Vegetated Riprap Survey of Highways in Southcentral and Interior Alaska

Prepared By:

Caroline Maniaci
Civil Engineer
Alaska Department of Transportation and Public Facilities

and

Andrew Nolen
Agronomist
Alaska Plant Materials Center
Division of Agriculture
Department of Natural Resources

Prepared For:
Alaska Department of Transportation
Statewide Research Office
3132 Channel Drive
Juneau, AK 99801-7898

Table of Contents

List of Figures

List of Tables

List of Photos

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Abstract

This report documents and presents the results of a site study of riprap armored stream banks along Alaskan highways. The study's intent was to evaluate and determine the governing parameters of a successful hybrid environment using rock to stabilize the stream banks in concert with vegetation to maintain healthy riparian habitat.

In order to design and build riprap revetments that successfully incorporate, support and promote successful revegetation on a sustainable basis, design and construction engineers require quantitative limits on the governing parameters. This evaluation was performed to support the development of engineering design guidelines for successful vegetated riprap installation. Study sites of focus were located along Alaskan highway/stream interfaces where riprap was designed and installed to protect stream banks and bridge structures.

For each study site, a combination of factors needs to be present in order to enable and encourage a successful hybrid environment of bank protective riprap coexisting with thriving vegetative reinforcement. The factors investigated during site evaluation include hydrologic and hydraulic, regional, existing riprap characteristics, and plant species present.

Findings of this study indicate that site specific hydrologic and hydraulic characteristics need to exist for a riprap armored stream bank to allow and sustain vegetative growth. In addition, given a vegetative friendly riprap structure, this study found that Alaska's diverse regional climate influences species composition.

Summary of Findings

Findings of this study are results of an observatory investigation of existing sites along Alaskan highways and are considered preliminary. Sites surveyed included locations along the Parks, Glenn, Richardson, and Dalton Highways. Investigation findings indicate that riprap can be successfully vegetated if specific parameters exist. Development of quantitative engineering design guidelines necessary to accommodate a hybrid environment warrants further investigation. Suggested subsequent research is noted in **Chapter 4**.

In general, this investigation found that given a riprapped site void of inhibiting or unfavorable attributes, *time* is the primary limiting factor that allows for the natural colonization of native riparian plant species.

Parameters observed are separated into categories for purposes of discussion: hydrologic and hydraulic (H&H), regional, and structural. These parameters, categorical and universal, and general definitions are illustrated and discussed further in **Chapter 2** of this report.

Hydrologic and Hydraulic Parameters

Findings revealed that some highway/stream interface designs had reconfigured the location and shape of the stream. Rivers exist in a dynamic environment, constantly equilibrating as environmental factors vary the amount of flow. If a highway/stream interface design is gauged for the channel's hydrologic characteristics, successful vegetation is more likely. Adequate hydraulically designed stream bank protection in concert with a favorable riprap configuration increases vegetative growth success. Inadequate hydraulic design ultimately results in unsuccessful vegetation, primarily due to the resulting effect of frequent inundation and possibly increased ice forces.

A rough analysis was performed comparing site/source average linear slope between sites that seemed to have a trend of success and failure characteristics. Although the results indicate a possible significant correlation, the level of analysis done only warrants a special mention here and consideration for further, more precise calculations. The analysis is discussed in **Chapter 3.**

The primary vegetative governing hydraulic factors identified in this investigation are defined below.

Frequent Inundation

Regular periodic flooding or recurring overflow limits establishment and growth of terrestrial plants. If the inundation is due to flooding, the flow velocity enables a relatively high stream sediment transport capacity, making sedimentation in riprap voids and fine material stability difficult. If inundation is due to normal channel flow, the recurrence of inundation prevents survival of terrestrial vegetation below the normal or ordinary high water levels.

Ice

Ice forces on riprap are complex to quantitatively analyze. This investigation surmised that the main areas of ice force influence on vegetation were outside bends and the constricted upstream sections of bridge crossings. In addition, destructive effects of ice forces on vegetation existed primarily at the sites effected by frequent inundation.

Structural Parameters

Structural parameters refer to the constructed stream bank protection system and any associated highway construction, such as bridges and adjacent roadways or walkways.

Inhibiting Structural Configurations

Research findings indicate that the following factors discourage establishment and growth of vegetation in riprap.

- Outside Bends of a meandering channel: This area of a channel has a tendency to experience higher velocity flows causing higher lateral flow friction along the stream bank and an increased sediment transport capacity, preventing fine material sedimentation. In addition, any existing fine material will have difficulty remaining stable. This area may also be prone to higher impinging ice forces relative to other areas of the channel.
- Solid-Mass bank armament is usually composed of a three to five foot thick layer of well-graded riprap and may be separated from the embankment by a geotextile fabric lining. The essentially solid mass of rock completely covers the fine embankment material, leaves few void areas, and thus, inhibits accretion of fine material necessary for plant establishment.

Favorable Structural Configurations

Given favorable hydrologic and hydraulic conditions, the primary structural factors apparent in enabling and encouraging indigenous vegetative success are listed below.

- Poorly Graded Riprap – A quantity of riprap material containing a high percentage of large diameter rock relative to the total quantity of material present. Poorly graded riprap provides void areas that allow room for plant growth. Voids leave fine embankment material exposed and are protected from erosion by adjacent larger rocks.
- Benches or Ledges – Level areas that allow fine material to exist, be deposited, and retain moisture. Benches are level areas similar to a step in the bank.
- A Buffer Bench Zone between the normal water level and the toe of the riprapped bank. This is an area whose surface elevation was within 1- 2 feet of the normal water surface elevation. The buffer zone areas sited provide level areas with distance between the water edge and the toe of the riprapped embankment ranging from less than one foot to greater than 30 feet.
- In-stream structures – These were random large rocks existing near the toe of the banks. These structures absorb energy from the stream, provide protection for the bank, and possibly influencing the thalweg from impinging on the bank.

Regional Parameters

At the preliminary level of investigation, only one regional factor was found: Woody plant species established on and around riprap structures varies among Alaska's geographic regions. Though many species similarities exist among all of the sites surveyed, significant differences in species composition was evident. Appendix A presents detailed species composition survey data on a site-specific basis. Table 1 lists the diversity of woody plant species occupying riprap on a regional basis. This table could aid in species selection for specific stream bank stabilization projects.

Table 1. Woody Riparian Vegetation Occupying RipRap Revetments Surveyed in Alaska.

Alaska Region	Elevation	Primary Trees/Shrubs	Secondary Trees/Shrubs
Interior	<1500 ft	*Salix alaxensis, Salix interior, Alnus crispa, Populus balsimifera*	*Picea glauca, Betula paprifera, Salix pseudomyrsinites, Populus tremuloides, Betula glandulosa, Rosa acicularis*
Interior	>1500 ft	*Salix alaxensis, Salix interior, Alnus crispa, Populus balsimifera, Salix candida*	*Salix barclayi, Salix bebbiana, Salix psuedomonticola, Salix hastata, Potentilla fruiticosa, Shepherdia canadensis*
Southcentral, Glenn Highway	<1500 ft	*Salix alaxensis, Alnus crispa, Populus balsimifera*	*Picea glauca, Betula paprifera, Salix bebbiana, Salix barclayi*
Southcentral, Parks Highway	<1500 ft	*Salix alaxensis, Salix sitchensis, Alnus crispa, Populus balsimifera,*	*Salix lasiandra, Picea glauca, Betula paprifera, Populus tremuloides, Salix Scouleriana, Salix bebbiana, Salix barclayi*
Southcentral	>1500 ft	*Salix alaxensis, Alnus crispa, Populus balsimifera, Salix pulchra, Salix mytillifolia, Picea glauca*	*Betula paprifera, Salix pseudomyrsinites, Populus tremuloides*
Far North*	<1500 ft	*Salix alaxensis, Salix interior, Alnus crispa, Populus balsimifera,*	*Salix Scouleriana, Salix bebbiana, Betula paprifera, Picea glauca*

*** Indicates limited survey area. The Far North Region was surveyed only as far as Wiseman.**

Chapter 1: Introduction and Research Approach

Alaska Department of Transportation and Public Facilities (AKDOT&PF) engineers commonly use riprap to stabilize stream banks at roadways and bridges. Resource industry professionals have advocated for bioengineered stream bank protection structures to maintain fish and other riparian habitat. A potential solution is to produce a hybrid revetment system using rock to stabilize the stream in concert with vegetation. Recent research indicates that vegetation can thrive with riprap if care is taken to construct environments that enable and encourage vegetated growth. Though vegetation species composition is dictated by eco-region, appropriate environments are governed by universal and site specific attributes.

Factors that promote healthy and thriving vegetation on riprap stream bank revetments in Alaska are not well understood. Evidence suggests that riprap can be successfully vegetated; however, vegetated riprap designs have not been systematically evaluated. In order to design and build riprap revetments that successfully incorporate, support and promote revegetation on a sustainable basis, design and construction engineers require quantitative limits on the governing parameters.

This project evaluated existing conditions at sites located along Alaskan highway/stream interfaces where riprap was designed and installed to armor stream banks and bridge structures. The evaluation was performed to support the development of engineering design guidelines for successful vegetated riprap installation. Results from this study will be used to aid in the determination of future stream bank protection/revetment construction methods and designs along Alaskan highways.

The project scope included: literature search, identification of study sites, acquisition of available site data, and study site visits to assess existing conditions. Available data was collected from Alaska Department of Transportation and Public Facilities (AKDOT & PF) departments of bridge design, highway design, and materials. Study sites were located along a route that included the Parks, Glenn, Richardson, and Dalton Highways. Site survey data included photographic documentation, preliminary channel reach morphology assessment, existing riprap conditions, and vegetation species and location identification. Plant species present between roadways and waterways were identified with an emphasis placed on riparian species existing in riprap structures near the stream channel edges and on stream banks.

Chapter 2: Definitions and Parameters

Definitions and parameters specific to this investigation, and successful and unsuccessful vegetated riprap sites are discussed and illustrated in this chapter.

Definitions

Healthy Riparian System

"Healthy riparian systems function to the benefit of many species, the ecosystem, and are essential for sustainable populations" (Walter, 2005) and "…are essential to sustain a well-functioning, natural environment." Riparian vegetation is the plant life that occurs adjacent to rivers, streams and lakes…" (Muhlberg, 1998) A Healthy riparian system is an environment that provides protection for riparian habitat, stream banks, adjacent properties, and stream integrity.

The coexistence of riprap and vegetation on a stream bank can enhance riparian system health by ensuring stream bank stability while functioning to maintain fish and other essential riparian habitat values when compared to non-vegetated riprap structures.

Riprap Bank Protection Design

Typically designed highway stream bank protection consists of an embankment with a 2:1 or 1 ½: 1 slope; covered by a 3 to 5 foot thick layer of Class II riprap. A geotextile fabric lining between the embankment material and the riprap may be also used. The riprap toe is usually installed several feet below the low water level or streambed elevation. (**Figure 1**) Sites observed were consistently within specifications of a typically designed embankment slope.

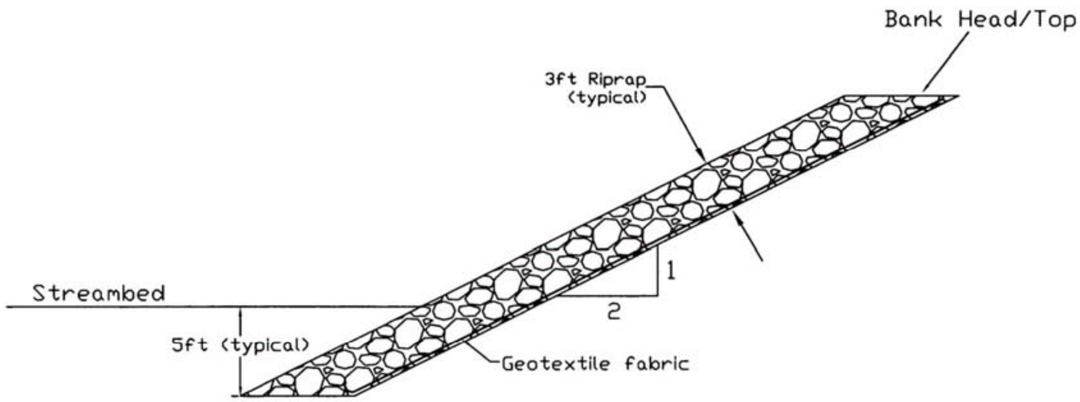


Figure 1 – Typical Riprapped Bank Cross-Section

(If used, Getextile Fabric installation location is illustrated)

Although within the basic typically designed specifications for stream bank protection, site investigations reveal that actual riprap size and gradation varied, probably due to the varied characteristics of individual material sources.

Alaska Department of Transportation and Public Facilities Standard Specifications for Highway Construction specifies riprap gradation by percent of total weight. (Green, 2004) Therefore, the varied densities of different mined material types govern the rock diameters of the installed riprap. **Figures 2-4** illustrate riprap size variations.

Nenana River, near Cantwell, (Parks Hwy)

Kashwitna River (Parks Hwy)

Sheep Creek (Parks Hwy)

Jack River (Parks Hwy)

Figure 2 – Riprap Variations

Granite Creek (Glenn Highway)

Kings River (Glenn Highway)

Matanuska River (Glenn Highway)
(sunglasses used as gauge)

Sunglasses vs. gauge

Figure 3 – Riprap Variations

Gulkana River (Glenn Hwy)

Gulkana River (Richardson Hwy)

Sourdough Creek (Richardson Hwy)

Figure 4 – Riprap Variations

Successful Vegetation

For the purposes of this project, successful vegetation consists of plants that have become established and remain stable in an environment with riprap armored stream banks. It is the belief of this report's authors that vegetation can become established and be sustainable in environments that provide the parameters and situations noted in the ***Successful Vegetation Parameters*** section of this report.

In a successful hybrid environment, the initial stage of manual installation or natural propagation of vegetation is the primary phase that leads and contributes to a subsequent cyclic series of growth phases. The sprouts and young vegetation screen flow and consequently promote sedimentation of fine material which, in turn, promotes the stability of vegetation.

In addition, the definition of the term 'successful' is limited to the objectives of this study. Thorough quantitative evaluation of stream bank stability was not the topic of focus. 'Successful' refers only to the observations evaluated during site and historical investigations of available data at the time of this study.

Unsuccessful Vegetation

Unsuccessful vegetation sites are sites that possess one or more factors which directly inhibit the establishment, propagation, and/or stabilization of vegetation in concert with riprap.

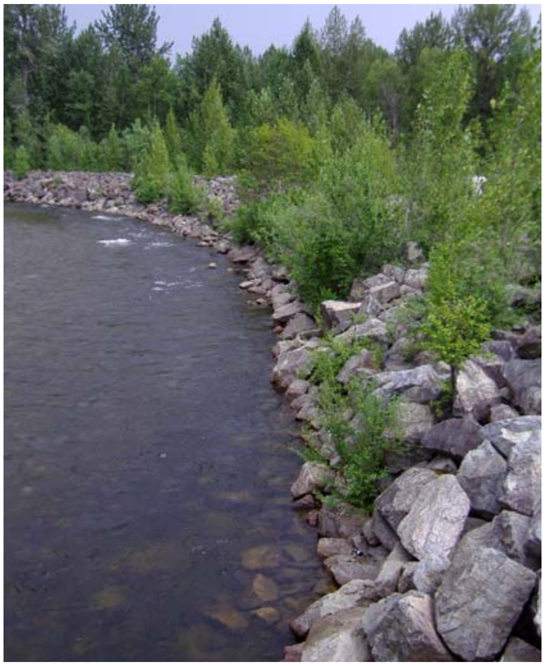
Normal (Average) Water Level

Normal or average water surface level refers to a water surface elevation that occurs most frequently or approximates the average discharge a stream experiences, disregarding outlying high flood flows. Normal water level can be synonymous with a channel's OHW level.

Universal Parameters

Ordinary High Water (OHW)

OHW is a level or elevation that indicates the most frequent high discharge elevation of a stream. Minnesota Department of Natural Resources (DNR) defines it as "…the highest water level that has been maintained for a sufficient period of time to leave evidence upon the landscape, commonly the point where the natural vegetation changes from predominantly aquatic to predominantly terrestrial…" (Minnesota DNR, 1993). This would be true for a lake or swamp, but stream banks do not tend to have exclusively aquatic or terrestrial plants. During the Alaskan Highway site survey, riparian plants found are categorized as facultative. Facultative plants can survive a very wet environment but do not tolerate constant standing water. Although fine material exists at and below OHW, vegetation growth is inhibited at these levels due to the high frequency of inundation.



In a study conducted by Leopold & Wolman (Leopold, 1957) vegetation is a common OHW indicator due to the fact that seed and other plant propagules are carried on the water surface and deposited on the stream bank. To enable growth, ample moisture exists due to the seeds' proximity to water flow and the moisture holding capacity of fine material deposited on the bank at OHW and below during lower discharges.

Photo 1 - Montana Creek (Parks Hwy)

Photo 2 – Sheep Creek (Parks Hwy)

Photos 1 and **2** illustrate a stream's OHW level by the lowest vegetated elevation level line along the stream bank.

Time

Time is a significant limiting factor influencing the level of vegetation on a disturbed (constructed) site. By designing bank protection using hydraulic parameters specific to the stream, successful vegetation can result. Although bank protection is designed adequately, flood inundation destruction is possible. Whether planted manually or naturally, and within the universal and site specific limits discussed in this report, a specific flood event can occur and essentially wash away seedlings and sprouts, as well as fine grained bank material. Given sufficient time before an extreme event occurs, vegetation can become stable and, thus, flourish for healthy riparian habitat as well as provide reinforcement for the constructed bank armament. **Figures 5** and **6** illustrate time series vegetative progression.

1988

1996

2005

Figure 5 – Vegetative Progression Time Series;

Montana Creek (Parks Hwy)

1978

1984

1996

2005

Figure 6 – Vegetative Growth Progression Time Series; Sheep Creek (Parks Hwy)

Successful Vegetation Parameters

Within the universal limits previously discussed for all vegetated sites, the following site conditions were found conducive to a successful hybrid environment.

Poorly Graded Riprap

Poorly graded riprap is defined as riprap containing a high percentage of large diameter rock relative to the total quantity of rock present. The lack of smaller diameter rock leaves voids (areas, pockets, or spaces) where fine embankment material is exposed and/or fine material can be deposited manually, via sedimentation at various discharge stages, or via wind. If exposed to stream flow, the larger rock protects the void area behind or immediately downstream of it by reducing flow energy, shear stresses, and excessive ice forces. The protected space provides a stable environment for sedimentation and vegetation growth. Examples of successfully vegetated voids are in **Figures 7 - 9**.

At the time of this site survey, existing woody vegetation had not shown evidence of causing nearby riprap displacement. However, it should be noted that the possibility of further growth in the vegetation's stem diameter may potentially cause riprap instability.

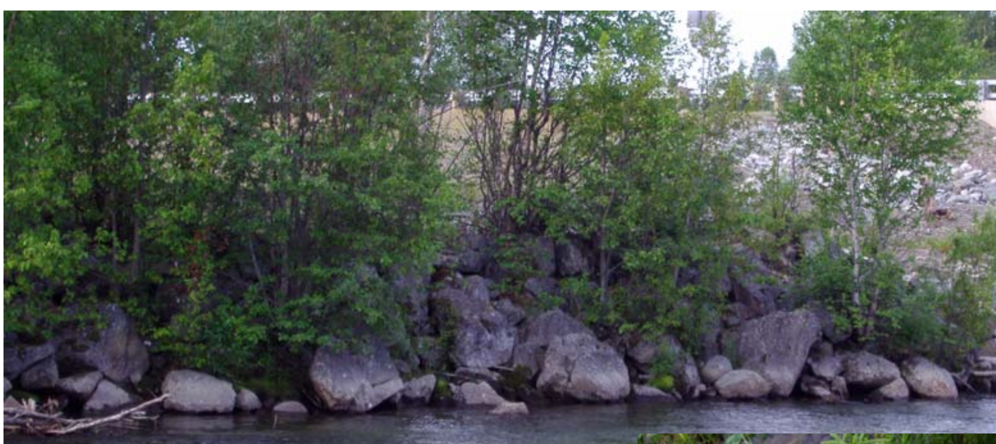


Figure 7 – Vegetated Voids

Willow Creek (Parks Hwy)

Montana Creek (Parks Hwy)

Nenana River at Tatlanika (Parks Hwy)

Willow Creek (Hatcher Pass)

Figure 8 – Vegetated Voids

North Fork Chena River

(Chena Hot Springs Rd)

Gulkana River by Paxson (Richardson Hwy)

Gulkana River (Richardson Hwy)

Figure 9 – Vegetated Voids

Benches or Ledges

A bench or ledge might be implemented in an area where the bank toe warrants heavy protection. It was found that this configuration enabled sedimentation during higher flows on a grade that allowed the existing fines to retain moisture. This design may be desirable for a stream location that experiences potentially aggressive ice forces and/or periodic flows that would pose a threat to lightly armored bank toes. The toe can be armored with riprap and a step can be constructed at the approximate OHW level to prevent frequent inundation effects while allowing some overflow and sedimentation. Although this condition focuses on growth only on the surface of the ledge, overhanging vegetation can develop while the stream bank toe is protected with riprap.

Photo 3 - Nenana River (Parks Hwy)

Photo 4 - Matanuska River (Glenn Hwy)

Buffer Bench Zone

The buffer bench zone is an area contiguous to the stream channel and whose elevation is within one to two feet of the stream's normal water level. The normal water level and the OHW level of sites observed were apparently close to synonymous. Vegetation age at the sites studied with this configuration indicates that the buffer zone was not inundated often; however, the water table's close proximity to vegetation maintained a continuous supply of moisture.

This is an area where naturally occurring vegetation may be left intact at the time of construction; thus, maintaining stream bank stability at the natural bank edge.

Photo 5 - South Fork Koyukuk River (Dalton Hwy)

Toe protection should be considered for this structure. **Photo 5** illustrates stabilizing toe protection while **Photo 6** illustrates evidence of bank erosion that may eventually eliminate the vegetated buffer zone.

Photo 6 - Tanana River at Fairbanks International Airport Dike

In-stream Structures

The in-stream structures noted during this study were naturally placed during the stream's ongoing process of equilibrating. In some cases, singular or clusters of 2 – 4 toe rocks were naturally resituated within 1 - 2 feet of the bank toe. Consequently, the backwater effect of the migrated rock(s) position(s) provided a pool area above (immediately upstream) the rock(s). In addition, the stream's thalweg was influenced away from the bank. The bank apparently self repaired with more rock at its toe and no erosion had taken place. Vegetation present in these areas was near the normal water surface level and overhanging the water surface.

As illustrated in the sites observed with this configuration (**Photos 7** and **8**, **Figure 10**), rock diameter of the toe protection and the migrated in-stream structures is relatively large.

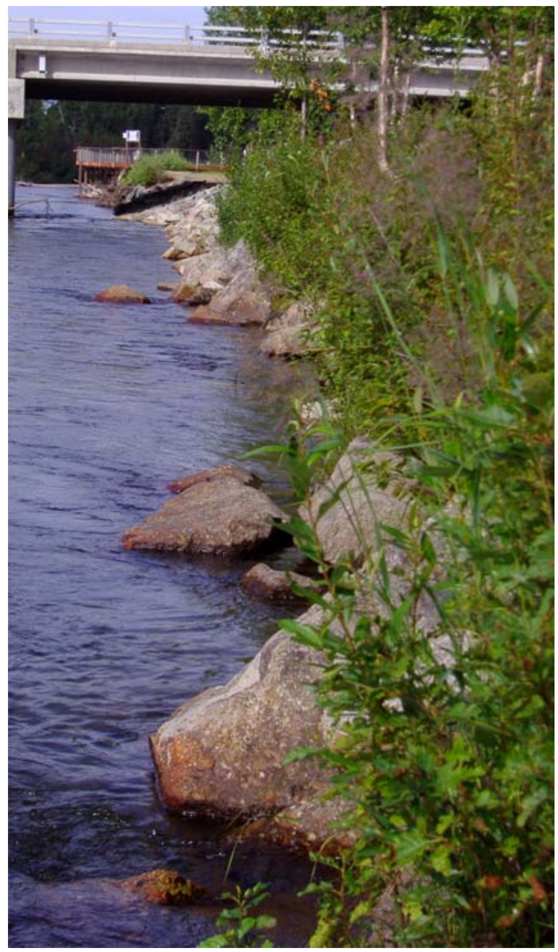


Photo 7 - Willow Creek (Parks Hwy)

- Looking downstream along right bank

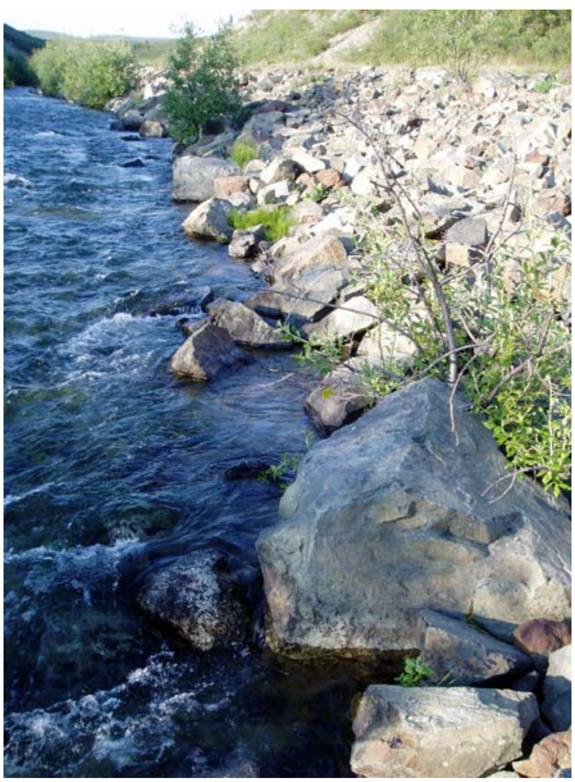


Photo 8 - Gulkana River (Richardson Hwy)

-Looking upstream along right bank

Looking downstream along right bank

Figure 10 – In-Stream Structures;

Gulkana River (Richardson Hwy)

Unsuccessful Vegetation Parameters

Frequent Inundation

Defined earlier in ***Hydrologic and Hydraulic Parameters***, frequent inundation, for the purposes of this section, refers to the periodic occurrence of inundation exceeding that tolerable for vegetation survival. Frequent inundation due to flooding overflow can be minimized by determining the stream's discharge frequency and capacity, and designing a highway crossing that will accommodate these values.

Historically, the site illustrated in **Figure 11** experiences periodic flooding which may demand emergency repair. The flooding and subsequent bank repair prevent vegetative stability.

Flood 1986 - Looking at upstream right abutment

2005 - Looking at upstream side of bridge

Figure 11 – Frequent Inundation;
Carlo Creek (Parks Hwy)

Outside Bends

Photo 9 - North Fork Chena River (Chena Hot Springs Rd)

A stream channel is characteristically deeper at its outside bends and shallower at its inside bends or points of inflection. Consequently, flow and average velocity is higher at the outside bend of a stream cross section than at the inflection point. Often, while equilibrating itself during discharge fluctuations, a stream's inside bend accretes with fine alluvial material and channel flow moves closer to the outside bend. The channel bed's thalweg shifts until it impinges on the outside bend bank with greater shear forces, higher average velocity, and the capacity to carry courser material. The lower discharge energy on the stream's inside bend results in finer material deposition where stream sediment transport capacity is lower. As illustrated in **Photos 9** and **10**, outside bends maintain little to no vegetation

Photo 10 - Carlo Creek (Parks Hwy)

- looking upstream from bridge.

Solid-Mass

A solid-mass is considered a heavily and/or thickly riprapped bank, such that no embankment surface material is visible or penetrable; thus, no vegetation can grow from the embankment material. If geotextile fabric with a smooth texture is used as a riprap liner, sediment and fine material may not adhere to its surface. In addition, no vegetation can sprout and penetrate through this type of geotextile fabric.

Sites with solid mass bank armament primarily allowed vegetative growth at the head of the embankment, where no riprap existed. (**Photo 11**)

Photo 11 - King River (Glenn Hwy)

If a solid mass armament is combined with a successful vegetative parameter such as a buffer bench zone (**Photo 12**), vegetation exists at the toe and head of the riprapped bank where no riprap exists

Photo 12 - Tanana River (Fairbanks Airport Dike)

Given time, vegetation at the base of a riprapped bank will grow enough to overhang an adjacent stream and cover the face of the bank. (**Photo 13**)

Photo 13 - Jack River (Parks Hwy)

Photo 14 - Willow Creek (Parks Hwy)

---Note that some vegetation has propagated in the bank face, but primarily exists at OHW and bank head.

If the solid mass armament contains large diameter rocks and time allows, vegetative growth from the toe and head may find spots in the bank face that accumulated enough organic and fine material to sustain plant growth. (**Photos 14** and **15**)

Photo 15 - Kashwitna River (Parks Hwy)

----Note: Vegetation at OHW level has grown to cover the bank face and some vegetation has propagated in the bank face.

Beneath Bridges

Photo 16 - Fish Creek (Dalton Hwy)

Most of the sites surveyed with riprapped areas directly underneath bridges had minimal plant cover. Many factors may play a role in this issue. The bridge may create a microclimate beneath it through shading and exclusion of precipitation. It also might reduce snow cover on establishing vegetation which would increase the plants susceptibility to winter kill. Increased water velocities and higher ice forces at a bridge crossing due to channel constriction may also contribute to the lack of vegetation. (**Photos 16** and **17**)

Photo 17 - Gulkana River (Richardson Hwy)

Chapter 3: Analysis of Findings

A literary study conducted by Oregon State University (Klingeman, 2002) discussed some concepts observed and evaluated during this project. Sites found supporting Klingeman's concept of interfacing highways and rivers by incorporating separate adjacent areas of vegetation and riprap are similar to the bench/ledge and buffer bench zone structures discussed in *Successful Vegetation Parameters.*

The primary analysis performed was visual assessment of the plant species, structural, and hydrological conditions present at each site. The observations are discussed in **Chapter 2**. Supplemental analysis performed used available data specific to each site.

An inventory of sites surveyed is located in **Appendix B, Table B-1**. Data was used to determine, first, if region governed success and failure factors. Being a preliminary investigation, United States Geological Survey (USGS) stream gage data sites were identified corresponding to the surveyed sites; however, no analysis was done using the existing data. (**Appendix B, Table B-2**)

At this level of study, no distinct regional characteristics governed the hydrologic factors evident in the general pattern of vegetation success or failure. Only vegetation species types were identified to be eco-regionally specific. (See ***Regional Parameters,*** in **Summary of Findings**) A vegetative inventory of study sites is illustrated in **Appendix A**.

A general analysis was performed to determine any apparent correlations with successful or unsuccessful vegetation tendencies. Data used consisted of: approximate elevation of study site, study site stream source, and approximate elevation of study site's stream source. Vegetation existence was categorized into areas of existence on the constructed banks: sparse vegetation, toe, head, ordinary water level, and bank face. (**Appendix B, Table B-3**) No notable correlations or patterns of vegetative success rates were evident from this analysis.

Some sites along the highways of study indicated similar success/failure characteristics. For example, along the Parks Highway, successful vegetation existed throughout the armored stream banks for the series of streams: Panguingue Creek, Nenana River (near Cantwell), Willow Creek, Little Willow Creek, Kashwitna River, Montana Creek, and Sheep Creek. An unsuccessful vegetation tendency existed along the Richardson Highway between Summit Lake and the Black Rapids area.

The predominately unsuccessfully vegetated stretch of Richardson Highway is near the glacial sources of the streams that the highway crosses. The obvious difference between the regions noted above is the proximity to their corresponding sources and resulting average linear slope. Distance from each stream's source to its corresponding study site via stream path was estimated. Using each estimated source-site distance and the estimated corresponding source and site elevations, an average slope was calculated. The rough slope calculations show a possible correlation to vegetative success/failure rate. The streams listed above for successfully vegetated sites range in average linear source/site slope from 2% to 3.5%. The unsuccessfully vegetated sites calculations resulted in an estimated linear source/site slope as high as 7%. This significant difference and apparent correlation warrants further, more accurate analysis. The effective slope of a channel would effect the resulting hydrologic characteristics of the streams, and thus, forces on constructed stream banks, as well as sediment transport capacity of the stream. Considering the overall average channel slope, the construction site reach slope needs to be specially addressed during hydraulic design of the highway/stream interface structure.

Chapter 4: Conclusions and Suggested Research

Conclusions

A time series of historical photos reveal that, if stream morphology and hydrologic characteristics are favorably considered in design and construction, time allows a natural process of vegetation establishment. However, this report's authors believe that a catalystic approach can successfully establish vegetation if indigenous species are properly planted during or after stream bank construction and conditions are provided to promote growth of vegetation in riprap armored stream banks.

The vegetated riprap site survey study determined that the bank stabilization hybrid design of riprap and vegetation can be successful in protecting stream banks, bridges, and riparian habitat simultaneously if, the specific parameters discussed in this report are satisfied. Comprehensive design guidelines may be developed if further investigation and analysis are performed.

Suggested Research

- Extended site history search: Information regarding each site's conditions and analyses at the time of original construction, photography, and emergency repairs and/or revetments, to determine general stability success of the past and existing constructions.
- Additional data acquisition consisting of: surveyed cross-sections in the site reach, discharge and velocity measurements at the time of cross-section survey, surveyed OHW elevations, and determination of the stream's natural morphology upstream of the study reach. (Upstream natural morphology can be used as a guide in determining stream reconfiguration limits.)
- Perform hydraulic analysis using the additional collected data:
    - Compare OHW level to corresponding calculated recurrence discharge (Q_x) to determine where vegetation installation level begins
    - Use historical data to determine the actual frequency of discharge elevations that flow above the determined OHW elevation.
    - Determine what common hydraulic conditions exist to determine which sites are likely to have successful vegetation and rate the probability of failure due to ice forces, channel reach and upstream morphology, flood magnitudes and frequencies.
- Include a habitat specialist in the next phase to assess existing conditions and to determine habitat concerns

- Form a flow chart of analysis and priority determination and/or a database(table) reflecting analyzed sites and determination of vegetation priority
- Cost analysis using historical data of successful design and construction vs. unsuccessful that has caused flood repair costs.
- Establish test sites using the discussed successful designs and monitor success/failure rate of installed vegetation in various conditions.
- Determination of favorable riprap gradation.
- Further monitoring of existing sites should be continued using this study's data. One specific condition of note is the existing woody vegetation in riprap voids. Monitoring growth and its effect on riprap stability would be of particular interest.
- Determine and investigate other possible hybrid designs not discussed in this report.
    - One favorable hybrid design may be a layer system:

        --Base Layer of riprap armor, vary the type of armor from solid-mass to poorly-graded

        --Layer of fine material to fill in voids, cracks, etc. (vary the thickness)

        --Layer of planted vegetation.

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Appendix A. Regional Vegetated Riprap Plant Survey Data

Surveys of vegetation growing in and around riprap revetments indicate that riparian species composition varies among Alaska's geographic regions and among varying elevations. Surveys of known and accessible riprap installations were accomplished between July 11 and August 16, 2005. Species composition for each site was documented with an emphasis on woody riparian species. Tables in this sections list the species observed. For the purpose of this section, "Primary Trees and Shrubs" refers to those that were most commonly observed in a region while "Secondary Trees and Shrubs" indicates presence but not dominance. Species listed in the tables correlate to those observed during the survey and do not represent a complete inventory of all riparian species present in a specific region.

Southcentral Alaska

The areas surveyed in Southcentral Alaska include the Parks Highway from Talkeetna to Wasilla, the Glenn Highway from Palmer to the Matanuska glacier and the Hatcher Pass road from Willow to Palmer. Surveys indicate that riprap vegetation in Southcentral Alaska can be divided into three distinct regions. Armorments throughout southcentral have *Salix alaxensis, Alnus crispa* and *Populus balsamifera* as major components of the woody riparian vegetation. Variations in primary and secondary woody species exist between locations along the Parks Highway and Glenn Highway as well as areas at higher elevations (above 1500 feet). One possible reason for the variation between the two highway sections is that the Glenn Highway has a more upland environment than that found along the Parks Highway.

Table A-1. South Central Alaska, Parks Highway Below 1500 feet

Sites Surveyed	Primary Trees and Shrubs	Secondary Trees and Shrubs	Grasses	Forbs
Willow Creek Little Willow Ck Kashwitna River Montana Creek Sheep Creek	*Salix alaxensis, Salix sitchensis, Alnus crispa, Populus balsimifera*	*Salix lasiandra, Picea glauca, Betula paprifera, Populus tremuloides, Salix Scouleriana, Salix bebbiana, Salix barclayi*	*Calamagrostis Canadensis, Schenoplectus tabernaemontani, Carex sp. Deschampsia beringensis, Festuca rubra, Poa pratensis, Phleum pratense*	*Epilobium angustifolium, Achillea millefolium, Taraxacum sp Epilobium Hornemannii, Plantago major, Stellaria media, Trifolium hybridum*

Photo A-1. Willow Creek

Photo A-2. Little Willow Creek

Photo A-3. Kashwitna River

Photo A-4. Montana Creek

Photo A-5. Sheep Creek

Table A-2. South Central Alaska, Glenn Highway Below 1500 feet

Sites Surveyed	Primary Trees and Shrubs	Secondary Trees and Shrubs	Grasses	Forbs
Matanuska River (Multiple sites) Granite Creek Kings River	*Salix alaxensis,, Alnus crispa, Populus balsimifera*	*Picea glauca, Betula paprifera, Salix bebbiana, Salix barclayi Rosa acicularis*	*Calamagrostis Canadensis, Schenoplectus tabernaemontani, Carex sp. Deschampsia beringensis, Festuca rubra, Hordeum jubatum, Poa pratensis, Phleum pratense Deschampsia caespitosa Trisetum spicatum, Agropyron pauciflorum*	*Epilobium angustifolium, Melilotis albus, Achillea millifolium, Artemsia tilesii, Polemonium pulcherimum, Taraxacum sp Aster sibiricus, Oxytropus campestris Hedysarum alpinum, Achillea sibirica, Trifolium hybridum, Chamarion latifolium Potentilla multifida Lepidium densiflorum, Plantago major*

Photo A-6. Matanuska River


Photo A-7. Granite Creek


Photo A-8 Kings River

Table A-3. South Central Alaska, Above 1500 feet

Sites Surveyed	Primary Trees and Shrubs	Secondary Trees and Shrubs	Grasses	Forbs
Willow Creek, Willow Fishhook Road, Hatcher Pass	*Salix alaxensis, Alnus crispa, Populus balsimifera, Salix pulchra, Salix mytillifolia, Picea glauca*	*Betula paprifera, Salix pseudomyrsinites, Populus tremuloides*	*Calamagrostis Canadensis, Festuca altaica*	*Achillea millifolium, Taraxacum sp., Chamarian latifolium, Sanguisorba stipulata*

Photo A-9. Willow Creek, Hatcher Pass

Interior Alaska

Interior Alaska areas surveyed include the following highway segments: the Parks Highway from Fairbanks to Cantwell, the Glenn Highway from Eureka to Glennallen, the Tok Cutoff from the Richardson Highway to Chistochina, the Richardson Highway from Glennallen to Fairbanks, Chena Hotsprings Road, and the Steese Highway from Fairbanks to Washington Creek. Riprap vegetation variations within this region were observed with increased site elevation (above 1500 feet). Similarly to Southcentral Alaska, the entire Interior Region had *Salix alaxensis, Alnus crispa* and *Populus balsamifera* as major components of the riparian vegetation observed. Most notable was the inclusion of *Salix interior* and *Salix candida* in this region with the latter found only at higher elevations.

Photo A-10. North Fork Chena River

Table A-4. Interior Alaska, Below 1500 Feet

Sites Surveyed	Primary Trees and Shrubs	Secondary Trees and Shrubs	Grasses	Forbs
North Fork Chena River Tanana River, Fairbanks Airport Dikes Nenana River, Teklanika Bridge Panguingue Creek Washington Creek Delta River, Delta Junction Gulkana River, Gulkana	*Salix alaxensis, Salix interior, Alnus crispa, Populus balsimifera*	*Picea glauca, Betula paprifera, Salix pseudomyrsinites, Populus tremuloides, Betula glandulosa, Rosa acicularis* *Potentilla fruiticosa* *Salix bebbiana, Salix psuedomonticola, Salix hastate* *Shepherdia canadensis*	*Calamagrostis canadensis* *Agropyron pauciflorum* *Arctagrostis latifolia Agrostis scabra, Poa ampla, Poa alpina, Poa alpigena, Festuca rubra, Beckmannia syzigachne* *Hordeum jubatum, Hordeum brachyantherum* *Carex aquatilis* *Carex sp.* *Alopecurus pratensis* *Trisetum spicatum*	*Epilobium angustifolium, Achillea millefolium, Hedysarum alpinum, Hedysarum Mackenzii, Oxytropis campestris* *Arctpstaphylos uva-ursi, Aster sibiricus, Melilotus albus, Artemisia Tilesii* *Chamerian latifolium* *Aquileigia brevistyla* *Galium boreale, Taraxacum sp., Rubus ideaus, Matricaria matricarioides, Plantago major, Achillea sibirica* *Crepis tectorum* *Solidago multiradiata* *Potentilla multifida, Cnidium cnidifolium* *Astragalus alpinus* *Rhinanthus minor*


Photo A-11. Tanana River, Fairbanks Aiport Dikes


Photo A-12. Nenana River, Teklanika Bridge


Photo A-13 Panguingue Creek

Photo A-14 Washington Creek

Photo A-15. Delta River, Delta Junction

Photo A-16. Gulkana River, Gulkana

Table A-5. Interior Alaska, Above 1500 feet

Sites Surveyed	Primary Trees and Shrubs	Secondary Trees and Shrubs	Grasses	Forbs
Carlo Creek Jack River Nenana River Gulkana River, Paxson Sourdough Creek McCallum Creek Phelan Creek	*Salix alaxensis, Salix interior, Alnus crispa, Populus balsimifera, Salix candida*	*Salix barclayi, Salix bebbiana, Salix psuedomonticola, Salix hastata, Potentilla fruiticosa, Shepherdia canadensis*	*Hordeum jubatum, Agropyron repens, Calamagrostis canadensis Carex aquatilis Poa alpigena Agropyron violaceum Agropyron pauciflorum Calamagrostis nutkaensis, Trisetum spicatum, Arctagrostis latifolia*	*Galium boreale, Crepis tectorum, Achillea millifolium, Epilobium angustifolium Chamerian latifolium, Artemesia tilesii, Hedysarum alpinum, Astragalus alpinus Hedysarum hedysaroides Aster sibiricis, Solidago multiradiata*

Photo A-17. Carlo Creek

Photo A-18. Jack River

Photo A-19. Nenana River, Cantwell

Photo A-20. Gulkana River, Paxson


Photo A-21. Sourdough Creek


Photo A-22. McCallum Creek


Photo A-23. Phelan Creek

Far North Alaska

The Far North Region of Alaska was surveyed from the south end of the Dalton Highway north to Wiseman. Riparian species composition in riprap revetments was generally consistent among the surveyed sites. The primary tree and shrub species observed were the same as what was found at the lower elevations of the Interior Region.

Table A-6. Far North Alaska

Sites Surveyed	Primary Trees and Shrubs	Secondary Trees and Shrubs	Grasses	Forbs
Fish Creek Jim River South Fork Koyukuk River Middle Fork Koyukuk River, Coldfoot Airport Dikes Middle Fork Koyukuk River, Wiseman Marion Creek	*Salix alaxensis, Salix interior, Alnus crispa, Populus balsimifera*	*Salix Scouleriana, Salix bebbiana, Betula paprifera, Picea glauca Rosa acicularis*	*Festuca rubra, Calamagrostis canadensis Hordeum jubatum*	*Epilobium angustifolium, Astragalus alpinus., Pyrola grandiflora Hedysarum alpinum Artemesia tilesii, Chamerian latifolium, Matricaria matricarioides, taraxacum sp., Potentilla norvigeca, Plantago major*

Photo A-24. Fish Creek


Photo A-25. Jim River


Photo A-26. South Fork Koyukuk River


Photo A-27. Middle Fork Koyukuk River, Coldfoot Airport Dikes

Photo A-28. Middle Fork Koyukuk River, Wiseman

Photo A-29. Marion Creek

Appendix B. Survey Site-Specific Data

Table B–1. Surveyed Sites

Location	Structure	Description/Notes
Chena Hot Springs Rd (CHS)		
approx. MP 37 CHS	**3 culverts - road crossing**	veg starting to try to get established--at head and water level of bank--from lower end of dike curiously growing veg about every 10-15 ft for first 100 or so feet. -some debris at water edge, debris from higher flow present; willow at water edge; some sediment from higher flows in between rocks; mainly a solid mass of rock with geofabric under neath-inhibiting growth. least growth(almost none) on outside bend area.
North Fork Chena	Dike	new construct--no veg
Parks Highway		
Nenana R. 1	at Tatlanika Bridge	good veg in riprap voids
Panguingue Creek	Bridge	cemented sand bags-small Q
Carlo Creek	bridge approach	swift Q - no veg in vicinity upstream of bridge
Nenana R. 2 - approx. MP 220	embank along road	good veg in riprap voids; Needs more toe support- bank head soft in some areas(more at MP221)- beginning to slough; Jet boat tours(large 20-40 passengers) wiz through here.
Nenana R. 3 - approx. MP 221	embank along road	
Jack River	dike	general pattern of veg at head and toe with sparse spots of veg in voids - some areas with less solid mass of RR shows more veg.
Willow Creek	dike & bridge	kings spawning in middle of xsec; some toe rocks migrated into stream and separate from bank by 1-2 ft absorbing some stream energy; no shady areas; weathered old banks w/ big rocks/moss/lichens and leaving large void areas filled in with fines and med fines(dirt)
Little Willow Crk	dike & bridge	clear; little to no human traffic evident on banks-no salmon spotted; Large rocks w/ large voids filled w/ fines, organics, & veg.
Kashwitna	dike & bridge	right side of stream has slower flow; left bank -little to no veg and heavily(solid mass) riprap
Montana Crk.	dike & bridge	clear water; kings present; this site has great shots of veg-line coinciding with ordinary high water level on left bank---debris on right bank exisisted form previous higher water level that was approximately at the same elevation as the veg-line on the left bank.
Sheep Crk.	bridge	veg-line and ordinary high water(OHW) line seem to coincide; veg at OHW and head of bank

Table B–1. Surveyed Sites, cont.

Location	Structure	Description/Notes
Hatcher Pass Rd		
Willow Crk	embank along road	Fast stream; fines blown into cracks from road traffic
Glenn Highway		
Granite Crk	bridge & approach	kings spawning; sediment from wind and road-none under bridge
Matanuska R.	embank along road	no veg-steep slope-
Kings R.	dike & bridge	tight Riprap, veg at head, then riprap is more open graded and veg is growing ; slope of bank grades out a bit and allows more veg at water level.
Matanuska R.	embank along road	a buffer ledge constructed at toe of road embankment that allowed veg growth
Gulkana R.	approach banks	veg at toe and head; buffer ledge with no riprap and some veg
Tok Cutoff		
Chistochina	old dike	pattern of toe and head veg; under major construction-only looked at part of old dike
Richardson Highway		
Sourdough Ck	brdg approach	small stream -not much rock or flow; established veg in voids, not a steep slope
Gulkana R.	roadside	great ex. of half island ledg at foot of bank with well established veg; sparse veg throughout roc; veg at head.
Phelan Crk	embank along road	buffer ledge, some veg in voids
McCallum Ck	reconstructed reach with in-stream weirs	glacial stream relatively close to source - relatively high Q; woody plants manually installed approx. 2001 -one bank has surviving but not flourishing veg.---other bank's veg not surviving.
Delta R.	dike behind groc. store	not often inundated; however, good sediment drop btwen rocks and good veg established
Fairbanks		
Tanana River	Dike embankment near FAI	great buffer ledge at foot of embankment --it is eroding, however, slowly and veg is well established in some areas. Rock bank behind ledge has little to no veg.

Table B-2. USGS Site Data

Location	Structure	Description/Notes	USGS Gauge/site number
Chena Hot Springs Rd			
North Fork Chena	Dike	sparse veg - trying to get established	no
Parks Highway			
Nenana R. 1	at Tatlanika Bridge	good veg in riprap voids	Nenana at Healy #15518040
Panguingue Creek	Bridge	cemented sand bags-small Q	no
Carlo Creek	bridge approach	swift Q	no
Nenana R. 2 - approx. MP 220	embank along road	good veg in riprap voids; Needs more toe support- bank head soft in some areas(more at MP221)- beginning to slough; Jet boat tours(large 20-40 passengers) wiz through here.	not nearby
Nenana R. 3 - approx. MP 221	embank along road		not nearby
Jack River	dike	general pattern of veg at head and toe with sparse spots of veg in voids - some areas with less solid mass of RR shows more veg.	Jack Ck nr Cantwell AK #15516050 Jack R AB Cantwell C nr Cantwell AK #632310148541800
Willow Creek	dike & bridge	kings spawning in middle of xsec; , toe rocks migrated into stream and separate from bank by 1-2 ft absorbing some stream energy; no shady areas; weathered banks w/ big rocks, moss, lichens. large void areas filled in with fines ,med fines(dirt)	6 sites listed-most applicable ones: Willow Ck. nr Willow AK #15294005 Willow C at Parks Hwy nr Willow AK #15294012 Willow C at upper bridge nr Willow AK #614522149401700
Little Willow Crk	dike & bridge	clear; no salmon spotted; Large rocks w/ large voids filled w/ fines, organics, veg.	Little Willow Ck. Nr Kashwitna AK #15293700
Kashwitna	dike & bridge	right side of stream has slower flow; left bank -little to no veg and heavily(solid mass) riprap	Kashwitna R nr Willow AK #15293200
Montana Crk.	dike & bridge	clear water; kings present; this site has great shots of veg-line coinciding with ordinary high water level on left bank---debris on right bank exisisted form previous higher water level that was approximately at the same elevation as the veg-line on the left bank.	Montana Ck nr Montana AK #15292800
Sheep Crk.	bridge	veg-line and ordinary high water(OHW) line seem to coincide; veg at OHW and head of bank	Sheep Ck nr Willow AK #15292990

Table B-2. USGS Site Data, cont.

Location	Structure	Description/Notes	USGS Gauge/site number
Hatcher Pass Rd			
Willow Crk	embank along road	Fast stream; fines blown into cracks from road traffic	Willow C at Hatcher pass road nr Willow AK #15294002
Glenn Highway			
Granite Crk	bridge & approach	kings spawning; sediment from wind and road-none under bridge	4 sites listed: nearest site-Granite C nr Sutton AK #614241148505500
Kings R.	dike & bridge	tight Riprap, veg at head, then riprap is more open graded and veg is growing ; slope of bank grades out a bit and allows more veg at water level.	Kings R nr Sutton AK #614357148150600
Matanuska R.	embank along road	a buffer ledge constructed at toe of road embankment that allowed veg growth	Matanuska R at Palmer AK #15284000
Gulkana R.	approach banks	veg at toe and head; buffer ledge with no riprap and some veg	several sites--2 are best fir: Gulkana R at Sourdough AK #15200280 Gulkana R at Gulkana AK #15200400
Tok Cutoff			
Chistochina	old dike	pattern of toe and head veg; under major construction-	Chistochina R nr Chistochina AK #62361044381500
Richardson Highway			
Sourdough Ck	brdg approach	small stream -not much rock or flow; established veg in voids, not a steep slope	Sourdough C at Sourdough AK #15200270
Gulkana R.	roadside	great example of half island ledg at foot of bank with well established veg; sparse veg throughout roc; veg at head.	several sites--2 are best fir: Gulkana R at Sourdough AK #15200280 Gulkana R at Gulkana AK #15200400
Phelan Crk McCallum	embank along road reconstructed reach	buffer ledge, some veg in voids	Phelan Ck nr Paxson AK #15478040, BL McCallum C nr Paxson #631404145394800
Fairbanks			
Dike near FAI	embankment	great buffer ledge at foot of embankment --it is eroding, however, slowly and veg is well established in some areas. Rock bank behind ledge has little to no veg.	Several sites at Fairbanks: @ Peger Rd #15485495, @ Fbks #15485500, @ chena pump campground(fbks) #15514470, goose Island and airport: #644730147523400, #644704147443100, #644656147422700, #644650147423600

Table B-3. Sources, Elevations, Vegetation Statistics

Location	Stream Source	Approx. Elev. (ft)	Approx Source Elev. (ft)	Elev. Difference (ft)	Vegetation				
					sparse	Toe	Head	OHW	Face
Chena Hot Springs Rd									
approx. MP 37 CHS	Chena River	1150	4000	2850	x				
North Fork Chena	mountainous	1150	4000	2850			x	x	
Parks Highway									
Nenana R. 1	**Nenana Glacier** with many contributing streams - mountainous, clear, glacier	1200	4700	3500	x				
Panguingue Creek	**ground** -clear water	1400	2000	600					
Carlo Creek	**mountainous** - AK Range-nr Panorama mtn.	2000	4500	2500	x				
Nenana R. 2 - approx. MP 220	**Nenana Glacier** with many contributing streams - mountainous, clear, glacier	2000	4700	2700		x	x		
Nenana R. 3 - approx. MP 221		2000	4700	2700		x	x		
Jack River	Mountains	2100	4500	2400		x	x		
Willow Creek	Talkeetna Mtns [4000 - 5000 ft elev.-as per gazetteer)	200	4000	3800		x	x		x
Little Willow Crk	Talkeetna Mtns [4000 - 5000 ft elev.-as per gazetteer)	200	4000	3800		x	x	x	x
Kashwitna	Talkeetna Mtns [4000 - 5000 ft elev.-as per gazetteer)	200	5000	4800		x	x	x	x
Montana Crk.	Talkeetna Mtns [4000 - 5000 ft elev.-as per gazetteer)	200	3200	3000			x	x	x
Sheep Crk.	Talkeetna Mtns [4000 - 5000 ft elev.-as per gazetteer)	200	4500	4300			x	x	

Table B-3. Sources, Elevations, Vegetation Statistics, cont.

Location	Stream Source	Approx. Elev. (ft)	Approx Source Elev. (ft)	Elev. Difference (ft)	Vegetation				
					sparse	Toe	Head	OHW	Face
Hatcher Pass Rd									
Willow Crk	mountain	1700	3900	2200			x		spots
Glenn Highway									
Granite Crk	Talkeetna Mtn. Glaciers	460	4500	4040	x				
Matanuska R.	**Matanuska Glacier /**Chugach Mtns with feeds from Talkeetna Mtn streams	500	11000	10500	x				
Kings R.	Talkeetna Mtn. Glaciers	500	4500	4000	x				
Matanuska R.	**Matanuska Glacier** in Chugach Mtns with feeds from Talkeetna Mtn streams	1500	11000	9500		x	x	x	x
Gulkana R.	**Gulkana Glacier/**Alaska Range	1400	3500	2100		x	x		x
Tok Cutoff									
Chistochina	**Chistochina Glacier** in Alaska Range 4400ft elev.	2000	4400	2400		x	x		
Richardson Highway									
Sourdough Ck	groundwater	1900	2000	100		x	x		
Gulkana R.	**Gulkana Glacier** /Alaska Range	1750	3500	1750		x	x		
Phelan Crk	Alaska Range/ **Glacier**	2800	5000	2200		x	x		
McCallum		2000	5000	3000					
Delta R.	Flat Top Mtns/Alaska Range & glacially fed	1200	6000	4800		x	x		
Fairbanks									
Dike near FAI	Glacially sourced and fed--Wrangell Mtns & Alaska Range	400	NA	NA	x	ledge			