

was not restored and downcutting continues. It is likely that several more moderate to large storms, similar to the 1999 storm, will be necessary to erode enough fill to allow nature to stabilize the road/stream crossings. Future contracts should be done by "time and equipment," with an inspector directing the work at each stream crossing and removing enough fill to stabilize road/stream crossings and prevent unnecessary erosion.

What Next?

The watershed monitoring plan has been implemented, and data continue to be collected to further determine the effects of the completed restoration projects. The next scheduled date for an interdisciplinary report of monitoring results is 2010. ~

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Biotechnical Slope Stabilization in Sheep Creek

Pierre Raymond and Dave Putt

In the spring of 1999, a debris slide and earth flow occurred on Sheep Creek Road near Salmo, B.C. The following year, Terra Erosion Control Ltd., in association with Dave Putt of Forterra Consultants Ltd., was retained by the B.C. Ministry of Transportation and Highways (MOTH) to do a field review and recommend biotechnical slope stabilization treatments. Terra Erosion Control implemented the project in May 2001 as a trial for the MOTH. Though the site was challenging for slope stabilization, the work to date has significantly reduced slide and earth flow activity at a cost substantially lower than conventional engineering treatments (e.g., geotextile and rock ballast). This article describes the biotechnical stabilization methods, maintenance, and monitoring work undertaken on site 1 (above the road) and site 2 (below the road, directly above Sheep Creek).

Background

The restoration site lies in the lower Sheep Creek drainage, approximately 11 km southeast of Salmo in southeastern British Columbia. Sheep Creek is a major tributary of the Salmo River, which has a high value sport fishery. This area receives about

750 mm of precipitation annually, most of which falls as snow. Mining development throughout the 20th century has been a major cause of impacts in this drainage. The initial debris slide and earthflow occurred in the spring of 1999, blocking Sheep Creek Road and running into Sheep Creek. A smaller debris slide and earthflow in spring of 2000 again spilled over the road into Sheep

Creek. These failures may have been related to old mining activities that altered the drainage patterns on the area upslope, although inspection did not reveal obvious drainage concentration. Removal of toe support during road construction is a likely contributing factor to the instability of site 1.

In April 2001, the MOTH considered three options other than biotechnical

slope stabilization:

- placing rock ballast on the toe and lower portion of the slide area above the road (site 1) (\$150,000);
- constructing a berm at the toe of the slide (\$30,000) with additional annual cleanout and endhauling costs; and
- annually cleaning the ditch and endhauling material deposited on the road (\$2,500).

The total cost for the biotechnical slope stabilization project, including

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monitoring and maintenance in 2001, was \$29,000. As only site 1 was to be treated, none of the above-proposed treatments would have reduced sedimentation into Sheep Creek from site 2, the fill slope below the road.



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Figure 1. Site 1 prior to project commencement.

flow which failed/flowed onto and over the road (Figure 1). The failure was approximately 30 m wide by 46 m long by a height at the failure headwall of 10 m. Total slide volume was more than 3000 m³. Gradients on the slide headwall ranged from 80 to 150% and from 30 to 60% on the debris at the toe of the slide. The material is primarily interbedded, glaciolacustrine silt and sand with some clay that is overlain by glaciofluvial sand and gravel. The glaciofluvial material is dry, loose, and well to rapidly drained. The underlying glaciolacustrine materials are poorly drained and include extensive areas of seepage. The water table is perched on silt and clay layers at several locations.

The site below the road (site 2) is a road fill slope (gravel, sand, and silt from site 1) with sidecast directly into Sheep Creek (Figure 2). The failing portion of the fill slope is 31 m long by 10 m wide. The fill slope gradients are 80–100%.

Remediation Measures

Site 1

Combinations of biotechnical slope stabilization methods were used on both sites to re-establish vegetation and provide stability. On site 1, modified brush layers were installed on the upper section in the glaciofluvial materials. These structures aimed to reduce the raveling of sands and gravels. Contour fascines and drain fascines used in combination with central live pole drains were installed to stabilize the areas with seepage and control excess surface water and seepage on the site.

As a ditch line retaining structure, a combination of live fascines and brush layers was used to prevent sloughing of materials. Pieces of semi-rotten logs were placed within the brush layer fill to supply organic material and to provide aeration to enhance root growth.

Live stakes 1.0–1.5 m in length were planted in the accumulated sandy debris in the slide runout zone to help stabilize accumulated materials. Wattle fences were also installed above the live pole drains to retain materials and prevent them from falling and obstructing the drains.

Objectives

The primary objectives were to stabilize the slope to avoid further road obstruction, to slow and eventually stop annual debris slides and earth flows above the road, and to reduce shallow debris slides on the fill slope below the road. As well, treatments were intended to substantially reduce sedimentation into Sheep Creek from both surface erosion and stream erosion at high flow. A secondary objective was to restore some riparian zone cover and function to improve local fish habitat.

Site Description

The main failure above the road (site 1) is a translational debris slide/earth



Figure 2. Site 2 prior to project commencement.

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Figure 3. Contour facine installation.



Figure 4. Site 1: Live pole drain installation.

Site 2

Treatment of site 2—the top of the fill slope immediately below the road bed—consisted of a combination of contour fascines with brush layers. This structure helps to keep road sidecast material from raveling and eroding. Modified brush layers were installed in a staggered pattern, between the creek high water mark and the contour fascines/brush layer structure at the top of the bank.

Both sites were hydroseeded with a balanced successional seed mix to reduce surface erosion. Sitka mountain alder (*Alnus incana ssp. tenuifolia*) seedlings were also planted on both sites to provide further stabilization and nitrogen fixation.

Live Materials and Implementation

The live materials used in the structures were composed of cuttings—75% black cottonwood (*Populus balsamifera ssp. trichocarpa*), 10% willow (*Salix scouleriana*), and 15% red-osier dogwood (*Cornus sericea*), all species that root easily. The high proportion of cottonwood was based on experience at other locations in southeastern British Columbia, where cottonwood has been found to best withstand the dry summers. Materials were gathered within 5 km of the site in late April 2001 and stored in water for 6–8 days to promote initial root growth.

A crew of seven people installed the structures in May 2001 (Figures 3, 4).

The brush layer materials were prepared by dipping the buried portion in a mixture of polymer moisture retainer and rooting hormone. This process helps to retain available moisture for the plant and promotes initial rooting. The exposed portion of the brush layers and live stakes were painted with a mix of 50% latex paint and 50% water to reduce desiccation and disease entry.



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Figure 5. Site 1 post treatment.

Results to Date

The above treatments have to date significantly reduced slide and earth flow activity in areas where, before the treatment, slides and earth flows occurred both onto the road and fill slope. About 95% of the structures sprouted in the first growing season; overall shoot growth averaged 70 cm, and alder height growth averaged 63 cm. Live pole drains were functioning

very well and remained in place after a heavy snowmelt. A few small failures of <math><200\text{ m}^3</math> occurred from the head and sidewall scarp, causing the collapse of some modified brush layer structures located below them. Overall, approximately 10% of structures failed, a rate within expectations.

Maintenance and repair were carried out in 2002. First-year growth was

pruned to help balance root and stem growth, failed structures were repaired, and debris accumulated on live pole drains was excavated.

Currently, the site is approximately 90% rehabilitated (Figure 5). Some of the very steep slopes (>120%) have again sloughed in spite of the 2002 repair work. Most of the sloughs are not in critical areas and are not significantly contributing to sediment delivery to the creek. In retrospect some of this sloughing could have been prevented if the slope angle had been reduced using machinery. Modified brush layers on both sites 1 and 2 showed dieback of approximately 40% on the drier areas. This may be due to competition from hydroseeded grasses and legumes. Shoot growth on the main structures ranges from 70 to 230 cm for an overall average of 150 cm.

Lessons Learned

- The use of a spyder hoe, had it been available (Editor's note: see Streamline Vol. 2/No.4), would have been an economical option for installing most of the structures on this site (<math><80\%</math> slope angle) at a cost similar to manual installation. It could be used to reduce the

slope angle and to move large boulders that could not be moved manually. By digging deeper trenches, the spyder hoe would also allow for the use of longer cuttings in the brush layers. This change would increase survival rate and provide deeper rooting.

- Pruning treatment, which was meant to balance top growth with root growth, was probably unnecessary given the good root growth in the first year.
- Where very dry summers are likely, the use of a higher component of black cottonwood is critical to successful revegetation/stabilization using cuttings.

Conclusion

This case study describes a cost-effective solution to restoring a landslide hazard site and partially restoring a riparian habitat ecosystem by stabilizing the soil and re-establishing vegetation. Implemented at a site with extremes of slope steepness and unstable materials, the biotechnical slope stabilization techniques successfully reduced slide and earth flow activity at one-fifth the cost of the alternative permanent conventional engineering treatments. ~

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A spyder hoe would have been an economical option for installing most of the structures on this site ($\leq 80\%$ slope angle) at a cost similar to manual installation.