-mostly sand and silt	
less than 2 mm. Note: small material, average	
2-10 mm, in downstream section of project and	
study reach, extends from bank out 2-3 feet,	
possibly from project construction.	

SECOND WATER SURFACE			
ELEVATION SURVEY			
Water Surface Elevations at Second Discharge			
Discharge	8870	cfs	
WSEL	at		
105	xsec 4		
105.2	xsec 5		
Bank survey at BECS-typical section			
Bank angle from horizontal at toe 19°			Depth to
Q = 3240 cfs			WSEL
0.00	94.1	channel	-5.8
18.00	99.9	REW, bottom of FESL	0
19.02	101.1	Bottom of FESL, willow layer	1.2
20.77	102.4	second willow layer	2.5
28.38	105	bank	5.1



Provisional Data Subject to Revision



SITE NAME, LOCATION, CROSS-SECTION SURVEY							
Deep Creek at Deep Creek State Campground					lat-long	N 60d01'50.0"	
Cross-sections surveyed June 23, 2002						W 151d40'44.7"	
Cross-sections numbered from downstream to upstream							
All units in feet							
Discharge	220.76	cfs					
Slope =	0.0047	ft/ft					
Cross-section resurvey November 03, 2002							
Survey based on local coordinate system							
Elevations shot to arbitrary benchmark.							
All cross-section stationing surveyed from Left Bank to Right Bank looking downstream							
Local elevation control, BM1, 102.25 ft-at water well, southeast corner of cg.							
Downstream Distance From 1-0				Downstream Distance From 2-1			
LOB	Center	ROB		LOB	Center	ROB	
0	0	0		318	196	195	
Cross-section 1				At bridge downstream side			
Station	Elevation			Cross-section 2			
-350.0	103	hvy veg		Station	Elevation		
-300.0	98.2	hvy veg		-120.0	105		
0.0	97.7	hvy veg		-100.0	99		
45.0	96.2	hvy veg		-20.0	96.8		
48.6	91.7	lew		25.0	96.4		
80.5	90.3	in chl		28.6	91.9	lew	
165.8	89.6	in chln		30.9	88.4	in chnl	
180.9	91.6	rew		89.8	89.4		
185.2	93			100.3	92.1	rew	
194.7	91.8			105.3	93.5		
253.8	94.9			170.0	95.4		
295.4	95			270.0	96		
342.7	95.6			280.0	106		
356.3	102.8	hwm		Ineffective Flow Area Left Bank			
360.0	104			-120	105		
				-120	93		
				0	105		
				0	93		
				Ineffective Flow Area Right Bank			
				152.3	105		
				152.3	95		
				280	105		
				280	95		
At bridge downstream side				At bridge upstream side			
Station	Elevation			Station	Elevation		
0.0	107.1	onbridge		-52.5	108.8		
9.8	100.5	riprap		-8.3	108.4		
28.6	91.9	lew		-6.7	107.3		
30.9	88.4	in chnl		0.0	101.8		
89.8	89.4			23.2	91.9	lew	
100.3	92.1	rew		30.4	90.6		
122.8	92.5			36.8	89.4		
137.3	100.8	HWM		45.2	90.8		
139.1	103.3	low steel		66.0	90.9		
142.3	101.9	concrete bags		87.0	89.8		
				101.7	89.3		
				105.7	90.5		
				108.2	91.9	rew	
				121.1	100.5		
				121.8	101.2		
				136.6	107.7	HWM may be 104	
				150.2	108.4		
Downstream Distance From 3-2				Downstream Distance From 4-3			
LOB	Center	ROB		LOB	Center	ROB	
50	50	50		199	197	206	

At bridge				Cross-section 4		
Cross-section 3				Station	Elevation	
Station	Elevation			-212.3	103.3	HWM
-199.6	101.6			-209.3	103.2	
-196.6	101.5			-192.5	101.7	
-179.8	100			-175.9	103.1	
-163.2	101.4			-146.4	102	paved
-133.7	100.3			-63.9	102.5	paved
-51.2	100.8			0.0	99.2	
12.7	97.5			10.5	93.6	lew
23.2	91.9	lew		13.0	91.8	
30.4	90.6			22.4	88.7	
36.8	89.4			32.4	90.2	
45.2	90.8			41.3	91.6	
66.0	90.9			54.1	92.5	
87.0	89.8			71.8	93.6	rew
101.7	89.3			96.9	94.1	
105.7	90.5			113.8	96	rb
108.2	91.9	rew		128.0	99.1	
133.3	92.4			155.8	103.8	
150.2	94.3			191.3	104.5	
164.4	97.4			221.3	104.5	paved
192.2	102.1			277.5	104.5	paved
227.7	102.8					
257.7	102.8	HWM may be 104				
313.9	102.8					
Ineffective Flow Area Left Bank						
-199.6	107.3					
-199.6	98					
-10	107.3					
-10	98					
Ineffective Flow Area Right Bank						
131.8	107.3					
131.8	92					
313.9	107.3					
313.9	92					
Downstream Distance From 5-4				Downstream Distance From 6-5		
LOB	Center	ROB		LOB	Center	ROB
269	179	32		220	128	79
Cross-section 5				Cross-section 6		
Station	Elevation			Station	Elevation	Notes
-2.0	111.4			-40.0	116.3	hvy veg
0.0	109.4			-21.0	107.6	HWM
0.2	94	lew		-7.0	103	hvy veg
1.7	93.3			0.0	96.3	hvy veg
6.8	91.5			0.0	99.7	
16.3	88.4			13.6	97.6	lb
24.8	90.1			16.6	94.1	lew
31.2	91.8			24.5	93.2	
52.1	93.8	rew		34.9	92.9	
76.9	96.1			41.3	94.1	rew
99.6	96			49.1	97.5	
136.0	103.2	gravel		132.8	96.6	
226.0	102.8	gravel		158.0	97	
232.9	103.97	HWM		184.0	95.45	lb
250.3	106.04	gravel		197.4	95.35	
296.6	108.1	gravel		206.3	96.35	
				227.4	95.55	
				247.4	93.85	lew-main chln
				253.4	92.45	
				258.1	91.45	
				262.7	90.05	
				267.0	90.55	
				274.1	91.05	
				276.0	94.15	rew-main chln

			283.3	100.65	
			296.2	102.75	
			303.9	101.95	
			360.0	103.2	gravel
			420.6	104.2	gravel
			500.6	102.8	gravel
			549.9	103.97	HWM
			555.8	106.04	gravel
			565.5	108.1	gravel
Downstream Distance From 7-6			Downstream Distance From 8-7		
LOB	Center	ROB	LOB	Center	ROB
255	186	176	131	142	180
Cross-section 7			Cross-section 8		
Station	Elevation	Notes	Station	Elevation	Notes
-278.0	112.7		-517.6	112.7	
-54.1	99.2		-293.7	99.2	
-27.4	100.9		-267.0	100.9	
0.0	100.15		-232.4	100.5	
19.5	97.85		-204.3	100.5	bank
23.7	99.45	hwm	-191.2	95.7	lew
36.9	97.15		-190.2	94.7	in chnl
43.4	94.55	lew	-130.2	95.1	
48.9	93.35		-108.1	96.4	
53.6	93.05		-73.9	98.6	
58.5	93.95		-53.7	97.9	
62.8	94.75	rew	-32.0	98.6	
73.1	95.65		0.0	98.45	
82.8	95.85		15.5	97.75	lb
85.9	98.45		16.5	96.75	lew-lft chnl
111.6	98.35		20.5	94.35	
147.6	98.45		26.1	93.25	
184.4	97.95		30.9	93.35	
214.7	97.55		41.3	94.95	
217.7	96.25	lew-main chln	57.9	96.65	rew
220.6	92.95		68.7	96.75	
224.9	93.05		77.5	96.45	lew
237.5	94.75		88.0	95.35	
244.6	93.55		98.3	94.45	
254.9	93.95		106.6	94.55	
261.6	94.75		110.0	94.25	
279.1	96.15	rew	113.7	96.25	rew-main chln
307.4	97.15		142.1	102.45	rb at railing
312.7	100.95		156.5	100.4	paved
323.6	102.75		175.7	103.3	paved
333.7	102.9		189.2	103.7	paved
338.6	103		239.0	104.6	paved
363.3	103.6		291.2	105.5	paved
395.3	104.2		344.8	106.4	edge of road
441.2	104.5	paved		106.8	HWM
483.5	103.1	paved			
490.9	101.7				
496.6	103.1				
534.3	105.3				
541.6	106.8	HWM 105			
Downstream Distance From 9-8			Downstream Distance From 10-9		
LOB	Center	ROB	LOB	Center	ROB
116	98	91	141	140	142
Cross-section 9			Cross-section 10		
Station	Elevation	Notes	Station	Elevation	Notes
0.0	98.7		0.0	100	lb
15.1	101.2	hwm	13.9	98.6	
16.3	98.7		39.2	97.7	lew
18.2	96.9	lew	47.2	95.7	
19.8	95.5		51.6	93.6	

26.2	95.3			53.0	93.2		
35.8	95.8			62.8	92		
68.3	96.1			73.0	93.04		
95.0	95.7			77.6	97.4	rew	
106.0	94.4			93.2	98.2		
111.6	95			107.5	102.1		
113.3	96.9	rew		114.4	101.7		
120.0	98.7	rb					
Downstream Distance From 11-10				Downstream Distance From 12-11			
LOB	Center	ROB		LOB	Center	ROB	
93	132	188		294	233	181	
Cross-section 11				Cross-section 12			
Station	Elevation	Notes		Station	Elevation	Notes	
0.0	99.9			0.0	102.6		
20.9	99.9			15.5	102.7		
22.9	97.8	lew		20.6	98.7	lew	
26.7	96.2			23.6	96.7		
33.4	95.7			25.1	96.3		
42.2	96			26.8	95.7		
55.7	96.6			36.3	95.9		
70.2	95.4			39.7	96.7		
77.3	97.7	rew		45.8	97.6		
88.1	97.7			50.5	98.4	rew	
116.7	96.1			58.4	99.2	lew	
134.6	98.1			64.3	98.9		
141.2	96.6			76.3	99.7	rew	
144.6	97.8			83.8	100.2		
168.3	99.3			92.9	100.2	lew	
194.9	99.8			102.6	99.5		
202.1	102.3			116.2	100	rew	
215.0	102.6	rb		151.7	101		
				207.5	100.6		
				242.3	98.9		
				246.7	100		
				251.2	101.2		
				254.4	102.5		

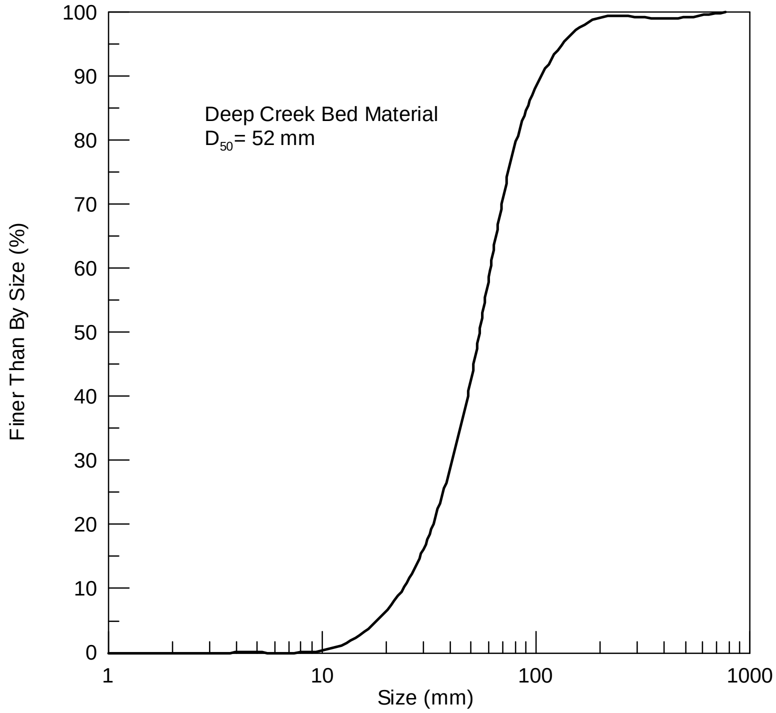
DISCHARGE MEASUREMENTS								
Discharge Measurements at			Deep Creek					
All measurements with AA current meter								
all units in English (feet, cubic feet per second)								
Discharge Measurement			23-Jun-02		Time Start	1730		
Main Channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
21	0	0	0	0	1.0	0	0.00	
23	0.65	20	40	0	3.0	1.95	0.00	
27	0.4	0	0	0	4.0	1.6	0.00	
31	0.5	40	44	2.02	4.0	2	4.04	
35	0.6	40	45	1.98	4.0	2.4	4.75	
39	0.65	50	51	2.18	4.0	2.6	5.67	
43	1	40	46	1.94	4.0	4	7.76	
47	1	40	45	1.98	4.0	4	7.92	
51	1.1	40	44	2.02	4.0	4.4	8.89	
55	1.2	50	48	2.31	4.0	4.8	11.09	
59	1.25	40	41	2.17	4.0	5	10.85	
63	1.4	50	48	2.31	4.0	5.6	12.94	
67	1.6	50	46	2.41	4.0	6.4	15.42	
71	1.95	50	46	2.41	4.0	7.8	18.80	
75	2.4	50	47	2.36	4.0	9.6	22.66	
79	2.7	40	41	2.17	4.0	10.8	23.44	
83	2.7	50	46	2.41	4.0	10.8	26.03	
87	2.45	40	40	2.22	4.0	9.8	21.76	
91	1.75	40	44	2.02	4.0	7	14.14	

95	1.8	10	42	0.543	4.0	7.2	3.91	
99	1.3	5	55	0.218	2.5	3.25	0.71	
100	0.9	0	0	0	0.5	0.45	0.00	
						Total	220.76	cfs
Discharge Measurement			27-Aug-02		Time Start	1145		
Right channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
8.3	0.2	0	0	0	0.35	0.07	0.00	
9	1.1	10	70	0.333	1.35	1.485	0.49	
11	1.45	20	45	0.998	2	2.9	2.89	
13	2	20	49	0.918	2	4	3.67	
15	1.75	30	52	1.29	2	3.5	4.52	
17	1.95	40	41	2.17	2	3.9	8.46	
19	2.25	30	45	1.49	2	4.5	6.71	
21	2.4	50	44	2.52	2	4.8	12.10	
23	2.3	40	40	2.22	2	4.6	10.21	
25	2.2	30	47	1.45	2	4.4	6.38	
27	2.1	60	43	3.09	2	4.2	12.98	
29	1.85	60	41	3.24	2	3.7	11.99	
31	1.4	50	44	2.52	2	2.8	7.06	
33	1.2	40	41	2.17	2	2.4	5.21	
35	0.7	40	49	1.82	2	1.4	2.55	
37	0.5	30	52	1.29	2	1	1.29	
39	0.3	20	60	0.753	2	0.6	0.45	
41	0.15	10	42	0.543	2	0.3	0.16	
43	0	0	0	0	1	0	0.00	
						Total	97.11	cfs
Discharge Measurement			27-Aug-02		Time Start			
Left Channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
110	0	0	0	0	1	0	0.00	
108	1.7	0	0	0	2	3.4	0.00	
106	2.45	10	67	0.347	2	4.9	1.70	
104	2.9	20	57	0.791	2	5.8	4.59	
102	3	30	54	1.24	2	6	7.44	
100	2.8	40	46	1.94	2	5.6	10.86	
98	2.95	40	45	1.98	2	5.9	11.68	
96	2.6	40	48	1.86	2	5.2	9.67	
94	2.65	40	51	1.75	2	5.3	9.28	
92	2.5	30	56	1.2	2	5	6.00	
90	2.25	30	53	1.27	2	4.5	5.72	
88	1.9	30	57	1.18	2	3.8	4.48	
86	1.6	20	46	0.976	2	3.2	3.12	
84	1.2	20	55	0.82	2	2.4	1.97	
82	1.05	20	64	0.707	2	2.1	1.48	
80	0.85	10	52	0.442	2	1.7	0.75	
78	0.4	10	53	0.434	2	0.8	0.35	
76	0.35	10	65	0.357	2	0.7	0.25	
74	0.05	0	0	0	1.5	0.075	0.00	
73	0	0	0	0	0.5	0	0.00	
						Total =	79.34	cfs
						Total =	176.46	cfs

VELOCITY PROFILE					
Velocity Profile at		Deep Creek		8/27/2002	
brush layering		Q=176.46 cfs			
Distance	Total	Depth From			Velocity
From bank	Depth	Surface	Revs	Seconds	(feet/sec)
0.5	2.4	0.1	100	47	4.71
0.5	2.4	0.5	80	40	4.43
0.5	2.4	1	80	45	3.94

0.5	2.4	1.5	80	48	3.69
0.5	2.4	2	60	44	3.02
1	2	0.1	200	60	7.37
1	2	0.5	100	44	5.03
1	2	1	80	48	3.69
1	2	1.5	60	44	3.02
1	2		80	48	3.69
2	1.3	average .6	80	48	3.69

BED MATERIAL PEBBLE COUNT-					
PARTICLE GRADATIONAL ANALYSIS					
Pebble Count at		Deep Creek			
date	23-Jun-02				
In mm					
28	100	54	79	79	
48	83	90	120	33	
36	121	150	22	47	
35	122	93	57	64	
110	122	90	76	59	
70	130	61	42	120	
44	62	98	57	94	
38	65	116	107	93	
60	90	75	19	125	
61	102	152	43	138	
115	48	81	58	220	
160	56	35	10	36	
650	85	57	77	40	
106	25	120	25	130	
104	57	41	52	58	
100	83	21	111	16	
90	143	72	210	71	
114	70	54	122	80	
28	165	128	53	93	
142	91	108	121	28	
Wenthworth size class					
(mm)		cumulative			
<2	0	0			
2-4	0	0			
4-8	0	0			
8-16	1	1			
16-32	9	10			
32-64	30	40			
64-128	47	87			
128-256	12	99			
256-512	0	99			
512-1024	1	100			
Bed material composition- mostly small to medium cobbles, with occasional					
medium gravels, large cobbles, and medium boulders.					
D50=52mm		D75=70mm			



SECOND WATER SURFACE ELEVATION SURVEY				
Water Surface Elevations at Second Discharge				
Discharge	176.46	cfs		
WSEL	at			
xsec 4	93.88			
xsec 5	96.01			
xsec 6	96.54			
Bank survey at BECS-xsec 6				
Bank angle from horizontal at toe 43°				Depth to
Q = 220.1 cfs				WSEL
0	91.1	channel		-3.1
2	94.2	REW, bottom of FESL		0
7	100.7	Top of bank		6.5
Bank survey at BECS-xsec 7				
Bank angle from horizontal at toe 3°				
Q = 220.1 cfs				
0	94.8	channel		-1.4
17.2	96.2	REW		0
7	97.2	Top of bank		1
45.5	100.95	start of BECS		4.75
61.7	102.8	Top of bank		6.6

SITE NAME, LOCATION, CROSS-SECTION SURVEY					
Kenai River at Centennial Park				lat	N60d28'55.5"
Cross-sections surveyed August 18, 2002				long	W151d05'27.0"
Cross-sections numbered from downstream to upstream					
All units in feet					
Discharge	12,800 cfs				
Slope =	0.0017				
Survey based on local coordinate system					
Elevations shot to arbitrary benchmark.					
All cross-section stationing surveyed from Left Bank to Right Bank looking downstream					
Local elevation control, BM1, 90.69 ft-large boulder on left bank near stairs.					
Downstream Distance From 1-0			Downstream Distance From 2-1		
LOB	Center	ROB	LOB	Center	ROB
0	0	0	1143	1273	1416
Cross-section 1			Cross-section 2		
Station	Elevation		Station		
-100	93	est	-100.0	93	est
0.0	89.38		0.0	89.05	
26.4	89.48	bnkfl	67.0	86.85	bnkfl
33.0	85.18		100.3	85.35	
38.1	80.88	lew	102.8	83.05	lew
68.4	79.28		102.8	81.95	
134.0	78.28		121.7	80.95	
173.0	77.18		135.8	78.25	
245.1	75.68		153.8	78.25	
296.0	75.08		204.8	74.95	
368.1	74.88		243.8	75.75	
428.1	74.98		303.8	79.35	
464.1	74.58		369.8	78.65	
512.1	75.88		432.8	78.25	
527.0	76.88		504.8	77.45	
533.0	80.88	rew	558.8	79.45	
545.0	92.88		576.8	83.05	rew
			586.0	93.05	
Dowstream Distance From 3-2			Downstream Distance From 4-3		
LOB	Center	ROB	LOB	Center	ROB
275	376	474	566	701	839
Cross-section 3			Cross-section 4		
Station			Station		Notes
-200.0	95		-100.0	99	est
0.0	90.89		0.0	95.98	
20.1	88.79		11.1	94.88	
41.8	87.29	bnkfl	18.5	91.08	
44.8	84.49		23.2	88.59	
49.5	83.69	lew	27.7	85.28	
68.0	81.19		31.3	84.88	lew
76.5	78.99		32.1	83.88	
142.5	75.79		46.9	81.98	
181.5	76.49		70.3	79.98	
211.5	72.89		130.3	78.58	
289.5	80.19		205.3	80.28	
352.5	80.49		244.3	79.78	
415.0	79.79		298.3	78.98	
460.5	78.69		352.3	79.58	
508.5	78.89		403.3	80.98	
538.5	79.29		451.3	82.18	
553.5	83.69	rew	496.3	81.48	
553.6	85.19		511.3	81.08	
556.6	85.29		529.3	83.28	
566.4	96.69		556.3	84.88	rew
			557.7	86.38	
			560.6	89.48	

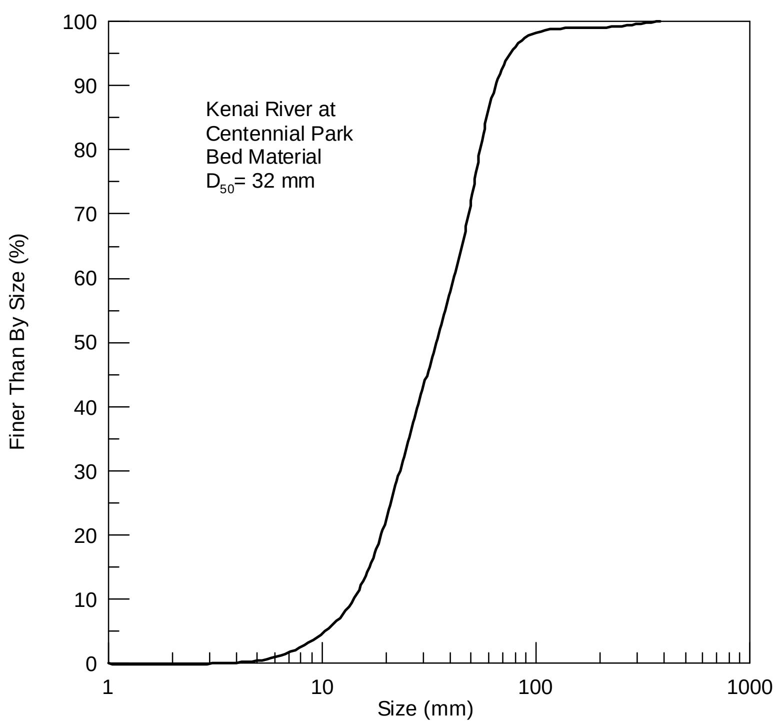
				570.0	99.48		
Downstream Distance From 5-4				Downstream Distance From 6-5			
LOB	Center	ROB		LOB	Center	ROB	
1358	1431	1510		620	593	569	
Cross-section 5				Cross-section 6			
Station	Elevation	Notes		Station	Elevation	Notes	
0.0	115.57			-60.0	103		
11.5	115.07			-50.0	93.4		
26.0	103.97			0.0	91.36		
43.3	94.37			19.0	90.9		
49.4	87.97			33.3	90.3		
50.1	87.17	lew		48.1	88.52	lew	
50.1	86.87			108.0	83.5		
62.7	85.25			159.1	83.6		
77.1	82.57			201.1	84.1		
104.1	81.87			234.1	84.6		
170.1	82.07			300.1	85.2		
209.1	84.57			366.1	84.3		
245.1	84.77			381.1	83.1		
290.1	84.87			444.1	83.1		
332.1	83.37			507.1	81.8		
377.1	80.67			534.1	83.3		
440.1	80.37			564.1	84.2		
470.1	81.87			570.0	88.5	rew	
509.1	80.27			570.5	91		
539.1	81.97			590.5	100.3		
551.1	82.17			600.0	110		
554.0	87.17	rew					
555.0	88.27						
560.0	90.07						
580.0	95.47						
600.0	101	est					
Downstream Distance From 7-6							
LOB	Center	ROB					
886	834	839					
Cross-section 7							
Station	Elevation	Notes					
0.0	109.7						
15.2	105.48						
31.3	99.4						
43.4	97.6						
62.1	89.73	lew					
113.1	73.5						
134.1	73.9						
167.1	76.2						
191.1	77.4						
209.1	79.5						
236.1	80.9						
266.1	82.5						
275.1	84.1						
296.1	86.1						
318.7	89.7	rew					
346.0	98.65						
376.3	106.5						
406.0	115						

DISCHARGE MEASUREMENTS					
Discharge Measurements at			Kenai River at Centennial Park		
All measurements with AA current meter					
all units in English (feet, cubic feet per second)					
Discharge Measurement					
from USGS gaging station			Kenai R at Soldotna AK		
			15266300		
date:	time	discharge		stage	
7/31/2002	1,800	15,500	cfs	9.87	ft
8/18/2002	900	12,800	cfs	9.29	ft
10/25/2002		27,600	cfs	12.36	ft

VELOCITY PROFILE					
Velocity Profile at		Kenai River at Centennial Park			
at root wads					
				date:	7/31/2002
				time:	1800
				discharge	15500 CFS
Distance	Total	Depth From			Velocity
From bank	Depth	Surface	Revs	Seconds	(feet/sec)
0.5	1.4	0.05	24	40	1.34
0.5	1.4	0.2	30	40	1.67
0.5	1.4	0.4	32	40	1.78
0.5	1.4	0.6	30	40	1.67
0.5	1.4	0.8	30	40	1.67
0.5	1.4	1	27	40	1.51
0.5	1.4	1.2	20	40	1.12
1	1.4	0.05	28	40	1.56
1	1.4	0.4	38	40	2.11
1	1.4	0.8	32	40	1.78
1	1.4	1.2	26	40	1.45
2	1.4	0.05	30	40	1.67
2	1.4	0.4	42	40	2.33
2	1.4	0.8	40	40	2.22
2	1.4	1.2	28	40	1.56
4	1.5	0.1	46	40	2.55
4	1.5	0.5	52	40	2.88
4	1.5	0.9	46	40	2.55
4	1.5	1.3	26	40	1.45
8	2	0.2	58	40	3.21
8	2	0.6	54	40	2.99
8	2	1	50	40	2.77
8	2	1.4	42	40	2.33
8	2	1.8	32	40	1.78

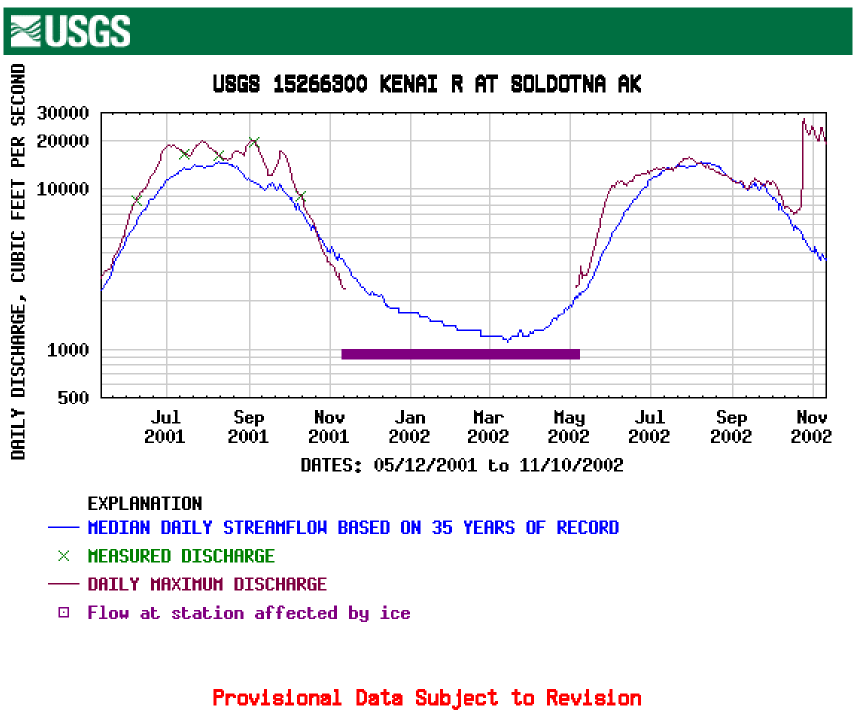
BED MATERIAL PEBBLE COUNT-					
PARTICLE GRADATIONAL ANALYSIS					
Pebble Count at		Kenai River at Centennial Park			
date	8/18/2002				
In mm					
58	27	82	45	10	
48	52	54	26	11	
50	80	57	30	16	
26	91	43	69	62	
69	22	104	60	82	

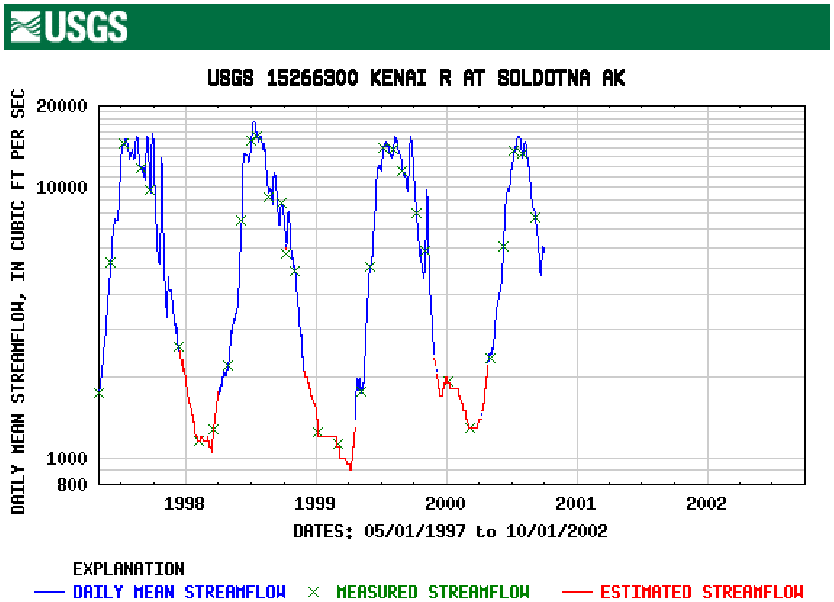
16	13	27	59	40	
12	50	65	27	108	
137	20	40	45	23	
14	70	38	23	48	
16	111	75	97	21	
40	40	70	67	99	
42	26	57	390	110	
20	107	49	54	80	
81	51	80	101	51	
54	28	32	62	120	
24	68	34	58	22	
53	16	50	50	65	
21	33	103	14	21	
19	79	88	34	48	
47	21	26	100	7	
Wentworth	size class				
(mm)		cumulative			
<2	0	0			
2-3	0	0			
4-7	1	1			
8-15	6	7			
16-31	25	32			
32-63	37	69			
64-127	29	98			
128-255	1	99			
256-512	1	100			
Bed material composition-Coarse and very coarse gravels, and small					
and medium cobbles, with occasional large and very large cobbles and rare					
small boulders.					
D50=32mm		D75=51mm			



SECOND WATER SURFACE

ELEVATION SURVEY			
Water Surface Elevations at Second Discharge			
Discharge	15,500	cfs	
WSEL	at		
85.54	xsec 4		
Discharge	23,100	cfs	
WSEL	at		
87.09	xsec 4	31-Oct-02	
Bank survey at BECS-xsec 6			
Bank angle from horizontal at toe 25°			
Q = 15,500 cfs			Depth to
			WSEL
0	81.98	channel	-2.9
8.8	83.88	channel	-1
-18.2	84.88	lew	0
22.8	85.28	center of root wad	0.4
29.8	88.59	top of coir	3.71




USGS
USGS 15266300 KENAI R AT SOLDOTNA AK
DAILY MEAN STREAMFLOW, IN CUBIC FT PER SEC
20000
10000
1000
800
1998
1999
2000
2001
2002
DATES: 05/01/1997 to 10/01/2002
EXPLANATION
DAILY MEAN STREAMFLOW
MEASURED STREAMFLOW
ESTIMATED STREAMFLOW

SITE NAME, LOCATION, CROSS-SECTION SURVEY						
Kenai River at Riddle-Rainey					lat	N60°32'22.2"
Cross-sections surveyed June 22, 2002					long	W151°08'47.4"
Cross-sections numbered from downstream to upstream						
All units in feet						
Discharge	12,100 cfs					
Slope =						
Survey based on local coordinate system						
Elevations shot to arbitrary benchmark.						
All cross-section stationing surveyed from Left Bank to Right Bank looking downstream						
Local elevation control, BM1, 99.80 ft-at flagpole on Riddle deck.						
Downstream Distance From 0-0				Downstream Distance From 2-1		
LOB	Center	ROB		LOB	Center	ROB
0	0	0		1292	1077	994
Cross-section 1				Cross-section 2		
Station	Elevation			Station		
-1636.4	88.6			-1200.0	92	
-1599.4	86.1			-734.0	89.5	
-1503.4	83			-694.0	87	
-1253.4	86.1			-178.2	87.1	
-453.4	88.6			-85.2	86.9	
-206.4	88.6			-50.0	83	eov
-81.4	86.1			0.0	81	lew
-44.1	86			24.0	79.5	
0.0	80.1	lew		48.0	77.2	
117.4	72.8			78.0	76.7	
176.5	73.6			99.0	71	
202.1	74.6			153.0	61	
233.7	76.9			213.0	60.3	
290.4	77.1			228.0	66.9	
326.7	75.1			258.0	71.7	
508.3	77.8			270.0	78	
567.6	77.8			273.0	81	rew
578.1	79			273.5	87.95	root wads
583.9	76.1			284.5	88.05	log bulwark
593.6	76.4			285.0	96.65	log bulwark
598.2	80.1	rew		287.0	96.65	
609.6	95					
Downstream Distance From 3-2				Downstream Distance From4-3		
LOB	Center	ROB		LOB	Center	ROB
282	442	498		204	908	1465
Cross-section 3				Cross-section 4		
Station				Station		Notes
-1050.0	92			-500.0	95	
-482.0	91.1			-7.0	95	
-422.0	88.6			0.0	87.2	lew
-153.6	88.6	lb		23.0	82.2	
-75.3	88.22			60.0	75.7	
-5.5	86			120.0	77.7	
0.0	81.5	lew		180.7	81.2	
29.1	76.7			282.0	84	
79.5	72.5			437.9	83.7	
140.0	69.6			610.5	84.7	
204.2	66.5			800.3	81.4	rew
271.3	71.5			904.7	87.2	rb
367.0	81.5	rew		986.5	88.6	
378.9	83.9			2348.0	88.6	
396.4	94			2350.0	91.6	
Downstream Distance From 5-4				Downstream Distance From 6-5		
LOB	Center	ROB		LOB	Center	ROB
704	682	691		1635	1261	714

Cross-section 5				Cross-section 6			
Station	Elevation	Notes		Station	Elevation	Notes	
-465.0	94.5			-670.0	93.5		
-460.0	92			-620.0	91		
-10.0	91.8			-16.3	88.5		
0.0	81.8	lew		0.0	81.9	lew	
18.0	74.3			12.1	77.8		
60.0	69.6			37.3	73.3		
96.0	71.8			120.7	71.3		
228.0	74.8			225.2	72.7		
238.0	76.8			324.7	75.9		
350.2	78.3			420.2	81.9	rew	
493.5	79			438.2	87.8	RB	
571.8	80.6			1490.0	88		
633.9	80.2			1500.0	90		
741.0	81.8	rew					
750.0	83						
790.0	85						
840.0	90						
2350.0	91						

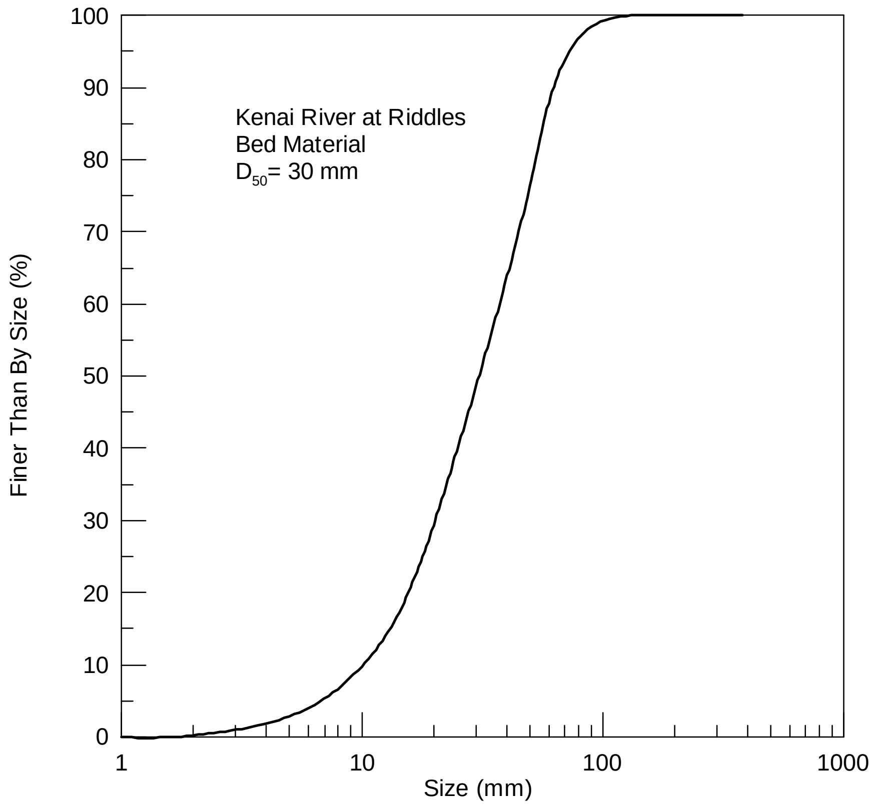
DISCHARGE MEASUREMENTS								
Discharge Measurements at			Kenai River at Riddle-Rainey					
All measurements with AA current meter								
all units in English (feet, cubic feet per second)								
Note-Due to extreme tide changes in this project area, discharge measurements								
may be unreliable.								
Discharge Measurement			Kenai R at Soldotna AK					
from USGS gaging station			15266300					
date:	time	discharge		stage				
6/22/2002	1,204	12,100	cfs	9.9	ft			
9/8/2002	1800	11,500	cfs	9	ft			
10/25/2002		27,600	cfs	12.36	ft			
Discharge Measurement			6/22/2002		Time Start	1200		
Main channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
0	0	0	0	0	3	0	0	
6	9.3	70	40	3.88	7.5	69.75	270.63	
15	9.1	57	40	3.162	19.5	177.45	561.0969	
45	14.1	96	40	5.31	22.5	317.25	1684.598	
60	20.7	93	40	5.145	22.5	465.75	2396.284	
90	22	92	40	5.09	30	660	3359.4	
120	10	89	40	4.925	42	420	2068.5	
174	10	88	40	4.87	37.5	375	1826.25	
195	4	75	40	4.155	25.5	102	423.81	
225	3.8	51	40	2.826	27	102.6	289.9476	
249	1.5	29	40	1.616	24	36	58.176	
273	0	0	40	0	12	0	0	
							12938.69	cfs

VELOCITY PROFILE						
Velocity Profile at		Kenai River at Riddle-Rainey				
at root wads			date:	9/8/2002		
			time:	1812		
			discharge	11,500	CFS	
Velocity measurements made at turn of 24 ft high tide.						
Start	6:12 PM		End	8:10 PM		
Distance	Total	Depth From			Velocity	
From bank	Depth	Surface	Revs	Seconds	(feet/sec)	
1		0	10	46	0.497	REW
1		2	10	44	0.519	
2		0	10	53	0.434	
2		2	10	48	0.477	

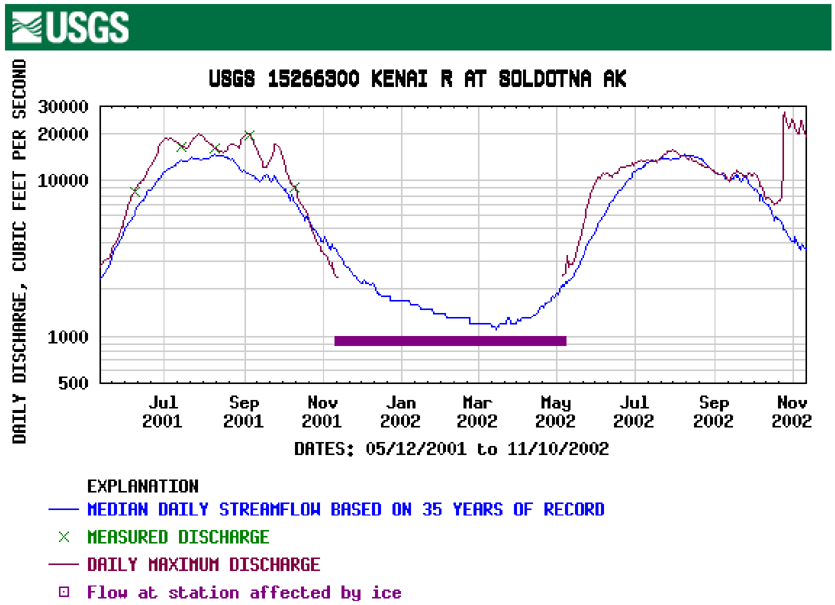
3		0	10	47	0.252	
3		2	10	64	0.362	
4		0	10	69	0.337	
4		2			0	in willow
5		0	10	60	0.385	
5		2	2		0	in willow
6		0	10	45	0.508	
6		2	15	56	0.608	
7		0	20	58	0.778	
7		2	10	67	0.347	
8		0	20	62	0.729	
8		2	20	66	0.686	
9		0	20	43	1.04	
9		2	20	40	1.12	
10		0	20	50	0.9	
10		2	10	40	0.569	
12		0	20	45	0.998	
12		2	40	42	2.12	
14		0	40	47	1.89	
14		2	60	45	2.96	
16		0	60	46	2.89	
16		2	80	54	3.28	
16		4	80	52	3.41	
16		6	80	65	2.73	
19		0	50	45	2.47	
19		2	80	50	3.55	
19		4	80	48	3.69	
19		0	60	43	3.09	
19		5	80	47	3.77	
19		6	60	42	3.17	

BED MATERIAL PEBBLE COUNT-					
PARTICLE GRADATIONAL ANALYSIS					
Pebble Count at		Kenai River at Riddle-Rainey			
date					
In mm					
16	60	21	22	70	
7	52	50	101	18	
44	98	18	15	43	
14	43	72	21	94	
64	24	44	46	70	
34	28	47	32	43	
20	67	33	85	46	
73	58	94	51	80	
45	57	17	17	75	
105	25	55	44	2	
62	43	30	55	5	
10	21	28	45	6	
27	65	60	47	11	
22	112	47	23	57	
39	32	78	66	77	
16	99	70	13	35	
16	95	65	9	39	
17	56	24	134	16	
21	48	40	11	78	
16	12	93	37	13	
Wentworth	size class				
(mm)		cumulative			
<2	0	0			
2-3	1	1			
4-7	3	4			
8-15	9	13			
16-31	25	38			
32-63	36	74			
64-127	25	99			

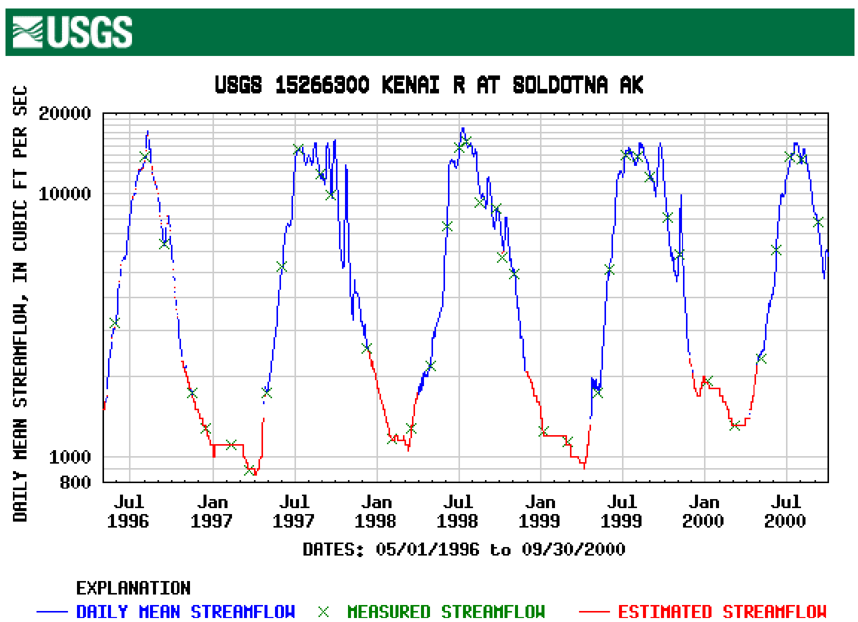
128-255	1	100				
256-512	0	100				
Bed material composition-coarse gravels, very coarse gravels, and						
small to medium cobbles, with some very fine and fine						
gravels, and large cobbles						
D50=30mm		D75=50mm				



SECOND WATER SURFACE			
ELEVATION SURVEY			
Water Surface Elevations at Second Discharge			
Discharge	1,105	cfs	
WSEL	at		
92.65	xsec 2		



Provisional Data Subject to Revision



SITE NAME, LOCATION, CROSS-SECTION SURVEY							
Ship Creek at Cottonwood Park					lat-long	N 61d14'26.7"	
Cross-sections surveyed June 28, 2002						W 149d41'49.7"	
Cross-sections numbered from downstream to upstream							
All units in feet							
Discharge	261.9	cfs		Slope =	0.0088	ft/ft	
Survey based on local coordinate system				Elevations shot to arbitrary benchmark.			
All cross-section stationing surveyed from Left Bank to Right Bank looking downstream							
Local elevation control, BM1, 110.60 ft-Top of pin (rebar) on island, xsec 5							
Downstream Distance From 1-0				Downstream Distance From 2-1			
LOB	Center	ROB		LOB	Center	ROB	
0	0	0		391	386	393	
Cross-section 1				Cross-section 2			
Station	Elevation			Station	Elevation		
-100.0	109	est		-100	110	est	
0.0	106.1			0.0	109.4		
3.4	103.9			7.2	107.6		
6.6	102.1	lew		10.2	105.6	lew	
14.1	101.4			25.4	104.4		
31.1	101.5			42.0	103.8		
49.4	102	rew-lf chl		64.0	105		
85.5	102	lew-rt chl		81.9	105		
107.3	101			96.3	106	rew	
120.7	101.9			100.1	108.3	bnkfl	
134.1	102.6	rew-rt chl		104.7	109		
141.6	106.8	bnkfl		200.0	110	est	
163.0	109	RB					
Downstream Distance From 3-2				Downstream Distance From 4-3			
LOB	Center	ROB		LOB	Center	ROB	
198	189	182		142	168	159	
Cross-section 3				Cross-section 4			
Station	Elevation			Station	Elevation	Notes	
-100	110	est		-100	111	est	
0.0	108.3			0.0	110		
6.6	106.9	lew		2.0	109		
18.1	105			2.3	108		
35.6	105			2.5	107.6	lew-lft chl	
55.7	106.3			28.0	105.6		
77.5	106.8	rew		38.4	107.6		
107.3	107.4			38.6	107.97	rew-lft chl	
128.9	107.7	rb		46.8	108.5		
230.0	110	est		64.9	107		
				73.5	107.6		
				82.1	108.2		
				94.0	108	lew-rt chl	
				109.4	106.9	in water	
				125.0	107.8	rew-rt chl	
				135.0	110		
				175.0	111		
Downstream Distance From 5-4				Downstream Distance From 6-5			

LOB	Center	ROB		LOB	Center	ROB	
199	235	243		162	209	209	
Cross-section 5				Cross-section 6			
Station	Elevation	Notes		Station	Elevation	Notes	
-100	114			-150	115		
-10.0	113			0.0	112.7	lb	
-2.0	109.7	lew		4.5	112.3		
0.0	109			4.8	111.4	lew	
19.5	109			10.4	109.5		
34.5	107.7			19.8	110.1		
47.2	109.6	rew-lft chl		28.2	111		
81.5	110.1	adjacent to pin		46.2	111.3		
81.6	110.6	LB-top		62.2	111.4		
102.4	110.6			80.8	111.4		
118.7	109.9	lew		93.3	112		
123.0	109.2			93.9	112.6	rew	
135.6	108.9			95.2	113.8		
145.2	109.3			105.2	117.1		
152.8	109.3						
157.3	107.9						
160.8	109.9	rew					
162.9	111.9						
165.6	113.25						
179.8	113.6	RB at post					
Downstream Distance From 7-6				Downstream Distance From 8-7			
LOB	Center	ROB		LOB	Center	ROB	
217	181	167		286	293	300	
Cross-section 7				Cross-section 8			
Station	Elevation	Notes		Station	Elevation	Notes	
-150	117			-150	119		
0.0	114.9			0.0	117.6		
2.2	112.7	lew		5.3	116.7	lew	
6.2	111.8			22.0	115.5		
17.0	112.5			37.9	115.6		
26.2	112.8	rew-lft chl		50.9	115.1		
27.6	113.1			60.6	114.3		
33.5	114.1	bnkfl		64.9	115.4		
61.6	114			70.8	114.4		
82.2	113.8			72.0	115.7	rew	
100.0	113.5	lew		86.7	118.3		
103.4	111.9			180.0	119	est	
109.8	111.4						
117.3	111.7						
125.3	111.9						
135.9	113						
154.5	113.5	rew					
156.3	116	boulders					
158.8	118						
164.2	118.1	rb					

Downstream Distance From 9-8							
LOB	Center	ROB					
300	296.0	293					
Cross-section 9							
-150.0	122						
0.0	120						
4.0	118.6	lew					
7.2	115.8						
12.3	116.9						
16.7	116.9						
27.0	117.7						
38.0	118						
54.0	117.6						
71.5	118.6	rew					
80.9	121						
180.0	122						

DISCHARGE MEASUREMENTS								
Discharge Measurements at Ship Creek -Cottonwood Park								
All measurements with AA current meter								
all units in English (feet, cubic feet per second)								
Discharge Measurement			6/28/2002		Time Start	12:12 PM		
Left Channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
57	0.25	0	0	0	1.0	0.3	0.0	
55	0.95	40	53	1.68	2.5	2.4	4.0	
52	1.4	50	44	2.52	3.0	4.2	10.6	
49	1.5	50	41	2.71	3.0	4.5	12.2	
46	1.5	80	44	4.03	3.0	4.5	18.1	
43	1.25	60	43	4.12	3.0	3.8	15.5	
40	1.1	80	45	3.94	3.0	3.3	13.0	
37	1.15	80	46	3.85	3.0	3.5	13.3	
34	1.3	80	46	3.85	3.0	3.9	15.0	
31	1.2	80	43	4.12	3.0	3.6	14.8	
28	1.3	80	40	4.43	3.0	3.9	17.3	
25	1.1	100	47	4.71	3.0	3.3	15.5	
22	1.2	60	43	3.09	3.0	3.6	11.1	
19	0.8	80	49	3.62	3.0	2.4	8.7	
16	0.75	60	40	3.33	3.0	2.3	7.5	
13	0.4	10	60	0.385	2.5	1.0	0.4	
11	0	0	0	0	1	0.0	0.0	
							177.0	
Right Channel			6/28/2002		Time Start:	11:51 AM		
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
50.4	0.4	0	0	0	1.2	0.5	0.0	REW

48	1.4	5	45	0.263	2.2	3.1	0.8	
46	1.65	40	40	2.22	2.0	3.3	7.3	
44	1.2	80	50	3.55	2.0	2.4	8.5	
42	1.2	80	49	3.62	2.0	2.4	8.7	
40	1.2	80	40	4.43	2.0	2.4	10.6	
38	1	100	44	5.03	2.0	2.0	10.1	
36	1.2	80	49	3.62	2.0	2.4	8.7	
34	1.2	100	48	3.69	2.0	2.4	8.9	
32	1.3	80	46	3.85	2.0	2.6	10.0	
30	0.8	80	49	3.62	2.0	1.6	5.8	
28	0.6	50	48	2.31	2.0	1.2	2.8	
26	0.7	30	49	1.37	2.0	1.4	1.9	
24	0.4	20	56	0.805	2.0	0.8	0.6	
22	0.2	10	60	0.385	2.0	0.4	0.2	
20	0.1	0	0	0	1.0	0.1	0.0	LEW
							84.9	
						Total Q=	261.9	cfs
Discharge Measurement			8/28/2002		Time Start	1340		
Right Channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
10	0	0	40	0	1	0	0	
12	0.2	20	42	1.07	2	0.4	0.428	
14	1.1	40	41	2.17	2	2.2	4.774	
16	1.6	40	40	2.22	2	3.2	7.104	
18	1.7	60	42	3.17	2	3.4	10.778	
20	1.65	60	40	3.33	2	3.3	10.989	
22	1.9	50	43	2.58	2	3.8	9.804	
24	1.75	40	48	1.86	2	3.5	6.51	
26	1.4	30	57	1.18	1.3	1.82	2.1476	
26.6	0.6	10	64	0.362	0.3	0.18	0.0652	
						Q=	52.6	cfs
Discharge Measurement			8/28/2002		Time Start	1340		
Left Channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
0.9	1.3	10	63	0.368	0.8	1.04	0.3827	
2.5	2.1	30	46	1.46	1.55	3.255	4.7523	
4	2.5	50	45	2.47	1.5	3.75	9.2625	
5.5	2.7	60	42	3.17	1.5	4.05	12.839	
7	2.6	80	50	3.55	1.5	3.9	13.845	
8.5	2.6	80	50	3.55	1.5	3.9	13.845	
10	2.35	60	41	3.24	1.5	3.525	11.421	
11.5	2.1	50	44	2.52	1.5	3.15	7.938	
13	1.9	50	49	2.27	1.5	2.85	6.4695	

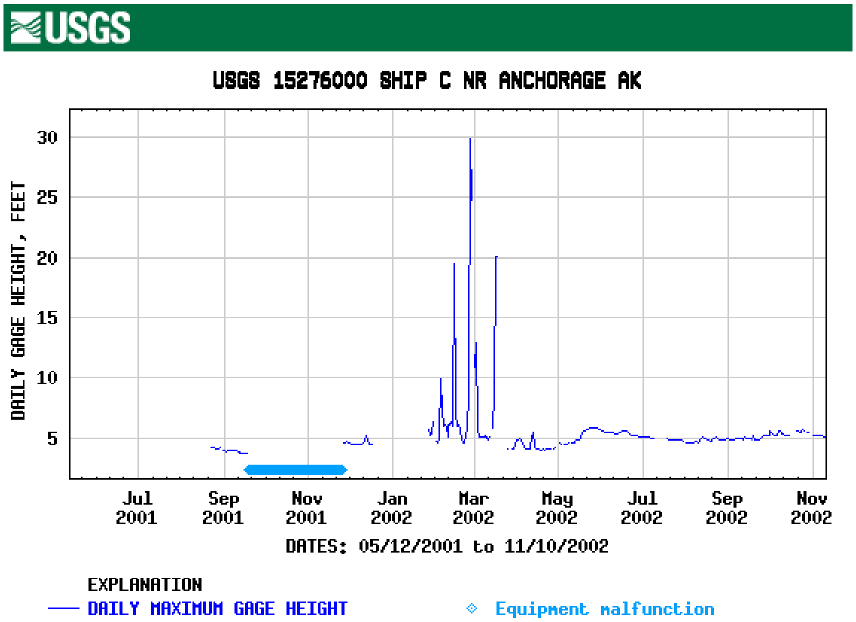
14.5	1.75	50	47	2.36	1.5	2.625	6.195	
16	1.7	40	40	2.22	1.75	2.975	6.6045	
18	1.3	40	53	1.68	2	2.6	4.368	
20	1.25	25	55	1.02	2	2.5	2.55	
22	1.05	15	45	0.753	2	2.1	1.5813	
24	0.7	5	40	0.293	2	1.4	0.4102	
26	0.2	0	40	0	1.2	0.24	0	
26.4	0	0	40	0	0.2	0	0	
						Q=	102.46	cfs
						Total Q=	155.06	CFS

VELOCITY PROFILE						
Velocity Profile at		Ship Creek at Cottonwood Park				
root wad structure				date:	8/28/2002	
				time:	1340	
				discharge	155.06	cfs
Distance	Total	Depth From			Velocity	
From bank	Depth	Surface	Revs	Seconds	(feet/sec)	
0.5	2.2	0.1	30	40	1.67	
0.5	2.2	0.5	50	49	2.27	
0.5	2.2	1	50	40	2.77	
0.5	2.2	1.5	40	40	2.22	
1	2.2	0.1	40	40	2.22	
1	2.2	0.5	60	40	3.33	
1	2.2	1	80	44	4.03	
1	2.2	1.5	60	45	2.96	
1	2.2	2	30	43	1.56	
2	1.9	0.1	80	44	4.03	
2	1.9	0.5	100	45	4.92	
2	1.9	1	80	40	4.43	
2	1.9	1.5	50	45	2.47	
3	1.8	0.1	100	41	5.4	
3	1.8	0.5	100	44	5.03	
3	1.8	1	100	46	4.81	
3	1.8	1.5	50	40	2.77	

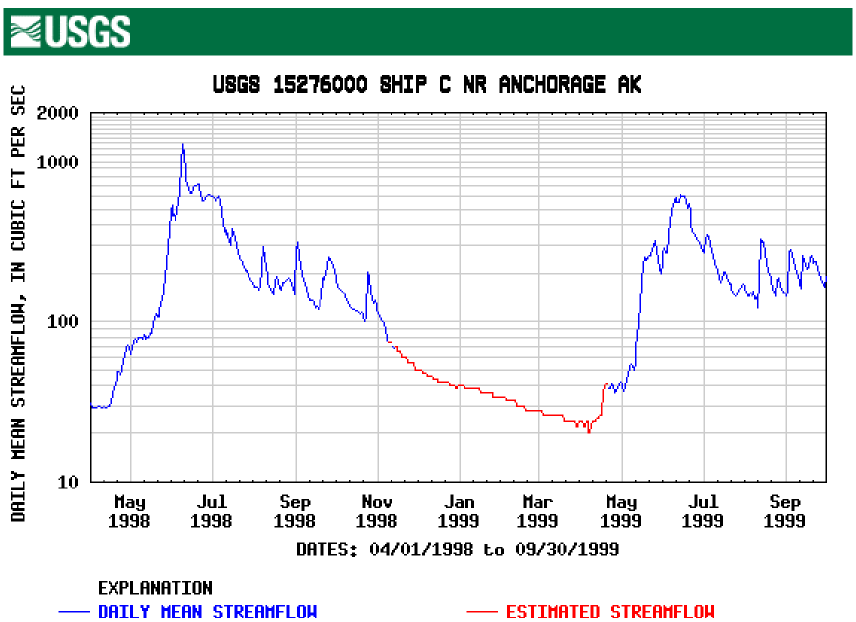
BED MATERIAL PEBBLE COUNT-					
PARTICLE GRADATIONAL ANALYSIS					
Pebble Count at Ship Creek					
date	6/28/2002				
In mm					
108	55	79	32	153	
58	100	84	70	56	
110	15	82	66	43	
30	44	99	112	30	
102	20	76	94	38	
58	61	270	82	48	
24	83	75	111	30	
94	97	125	113	70	
96	120	13	70	59	
92	79	100	158	131	
80	40	37	53	150	
88	70	135	120	58	
85	37	35	136	115	

58	30	31	59	55	
52	141	85	79	81	
170	120	37	56	75	
69	86	25	17	96	
144	27	73	130	58	
92	91	79	45	25	
99	16	21	35	60	
Wentworth	size class				
(mm)		cumulative			
<2	0	0			
2-4	0	0			
4-7	0	0			
8-15	2	2			
16-31	13	15			
32-63	27	42			
64-127	47	89			
128-255	10	99			
256-512	1	100			
Bed material composition-small to medium cobbles, with some coarse to					
very coarse gravels, and some large cobbles.					
D50=52mm		D75=70mm			

SECOND WATER SURFACE				
ELEVATION SURVEY				
Water Surface Elevations at Second Discharge				
Discharge	155	cfs		
WSEL	at			
108.04	xsec 4			
109.85	xsec 5			
Bank survey at BECS-xsec 5				
Bank angle from horizontal at toe 33°				Depth to
Q = 155.1 cfs				WSEL
107.56	channel			-2.29
109.85	REW			0
110.21	center of root wad			0.36
110.75	base of first soil lift			0.9
111.35	base of first willow layer			1.5
111.75	base of second soil lift			1.9
112.55	base of second willow layer			2.7
112.95	top of bank			3.1



Provisional Data Subject to Revision



SITE NAME, LOCATION, CROSS-SECTION SURVEY								
Theodore River					lat-long	N 61° 15' 59.8"		
Cross-sections surveyed July 27, 2002						W -150° 52' 39.0"		
Cross-sections numbered from downstream to upstream								
All units in feet								
Discharge	69.4	cfs						
Slope =	0.0009							
Survey based on local coordinate system								
Elevations shot to arbitrary benchmark.								
All cross-section stationing surveyed from Left Bank to Right Bank looking downstream								
Local elevation control, BM1, 110.60 ft-Southwest corner of bridge, at concrete rail.								
Downstream Distance From 1-0				Downstream Distance From 2-1				
LOB	Center	ROB		LOB	Center	ROB		
0	0	0		458	384	278		
Cross-section 1				Cross-section 2				
Station	Elevation			Station	Elevation			
-100	101	est		-100	104			
0.0	99.4			0.0	103.2	LB Veg'd		
3.9	99			5.2	101.2			
7.6	96.9			7.8	96.3	LEW		
10.8	95.96	LEW		9.9	93.6			
17.3	95.4			14.7	93.1			
32.8	95.1			23.5	93.8			
40.3	94.9			29.6	94.3			
50.7	95.2			39.5	94.7			
62.6	95.3			45.9	95.4			
69.5	95.9	REW		56.9	95.7			
84.9	96.9			61.7	96.3	REW		
105.0	98.2			70.9	96.8			
200.0	101	est		82.0	98.9	bnkfl		
				128.3	100.3			
				152.4	101	Edge of Gravel		
				155.6	101.4	Veg		
				200.0	104	est		
Downstream Distance From 3-2				Downstream Distance From 4-3				
LOB	Center	ROB		LOB	Center	ROB		
277	220	151		77	58	61		
Cross-section 3					Cross-section 4		at bridge	
Station	Elevation				Station	Elevation	Notes	
-75	105				0	106		
0.0	103.4	LB			0.0	96.9	LEW - at vertical sheet pile	
4.2	100.9				0.1	93.4	At sheet pile	
5.7	97.9				6.3	94		
9.5	96.4	LEW			15.3	94.8		
12.0	95.9				24.2	96.1		
19.2	95.9				29.2	95.9		
22.5	95.9				34.0	94.5	Double middle pilings	
27.9	96.6	Gravel Bar			37.2	95.1		
30.2	96.9	Gravel Bar			40.4	95.9		
33.7	96.9	Gravel Bar			40.5	95.6		
38.2	96.4	Gravel Bar			45.2	94.4		
43.5	95.7				53.9	96.1		
50.9	95.3				68.6	96.6	REW	
58.1	95.2				81.3	97.7	Sheetpile	
66.6	95.5				81.4	106		
74.4	96.5	REW						
81.4	97.1					102.9	hwm at bridge	
96.2	98.6							
113.6	99.5	Bnkfl						
121.4	100.2	Veg						
124.2	101.4	RB Veg'd						

200.0	105	est						
Downstream Distance From 5-4				Downstream Distance From 6-5				
LOB	Center	ROB		LOB	Center	ROB		
138	119	71		65	182	280		
Cross-section 5				Cross-section 6				
Station	Elevation	Notes		Station	Elevation	Notes		
-50	106			-50	106	est		
0.0	101.1	Veg/Gravel edge		0.0	101.4			
42.4	100.7	Gravel		27.7	100.8			
51.0	98.9			73.0	97.5			
55.9	99.8	Sand		75.7	96.8	LEW		
67.8	96.4	LEW		83.0	95.8			
70.8	95.9			93.2	94.6			
75.1	94.3			102.3	95.2			
82.0	94.6			116.6	95.8			
93.0	93.8			133.2	95.4			
98.8	94.8			146.5	95.5			
106.7	95.7			149.2	95.2			
116.2	93.7			151.4	96.7	REW		
124.3	95.4			155.6	101.2	undercut		
127.9	96.5	REW		156.7	102.6			
133.3	99.6			160.9	103.4	RB flat on top		
141.2	104.3			200.0	107	est		
147.2	104.6	RB hvy veg						
190.0	105							
200.0	109	est						
	104	hwm						
Downstream Distance From 7-6				Downstream Distance From 8-7				
LOB	Center	ROB		LOB	Center	ROB		
80	162	229		293	234	151		
Cross-section 7				Cross-section 8				
Station	Elevation	Notes		Station	Elevation	Notes		
-90	106	est		-100	109	est		
0.0	102.7	LB - veg'd		0.0	103.5	LB flat to left		
6.4	101.4			12.0	102.7			
11.9	97.1	LEW		14.6	97.3	LEW		
16.4	96.1			20.3	94			
27.8	95.4			25.7	93.4			
46.8	96.2			41.9	95.1			
72.3	95.9			52.8	95.9			
85.7	97.2	REW		60.9	97.2	REW		
88.5	100.8			71.9	99.1			
117.9	101.3			124.5	101.6			
131.1	99.4	High Water Channel		182.8	103			
147.8	101.1			300.0	109	est		
260.0	108	est						
Downstream Distance From 9-8								
LOB	Center	ROB						
228	163	87						
Cross-section 9								
-80.0	110	est						
0.0	102.9							
4.1	99.8							
27.2	101.1	Bnkfl						
34.6	98.9							
38.7	97.4	LEW						
43.6	96.4							
55.3	96.5							
76.5	96							
89.1	96							
104.3	96.1							
107.3	97.3	REW						

112.8	100.9							
121.1	102.4	RB						
270	109	est						

DISCHARGE MEASUREMENTS								
Discharge Measurements at Theodore River					7/27/2002			
All measurements with AA current meter								
all units in English (feet, cubic feet per second)								
Discharge Measurement					Time Start	1650		
Left Channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
28.0	0.0	0	0	0	1.25	0.0	0.0	LEW
30.5	0.3	10	56	0.412	2.50	0.6	0.3	
33.0	0.5	20	42	1.07	2.50	1.1	1.2	
35.5	0.8	30	40	1.67	2.50	1.9	3.1	
38.0	1.1	40	42	2.12	2.50	2.8	5.8	
40.5	1.3	50	47	2.36	2.50	3.1	7.4	
43.0	1.3	50	47	2.36	2.50	3.3	7.7	
45.5	1.0	40	42	2.12	2.50	2.5	5.3	
48.0	0.8	40	47	1.89	2.50	2.0	3.8	
50.5	0.5	30	55	1.22	2.10	1.1	1.3	
52.2	0.0	0	0	0	0.85	0.0	0.0	REW
							35.8	cfs
Right Channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
10.0	0.0	0	0	0	1.00	0	0.0	LEW
12.0	0.2	0	0	0	2.00	0.3	0.0	
14.0	0.3	20	52	0.866	2.00	0.5	0.4	
16.0	0.5	30	48	1.4	2.00	0.9	1.3	
18.0	0.6	30	45	1.49	2.00	1.1	1.6	
20.0	0.7	30	40	1.67	2.00	1.4	2.3	
22.0	0.9	40	50	1.78	2.00	1.8	3.2	
24.0	1.3	40	53	1.68	2.00	2.5	4.2	
26.0	1.8	40	49	1.82	2.00	3.6	6.6	
28.0	2.5	40	45	1.98	2.00	4.9	9.7	
30.0	1.9	20	40	1.12	2.00	3.8	4.3	
32.0	0.0	0	0	0	1.00	0	0.0	REW
							33.6	cfs
						Total Q=	69.4	CFS

VELOCITY PROFILE					
Velocity Profile at Theodore River					
Distance	Total	Depth From			Velocity
From bank	Depth	Surface	Revs	Seconds	(feet/sec)
None	low water at time of survey				

BED MATERIAL PEBBLE COUNT-					
PARTICLE GRADATIONAL ANALYSIS					
Pebble Count at Theodore River					
date	27-Jul-02				
In mm					
11	6	8	23	23	
11	13	10	20	30	
9	15	12	25	31	
16	2	17	17	17	
3	15	13	23	39	
8	18	7	33	11	
16	30	31	20	26	
7	32	15	12	37	

<2	17	9	28	25	
<2	14	15	14	20	
<2	12	17	16	8	
<2	12	21	9	25	
<2	<2	24	19	19	
11	<2	24	31	16	
7	<2	17	36	23	
14	6	13	20	14	
13	19	13	41	11	
10	7	21	24	18	
17	6	32	12	38	
9	8	20	15	65	
Wentworth	size class				
(mm)		cumulative			
<2	9	9			
2-4	1	10			
4-7	7	17			
8-15	34	51			
16-31	40	91			
32-63	8	99			
64-127	1	100			
128-255	0	100			
Bed material composition-coarse gravels, with some very coarse gravels,					
some fine gravels, and some silt and sand.					
D50=11mm		D75=15mm			

SITE NAME, LOCATION, CROSS-SECTION SURVEY							
Willow Creek at Lapham Property					lat-long	N 61° 46' 20.0"	
Cross-sections surveyed July 11, 2002						W -149° 57' 32.4"	
Cross-sections numbered from downstream to upstream							
All units in feet							
Discharge	325.98	cfs					
Slope =	0.0041	ft/ft					
Survey based on local coordinate system							
Elevations shot to arbitrary benchmark.							
All cross-section stationing surveyed from Left Bank to Right Bank looking downstream							
Local elevation control, BM1, 99.90 ft-Southeast corner of property, at rebar.							
Downstream Distance From 1-0				Downstream Distance From 2-1			
LOB	Center	ROB		LOB	Center	ROB	
0	0.0	0		283	273.0	257	
Cross-section 1				Cross-section 2			
Station	Elevation			Station	Elevation		
-50	97	est		-50	97	est	
0.0	95.4			0.0	95		
10.0	95.4			20.1	94.6	LB	
22.0	90	lew		23.4	91.1	LEW	
28.7	87.9			30.0	89.4		
44.2	87.5			42.9	89		
57.5	88.8			56.3	89.8		
65.9	88.3			72.1	90		
75.4	88.9			87.9	90.2		
85.0	89.2			103.2	91.44	REW	
100.8	90.1	rew		132.4	92.7	bnkfl	
120.2	91.8	bnkfl		160.0	95		
130.0	94			260.0	95.5		
250.0	96			280.0	97	est	
280.0	97	est					
Downstream Distance From 3-2				Downstream Distance From 4-3			
LOB	Center	ROB		LOB	Center	ROB	
402	351.0	271		234	320.0	376	
Cross-section 3				Cross-section 4			
Station	Elevation			Station	Elevation		
-50	98			-250	100		
0.0	95.5	LB		-200	97		
12.2	94.7			-191	94		
13.7	92.3	LEW		-138	93.9		
24.5	91			-130	96.9		
37.0	91.2			-75	97.1		
51.4	90.1			0.0	96.9		
69.6	90.2			19.2	96.1		
94.5	92.4	REW		48.6	93.8	lew	
119.2	93			57.4	92.8		
135.0	93.22			74.3	92.2		
140.0	95			84.3	91.3		
240.0	96			94.2	90.7		
280.0	98			107.6	90.6		

				110.0	93.8	rew	
				124.3	99		
				200.0	100		
Downstream Distance From 5-4				Downstream Distance From 6-5			
LOB	Center	ROB		LOB	Center	ROB	
146	286.0	360		104	180.0	227	
Cross-section 5				Cross-section 6			
Station	Elevation			Station	Elevation		
-290	100			-300	101		
-251	98			-270	99		
-248	96			-261	96		
-221	96			-225	96.5		
-215	98.5			-220	98.5		
-100	98			-100	98		
0.0	97.4			0.0	97.9		
19.6	96.3			7.3	95.5	lew	
34.0	95.1	LEW		21.5	94.2		
47.4	93.8			25.8	93.5		
61.9	93.3			39.2	93.5		
76.7	93.1			52.1	93.7		
91.6	92.8			70.0	93.8		
108.6	95	REW		81.9	93.7		
113.9	99.4	TOBatproject		93.7	95.1	rew	
128.2	99.6	LAPHAM YARD		95.1	98.8		
190.0	100			103.4	99.8		
				200.0	101		
Downstream Distance From 7-6				Downstream Distance From 8-7			
LOB	Center	ROB		LOB	Center	ROB	
236	262.0	281		135	184.0	198	
Cross-section 7				Cross-section 8			
Station	Elevation			Station	Elevation		
-290	103			-180	106		
-240	99			-93	101		
-234	95.8			-87	-97.5		
-205	95.5			-45	98		
-200	99.5			-40	100		
-100	99			0.0	99.4		
0.0	98.7			13.9	99.4		
6.7	96.2	lew		25.0	97	lew-lft chnl	
22.0	95.4			37.2	95.7		
33.7	94.6			52.0	95.9		
46.6	94.6			64.0	96.9	rew-lft chnl	
64.2	94.3			88.5	98.3		
77.1	94.2			115.7	99.7	island	
86.5	94.7			145.1	97.6	lew-rt chnl	
87.6	96.1	rew		156.0	95.9		
91.5	102.1			168.5	94.7		
111.1	102.5			179.3	95.2		
200.0	103			191.2	97.6	rew-rt chanl	
				201.8	105.4	RB	
				300.0	106		

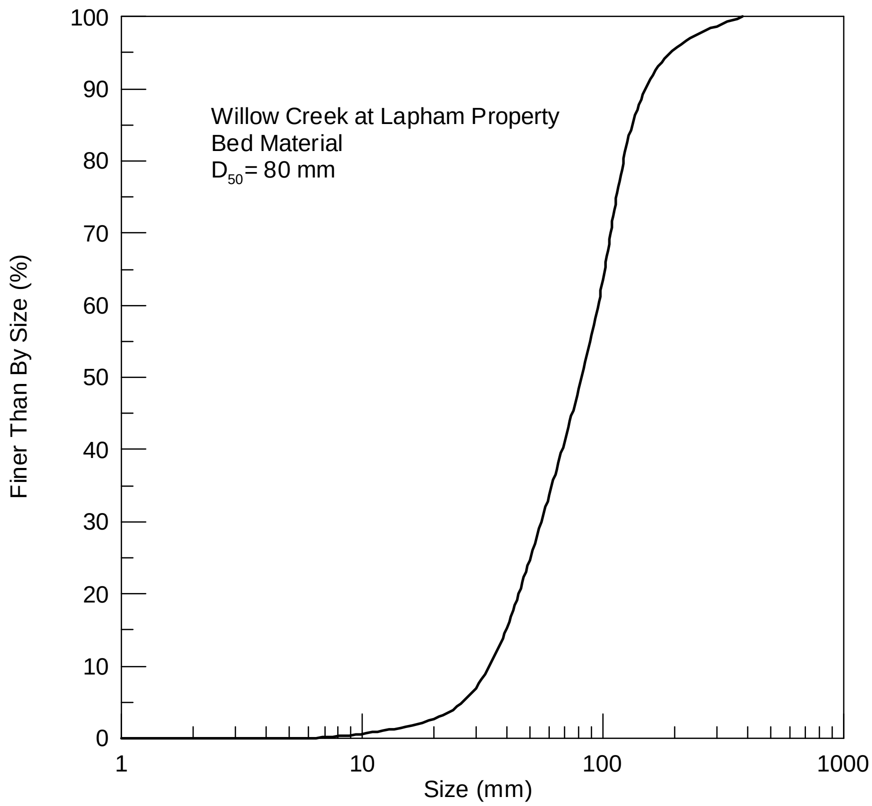
Downstream Distance From 9-8				Downstream Distance From 10-9			
LOB	Center	ROB		LOB	Center	ROB	
138	217.0	322		221	216.0	223	
Cross-section 9				Cross-section 10			
Station	Elevation			Station	Elevation		
-170	106			-50	106		
0.0	100.1	LB		0.0	105.5	LB at bridge	
16.4	98.95	lew		15.6	99.5	Lew	
32.8	97.8			47.5	97.8		
48.8	97.4			60.4	96.9		
63.1	97.2			77.0	96.5		
78.9	96.8			88.8	97.5		
91.0	96.8			104.2	97.1		
104.7	98			115.2	99.7	rew	
111.7	98.98	rew		120.6	103.5		
116.6	100.1	flat fldpln to right		250	105		
260.0	102						
300.0	106						

DISCHARGE MEASUREMENTS								
Discharge Measurements at Willow Creek at Lapham								
All measurements with AA current meter								
all units in English (feet, cubic feet per second)								
Discharge Measurement			7/11/2002		Time Start	3:45 PM		
Main Channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
73	0	0	0	0	1.5	0		
70	0.8	40	41	2.17	3	2.4	5.208	
67	1.4	60	41	3.24	3	4.2	13.608	
64	1.7	60	40	3.33	3	5.1	16.983	
61	1.7	80	46	3.85	3	5.1	19.635	
58	1.8	80	43	4.12	3	5.4	22.248	
55	1.55	80	45	3.94	3	4.7	18.321	
52	1.7	80	42	4.22	3	5.1	21.522	
49	1.6	80	44	4.03	3	4.8	19.344	
46	1.8	60	42	3.17	3	5.4	17.118	
43	1.8	80	50	3.55	3	5.4	19.17	
40	1.9	80	48	3.69	3.5	6.65	24.5385	
36	1.8	80	47	3.77	4	7.2	27.144	
32	1.7	80	41	4.32	4	6.8	29.376	
28	1.8	80	47	3.77	4	7.2	27.144	
24	1.5	80	49	3.62	4	6	21.72	
20	0.95	60	51	2.61	4	3.8	9.918	
16	0.7	60	48	2.77	4	2.8	7.756	
12	0.55	30	43	1.56	4	2.2	3.432	
8	0.4	20	40	1.12	4	1.6	1.792	
4	0	0	0	0	2	0	0	
						Q=	325.98	cfs
Discharge Measurement								
from USGS gaging station			Willow C Nr Willow AK					
			15294005					
date:	time	discharge						
7/11/2002	1,800	276	cfs					
8/26/2002	2100	696	cfs					

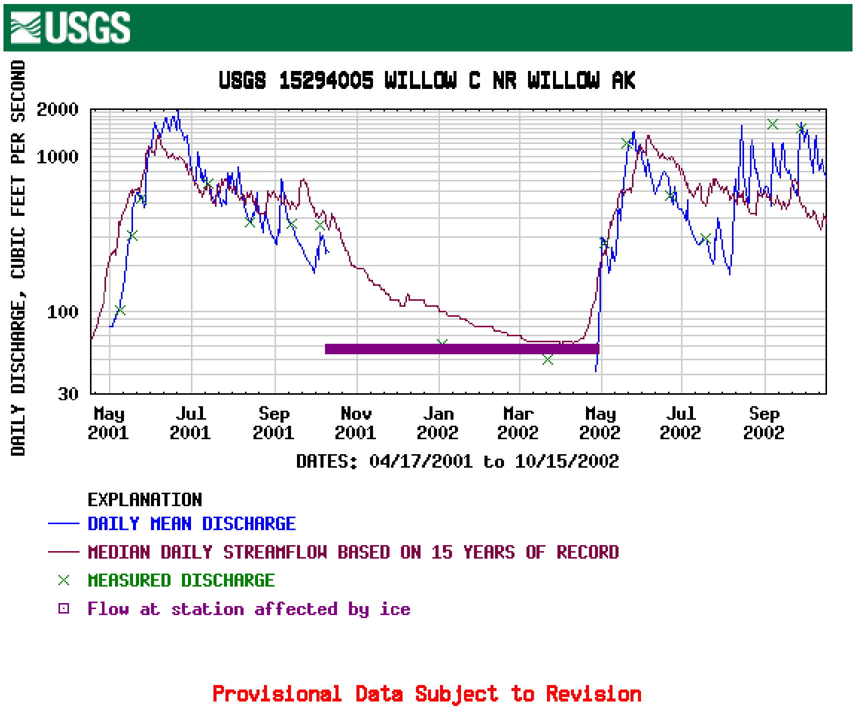
VELOCITY PROFILE					
Velocity Profile at		Willow Creek at Lapham Property			
root wad structure		date:	8/26/2002		
		time:	2100		
		discharge	696	cfs	
Distance	Total	Depth From			Velocity
From bank	Depth	Surface	Revs	Seconds	(feet/sec)
0.5	1.7	0.1	40	46	1.94
0.5	1.7	0.5	40	42	2.12
0.5	1.7	1	50	41	2.71
0.5	1.7	1.5	40	44	2.02
1	1.8	0.1	40	47	1.89
1	1.8	0.5	50	40	2.77
1	1.8	1	60	44	3.02
1	1.8	1.5	30	40	1.67
2	1.9	0.1	50	45	2.47
2	1.9	0.5	80	51	3.48
2	1.9	1	80	51	3.48
2	1.9	1.5	60	43	3.09
3	3.1	.6 depth	80	43	4.12
4	2.5	.6 depth	100	43	5.15
5	2.6	.6 depth	100	44	5.03

BED MATERIAL PEBBLE COUNT-					
PARTICLE GRADATIONAL ANALYSIS					
Pebble Count at Willow Creek Latham					
date	7/11/2002				
In mm					
15	74	70	122	230	
25	74	168	94	93	
30	200	42	147	100	
37	156	260	85	59	
45	125	170	142	270	
49	90	152	178	212	
54	93	111	88	80	
79	88	131	127	142	
87	151	37	127	68	
107	135	87	84	79	
110	129	190	57	91	
126	61	63	152	196	
141	100	155	36	110	
185	43	54	72	48	
194	28	111	37	123	
240	59	300	40	71	
245	161	98	115	180	
250	145	59	143	200	
280	128	112	33	119	
300	138	215	128	137	
Wentworth	size class				
(mm)		cumulative			
<2	0	0			
2-3	0	0			
4-7	0	0			
8-15	1	1			
16-31	3	4			
32-63	19	23			
64-127	37	60			
128-255	35	95			

256-512	5	100			
Bed material composition-small, medium, large, and very large cobbles, with					
some scattered small boulders.					
D50=80mm		D75=110mm			



SECOND WATER SURFACE				
ELEVATION SURVEY				
Water Surface Elevations at Second Discharge				
Discharge	696	cfs		
WSEL	at			
95.59 ft	xsec 5			
Bank survey at BECS near xsec 5				
Bank angle from horizontal at toe 39°				Depth to
Q = 696 cfs				WSEL
93.92	channel			-1.6
95.52	REW			0
96.74	center of root wad			1.22
98.15	top of header log			2.63
99	top of FESL, bottom of willow layer			3.48
99.6	top of bank			4.08


USGS
USGS 15294005 WILLOW C NR WILLOW AK
DAILY DISCHARGE, CUBIC FEET PER SECOND
2000
1000
100
30
May 2001
Jul 2001
Sep 2001
Nov 2001
Jan 2002
Mar 2002
May 2002
Jul 2002
Sep 2002
DATES: 04/17/2001 to 10/15/2002
EXPLANATION
DAILY MEAN DISCHARGE
MEDIAN DAILY STREAMFLOW BASED ON 15 YEARS OF RECORD
MEASURED DISCHARGE
Flow at station affected by ice
Provisional Data Subject to Revision

SITE NAME, LOCATION, CROSS-SECTION SURVEY						
Willow Creek at Pioneer Lodge					lat	N 61° 46' 02.6"
Cross-sections surveyed June 27, 2002					long	W 150° 04' 03.0"
Cross-sections numbered from downstream to upstream						
All units in feet						
Discharge	504	cfs				
Slope =	0.0019	ft/ft				
Survey based on local coordinate system						
Elevations shot to arbitrary benchmark.						
All cross-section stationing surveyed from Left Bank to Right Bank looking downstream						
Local elevation control, BM1, 122.3 ft-Northeast abutment of Parks Highway bridge bm.						
Downstream Distance From 1-0				Downstream Distance From 2-1		
LOB	Center	ROB		LOB	Center	ROB
0	0	0		156	186	229
Cross-section 1				Cross-section 2		
Station	Elevation			Station	Elevation	
-106.2	107			-116.1	107	
-6.2	105.3			-16.1	105.4	
-0.7	105			-5.9	105.4	
0.0	102.6	lew		0.0	103.2	lew
15.5	101.6			2.1	101.4	
27.1	101.4			12.7	99.5	
67.3	100			26.4	99.3	
86.3	100.8			36.8	99.5	
112.1	102.6	rew		58.9	100.4	
136.7	105.1			89.2	102.9	rew
336.7	107			97.6	103.4	
				122.1	105	
				322.1	107	
Downstream Distance From 3-2				Downstream Distance From 4-3		
LOB	Center	ROB		LOB	Center	ROB
208	199	183		279	257	204
Cross-section 3				Cross-section 4		
Station	Elevation			Station	Elevation	Notes
-109.9	107.5			-57.2	109	est
-9.9	106			-7.2	107.8	
-5.4	106.2			-0.4	105.89	hwm
0.0	103.2	lew		0.0	103.3	lew
12.0	100.1			9.7	101.3	
16.4	99.7			20.1	100.9	
28.7	100.1			33.5	99.2	
39.6	101.2			36.4	99.7	
45.1	99.9			52.3	103.4	rew
49.1	99.9			91.6	105.7	bnkfl
66.7	101.1			144.9	105.4	
81.1	103	rew		172.9	104.1	
108.3	104.3			205.5	105.5	
167.1	104.7	bnkfl		262.6	108.4	
191.7	106.7			412.6	109	est
391.7	107.5					

Downstream Distance From 5-4				Downstream Distance From 6-5		
LOB	Center	ROB		LOB	Center	ROB
181	213	178		222	230	233
Cross-section 5				Cross-section 6		
Station	Elevation	Notes		Station	Elevation	Notes
-73.6	111			-65.9	112	est
-23.6	110.1			-15.9	109.5	fence railing
-5.0	109.5			-1.9	107.2	at us rootwad
-0.6	105.42	hwm		-0.4	105.42	hwm
-0.2	104.2			0.0	104.95	lew
0.0	103.8	lew		0.0	102.5	
10.5	102			20.9	103	
24.1	103.2			51.7	104.1	
39.7	102.3			86.0	104.9	
61.4	102.9			123.8	104.5	
102.8	103.6			151.3	103.8	
111.8	102.9			180.1	105.3	rew
126.7	103.4			189.5	109.2	log bulkhead
145.6	102.2			204.6	111.1	
169.5	104.5	rew		354.6	112	est
209.3	108.8					
230.5	109.3					
380.5	111					
Downstream Distance From 7-6				Downstream Distance From 8-7		
LOB	Center	ROB		LOB	Center	ROB
146	119	117		288	209	200
Cross-section 7				Cross-section 8		
Station	Elevation	Notes		Station	Elevation	Notes
-169.6	112	esr		-12.7	111.7	Rock abutment at bridge
-104.6	105.4			0.0	105.6	lew
-99.6	102.9			16.8	103.4	
-39.6	103.9			31.5	102.9	
-34.6	105.4			47.2	102.8	
-19.6	108.1			59.7	102.9	
-5.6	110.2			74.6	103	
0.0	105.4	lew		83.9	102	
8.8	103.8			95.2	103.2	
35.0	104.3			103.0	106	rew
66.4	104			108.8	108.7	Rock abutment at bridge
93.6	104.1			121.3	113.7	
121.8	103.1					
140.0	104.5					
140.3	105.5	rew				
141.6	110.7	Edge of bulkhead				
291.6	112					
Downstream Distance From 9-8				Downstream Distance From 10-9		
LOB	Center	ROB		LOB	Center	ROB
179	167	180		235	210	189
Cross-section 9				Cross-section 10		
-155.7	113			Station	Elevation	Notes

-5.7	107.9			-179.0	114	est	
0.0	105.7	lew		-29.0	108		
2.0	102.9			-21.0	106.4		
4.2	103.2			0.0	106	lew	
16.0	103.6			34.0	103.3		
57.1	103.1			42.1	102.3		
83.5	103.5			88.5	103.5		
94.1	103.1			92.8	103.7		
97.4	105.7	rew		97.1	106	rew	
98.7	107.2			99.0	108.1		
248.7	113			249.0	114		

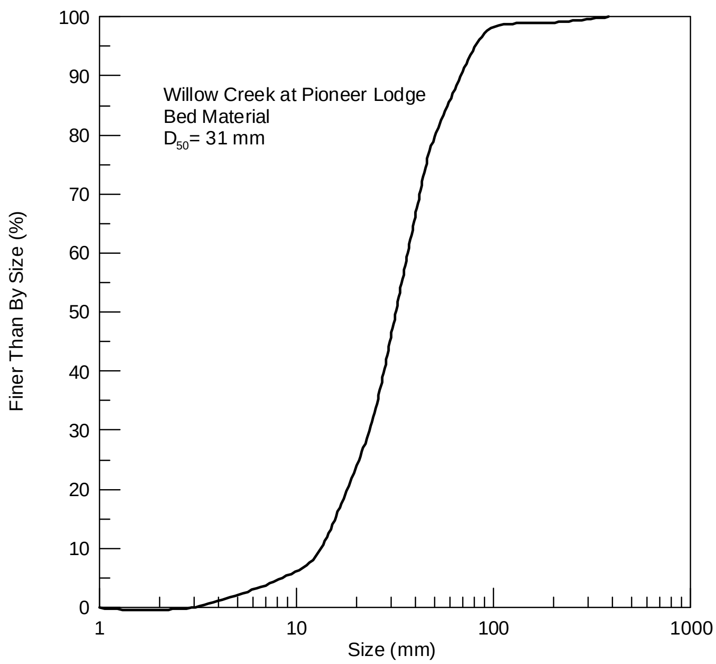
DISCHARGE MEASUREMENTS								
Discharge Measurements at Willow Creek at Pioneer					6/27/2002			
All measurements with AA current meter								
all units in English (feet, cubic feet per second)								
Discharge Measurement					Time Start	7:10 PM		
Left Channel								
Dist	depth	Revs	Time	Velocity	Horizontal	Area	Discharge	
4.5	0.5	0	0	0	1.3	0.6	0.0	REW
7	0.4	10	58	0.398	3.8	1.5	0.6	
12	1.75	20	51	0.882	5.0	8.8	7.7	
17	2.1	20	40	1.12	5.0	10.5	11.8	
22	2.1	25	42	1.33	5.0	10.5	14.0	
27	2.4	40	45	1.98	5.0	12.0	23.8	
32	2.7	50	50	2.22	5.0	13.5	30.0	
37	2.8	40	40	2.22	5.0	14.0	31.1	
42	3	50	43	2.58	5.0	15.0	38.7	
47	3.1	40	41	2.17	5.0	15.5	33.6	
52	3	50	45	2.47	5.0	15.0	37.1	
57	3.1	40	43	2.07	5.0	15.5	32.1	
62	3	50	48	2.31	5.0	15.0	34.7	
67	3	50	44	2.52	5.0	15.0	37.8	
72	2.95	50	45	2.47	5.0	14.8	36.4	
77	2.95	40	44	2.02	5.0	14.8	29.8	
82	3	50	43	2.58	5.0	15.0	38.7	
87	3.05	30	47	1.43	5.0	15.3	21.8	
92	3.25	40	51	1.75	5.0	16.3	28.4	
97	3.05	20	55	0.82	5.0	15.3	12.5	
102	2.85	5	40	0.293	5.0	14.3	4.2	
107	0.8	0	0	0	2.6	2.1	0.0	
107.3	0	0	0	0	0.1	0.0	0.0	LEW
							504.6	
Discharge Measurement			Willow C Nr Willow AK					
from USGS gaging station			15294005					
date:	time	discharge						
6/27/2002	1,930	470	cfs					
8/26/2002	2100	696	cfs					

VELOCITY PROFILE						
Velocity Profile at		Willow Creek at Pioneer Lodge				
Adjacent to center viewing platform at root wad structure						
date:	8/26/2002					
time:	1800					
discharge	696	cfs				

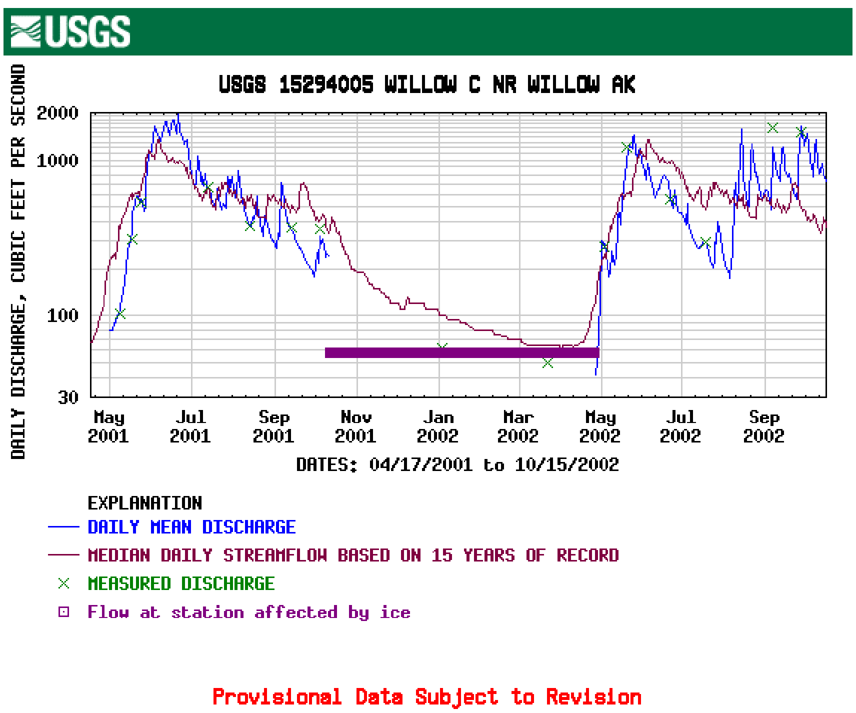
Distance	Total	Depth From			Velocity	
From bank	Depth	Surface	Revs	Seconds	(feet/sec)	
0.5	2	0.1	20	40	1.12	
0.5	2	0.5	30	47	1.43	
0.5	2	1	40	49	1.82	
0.5	2	1.5	40	47	1.89	
0.5	2	1.8	10	54	0.426	
1	2.1	0.1	30	47	1.43	
1	2.1	0.5	40	50	1.78	
1	2.1	1	40	40	2.22	
1	2.1	1.5	40	47	1.89	
1	2.1	1.8	40	60	1.49	
2	2.3	0.1	30	40	1.67	
2	2.3	0.5	40	40	2.22	
2	2.3	1	40	41	2.17	
2	2.3	1.5	40	42	2.12	
2	2.3	2	30	53	1.27	
3	2.5	0.1	30	41	1.63	
3	2.5	0.5	50	47	2.36	
3	2.5	1	50	46	2.41	
3	2.5	1.5	40	43	2.07	
3	2.5	2	30	40	1.67	
3	2.5	2.4	20	40	1.12	
4	2.6	.6 depth	50	47	2.36	
5	2.6	.6 depth	40	40	2.22	
Adjacent to west end of east viewing platform at root wad structure						
0.5	2.2	0.1	60	45	2.96	
0.5	2.2	0.5	50	44	2.52	
0.5	2.2	1	30	40	1.67	
0.5	2.2	1.5	40	46	1.94	
0.5	2.2	2	60	41	3.24	
1	2.6	0.1	80	41	4.32	
1	2.6	0.5	100	45	4.92	
1	2.6	1	80	44	4.03	
1	2.6	1.5	40	48	1.86	
1	2.6	2	60	45	2.96	
2	3	0.1	100	40	5.53	
2	3	0.5	80	42	4.22	
2	3	1	80	52	3.41	
2	3	1.5	60	41	3.24	
2	3	2	60	44	3.02	
2	3	2.5	60	42	3.17	
3	2.9	0.1	80	41	4.32	
3	2.9	0.5	80	45	3.94	
3	2.9	1	80	49	3.62	
3	2.9	1.5	60	41	3.24	
3	2.9	2	60	40	3.33	
3	2.9	2.5	60	46	2.89	
4	3.2	.6 depth	80	51	3.48	
5	3.8	.6 depth	50	45	2.47	

BED MATERIAL PEBBLE COUNT-						
PARTICLE GRADATIONAL ANALYSIS						
Pebble Count at Willow Creek at Pioneer						
date	6/27/2002					
In mm						
49	39	6	28	31		
34	22	16	49	38		
29	48	67	86	68		
40	43	100	44	90		
85	38	125	82	95		
77	50	59	72	58		
40	66	32	6	25		
23	36	27	93	50		

103	13	18	23	5		
26	17	47	14	47		
68	26	97	62	70		
54	27	42	135	53		
23	46	14	280	22		
33	57	55	60	32		
13	27	56	46	34		
48	51	30	65	43		
22	14	35	39	27		
34	62	105	39	41		
30	37	34	24	40		
48	31	37	42	77		
Wentworth	size class					
(mm)		cumulative				
<2	0	0				
2-4	0	0				
4-7	3	3				
8-15	5	8				
16-31	23	31				
32-63	47	78				
64-127	20	98				
128-255	1	99				
256-512	1	100				
Bed material composition-very coarse gravels, with some small and medium						
cobbles, and some fine gravel.						
D50=31mm		D75=45mm				



SECOND WATER SURFACE				
ELEVATION SURVEY				
Water Surface Elevations at Second Discharge				
Discharge	710	cfs		
WSEL	at			
104.13 ft	xsec 4			
104.42 ft	xsec 5			
105.42 ft	xsec 6			
Bank survey at BECS near xsec 5				
Bank angle from horizontal at toe 39°				Depth to
Q = 710 cfs				WSSEL
91.6	channel			-0.4
92	LEW			0
94.08	center of root wad			2.08
95.5	top of header log			3.5
95.67	first willow layer			3.67
95.8	top of first FESL			3.8
96.27	second willow layer			4.27
96.47	top of second FESL			4.47
96.8	third willow layer			4.8
97.5	top of bank			5.5



From Mulberg and Moore, 1998.

LIVE STAKING

Live staking is a simple technique that installs a dormant cutting (see *Dormant Cuttings*) directly into the ground. This technique is often utilized where single stem plantings will provide adequate plant cover, slope stability and fish habitat. Live staking may be combined with other revegetation techniques to anchor bundles, brush mats and erosion control fabric.

Collection, storage and planting information is described in the *Dormant Cuttings* section.

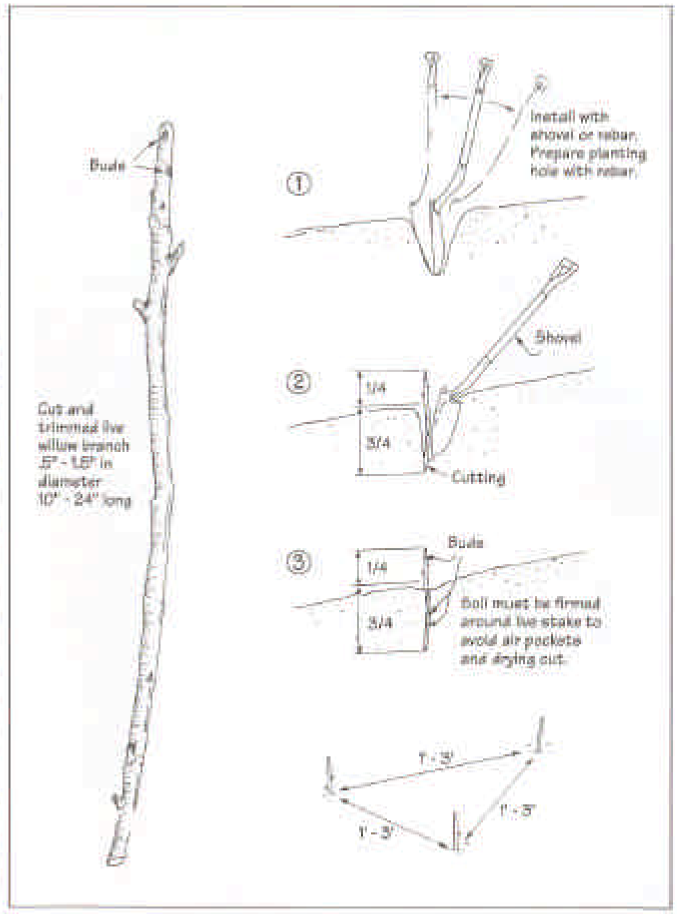
Prepare several live stakes from one dormant cutting. Cut stakes 10 to 24 inches long, ¼ to ½ inches in diameter (slightly larger diameter cuttings will also work). Discard flower buds ("pussy willows"). Flower buds typically occur at the top ⅓ of a branch that was produced during the past growing season. At least one or two leaf buds which are smaller than flower buds must be present near the top of each live stake.

Select planting sites carefully since live stakes require moist soils. Watering is not required; however, watering could increase survival and promote plant growth. Occasional deep watering is more effective and encourages deeper rooting than frequent light watering. Water during the first 6 weeks after planting if the soil is dry.

Use rebar, ½ inch or less in diameter, to create a planting hole for longer stakes, particularly when planting in compact and gravelly soils. Tightly pack the soil around the stake so that no air pockets remain.

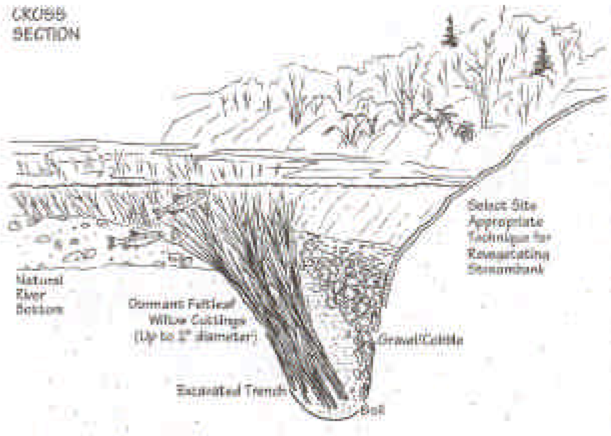
Plant stakes upright 1 to 3 feet on center. Stakes should be planted as vertically as possible, placing **at least** ¾ of the stake below ground so that **only one or two leaf buds** are left exposed above the ground. The intent is to maximize the surface area for rooting so a good root system can develop and support a healthy shoot system. If more than one or two buds, ¼ of the stake, or 4 inches of the live stake is extending above the soil surface, trim the stake.

Water to help remove air pockets and increase contact between the soil and surface of the live stake. Moist soil is needed during the period the live stake is rooting and becoming established, at least 4 to 6 weeks after planting. Topsoil is not required. Survival rates for drier sites may be increased if larger cuttings are used.



LIVE SILTATION

CROSS SECTION

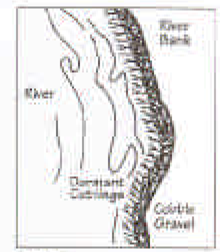


Live siltation is a revegetation technique used to secure the toe of a slope, trap sediments and create fish rearing habitat. The system can be constructed as a living or a non-living brushy system at the water's edge. This technique is particularly valuable for providing immediate cover and fish habitat while other revegetation plantings become established.

Collection, storage and planting information is described in the *Dormant Cuttings* section. The dormant branches need to be a minimum of 3 feet long with side branches still attached. If a living system is planned, Feltleaf, Pacific or Sitka willow is recommended (see *Streambank Revegetation Plant Species Selection List, Shrubs and Trees*). Any woody plant material such as alder, can be installed for a non-living system.

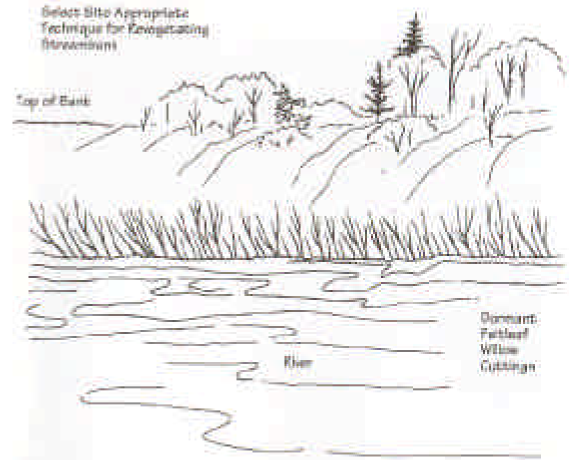
Construct a v-shaped trench at the ordinary high water (OHW) level, with hand tools or a backhoe. Excavate a trench so that it parallels the toe of the streambank and is approximately 2 feet deep. Lay a thick layer of willow branches in the trench so that ¾ of the length of the branches is above the trench and the branches angle out toward the stream. Place a minimum of 40 willow branches per yard in the trench.

Backfill over the branches with a gravel soil mix and secure the top surface with large washed gravel, bundles (see *Bundles/Coir Logs* Sections). Both the upstream and downstream ends of the live siltation construction need to transition smoothly into a stable streambank to reduce the potential for the system to wash out. More than one row of live siltation can be installed. A living and growing siltation system typically is installed at OHW. A non-living system can be constructed below OHW during low water levels. If it is impossible to dig a trench, the branches can be secured in place with logs, armor rock, bundles or coir logs.

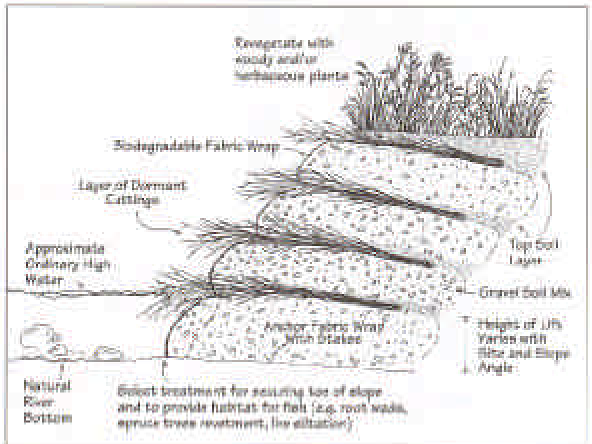


Plan View

FRONT VIEW



BRUSH LAYERING



Brush layering is a revegetation technique which combines layers of dormant cuttings (see *Dormant Cuttings*) with soil to revegetate and stabilize both streambanks and slopes. It is one of the best techniques for these purposes. Living and non-living brush layers provide fish habitat. Branches are placed on horizontal benches that follow the contour of the slope and provide reinforcement to the soil. Steep slopes and streambanks are better stabilized when a biodegradable revegetation fabric is used to hold the soil in place between the plant layers. Additional stability is provided when the front of the soil layer is seeded with grass while the woody plants are becoming established.

Collection, storage and planting information is described in the *Dormant Cuttings* section. Different species of woody cuttings that root easily (see *Streambank Revegetation Plant Species Selection List, Shrubs and Trees*) can be mixed in the layers; rooted plants can also be added to create a hedge-brush layer (see *Hedge-Brush Layering*). If the brush layer is installed below the ordinary high water (OHW) level, branches from alders and willows that do not root readily may be used, since these plant layers probably will not survive and become established, living plants.

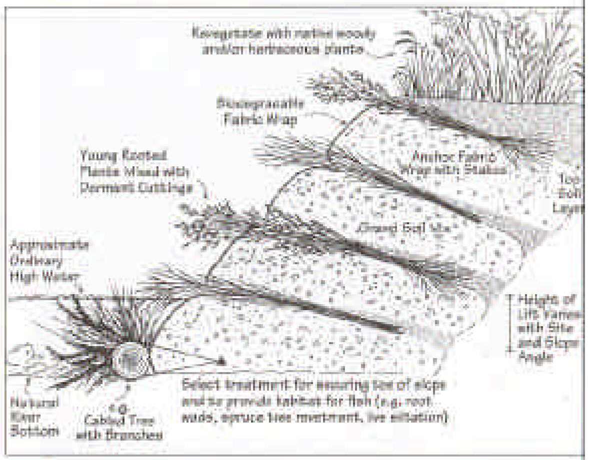
hoose a technique such as root wads, live siltation, coir logs, spruce tree evetments, or buried toe rock to secure the toe of the slope. Begin layering t the bottom of the slope. Along a stream, the first brush layer typically ccurs at the OHW level, often identified by the line of growing vegetation. . brush layer may be installed below OHW to create fish habitat and temorary plant cover.

xcavate a bench 2 to 3 feet deep so that it angles slightly down and into e slope. Twenty to 25 branches are placed on the bench, slightly crissrossed. The cut ends are placed into the slope with the tips extending eyond the edge of the bench **no more than ¼ the total branch length**. lace 2 to 4 inches of soil on top of the branches and tamp into place. A evegetation fabric is often used to keep soil in place when a brush layer is istalled on steep slopes and streambanks. The fabric is installed by placig it on top of the soil so that at least two to three feet can be anchored by ooden stakes and the next soil-gravel layer. Allow 5 to 6 feet of fabric to xtend beyond the brush layer so that it will lap over and cover the soilravel mix, then stake into place.

epeat the branch, topsoil, rapped soil-gravel mix layerg sequence until the desired ank height is achieved (see *ledge Brush Layering/Brush ayering, Step by Step*). Fill lopes can be created at the ame time a brush layer is istalled. On a cut slope and xisting streambanks, each lyer is excavated at the time e brush layer is installed.

Brush layering, Kenai River

HEDGE BRUSH LAYERING



Hedge brush layering is a revegetation technique which combines layer of plant material, both dormant cuttings and rooted plants, with soil t revegetate and stabilize a streambank. Greater plant diversity can be pro vided with a hedge brush layer than with a simple brush layer. Roote plants of species that do not root readily, such as alder, scouler and bebb willow, can be included in the plant layer. A mixture of species may allow the revegetation project to blend with existing vegetation.

Branches and transplants are placed on horizontal benches that follow the contour of the slope and provide reinforcement to the soil. The trans plants will add stability quickly as their roots become anchored. Relativel steep slopes can be stabilized with this technique if a biodegradable re vegetation fabric is used to hold the soil in place between the plant layers The front of the wrapped soil layer can be lightly seeded with grasses t increase soil stability while the woody plants become established Overhanging branches provide fish habitat.

Select plant species suitable for site conditions (see *Streambank Revegetation Plant Species Selection List, Shrubs and Trees*). For the best results dig transplants in spring or late summer and plant them the same day. If possible root prune the plants several weeks prior to transplanting. Select plants less than 5 to 6 feet tall and root prune the plant by inserting the shovel into the soil slightly outside of the drip line. Skip every other shovel width. After the plant has been dug for transplanting, trim branches to compensate for root loss.

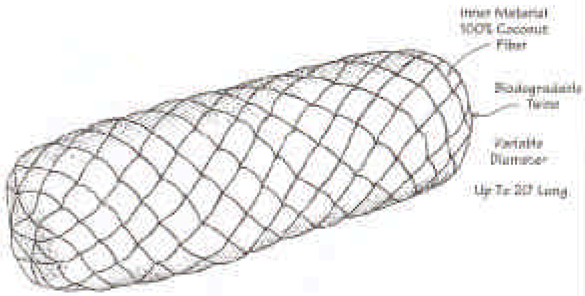
Collection, storage and planting information is described in the *Dormant Cuttings* and *Transplanting* sections. A hedge layer, which uses all rooted plants can be planted throughout the growing season from spring through early fall.

Choose a technique to secure the toe of the slope. Begin layering at the bottom of the slope. Along a water body, the first layer is typically installed at the ordinary high water (OHW) level. Brush layers may be installed below OHW to provide cover and fish habitat. These plants probably will not root and become established.

Excavate the first bench two to three feet deep so that it angles slightly down and into the slope (see *Hedge Brush Layering/Brush Layering, Step by Step*). Lay branches and transplants on the bench, slightly crisscrossing them. Place the cut ends of the branches and the roots of the transplants into the slope with the tips or shoots extending beyond the edge of the bench **no more than ¼ the total branch length**. Plant 20 to 25 stems per yard. Higher density plantings are needed for more erosive sites and if the diameter of the plant material is small. Fill the newly planted bench with 2 to 4 inches of soil and tamp into place. Continue building layers until the desired bank height is reached. The spacing between layers will vary with the erosion potential of the site. Sites with a shallow slope and low erosion potential can have wider spacing than sites with a steep slope and higher erosion potential. This technique can be easily mechanized, layer by layer, if it is installed during construction of a fill slope. On cut slopes and existing banks each layer must be excavated.

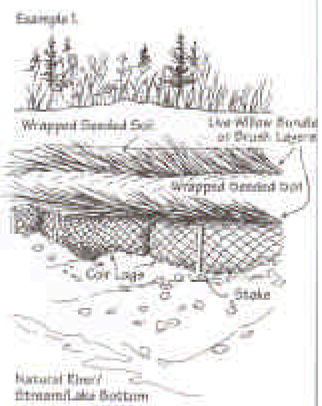
Hedge brush layering is a variation of brush layering (see *Brush Layering*).

COIR LOGS

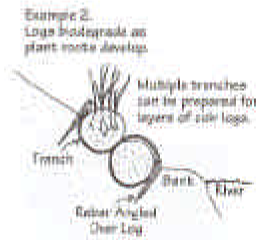


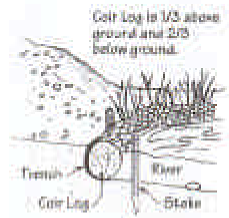
Coir logs are constructed of interwoven coconut fibers that are bound together with biodegradable netting. Commercially produced coir logs come in various lengths and diameters. The product needs to be selected specifically for the site. Fiber logs composed of other sturdy biodegradable materials may function equally as well.

Applications for coir logs occur in many streambank, wetland and upland environments. The log provides temporary physical protection to a site while vegetation becomes established and biological protection takes over. The logs can provide a substrate for plant growth, protect plants growing adjacent to the log, can be used as a transition from one revegetation technique to another, and used to secure the toe of a slope. Both the upstream and downstream ends of the coir log(s) need to transition smoothly into a stable streambank to reduce the potential to wash out.



Install the logs to ensure contact with soil along the entire length. In most cases, excavate a shallow trench to partially bury the log. At no time should the coir log span any open space that may occur between rocks, logs or uneven ground. Tie logs together that have been placed end to end and stake into place. Flowing streams, particularly those carrying ice during breakup, could rip the log out of the streambank, if it is not adequately anchored. Wooden stakes, curved rebar and earth anchors have all been used to securely anchor these logs.





Sod or **sprig** coir logs when they are placed in locations that will provide adequate moisture for plant growth. Small holes can be created in the surface of the logs and sprigs, or small plugs of suitable plant species can be transplanted into the log (see *Streambank Revegetation Plant Species Selection List, Grasses and Sedges*). These plantings should be fertilized (see *Fertilizer* section).

Partially tucked coir log with live siltation immediately behind.

SPRUCE TREE REVETMENT

Spruce tree revetments protect streambanks from erosion and provide increased bank stabilization. This is an excellent, relatively inexpensive and functional bank stabilization technique. Spruce trees deflect water flow away from the bank aiding in protection from scour and erosion. They trap sediment, and over time, aid in rebuilding bank structure and establishing long-term bank stability. The tree limbs reduce water velocities; provide cover for juvenile fish and a source of organic debris.

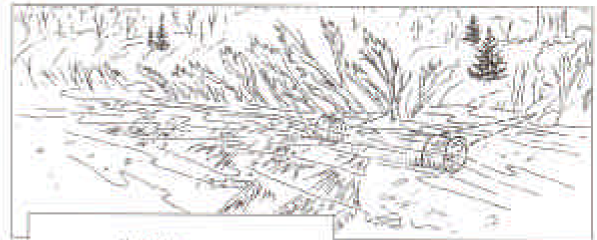
Spruce tree revetment used as a temporary protection measure at the toe of the slope while the live siltation becomes established.

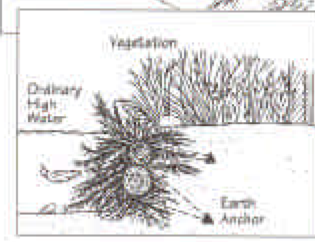
Spruce tree revetments are often used in combination with revegetation techniques. They provide immediate cover for fish until living plant cover is provided by the revegetation techniques.

Install spruce trees parallel to the streambank and overlap ¼ to ½ of their length in a shingle fashion. The top of the tree should be orientated downstream. Care should be taken to avoid unnecessary damage to or removal of tree limbs. The trees are secured tightly to the bank with cable and earth anchors.

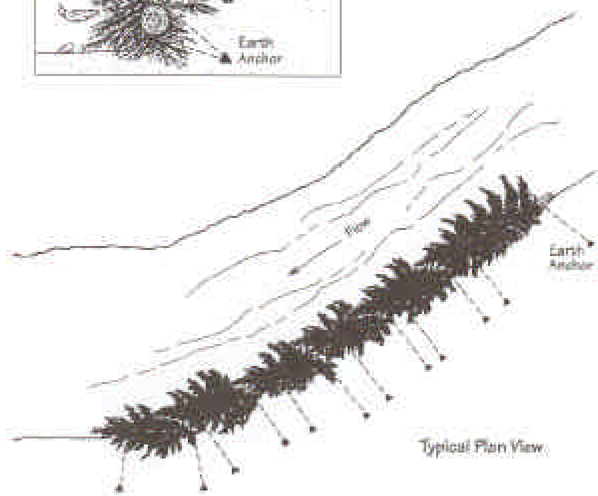
Maintain new spruce tree revetments by replacing or adding new trees. Fresh, bushy trees can usually be cabled directly in front of the original revetment.

Spruce tree revetment providing cover for juvenile fish.



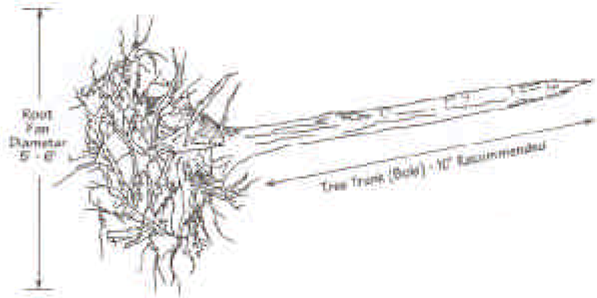


Typical Cross Section



Typical Plan View

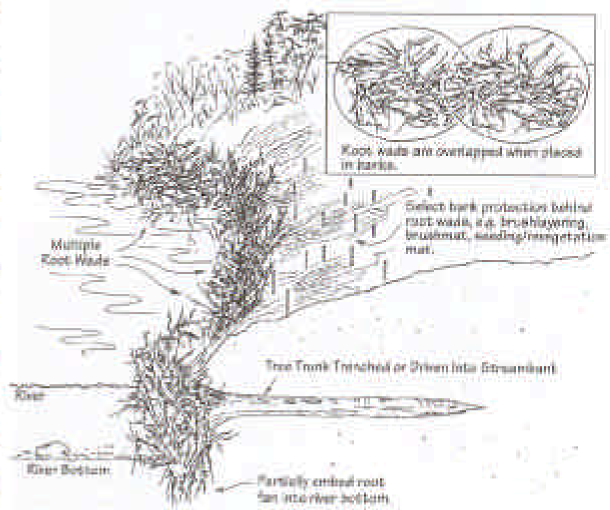
ROOT WADS



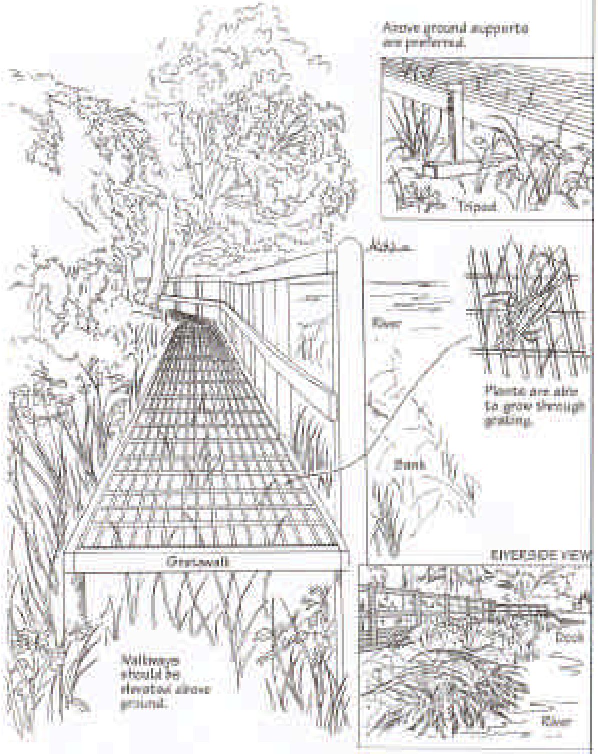
Root wads are a streambank protection technique, that provides immediate riverbank stabilization, protects the toe of slope and provides excellent fish habitat, especially for juveniles. Root wads are particularly well suited for higher velocity river systems and riverbanks which are severely eroded. They provide toe support for bank revegetation techniques and collect sediment and debris that will enhance bank structure over time. Because of their size, root wads usually require the use of heavy equipment for collection, transport and installation.

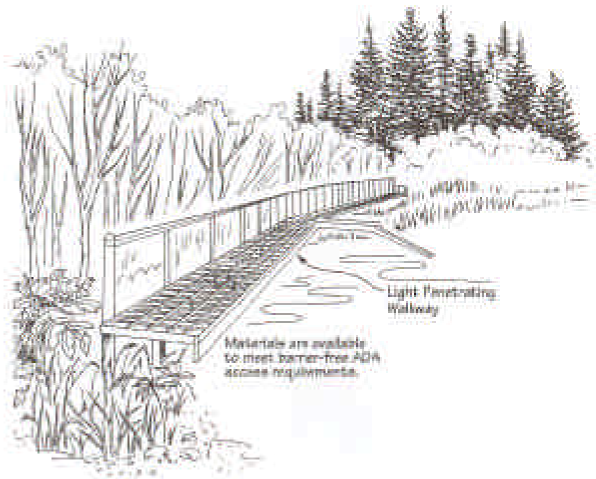
Collect root wads from forested areas being cleared for development, or selectively remove from any treed area. Identify a collection site and obtain permission to remove trees. Larger diameter trees (minimum of 12 inches DBH) can be pushed over when soils are not frozen, leaving root fans intact. The tree tops should be removed, leaving the boles a minimum of 10 feet in length with root fans attached. Optimal root fans are a minimum of 5 to 6 feet in diameter.

Install root wads with one of two methods. The most commonly used method excavates a trench into the riverbank deep enough to accommodate an 8 to 10 foot long tree bole. The bole of the root wad is placed into the prepared trench and back-filled. The bole is typically embedded at the level of the riverbed, perpendicular to the river, with the fans parallel to the bank. This placement requires that the riverbed be excavated to partially bury the root fan. The second method bores a hole into the riverbank to accommodate the tree bole or simply drives a pointed tree bole into the bank. Again, the riverbed is excavated to allow the root fans to be partially embedded into the river substrate. Root wads should be installed so that the root fans overlap to provide continuous cover along the bank area being treated. The fans should be positioned to undulate with the natural bank, providing additional cover for fish. Additional application methods, utilizing a "footer-log" for tree bole support, are described in *Applied River Morphology*, (Rosgen, 1996).

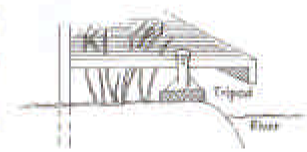


ELEVATED WALKWAYS





Elevated, light-penetrating walkways are a protection technique which provides access while protecting riparian habitat. Walkways should be constructed in a manner which allows riverbank vegetation to grow unimpeded.



Walkway cantilevered over streambank

Materials: Walkways can be constructed of a variety of materials: expanded metal, aluminum, fiberglass, and wood.

Construct walkways to protect the integrity of the existing riverbank. If it is necessary to drive posts into the bank for walkway support, care should be taken to avoid placing posts too close to the edge of the bank. Walkways can be placed on above-ground supports, such as the tripod.