Integrated Erosion Control Methods For Highway Construction And Slope Maintenance

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FINAL REPORT
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INTRODUCTION

Surface erosion, sedimentation, and shallow-seated slope failures associated with highway slopes in Idaho present a significant challenge to roadway construction and maintenance. Soil losses from these slopes deplete an important natural resource, cause significant maintenance costs, and also may adversely affect the quality of surface waters in the state.

Traditional practices employed by state and county road departments and their contractors to mitigate such problems have not proven entirely effective in many areas of the state. In some parts of the state, especially in the more humid regions of central and northern Idaho, there are numerous examples of cut or fill slopes that have been affected by soil erosion and/or shallow-seated soil slips that commonly occur during wet periods in the cold season (late autumn though early spring). The typical response to such activity is to clean it up and re-dress the slope, which often results in an enlarged ditch at the base of the slope that oversteepens the slope and tends to aggravate the instability problems.

Also, road construction activities throughout the state require increasingly greater attention to erosion and sediment control practices due to economic and environmental pressures. Compliance with the federal Clean Water Act and especially the aspects related to NPDES regulations (National Pollutant Discharge and Elimination System) is a goal that Idaho Transportation Department (ITD) Districts must pursue. To address these concerns, ITD has initiated efforts in research, field evaluation, training, and dissemination of technical information pertaining to erosion and sediment control. For example, ITD published and distributed its *Catalog of Stormwater BMPs for Highway Construction and Maintenance* (1994).

As part of this growing ITD endeavor to improve erosion control, a multi-disciplinary research project was funded in late 1996 to investigate new technologies for erosion and sediment control, including a focus on shallow-seated slope failures. The project was part of the ongoing cooperative research program between the University of Idaho and the Idaho Transportation Department, as overseen by the University's National Center for Advanced Transportation Technology (NCATT). The name of this organization recently was changed to the National Institute for Advanced Transportation Technology (NIATT).

The research involved a synergistic approach relying on plant science and agronomy, geotechnical engineering, and on new state-of-the-art technology in regard to soil biostimulants and organic soil amendments used to enhance low-fertility sites, such as those common to disturbed highway slopes. Field demonstration plots were established and monitored at several locations across southwestern Idaho and northern Idaho. Existing slope failures in the Moscow-Lewiston area were mapped and described for engineering back-analysis and investigation. The primary goal was to provide technical information and field experiences that would lead to enhanced highway slope design, planning, construction, maintenance, and rehabilitation.

The primary specific tasks that were addressed during the research project were:

1. Deep-rooted shrub species were identified and transplant studies were conducted to evaluate survivability and potential erosion control benefits.

2. Initial field tests and demonstration plots were used to evaluate seed mixes, seeding rates, and soil treatments that provide organic matter and enhance biological activity on sterile, disturbed sites.

3. The development of a highway revegetation handbook was initiated, with the goal being to publish a draft version by the end of the research period.

4. Shallow-seated slope failures were investigated through soil direct-shear testing and engineering back-analysis of existing failures; potential treatments were studied and a case study was conducted for a geosynthetic slope reinforcement system.

PERFORMANCE OF TRANSPLANTED SHRUBS

To assess the survivability of transplanted shrubs for erosion control on roadway slopes, field demonstration plots were established at several locations in southwestern Idaho and in northern Idaho beginning in July of 1996. Each plot contained at least one repeat for most of the transplant treatments, which included a water-soluble chemical fertilizer, an organic biostimulant, a poultry-manure/seedmeal organic fertilizer, and a mycorrhizal inoculant. For the sites on fairly sterile cut-slope soils, nearby topsoil was imported and also was tested as an additive to some of the transplant basins into which shrubs were planted. When transplanting was done during the summer (late June through August), a gelatin form of slow-release water was applied to the plants to improve the chances for survival.

Plants selected for the transplanting program were native species for the most part and considered to be well adapted to the specific locales. In southwestern Idaho, the following species were transplanted in demonstration plots along US 95 north of Weiser and along SH 55 on Horseshoe Bend Hill:

silver sage
big sage
winterfat
rabbitbrush
bitterbrush
prairie sedge
western clematis

In northern Idaho, the following species were transplanted along US 95 near Moscow, Genesee, and Potlatch; and also along US 2 near Sandpoint:

snowberry
woods rose
creeping oregon grape
golden currant
western clematis

In general, these species were selected because of their hardiness and because they are low-growing plants that require minimal maintenance and would not interfere with sight distances along roadways. Some are propagated by seed, while others spread through rooting rhyzomes.

Each plant was hand transplanted, supplied with the specified treatment, and given approximately 1 liter of water. Most of the planting stock consisted of 10-20 cu. inch root tubes, but a few of them were the larger 1-gal. size. Generally, the planting time was from 5 to 10 minutes per plant, with most of the effort expended in digging the hole. In soft soil with few rocks, the planting time typically was less than 5 minutes per plant. Each completed transplant also was photographed with a scale-bar in the background. For planting programs conducted during midsummer, each plant was treated with one quart of slow-release gelled water to provide continuous moisture to the root zone for several months (see product listing at the end of this chapter).

The demonstration plots were visited several weeks after the transplanting, then followed up with annual visits. A relative scoring system for plant health was developed as follows:

1 = healthy, as evidenced by new growth;

2 = some signs of stress, such as curled or distressed leaves;
3 = significant signs of stress;
4 = apparently dead.

Results of the field surveys are summarized in Tables 2.1, 2.2, and 2.3. Test sites were inventoried/evaluated during follow-up visits as shown. Site visits made recently during the summer of 1998 did not show any significant differences from earlier conditions; some 3's could be upgraded to 1's or 2's.

Table 2.1. Results of shrub transplanting on roadway slopes in southwestern Idaho (planting completed in July 1996; field checked in May 1997)

Location	Species	Fertilizer + Topsoil	Biostimulant + Topsoil	Biostimulant Only	Fertilizer + Mycorr.	Biostimulant + Mycorr.
SH 55, Horseshoe Bend (MP 60.6)	silver sage	11	11			
	big sage	11	11			
	winterfat	11	11			
	prairie sedge	12	44	14		
	western clematis			24	11	11
US 95, Weiser (MP 89.6, 91.5)	silver sage	1111	1111	1111		
	winterfat	22	11	22		
	bitterbrush	21	14	4		
	rabbitbrush	11	44	44		
	prairie sedge	1111	4241	14		
	western clematis			11	11	44

Comments:
Overall performance was 55 of 70 survived (78.5%). Very little rainfall occurred from July through September after planting, so the survival rate likely was enhanced significantly by the slow-release water gel, particularly on the south-facing test sites. Field inspections in September and October of 1997 showed similar conditions, with the sages performing especially well in producing large seed heads. Generally, the larger transplant stock (1-gal. size) performed best.

Table 2.2. Results of shrub transplanting on roadway slopes in northern Idaho (planting completed in July 1996, unless otherwise noted; field checked in May 1997).

Location	Species	Fertilizer + Topsoil	Biostimulant + Topsoil	Biostimulant Only	Biostimulant + Mycorr.	Organic Blend

US 95, North of Genesee (MP 332.5)	snowberry	11	11	11		
	woods rose	11	11	11		1111111*
	cr. oregon grape	11	11	11		
	western clematis	14	11	21		

*Planted November 1996, with no water gel.

US 95, North of Moscow (MP 346.8 and 347.8)	snowberry**	4	3	4		
	woods rose**	3	2	2		
	cr. oregon grape**	1	1	3		
	western clematis**	3	4	4		
	western clematis	44	3B	41		

**Site was damaged by mudslides in Jan. 1997. These scores were assigned in November 1996.
B = Buried by mud debris.

US 95, North of Viola (MP 354.6)	snowberry	11	41	11		111[+]
	woods rose	11	11	11		
	cr. oregon grape	12	11	22		

[+] Planted November 1996, with no water gel.

US 95, Mineral Mtn. Rest Area (MP 370.6)	snowberry	12*	11	11	11	
	woods rose	11	11	11*	11	
	cr. oregon grape	1*1*	1*1*	21	1*1*	

*Rating obtained November 1996 prior to plant being buried by mud debris.

						Fertilizer Only
US 2, West of Sandpoint (MP 16.0)	snowberry	11	11		11	
	woods rose	11	11	11	11	11
	cr. oregon grape	11	11	11	22	11
	western clematis	BB	BB	BB		

Planted September 1996. B = Buried by mud debris.

Comments:
Overall performance was 100 of 109 survived (91.7%). Very little rainfall occurred from July through September after planting, so the survival rate likely was enhanced significantly by the slow-release water gel, particularly on the south-facing test sites. Field inspections in September and October of 1997 showed similar conditions, with the woods rose performing especially well. Generally, the larger transplant stock (1-gal. size) performed best.

Table 2.3. Results of shrub transplanting in spring, 1997, northern Idaho.

Location	Species	None	Fertilizer Only	Biostim. + Fertil.	Biostimulant + Org.Blend	Org.Blend + Mycorr.	Org.Blend Only

US 95, North of Genesee (MP 332.5)	w.rose - w/gel	12	11	11	43	23	3311113	
	w.rose - no gel	4241	14	11	32	11	1314124	
	ore.grape - w/gel	3	1	2	4	2	4	
	ore.grape - no gel	2	2	4	4	4	4	
	gld.currant -w/gel		3	1	2	4	2	413222
	gld.currant - no gel	3	2	2	4	4	412144	
US 2, West of Sandpoint (MP 16.0)	w.rose - w/gel	112	141	211	1P1	111	114	
	w.rose - no gel	222	443	322	143	211	344	
	ore.grape - w/gel	4	4	2	2	3	3	
	ore.grape - no gel	3	4	3	4	3	4	

P = damaged by predators (insects, rodents, grazing mammals)

Comments:
Above-average rainfall occurred from April through June, 1997.
Overall performance of plants not treated with water gel was 39 of 60 survived (65%).
Overall performance of water-gel treated plants was 48 of 57 survived (84.2%).

To evaluate if the water gel provided any significant improvement to survivability of the spring transplants (Table 2.3), a statistical hypothesis test of proportions was conducted. Using the following data, the calculated value of the z statistic was:

$$x_1 = 48 \qquad n_1 = 57$$

$$x_2 = 39 \qquad n_2 = 60 \qquad p = 87 / 117 = 0.744 \qquad 1 - p = 0.256$$

$$z = [(48/57) - (39/60)] / [(.744)(.256)\{(1/57) + (1/60)\}]$$

$$= (0.192) / [.190(.0342)] = 29.5$$

This value far exceeds the tabled z value at a significance level of 0.05 (equal to 1.645), so we reject the null hypothesis that the two proportions are the same. Thus, we conclude that the plants treated with water gel had significantly better survival rates than those not treated with the gel.

General observations for the transplant sites during the study period from 1996 through 1998 are summarized below:

1. Transplant survival rates for shrubs planted in mid-summer, 1996 (using the water-gel product), were 78.5% for southwestern Idaho and 91.7% for northern Idaho. The combined rating of 86.6% (155/179) indicates the water gel was successful in boosting transplant survivability for summer plantings, especially in light of the low to nil rainfall for late summer at the field sites.

2. If transplants survived for at least one year (through a cycle of seasons), then they appear to be “permanently” established. In many cases, shrubs that received a rating score of 4 (apparently dead) had died soon after transplanting.

3. Generally, shrubs in larger stock containers (e.g., one-gallon size vs. the 10 cubic inch size) showed better survival rates, especially the big sage and silver sage transplanted at the southwestern Idaho sites. This may be due to a larger initial root mass that better buffers the transplant shock, or to a larger initial plant mass that better resists predator attack.

4. In southwestern Idaho, plants treated with chemical fertilizer showed better survival rates than those treated with the organic biostimulant. There was no apparent difference in performance for the northern Idaho shrubs.

5. For the spring 1997 plantings in northern Idaho, shrubs treated with the water gel showed statistically better survival rates than those not treated.

6. No significant differences (improvements) were noted for shrubs treated with the mycorrhizal inoculant, though such plants generally scored well.

7. The best performing species were silver sage and big sage in southwestern Idaho and woods rose in northern Idaho, but this may depend heavily on local soil type.

8. Transplants treated with topsoil did not appear to have significantly higher survival rates than those not treated.

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Guide to products/treatments:

Chemical fertilizer	Water-soluble Miracle Gro™ Plant Food 15-30-15
Biostimulant	Quattro Kiwi Power™
Water gel	DriWater™
Organic blend	Quattro Fertil-Fibers™ (key ingredients: composted poultry manure, seed meal, humates)
Mycorr. inoculant	PHC MycorTree™ Tree Saver (contains Vesicular-Arbuscular endomycorrhizal fungi and an ectomycorrhizal fungus)

EVALUATION OF ORGANIC SOIL AMENDMENTS FOR HYDROSEEDING
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To evaluate the benefit of various types of organic soil amendments used to enhance revegetation of disturbed sites with little or no topsoil, field demonstration plots were established at several locations in southwestern Idaho and in northern Idaho beginning in October of 1996. Generally, cut slopes consisting of subsoils with very poor fertility were selected for the tests. Basic soil fertility tests indicated very low amounts of organic matter and available phosphorus and nitrogen (Table 3.1). Potassium levels also were low, except for the Weiser sites where remnants apparently persisted of a fertilization/seeding program from recent years. In most cases, the demonstration sites were locations where previous revegetation efforts had been unsuccessful.

Organic soil amendments that provide nutrients to the soil tend to rely on slow-release, organically bound nitrogen from a seed-meal source. Biosol™ is a seed-meal based product (with overall NPK of 6-1-3), which is derived from 90% fungal mycellium, a by-product from manufacturing penicillin, and containing 10% potassium-magnesia. Quattro Fertil-Fibers™ consists primarily of seed-meal and poultry-waste products (composted poultry manure and feather meal), along with humic acid (overall NPK of 6-4-1). Two different blending sources were available for testing: the "H" Fertil-Fibers™ was a standard mix, while the "C" material was based mainly on seabird guano rather than on poultry manure. The Wolfkill brand organic mix also has an NPK of 6-4-1, with seed-meal and poultry manure but without the humic acid. Laboratory nutrient analyses were conducted for these products, and the results

Table 3.1. Results of laboratory soil fertility tests of disturbed highway cutslopes.

Location	Satur. Paste	Organic Matter	0.75N NaOAC Extrac.(mg/g)		2M KCL Extrac.(mg/g)	
	pH	%	P	K	NO_3-N	NH_4-N
US 95, Weiser Devil's Elbow Site A	4.3	0.66	<0.3	129	1.5	2.8
US 95, Weiser Devil's Elbow Site B	7.1	0.31	21.7	211	4.4	9.6
SH 55, Horseshoe Bend Hill	6.6	0.23	2.4	89	<0.4	1.6
US 95, North of Genesee, Borgen Road Jnc.	6.2	0.49	1.3	76	<0.4	3.2
US 95, North of Moscow	6.5	0.46	1.9	96	<0.4	2.8
US 95, North of Viola	6.9	0.47	2.9	67	<0.4	3.1
US 95, Mineral Mtn. Rest Area	6.4	0.42	3.2	41	<0.4	1.4
US 2, West of Sandpoint	6.4	0.56	2.3	44	<0.4	1.3

Tests were conducted by the University of Idaho Analytical Sciences Laboratory.

are presented in Table 3.2. Significant differences among the products can be seen in the pH, P, available nitrogen, sulfate, and some of the metallic ions.

Table 3.2. Results of laboratory analyses of organic soil amendments.

Material	No.	Saturated Paste pH	Organic Matter %	0.75N NaOAC Extrac. (mg/g)		2 M KCL Extraction (mg/g)			
				P	K	NO_3-N	NH_4-N	SO_4-S	B
Biosol™	1	2.8	66	2400	14000	6	3900	17000	9
	2	2.8	61	2500	15000	5	4000	28000	7
Quattro-C Fertil-Fibers™	1	7.2	52	5300	13000	47	2100	1400	10
Quattro-H Fertil-Fibers™	1	5.5	49	16000	18000	110	8400	7500	22
	2	5.7	48	16000	17000	100	8000	6300	21
	3	5.7	49	16000	18000	100	8700	7600	21
Wolfkill Organic Mix	1	5.9	61	10000	18000	9	4900	1600	20

		Ammonium Acetate Extrac. Cations (cmol/kg)				DTPA (Chelating Agent) Extraction (mg/g)				%		
		Ca	Mg	Na	K	Zn	Mn	Cu	Fe	C	H	N
Biosol™	1	15	7	47	38	10	8	3	63	42	5.8	6.60
	2	16	8	47	37	10	9	3	64	42	5.5	6.57
Quattro-C Fertil-Fibers™	1	49	28	11	42	55	34	7	27	34	4.5	5.93
Quattro-H Fertil-Fibers™	1	19	37	9.1	47	410	600	21	86	37	5.2	7.07
	2	18	29	9.1	41	340	440	20	78	36	5.2	6.84
	3	17	28	8.8	43	360	470	20	78	35	5.1	6.78
Wolfkill Organic Mix	1	82	21	11	37	190	110	32	94	35	4.8	7.02

Tests were conducted by the University of Idaho Analytical Sciences Laboratory.

To evaluate the field performance of organic soil amendments over time, poor soils at one of the US 95 demonstration sites near Weiser were analyzed before and after a fall hydroseeding application. As seen in Table 3.3, the treatment provided significant increases in all constituents except for potassium (K). Plant-available nitrogen and phosphorus were especially enhanced at the site, and still available for plant uptake six months after the treatment. Common forms of water soluble nitrogen used in chemical fertilizer would likely have diminished over the winter months.

Table 3.3. Results of laboratory soil fertility tests to evaluate Quattro organic soil amendments at US 95 Weiser test site (MP 89.6).

		Satur. Paste	Organic Matter	0.75N NaOAC Extrac.(mg/g)		2M KCL Extrac.(mg/g)	
		pH	%	P	K	NO_3-N	NH_4-N
October 1996 Prior to Treatment							
North Cut	1	7.1	0.31	22	211	4.4	9.6
	2	7.3	0.31	11	254	2.1	9.6
South Cut	1	6.6	0.45	4	266	1.9	11.0
	2	6.8	0.27	4	252	1.4	5.4
May 1997 Six Months Later							
North Cut	1	6.6	0.93	35	251	46.3	82.9
	2	6.8	0.60	49	221	37.5	103.0
South Cut	1	6.3	0.73	17	322	43.6	119.0
	2	6.2	0.79	16	279	62.0	72.8

Treatment was based on the manufacturer's recommended rate of Quattro Kiwi Power™ at 5 gal./acre and Fertil-Fibers™ at 2,000 lb./acre.
Laboratory analyses were conducted by the University of Idaho Analytical Sciences Laboratory.

Summary of Observations at Field Demonstration Sites

Conditions, treatments, and observations at the various field demonstration sites are summarized below. In most cases, the amended sites showed clear visual distinctions in regard to greater plant establishment and vegetation density when compared to surrounding areas that were not treated.

1. **US 95, North of Weiser (MP 89.6)**; hydroseeded October 30, 1996
   One-pass application; SE and NW facing cuts

Seed Mix #1: bluebunch wheatgrass, cereal barley, small burnet, blue flax, squirreltail, Indian blanketflower, bitterbrush, penstemon, white yarrow, basin sagebrush, rabbitbrush
Seed Mix #2: basin wildrye, small burnet, squirreltail, Sherman big bluegrass, cereal barley, blue flax, Indian blanketflower, bitterbrush, penstemon, white yarrow, basin sagebrush, rabbitbrush
Treatments: Quattro Fertil-Fibers™ and Kiwi Power™, straw erosion control blanket

Results: Seed mix #1 showed slightly better performance than #2. The best early establishment was shown by yarrow, sagebrush, and cereal barley. Sample plots with only Kiwi Power™ showed a small improvement over the pre-existing sparse vegetation. Plots with Kiwi Power™ and Fertil-Fibers™ showed significant improvement in revegetation, with the best performance shown in the area covered by the straw erosion control blanket. This likely was due to the blanket holding seed and nutrients in place on the easily eroded soil on the cutslope.

2. **US 95, North of Viola (MP 354.6+)**; hydroseeded October 9, 1996
   Two-pass application; E and W facing cuts

Seed Mix #1: intermediate wheatgrass, creeping red fescue, meadow brome, Canada bluegrass, alfalfa
Seed Mix #2: same four grasses plus Highland bent grass, Kura clover
Treatments: Biosol™ with SoilGuard™ (bonded fiber matrix), yard-waste compost with wood-fiber mulch, Quattro Kiwi Power™, straw erosion control blanket

Results: There was no apparent difference in the seed mix performance; alfalfa and clover were very sparse. All sample plots that received Biosol™ and Kiwi Power™ performed very well, especially those areas covered with SoilGuard™ and the straw erosion control blanket, which seemed to provide equivalent protection for the seed/nutrients (the enhanced vegetation of these areas was still noticeable in the summer of 1998). Plots treated with compost and Kiwi Power™ showed no improvement over the existing sparse vegetation.

3. **US 95, North of Viola (MP 354.6)**; hydroseeded April 25, 1997
   One-pass application; E and W facing cuts

Seed Mix #1: intermediate wheatgrass, sheep fescue, hard fescue, smooth brome, Sherman big bluegrass, timothy, annual ryegrass, alsike and white Dutch clover
Seed Mix #2: western wheatgrass, sheep fescue, Canada bluegrass, crested wheatgrass, creeping red fescue, Kura clover
Treatments: Quattro Kiwi Power™, Fertil-Fibers™, small amount of 16-12-12 fertilizer

Results: Seed Mix #2 showed slightly better performance than #1; clover was very sparse. Plots treated with the Quattro products and the fertilizer showed very significant improvement in vegetation establishment over the existing sparse conditions on the road cuts, with the bunch grasses performing very well (the enhanced vegetation of these areas was still noticeable in the summer of 1998).

4. **US 95, North of Genesee (MP 332.5)**; hydroseeded May 22, 1997
   One-pass application; minibenched east-facing cut

Seed Mix #1: intermediate wheatgrass, sheep fescue, hard fescue, smooth brome, Sherman big bluegrass, timothy, annual ryegrass, alsike and white Dutch clover
Seed Mix #2: western wheatgrass, sheep fescue, Canada bluegrass, crested wheatgrass, creeping red fescue, Kura clover
Treatments: Wolfkill organic mix, Quattro Kiwi Power™, Fertil-Fibers™, wood-fiber mulch

Results: Seed Mix #2 showed slightly better performance than #1. Plots treated with Wolfkill + Kiwi Power™ and Fertil-Fibers™ + Kiwi Power™ showed very good vegetation establishment, with no apparent difference between these two applications (the Wolfkill plot did have more weeds than the Quattro plot). Wood-fiber mulch showed no apparent benefit in revegetation when compared to plots not so treated. Areas treated with the organic amendments continued to show enhanced vegetation into the summer of 1998.

5. **US 2, West of Sandpoint (MP 18 approx.)**; hydroseeded late May, 1997
   One-pass application; SE facing cut with rock mulch already applied (approx. 12-in. thick)

Seed Mix #1: western wheatgrass, sheep fescue, Canada bluegrass, crested wheatgrass, creeping red fescue, Kura clover
Treatments: Quattro Kiwi Power™ and Fertil-Fibers™, with some wood-fiber mulch

Results: Germination rates were poor, with very little vegetation being established (approx. 10% coverage by late summer); this suggests that hydroseeding should be done prior to spreading the rock mulch and probably only done during the fall season.

6. **US 95, North of Genesee (MP 332.5)**; broadcast seeded September 17, 1997
   Two-pass application; minibenched east-facing cut

Seed Mix #1: intermediate wheatgrass, meadow brome, creeping red fescue, Canada bluegrass, woods rose, white Dutch clover, oregon grape, snowberry (some wildflower mix also was included)
Treatments: Two different seeding rates (60 lb./ac. and 120 lb./ac.), Quattro Kiwi Power™

Results: Germination was generally poor, with the wheatgrass and bluegrass performing the best. A slightly greater density of plants was seen in the plot with the higher seeding rate, but this difference became minimal by the summer of 1998. Some wildflowers were showing, but no signs of any small shrubs were observed in summer, 1998.

7. **US 95, North of Weiser (MP 89.6)**; hydroseeded September 8, 1997
   One-pass application; north-facing cut

Seed Mix: Grassland West Competitor (sheep/hard fescue, intermediate wheatgrass, Sherman big bluegrass) plus some wildflower mix
Treatments: Two different seeding rates (40 lb./ac. and 80 lb./ac.), Quattro Fertil-Fibers™ and Kiwi Power™, Bonterra fiber wattles (used to help check slope erosion)

Results: In May of 1998, plant counts were taken in the area treated with wattles, because this area showed significant vegetation establishment. A one-quarter square meter sampling frame was used. For the lower seeding rate, there was an average of 128 plants/sq.m, and for the higher rate, there was an average of 231 plants/sq.m. Typically, in a semiarid region like this, a thriving plant community in decent soils would have about 100 - 200 plants/sq.m.

In September of 1998, the plots were resampled:

wattle area – plot with low seeding rate showed 161 plants/sq.m, and the plot with high seeding rate showed 280 plants/sq.m

no-wattle area – plots showed 43 and 68 plants/sq.m, respectively

The success shown in the wattle-treated area apparently was due to moisture retention and to runoff protection that helped hold seed and nutrients in place.

8. **US 95, North of Weiser (MP 91.5)**; hydroseeded November 7, 1997
   One-pass application; north-facing cut

Seed Mix: streambank wheatgrass, thickspike wheatgrass, western wheatgrass, cereal rye, plus some wildflower mix
Treatments: Two different seeding rates (40 lb./ac. and 80 lb./ac.), Quattro Fertil-Fibers™ and Kiwi Power™, Atlas SoilLok™ soil binder/tack

Results: In September of 1998, plant counts were taken in the test plot areas using 30-m long transects. A one-quarter square meter sampling frame was used.

Plot #1 – Kiwi Power™ 10 gal./ac, Fertil-Fibers™ 2000 lb./ac., SoilLok™ 50 gal./ac., coir/straw mulch 150 lb./ac., wood-fiber mulch 500 lb./ac.
Plant densities of 49 plants/sq.m and 205 plants/sq.m for the low and high seeding rates, respectively.

Plot #2 – Kiwi Power™ 10 gal./ac, Fertil-Fibers™ 2000 lb./ac., SoilLok™ 20 gal./ac., wood-fiber mulch 2000 lb./ac.
Plant densities of 61 plants/sq.m and 89 plants/sq.m for the low and high seeding rates, respectively.

Significantly better vegetation establishment was realized at the higher seeding rate for Plot #1, which likely is due to the higher rate of SoilLok, which binds surficial soils in place and helps prevent erosion of seed and nutrients on the slope. Some benefits also may have been realized by the new coir/straw experimental mulch that tends to provide a more consistent blanket on the slope than does wood fiber mulch.

9. **US 95, South of Genesee (MP 327.1)**; hydroseeded November 11, 1997
   One-pass application; north-facing cut

Seed Mix: ITD Standard North Idaho roadside mix (primarily bluegrass and fescue) plus some western wheatgrass and annual rye
Treatments: Two different seeding rates (40 lb./ac. and 80 lb./ac.), EKO yard-waste compost, Biosol™, Quattro Fertil-Fibers™ and Kiwi Power™, Atlas SoilLok™ soil binder/tack

Results: In September of 1998, plant counts were taken in the test plot areas using 30-m long transects. A one-quarter square meter sampling frame was used. Typically, in this north Idaho region, a thriving plant community in decent soils would have about 300 - 500 plants/sq.m.

Plot #1 – EKO compost approximately 400 cu.ft/ac., SoilLok™ 50 gal./ac.
Plant densities of 251 plants/sq.m and 383 plants/sq.m for the low and high seeding rates, respectively.

Plot #2 – Biosol™ 2000 lb./ac., SoilLok™ 50 gal./ac.
Plant densities of 320 plants/sq.m and 910 plants/sq.m for the low and high seeding rates, respectively.

Plot #3 -- Quattro Fertil-Fibers™ 2000 lb./ac., Kiwi Power™ 5 gal./ac., Atlas SoilLok™ 50 gal./ac.
Plant densities of 280 plants/sq.m and 842 plants/sq.m for the low and high seeding rates, respectively.

Statistical tests were not conducted on these data sets, but it appears that at the lower seeding rate of 40 lb./ac. there was no significant difference among the three plots. However, at the higher seeding rate, the compost did not perform nearly as well as the seed-meal based products.

Results from these seeding rate demonstration plots are preliminary and were intended to provide basic insight into the survival/germination rate of seed mixes applied by modern hydroseeding equipment. Follow-up studies should focus on not the raw weight of seed, but on the number of pure live seeds per unit weight (as provided by certified testing) for each species selected for the seeding program. However, these recently completed demonstration plots do indicate that hydroseeding rates on the order of 35 to 50 lb./ac. generally will suffice for disturbed roadway slopes when using the proper organic amendments.

All three test plots showed considerably more vegetation coverage (better than 70%) than the surrounding cuts (10 to 50% coverage) that were hydroseeded one week earlier by an ITD contractor using a traditional tank mix with chemical fertilizer and wood-fiber mulch. This comparison clearly shows the benefit for fall hydroseeding programs on roadway slopes with commercially available organic soil amendments and a high-quality soil binder, particularly in northern Idaho where autumn rains can cause extensive erosion on newly hydroseeded bare slopes.

STABILITY ANALYSIS OF SHALLOW-SEATED SLOPE FAILURES

To investigate shallow-seated slope failures that occur during wet conditions on roadway slopes (primarily cut slopes), a two-part study was conducted as part of this erosion control research project. The first component was an extensive direct-shear testing program on two types of moisture-sensitive soils: Palouse silty clay loess and a glacial-derived silt from the Sandpoint area. The second was an engineering back-analysis of shallow, translational (planar) slope failures mapped in northern Idaho. A modified infinite-slope computer model was used in this analysis.

Shallow soil slips (typically less than one meter deep) commonly occur on constructed highway slopes that are 2:1 or steeper, comprised of native clay or silt soils, and which are prone to repeated cycles of freeze-thaw and heavy rain events during otherwise cold weather. Such conditions can occur in the Inland Northwest from late fall through early spring, causing shallow-seated slope failures that fill roadside ditches with mud and leave bare erosion-prone scars on the slopes.

Direct-Shear Testing Results

A Wykeham-Farrance laboratory direct-shear apparatus with a 2.5-inch (63.5-mm) diameter shear box was used to test remolded soil samples collected from Palouse silty clays in the Moscow area and those collected from glacial silts west of Sandpoint. Testing was conducted in general accordance with ASTM D-3080. Water content of the remolded specimens was varied to help describe the relationship between moisture and shear strength. The laboratory shearing rate was a constant value of 0.3 mm per minute, and normal loads on the test specimens focused on a low range (for shallow failures), from 145 to 967 psf (6.9 to 46.3 kPa), but some test runs were conducted at higher normal loads, up to 3,160 psf (151.3 kPa). For each normal load, a shear-load vs. displacement curve was generated from the computer-acquired laboratory trace data. The peak shear load was identified on each plot so that the peak shear strength (stress) could be computed from the set of traces for each sample group at a given water content.

The testing was conducted in two phases, the first being a broad approach to examine the effects of moisture content on shear strength. Results of this testing are summarized in Table 4.1. They indicate that the shear strengths of the Palouse silty clays are more sensitive to moisture content than are the Sandpoint silts. For the selected range of normal loads, least-squares regression models were fitted to the testing data. If a linear model did not provide a reasonably good fit, then a nonlinear power model also was fitted to that particular normal-shear stress plot. Measures of “goodness” of fit for the models included the coefficient of linear correlation, R, and the mean absolute deviation, MAD.

The second phase of testing was more focused on lower levels of normal stress and the effects of submerging the test samples in a water bath during shearing. Examples of laboratory data sheets and load-displacement graphs for these direct-shear tests are given in Appendix A. Such graphs were used to develop the subsequent normal vs. shear stress plots, from which linear and power failure envelopes could be fitted by least-squares regression methods. Examples of these plots and results are given in Appendix B. The shear strength models are summarized in Table 4.2.

Table 4.1. Results of the first phase of direct-shear testing of remolded soils.

	Water	Shear Strength Model	Measure	Friction

Soil Type	Content (%)	(tonne/sq.m)	of Fit	Angle
Sandpoint glacial silt	1.4	linear: $\tau = 0.778\sigma + 0.739$	R = 0.991	38°
	10.0	linear: $\tau = 0.796\sigma + 0.113$	R = 0.982	38°
	15.0	linear: $\tau = 0.694\sigma + 0.612$	R = 0.999	35°
	21.0	linear: $\tau = 0.535\sigma + 1.147$	R = 0.932	28°
	21.0	power: $\tau = 1.496\sigma^{.565} + 0.0$	MAD=0.182	
Palouse loess silty clay	6.5	linear: $\tau = 0.836\sigma + 1.010$	R = 0.963	40°
	6.5	power: $\tau = 1.799\sigma^{.627} + 0.012$	MAD=0.181	
	20.8	linear: $\tau = 0.628\sigma + 0.684$	R = 0.997	32°
	20.8	power: $\tau = 1.251\sigma^{.674} + 0.0$	MAD=0.125	
	25.4	linear: $\tau = 0.222\sigma + 0.536$	R = 0.958	13°
	25.4	power: $\tau = 0.731\sigma^{.476} + 0.0$	MAD=0.109	

Note: R = coefficient of linear correlation; MAD = mean absolute deviation.
1 tonne/sq.m = 9.81 kPa = 1.42 psi = 204.8 psf

Table 4.2. Results of the second phase of direct-shear testing of remolded soils, emphasizing low normal stresses in the range 0.7 to 3.0 tonnes per square meter (tsm).

Soil Type	Water Content (%)	Shear Strength Model (tonne/sq.m)	Measure of Fit	Friction Angle
Sandpoint glacial silt	2	linear: $\tau = 0.836\sigma + 2.733$	R = 0.993	40°
		power: $\tau = 2.655\sigma^{.639} + 0.0$	MAD=0.453	

	10	linear: $\tau = 0.697\sigma + 2.517$	R = 0.998	35^{o}
		power: $\tau = 2.365\sigma^{.628} + 0.0$	MAD=0.599	
	15	linear: $\tau = 0.616\sigma + 2.351$	R = 0.971	32^{o}
		power: $\tau = 2.263\sigma^{.598} + 0.025$	MAD=0.340	
	21	linear: $\tau = 0.594\sigma + 1.397$	R = 0.917	31^{o}
		power: $\tau = 2.263\sigma^{.598} + 0.025$	MAD=0.340	
	23*	linear: $\tau = 0.733\sigma + 0.331$	R = 0.998	36^{o}
		power: $\tau = 0.891\sigma^{.935} + 0.0$	MAD=0.165	
Palouse loess silty clay	5	linear: $\tau = 1.104\sigma + 0.643$	R = 0.998	47^{o}
		power: $\tau = 1.358\sigma^{.939} + 0.0$	MAD=0.391	
	16	linear: $\tau = 0.661\sigma + 3.490$	R = 0.978	33^{o}
		power: $\tau = 3.677\sigma^{.417} + 0.0$	MAD=0.152	
	20	linear: $\tau = 0.762\sigma + 2.459$	R = 0.994	37^{o}
		power: $\tau = 2.331\sigma^{.656} + 0.0$	MAD=0.465	
	26	linear: $\tau = 0.231\sigma + 1.484$	R = 0.895	13^{o}
		power: $\tau = 1.334\sigma^{.483} + 0.009$	MAD=0.428	
	28*	linear: $\tau = 0.654\sigma + 0.516$	R = 0.994	33^{o}
		power: $\tau = 1.013\sigma^{.839} + 0.0$	MAD=0.204	

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* Original water content was 17-18% for remolding, then the specimens were submerged in a water bath for shearing.
1 tonne/sq.m = 9.81 kPa = 1.42 psi = 204.8 psf

Results from the second phase of testing confirmed the initial results from the earlier work. That is, the Palouse loess soils have a shear strength that is much more sensitive to moisture content than that of the Sandpoint silts. When the remolded water content of the loess approaches 24-25%, the friction angle can be as low as 13^{o}. Testing at the lower normal stresses also seemed to produce consistently higher apparent cohesion values for both types of soil (compare the cohesion values in Tables 4.1 and 4.2). For example, the Sandpoint silt samples at a moisture content of 15% had an apparent cohesion of 0.612 tsm when tested at higher normal stresses, but a value of 2.351 tsm when tested at lower stress levels. Also, the Palouse loess samples at a moisture content of 20% had an apparent cohesion of 0.684 tsm versus 2.459 tsm for lower normals being included in the analysis. If these higher cohesion values are used as part of the shear strength input for slope stability analyses of shallow failure modes, experience has shown that the computed safety factors will be unrealistically high. Thus, the power shear-strength model may be preferred to the linear one for such analyses.

The other important result from this testing program was that the initial moisture content used to remold and pack the soil in the shear box has a greater influence on shear strength than does submerging and saturating the specimen with water after it has been placed in the shear box. Apparently, the structure, packing, and density of the remolded specimens dictate the resulting shear strength, regardless of subsequent wetting and increased moisture content. The series of test specimens denoted in Table 4.2 by the * symbol were remolded and packed into the shear box at a moisture content of 17 to 18%. Prior to shearing, the specimens were submerged in water in the shear box; after shearing, the moisture content was measured at 23% for the Sandpoint silt and 28% for the loess soil. However, the resulting friction angles reflected values expected at a water content of 17% rather than at the higher levels (36^{o} friction angle for the silt and 33^{o} for the loess). If the specimens had been remolded at these higher moisture contents, the resulting friction angles likely would have been much lower. Consequently, care must be taken in the laboratory with regard to moisture content when remolding specimens for direct-shear testing; also, compacted fills in the field should be monitored carefully to avoid fill placement at moisture contents greater than those specified by the engineer (as per Proctor compaction test results).

Back-Analysis of Translational Slope Failures

Initial field work for this study consisted of mapping/describing roadway slope failures in the Moscow-Lewiston area during the summer and fall of 1996. Of the 15 sites visited, seven of the planar slope failures were subsequently analyzed using a modified infinite slope computer model. The traditional infinite slope model was modified in two ways. First, the shear strength model for the soil was converted to a general failure envelope (rather than a linear, Mohr-Coulomb envelope), so that both a nonlinear power model and a linear model could be used in the slope stability analysis. Second, an option was added for handling seepage forces due to the movement of groundwater down the slope parallel to the failure surface. Both of these changes provided results in the analysis that were more realistic and more consistent with field-observed conditions than output from the traditional infinite slope model.

Transient soil properties used in the following analyses were based on experience with Palouse loess soils and research conducted in the last decade at the University of Idaho and Washington State University. Shear strengths were based on the testing results presented in Tables 4.1 and 4.2.

Dry unit weight, $\gamma_d = 1.45$ tcm (90.5 pcf)

Moisture content, w = 20% and 25%

Total unit weight, $\gamma_t = \gamma_d(1 + w)$

Unit wt. of water, $\gamma_w = 1.0$ tcm (62.4 pcf)

Specific gravity of solids, $G_s = 2.65$ Saturated density, $\gamma_{sat} = \gamma_w + \gamma_d[1 - (1/G_s)]$

$\gamma_{sat} = 1.90$ tcm (118.8 pcf)

Moisture content at saturated condition, $w_{sat} = (\gamma_{sat}/\gamma_d) - 1 = 31\%$

Root cohesion considered as a function of soil depth (primarily sod grass vegetation; adapted from Gray and Sotir, 1996, "Biotechnical and Soil Bioengineering Slope Stabilization", John Wiley & Sons):

Depth (m)	Root Cohesion, c_r (tsm)
0.15	0.27
0.30	0.23
0.46	0.20
0.61	0.16

Shear Strength:

w = 20% Linear model: $\phi = 32^o$, c = 0.6 tsm; Power model: A = 1.251, B = 0.674

w = 25% Linear model: $\phi = 13^o$, c = 0.4 tsm; Power model: A = 0.731, B = 0.476

Key to safety factor computations:

SF_{L1} = traditional infinite slope model; linear shear-strength model
SF_{L2} = infinite slope model with seepage forces; linear shear-strength model

SF_{P1} = traditional infinite slope model; power shear-strength model
SF_{P2} = infinite slope model with seepage forces; power shear-strength model

Site 1 – Junction of US 95 and SH 66; Translational Slope Failure on a Fill Slope

Slope Angle 40° Avg. Depth (Thickness) of Failure 0.54 m

Results of back analysis:

Water Content %	Ht. of Groundwater (m)	Computed Safety Factor Values SF_{L1}	 SF_{L2}	 SF_{P1}	 SF_{P2}
20	0.0	2.41	2.41	2.18	2.18

	0.13	2.27	1.92	1.98	1.68
	0.27	2.13	1.57	1.79	1.32
	0.41	2.00	1.31	1.60	1.05
	0.54	1.88	1.11	1.40	0.83
25	0.0	1.46	1.46	1.52	1.52
	0.13	1.41	1.20	1.43	1.21
	0.27	1.36	1.00	1.34	0.99
	0.41	1.31	0.86	1.24	0.81
	0.54	1.26	0.75	1.13	0.67

Site 2 – Junction of US 95 and Rudd Rd.; Translational Slope Failure on a Cut Slope

Slope Angle 37° Avg. Depth (Thickness) of Failure 0.4 m

Results of back analysis:

Water Content	Ht. of Groundwater	Computed Safety Factor Values			
%	(m)	SF_{L1}	SF_{L2}	SF_{P1}	SF_{P2}
20	0.0	3.25	3.25	2.79	2.79
	0.1	3.08	2.62	2.55	2.17
	0.2	2.92	2.17	2.32	1.72
	0.3	2.76	1.83	2.08	1.38
	0.4	2.61	1.57	1.85	1.11
25	0.0	2.06	2.06	2.06	2.06
	0.1	1.99	1.71	1.94	1.66
	0.2	1.93	1.45	1.83	1.37
	0.3	1.87	1.25	1.70	1.13
	0.4	1.82	1.09	1.57	0.95

Site 3 – SH 9 Northwest of Avon; Translational Slope Failure on a Cut Slope

Slope Angle 42° Avg. Depth (Thickness) of Failure 0.3 m

Results of back analysis:

Water Content	Ht. of Groundwater	Computed Safety Factor Values			
%	(m)	SF_{L1}	SF_{L2}	SF_{P1}	SF_{P2}
20	0.0	3.89	3.89	2.97	2.97
	0.08	3.72	3.13	2.73	2.30

	0.15	3.56	2.60	2.50	1.83
	0.23	3.41	2.21	2.27	1.47
	0.30	3.26	1.91	2.04	1.19
25	0.0	2.59	2.59	2.38	2.38
	0.08	2.53	2.13	2.26	1.91
	0.15	2.46	1.81	2.13	1.56
	0.23	2.40	1.56	1.99	1.29
	0.30	2.34	1.37	1.85	1.08

Site 4 – US 95 South of Eid Rd.; Translational Slope Failure on a Cut Slope

Slope Angle 37° Avg. Depth (Thickness) of Failure 0.64 m

Results of back analysis:

Water Content	Ht. of Groundwater	Computed Safety Factor Values			
%	(m)	SF_{L1}	SF_{L2}	SF_{P1}	SF_{P2}
20	0.0	2.23	2.23	2.14	2.14
	0.16	2.08	1.77	1.94	1.65
	0.32	1.94	1.44	1.74	1.29
	0.48	1.81	1.20	1.55	1.03
	0.64	1.68	1.01	1.35	0.81
25	0.0	1.29	1.29	1.41	1.41
	0.16	1.24	1.06	1.32	1.13
	0.32	1.19	0.89	1.23	0.92
	0.48	1.14	0.76	1.14	0.76
	0.64	1.09	0.66	1.03	0.62

Site 6 – Eid Rd. South of Jnc. with Lenville Rd.; Translational Slope Failure on a Cut Slope

Slope Angle 44° Avg. Depth (Thickness) of Failure 0.2 m

Results of back analysis:

Water Content	Ht. of Groundwater	Computed Safety Factor Values			
%	(m)	SF_{L1}	SF_{L2}	SF_{P1}	SF_{P2}
20	0.0	5.42	5.42	3.59	3.59
	0.05	5.22	4.37	3.32	2.78
	0.10	5.03	3.64	3.06	2.22

	0.15	4.85	3.11	2.80	1.80
	0.20	4.68	2.70	2.54	1.47
25	0.0	3.72	3.72	3.09	3.09
	0.05	3.65	3.06	2.94	2.47
	0.10	3.57	2.60	2.79	2.03
	0.15	3.50	2.25	2.63	1.69
	0.20	3.43	1.98	2.46	1.42

Site 13 – Junction of Burr Rd. and Danielson Rd.; Translational Slope Failure on a Fill Slope

Slope Angle 33° Avg. Depth (Thickness) of Failure 0.4 m

Results of back analysis:

Water Content	Ht. of Groundwater	Computed Safety Factor Values			
%	(m)	SF_{L1}	SF_{L2}	SF_{P1}	SF_{P2}
20	0.0	3.51	3.51	3.09	3.09
	0.1	3.32	2.84	2.83	2.42
	0.2	3.13	2.36	2.56	1.93
	0.3	2.96	2.00	2.30	1.55
	0.4	2.79	1.71	2.03	1.25
25	0.0	2.20	2.20	2.24	2.24
	0.1	2.13	1.83	2.11	1.82
	0.2	2.06	1.56	1.98	1.50
	0.3	1.99	1.35	1.85	1.25
	0.4	1.93	1.18	1.70	1.05

Site 14 – Greiser Rd. West of Jnc. with US 95; Translational Slope Failure on a Cut Slope

Slope Angle 38° Avg. Depth (Thickness) of Failure 0.3 m

Results of back analysis:

Water Content	Ht. of Groundwater	Computed Safety Factor Values			
%	(m)	SF_{L1}	SF_{L2}	SF_{P1}	SF_{P2}
20	0.0	4.08	4.08	3.22	3.22
	0.08	3.89	3.30	2.96	2.51
	0.15	3.71	2.75	2.70	2.00
	0.23	3.54	2.34	2.45	1.62

	0.30	3.38	2.03	2.19	1.31
25	0.0	2.69	2.69	2.53	2.53
	0.08	2.62	2.23	2.39	2.04
	0.15	2.55	1.90	2.26	1.68
	0.23	2.48	1.65	2.11	1.40
	0.30	2.42	1.45	1.96	1.18

Overall, results of these stability analyses tend to be non-conservative (i.e., the computed safety factor values exceed 1.0, indicating stability when an actual slope failure has occurred). This condition is most pronounced for the shallow failures less than 0.4 m in thickness (Sites 3, 6, and 14). In fact, none of the calculated safety factor values from the traditional infinite slope model is less than 1.0, even for saturated conditions. Thus, unless artificially low values of cohesion are assumed, the traditional model should be rejected in favor of one that incorporates seepage forces into the stability analysis (note the realistic safety factor values listed under SF_{L2} and SF_{P2} for Site 4).

In order to provide more realistic output for **very shallow** slope failures, the infinite slope model must include lower values of soil cohesion and/or root cohesion. For example, if root cohesion, c_r, is reduced to 0.10 tsm (instead of 0.23 tsm) for Site 6, the SF_{P2} value for saturated conditions is approximately 1.0. If the soil cohesion, c, is reduced to zero, then the linear shear-strength model for Site 6 predicts SF values less than 1.0 for partially saturated conditions when the infinite slope model with seepage forces is applied.

Assuming conservative conditions of 25% moisture content, nearly saturated conditions, $c_r = 0.0$ (for newly constructed slope with no vegetation), and a nonlinear shear-strength model, the infinite slope model with seepage forces indicates that slopes flatter than 26° (2H:1V) should not experience shallow translational failures in loess soils typical to the Palouse region in northern Idaho (0.3m depth – SF=1.23). For the Sandpoint silts, the constructed slopes should be flatter than 33° (1.5H:1V) to avoid shallow translational failures (0.4m depth – SF=1.22). This does not imply that all slopes steeper than these angles will fail; rather, that steeper slopes will be prone to shallow failures during persistently wet weather conditions. These guidelines are based on limiting-equilibrium slope stability considerations only, and do not include any potential slope degradation by surface erosion. Thus, a prudent erosion control plan for newly constructed or altered roadway slopes is recommended to maintain the slope integrity.

Case Study of Soil-Pinned Geosynthetic Reinforcement

One method proposed to treat shallow-seated slope failures along roadways is to provide temporary structural support to the near-surface zone. These shallow failures often occur on slopes that are vegetated with reasonably good stands of grass, but which have rooting depths insufficient to prevent such failures during very wet periods. The establishment of deeper-rooted shrubs (such as woods rose, snowberry, oregon grape) could help stabilize the slopes and resist such failures. However, after seeding or transplanting, these shrubs require several years to become sufficiently mature and pervasive enough to provide bio-geotechnical support to a slope. Thus, some type of artificial support is needed to support the near-surface zone for five to ten years until the shrubs get well established.

A field demonstration study was conducted on US 95 south of Moscow, where a geogrid-reinforced, synthetic erosion control blanket was pinned to the slope using 1.2-meter long steel dowels. The continuously threaded dowels were pushed into the slope using a backhoe bucket, then capped with small steel plates. They provide some shear resistance to the slope and a compressive load due to the tightening of threaded nuts against the steel plates at the ground surface. Details of the September 1997 field installation are given below.

The slope-failure scar was smoothed and dressed with the backhoe bucket. This was necessary because some erosional rills had formed on the bare cutslope, and a reasonably smooth surface was needed for anchoring the geogrid-backed erosion control blanket. A regular, staggered pattern for the soil pins was laid out using a uniform 2-m spacing. The soil pins consisted of continuous-threaded, No. 6, grade 70 steel dowels, which were pushed into the ground using the backhoe bucket. Approximately 125 mm of each dowel was left protruding from the ground. A few of the dowels encountered strong resistance in the subsurface and bent prior to reaching the desired penetration depth. These were cut off to the correct length; the continuous-threaded bars were well adapted for this application, because plates and nuts could be installed readily on such cut-off bars.

Prior to installing the reinforced erosion control blanket, the slope was hydroseeded with Quattro organic soil amendments (Kiwi Power^{TM} and Fertil-Fibers^{TM}) and a seed mix that included: intermediate wheatgrass, meadow brome, creeping red fescue, Canada bluegrass, woods rose, white Dutch clover, Oregon grape, and snowberry. The shrub seeds were added to provide species diversity and deeper rooted vegetation for future bio-geotechnical stabilization of the slope.

A typical rolled synthetic erosion control blanket measuring 2.29 x 27.43 m (7.5 x 90 ft) and consisting of polypropylene fibers and UV-stabilized netting with an overall weight of 10 oz./sq.yd. (BonTerra SFB10^{TM}) was reinforced by sewing on a backing of geogrid. This grid was a flexible, PVC-coated polyester yarn grid (Huesker Fortrac^{TM}) with a rated wide-width tensile strength of 3,700 lb./ft (5.02 kN/m) in the machine direction and 2,020 lb./ft (2.74 kN/m) in the cross direction. The sewing was done by specially adapted machinery at the BonTerra manufacturing facility in Genesee, Idaho. Two of these composite rolls were spread out on the slope and then placed over the protruding steel dowels. Along the top edge of the upper blanket, a shallow trench was excavated so that the blanket could be keyed into the slope to prevent undercutting by runoff water. This edge, the overlap joint in mid-slope, and the edge along the toe of the slope were secured to the ground with 9-gauge wire staples, 150-mm long. Square steel plates (152 x 152 mm) and threaded nuts then were placed over the dowels, "clamping" down the blanket to the ground surface. The nuts were tightened by hand using a large wrench and cheater bar. Post-tensioning of the blanket system was achieved by having the backhoe operator use the hydraulic bucket to push each dowel/plate another 10 - 30 mm into the ground.

The cost for this slope reinforcement treatment was estimated according to the following schedule of unit costs:

geogrid-reinforced erosion-control blanket	\$8.90/sq.yd. (\$9.74/sq.m)

hydroseeding and soil amendments	$0.25/sq.yd. ($0.27/sq.m)
one steel dowel, one plate, one nut	$9.60 per each set
equipment/backhoe time	7 hours at $65/hr.
labor	18 manhours at avg. of $15/hr
Total	$17.55/sq.yd. ($19.20/sq.m)

The total area treated was approximately 120 sq.yd. (131 sq.m).

Due to the time and expense involved in such an operation, this slope reinforcement treatment is recommended only for those areas along roadways where persistent slope failures occur or where a slope cut is designed to be overly steepened due to preservation of right-of-way or for construction convenience.

Following an extended period of wet weather in November-December 1997, several small mud flows occurred near the top of the slope and ran down across the blanket-treated area; none reached the bottom of the slope. Some of the grass seed germinated in the fall, and small plants began showing through the blanket by late November. By the spring and summer of 1998, several species of grasses were growing through the blanket, and a few small leafy forbs or shrubs were visible, some believed to be woods rose. Overall vegetation coverage was about 60 to 70% of the treated area, with a greater density near the toe of the slope, where seed and nutrients tended to concentrate during the hydroseeding operation. The sod-forming grasses and rhizomatous shrubs selected for this project should eventually fill in most of the area covered by the geogrid-reinforced erosion control blanket. This site will continue to be monitored over the next several years.

CONCLUSIONS AND RECOMMENDATIONS

Field demonstration plots along roadways in western and northern Idaho have shown that hydroseeding and shrub transplanting programs can be significantly enhanced by the use of properly selected soil amendments. Organic amendments and biostimulants apparently provide immediate improvements to the soil health and microlife essential to rebuilding a sustainable growth regime at disturbed sites where there is little or no topsoil. The vast improvement over traditional hydroseeding operations based on chemical fertilizers and wood fiber mulch were evidenced in side-by-side comparisons at study sites north of Weiser (US 95) and near Genesee, Moscow, and Viola (US 95). Such improvements were recognized through visual field inspections and by soil fertility tests conducted at the University of Idaho Analytical Sciences Laboratory. Though initial costs of these soil amendments may be 10 to 25% higher than most current practices, the likelihood of obtaining sustainable revegetation is vastly improved and likely will eliminate the need to retreat areas or deal with future chronic slope and ditch maintenance problems.

Structural erosion control practices on hydroseeded bare slopes were shown to further enhance revegetation, particularly on easily eroded slopes. Straw erosion control blankets installed after hydroseeding operations near Viola (US 95, northern Idaho) and near Weiser (US 95, southwestern Idaho) showed markedly better revegetation success than adjacent unblanketed areas when organic soil amendments were included in the hydroseeding program. One demonstration plot near Weiser included the installation of fiber wattles along slope contours in the fall of 1997. This wattle-treated area showed nearly five times the plant density of adjacent areas during a follow-up plant density count in the spring of 1998. Apparently, the wattles enhanced moisture retention and runoff protection that helped hold seed and nutrients in place throughout the winter on the highly erodable slope.

Seeding rates of 40 lb./ac. and 80 lb./ac. for typical grass seed mixes were compared at study sites near Weiser and Genesee. In both locations, the lower seeding rates seemed to provide adequate plant establishment during the first year, but this success likely resulted from the use of organic soil amendments. When such treatments are used, seeding rates greater than 35-40 lb./ac. are probably not justified. Designers need to consider a number of factors when specifying seed mixes and rates, including the size of seeds (number per pound), the percentage of pure live seed (PLS), and the local climate and soil conditions.

Survival rates of transplanted shrubs or trees can be significantly improved by using a water gel product known as DriWater^{TM}. This product provides slow-release irrigation to the root zone of plants to sustain them through the dry summer months in the Inland Northwest. It also extends the transplanting season throughout the summer, instead of being limited to the early spring and fall of the year. Nearly 87% of shrubs planted with this product in the mid-summer of 1996 survived. A spring 1997 planting program that compared treated with untreated plants indicated that the treated population had statistically higher survival rates than the untreated population.

Generally, shrubs planted in larger stock containers (1 gal. size vs. 10 cu.in. size) had the best survival rates, especially for the study sites in arid southwestern Idaho. Species that performed well here were silver sage and big sage. In northern Idaho, woods rose tended to have greater success than other native species, such as snowberry and Oregon grape. Also, in general, transplants treated with topsoil did not appear to have significantly higher survival rates than those not treated with topsoil. If transplants survived for at least one year, then they appeared to be permanently established, unless they were later damaged by predators. In most cases, shrubs that did not survive the first year had died within the first few weeks after transplanting.

An extensive direct-shear testing program was conducted to investigate shear strengths of remolded Palouse loess soil (silty clay) and Sandpoint glacial silt. Shear strength of the loess was much more sensitive to moisture content than was that of the Sandpoint silt. Dry loess (moisture content of 5-6%) had a friction angle of 40 - 47^{o}, whereas wet loess (moisture content of 25%) had a friction angle of 13^{o}. The corresponding drop for the Sandpoint silt was from 40^{o} to 28^{o}. Both linear and nonlinear (power curve) shear-strength envelopes were fitted to the direct shear data. For shallow-seated slope failures having low normal stresses, the power-envelope often provides a better description of shear strength, as demonstrated by back analyses of actual slope failures. The apparent cohesion that results from fitting a linear model often causes unrealistically high safety factors to be computed for shallow slope failures.

The infinite slope model was used to analyze seven translational slope failures mapped in the Moscow-Lewiston region. A traditional analysis based on the infinite slope model and a linear shear-strength envelope produced safety factors greater than one, even for saturated conditions. The computer model was modified to include seepage forces as groundwater migrates through the potential failure mass. The combined use of seepage forces and a nonlinear (power) shear-strength model produced more realistic safety factor values in the 0.7 to 1.1 range for the failed slope geometries. However, for the most shallow of slope failures (0.2 m for this study), the predicted root cohesion had to be reduced to zero to obtain viable safety factor values.

Results of the back analyses indicated that to avoid chronic slope stability problems due to shallow translational failures in loess soils of the Palouse region in northern Idaho, slopes should be constructed no steeper than 26^o (2H:1V). For the Sandpoint silts, the constructed slopes should be flatter than 33^o (1.5H:1V) to avoid shallow translational failures. This does not imply that all slopes steeper than these angles will fail; rather, that steeper slopes will be prone to shallow failures during persistently wet weather conditions. These guidelines are based on limiting-equilibrium slope stability considerations only. The surface of a newly constructed slope also needs to be treated with erosion control measures.

When overall slopes need to be steeper than the above recommended angles due to construction cost or limited corridor width, then a split slope configuration is recommended for cut slopes, whereby a flatter angle (say, 26^o) extends back from the road ditch and then breaks to a much steeper angle ($75\text{-}85^o$) at the back of the cut. If this face is not too high (say, less than 3-4 m), overall stability is not a major concern because water infiltration is minimized on the near-vertical face. For fill slopes that need to be steepened, the preferred option likely will be geosynthetic reinforcement layers placed as the compaction lifts are built up in the fill. This will provide internal strength to the fill slope. Soil-pinned geosynthetic blankets also can be used in problem areas to stabilize the near-surface section of the slope.