Research Report

Research Project WA-RD 491.1
Soil Bioengineering for Slopes

SOIL BIOENGINEERING FOR UPLAND SLOPE STABILIZATION

by

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February 2001

1. REPORT NO. WA-RD 491.1	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE. SOIL BIOENGINEERING FOR SLOPE STABILIZATION	5. REPORT DATE February 2001 6. PERFORMING ORGANIZATION CODE	
7. AUTHORS Lisa Lewis, Shannon Hagen, and Sandra Salisbury	8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Lisa Lewis National Riparian Service Team USDA, Forest Service c/o Bureau of Land Management PO Box 550 Prineville, OR 97754	10. WORK UNIT NO. 11. CONTRACT OR GRANT NO.	
12. SPONSORING AGENCY NAME AND ADDRESS: Washington State Department of Transportation PO Box 47329 Olympia, WA 98504-7329 Program Manager Jim Schafer 360-705-7971	13. TYPE OF REPORT AND PERION COVERED Research Report 14. SPONSORING AGENCY CODE	

15. SUPPLEMENTARY NOTES:
This study was conducted in cooperation with WSDOT, National Riparian Service Team (USDA Forest Service, Bureau of Land Management, Natural Resource Conservation Service), Washington State Department of Ecology, and the Washington Conservation Corps.

16. ABSTRACT:
The objective of the study was to provide alternatives called soil bioengineering methods for slope and shallow rapid landslide stabilization along different roadside environments. Additional objectives were to educate WSDOT personnel in site selection, soil bioengineering techniques, and construction; to provide soil bioengineering decision-making skills. Three study sites were selected: based upon the following criteria: safety, visibility, accessibility, representation of disparate moisture conditions, climate, and erosion types, illustration of different techniques, availability of additional funding, and WSDOT input. Three different combinations of soil bioengineering techniques were used to stabilize upland slopes on the roadside. Results indicate soil bioengineering is an effective means of upland slope stabilization on erosional slopes and shallow rapid landslides and is practical and economical. Composted biosolids improved soil workability and enhanced the native plant community during the first year.

17. KEYWORDS: Soil bioengineering, slope stabilization, erosion, erosion control, landslides, native plants, cribwall, fascine, branchpacking, brush layering, cordon, live cribwall, live gully repair, live staking, willow wall, biosolids, cost/benefit	18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19.SECURITY CLASSIF. (of this report) None	20. SECURITY CLASSIF (of this page) None	21. NO. OF PAGES 96	22. PRICE

DISCLAIMER

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EXECUTIVE SUMMARY

RESEARCH OBJECTIVE

The purpose of this research project was to present viable soil bioengineering alternatives, or "living" approaches, to slope stabilization. This is not to argue soil bioengineering is better than traditional engineering treatments, but to introduce the concept of soil bioengineering, to expand on the knowledge of WSDOT personnel, to provide additional alternatives, and to encourage integration of these two practices. Specifically, this research project provides field personnel with examples of soil bioengineering restoration techniques intended primarily for upland roadside slope stabilization and revegetation. There are numerous soil bioengineering techniques and multiple methods are often combined for stabilizing one erosion feature. An additional goal of this project was to improve communication between disciplines within WSDOT.

PROJECT SITES

After a team field review of over 88 potential sites throughout most of Washington State, three project sites were selected by the Principal Investigator (PI). These sites were chosen based on the following criteria:

- Safety of the public and work crews (both road and slope-related safety issues were addressed).
- Visibility and accessibility for educational opportunities.
- Representation of the disparate soil moisture conditions, climate, and erosion types common to Washington State.
- Illustration of soil bioengineering techniques that could be used on large erosion sites, small erosion sites, and combined soil bioengineering and traditional engineering treatments.
- Allocated dollars and the availability of additional funding.
- Recommendations by WSDOT personnel.

The three selected sites are located in three different regions of Washington State and include:

- Chelan - North Central Region
- Lost Creek/Forks - Olympic Region
- Raymond - Southwest Region

ACCOMPLISHMENTS

A combination of WSDOT research, road maintenance, engineering, and environmental funding Washington was used to implement three large soil bioengineering projects during the period of November 1999 through April 2000.

Challenges were encountered on all three sites and resulted in design changes and additional learning opportunities. Maintenance personnel were actively involved in excavation and construction on the Raymond site and in the selection of the heavy equipment contractor for the Chelan excavation. Six Washington Conservation Corps crews, involving 42 crew members, were involved in the construction of the three soil bioengineering projects. The soil bioengineering work involved:

- Willow wall construction
- Willow walls with a brush layer base
- Live cribwall construction
- Cordon construction
- Live fascine construction
- Cedar bender board fencing
- Planting diverse native vegetation
- Seeding
- Biosolid application on the Lost Creek and Chelan sites.

OUTCOMES

- Using multiple soil bioengineering techniques, three large upland slope stabilization projects were constructed.
- The PI and the research team presented the research findings to WSDOT personnel, in January 2001**.** See Appendix A for research team members.
- The full research report is available on the OSC Roadside and Site Development Unit internet homepage at http://www.wsdot.wa.gov/eesc/cae/design/roadside/rm.htm.
- Soil Bioengineering chapter was written for the *Roadside Manual,* and the *Design Manual* soil bioengineering chapter has been updated.
- OSC Roadside and Site Development Unit has been contracted by FHWA to do soil bioengineering Plans, Specification, and Estimates for the Blaine Road project in southwestern Oregon.
- WSDOT right to use and reproduce all materials from Lewis, E.A. *Soil Bioengineering: An Alternative for Roadside Management: A Practical Guide*. United States Forest Service. San Dimas Technology and Development Center. San Dimas, California. 2000.
- Communication between disciplines within WSDOT has been enhanced. Opportunities for improved communication have been highlighted.
- Awareness of soil bioengineering as an option for roadside stabilization and erosion control has increased within WSDOT.
- Relations with the public has been enhanced by the publication of four print articles (two local newspapers, an-in house newsletter, and a nationally-distributed magazine) about WSDOT's use of a natural method of erosion control.

INTRODUCTION

Soil bioengineering is the use of plant material, living or dead, to alleviate environmental problems such as shallow rapid landslides, and eroding slopes and stream banks. In bioengineering systems, plants are an important structural component. This approach to slope stabilization requires a true partnership between many disciplines, including soil scientists, hydrologists, botanists, engineering geologists, maintenance personnel, civil engineers, and landscape architects.

Soil bioengineering most often mimics nature by using locally available materials and a minimum of heavy equipment, and can offer roadside managers an inexpensive way to resolve local environmental problems. These techniques can also be used in combination with traditional engineering techniques such as rock or concrete structures.

PROBLEM STATEMENT

Transportation systems provide access and allow utilization of land and resources. Development priorities usually emphasize access, safety, and economics. Environmental concerns involve operational and maintenance problems such as surface erosion, plugged drainage structures, and mass failures.

Transportation systems provide tremendous opportunities and, if properly located on the landscape with well designed drainage features, can remain stable for years with negligible affects to adjoining areas. Roads, however, are often linked to increased rates of erosion and accumulated adverse environmental impacts to both aquatic and terrestrial resources. This has become even more apparent during major winter storm events in recent years.

This is not new information to road managers. Road maintenance personnel, for example, face a huge task in maintaining roads under their jurisdiction. Major winter storms, resulting in significant increases in road landslides and impacts to adjoining resources, have compounded the road manager’s challenge.

The Washington State Department of Transportation (WSDOT) has been using soil bioengineering methods since the 1980’s. The early focus was on stream bank stabilization. In 1995 a soil bioengineering task force was formed to study opportunities for the application of soil bioengineering methods along our roadways and the workgroup agreed that the time had come for WSDOT to consolidate various soil bioengineering efforts currently underway in the department. From this work, a chapter on soil bioengineering was written for our *Design Manual* - a document used by all roadway design engineers working for and with WSDOT. This report documents the planning, design, and construction of three soil bioengineering projects on upland slopes in the roadside.

RESEARCH OBJECTIVES

The objectives for this study were:

- Provide viable alternatives called soil bioengineering or “living” approaches for slope and shallow rapid landslide stabilization along different roadside environments.
- Educate WSDOT personnel in site selection and evaluation, and soil bioengineering techniques including construction, monitoring, and maintenance.
- Provide soil bioengineering decision making skills.
- Produce a report of the research project results.

This report documents the project process and its outcomes. It begins by setting this soil bioengineering project within the context of slope stabilization and soil bioengineering in general. It then describes the three projects in detail.

LITERATURE REVIEW

Much like practices of medicine, engineering, and architecture, soil bioengineering developed historically as discrete techniques designed to solve specific problems. Knowledge of these techniques was part of the body of folk wisdom accumulated in prehistoric times and passed orally from generation to generation. In the last two centuries, this knowledge has been compiled and codified, and finally in fairly recent times, has been taught formally and practiced as a profession.

History

The system of technologies, which today we call soil bioengineering, can be traced to the ancient peoples of Asia and Europe. Chinese historians recorded use of soil bioengineering techniques for dike repair as early as 28 BC (Needham, 1971, p. 331). Early Western visitors to China told of river banks and dikes stabilized with large baskets woven of willow, hemp, or bamboo and filled with rocks. In Europe, Celtic and Illyrian villagers developed techniques of weaving willow branches together to create fences and walls. Later, Romans used fascines, bundles of willow poles, for hydroconstruction.

By the 16^{th} century, soil bioengineering techniques were being used and codified throughout Europe from the Alps to the Baltic Sea and west to the British Isles. One of the earliest surviving written accounts of the use of soil bioengineering techniques, a publication by Woltmann from 1791, illustrated the use of live stakes for vegetating and stabilizing stream banks (Stiles, 1991, p.ii). About the same time, other early bioengineers working in Austria were developing live siltation construction techniques, planting rows of brushy cuttings in waterways for trapping sediment and reshaping channels.

Much of the development and documentation of soil bioengineering techniques, since the Industrial Revolution, has been done in the mountainous areas of Austria and southern Germany. Extensive logging of the forests in the region resulted in increased environmental problems, much like what is found in parts of the western U.S. today. Such problems as extreme slope erosion, frequent landslides and avalanches, and severe stream bank degradation, required repair. By the turn of the century, European bioengineers had begun to study traditional techniques and to publish their work. It is from this compilation that soil bioengineering professions would develop in the following decades.

The biggest boost to development of new soil bioengineering techniques in Europe came as a result of political developments during the 1930's. Financial restrictions of pre-war years in Germany and Austria favored use of low cost, local materials and traditional construction methods for public works projects. Construction of the German Autobahn system, during this time, involved extensive applications of soil bioengineering technologies. The use of indigenous materials and traditional methods was also consistent with spreading nationalist ideology. In 1936, Hitler established a research institute in Munich charged with developing soil bioengineering techniques for road construction (Stiles, 1988, p. 59). Although this development work was lost, a Livonian forester named Arthur von Kruedener, the head of the institute, continued to work in the field and is known in central Europe as the father of soil bioengineering.

At the same time the Germans were establishing their research institute, some of the most important early soil bioengineering work in the United States was being done in California. Charles Kraebel, working for the US Forest Service, was developing his "contour wattling" techniques for stabilizing road cuts. Kraebel used a combination of soil bioengineering techniques including live stakes, live fascines, and vegetative transplants to stabilize degrading slopes in National Forests of central and southern California. His unfortunate and confusing misuse of the term "wattle" to describe his live fascine system has stuck with us and continues to be used today. Kraebel's work was well documented in USDA Circular #380, published in 1936. Two years later the Natural Resource Conservation Service (NRCS), formally known as the Soil Conservation Service, began a study of bluff stabilization techniques along shores of Lake Michigan. That agency's work, which included use of live fascines, brush dams, and live stakes was published in 1938 (Gray and Leiser, 1982, p. 188).

During the post-war period, many European bioengineers returned to studying, developing and evaluating new techniques. In 1950, a committee of bioengineers from Germany, Austria, and Switzerland was formed to standardize emerging technologies which became part of the German national system of construction specifications, the DIN (Robbin B. Sotir & Associates, n.d.).

Arthor von Kruedener's book, Ingenieurbiologie, (Engineering biology), was published in 1951 and it was the mistranslation of the German title which gave us the English term we use today. The use of the term bioengineering has caused some confusion and has proven problematic for researchers who find, in this country, the term is most often referred to as an area of medical research.

German and Austrian soil bioengineers continued to perfect their techniques and to publish their work through the 1950's and 60's. This was an important step in launching a more structural approach, laying the foundation for development of the professional field of soil bioengineering. In the United States, two important projects were carried out in the 1970's. These include the Trials of Bioengineering Techniques in the Lake Tahoe Basin designed by Leiser and others (1974), and Revegetation Work in Redwood National Park (Reed and Hektner, 1981, Weaver,et al., 1987). Both studies have been well documented and provide important information about application of soil bioengineering techniques in the western United States.

In 1980, Hugo Schiechtl's Bioengineering for Land Reclamation and Conservation was published in Canada. It presents, for the first time in English, work of many important European soil bioengineers including Lorenz, Hassenteufel, Hoffman, Courtorier and Schiechtl himself. The book made the technologies, and the history of their development and applications accessible to the English speaking world. In 1997, another Schiechtl book was published, Ground Bioengineering Techniques for Slope Protection and

Erosion Control. To date, his writings remain the most important work on bioengineering in the English language.

With subsequent publications including Gray and Leiser's Biotechnical Slope Protection and Erosion Control in the United States and the British Construction Industry Research, Sotir and Gray's Soil Bioengineering for Upland Slope Protection and Erosion Reduction in the Natural Resource and Conservation Service's Engineering Field Handbook, Gray and Sotir's Biotechnical and Soil Bioengineering Slope Stabilization, and Information Association's Use of Vegetation in Civil Engineering bioengineering technologies are better known in the engineering profession. There is still, however, resistance to the techniques in this country.

Soil bioengineering approaches most often use locally available materials and a minimum of heavy equipment, and can offer local people an inexpensive way to resolve local environmental problems. The public's increased "green" consciousness often makes soil bioengineering solutions more acceptable than traditional engineering approaches. Despite, and maybe because of, the difference in approach and philosophy between soil bioengineering and other engineering methods of addressing environmental problems, soil bioengineering technologies are especially appropriate today. The scale and range of environmental problems require consideration of new technologies even when, as illustrated earlier, they are in fact centuries old.

METHODS

Site Selection

WSDOT Engineering Geologists, in the Olympia Service Center Materials Laboratory, keep a record of erosional slopes. These data were provided to the Research Team (see Appendix A for a list of team members). The eastern half of the state was not considered for this project because the team wanted slopes closer to Olympia for easier logistics in construction and monitoring.

Emails were sent in March to four of the Region Materials Engineers (OR, SWR, NCR, SCR) to seek their help in locating erosional slopes within quarry and pit sites, or on the highway. Also they were asked if there were any maintenance areas that would be most likely to have erosional slopes that might be included in this project. At this time the PI thought that there could possibly be 50 bioengineering sites statewide used in the research project, if they had all be less than ¼ acre in size and all erosional features. The slopes identified by the Region Materials Engineers and Maintenance personnel were compiled into a list of potential sites. Some slopes were also nominated by the Olympic Region LA.

On June 15, 1999 the PI and members of the research team made site visits to problem slopes along over 350 miles of Highway 101 around the Olympia Peninsula. The special stops included three major landslides on SR 101(MP 321, MP 322, and MP 326) that were clearly not soil bioengineering candidates for this project

From June 16 through June 18, 1999 the PI and research team members traveled over 1500 miles evaluating additional sites suggested by the region Materials Engineers. See Figure 1 for site visit routes:

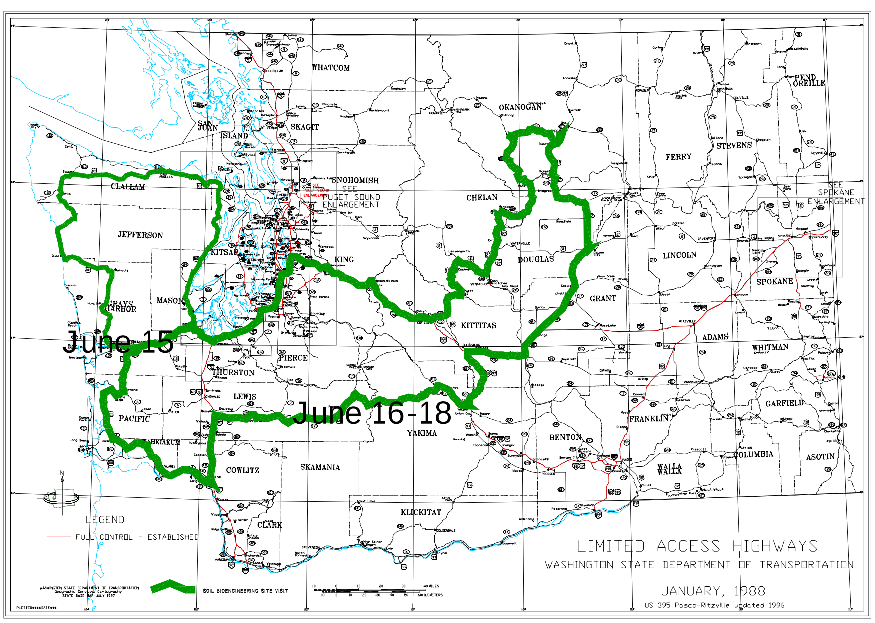

Figure 1. Screening Site Visit Route

From June 16 through 18, 1999, the team reviewed 82 sites, analyzing their potential use as research sites. Later in June the PI made additional site visits to slopes on SR 101, SR 14, and SR 3 to view sites requested by maintenance. The following criteria were used to select three sites from those candidates.

Site Selection Criteria

The PI took comment from all team members on site selection, but the final decision was hers. She wanted a combination of fill slope and cut slope erosional features represented in the research project. However, no fill slope areas met all the site selection criteria. The criteria for selection were:

- Safety of the public and work crews (road and slope related safety issues were addressed).
- Visibility and accessibility for educational opportunities.
- Representation of the disparate soil moisture conditions, climate, and erosion types common to Washington State.
- Illustration of techniques that could be used on large erosion sites, small erosion sites, and combined soil bioengineering and traditional engineering treatments.
- Allocated dollars and the availability of additional funding.
- Input from WSDOT personnel.

Sites Selected

The team had originally intended to work on several smaller sites, however because of the difficulty of working on so many sites over long distances in a limited amount of time, the PI decided to use several techniques on each of the selected sites. Three sites were selected and include two west-side sites and one site east of the Cascade Mountains. Two of the sites, Raymond and Chelan, are considered large sites. Because of the many storm damaged slopes in the state, the Engineering Geologists and Geotechnical Engineers were too busy to do a special project combining soil bioengineering with a traditional treatment. The Lost Creek site, near Forks, was selected because it had a rock apron at the base. Throughout the rest of this report, the three sites will be discussed separately.

Chelan

Located at Mile Post 8.22 on State Route 971, above Lake Chelan, this 630 foot long by 70 feet high, north-facing slope has been a chronic source of surface erosion and ditch maintenance needs.

Figure 2. SR 971, Mile Post 8.22 vicinity, June 1999

Geology and Soils

Soils on site are composed of glacial deposits and volcanic ash overlying granitic bedrock. The glacial deposits are composed of sand, gravel, cobbles, and boulders. The weathering of the granite bedrock into rocks, fragments, and mineral components is called grus; in particular the feldspar minerals weather rapidly to a fine or "ashy" size. There is evidence, as seen in Figure 2, of chronic surface erosion with rilling and associated accumulated debris in the ditch line.

Climate and Moisture

During the June 1999 site visit, the soil was moist. This is a north-facing slope which receives no direct sunshine from fall through spring.

This area receives an average of 10.9 inches of precipitation per year. Snow depth in January is approximately five inches. Average maximum temperature is 85ºF which occurs during the month of July. Average minimum temperature is 22.2ºF in January. Further climate data can be found at:

http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wachel

Existing Vegetation

There was sparse existing vegetation on the slope face consisting of a bitterbrush (Purshia tridentata) and ponderosa pine (Pinus ponderosa) community and one willow (salix exigua). See Appendix G. This vegetation was located on portions of the slope that were at an angle of repose of 1.5(V):1(H). Where the slope was steeper, there was no vegetation growing.

The slope above the vertical lip has a ponderosa pine community established. The vegetation, especially the mature trees, growing on the edge are at risk because of continual erosion.

Figure 3. Vegetation community on stable soils

Opportunities and Constraints

This site had some moisture present combined with a favorable slope aspect, high public visibility, and a large bank of volunteer plants on the slope above. The adjacent landowners were willing to grant WSDOT a construction easement allowing an excavator to flatten the slope angle and increase stabilization of the site.

The team's engineering geologist said that traditionally, she would not have recommended additional work beyond reducing slope steepness. A flatter slope angle would help reduce surface erosion and provide favorable ground to establish vegetation. As with traditional engineering methods, soil bioengineering also requires "re-working" the slope profile, but also incorporates vegetative treatments to accelerate site recovery while providing a more permanent solution to the erosion problem.

The constraints were the large amount of excavation necessary to lay the slope back to 1 ½ :1 and the small amount of moisture in the soil during the summer. Because of the relatively dry conditions, traditional soil bioengineering techniques were altered to fit the dry site conditions.

Design Solution

After consultations with fellow scientists and lumber experts, the PI's solution was to use cedar bender board fencing. The consensus was that the slope would benefit from terracing, but traditional soil bioengineering plant species, such as willow, would not be appropriate for these site conditions. As a result, cedar bender board fencing was used as an alternative to willow walls to reduce the length and steepness of the slope and to create stable planting platforms for easier establishment of native (dry climate) vegetation.

The PI’s original bender board fencing detail and specifications are found in Figure 4:

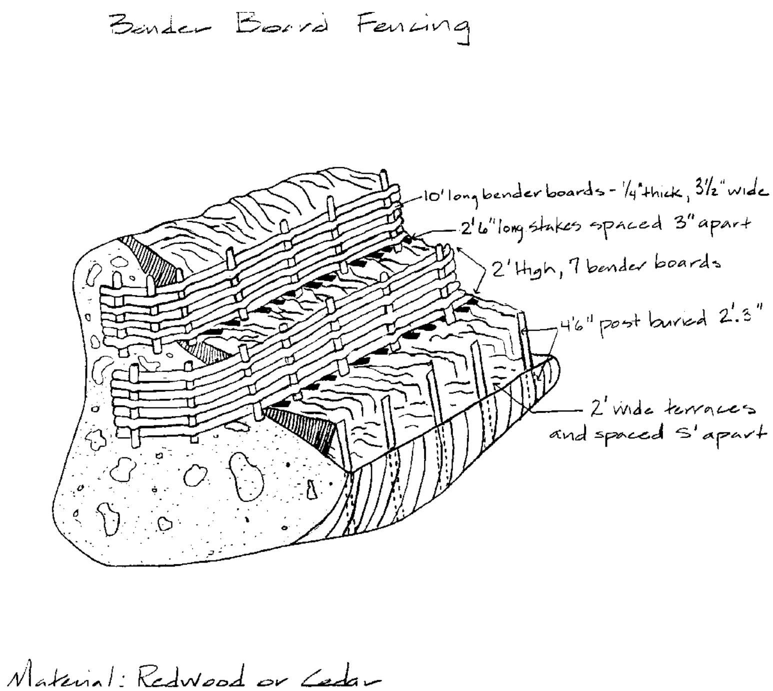

Figure 4. Bender board fencing

Bender board Fence Specifications

Redwood or cedar bender board fencing is essentially a fence supported on a short layer of shrub or tree stems. Specifically, it is a short retaining wall built of redwood or cedar bender fencing with a stem layered base.

<u>Tools needed:</u>

Hand pruners and clippers

Pulaski or hazel hoe

McLeod rake

Deadblow or rubber hammer

Pickaxe

Wood stakes

Stem Layered Base

Begin project at base of treatment area. Excavate 24" deep terrace along slope contour and for full width of treatment area. The back of the terrace should be dug with an approximate 70 degree angle. To allow ample planting platforms, space terraces about 5' apart.

Lay 2'6" long stems and 2'6" long wood stakes (50/50 mix) 2 inches apart and for full length of terrace. Diameter can range from 1/2" to 2". Approximately 6" will extend beyond slope face. Every 1’, place plant material (plugs) within the terrace.

Bender Board Fencing Construction

Drive supporting 4'6" (2' x 2') long stakes 2'3" into ground, vertically, and spaced 2' apart.

Weave 10' long bender boards through these stakes until the wall reaches a height of 2'. Once complete the bender board fence wall should be at a 15 degree angle to the slope. Once the wall frame is constructed, carefully rake enough soil into the terrace to cover the stem layered base.

Stand in terrace and begin excavation of second row. This process will allow soil from second trench to cover first bender board fencing row.

A goal should be to construct a 2:1 slope, or flatter, between the top of the bender board fence wall and the bottom of the one above.

Move upslope to next terrace alignment and repeat process.

Plant trees and shrubs on terraces. Species mix has been selected by PI, RA, and WSDOT Landscape Architects. Location of installation will be determined by RA and Landscape Architect(s) at WSDOT. PI will review to make sure placement meets slope stability objectives.

Construction

- North Central Region (NCR) Maintenance and the Environmental Office surveyed, staked, and created a topographic map of the site.
- NCR Real Estate Services contacted the landowners and obtained a construction easement for work through April 30, 2000.
- NCR Maintenance opted to use a contractor to excavate the vertical lip of the slope. The contractor removed approximately 11,000 cubic yards of material.
- NCR Maintenance provided traffic control during the 5.5 days of excavation.

Problems and Solutions During Construction

The contractor began working on Monday, November 1, 1999. His crew removed approximately 14 trees near the right of way line, and then attempted to remove the vertical lip of the slope from above. Because of the large amount of volcanic ash and glacial materials, the top soil layer was soft and difficult to excavate. As a result, the front-end loader left deep track marks and began slipping near the slope edge and had to be pulled out by an excavator. The soil disturbance on their property upset the landowners. As a result, the contractor removed his machinery and began working from the base of the slope with an excavator.

Soil below the soft top layer was composed of compacted glacial materials. These compacted materials were hard and required the contractor to use a bucket with teeth to scrape at the "rock-like" material. These conditions lengthened the excavation time beyond the anticipated three to four days.

The Washington Conservation Crew (WCC, hereinafter referred to as "the Crew") arrived on Thursday afternoon, November 4, 1999 while the heavy equipment contractor was still working. However, the contractor had finished excavation on the west end of the site by that time. The Crew spent Thursday setting up their materials. The Research Assistant (RA) used a laser level to stake level terraces. Beginning from the west, the Crew began digging out the terraces with great difficulty. In addition, the Crew could not start from the bottom of the slope because the excavator was working there. Therefore, they began with one of the middle terraces working from the west end of the site. Because of the hardness of the soil, terrace construction took much more time than anticipated. Once the soil was broken up however, it became a fine powder mixed with sand and rounded rocks. This mix of soil materials made walking on the slope difficult.

As the RA and the Crew began trying to construct the bender board fencing as designed, they discovered they could not get the specified wooden stakes into the ground. The RA decided to try ½ inch diameter rebar and to use the wood stakes as the brush layer base. In addition, the bender board material was much thinner and weaker than anticipated. This necessitated a change in the design. Plant plugs had been heeled-in within the right of way and were now frozen. To plant the plugs, the Crew chief thawed the plugs and set them between the brush layer every 3 feet where they froze again.

When the WSDOT Landscape Designer, hereinafter referred to as the Landscape Designer, arrived on Sunday, November 7, 1999 approximately 110 feet of bender board terrace 7 boards high had been constructed and approximately two-thirds of the slope had been excavated back to 1 ½ (H):1 (V).

On Monday, the heavy equipment contractor returned to finish the excavation on the eastern end of the site and the Crew continued constructing the level terrace. The Landscape Designer had the Crew leave the terrace and had the excavator operator backfill the terrace with excavated material. The operator was very careful and worked to shake out boulders before he placed the soil behind the bender board fencing. Immediately after backfilling, the terrace looked good. However, three hours later, sections of the terrace had warped out of alignment in a slow deformation. The Landscape Designer had the Crew remove the soil down to a depth of less than 1 foot in an attempt to halt the bending of the rebar and the breaking of the bender board material. The Crew also began repairing the damaged area, including the landowner's property. Repair work included raking, seeding, and planting.

Planted on the landowner's property were:

Service berry (Amelanchier alnifolia)	10
Snow berry (Symphoricarpos albus)	20
Blue Elderberry (Sambucus cerulea)	5
Mock Orange (Philidelphus lewisii)	5
Ponderosa Pine (Pinus ponderosa)	50
Squaw currant (Ribes cereum)	10
Native seed mix	10lbs

Even after attempting repairs on the bender board fence, the Crew could still feel the brush layer on the base of the terrace moving and hear bender boards cracking. The Crew leader did not feel that ½ inch rebar had enough strength to be driven into the soil without bending. The Landscape Designer consulted with the PI by phone and a decision was made to halt Crew work on the site at the end of the day on Monday, pending a site visit by the PI and WSDOT technical advisors. The Landscape Designer was also concerned by the large amount of rebar going into a soil bioengineering project.

The Contractor completed excavation of the slope face by noon on Tuesday, November 9th.

Further hand construction was delayed until after the first week in December when the PI, the OSC Roadside and Site Development Manager, and Department of Ecology Soil Scientist Mark Cullington could examine the slope conditions. They made the on site decision to continue using rebar to reinforce the terraces and to adjust bender board structures from two feet to a one foot height (3 boards instead of 6).

Construction resumed with a different Crew in mid December. The RA and the Crew made an additional decision to discontinue weaving the bender board through the rebar because the bender board was breaking. The poor quality bender board was thin and had many knots. In addition, the gaps in the fencing, created by the weave, allowed soil to erode out from the bender board face. Instead, they had the soil hold the boards against the rebar. This adjustment also held the soil in place.

Biosolid Application

In addition to reshaping the slope to 1 ½ to 1 and constructing bender board fencing terraces, the PI recommended biosolid application to increase soil moisture holding capacity and improve soil nutrient levels. The objective was to accelerate native plant establishment and provide long-term site recovery.

Mark Cullington prescribed a Class-A-biosolid and fir-compost mixture for the slope to provide the soil and native plants with an ideal carbon to nitrogen ratio. Class A biosolids undergo an additional process to kill pathogens. The biosolid industry is highly regulated. Cullington developed the application formula in his Master's thesis in Soil Science at the University of Washington. In addition Cullington states that a high carbon to nitrogen ratio (C:N) suppresses weeds. The addition of Class A biosolids improves the moisture holding capacity of mineral soil and is especially beneficial in arid climates. (Cullington's worksheet is found as Appendix F).

GroCo compost was blown onto two-thirds of the slope on December 22, 1999. The prescription was for a very fine layer, of approximately 3/4 inch, to cover the slope. Due to the high moisture content of the compost and weight restrictions, the contractor could not haul all of the compost that he had anticipated. This high moisture content also caused the blower to lay on a thicker cover (but less than 2") and, therefore, ran out of compost before covering the entire site. Because of cost and distance, the team decided to use the uncovered area as a control.

The prescription also required incorporation of the biosolids into the soil immediately upon application. This was not done until the terraces were constructed, and only in the terrace itself. Due to the cemented soil conditions of the substrate, the RA considered that it would add several weeks to the workload of the crew. Where soils were pliable, the crew did incorporate the soil amendments and in the terraces, where the crew chipped off mineral soil with pickaxes to fill the terraces, the amendment was also incorporated.

The Crew stated there was a large difference in the ability to construct the terraces and pound in the rebar after the application of the compost. The soil was much easier to work with after the compost application.

Terrace Construction

The Crew continued to construct the terraces and bender board fencing until the ground froze too deeply to work. They quit for the season on January 13,1999. The photo below shows the site at that time.

Figure 5. End of season - January 13, 2000

The Landscape Designer checked the site on March 15, 2000 to determine if the soil had thawed and to check for disturbance to the site during winter. Without snow mixed into the soil, the soil had settled, allowing some of the boards to fall back onto the terrace. This can be seen in Figure 6. With the addition of water, areas on the control section had liquefied and moved down slope. However, where compost had been applied, there was no visible movement of soil.

Figure 6. Status before Spring construction - March 15, 2000

Work resumed on April 6, 2000 with the original crew. This crew worked an 8-day shift. The Crew completed the planting and constructing of the 1875 feet of terraces by April 13, 2000.

Planted within WSDOT right of way:

Service berry (Amelanchier alnifolia)	155
Snow berry (Symphoricarpos albus)	155
Blue Elderberry (Sambucus cerulea)	350
Mock Orange (Philadelphus lewisii)	160
Basin Big Sage (Purshia tridentata)	450
Antelope Bitterbrush (Artemis tridentata tridentata)	450
Rubber Rabbit Brush (Chrysothamnus nauseosus)	450
Ponderosa Pine (Pinus ponderosa)	950
Squaw currant (Ribes cereum)	190
Antelope Bitterbrush (Purshia tridenta)	200

The RA returned to the site during the last week in April to clean up unused rebar, bender board, and other remaining construction materials. Construction was complete by April 28, 2000.

By the end of June the bender board appeared to have stabilized the surface erosion and grass was growing on all terraces, however, where the composted biosolids were applied, The annual rye was thicker, greener and withstanding drought conditions better than the control section without compost as seen in the photo below. The predominant vegetation on the control section was Idaho fescue.

2000 Monitoring Results

- Trend is improving.
- Slight evidence of continued surface erosion in unvegetated areas.
- Site is showing 43% vegetative cover.
- Survivability of woody vegetation planted as the brush layer base of each terrace varies with position on slope. Possibly related to soil moisture availability, thawing and refreezing, or installation date. Plants installed at the base of the structures:
    - Terraces 1-5 showed 40% survival.
    - Terrace 6 showed 75% survival.
    - Terrace 7 showed 70% survival.
    - Terrace 8 showed 75% survival.
    - Terrace 9 showed 60% survival.
    - Terrace 10 showed 80% survival.
- Native woody vegetation survivability planted on top of the terraces:
    - Uniform groundcover of native plants – 15% overall.
    - Uniform survival of native plants – 70% overall.
    - Uniform survival of native plants (Ponderosa Pine sp.) – 90% overall.
    - No survival difference in first 6 months in woody vegetation between areas with/without compost.
    - Marked increase in vigor in horizontally planted vegetation with compost added to area.

As of October 2000, trees planted on the landowners' property were green, as seen from below, and grass and trees were growing in the soil disturbed by the bobcat.

Figure 7. Grass communities differ with biosolids

Long-term monitoring will allow WSDOT to determine long term slope stability and to further understand the relationship between native plants, native soil, and biosolids. The status of this site in July 2000 is shown in Figure 8.

Figure 8. Chelan, July 20, 2000

Lost Creek, SR 101, MP 174

Regional Geology

The project area is in the Hoh River valley, on the western flanks of the Olympic Peninsula. The Hoh River is one of the major river valleys originating in the interior of the Olympic Mountains. Bedrock consists of interbedded sandstone and siltstone units that originally deposited in a marginally deep marine environment during the Tertiary (5 to 35 million years ago). These deposits were subsequently tectonically folded and faulted.

The earliest and most extensive glacier occupied the Hoh valley during the mid or late Pleistocene (20,000 to 750,000 years ago). The glacier flowed westward across a landbase that extended beyond the present day coastline. Glacial deposits are found on Mount Hoh, north of the mouth of the river, at an elevation of 1200 feet, indicating that the existing Hoh River valley was once probably filled with glacial deposits.

West of the project area, near the coast, massive and laminated clay deposits have been observed. These deposits suggest stagnation of the Hoh glacier, with the accompanying lake formation in the area occupied by the terminal lobe. This was the last glacier to reach this far west of the Hoh River Valley. Peat bogs north and east of the project area are associated with younger glacial lobes. Alpine glaciers are presently active on the slopes of mount Olympus (7950 foot elevation); the terminus of the Hoh Glacier was at an elevation of 3940 feet in 1955.

Site Geology

Thick glacial deposits that include lacustrine silts/clays and outwash silty sands and gravels are the dominant soils within the project limits. These deposits, left by the alpine glaciers that originated in the Olympic Mountains during the Pleistocene, include a thick sequence of laminated and massive silts and clays, similar to those identified along the present day coastline at the mouth of the Hoh River. These clays are thought to have been deposited in a glacial lake that formed from the stagnation of the Hoh River glacial lobe. Underlying the lacustrine deposits is a sequence of over-consolidated advanced outwash consisting of silty sands and sandy silts with gravels and glacial tills.

Climate And Moisture

This northwestern Washington site on the Olympic Peninsula receives an average of 119.5 inches of precipitation per year. Snowfall averages 13.6 inches per year falling between December and April with the greatest average depth of 5.6 inches in January. Average maximum temperature is 72.4º F in August and average minimum temperature is 33.5º F in January. Further climate information can be found at:

http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wafork

Existing Vegetation

Existing vegetation on site consisted of a cover of annual rye grass that had been seeded to prevent erosion.

Opportunities and Constraints

This site is part of a much larger road project. The project area had soil conditions that presented different challenges than those of the Chelan and Raymond project sites. For example, heavy marine clay soil on site, naturally dense material, had been further compacted by heavy equipment use during roadway construction.

The Olympic Region Landscape Architect, requested that the Lost Creek site be included in the soil bioengineering research project. The road construction project provided additional funding for roadside work on that site.

This west facing, 180 feet long by 86 feet high slope has ample rainfall. There is a source of willows nearby to aid in constructing the willow walls and brush layers.

The slope had rills and gullies and a shallow rapid landslide with a head scarp near the top of the cut slope. The dense and heavily compacted marine clay presented challenges to all involved, especially the Crews. Prior to the start of the research project, the geological engineer and project manager had placed a rock apron at the base of the slope to counter-weight the slope and to prevent further movement.

Two parallel lines of hay bales had been placed on the slope, approximately along the contours. These had apparently slipped and the resulting downward slope of the bales was channeling surface water to the end of the hay bale row and in addition, water was seeping from between the bales. Exit points of these, concentrated water flows and resulted in small rill and gully formations.

Design Solution

The Lost Creek project was divided into three sub-sites, Site 1, Site 3, and Site 5. Locations of these sites are shown in Figure 9.

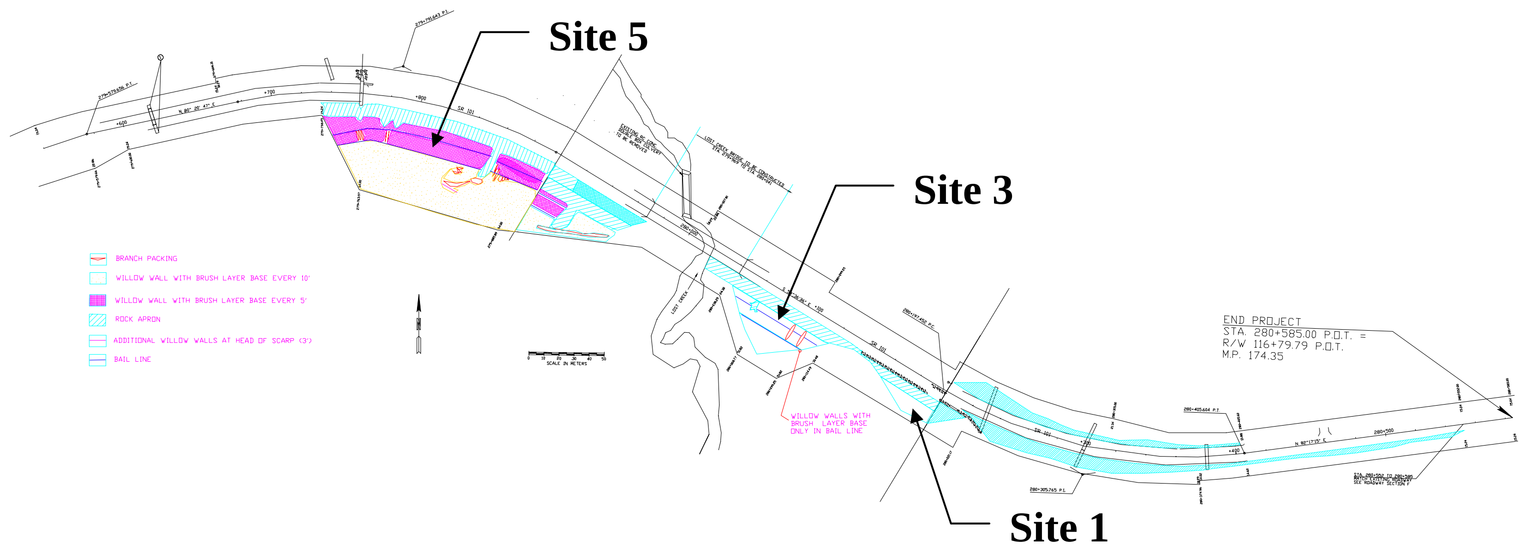

Figure 9. Lost Creek Project Areas

The PI's original design had techniques for all three sites. Her original prescription for Lost Creek follows:

Lost Creek Project Objectives

Site 1 (Sections A, B, C, and D)

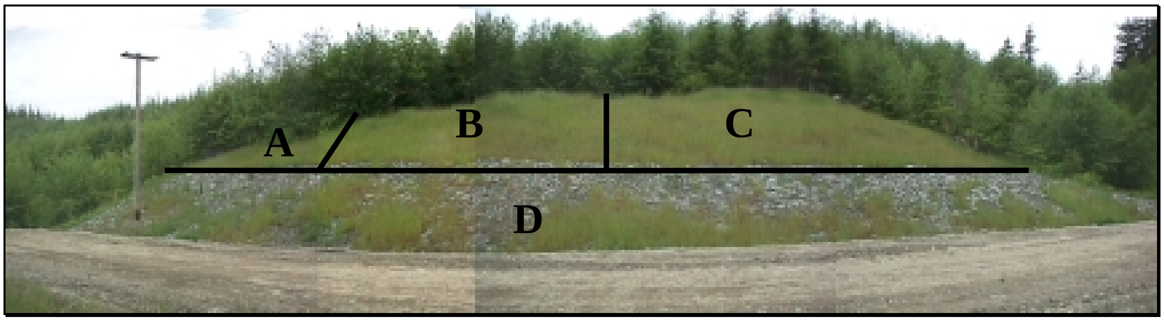

Figure 10. Site 1

Site 1 - Section A

Grasses were effective in stabilizing surface erosion. To maintain surface stability and to prevent shallow rapid landsliding:

Plant trees (20%) and shrubs (80%) at minimum of 4 foot x 4 foot spacing. Species mix has been selected. RA and WSDOT Landscape Architects will determine placement and spacing.

Benefit:

- With root development, increases soil strength and slope stability

Site 1 - Section B

Grass minimized surface erosion. To maintain stability and prevent further surface erosion and shallow rapid landsliding:

Create planting "islands" by constructing willow fences.
Dimensions: 10 foot length and 2 foot height or 5 foot to 6 foot length and 2 foot height. Use 3 foot to 4 foot long willows for stakes to support fencing. Follow instructions in attached technical manual. Once constructed, fill behind *willow fence* with soil (preferably a silt loam). Plant shrubs and small trees (i.e. dogwood) within these terraces.

Benefits:

- Reduces slope angle
- Reduces surface erosion (rills and gullies)
- Traps sediments
- Captures and utilizes both surface and subsurface water
- With root development, increases soil strength and slope stability

Site 1 - Section C

Grass minimized surface erosion. Within Site 1, Section C experienced the highest level of surface erosion. This erosion was caused by overland flow and insufficient plant cover and root development. To maintain stability, inhibit additional surface erosion, and prevent shallow rapid landslides:

> Create planting "islands" by constructing *willow fence* and *willow fences with a brush layer base*. As noted on the design, locate the *willow fence with a brush layer base* above rocked gullies. Once constructed, fill behind *willow fence with a brush layer base* with soil (preferably a silt loam). Plant shrubs and small trees (i.e. dogwood) within these terraces.

Benefits

- Reduces slope angle.
- Reduces surface erosion (rills and gullies).
- Traps sediments.
- Captures and utilizes both surface and subsurface water.
- With root development, increases soil strength and slope stability.
- Slows water movement through sand layer.
- *Willow fence with a brush layer base* provides additional slope protection for critical areas above gullies.

Plant trees and shrubs throughout Sections A, B, and C. Species mix has been selected by PI, RA, and WSDOT Landscape Architects. Location of installation will be determined by RA and Landscape Architect(s) at WSDOT. PI will review to make sure placement meets slope stability objectives.

Site 1 - Section D

To mitigate erosion, a rock apron was placed at base of slope. To complement buttressing effect:

> Install live stakes in rock apron. Use stems 1.5 inches to 3 inches in diameter and 2 feet to 3 feet long. Space 2' to 3' apart and tamp into the ground at right angles to the slope. Four-fifths of the stem should be installed into soil. Firm soil around the stem. Trim any splits. If needed, use an iron bar to pilot a hole.

Benefit:

- Root systems form a mat which strengthens the soil and removes excess slope moisture.

LOST CREEK
Site 3 (Sections A, B, C, and D)

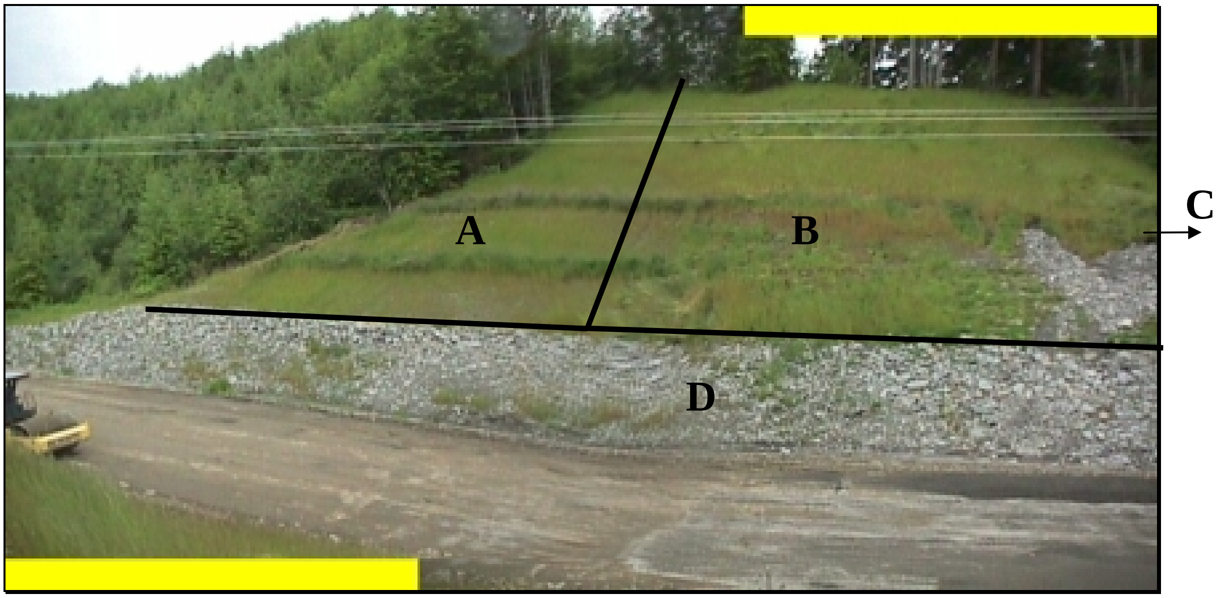

Figure 11. Site 3

<u>Site 3 - Section A</u>
Grasses were effective in stabilizing surface erosion. To maintain surface stability and to prevent shallow rapid landsliding:

- Remove all hay bales and rake smooth trapped silts.
- Plant trees (30%) and shrubs (70%) throughout Section A. *Use predominantly (90+%) shrubs in terraced areas behind willow fence.* Plant species have been selected and approved. RA and WSDOT Landscape Architects will determine placement and spacing (minimum 4'x4'). PI will review to make sure placement and spacing meets slope stability objectives.

Benefit:

- With root development, increases soil strength and slope stability.

Starting above rock apron, construct continuous row of *willow fence.*
Dimensions: continuous length and 2 foot height. Use 3 foot to 4 foot long willows for stakes to support fencing. Additional instructions can be found in the soil bioengineering technical manual. Once constructed, fill behind *willow fence* with soil (preferably a silt loam).

Plant shrubs and small trees (i.e. dogwood) within these terraces. RA and WSDOT Landscape Architects will determine placement and spacing (minimum 4'x4'). PI will review to make sure placement and spacing meets slope stability objectives.

Benefits:

- reduces slope angle
- reduces surface erosion (rills and gullies)
- traps sediments
- captures and utilizes both surface and subsurface water
- with root development, increases soil strength and slope stability

Site 3 - Section B

Grasses were effective in stabilizing surface erosion of upper B section. Below this upper section, however, grasses had minimal effect in preventing erosion. Within Site 1, Section C experienced the highest level of surface erosion (rills and gullies). This erosion was caused by overland flow and insufficient plant cover and root development. To maintain stability, inhibit additional surface erosion, and prevent shallow rapid landsliding:

- Remove all hay bales and rake smooth trapped silts.
- In the upper B section, plant trees (40%) and shrubs (60%). Species mix has been selected and approved. RA and WSDOT Landscape Architects will determine placement and spacing (minimum 4'x4'). PI will review to make sure placement and spacing meets slope stability objectives.

Benefit:

- with root development, increases soil strength and slope stability

Starting above rock apron, construct continuous row of *willow fence with a brush layer base.*

Dimensions: continuous length and 2 foot height. Use 3 foot to 4 foot long willows for stakes to support fencing. Four-fifths of length of brush layering willows should be buried within the terrace. Once constructed, trim any excess. *The more stem exposed to air, the more moisture is lost for critical root development.* Additional instructions can be found in the soil bioengineering technical manual. Once constructed, fill behind *willow fence with a brush layer base* and *willow fence* with soil (preferably a silt loam). Plant shrubs and small trees (i.e. dogwood) within these terraces. RA and WSDOT Landscape Architects will determine placement and spacing (minimum 4'x4'). PI will review to make sure placement and spacing meets slope stability objectives. *Note: as noted in the drawing, the upper row has a small section of willow fence.*

Benefits:

- reduces slope angle
- reduces surface erosion (rills and gullies)
- traps sediments
- captures and utilizes both surface and subsurface water
- with root development, increases soil strength and slope stability
- *willow fence with a brush layer base* provides additional slope protection

Construct "live gully repairs" in all gullies, except the one already filled with rock. Use willow stems 1 inch to 2 inch diameter and length determined by depth of gully. Additional instructions can be found in the soil bioengineering technical manual.

Install live stakes in rocked gully. Use stems 1.5 inches to 2.5 inches in diameter and 2 feet to 3 feet long. Space 2' to 3' apart and tamp into the ground at right angles to the slope. Four-fifths of the stem should be installed into soil. Firm soil around the stem. Trim any splits. If needed, use an iron bar to pilot a hole.

Benefit:

- Root systems form a mat which strengthens the soil and removes excess slope moisture.

Plant trees (30%) and shrubs (70%) throughout Section B (excluding rocked gully). *Use predominantly (90+%) shrubs in terraced areas behind willow fence with a brush layer base and willow fence.* Species mix has been selected and approved. RA and WSDOT Landscape Architects will determine placement and spacing (minimum 4'x4'). PI will review to make sure placement and spacing meets slope stability objectives.

<u>Site 3 - Section C</u>

Grasses were effective in stabilizing surface erosion of upper C section. Saturated soils, however, led to small shallow rapid landslide located in center C section. To inhibit area from enlarging and stabilize feature:

Remove all hay bales and rake smooth trapped silts.

Install "branch packing" in shallow rapid landslide. Use willow stems ½ inch to 2 inch diameter. Additional instructions can be found in the soil bioengineering technical manual.

Benefits:

- reconstruction of slope by refilling localized slump
- retards runoff
- reduces surface erosion (rills and gullies)
- captures and utilizes both surface and subsurface water
- with root development, increased soil strength and slope stability

Starting at rock apron, construct continuous rows of *willow fence with a brush layer base.*

Dimensions: continuous length and 2 foot height on both sides of branch packing area. Use 3 foot to 4 foot long willows for stakes to support fencing. Four-fifths of length of brush layering willows should be buried within the terrace. Once constructed, trim any excess. *The more stem exposed to air, the more moisture is lost for critical root development.* Additional instructions can be found in the soil bioengineering technical manual. Once constructed, fill behind *willow fence with a brush layer base* and *willow fence* with soil (preferably a silt loam). Plant shrubs and small trees (i.e. dogwood) within these terraces. RA and WSDOT Landscape Architects will determine placement and spacing (minimum 4'x4'). PI will review to make sure placement and spacing meets slope stability objectives. *Note: as noted in the drawing, the upper row is a small section of willow fence.*

Benefits:

- reduces slope angle
- reduces surface erosion (rills and gullies)
- traps sediments
- captures and utilizes both surface and subsurface water
- with root development, increases soil strength and slope stability
- *willow fence with a brush layer base* provides additional slope protection

Site 3 - Section D

Install live stakes in rock apron. Use stems 1.5 inches to 3 inches in diameter and 2 feet to 3 feet long. Space 2' to 3' apart and tamp into the ground at right angles to the slope. Four-fifths of the stem should be installed into soil. Firm soil around the stem. Trim any splits. If needed, use an iron bar to pilot a hole.

Benefit:

- Root systems form a mat which strengthens the soil and removes excess slope moisture.

LOST CREEK
Site 5 (Sections A and B)

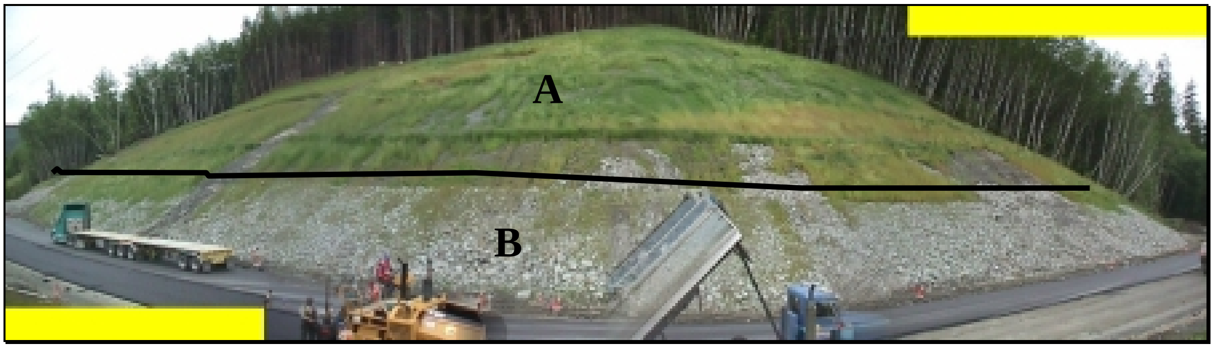

Figure 12. Site 5 before treatment

<u>Site 5 - Section A</u>

Grass minimized surface erosion. Within Site 5, Section A experienced the highest level of surface erosion. This erosion was caused by high rainfall and subsequent saturated soils. This condition led to excess overland flow and draining hay bales. There was insufficient plant cover and root development to maintain slope stability. To inhibit additional surface erosion and shallow rapid landsliding:

- Remove all hay bales and rake smooth trapped silts.
- Create planting "islands" by constructing (*willow fence with a brush layer base*). Once constructed, fill behind *willow fence with a brush layer base* with soil (preferably a silt loam). Plant shrubs and small trees (i.e. dogwood) within these terraces.

Benefits:

- Reduces slope angle
- Reduces surface erosion (rills and gullies)
- Traps sediments
- Captures and utilizes both surface and subsurface water
- With root development, increases soil strength and slope stability
- Slows water movement through sand layer
- *Willow fence with a brush layer base* provides additional slope protection for critical areas above gullies

Install "branchpacking" in shallow rapid landslide. Use willow stems ½ inch to 2 inch diameter. Additional instructions can be found in the soil bioengineering technical manual.

Benefits:

- Reconstruction of slope by refilling localized slump
- Retards runoff
- Reduces surface erosion (rills and gullies)
- Captures and utilizes both surface and subsurface water
- With root development, increased soil strength and slope stability

Plant trees and shrubs throughout Section A. Species mix has been selected by PI, RA, and WSDOT Landscape Architects. Location of installation will be determined by RA and Landscape Architect(s) at WSDOT. PI will review to make sure placement meets slope stability objectives.

Site 5 - Section B

Install live stakes in rock apron. Use stems 1.5 inches to 3 inches in diameter and 2 feet to 3 feet long. Space 2' to 3' apart and tamp into the ground at right angles to the slope. Four-fifths of the stem should be installed into soil. Firm soil around the stem. Trim any splits. If needed, use an iron bar to pilot a hole.

Benefits:

- Root systems form a mat which strengthens the soil and removes excess slope moisture.

Construction

Construction began on Site 3 on October 25, 1999 with one Crew on willow wall construction. The Crew began using branch packing for one gully according to the original design.

Construction on Site 5 began on November 9, 1999 with the uppermost willow wall. The original intention was to use a winch to bring fill dirt up to the top of the slope. The Crew supervisor had safety concerns with that method and decided hand-carrying buckets of soil up the slope was his preferred method. The Crew had successfully used that method on Site 3 for the previous 2 weeks.

Problems and Solutions During Construction

Construction on the Lost Creek site ran concurrently with construction on the Chelan site. The RA managed her time to be on both sites as much as possible during construction. Members of the research team helped on each site in the RA's absence. However, because of other projects, team members in Olympic Region were not able to be at the Lost Creek site at the same time as the RA to discuss ongoing work, this resulted in some communication problems and caused confusion and conflict with Crew time and work assignments.

Because of the compost contractor's busy schedule, compost was applied to Site 3 before willow walls were constructed, causing erosion problems and slippery footing for the Crew. Without the terraces in place, heavy rains washed some of the compost into the ditch and into Lost Creek.

Sandy, rocky waste soils were delivered to the site, and accepted by the RA instead of the Class C topsoil specified by the PI. The steepness of the slope and the heavy materials that were to be transported up the slope were a source of problems. Various methods of bringing topsoil up this slope were suggested, but none were safe enough with the combination of slick clay, compost, and rain. The Crews had to carry soil and rock up the slope by bucket to fill in gullies and construct the brush layers.

The original plan called for willow wall construction in the same general location as existing hay bales. However, the hay bale rows were not level and encouraged runoff beginning from the center of the hay bale row and extending to the edges of each row. This resulted in erosion of material from behind the hay bales and at each end. After consultation with the PI, the Crew was to begin at the highest point of the hay bale row and continue constructing the willow walls level with that highest point. The RA used a laser level to stake all terraces for the Crews with pink flagging tape as seen in Figure 13. At this point, the RA had to leave for Chelan. While she was gone, the Crew did not follow the RA's instructions and continued to construct the willow wall in the straw bale line. The Crew constructed two additional rows of willow wall that were also not level. The Crew did not understand how to keep the terraces level on a convex surface. For example, Figure 13, below, shows the marking tape where the wall should have been constructed above and behind the stakes the Crew placed.

Figure 13. Site 3 - Stakes placed below level terrace marking tape

Due to the amount of surface water received by the gullies on Site 3, the original branch packing design washed out. Additional willow walls were constructed at the head of this gully and the branch packing design was changed to the design seen below.

Figure 14. Branch packing Parallel to Contours

Heavier than normal rains, during project construction, led to increased surface and subsurface water movement, resulting in increased surface erosion. Due to water quality concerns, the Hoh Tribe and Washington Department of Fish and Wildlife (WDFW) shut the project down in December until this erosion and sediment runoff could be stopped and additional sediment control measures were installed or improved.

Site 5 dropped from research project

The Crew supervisor designed a winch system for Site 5. This system was very slow and the amount of time projected to complete the work on Site 5 was out of the scope of the soil bioengineering research project. Because of the size of Site 5 and its complexity and the problems associated with running two projects on the same slope at the same time, Site 5 was dropped from the research project.

Concurrent with this decision, the head scarp on Site 5 began rapidly moving, this rotational failure moved 10-15 feet within a week. A WSDOT geotechnical engineer was brought in, and upon field review, placed this site on WSDOT's list of major erosion sites to be considered for engineering solutions. This confirmed the PI's decision to discontinue soil bioengineering on Site 5.

Construction concluded on Site 3 on January 27, 2000. Native vegetation was planted on Site3 the week of January 24.

Planted on the Forks site:

Mix A	%Mix	# plants
Alnus crispa (Sitka Alder)	3	16.5
Oemleria cerasiformis (Indian-plum)	5	27.5
Mahonia nervosa (Oregon Grape)	6	33
Cornus sericea (Red-osier Dogwood)	14	77
Rubus spectabilis (Salmonberry)	12	66
Amelanchier alnifolia (Serviceberry)	12	66
Salix sitchensis (Sitka Willow)	14	77
Symphoricarpos alba (Snowberry)	12	66
Rubus parviflorus (Thimbleberry)	12	66
Rhamnus purshiana (Cascara)	4	22
Rosa nootkana (Nootka Rose)	4	22
Physocarpus capitatus (Pacific Ninebark)	2	11
Totals	**100**	**550**

Mix B	%Mix	# plants
Alnus crispa (Sitka Alder)	18	99
Oemleria cerasiformis (Indian-plum)	5	27.5
Mahonia nervosa (Oregon Grape)	5	27.5
Cornus sericea (Red-osier Dogwood)	7	38.5
Rubus spectabilis (Salmonberry)	9	49.5
Amelanchier alnifolia (Serviceberry)	4	22
Salix sitchensis (Sitka Willow)	4	22
Symphoricarpos alba (Snowberry)	23	126.5
Rubus parviflorus (Thimbleberry)	4	22
Rhamnus purshiana (Cascara)	4	22
Rosa nootkana (Nootka Rose)	3	16.5
Totals	**86**	**473**

MIX C	%Mix	# plants
Thuja plicata (Western Red Cedar)	25	15
Pseudotsuga menziesii (Douglas Fir)	25	15
Tsuga heterophylla (Western Hemlock)	25	15
Picea sitchensis (Sitka Spruce)	25	15
Totals	**100**	**60**

Figure 15. Site 3 Immediately After Construction

In Figure 16 the top photo shows the site 6 months after construction. The lower photo shows the site prior to construction.

Figure 16. Site 3 Before and After Soil Bioengineering

As of July, the head scarp was stabilizing with grasses, shrubs, trees , and willow structures.

2000 Monitoring Results

- Trend is improving to stable
- No evidence of mass movement or gully erosion.
- Site is showing 95% vegetative cover.
- Brushlayer survivability:
    - Brushlayer structures - 80% show new growth.
    - Willow wall structures – 40% show new growth.
- Survivability of vegetation on terraces:
    - Uniform survival above rock apron – 70% overall.
- Uniform survival within the rock apron – 40% overall.

Raymond, SR 101, MP 60.35

Geology and Soils

Soils on this 591 feet long by 112 feet high east-facing slope are composed of marine sedimentary rocks that are weathered. Small shallow rapid landslides have occurred where these weathered clay layers have left slope sections exposed to water movement. With excess surface and subsurface moisture, these layers slipped and moved downhill into the ditch. To manage stormwater runoff, maintenance activities required clearing of these plugged ditch lines. In doing so, the base of the shallow rapid landslide was undercut, leaving a portion of the area with an exposed vertical face. During the year, the slope would "adjust," move again into the ditch line, leaving a larger head scarp exposed to surface and subsurface water movement.

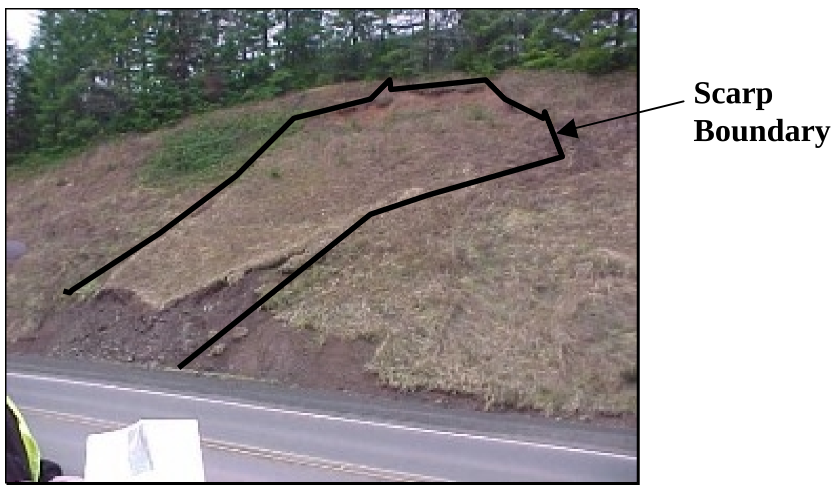

Figure 17. Area of Instability

Climate and Moisture

This southwestern Washington site receives an average of 85 inches of precipitation per year. The site receives very little snowfall. January is the only month that generally receives snow with on average 0.4 inches. No other snowfall is recorded during other months. Average maximum temperature is 72.9º F in August and average minimum temperature is 32.5º F in December. Further climate information can be found at: http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?waraym

Existing Vegetation

Onsite vegetation consisted of a very young community of Douglas fir, red alder, salal, palmate coltsfoot, common horsetail, and sword fern, with a good grass cover. There is a mature Douglas fir, western red cedar, and western hemlock community at the top of the slope which provides ample seed source for plant recruitment. Tree seedlings had been cut from the hillside on a regular basis, however WSDOT area maintenance personnel had not been involved in any tree removal at that site.

Opportunities And Constraints

This large slope, located on an outside curve, just north of the city of Raymond, is highly visible and receives ample rain throughout the year. The local climate and soils were supporting a diverse plant community. Trees and shrubs were needed to stabilize the slope, but were being cut on a regular basis. The PI and RA worked with road maintenance to select trees and shrubs that were acceptable to maintenance personnel.

In addition, WSDOT's chief engineering geologist thought this was a good candidate for a soil bioengineering project because the erosion process of the site involved surface erosion and a shallow rapid landslide. Both these erosion processes fall under the parameters of soil bioengineering techniques.

Design Solution

Raymond Soil Bioengineering Design 12-28-99

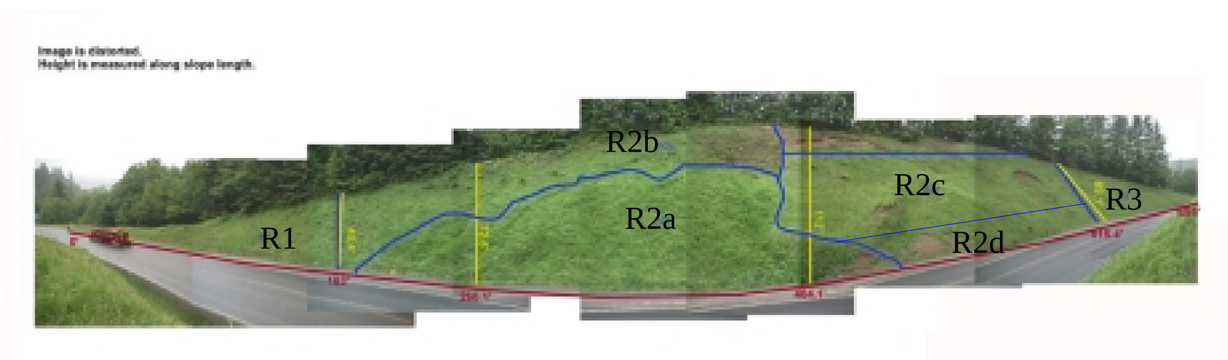

Figure 18. Raymond Research Site with Sub-areas

Area R1 and R3:

Primary focus is aesthetic.

- Plant with recommended mix of vegetation. Install bender board fencing to complement the existing bronze animal sculptures by local artists. Do not excavate a terrace behind the fencing (contrary to usual installation), add fill to create a planting platform. Be sure to mix the added soil with the original slope material.
- Construct cordons

Area R2:

Primary focus is stabilization.

R2a: Plant with approved mix of water-loving vegetation.

R2b: Plant with approved mix of vegetation.

R2c: Soil bioengineering. Starting at 6’ above cribwall at slope base:

- Construct a brush layer 5’ deep across the slope in the area.
- Construct a willow wall with a brush layer base across the slope above the brush layer.
- Alternate these two treatments at a maximum of 10’ intervals up to 75’.
- At 75’ above the cribwall, construct willow walls at 10’ intervals.
- Goal of these treatments: provide slope stability and easy access to planting areas.

R2d: Construct a live cribwall at the base of the slope.

- 183’ to 515.4’ = total length of cribwall (as seen from width markings on photo.
- From 260.1’ to 515.4’ construct cribwall 6’h X 6’w X 255.3’l.
- 77’ on either end, construct cribwall 5’h X 5’w.
- 10’ on either end, construct cribwall 4’h X 4’w.
- Flange ends to blend in with slope and to eliminate any potential “snagging” safety concerns.

Construction

Construction began with region Maintenance personnel using heavy equipment and two WCC crews using hand equipment on February 1, 2000. They began by excavating at the northern end of the site and installing the first cordon. Figure 19 shows the cordon construction after the bottom two logs have been placed in the terrace parallel to the slope.

Figure 19. Cordon Construction

Figure 20 was taken on February 10, 2000. It shows cribwall construction at the end of the first week of construction.

Figure 20. End of first week of construction.

Problems and Solutions During Construction

An email from the RA on February 15, 2000 reads:

> Some excitement here in Raymond this morning. About 80' into the 6X6 section of cribwall, an area approximately 70'W x 90' high began to slide as the excavator was removing the toe. It slid in one piece about 4' vertically in less than 30 seconds. I really hesitate to excavate any more of this area until we have a plan. I instructed the operator to continue to fill in the cribwall that has already been completed (to the right of the slide) as much as possible to counter weight the movement. The current cribwall is about 20' under the slide zone. Additional comments on the movement: the borders of the slide zone on the left is flaking away fairly normally (in response to the oversteepening and removal of the toe), but the one on the right seems to border a fracture area. The border on the right is almost vertical and the two areas are moving independently.

During site preparation for the base of the cribwall, the heavy equipment operator removed a portion of the slope toe the night before. The fresh cut was left unsupported overnight and when excavation resumed the next morning, the slope moved. The slope was oversteepened in the adversely oriented bedrock causing failure of the bedrock and colluvial soils overlying the bedrock. In different material this might now have happened, and if the site had not been excavated and left exposed overnight, this slope movement might have been prevented. For future projects, on sites of this size and with propensity for large movement, however, it is recommended that a slope stability analysis be a part of project design.

Figure 21. Slope Failure

Soil bioengineering work was halted in the area of the slide until an interdisciplinary team of experts could visit the site. On February 16th the PI and research team and the region maintenance supervisor, Mike Whipple, held an interdisciplinary conference call discussing all safety concerns and issues. The group developed preliminary alternatives to be considered for the following day's field review.

On February 17, members of the research team visited the site with two WSDOT engineering geologists to determine the cause and to decide upon a course of action.

The research team recommended, and the PI approved construction could continue but with excavating no more than 10 to 15 feet of the slope toe at any one time. It was also recommended that exposure of personnel to the slope be avoided or minimized. Mike Whipple, Maintenance Area Superintendent, devised a plan to construct the log cribwall frames off site and to install them onsite in modules. No crew members were allowed behind or inside the cribwalls at any time.

The modular cribwall frames were constructed off-site by February 28, 2000. They were installed in two vertical sections so willow branches could be installed between the lifts and soil could be added and compacted with the excavator bucket. Installation can be seen in Figure 22. Each 15 foot cribwall framed section was cabled to the adjacent unit and to the ones above and below it.

Figure 22. Installation of modular live cribwall sections

The live cribwall and cordon construction was completed with these changes, without incident, on March 2, 2000. The Crews finished the Raymond project, with willow wall construction further up the slope and with plantings and straw mulch application, on March 28, 2000. Figure 23 shows the willow walls constructed above the live cribwalls.

Figure 23. Live Cribwall and Willow Walls

The Landscape Architect specified a mixture of cuttings and container plantings of the same species. These will be observed during the monitoring period to see if the cuttings thrive.

Species planted on this site are:

Twinberry (Lonicera involucrata)	50
Salmonberry (Rubus spectabilis)	100
Sword fern (Polystichum munitum)	50
Snowberry (Symphoricarpos albus)	100
Salal (Gaultheria shallon)	50
Scouler's Willow (Salix scouleriana)	50
Red Osier Dogwood (Cornus sericea)	100
Sitka Alder (Alnus sitchensis)	100
Ninebark (Physocarpos capitus or pacifica)	50

Figure 24 shows the entire project after completion.

Figure 24. Completed Soil Bioengineering Research Site

2000 Monitoring Results

- Trend is improving to stable
- No evidence of mass movement or surface erosion.
- Site is showing 95% vegetative cover.
- Structure survivability:
    - Cribwall structure - 90% new growth.
    - Willow wall structures – 30% show new growth.
    - Fascines – 10% show new growth.
- Native woody vegetation survivability:
    - Nursery stock – 80% survival.
    - Woody vegetation cuttings – 80% show new growth.
    - No difference in survival between nursery stock and cuttings of the same species.

FINDINGS AND DISCUSSION

As with most construction projects, each of the three research sites presented complications and unique challenges and resulted in modifications to the original plans.

Chelan

Construction on the Chelan project site began November 4, 1999 and concluded April 19, 2000. The original design had to be changed because we encountered harder than expected sub soil. The principle design changes included substitution of rebar for wood stakes as the upright members of the bender board fencing units and the lowering of the fencing height from 2 feet to 1 foot.

In addition, the PI was concerned that the biosolids were not raked into the parent material as instructed. However, not following her instructions gave us the opportunity to compare three areas within the site. For example, the control area had no biosolid application, a second area had biosolid application that was not raked in, and the third area had biosolid application that was raked in. During the first season, the principle grass species growing in the control area was fescue. Within the area where compost was raked in, rye was the principle grass species the first summer. On the west end of the site, where compost was left on the surface, fescue was also the principle species and it was more vigorous than the area without compost. During the first summer, trees grew at the same rate throughout the project slope. Shrub growth appeared to correlate to shading – there was more growth where there was shading.

Table 1 provides a summary of the costs for the Chelan project:

Item	***Cost***
Total WCC Crew Time (10.5 weeks)	$26,250.00
Total Materials Cost	$ 3,945.24
Vegetation Costs	$ 2,640.80
Biosolid Application	$ 1,329.00
RA’S Salary and Per Diem	$ 5,522.00
Contractor/Excavation Costs	$ 7,296.10
Total Cost for Project	$46,983.14
Cost per Square Foot	$ 1.96

Table 1. Chelan Costs

Lost Creek

Construction on the Lost Creek project began October 25, 1999 and concluded December 27, 1999. The original design was altered because heavy rains caused springs to flow from areas in the slope, which drained directly through the conventional brush layers placed perpendicular to the slope contour, as seen in Figure 25.

Figure 25. Brushlayers failed when placed perpendicular to slope.

The design was changed so the brush layers were laid parallel with the slope contour to better manage surface flow. This is shown in Figure 26.

Figure 26. Branch packing parallel to slope contours.

Secondly, mineral soils were used in place of specified topsoil and compost was prematurely applied to the project site and prior to PI and RA approval. In addition, the geotechnical engineer and the PI recommended removing Site 5 from the research project because of a reactivated deep-seated rotational failure. This and other problems. Led to the situation of the site exceeding the scope and time frame of the research project.

Table 2 provides costs for the Lost Creek project.

Item	***Cost***
Total WCC Crew Time (8 weeks)	$20,000.00
Total Materials Cost	$ 210.82
Vegetation Costs	$ 1,131.64
Biosolid Application	$ 3,200.00
RA Salary and Per Diem	$ 3,712.00
Geotechnical Rock Apron	$15,020.00
Total Cost for Project	$30,774.46
Cost per Square Foot	$ 3.55

Table 2. Lost Creek Costs

Raymond

Construction on the Raymond project began January 31, 2000 and concluded March 23, 2000. The original design was altered because underlying sheets of bedrock failed when the toe was removed and left overnight without support. The principal design change was the off site construction of the log cribwalls and their installation as modular 15 foot units. The slope was excavated in 15 foot sections, the cribwall units placed, cabled to the adjoining unit, willow stakes placed, and the cribwall backfilled in approximately 2 hours per unit. This change allowed the project to continue and with minimum exposure for the Crew to the unstable slope condition and with minimum time for the undercut slope to strain without a stabilized toe.

Additionally, the design had to be changed because the delivered logs were larger than those specified in the drawings. Rebar was used to link the logs instead of ¼” by 8” long spikes. Cables were used to link the cribwall sections that had been constructed off site. Spaces between the logs were larger than originally designed and allowed for greater soil exposure than was intended in the original design. The larger logs, however, did result in use of fewer logs.

Table 3, below, is a summary of the time and materials costs for the Raymond project:

Item	***Cost***
Total WCC Crew Time (10 weeks)	$25,000.00
Total Materials Costs	$ 5,996.32
Heavy Equipment Rental	$ 7,296.08
Vegetation Costs	$ 1,820.00
RA's Salary and Per Diem	$ 4,212.00
SWR Costs	$ 185.25
Total Cost for Project	$44,509.65
Cost per Square Foot	$ 1.59

Table 3. Raymond Costs

COST/BENEFIT ANALYSIS[1]

Purpose

The purpose of benefit/cost analysis was to:

- Assist decision-makers in justifying the promotion of soil bioengineering as a cost-saving and environmentally friendly alternative for surface erosion and shallow rapid landslide stabilization.
- Evaluate cost-efficiency and help select the best alternative from traditional engineering treatment, soil bioengineering, or their combinations.
- Educate WSDOT personnel, other land managers, and the public about integration of economic efficiency and environmental values of soil bioengineering.

Soil bioengineering, as an alternative for roadside management offers, but is not limited to the following benefits:

- Increase Practicability:
    - Useful on sensitive or steep sites
    - Installed in construction slow seasons
    - Long term soil stability
- Provide Cost Saving:
    - Reduce/Eliminate Maintenance
    - Treat erosion earlier & avoid costly solution
    - Use indigenous plant species

[1] Research analyst: George Xu, Ph.D. WSDOT Environmental Economist

- Improve the Environment:
  - Less soil disturbance to the site and adjoining areas
  - Improved air and water quality
  - Improved landscape and habitat values

Methodology

Cost Assessment

Soil bioengineering treatment costs were actual costs for achieving the designed functions.

Hypothetical traditional treatments costs were estimated based upon phone interviews with WSDOT personnel. They were asked what treatments would be used on the three sites if the department had chosen to treat those slopes using traditional treatment. Costs for those treatments were estimated using bid tabs of nearby projects.

For the Chelan site, the traditional engineering treatment would be to excavate the slope back to a 1 ½ H to 1V angle (Moses) and to apply a hydroseed mix with tackifier to control surface erosion (Tveten, Belmont, and Salisbury).

The traditional engineering treatment for Lost Creek involves treating surface water runoff by collecting runoff at the base of the slope in a quarry spall-lined ditch, moving it under the road in a culvert, and into a detention pond to allow sedimentation. (Witecki, Tveten, Salisbury) The fine, compacted soils on the site resist infiltration and large amounts of overland flow contributed to sedimentation problems during and post road construction. (Lewis) A rock apron was installed on this site to prevent slope movement prior to the research project. Its cost is included in the estimated cost for the non-soil bioengineering treatment.

For the Raymond site, the traditional engineering treatment would be to construct a rock buttress similar to one directly across the highway from the project location. It should be noted that typically a soil stability analysis would be needed to determine the size (mass) of a rock buttress (Moses). Without this study, the size of proposed buttress was estimated at the same volume of the constructed cribwall. It should also be noted that in this example, the purpose of the rock buttress is only to add a vertical component to the slope by which the toe of the slope is elevated to reduce overall steepness and to provide support for eroding materials. A bench would have to be excavated for placement of the rock buttress.

Benefit Assessment

Soil bioengineering was evaluated as an alternative investment option in this benefit cost analysis. Soil bioengineering projects were designed to produce the same roadside stabilization effect as their traditional alternatives. Therefore, the cost saving resulting from adoption of soil bioengineering projects was evaluated as a net benefit. The benefit of stabilization was assessed using cost pricing method for both soil bioengineering and traditional alternatives.

Environmental benefits generated by the projects were assessed using benefit transfer approach that is a common method in environmental economic assessment when time and resources are limited. Environmental benefits were derived based on the results and findings of similar studies (Sotir 2001; EPA 1998, California Department of Transportation 1998; McPherson & Simpson 1999) and transferred values were adjusted according to the changes of key factors.

Trees remove pollutants from the atmosphere and also eliminate or reduce the source of pollution. Pollutants deposited and particulates intercepted include Ozone, NO2, and PM10. Air pollutant uptake benefits were assessed based on number of trees planted, growth rate and canopy cover information, unit value of pollutant uptake, and effectiveness. Effectiveness was determined by evaluating source elimination and pollutant uptake effects.

Stormwater runoff reduction benefits were assessed using runoff coefficients of different land covers, local hydrograph, sediment treatment requirement, and unit value of stormwater treated.

Carbon sequestration benefits were assessed based on the assumption that 80 percent of carbon will be released at the end of life cycle (removal of trees) and unit value of carbon sequestration derived by other studies.

There are many other environmental and aesthetic values are associated with the soil bioengineering treatments. They are not assessed because of either intangibility or the time constraints.

Comparability

Three key factors were considered to ensure the comparability of both benefits and costs. They are effectiveness, life cycle, and discounting.

1. Effectiveness

The benefit of soil bioengineering alternatives should be adjusted in terms of effectiveness of their functions. Soil bioengineering techniques are assumed to have the same effective as traditional engineering methods, when used on appropriate sites for roadside stabilization and the treatment of runoff. However, soil bioengineering, since it uses living plants, has additional benefits that rock and cement do not have. For example, plants can provide air pollutant uptake and carbon sequestration. Plants also provide visual benefits such as distraction screening, guidance and navigation enhancement, and they are aesthetically pleasing. When we applied benefit transfer to evaluate environmental benefits, effectiveness for related functions were assessed based on the different conditions between the original study sites and the sites of this study.

The following table shows the assumptions of effectiveness used in this study.

Effectiveness Assumptions Used in This Study

	Roadside Stabilization	Runoff Treatment	Air Pollutant Uptake	CO2 Sequestration
Chelan	100%	100%	34%	100%
Raymond	100%			
Forks	100%	50%	9%	100%

Figure 27. Effectiveness Assumptions

Benefits for runoff treatment, air pollutant uptake, and CO_2 sequestration for Raymond site are not shown. Because the slope was previously vegetated, those functions were already taking place and no improvement is assumed.

Air pollutant uptake effectiveness for soil bioengineering treatments were determined by two factors: seriousness of air pollution and air pollutant-taking capacity of the alternative.

Data sources for the effectiveness analysis include (Sotir 2001, EPA 1998, California Department of Transportation 1998, McPherson & Simpson 1999)

2. Life Cycle Analysis

Life cycle analysis is used to adjust costs in terms of life cycle of the both traditional and soil bioengineering alternatives. The initial investment for a soil bioengineering project can be higher than a traditional engineering technique, especially if no structure or heavy riprap is involved. However, the project life is historically longer with a living system, such as soil bioengineering. Therefore the annualized life cycle cost is lower with soil bioengineering since those systems can work at least 50 years (Sotir 2001, Schiechtl 1980). Life cycle costs for soil bioengineering techniques were analyzed using a cycle of 30 years. Twenty year life cycle was used for traditional alternatives for roadside management.

3. Discounting

Discounting was used to make benefit and cost streams over the project life comparable. In other words, it makes the benefits of different times comparable. The discounting rate used in the analysis is four percent.

Data Sources

The following are major data sources used in this analysis.

- Actual costs
- Estimated costs using historic data
- Environmental Protection Agency (EPA)
- USDA Forest Service
- California Department of Transportation
- Experts' opinions

Findings

Costs

The costs for three sites were summarized in the following table:

Summarized Costs of Traditional Treatments								
		Chelan		**Raymond**		**Forks**		**Sum**
Capital Cost	$	12,451	$	130,910	$	45,130	$	188,491
O&M	$	2,990	$	-	$	22,745	$	25,734
Total Cost	$	15,441	$	130,910	$	67,875	$	214,225
Annualized Cost for Life Cycle	$	772	$	6,546	$	3,394	$	10,711

Figure 28. Costs of "Traditional" Treatments

Summarized Costs of Soil Bioengineering Treatments				
	Chelan	**Raymond**	**Forks**	**Sum**
Capital Cost	$ 46,983	$ 44,510	$ 30,774	$ 122,267
O&M	$	$	$	$
Total Cost	$ 46,983	$ 44,510	$ 30,774	$ 122,267
Annualized Cost for Life Cycle	$ 1,566	$ 1,484	$ 1,026	$ 4,076

Figure 29. Soil Bioengineering Treatment Costs

Benefit Composition

The benefits were broken into the categories seen in the following figure. (RM stands for Roadside Maintenance). Cost saving is the dominant source of the benefits of soil bioengineering projects compared to traditional alternatives.

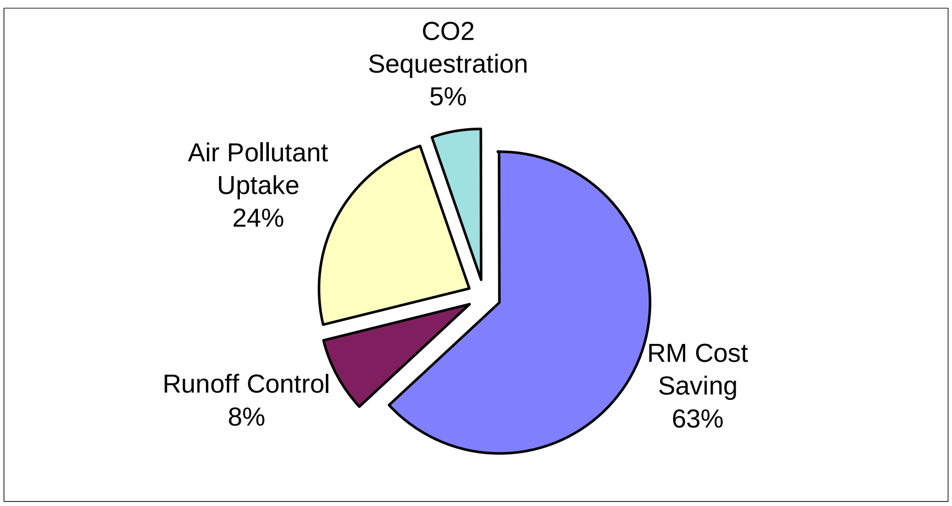

Figure 30. Benefit Composition

Cost Saving

Initial construction costs for the three soil bioengineering research sites are shown below as they compare to the traditional engineering treatment that would have been used if WSDOT had chosen to stabilize those slopes.

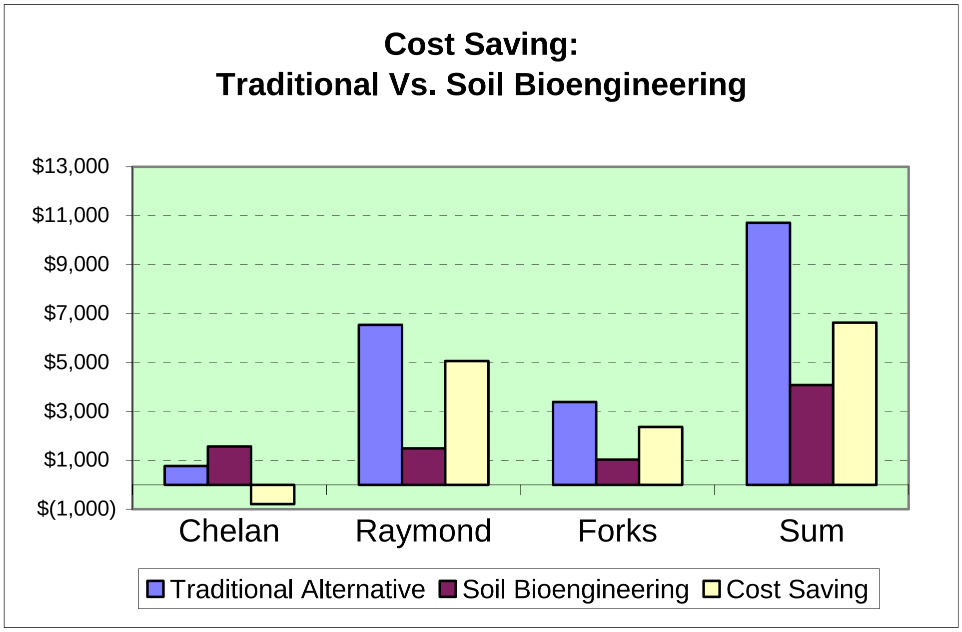

Figure 31. Initial Construction Cost Saving

Annualized cost, which includes maintenance savings, between soil bioengineering and traditional engineering shows that all three projects were cost effective.

Benefits

The following figure shows the benefits of the soil bioengineering project.

Assessed Benefits: Soil Bioengineering Alternatives						
	CHELAN		RAYMOND		FORKS	
	Life Cycle Benefit	Annualized Benefit	Life Cycle Benefit	Annualized Benefit	Life Cycle Benefit	Annualized Benefit
Total Benefit:	$67,499	$2,250	$133,404	$4,447	$85,622	$2,854
Stabilization	$15,441	$515	$133,404	$4,447	$67,872	$2,262
Runoff Control	$1,638	$55			$13,338	$445
Air Pollutant Uptake	$43,837	$1,461			$1,020	$34
CO2 Sequestration	$6,583	$219			$3,391	$113
Total Costs:	$46,983	$1,566	$44,510	$1,484	$30,774	$1,026
Net Benefit:	$20,516	$684	$88,895	$2,963	$54,847	$1,828
B/C Ratio	1.44	1.44	3.00	3.00	2.78	2.78

Figure 32. Assessed Benefits of Soil Bioengineering Alternatives

B/C Ratio

The benefit to cost ratio is a means of comparing the dollar figure of benefits derived in relation to the cost of a project. The benefit/cost figures include annualized maintenance cost savings. For each dollar spent on this soil bioengineering project, $1.44 benefit was generated at Chelan site, $3 at Raymond site and $2.78 at Forks site.

Compared with the traditional treatments, for each dollar invested in roadside stabilization using the soil bioengineering alternative $1.01 more benefit than traditional alternative was generated ($2.41 – $1.40 = $1.01).

B/C Ratio	CHELAN	RAYMOND	FORKS	Average
Soil Bioengineering	1.44	3.00	2.78	2.41
Traditional Alternative	1.95	1.00	1.26	1.40

Figure 33. Benefit/Cost Ratio

CONCLUSION AND RECOMMENDATIONS

The following conclusions are based on experience acquired during the design and construction phases of this project.

1. Soil bioengineering projects can be constructed and used successfully on WSDOT projects. All three project sites are revegetating and appear stable. They are viable alternatives for stabilizing upland slopes.
2. When technically feasible, soil bioengineering alternatives can be adopted to produce equal or better economic and environmental results compared to the traditional geotechnical solutions alone. The average benefit to cost ratio in this study is 2.41. It is a favorable economic alternative in roadside management.
3. Incorporated (“raked in”) composted Class A biosolids used on the Chelan site correlate to enhanced grass growth.
4. The addition of composted Class A biosolids increased soil workability and influenced the grass community composition.
5. On project areas with potential for mass wasting, such as sections of both Lost Creek and Raymond sites, an engineering slope stability analysis should be performed. This was done on the Lost Creek site.
6. Woody vegetation planted as 10-inch plugs had an increased survival rate as compared to bare root plants at the Chelan site. Purchasing plugs or containerized plants in Central and Eastern Washington may increase survival rates.

7. The creation of terraces at the Chelan site allowed for enhanced plant growth. Little vegetation is growing on the steep areas between the terraces. This correlates to the conditions onsite before this research project. While initial costs for soil bioengineering are higher than slope flattening and hydroseeding (the "traditional" approach), more vegetation is establishing with the soil bioengineering method. This allows for higher long-term environmental benefits, such as air and water quality improvements.
8. Communication and education are important components of any "new" technology.
9. An interdisciplinary team, continuously involved in the project, is critical for success.

RECOMMENDATIONS:

- Further monitoring is recommended to analyze the long-term stability of these slopes. This monitoring must include observations by local maintenance personnel and will be carried out by the OSC Roadside and Site Development Office.
- Further application of composted biosolids using a carbon-to-nitrogen ratio formula can be used on other projects to reduce weed competition, reduce soil erosion, and enhance native plant growth. It is critical to incorporate (rake in) these biosolids as they are being applied.
- Further research into the cost/benefit ratio of soil bioengineering techniques needs to be carried out in various climate and soil regimes.
- Research projects should have one project manager. That person, preferably the PI, should be in charge of authorizing all expenses and tracking the budget. The PI should do a thorough cost estimate before beginning work. Allow additional dollars for contingencies.
- Further study is needed to analyze the shear stress of different plant root masses under varying slope angles, moisture conditions, and soil types. Currently this type of research is underway in the United Kingdom. Results of their work can be found at:

  http://www.highways.gov.uk/info/techinf/randd/compen/8a.htm#1
- Long term survival and vigor of plants in the control and composted biosolids areas of the Chelan site should be studied to determine residual benefits of biosolids application.
- This type of work should be translated to local ecosystems (soils and plant types).
- Persons or agencies wishing to use this technology should do so with a team of experts and should begin with small erosional features on small slopes before working on large slopes.

- Plants used, and soil bioengineering techniques used need to be specific to each site.

LIMITATIONS OF THE STUDY

- The project was limited by funding levels to deal with the extent of the unexpected problems encountered at each site. In addition, all three sites were large and complicated, and funding levels limited the scope of the numerous soil bioengineering techniques the team could have use to stabilize the sites.
- The benefit cost study was limited by funding and time. Further study into the benefit/cost ratios of soil bioengineering methods in varying ecosystems is needed, especially those in Eastern Washington.
- When changes were necessary, it was difficult for the PI, because of her location in Oregon, to be physically present. However, the use of digital cameras, electronically sending photographs, and frequent conference calls with the research team kept the project moving forward without interruption.

OUTCOMES

This research project had the following outcomes directly associated with the project:

- Three large upland slope stabilization projects constructed.
- The research report published on the OSC Roadside and Site Development Unit internet homepage at http://www.wsdot.wa.gov/eesc/cae/design/roadside/rm.htm.
- WSDOT personnel have been trained in the selection of soil bioengineering sites and in the design, and construction of soil bioengineering techniques.
- The Olympia Service Center Roadside and Site Development Unit has been contracted by FHWA to analyze slopes in southwestern Oregon for possible design of soil bioengineering treatments.
- Regional offices within WSDOT have shown an interest in using soil bioengineering on specific sites on their roadsides.
- A chapter on soil bioengineering has been written for the department's *Roadside Manual*.
- Workshop conducted by the Principal Investigator and the research team for WSDOT personnel.
- WSDOT right to use and reproduce all materials from Lewis, E.A. *Soil Bioengineering: An Alternative for Roadside Management: A Practical Guide*. United States Forest Service. San Dimas Technology and Development Center. San Dimas, California. 1999.
- The value of using soil amendments to enhance plant survival has been demonstrated.
- Communication skills, for example use of interdisciplinary team process, have been highlighted and enhanced.
- Project management skills have been highlighted and awareness enhanced.
- Partnerships have been formed that will carry into the future.

- Awareness of soil bioengineering as an option for roadside stabilization and erosion control has increased within WSDOT.
- Relations with the public have been enhanced by the publication of four print articles (two local newspapers, an-in house newsletter, and a nationally-distributed magazine) about WSDOT’s use of a natural method of erosion control.

ACKNOWLEDGMENTS

The authors express their appreciation to the personnel of the Washington State Department of Transportation who provided information and help with all the various aspects of this project. Special thanks go to the USDA Forest Service for funding of the Principal Investigator's time and travel and to the Entiat Ranger Station for their logistical support. The authors would like to recognize the contribution of the Washington State Department of Ecology's donation of Washington Conservation Crew time to this project. The authors gratefully acknowledge the support of WSDOT's Research Office, the Environmental and Engineering Service Center, and the Field Operations Service and Support Center. The author's wish to thank Dr. George Xu for his work on the benefit/cost analysis.

The Chelan project would not have been possible without the granting of a construction easement by the adjacent landowners, Art and Susan Douglas. The authors are very grateful for their contribution to this project. Mark Cullington, formerly of the Department of Ecology provided guidance and calculations for the application of composted biosolids and we are most grateful for his contributions. Thanks go to McCully Orchards for providing apple stakes for the Chelan project. The authors appreciate the research of Kevin Finney on the history of soil bioengineering.

The authors wish to thank the City of Raymond and the Willapa Port Authority for allowing us to taking willow cuttings from their lands for the Raymond project. The authors wish to thank the Rayonier Timber company for allowing us to taking willow cuttings from their land for the Forks project. We appreciate the help of the Jefferson County Extension Service, the Natural Resource Conservation Service, and the National Park Service for their help with plant selections adaptable to marine clay. We appreciate the opportunity to coordinate with the Hoh Tribe on the Forks project. Finally, this project could not have been completed without the active participation of maintenance personnel in the North Central, Olympic, and Southwest regions.

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APPENDIX A: PROJECT PARTICIPANTS

Team Member	***Role***	***Representing***
Lisa Lewis	Team Leader & Principal Investigator	USDA Forest Service
Shannon Hagen	Research Assistant	WSDOT
Jim Schafer	Research Coordinator	WSDOT, Environmental Affairs Office
Mark Maurer, L.A.	Technical Support	WSDOT, OSC Roadside and Site Development Manager
Bob Barnes, L.A.	Technical Support	WSDOT, Olympic Region Landscape Architect
Lynn Moses	Technical Support	WSDOT, Materials Lab. Engineering Geologist
Sandy Salisbury	Technical Support, compiled this report	WSDOT, OSC Roadside and Site Development
Terri Dukes	Technical Support, Lost Creek site	WSDOT, Olympic Region Landscape Architecture
Carrie Sunstrom	Technical Support, wrote original grant application	WSDOT, Olympic Region Landscape Architecture
Ed Winkley	Technical Support, Lost Creek site	WSDOT, Olympic Region Landscape Architecture
Dan Corlett, L.A.	Technical Support, Raymond site	WSDOT, Southwest Region Landscape Architecture
Mike Whipple	Raymond site excavation & construction	WSDOT, Raymond Maintenance Supervisor

Team Member	***Role***	***Representing***
Sally Anderson, L.A.	Technical Support	WSDOT, Northwest Region Principal Landscape Architect
Ray Willard, L.A.	Technical Support	WSDOT, OSC Roadside Maintenance Landscape Architect.
Russ Rosenthal, PhD	Technical Support	WSDOT, State Horticulturist
Dave Rodin, L.A.	Technical Support, Raymond	WSDOT, Southwest Region Landscape Architectect
Claton Belmont	Technical Support, Chelan	WSDOT, North Central Region Environmental Manager
Jim Flack	Technical Support, Chelan	WSDOT, North Central Region Environmental Office
DeWayne Standerford	Technical Support, Chelan	WSDOT, North Central Region Maintenance Superintendent
Darrel Anderson	Technical Support, Chelan	WSDOT, North Central Region, Chelan Area Maintenance Supervisor
Dick Albin	Technical Support	WSDOT, OSC Design Office, Standards Engineer

APPENDIX B: DEFINITIONS

angle of repose the angle between the horizontal and the maximum slope that a soil assumes through natural processes.[2]

Approximate Angle of Repose for Soil Texture	
Very wet clay and silt	1V:3H
Wet clay and silt	1V:2H
Dry sand and gravel	1V:1¾
Dry clay	1V:1½
Moist sand	1V:1¼

ecosystem a complex of biological communities and the physical and chemical environment forming a functioning whole in nature. Wetlands, upland forests, lakes, and streams are examples of types of ecosystems.[3]

physiographic a geographic unit with discrete physical characteristics, such as elevation, aspect, and rainfall patterns.

rotational failure a slide that moves along a surface of rupture that is curved and concave.[4]

slope gradient the angle of the slope as expressed in a percentage.

soil bioengineering the use of live plant materials and engineering techniques to reinforce soil and stabilize slopes.

translational failure a slide mass that displaces along a planar or undulating surface of rupture and slides out over the original ground surface. Translational slides frequently grade into flows or spreads.

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[2] Robert W. Zolomij. “Vehicular Circulation.” *Handbook of Landscape Architecture Construction.* 1975. p. 66.
[3] Transportation Research Board. “Report 379: Guidelines for the Development of Wetland Replacement Areas. Washington D.C.. National Academy Press. 1996. p. 72.
[4] Turner & Schuster, eds, 1996, *Landslides Investigation and Mitigation, Special Report, Transportation Research Board,* pp. 56-57.

APPENDIX C: CHECKLIST FOR EVALUATING EROSION SITES

Name of Erosion Site: ____

Date: _______________ **Road Number or Name:** _______________________

Milepost Number: ____

Name of Observer(s): ____

Yes	No	N/A	
			1. Overland water flow is not contributing to accelerated erosion (i.e., formation of rills and gullies)
			2. Upland watershed is not contributing to site degradation
			3. Diverse composition of vegetation
			4. Site is comprised of those plants, or plant communities, with root masses capable of preventing further erosion
			5. Plants exhibit high vigor
			6. Adequate vegetative cover present to protect slopes and dissipate overland water flow
			7. Erosion site is revegetating with native vegetation
			8. Erosion site shows no sign of additional soil movement
			9. Ditch line has no evidence of fresh soil deposits

Remarks

Summary Determination

Stabilization Rating:
_____ **Stable**
_____ **Stability - At risk**
_____ **Not Stable**
_____ **Unknown**

Trend for Stability - At Risk:
_____ **Upward**
_____ **Downward**
_____ **Not Apparent**

Photograph or Sketch

APPENDIX D: MONITORING FORM

Soil Bioengineering Project

Date:_______________ Preparer(s):____________ Site Name:____________
SR ________________ Road Mp:_____________

Geographic Features

Elevation:__________________Slope%_____________ Aspect:__________
Soils:______________________Erosion Source:_______________________
Shade (H-M-L):_____________Dimensions:_______L x______W x______D
Ground Cover:____%Vegetation______%Soil___%Rock

Vegetation Information

Trees		Shrubs		Herbaceous	Grasses
Evergrn	Decid	Evergrn	Decid		

Species Noted:____
____
____

Noxious Weeds:____
____

Treatment Information

Treatment Date` Description Success/Vigor (H-M-L)

________ _______________________________________ _____
________ _______________________________________ _____
________ _______________________________________ _____
________ _______________________________________ _____
________ _______________________________________ _____
________ _______________________________________ _____
________ _______________________________________ _____
________ _______________________________________ _____

Overall Condition

Current Condition:	Improving	No Change	Worsening

Narrative

Maintenance Needed?	High Priority	Low Priority	Not Needed

Site Sketch

(Please include groundcover, structures, plants and any erosion evidence)

APPENDIX E: RESEARCH PROPOSAL

SOIL BIOENGINEERING, PROVIDING ALTERNATIVES FOR ROADSIDE MANAGEMENT

Elizabeth Lewis, USDA Forest Service

National Riparian Service Team

March 16, 1999

Status of Document: Final

TABLE OF CONTENTS

Soil Bioengineering, Providing Alternatives For Roadside Management

PROBLEM STATEMENT

Transportation systems provide access and allow utilization of land and resources. Development priorities usually emphasize access, safety and economics while environmental concerns refer to operational and maintenance problems such as surface condition; plugged drainage structures, including ditches; mass failures and surface erosion; or reduced access.

Transportation systems provide tremendous opportunities and, if properly located on the landscape with well designed drainage features, can remain stable for years with negligible affects to adjoining areas. Roads, however, are often linked to increased rates of erosion and accumulated adverse environmental impacts to both aquatic and terrestrial resources. This has become even more apparent during major winter storm events in recent years.

This is not new information to road managers. Road maintenance personnel, for example, face a huge task in maintaining roads under their jurisdiction. Major winter storms, resulting in significant increases in road landslides and impacts to adjoining resources, have compounded the road manager's challenge.

BACKGROUND

Soil bioengineering is an applied science which uses live plant materials and "soft" engineering techniques to alleviate environmental problems such as destabilized slopes. Soil bioengineering approaches to environmental problems involve building living systems using plants, soil and other materials. Unlike other technologies in which plants are chiefly an aesthetic component of the project, in bioengineering systems, plants are an important structural component.

Much like practices of medicine, engineering and architecture, soil bioengineering developed historically as discrete techniques designed to solve specific problems. Knowledge of these techniques was part of the body of folk wisdom accumulated in prehistoric times and passed orally from generation to generation. In the last two centuries, this knowledge has been compiled and codified, and finally in fairly recent times, has been taught formally and practiced as a profession.

The system of technologies, which today we call bioengineering, can be traced to the ancient peoples of Asia and Europe. Chinese historians recorded use of bioengineering techniques for dike repair as early as 28 BC (Needham, 1971, p. 331). Early Western visitors to China told of river banks and dikes stabilized with large baskets woven of willow, hemp or bamboo and filled with rocks. In Europe, Celtic and Illyrian villagers developed techniques of weaving willow branches together to create fences and walls. Later, Romans used fascines, bundles of willow poles, for hydroconstruction.

By the 16th century, bioengineering techniques were being used and codified throughout Europe from the Alps to the Baltic Sea and west to the British Isles. One of the earliest surviving written accounts of the use of bioengineering techniques, a publication by Woltmann from 1791, illustrated the use of live stakes for vegetating and stabilizing streambanks (Stiles, 1991, p.ii). About the same time, other early bioengineers working in Austria were developing live siltation construction techniques, planting rows of brushy cuttings in waterways for trapping sediment and reshaping channels.

Much of the development and documentation of bioengineering techniques, since the Industrial Revolution, has been done in the mountainous areas of Austria and southern Germany. Extensive logging of the forests in the region resulted in increased environmental problems, much like what is found in parts of the western U.S. today. Such problems as extreme slope erosion, frequent landslides and avalanches, and severe streambank degradation, required repair. By the turn of the century, European bioengineers had begun to study traditional techniques and to publish their work. It is from this compilation that bioengineering professions would develop in the following decades.

The biggest boost to development of new bioengineering techniques in Europe came as a result of political developments during the 1930's. Financial restrictions of pre-war years in Germany and Austria favored use of low cost, local materials and traditional construction methods for public works projects. Construction of the German Autobahn system, during this time, involved extensive applications of bioengineering technologies. The use of indigenous materials and traditional methods was also consistent with spreading nationalist ideology. In 1936, Hitler established a research institute in Munich charged with developing bioengineering techniques for road construction (Stiles, 1988, p. 59). Although this development work was lost, a Livonian forester named Arthur von Kruedener, the head of the institute, continued to work in the field and is known in central Europe as the father of bioengineering.

At the same time the Germans were establishing their research institute, some of the most important early bioengineering work in the United States was being done in California. Charles Kraebel, working for the US Forest Service, was developing his “contour wattling” techniques for stabilizing road cuts. Kraebel used a combination of bioengineering techniques including live stakes, live fascines and vegetative transplants to stabilize degrading slopes in National Forests of central and southern California. His unfortunate and confusing misuse of the term “wattle” to describe his live fascine system has stuck with us and continues to be used today. Kraebel’s work was well documented in USDA Circular #380, published in 1936. Two years later the Natural Resource Conservation Service (NRCS), formally known as the Soil Conservation Service, began a study of bluff stabilization techniques along shores of Lake Michigan. That agency’s work, which included use of live fascines, brush dams and live stakes was published in 1938 (Gray and Leiser, 1982, p. 188).

During the post-war period, many European bioengineers returned to studying, developing and evaluating new techniques. In 1950, a committee of bioengineers fromGermany, Austria and Switzerland was formed to standardize emerging technologies which became part of the German national system of construction specifications, the DIN (Robbin B. Sotir & Associates, n.d.).

Arthor von Kruedener’s book, Ingenieurbiologie, (Engineering biology), was published in 1951 and it was the mistranslation of the German title which gave us the English term we use today. The use of the term bioengineering has caused some confusion and has proven problematic for researchers who find, in this country, the term is most often referred to an area of medical research. The NRCS now refers officially to bioengineering work as “soil bioengineering”, a term which emphasizes the soil component of the system.

German and Austrian bioengineers continued to perfect their techniques and to publish their work through the 1950's and 60's. This was an important step in launching a more structural approach, laying the foundation for development of the professional field of bioengineering. In the United States, two important projects were carried out in the 1970's. These include the Trials of Bioengineering Techniques in the Lake Tahoe Basin designed by Leiser and others (1974), and Revegetation Work in Redwood National Park (Reed and Hektner, 1981, Weaver,et al., 1987). Both studies have been well documented and provide important information about application of bioengineering techniques in the western United States.

In 1980, Hugo Schiechtl's Bioengineering for Land Reclamation and Conservation was published in Canada. It presents, for the first time in English, work of many important European bioengineers including Lorenz, Hassenteufel, Hoffman, Courtorier and Schiechtl himself. The book made the technologies, and the history of their development and applications accessible to the English speaking world. In 1997, another Schiechtl book was published, Ground Bioengineering Techniques for Slope Protection and Erosion Control. To date, his writings remain the most important work on bioengineering in the English language.

With subsequent publications including Gray and Leiser's Biotechnical Slope Protection and Erosion Control in the United States and the British Construction Industry Research, Sotir and Gray's Soil Bioengineering for Upland Slope Protection and Erosion Reduction in the Natural Resource and Conservation Service's Engineering Field Handbook, and Information Association's Use of Vegetation in Civil Engineering bioengineering technologies are better known in the engineering profession. There is still, however, resistance to the techniques in this country.

Bioengineering approaches most often use locally available materials and a minimum of heavy equipment, and can offer local people an inexpensive way to resolve local environmental problems. The public's increased "green" consciousness often makes bioengineering solutions more acceptable than traditional "hard" engineering approaches.

Despite, and maybe because of, the difference in approach and philosophy between bioengineering and other engineering methods of addressing environmental problems, bioengineering technologies are especially appropriate today. The scale and range of environmental problems require consideration of new technologies even when, as illustrated earlier, they are in fact centuries old.

OBJECTIVE

Washington State Department of Transportation (WSDOT) expends considerable resources in an effort to improve road conditions. Historically, civil engineers relied primarily on traditional engineering solutions, or "non-living" approaches, for slope and landslide stabilization. The purpose of this research project is to provide viable alternatives called soil bioengineering, or "living" approaches. This proposal is not to argue one solution is better than the other, but to provide additional alternatives, or an integration of these two practices. Road managers need all available tools to effectively do their jobs. This is an effort to meet that need.

BENEFITS

Soil bioengineering measures should not be viewed as a panacea or solution for all slope failure and surface erosion problems. Soil bioengineering has unique attributes, but is not appropriate for all sites and situations. In certain cases, for example, grass seeding and hydromulching may be satisfactory and less costly. In other cases, it may be a more effective solution to use a structural retaining system alone or in combination with soil bioengineering. The following are specific attributes applying to soil bioengineering techniques:

(A) Environmental compatibility

Soil bioengineering systems generally require minimal access for equipment and workers and cause relatively minor site disturbance during installation. These are generally priority considerations in environmentally sensitive areas, such as parks, woodlands, riparian areas and scenic corridors where aesthetic quality, wildlife habitat and similar values may be critical.

(B) Cost effectiveness

Erosion sites often begin small and eventually expand to a size requiring costly engineered solutions. Soil bioengineering is a useful tool to consider in these situations. Initiation of soil bioengineering while the site is fresh and new could minimize impacts of this erosion to the damaged site, the road and adjacent resources. If left untreated, these sites usually worsen and increase damage to adjacent resources. In addition, the larger a site becomes the more costly it will be to repair.

Use of indigenous material provides savings because plant costs are limited to labor for harvesting and handling and direct costs for transporting the plants to the site.

(C) Planting times

Soil bioengineering systems are most effective when they are installed during the dormant season, usually late fall, winter and early spring. This often coincides with the time other construction work is slow.

(D) Difficult sites

Soil bioengineering is often a useful alternative for small, highly sensitive or steep sites where machinery use is not feasible and hand labor is a necessity. Rapid vegetative establishment, however, will be difficult on extremely steep slopes.

The usefulness of soil bioengineering methods may be limited by the quality of growth medium, such as rocky or gravelly slopes which lack sufficient fines or moisture to support the required plant growth. In addition, soil restrictive layers, such as hardpans, may prevent required root growth.

(E) Harvesting local plant material

Appropriate vegetation is often obtained from local stands of willows and other suitable species. This stock is readily available and well suited to climate, soil and available moisture conditions, making it a good candidate for survival.

(F) Soil Bioengineering strengths

Soil bioengineering systems are strong initially and grow stronger with time as vegetation becomes established. In some instances the primary role of the structural component is to give the vegetation a better chance to become established. It has been shown in slope reconstruction projects that soil bioengineering systems can withstand heavy rainfalls immediately after installation. Even if established vegetation dies, the plant roots and surface residue may continue to play an important protective role during reestablishment.

Another critical benefit of soil bioengineered projects, is once plants are established, root systems pull excess subsurface moisture out of the soil profile. This is often the key to long term site stability.

(G) Maintenance requirements

Once vegetation is well established on a soil bioengineering project, usually within one growing season, it generally becomes self-repairing by regeneration and growth, requiring little maintenance. However, a newly installed soil bioengineering project will require careful periodic inspections until it is established. Establishing vegetation is vulnerable to trampling, drought, grazing, nutrient deficiencies, toxins and pests and may require special management measures at times.

PRODUCTS

Products and tasks of the proposed work include:

- Sites will be selected to address disparate climate, and soil moisture conditions, found in the state. Selection of soil bioengineering demonstration project areas will illustrate:
    - Soil bioengineering on larger erosion site(s).
    - Combined slope protection systems of soil bioengineering and structural (traditional engineering) treatments.
    - Soil bioengineering on small erosion sites.
- Development of effectiveness monitoring strategy to establish “standards of success” for future soil bioengineering work by WSDOT.
- Oversight of survey, design, implementation, monitoring and maintenance of the selected soil bioengineering projects.
- Cost/benefit analysis.
- Soil bioengineering workshop for WSDOT personnel.
- Submission of a final report to include a cost/benefit analysis and monitoring information.

IMPLEMENTATION

Information and methods developed will be transferred to managers in different ways. WSDOT landscape architects, geotechnical engineers, engineering geologists and road maintenance personel, for example, will participate in the aforementioned **Product** steps. WSDOT employees, will attend a workshop familiarizing them with soil bioengineering applications. Results of the study will be presented at local, state, regional and national workshops for road managers and natural resource specialists.

WORK PLAN

The following list of tasks outlines the proposed work for this research project.

Task 1 - Review and selection of demonstration project areas.

Task 2 - Development of effectiveness monitoring strategy to establish “standards of success” for this project and future soil bioengineering work.

Task 3 - Survey and design of soil bioengineering projects.

Task 4 - Inspection of project implementation.

Task 5 - Monitoring and maintenance of completed projects.

Task 6 - Cost and benefit analysis.

Task 7 - Peer review and participation in a workshop for WSDOT personnel.

Task 1 - **Review and selection of demonstration project areas** by Principle Investigator (PI) and Research Assistant (RA). With assistance from WSDOT landscape architects, engineering geologists, geotechnical engineers and road maintenance personnel, a search will be conducted to review and select the soil bioengineering research sites. Clear project objectives will be established and recorded.

Task 2 - PI and RA will develop **effectiveness monitoring strategy** to establish “standards of success” for this project and future soil bioengineering work by WSDOT.

Task 3 - **Survey and design of soil bioengineering projects**.

With assistance from PI and RA, WSDOT landscape architects, engineering geologists and geotechnical engineers will survey and design proposed soil bioengineering work. To ensure project objectives are understood, a field review will be completed prior to design. This review can occur during survey. Once project designs are complete, a plan-in-hand field review will be conducted.

Task 4 - **Inspection of project implementation**.

Prior to beginning project work, a field pre-work meeting will be held (PI, RA and WSDOT) with contract soil bioengineering crews (Washington Conservation Corps) to highlight key points of the project. RA will conduct daily inspections of project work during implementation. PI will oversee the inspections and WSDOT will provide periodic inspection assistance.

Task 5 - Monitoring and maintenance of completed projects.

Using the strategy developed in Task 2, RA and PI will monitor areas before and after project implementation. Results will be documented and submitted to WSDOT upon completion of the projects. Monitoring results will be used to adjust future soil bioengineering prescriptions.

Task 6 - Cost/benefit analysis.

With information gathered from Tasks 1-5, the RA and PI will complete a cost/benefit analysis providing a comparison of traditional engineering techniques with soil bioengineering methods.

Task 7 - PI and WSDOT will conduct **peer reviews** of project work for WSDOT managers. PI will participate in a soil bioengineering **workshop** for WSDOT personnel.

STAFFING PLAN

This project will be staffed by individuals from USDA Forest Service and WSDOT.

USDA Forest Service Personnel

Lisa Lewis, Soil Scientist with the interagency National Riparian Service Team, will act as PI for this project. Refer to the following chart for specific information concerning PI's responsibilities under each task.

WSDOT Personnel

Mark Mauer, landscape architect, and Lynn Moses, engineering geologist, will help select, survey and design the proposed soil bioengineering work areas. These individuals will also participate in inspection of project work and with development and implementation of the monitoring strategy. In addition, meetings and field reviews held at various points in the stated tasks will include other WSDOT employees, with emphasis on participation of road maintenance personnel.

Shannon Hagen, temporary employee with WSDOT and student at The Evergreen State College, will serve as RA for this project. Refer to the following chart for specific information concerning RA's responsibilities under each task.

LEVEL OF EFFORT

	Task (hours)							
Personnel	1	2	3	4	5	6	7	Total
Lisa Lewis	40	20	40	40	40	40	40	260
Student Research Assistant	40	120	120	288	280	160	0	1008
Total	80	240	160	328	320	200	40	1268

FACILITIES AVAILABLE

The research effort will be conducted through the National Riparian Service Team Department in Prineville, Oregon and out of the WSDOT office in Olympia.

SUPPORTING DATA

The following is being provided as information on the PI. Lisa Lewis is currently working as a Soil Scientist on the interagency National Riparian Service Team where her responsibilities include providing training and technology transfer; consulting and advisory services and program review for riparian restoration on both public and private lands nationwide. Up until November, she worked 12 years as a Soil Scientist where duties included role as Operations Staff Officer on both Hood Canal and Quinault Ranger Districts, Olympic National Forest. Her responsibilities included oversight of soils, hydrology, flood recovery, fisheries, wildlife, timber, fire, recreation, facilities, engineering and roads programs. In road management, she was responsible for 1500 road miles.

WORK TIME SCHEDULE

Work on this project may begin as early as April 1999 and is planned to be completed by December 2000.

Activity Name	1999 M A M J J A S O N D	2000 J F M A M J J A S O N D
Task 1: Selection of Projects	A M	
Task 2: Develop Monitoring Strategy	A M J	
Task 3: Complete Survey and Design	M J J	
Task 4: Soil Bioengineering Work, including logistics and inspection	S O N D	J F M A
Task 5: Monitor and Maintenance of Projects	A N D	J F M A N D
Task 6: Complete Cost and Benefit Analysis	J A	M
Task 7: Teach at WSDOT Soil Bioengineering Workshop		S O N D
	M A M J J A S O N D	J F M A M J J A S O N D

BUDGET ESTIMATE

Item	Year 1	Year 2
Salary	**$13,875.00**	**$10,000.00**
Principal investigator (@$250 per 8 hour day)	4,375	3,750
Research assistant (@$125 per 8 hour day)	9,500	6,250
Transportation and Travel	**$2,000.00**	**$1,400.00**
Vehicle lease for principle investigator (PI)	200	100
Flights: Redmond, OR to Seattle, WA (PI)	300	300
Research assistant per diem Principle investigator per diem	1,050 450	700 300
Equipment	**$200.00**	**$300.00**
Computer facilities * Miscellaneous equipment	0 200	0 300
Supplies (Photos and development)	**$250.00**	**$300.00**
Miscellaneous	250	300
Construction and Installation of Soil Bioengineering Projects (includes project supplies)	**$12,500.00**	**$19,175.00**
Implementation of Projects using Washington Conservation Corps	12,500	19,175
Annual Total	**$28,825.00**	**$31,175.00**
Project Total		**$60,000.00**

1 Use of personal computer contributed by WSDOT, BLM and USFS.