EVALUATION OF BIOENGINEERED STREAM BANK STABILIZATION IN ALASKA
Research Project

- Performed under Alaska Department of Transportation and Public Facilities Agreement No. RES-02-001

- Kenneth F Karle, P.E.
  Hydraulic Mapping and Modeling

- William W Emmett (USGS retired)
- Nancy Moore, AKDNR Plant Materials Center
- Many others
Biotechnical Erosion Control

- a "mixed construction" approach to slope and streambank protection and erosion control; combines both vegetative and structural inert materials.

- vegetation - living and/or dead - is planted, inserted, driven, buried or placed on the ground surface to prevent erosion, protect erosion control structural components, and to provide for the establishment of a permanent vegetative cover.
Increasingly, regulatory and natural resource agencies are requesting that bioengineered stream bank stabilization methods be used in lieu of traditional ‘hard’ methods, which are perceived to have greater impacts to aquatic resources and habitat.
Many reports, guidance manuals, web sites, and short courses are available which describe the design and installation of bioengineering techniques.

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.
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.
Study Objective

- Gather quantitative data to supplement existing knowledge and ongoing research.
- Gain an understanding of the factors and conditions that govern successful implementation of bioengineered structures in Alaska.
- Increase the understanding and confidence necessary to design and construct BECS.
Study Approach

- Conduct a comprehensive analysis, using field data from a variety of BECS sites around the State
- Quantify performance values
- Identify modes of failure
- Identify and describe influences from climate, hydrology, vegetation
Methods/Analysis

- Evaluation of existing BECS installations
- Interviews, design documents
- Vegetation evaluation
- Hydraulic analysis
Research Approach-Hydraulic

- Assess how well the structures performed in high water conditions which occurred during the project life, or:

- Predict how well the structures would perform in simulated high water conditions using numerical modeling.
Fieldwork

- Survey of channel geometry (cross-sections, profile)
- Discharge measurements or USGS gaging station data
- Water surface elevation for each discharge
- Channel material gradation
- Near-bank velocity profile
- River morphology
Research Approach-Vegetation

- Assessment of vegetation condition
- Assessment of appropriate plant species in design
- Assessment of site conditions
Fieldwork - Vegetation

- For each species, vigor, overall plant height, diameter breast height, current shoot growth measured

- Site conditions (aspect, depth to water)

- Soil samples taken for N, P, K, OM, pH, and particle size
Study Sites

- Technical Advisory Committee meeting in May 2002
- Variety of techniques, conditions
- High energy sites preferred
- Design drawings, plans, and interviews with owners, designers, engineers
<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Length</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor R- Silverking</td>
<td>1999</td>
<td>200’</td>
<td>BL, STR, CL</td>
</tr>
<tr>
<td>Anchor R- Steelhead</td>
<td>2002</td>
<td>120’</td>
<td>RW, BL, VM</td>
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<tr>
<td>Campbell Cr- Taku</td>
<td>1995</td>
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<td>RW, LSt</td>
</tr>
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<td>Chena R- Doyon</td>
<td>1998</td>
<td>546’</td>
<td>BL, RR</td>
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<tr>
<td>Deep Cr</td>
<td>1994</td>
<td>350’</td>
<td>BL, BM, LSi, RR,</td>
</tr>
<tr>
<td>Kenai R- Centennial</td>
<td>1997</td>
<td>500’</td>
<td>RW, BL, CL, LSi, LSt</td>
</tr>
<tr>
<td>Kenai R- Riddle</td>
<td>1996</td>
<td>200’</td>
<td>RW, BL</td>
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<tr>
<td>Ship Creek</td>
<td>2000</td>
<td>425’</td>
<td>RW, BL, VM</td>
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<tr>
<td>Theodore R</td>
<td>1994</td>
<td>55’</td>
<td>RW</td>
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<tr>
<td>Willow Cr -Pioneer</td>
<td>2001</td>
<td>425’</td>
<td>RW, BL</td>
</tr>
<tr>
<td>Willow Cr-Lapham</td>
<td>2000</td>
<td>121’</td>
<td>RW, BL</td>
</tr>
</tbody>
</table>
CALL BEFORE YOU DIG
The State of Alaska encourages you to call before you dig to locate underground utility lines in your area.

CAMPBELL CREEK NEAR TAKU PARK
BANK STABILIZATION SCHEDULE A
(UPTREAM)
Typical Bank Section

- Anchor root wads by infilling voids between root wad and footer logs with 3-6" rock to a minimum depth of 12".
- 6"x6" helix anchor @ 18" O.C. TYP.
- 8"-12"x8" long tree trunk / root wad @ 6" O.C. along bank
- 12"-18"x40' long footer log
- Fasten footer log to helix anchor with double wrap of 3/8" steel cable & double clamp TYP.

Dimensions:
- 12"-thick vegetated, soil-covered brush layers from mean high tide line as shown @ 18' O.C.
- +18' MLLW mean high tide line
- +11' MLLW

- Line of existing bank
- 0.5% grade

Note:
- The diagram illustrates the method for bank restoration and protection.
- The application is for Kenai River Lower Kasilof, AK.
- Sheet 2 of 2
- Dec. 26, 1995
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 (fatleaf 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 topsoil 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 Proposed Design
CONCEPTUAL SKETCH

Not to Scale

Elevated, light-penetrating walkway and removable angler access stairs
(To be installed under separate contract by Parks.)

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.

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

Existing vegetation with dormant willow plantings placed as directed by Parks.

Mean water level

Anchor River

Top of bank

WILDLIFE HABITAT INCENTIVES PROGRAM
ANCHOR RIVER STATE PARK
STREAMBANK STABILIZATION

U.S. DEPARTMENT OF AGRICULTURE
NATIONAL RESOURCES CONSERVATION SERVICE
Vegetation-Findings
Ship Creek - vegetation descriptions

- Upper BL plant cover was 50 to 95%
- Lower BL plant cover 40 to 60%
- BL provides overhanging veg

<table>
<thead>
<tr>
<th>Treatment rootwad</th>
<th>Species</th>
<th>Height</th>
<th>Sht Grth</th>
<th>DBH</th>
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<tr>
<td></td>
<td>S. alaxensis</td>
<td>3 to 6’</td>
<td>6 - 26”</td>
<td>0.5”</td>
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<tr>
<td></td>
<td>S. barclayi</td>
<td>3’</td>
<td>5 to 12”</td>
<td>nd</td>
</tr>
<tr>
<td></td>
<td>S. scouleriana</td>
<td>4’</td>
<td>18”</td>
<td>nd</td>
</tr>
<tr>
<td></td>
<td>S. sitchensis</td>
<td>4’</td>
<td>9”</td>
<td>nd</td>
</tr>
<tr>
<td></td>
<td>Populus</td>
<td>4 to 5’</td>
<td>10 to 34”</td>
<td>nd</td>
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</table>
Ship Creek at BECS-xsec 5

<table>
<thead>
<tr>
<th>Feature</th>
<th>Elevation (ft)</th>
<th>Distance to WSEL (ft)</th>
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</thead>
<tbody>
<tr>
<td>Channel</td>
<td>107.56</td>
<td>-2.29</td>
</tr>
<tr>
<td>REW</td>
<td>109.85</td>
<td>0.0</td>
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<tr>
<td>Center of root wad</td>
<td>110.21</td>
<td>0.36</td>
</tr>
<tr>
<td>Base of 1(^{st}) soil lift</td>
<td>110.75</td>
<td>0.9</td>
</tr>
<tr>
<td>Base of 1(^{st}) willow layer</td>
<td>111.35</td>
<td>1.5</td>
</tr>
<tr>
<td>Base of 2(^{nd}) soil lift</td>
<td>111.75</td>
<td>1.9</td>
</tr>
<tr>
<td>Base of 2(^{nd}) willow layer</td>
<td>112.55</td>
<td>2.7</td>
</tr>
<tr>
<td>Top of bank</td>
<td>112.95</td>
<td>3.1</td>
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## Deep Creek-soil analysis

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<th>pH</th>
<th>NH$_4$ ppm</th>
<th>NO$_3$ ppm</th>
<th>P ppm</th>
<th>K ppm</th>
<th>Gravel &gt;2mm %</th>
<th>LIO %</th>
<th>% Sand</th>
<th>% Silt</th>
<th>% Clay</th>
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<td>1 Brush Mat</td>
<td>6.20</td>
<td>1</td>
<td>&lt;1</td>
<td>32</td>
<td>268</td>
<td>49.6</td>
<td>5.74</td>
<td>65.2</td>
<td>25.2</td>
<td>9.6</td>
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<tr>
<td>2 Brush Layer</td>
<td>6.08</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>24</td>
<td>136</td>
<td>13.8</td>
<td>4.53</td>
<td>57.6</td>
<td>32.8</td>
<td>9.6</td>
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<tr>
<td>3 Brush Layer</td>
<td>5.90</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>25</td>
<td>154</td>
<td>48.5</td>
<td>3.96</td>
<td>61.6</td>
<td>26.8</td>
<td>11.6</td>
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</table>
Interpretation of Study Results - Vegetation

- Soils - Nutrient levels are generally low - however, Alaska native plants are adapted to nutrient poor soils.

- Plants at project sites did not show signs of nutritional stress.

- Water stress noted at only one site.

- Marginal root conditions noted at only one site.
-Roots thin, low density.
-Root development low or, roots broken off by flooding and boat wakes.
Interpretation of Study Results - Vegetation

- Alaska has several species of willow that root readily, and are tolerant of periodically-saturated soils.

- Use of such species well understood and utilized in Alaska.

- Sole exception at Deep Creek - *S. barclayi* used at rock-toe/water interface.

- *S. alaxensis* more tolerant of flooding, ice scouring.
Hydraulic Analysis

- Assess the success of structure in flooding conditions, when velocities are high and maximum protection is required at the bank.
Hydraulic Analysis-Flow Velocity

- Water velocity profiles based on measurements taken adjacent to BECS
- Measurements at incremental depths from the surface, and incremental distances from the BECS
Distance From Right Bank (ft)

Depth (ft)

Chena River at Doyon Estates

Brush layering

Isovel in feet per second

Main Channel

Right Bank

-7.0
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
-7.0
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
Obtaining hydraulic measurements during high river stage is difficult, so numerical modeling is used to estimate hydraulic parameters.

- HEC-RAS-water surface profile computational model for one-dimensional, gradually varied flow.

- Calculates velocities adjacent to BECS by dividing each section into multiple subdivisions; once WSEL is calculated, model will compute conveyance (velocity) for each slice, based on area, wetted perimeter.

- Is not 2-dimensional model; use with caution.
Hydraulic Analysis

- Discharge magnitudes include the 2-year flood ($Q_2$), 50-year flood ($Q_{50}$), the 100-year flood ($Q_{100}$) and the largest flood occurring at the project site.

- Magnitudes for the largest project flood were obtained either through USGS gaging records or analysis of high water field indicators.
Problems With Velocity As A Performance Indicator

- Difficulty in determining where measurement should be made.
- Difficulty in making measurements at high stage.
- In turbulent conditions, velocities may vary in magnitude up to 2 times the mean.
- Velocity provides no indication of site specific characteristics which may affect performance.
Hydraulic Analysis-Shear Stress

- Tractive Force-defined as force exerted by moving water on bed and bank material.
- When tractive force < some critical value, bed material remains motionless.
- When tractive force > critical value, particle motion begins, potential for bed and bank erosion.
- Tractive force per unit bed area is shear stress.
Procedure For Shear Stress Analysis

- At each site, using cross-section through BECS:
- Estimate average shear stress for $Q_2$, $Q_{50}$, $Q_{100}$, and $Q_{\text{flood}}$, using numerical model
- Calculate critical shear stress, using field data (particle size, bank angle)
- Ratio of average to critical shear stress:
  > 1 indicates potential for erosion
  < 1 indicates stable channel geometry
### Kenai River-Centennial

<table>
<thead>
<tr>
<th></th>
<th>Critical (lb/ft²)</th>
<th>Average (lb/ft²)</th>
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<th></th>
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<tbody>
<tr>
<td></td>
<td>Q₂</td>
<td>Q₅₀</td>
<td>Q₁₀₀</td>
<td>Q₅₀</td>
<td></td>
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<tr>
<td>bed</td>
<td>0.84</td>
<td>0.67</td>
<td>0.87</td>
<td>0.92</td>
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<td>0.67</td>
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<table>
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<th></th>
<th>Average/Critical Shear Stress Ratio</th>
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<td>bed</td>
<td>0.80</td>
<td>1.04</td>
<td>1.10</td>
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<td>Kenai River Riddle</td>
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<tr>
<td>-------------------</td>
<td>------------------</td>
<td>-----------------------------------</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Q₂</td>
<td>Q_{50}</td>
<td>Q_{100}</td>
<td>Q_{flood}</td>
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<td>Ship Crk</td>
<td>Critical (lb/ft²)</td>
<td>Average/Critical Shear Stress Ratio</td>
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<tr>
<td>---------</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bed</td>
<td>1.15</td>
<td>Q₂</td>
<td>Q₅₀</td>
<td>Q₁₀₀</td>
<td>Q₊flood</td>
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<td></td>
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<td>0.61</td>
<td>0.79</td>
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<td>Anchor</td>
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<td>Average/Critical Shear Stress Ratio</td>
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<td>------------------------------------</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>R Silver</td>
<td></td>
<td>Q₂</td>
<td>Q₅₀</td>
<td>Q₁₀₀</td>
<td>Q_{flood}</td>
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<tr>
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<td>0.44</td>
<td>1.01</td>
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<td>1.62</td>
<td>3.71</td>
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Cross-section 5

June 19, 2002
<table>
<thead>
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<th>Critical (lb/ft²)</th>
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<td></td>
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<tr>
<td>bed</td>
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<td>1.08</td>
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<td>Campbell Crk</td>
<td>Critical (lb/ft²)</td>
<td>Average/Critical Shear Stress Ratio</td>
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<td>-------------------</td>
<td>-----------------------------------</td>
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<tr>
<td>bed</td>
<td>0.49</td>
<td>Q₂, Q₅₀, Q₁₀₀, Q₀₀₀, Q₉₀₀, Q₀₀₀₀</td>
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<td>Deep Crk Xsc 6</td>
<td>Critical (lb/ft²)</td>
<td>Average/Critical Shear Stress Ratio</td>
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<td>---------------</td>
<td>-------------------</td>
<td>------------------------------------</td>
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<tr>
<td>bed</td>
<td>1.18</td>
<td>Q₂ 0.57  Q₅₀ 0.42  Q₁₀₀ 0.40  Q₅₀₀ 0.41</td>
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<td>NA  NA  NA  NA  NA</td>
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</table>

Average/Critical Shear Stress Ratio

Deep Crk Xsc 6

Critical Shear Stress (lb/ft²)

Q₂, Q₅₀, Q₁₀₀, Q₅₀₀, Q₅₀₀₀

NA: Not Available
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<thead>
<tr>
<th>Deep Crk Xsc 5</th>
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<tr>
<td>bed</td>
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<td>0.52</td>
</tr>
<tr>
<td>bank</td>
<td>1.17</td>
<td>0.40</td>
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</tbody>
</table>
Soil lifts constructed of inner burlap fabric and outer geogrid.

Inner fabric completely deteriorated.

During flood, gravel removed from lifts though large open gridding spaces.
<table>
<thead>
<tr>
<th>Theodore R</th>
<th>Critical (lb/ft²)</th>
<th>Average/Critical Shear Stress Ratio</th>
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<td>bed</td>
<td>0.25</td>
<td>Q₂</td>
</tr>
<tr>
<td>bank</td>
<td>0.20</td>
<td>0.45</td>
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</table>
Buoyant Force

- Buoyant force equal to weight of displaced water minus weight of wood.

- In 40 ft section of root wads, buoyant force of 26,000 lb.

- If anchoring is insufficient, or fill erodes away during high water, buoyant force could be large enough to float root wads and initiate failure.
<table>
<thead>
<tr>
<th>Chena River</th>
<th>Critical (lb/ft²)</th>
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<td>Q₂</td>
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<td>0.20</td>
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<tr>
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<tr>
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<td>Q₁₀₀</td>
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<td>Q₅₀₀</td>
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<td>Q₀₀₀₂₀</td>
<td>Q₀₀₀₂₂</td>
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<td>0.22</td>
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<td>0.25</td>
<td>0.19</td>
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<td>Location</td>
<td>Critical (lb/ft²)</td>
<td>Average/Critical Shear Stress</td>
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<tr>
<td>Willow Crk</td>
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<tr>
<td>Lapham bed</td>
<td>1.80</td>
<td>Q₂ 0.60 Q₅₀ 0.84 Q₁₀₀ 0.88 Q₅₀₀ 0.67</td>
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<tr>
<td>Lapham bank</td>
<td>0.37</td>
<td>Q₂ 2.24 Q₅₀ 3.16 Q₁₀₀ 3.30 Q₅₀₀ 2.51</td>
</tr>
<tr>
<td>Location</td>
<td>Critical Shear Stress Ratio (lb/ft²)</td>
<td>Average/Critical Shear Stress Ratio</td>
</tr>
<tr>
<td>----------</td>
<td>-------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Willow Crk bed</td>
<td>0.74</td>
<td>Q₂ 0.27</td>
</tr>
<tr>
<td>Willow Crk bank</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Pioneer bed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pioneer bank</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Damage from spring ice floes and/or bank ice.
No impacts from aufeis noted.
No impacts from permafrost noted.
Cold soils seasonal solar regime slow revegetation rates—much longer time required to develop adequate root mass.
Could be up to 10 years for revegetation to provide surface erosion control.
Longer establishment period, lower factor of safety.
2 sites (Kenai River) appear to protect banks against boat wake erosion, spring ice floes and/or bank ice.

3 sites (Willow Creek, Ship Creek) in good condition, but sites only a few years old.

3 root wad sites suffered partial or complete failure (buoyancy effects, scour, bank erosion).
Engineering Design Considerations

Toe Scour

- Undermining of revetment toe protection one of the primary mechanisms of revetment failure.
- Root wads are designed to be embedded so that root fan protects against bed erosion.
- Little evidence of depth of scour or shear stress calculations during design phase.
Engineering Design Considerations
Toe Scour

Total depth of scour estimates must be calculated. 3 major components of scour are additive:

1. Long-term bed elevation change.
   - *May be natural or due to watershed modification.*
   - *Streambed may be aggrading or degrading.*

2. General scour and contraction scour.
   - *Channel adjustment based on sediment inflow.*

3. Local scour.
   - *Pier scour and abutment scour.*
Engineering Design Considerations

- Channel Geometry - bank stabilization will often cause a channel to deepen, especially at a bend.
- Cross-section data may vary by up to 50% from long-term mean.
Engineering Design Considerations

- Extent of Bank Protection: longitudinal extent required to adequately protect bank not noted in most designs.
Engineering Design Considerations

- Filters—should be used to prevent migration of fine soil particles, permit the relief of hydrostatic pressure; not noted in most designs.

- Two types of filters (gravel and geosynthetic).
Recommendations

Hydraulic Conditions For Successful Applications

- Identification of bank erosion potential is essential.
- Shear stress analysis should be conducted; BECSs should not be used where average shear stress approaches critical shear stress at design flood magnitude.
- Total depth of toe scour should be estimated.
- Root wads should be used to protect willow plants and fabric soil wraps on rivers with spring ice floes and or boat wakes.
Recommendations

Design Improvements

- Design improvements needed to protect foundation from large tractive forces. Need seamless and substantial toe scour protection.

- Techniques needed to provide self-healing capabilities.

- Improvements to materials needed (greater tensile strength, abrasion resistance). Need to correlate rates of degradation to root mass development.
Until current designs are improved to provide toe erosion protection, BECSs should be used only in areas where failure results in insignificant consequences.

For design, hydraulic analysis should be conducted by an experienced engineer.

Scheduled inspection and maintenance should be conducted (especially after large floods).
Evaluation of Bioengineered Stream Bank Stabilization in Alaska

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Date: June 2003

Prepared for:
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FHWA-AK-RD-03-03
Hedge brush layering is a revegetation technique which combines layers of plant material, both dormant cuttings and rooted plants, with soil to revegetate and stabilize a streambank. Greater plant diversity can be provided with a hedge brush layer than with a simple brush layer. Rooted 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.
Brush Layering: Rootwad Toe

Root wads are overlapped when placed in banks.

Multiple Root Wads

Bank Protection Behind Root Wads

Tree Trunk Embedded In Streambank

If possible partially embed root fan into river bottom.

Dormant Cuttings

Two Layers Coir Fabric

Wood Stake

Header Log

Vegetative Mat or Riparian Seed Mix

Top Soil/Gravel Mix

Natural Substrate

12"
Dormant Feltleaf Willow Cuttings (Up to 2” Diameter)

Example 1.

COIR LOGS
(Coconut Fiber)

Example 2.

Logs biodegrade as plant roots develop.

Inner Material
100% Coconut Fiber
Biodegradable Twine
Up To 20’ long

Example 2.

Trench
Coir Log is 1/3 above ground and 2/3 below ground.
Shear Stress Analysis

- Shear stress is the frictional force which causes flow resistance along a channel boundary.
- An equal and opposite force caused by shearing of water is exerted on bed and bank material, also called tractive force.

\[ \tau_{\text{bed}} = \gamma RS \]

\[ \tau_{\text{bank}} = 0.77 \tau_{\text{bed}} \]
Critical Shear Stress

- As applied stress is increased, grains of material begin to move at some point-critical shear stress.
- Many studies of critical shear stress for initial particle motion.
- For coarse material:

\[ \tau_{\text{bed}} = 0.08D_{75} \]
Critical Shear Stress

- On a channel bank, critical shear stress is not only from water force downstream but from gravity force.

- Calculated from estimated angle of repose $\Phi$ and estimated bank angle $\theta$:

\[
\frac{\tau_{c_{\text{bank}}}}{\tau_{c_{\text{bed}}}} = \cos \theta \sqrt{1 - \frac{\tan^2 \theta}{\tan^2 \phi}}
\]