Schuster Slope Landscape Management Plan Revisited

A re-design plan for a steep slope restoration project in the Pacific Northwest

Luís Yañez

12/3/2019

Submitted in partial fulfillment of the requirement of the

Masters in Natural Resources Degree

Oregon State University

Table of Contents

Abstract 2
Introduction 3
Bioengineering for Steep Slopes 7
Schuster Slope Restoration Project 11
Restoration Activities to Date 15
Treatment Plot 6 18
Recommendations for a Revised Restoration Plan 26
Conclusion 35
References 40
Appendix A. Figures 45
Appendix B. Tables 48
Appendix C. Maps 52
Appendix D. Photos 54
Appendix E. Installation Methods. 59

Abstract

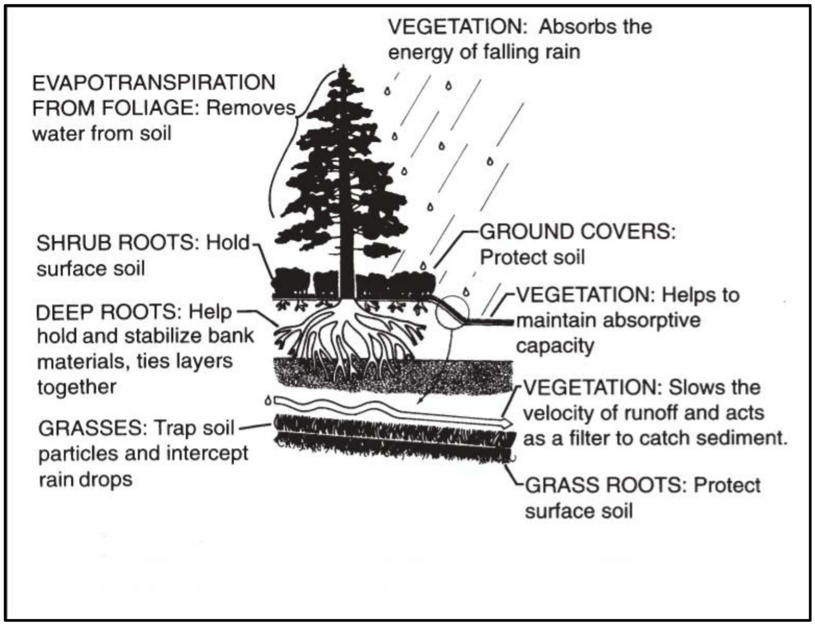
Proper steep slopes management in urban settings are important to protect human life and property and only becoming more necessary as density of urban populations increases. A low-tech solution to manage slopes is bioengineering, which consists of using plant materials, rock, and soil in various configurations to stabilize slopes. This project evaluates the efficacy of on-going restoration work on the Schuster Slopes in Tacoma, Washington. Restoration work on these steep slopes has shown low plant establishment success and continued erosion despite high materials cost and several years of work. Alternative bioengineering methods to establish vegetation and stabilize slopes are proposed. Methods recommended include live cribwalls, modified brush layers, and live pole drains.

Introduction

Dramatic panoramic views from the top of hills and cliffs have always been highly prized in human history. Having the high ground gave ancient towns and castles a vantage view against invaders. The Greek Acropolis sits high above the city to impress the importance of the government and the rule of law. Modern societies too, value views from the top especially if the views afforded are over large bodies of water. For example, family homes with unobstructed water views can be appraised for between 15-80% more than a similar home without such a view (Pruser, 2010). Sweeping panoramas over a countryside or a water body may come into conflict with sustainable natural resource management, when clearing the view includes removing the vegetation important for the stability of the slopes. Preserving or creating broad vistas is compatible with slope stability through careful vegetation management such as tree trimming, invasive species control, and native plant community preservation (Environmental Services, 2015; Menashe, 1993).

Proper vegetation management on steep slopes is of elevated importance when the parent material of the hills or cliffs are not solid bedrock material, but rather unconsolidated and erodible sand, silts, and clays. Thus, further heightening the importance of proper vegetation management in light of human desires for views is the particular climate where slopes are located. Heavy and/or persistently rainy climates create a heavier load on steep slopes when the soils reach saturation. In these cases, vegetation plays a major part in maintaining slopes by physically holding soils together, protecting the soil surface from rainfall impact, and removing water from the soil through the vegetation's biological processes. As plant roots grow and decay through soil, they create pore space which maintains the capacity of soil to hold water. As water penetrates through the pores, roots grow downward removing water by their biological activity and repeat the cycle (Figure 1).

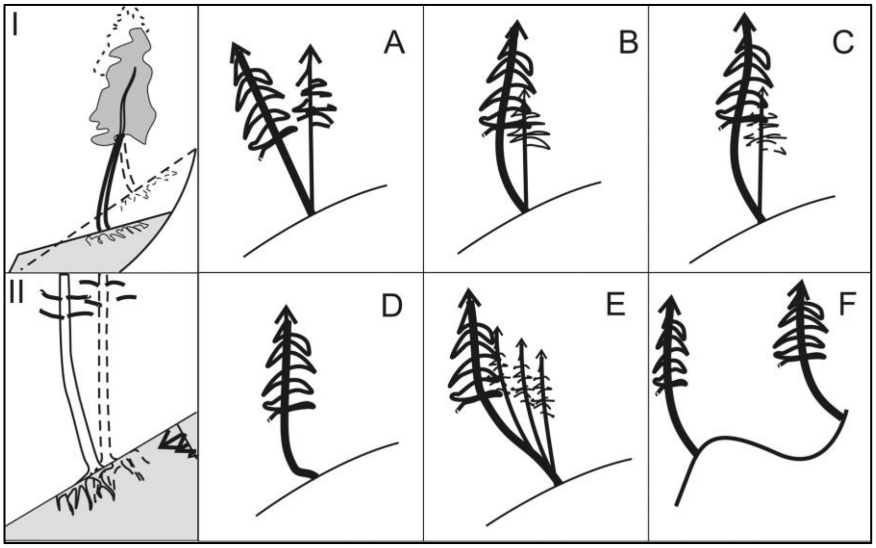
Figure 1. Effects of vegetation in minimizing erosion.



From Menashe (1993). This image has been digitally altered.

Slopes with simplified vegetation communities such as solitary trees do not provide adequate stabilization. In shallow soils, tall trees may be more susceptible to falling during wind storms, and thus may not be ideal as the sole vegetation type. While tree roots do provide increased soil cohesion strength, this may only have positive benefits on surficial soil creep (Cammeraat et al., 2007) and have limited benefits for deep soil movements. Specifically, persistent and/or intense rainfall impact can destabilize large (sand and gravel) and small (fine silt) particles at the forest floor surface, creating rivulets then rills and gullies (Styczen and Morgan, 1995). Similar to root structures adapting to wind forces, trees and woody shrub plants can form reaction wood as slopes shift that leads to corrective growth (Stokes et al., 1995; Stokes et al., 1997). Reaction wood is anatomically different than normal stem or branch wood due to mechanical stressors, such as strong wind, weighted loading, or soil movement (Scurfield, 1973). Figure 2 demonstrates differing tree growth responses to moving slopes based on species and the timeframe of the soil movement. Apart from this growth pattern being a natural growth reaction, it is also a salient indicator of slopes that have moved downward in the past.

Figure 2. Tree growth response to moving soil.



From Andreu et al., (2007)

Plant roots soil stabilization characterization

The ability of vegetation to grow on steep slopes and difficult terrain is due to the roots' ability to anchor themselves in place and has been well documented (Waldron, 1977; Waldron and Dakessian, 1981, 1982; Terwilliger and Waldron, 1991). As compared to pasture-only sites, Douglas et al., (2011) found tree and shrub treatment plots reduced "slippage" of soils by up to 95% in New Zealand. The average diameter of the trees were found to be significant factors in the amount of erosion that occurred: greater average tree diameter resulted in less erosion occurring in the immediate vicinity of the trees and shrubs (2011). It should be noted that these trees and shrubs were growing as individuals and not part of a wattle or living fence structure, as is being advocated in this restoration design paper. To that point, McIvor et al., (2011) noted that higher densities of young poplars and willows are necessary at time of installation to provide soil protection depending on growth rate and exposure to storm events (p. 263).

In pastoral and hilly New Zealand, willow (*Salix* spp.) and poplar (*Populus* spp.) live stakes are the preferred and recommended plants for quickly and cost effectively stabilizing steep slopes on the scale necessary in the pastoral country (McIvor et al., 2011). The primary use of these techniques in New Zealand, as many other places where bioengineering is practiced, is in stabilizing surficial soils up to 1m deep especially in moist soils. Gullies, shallow channels in hillsides, and stream banks are successfully stabilized using bioengineering techniques including planting of live stakes. When comparing the effectiveness of stabilizing slopes using live stakes versus planted herbaceous ground cover in an either-or discussion, McIvor et al., (2011) noted the many advantages of trees, in particular including improved slope drainage, deeper root penetration, and a physical barrier to soil movement, among many other benefits. Table 1 illustrates desirable characteristics of vegetation on slopes.

Table 1. Desirable plant characteristics for functions of vegetation in preventing or reducing erosion.

Function	**Desirable Plant Characteristics**
Capture and restrain moving soil/rocks	Strong, multiple, and flexible stems; rapid stem growth; ability to re-sprout after damage; ready propagation from cuttings and root suckers
Cover and protect soil surface	Extensive, tight, and low canopy; dense, spreading, surface growth; fibrous root mat
Reinforce and support slope soils	Multiple, strong, deep roots; rapid root development; high root/shoot biomass ratio; good leaf transpiration potential
Improve ecosystem community	Shade and cover to moderate temperatures and improve moisture retention; soil humus development from litter; nitrogen fixation potential

Adapted from Gray and Sotir (1996), as cited in Stokes, (2008)

Vegetation and slope protection

Research results of solely tree roots' strength and stability on slopes is mixed. After an overview of existing literature comparing in-field and controlled experiments across regions and ecotones, Stokes et al., (2008) concluded that root tensile strength depends on site, species, and age and no general rules for root development on slopes can be characterized. And while tree mass adds weight to slopes, it is commonly believed that this is balanced by the increase in shear strength from root cohesion in unsaturated soils (Ziemer, 1981). The takeaway for land managers trying to stabilize and restore slopes is that hillsides with loose soils, steep grade, and sparse or undesirable vegetation are more likely to fail, and trees alone may not suffice to achieve restoration goals.

Rainfall interception occurs at all levels of a mature forest canopy and the interception reduces the impact velocity on the forest soil. Interestingly, a tall canopy without middle height or groundcover vegetation provides no more protection against erosion as an open floor (Styczen and Morgan, 1995). This is due to the accumulation of raindrops falling from leaves and reaching terminal velocity at they fall and then impacting the forest floor. A well-designed forest restoration plan should thus seek to develop a full Pacific Northwest forest ecosystem with a mixed conifer-deciduous canopy, a mid-story layer of trees and tall shrubs, and a dense forest floor of native groundcovers and leaf litter. These goals are supported by experimental research on erosion in tropical forests: Coster (1938) and Wiersum (1985) found the greatest soil protection from intact forests with tall trees, shrubs, and leaf litter in comparison to conditions where one or more factor were removed (Styczen and Morgan, 1995, pp.45-46).

All vegetation has an important influence on hill slope stability and hydrology and vice versa, where slope and hydrology influence the plant community that develops on the hill slopes. Erosional factors affected by vegetation include canopy interception of rainfall both in volume and intensity, evapotranspiration which pulls moisture from the soil thereby decreasing the weight load of saturated soil but also creating a cohesion force through the suction of water vertically (Styczen and Morgan, 1995). On stable slopes or along game trails roots prevent compaction by penetrating soil layers, building the ground for further vegetation establishment. This root penetration also allows for more moisture penetration and deeper root structures (Figure 1).

Bioengineering for Steep Slopes

The use of vegetation to control erosion on slopes, stabilize stream and river banks, and enhance ecosystem functions is a common practice dating back millennia across different parts of the world (Lewis et al., 2001). Terrace agriculture is a common practice even today on marginal agricultural lands dominated by steep slopes. The practice is commonly known as bioengineering, soil biotechnology, or ecological engineering and the treatments consist of planting dormant, nonrooted woody shrubs and trees in particular orientations. The installation methods and plant selection will vary by hydric conditions, climate, and particular native plant species but some common installation techniques include brush wattles, live fascines, wattle fences, and live pole drains (Figure 3, 4, 5). The installed vegetation provides structural support holding soil and rocks that fall down slopes as well as mechanical support by increasing the shear stress within the soil pores (Hoag and Landis, 2001; Styczen and Morgan, 1995). Incorporating traditional hard engineering methods with bioengineering techniques is a common practice as well, though hard engineering methods are not discussed here.

Figure 3. Fascine aka living-cribwall design. Live stakes are staked horizontally across the slope to retain soil and rocks. Stakes then can sprout adventitious roots and stabilize slopes with pioneering vegetation. Vertical stakes can be live stakes, natural wood stakes that will not grow from cuttings, or processed timber.

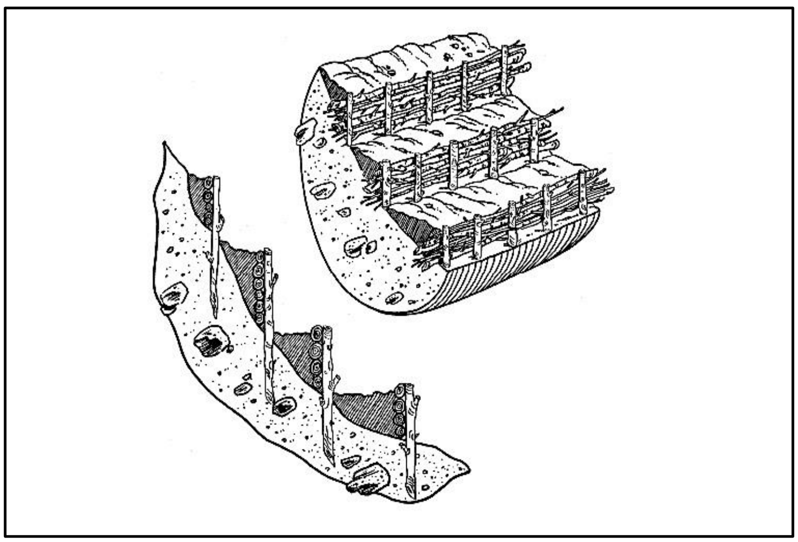


Figure 4. Offset modified brush layers with wooden fence board displayed. Brush layers are recommended for drier slopes where willow and cottonwood stakes may not be viable. Processed timber face-board is displayed as an option to retain backfilled soils.

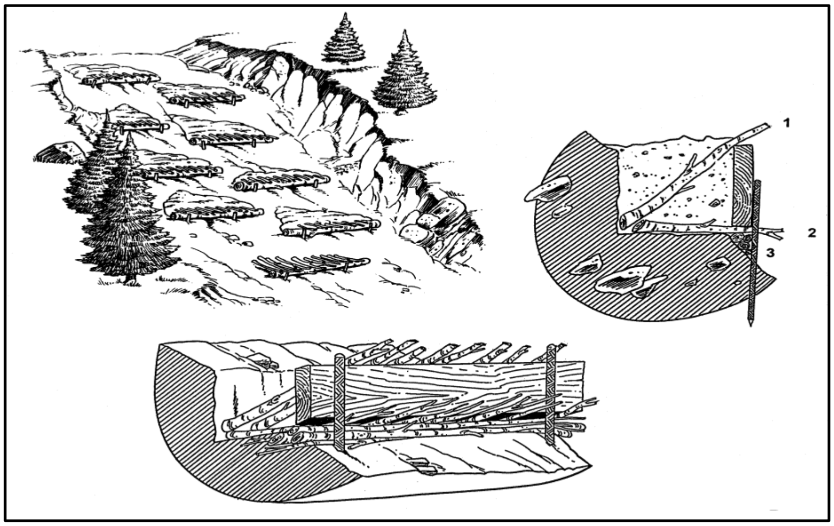
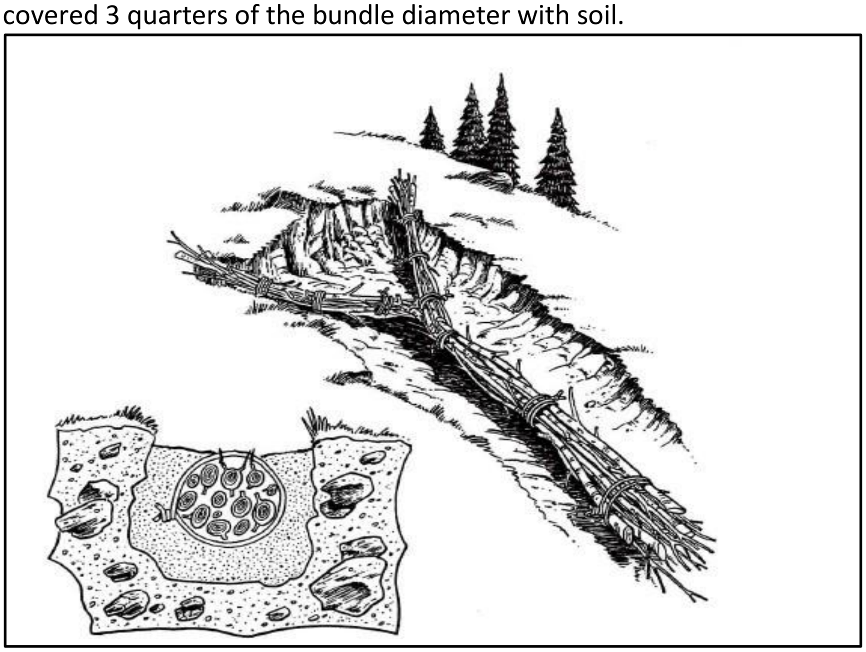


Figure 5. Live drain poles installation. Long bundles of moisture-tolerant cottonwoods and/or willows are bundled in a rill, gully, or other saturated area where soil stability is of concern. All stakes should be arranged to face uphill, tightly bound together with separate bundles in contact with each other, and covered 3 quarters of the bundle diameter with soil.



From David Polster, polsterenvironmental.com, used with permission

Like terrace agriculture, the benefits of bioengineering techniques on a slope are primarily to arrest surface soil movement, capture moisture from running off site, and allow humans to traverse a slope safely and efficiently. The initial vegetation installation and the growing roots are not likely to provide mechanical soil protection, but as fast-growing vegetation spreads a dense root mat may develop as shoots spread and woody vegetation grows in size. Even under ideal conditions, plant growth is limited by biological constraints, time being one (Norris et al., 2008). To give the roots time to grow and hold soil, the bioengineering techniques must provide structural stability at the time of installation. Species to consider for bioengineering should be appropriate for soil moisture and light conditions on the slope where they are being installed, as well as being flexible to grow through soils that may be actively moving. Common restoration bioengineering techniques and potential benefits from their application are summarized in Table 2**.**

Table 2. Bioengineering techniques

Name	*Construction*	*Primary functions(s)*
1. Live stake	Sticks are cut from rootable plant stock and tamped directly into ground	Live plants reduce erosion and remove water by evapotranspiration. Plant roots reinforce soil
2. Live fascine (cribwall)	Sticks of live plant material are bound together and placed in a trench. They are anchored to the ground by live stakes (Figure 3)	Same as 1
3. Brush mattress	Live branches are placed close together on the surface to form a mattress	Same as 1. In addition, it provides immediate protection against surface rainfall impact.
4. Brushlayer, branchpacking	Live branches are placed in trenches or between layers of compacted fill (Figure 4)	Same as 1
5. Live drain poles	Live poles bound together end-to-end and anchored by live stakes (Figure 5)	Same as 1. In addition, drain excess moisture from seepage zones. Acting like living French drains.

Adapted from Wu (1995) and Polster (2006)

Steep growing conditions are not uncommon in the Pacific Northwest and many hillsides in the Olympic Peninsula and the Cascade Mountain Range are vegetated with dense forests. The natural process of disturbance-resilience and reforestation have occurred in this part of the world since the last retreat of the glaciers through the Puget Sound (Map 1). As the glaciers retreated, the process of soil building, invasion by nitrogen fixing plant species, hardwoods, and finally evergreen shrubs and conifers repeated itself over the newly available land. Disturbances such as fire, flooding, landslides, and wind and ice storms reset the successional processes constantly in mature PNW forests. Even today as glaciers retreat, lichens and mosses colonize open ground followed by herbaceous forbs, small woody shrubs, alders and poplars, maples, and so on. Herbivore impacts were historically moderated by the presence of predators that not only hunted deer and elk but also kept the herds moving which allowed the vegetation to bounce back and the successional trajectory to continue (Sustainable, 2014).

Map 1. Extent of last glacier through the Puget Sound area, approximately 15,000 years ago.

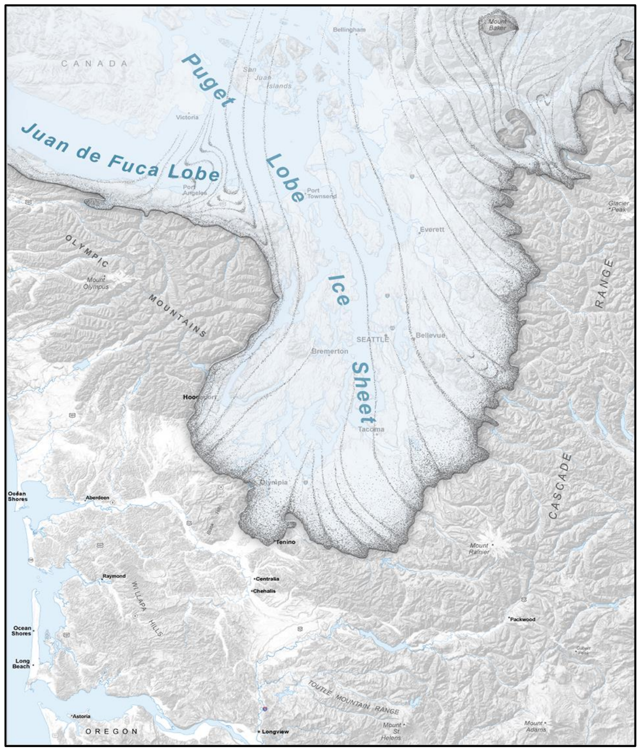


Photo source: https://www.dnr.wa.gov/programs-and-services/geology/explore-popular-geology/puget-sound-and-coastal-geology#puget-sound-geology

Schuster Slope Restoration Project

The Schuster Slopes project site is a 31-acre natural area along the shoreline of the City of Tacoma, Washington marked by decades of change and human influence. After the last glacial retreat, much of the Puget Sound coastline was left as active “feeder” bluffs that occasionally and consistently eroded soil and sediment into the Puget Sound. Feeder bluffs are eroding bluffs that provide the majority of sand and gravel that support near-shore estuarine fish and invertebrates (Johannessen, 2015; MacDonald et al., 1994). In a time when much of the Puget Sound shoreline has been stabilized with various types of armoring such as seawalls, breakwaters, and rip rap all intended to protect land from wave erosion. As a result, feeder bluffs that send sediment and gravel into the nearshore environment are being restricted by infrastructure. Since the city of Tacoma was established, the Schuster Slopes have seen major alterations from the eroding feeder bluffs they once were. Portions of the slope were once a part of a railroad and tracks are still visible on the northern edge of the site. A small gulch was filled in and a preparatory school now sits on the fill, also forming a dividing point between the north and south acres.

The Schuster Slope Landscape Management Plan (Environmental Services, 2015) was developed as a guidance document to conduct restoration activities on critical areas within the city of Tacoma, WA. The Landscape Management Plan (LMP) was developed out of growing public demands for vegetation control, homeless encampment abatement, public safety concerns from unstable slopes above a major arterial roadway, and the city government's stewardship goals. The plan was developed using input from consultants, city staff, and a citizens' advisory committee. After small working group and open public meetings, a final plan was submitted to the city of Tacoma Permit and Development Services Department and a Minor Development Permit was secured in December 2015.

The overarching goal of the Schuster project is to achieve a Target Ecosystem, identified by the Washington State Department of Natural Resources for the Schuster Slope as a North Pacific Maritime Mesic-Wet Douglas-fir-Western hemlock Forest (WDNR, 2011). The intent of restoring the Schuster Slope to a self-sustaining, conifer-dominated Target Ecosystem is to realize the many benefits of stormwater management, maintenance of native ecosystems and human well-being that comes from such a native restored forest. In the LMP, strong emphasis is placed on stormwater benefits because the Passive Open Space program which oversees the Schuster Project is funded with stormwater utility funds, a highly envious position for an urban natural spaces program to be in. While off-site stormwater is not directed onto the Schuster Slopes site to improve quality or manage quantity, the benefits of a healthy forest ecosystem in relation to capturing rainfall and transpiration of water by conifer trees is heavily emphasized in the LMP. Reduction of surficial landslides and erosion is emphasized through the establishment and maintenance of thriving native mid-story and forest floor vegetation. To maximize the rainfall interception capacity and forest floor protection during the rainy winter months, the LMP has a target of evergreen species comprising 75% of the forest vegetation, both at full maturity and during planting activities. At the time of the writing of the LMP, all layers of the canopy and forest floor were described as fair to poor condition. High invasive species competition was suppressing native species regeneration, bare soils were actively eroding on much of the site, and “soil-binding root mass” was diminishing as mature pioneer trees age out (Environmental Services Department, 2015, § 9-45).

There are five “management considerations” described in the LMP that, if executed successfully, are intended to lead to a healthy forest and the desired Target Ecosystem:

1. Slope Stability and Geologic Hazard Mitigation
2. Forest Health
3. Public Safety
4. Views from Adjacent Areas
5. Voluntary Stewardship

Each management consideration has objectives, standards, and performance measures along with estimates of a timeframe and level of effort necessary to complete. Slope stability and geologic hazard mitigation is achieved through the establishment of a 100% soil-binding root zone specifically of tree roots. Forest health is described as a self-sustaining PNW forest that mimics the Target Ecosystem. Public safety includes the protection of the Schuster Parkway road at the base of the slopes from surface erosion and soil sloughing, however mass slope wasting is not addressed in the LMP. The presumption that most landslides occur during or shortly after rainstorms (Crozier, 2005) is a near certainty on the Schuster Slopes where an average five slides occur each winter (Environmental Services, 2015; Photo 1).

Photo 1. Surficial slide on Schuster Slope near pedestrian walkway, January 2019.

Photo source Luis Yanez, 2019

Restricting and discouraging transient peoples from accessing the Schuster Slopes was a major concern from the public process and discussed at length (Desiree Radice, city of Tacoma, personal communication; Photo 2). Public input also focused on the desires to open and expand panoramic views of the Puget Sound from the top of the slopes for public benefit from the sidewalk, as well as for private homeowners situated at the top of the slopes. Notably absent from the Plan's goals and objectives are traditional benefits of a healthy urban forest such as reducing the urban heat island effect, capturing pollutants from the air, and providing a connection to greenspaces in the city for people and wildlife to enjoy nature.

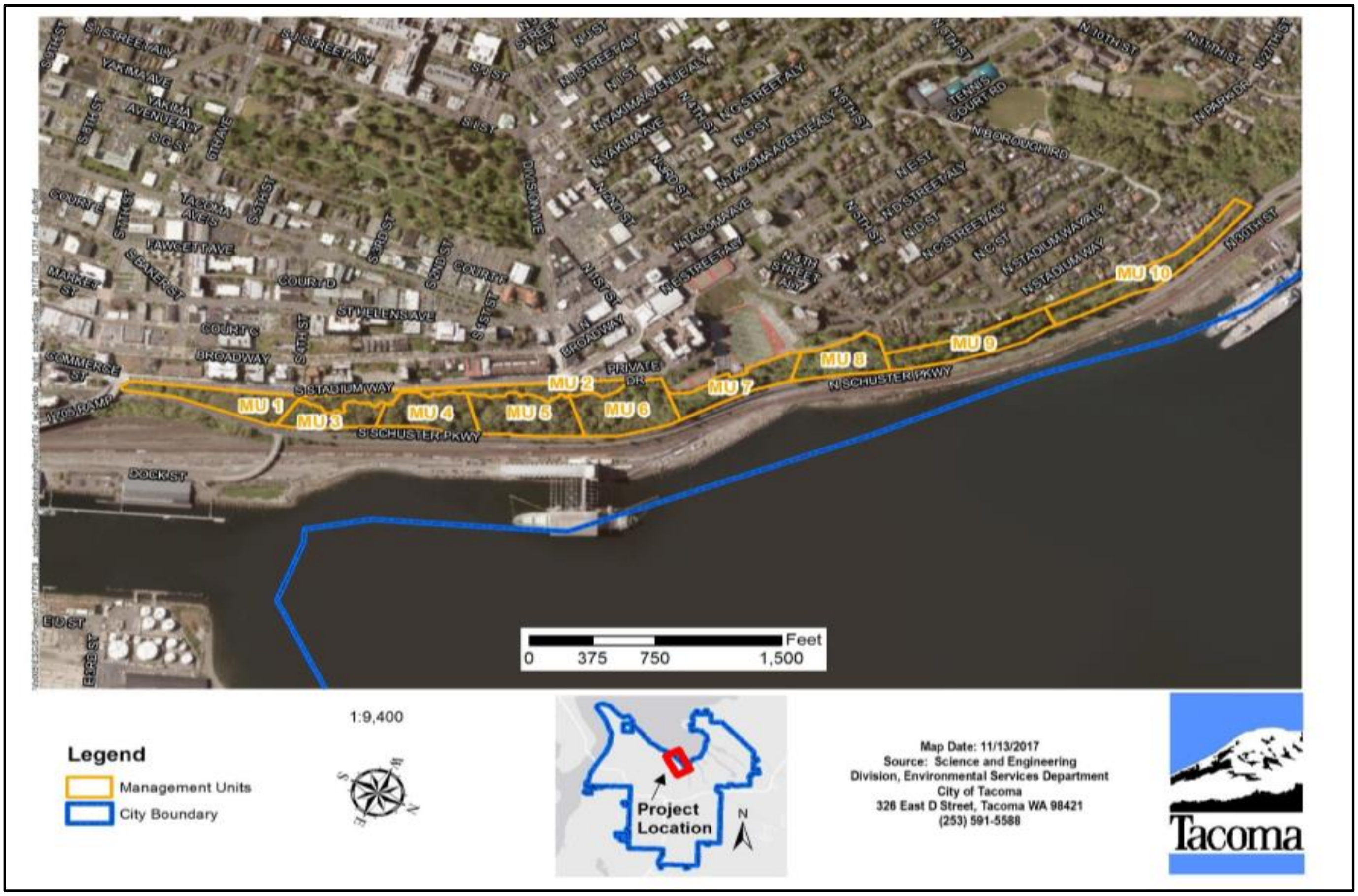
Photo 2. Typical homeless encampment on Schuster Slope

Photo source: Luis Yanez 2019

Restoration Activities to Date

The Schuster Slopes project area was divided into 10 Management Units (MUs), each approximately 3 acres in size (Map 2). The division was made to identify areas of similar topography and vegetation composition that would be a manageable work size during the fall/winter planting seasons.

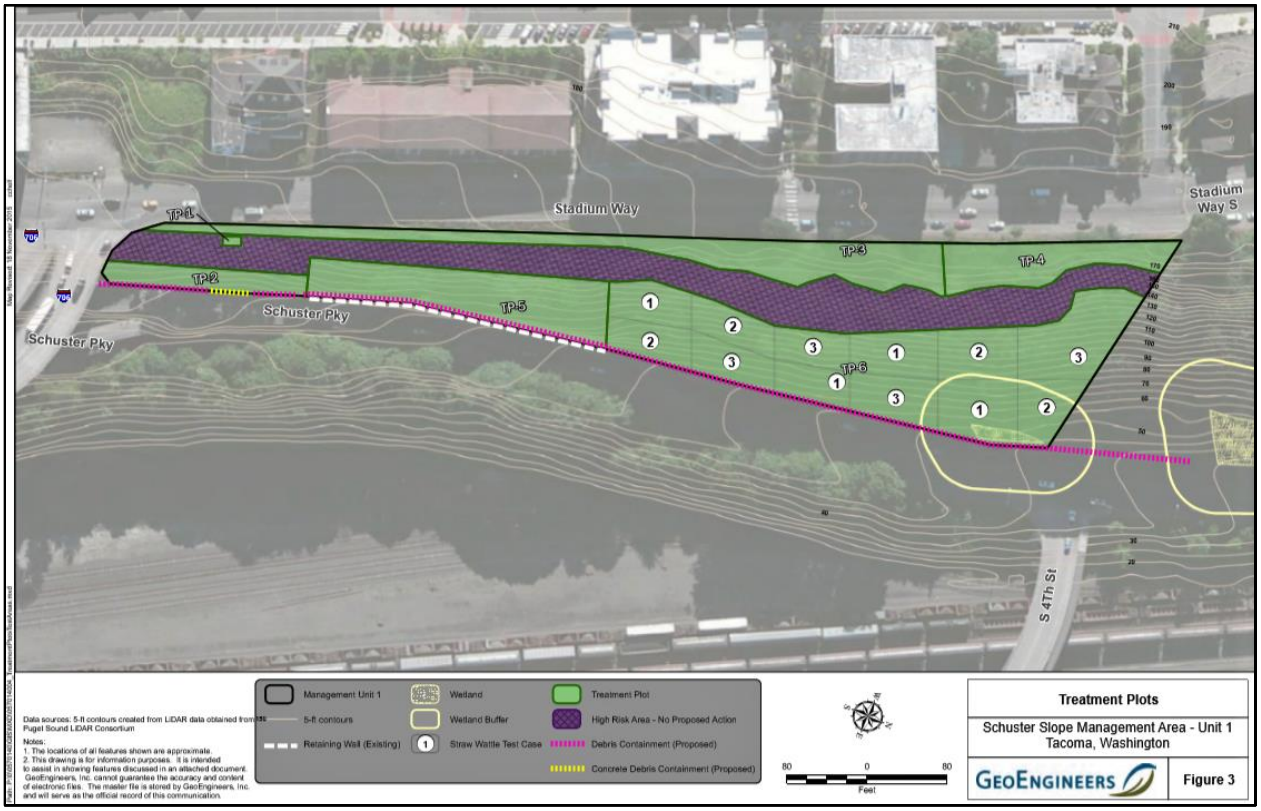
Map 2. Schuster Slope project area with Management Units identified.



From Passive Open Space Program (2017). This image has been digitally enhanced.

Following the completion of the LMP and permit acquisition from the Planning and Development Services' Critical Areas Department, the Passive Open Space Program contracted a professional engineering firm to create a Work Plan for Management Unit 1 (Map 3). The contracted services were in part to comply with permit regulations requiring geotechnical consultation for work activities on slopes ≥67% (Environmental Services Department, 2015). In addition, the Work Plan (GeoEngineers, 2015) was developed to elicit best practices from an interdisciplinary team on how to stabilize steep slopes and establish a forest within the confines of the permitted restoration plan. The Minor Development Permit prohibits permanent anchors or structures, filling, grading, excavation, or other major earth disturbing work and prohibits all work on slopes above 80% grade.

Map 3. Management Unit 1 with Treatment Plots identified.



From GeoEngineers (2015). This image has been digitally enhanced.

Major recommendations and components of the Work Plan include:

- Dividing the work Unit into six smaller Treatment Plots (TPs)
- Installation of biodegradable temporary erosion control blankets and straw wattles over a majority of the 2.62-acre work area
- Outsourcing location of access points and rope rappelling points to the minimally experienced work crews
- Purchase of 1-gallon potted native plant material for installation
- Incorporation of compost amendment into the planting hole at a ratio of 1:1 for the plant container size
- Invasive species control with minimal soil disturbing techniques

- Experimental planting recommendations to deal with invasive species competition, projected summer drought conditions, and the large cobble/gravel soil media

Beginning in late 2015, the Passive Open Space Program has worked on the Schuster Slopes controlling invasive vegetation, installing erosion control materials, and planting native species to achieve the Target Ecosystem following the guidelines set forth in the Work Plan as resources allowed. Site conditions and weather prevented all planned work from being completed in the first work season of winter 2015/16. Treatment Plot 6 was only partially covered in erosion control blanket material and planted with restoration plants, approximately 60% of the 1-acre area (Passive Open Space, 2018). Restoration activities were completed in MU1, TP6 during the 2016/2017 planting season.

Treatment Plot 6

This Restoration Design paper will focus on the most difficult section of Management Unit 1, Treatment Plot 6. The roughly 1-acre area has proven the most difficult area to establish vegetation to date. This area of MU 1 constitutes slopes ranging from 67% to over 100%. The precise soil type is not identified in the work plan but from site observations the entire area appears to be unconsolidated glacial outwash and till with fines and course gravel at mid-slope ranging down to large cobble-sized stones at the toe and northern extent of the slope. A wetland buffer extends into a portion of the site (Map 3). A deep summer shade extends over the entire Plot from a mature deciduous forest with minimal shrubs and groundcovers, native or invasive (Photo 3, 4). No conifer trees were growing on site prior to restoration activities commencing in 2015. Maples and cottonwood trees pepper the site at 25-50’ spacing. A difficult combination of actively moving slopes, deep shade from mature pioneer tree species, and dry soil conditions during the Pacific Northwest summers all contribute to a sparse understory.

Photo 3. Treatment Plot 6 understory. Note large cobble stone pervasive onsite.

Photo credit: Michael Carey, city of Tacoma, used with permission

Photo 4. Treatment Plot 6 with erosion control materials installed.

Photo source: Brandon Drucker, 2019. This image has been digitally enhanced.

In a healthy PNW forest, native deciduous trees and large shrubs that are capable of exploiting an open forest canopy would grow in an exposed forest floor like TP 6, eventually succeeding to a mature conifer-hardwood ecosystem. The conifers would grow from the seed bank or seed recruitment would originate from the forest edges. However, the history of disturbances on this site and the ensuing urbanization has changed the potential for conifer recruits on the Schuster Slopes. Hardwood species that currently dominate the slopes are not regenerating as the canopy has closed in and soil creep is pervasive and conifer trees are not present in the surrounding area to seed in. At the upper bench of the slope along Stadium Way the un-canopied areas are dominated by invasive species that are drought tolerant and adapted to compact and nutrient poor soils.

Novel and complicated planting techniques were proposed in the Work Plan to address the poor or completely lacking organics in the soil and aid initial establishment. The intent of the various planting-hole lining material was to determine which treatment best would retain soil and moisture while allowing plant roots to grow into the hillside and providing the stabilizing benefits of a dense root system. Table 3 summarizes the complicated recommendations for lining the planting holes with different materials and whether installation of smaller groundcovers was initially recommended.

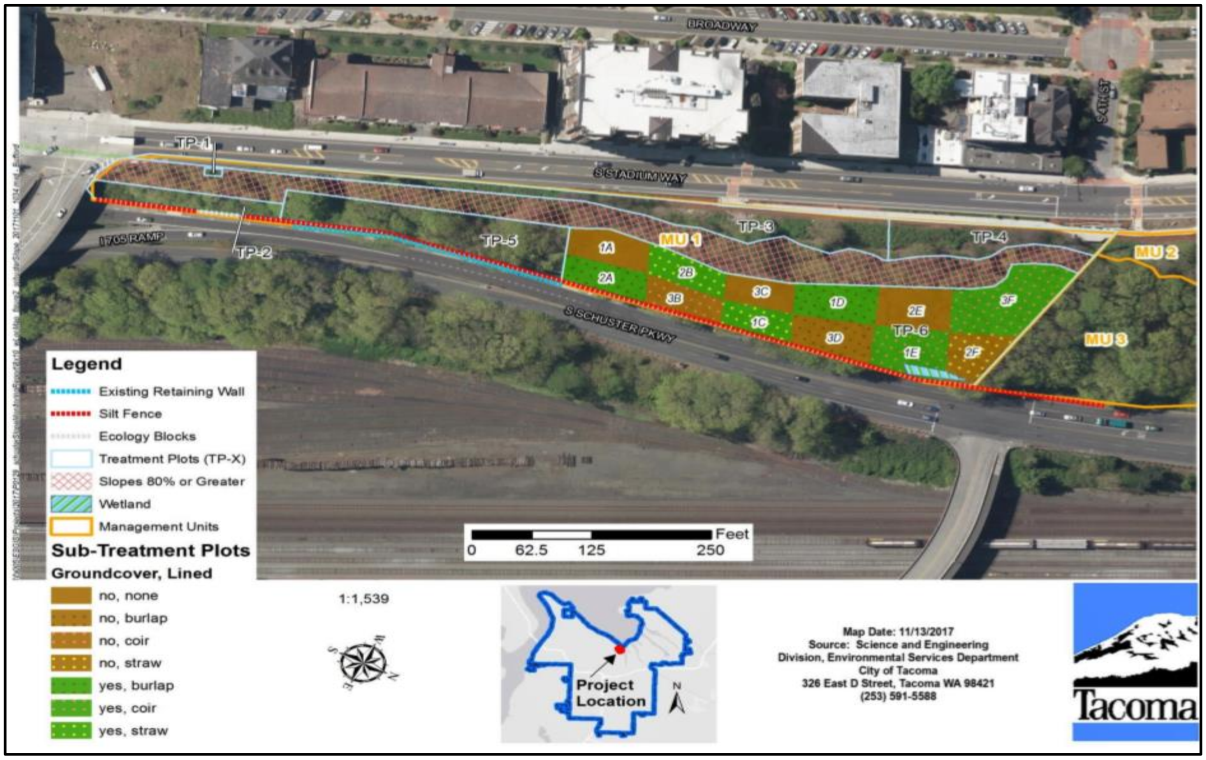
Table 3. Treatment Plot 6 Sub-plot treatments

Groundcover	absent				present			
Planting Fabric	none	straw	burlap	coir	none	straw	burlap	coir
Sub-TP								
1A	X							
2A							X	
2B						X		
3B				X				
3C	X							
1C						X		
1D							X	
3D			X					
2E	X							
1E								X
3F								X
2F		X						

From Passive Open Space Program (2017), used with permission.

Work on Management Unit 1 (Map 4) was initiated in late 2015 but work on Treatment Plot 6 began in late February 2016. Work crews were over extended with the erosion control material installation, dense planting requirements, and steep slope traverse. Erosion control blanket and straw wattle installation on Treatment Plot 6 was resumed in summer 2016 in anticipation of planting during the fall and winter of 2016.

Map 4. Mangement Unit 1 with sub-plots of Treatment Plot highlighted



From Environmental Services (2016). This image has been digitally enhanced.

Using a line-transect and quadrat sampling methods, the Open Space Program gathered percent cover data to estimate the efficacy of restoration planting and estimate survivability. The results are unequivocally terrible in terms of plant success and establishment. During the first year of monitoring the average survival across all of MU 1 was 80.7%, though this average appears to be heavily weighted by the good survival rate of certain deciduous shrubs. While the successful growing result of these deciduous shrubs is a positive, the establishment goal of a two-thirds evergreen plant community is not being met.

Examining the monitoring data in Table 4 from the first year's monitoring efforts, it is important to note that the percentages described as "Average Survival Rate" is not an accurate representation of installed plant survival. Rather, the data reported includes existing vegetation and percentage of native vegetation cover is being reported (Passive Open Space, 2017). Above 100% "survival" is reported when there is an enclosed tree canopy.

Table 4. Monitoring results for Schuster Slopes Management Unit 1 after the first growing season.

Treatment Plot	Average Survival Rate (%)	Well-Performing Species	Conditions
1	16.7	Grand-fir (*Abies grandis*)	Dry to Moist Soil, Sand, Sun to Part-shade
2	142.9	Tall Oregon Grape (*Mahonia aquifolium*), Nootka rose (*Rosa nutkana*)	Dry to Moist Soil, Sand, Sun to Part-shade
3	140	Snowberry (Symphoricarpos albus), Vine maple (Acer circinatum), Shore pine (Pinus contorta)	Dry to Moist Soil, Sand, Sun to Part-shade
4	100	Cascara (Rhamnus purshiana)	Dry to Moist Soil, Sand, Sun to Part-shade
5	66.7	Swordfern (Polystichum munitum), Snowberry (Symphoricarpos albus)	Dry to Moist Soil, Sand-Gravel, Shade to Part-shade
6-1C	17.6	Snowberry (Symphoricarpos albus)	Dry to Moist Soil, Sand-Gravel, Shade to Part-shade
Average	80.7		

From Passive Open Space (2017). Recreated with permission.

Other forest health indicators collected during the monitoring sessions did not rate high in abundance or presence as would be expected in a mature PNW forest. Coarse-woody debris, leaf litter, uncompacted soils, and soil moisture were observed to be absent or rated unfavorably. Transient activity, bare ground, and surficial erosion were observed in most of the Treatment Plots. Per the Work Plan (2015), 434 trees, 2278 shrubs and 3393 groundcovers were purchased from local nurseries, in 1-gallon size. At an average cost of $3.85/plant, the realized costs in plant material alone was $23,492.70 for Management Unit 1. Treatment Plot 6 alone had an estimated plant material cost of $12,755 from the 3,313 plants called for in the Work Plan. Erosion control material costs are estimated to have cost a total $10,000 from the range of costs in the Work Plan (Table 5).

Table 5. Estimated costs for erosion on materials, Management Unit

Type	Material/ Alternatives	Description	Unit Cost ($)		Units	Quantity	Cost Range ($)	
			Low	High			Low	High
Nets or Blankets	Jute	Made from Jute Fiber; 100% biodegradable	$0.20	$0.30	SF	63,000	$12,600.00	$18,900.00
	Coir	Made from coconut husk; 100% biodegradable	$0.20	$0.30	SF	63,000	$12,600.00	$18,900.00
Debris Containment	Silt Fencing	As described in BMP C223 Tacoma Stormwater Management Manual Vol. 2	-	$1.00	LF	1,200	-	$1,200.00
	Ecology Blocks	2'Wx2'Hx3'L concrete block	$35.00	$45.00	each	14	$490.00	$630.00
		2'Wx2'Hx6'L concrete block	$35.00	$45.00	each	7	$245.00	$315.00
	Traffic Barriers	120"L x 24"W x 34"H	$250.00	$846.00	each	5	$1,250.00	$4,230.00
Wattles	Straw	Straw bundled with biodegradable material	-	$1.00	LF	3,840	-	$3,840.00

From Passive Open Space (2018). Reprinted with permission.

Monitoring data from the second year did not find better results: by the end of the second growing season plant survival across the Unit had dropped to 58% (Table 6) and TP 6 in particular had dismal results with only an average 23% survival (Passive Open Space, 2018). Though there are no slope stability or vegetation performance measures for monitoring year 1 based on the LMP or permit requirements, the goals are to have 80% planted species survival in monitoring year 3 and 60% survival in monitoring year 5. The long-term goal of restoration is to establish a two-thirds tree cover consisting of evergreen conifer trees and two-thirds shrub and groundcover consisting of evergreen species. Having 100% soil-binding root zone is a long-term goal that will not be achieved until installed vegetation begins to mature. To date, neither of these goals are on target from the recorded monitoring results.

Following the poor monitoring results, the Passive Open Space Program attempted a second planting effort on MU1 during the late 2018 and early 2019 planting season. For TP6, the second planting effort focused on planting more evergreen trees from smaller plant stock and at denser quantities (Table 7). Conifer trees were procured bare-root at approximately $0.55 per tree and no plants had soil amendment added to the plant hole. At the time of writing, monitoring results had not been summarized for the combined survival of installed plants or coverage but similar poor survival rates are estimated from site visits and summer-time invasive species control work (Brandon Drucker, city of Tacoma, personal communication October 2019). Even at the reduced costs per plant, the second restoration effort cost the city of Tacoma an estimated $19,000 in plant stock alone for the single acre on TP6.

Table 6. Management Unit 1 Year-2 monitoring results.

TP	Average Survival Rate (%) 2016/2017 to 2017/2018	Survival Rate (%) from Y0	Well performing species 2017/2018 only **Well performing Species 2016/2017 and 2017/2018** Well-Performing Species 2016/2017	Conditions
2*	50	71	**Tall Oregon Grape (*Mahonia aquifolium*)**, Nootka Rose (*Rosa nutkana*)	Dry to Moist Soil, Sand, Sun to Part-Shade
3*	64	90	**Snowberry (*Sympharicarpos albus*)**, Vine Maple (*Acer circinatum*) Shore Pine (*Pinus contorta*)	Dry to Moist Soil, Sand, Sun to Part-Shade
4*	100	200	**Snowberry (*Sympharicarpos albus*),** Cascara (*Rhamnus purshiana*)	Dry to Moist Soil, Sand, Sun to Part-Shade
5*	17	11	**Snowberry (*Sympharicarpos albus*),** Sword Fern (*Polystichum munitum*)	Dry to Moist Soil, Sand-Gravel, Shade to Part-Shade
6-1C*	33	6	**Snowberry (*Sympharicarpos albus*),** Pacific Wax Myrtle (*Myrica californica*)	Dry to Moist Soil, Sand-Gravel Shade to Part- Shade
6-1D	N/A	23	Snowberry (*Sympharicarpos albus*)	Dry to Moist Soil, Sand-Gravel, Shade to Part-Shade
6-2E	N/A	42	Sword Fern (*Polystichum munitum*)	Dry to Moist Soil, Sand-Gravel Shade to Part-Shade
6-3F	N/A	23	Nothing of note	Dry to Moist Soil, Sand-Gravel, Shade to Part-Shade
Average	53	58		

*The number of plants installed per monitoring location was estimated based upon the total number of plants installed per treatment plot, no baseline monitoring was performed.

From Passive Open Space (2018). Reprinted with permission.

Table 7. Replanting charts for Treatment Plot 6, 2017/2018

Treatment Plot 6 - Slope Face and Toe, Dry to Moist Soils, Shade to Part Shade

Tree Layer	45,273			
Species	Common Name	% Total	Spacing (Ft)	Quantity
Abies grandis	Grand fir	50%	8	409
Rhamnus purshiana	Cascara	10%	8	82
Thuja plicata	Western red cedar	20%	8	164
Tsuga heterophylla	Western Hemlock	20%	8	164
TOTALS		100%		819

Shrub Layer	45,273			
Species	Common Name	% Total	Spacing (Ft)	Quantity
Acer circinatum	vine Maple	10%	6	145
Corylus cornuta	beaked hazelnut	10%	6	145
Holodiscus discolor	oceanspray	20%	6	290
Morella californica	California wax myrtle	30%	6	436
Oemleria cerasiformis	Indian plum	15%	6	218
Vaccinium ovatum	Evergreen huckleberry	15%	6	218
TOTALS		100%		1452

Groundcover Layer	45,273			
Species	Common Name	% Total	Spacing (Ft)	Quantity
Gaultheria shallon	salal	20%	4	654
Mahonia nervosa	dull Oregon grape	15%	4	491
polystichum munitum	sword fern	35%	4	1,144
Symphoricarpos albus	snowberry	30%	4	981
TOTALS		100%		3270

Treatment Plot 6 - Wetland/Streams, Moist to Wet Soils, Shade to Part Shade

Tree Layer	627			
Species	Common Name	% Total	Spacing (Ft)	Quantity
Thuja plicata	Western red cedar	40%	8	5
Picea sitchensis	Sitka Spruce	40%	8	5
Rhamnus purshiana	cascara	20%	8	3
TOTALS		100%		13

Shrub Layer	627			
Species	Common Name	% Total	Spacing (Ft)	Quantity
Cornus sericea v. stolonifer	red-osier dogwood	25%	6	6
Oplopanax horridus	Devil's club	0%	6	0
Physocarpus capitatus	Pacific ninebark	25%	6	6
Rubus spectabilis	salmonberry	50%	6	11
TOTALS		100%		23

Groundcover Layer	627			
Species	Common Name	% Total	Spacing (Ft)	Quantity
Athyruim felix-femina	lady fern	0%	3	0
Carex obnupta	slough sedge	50%	3	40
Juncus effusus	soft rush	50%	3	40
TOTALS		100%		80

Source: Brandon Drucker, city of Tacoma, personal communication.

Recommendations for a Revised Restoration Plan

Urban ecosystems are under pressure from unique threats and stressors many of which were addressed in the Schuster Slope LMP (2015), including homeless individuals living on the site, legacy debris dumping, and aggressive invasive species. In addition, the Schuster Slopes project area is completely lacking native coniferous trees as a source of plant propagule, save for a half dozen trees between the sidewalk and Schuster Parkway at the toe of the slope. Furthermore, Management Unit 1 is constrained between two busy arterial roadways with limited access for work vehicles or crews.

The soils on Treatment Plot 6 are glacial till laid down over several glaciation periods (Environmental Services, 2015). The resulting slopes are unstable gravels and silts at mid slope, to fist-sized cobble at the toe of slope immediately adjacent to the pedestrian sidewalk. Moisture content during the summer season was visually assessed during monitoring protocols and reported dry to low (Passive Open Space, 2017). These abiotic “filters” (Polster, 2011) coupled with deep shade of a deciduous tree dominated forest and a lack of plant propagule material are preventing the forest ecosystem from regenerating and the filters have limited the success of the City’s restoration efforts. Sliding gravel and large cobble at the base of the slope make these moisture conditions unsurprising if not predictable. To address both conditions, bioengineering techniques must stabilize the slope and provide for organics to accumulate in order to give the soil more moisture holding capacity. While adding soil, compost, or biosolid amendments to the planting media could improve the organics and nutrient contents of the soil, such additions to a slope in quantity is prohibited by City of Tacoma Ordinance for work in critical areas, such as slopes (TMC, 2019), and therefore the gradual accumulation of organics from leaf litter, falling limbs, and decomposing plants must be the source of organic inputs. The restoration efforts to date have attempted to install a late succession plant community without the proper soil organics composition. The bioengineering techniques recommended here will, under an ideal development trajectory, grow early succession species that will add the organics and macro nutrients necessary to support the growth of the desired forest ecosystem.

Surface erosion continues on the site and temporary erosion materials are degrading at a rate too fast to successfully capture rocks and soils that could serve as a foundation of growing media. Despite a deteriorating maple forest, very little coarse woody debris has been recorded during monitoring activities (Passive Open Space, 2017). The glacial till gravel and cobble that dominate the work area of MU1 Treatment Plot 6 have presented to be difficult conditions for successful plant growth.

Resetting the ecological successional trajectory is the ultimate aim of the Schuster LMP. Attempts to establish a plant community that resembles the climax community of an old-growth PNW forest at the outset of the restoration project have proven a fool's errand. The quality of soil, light penetration, and mycorrhizal relationships are not in place to support a typical Western Washington old-growth forest of specimen Douglas-firs towering over Western hemlocks growing on humus-rich soil that has been nurtured from decayed logs over time (Photo 5). Instead, the one-acre work site resembles a slide area or the reworked banks of a swiftly moving river. Viewing the Schuster Slope and Treatment Plot 6 through the lens of a long-term ecosystem recovery area is in line with the City of Tacoma issued work permit allowing restoration activities to occur over a 20-year period (Schuster, 2015). This long period gives time and space for the site to be slowly recolonized by native evergreen and conifer species after the successional clock is reset using bio-engineering techniques.

Photo 5. Western hemlock (*Tsuga heterophylla*) growing on an old stump.

Source: Ken Denniston, www.nwconifers.com, used with permission

The target or naturally occurring undisturbed ecosystem identified by the Washington State Department of Natural Resources for the Schuster Slope is a North Pacific Maritime Mesic-Wet Douglas-fir-Western hemlock Forest (WDNR, 2011). As such, a late succession forest at this site should be dominated by conifer trees with few mature deciduous trees aging out or young dense stands in large canopy breaks. While the target ecosystem may be considered a native reference ecosystem (SER, 2019), the ecological processes of nutrient cycling, mycorrhizal association building, and moisture retention are not in place in a “drastically disturbed site” (Polster, 2012) such as the Schuster Slope.

The slopes are in a successional stagnated state with only middle-age to mature hardwoods, mostly maples trees, growing on the site (Environmental Programs, 2015). Young sapling trees under 2” dbh are absent from MU1 as regeneration of pioneer species is hampered; seedlings cannot establish themselves in the dark understory of the deciduous canopy and on the unstable gravel-cobble slopes. An intact PNW conifer forest with a high level of disturbance resistance will experience the processes of windthrow, fungal disease, and small slides. These events serve to open canopy gaps and maintain deciduous pioneer species which then regenerate and recover the disturbed sites (Straker, 1996, as cited in Polster, 2012). The root wads of fallen trees create topographic heterogeneity and turn up fresh soil "thus the simple process of trees blowing over in the forest ensures the maintenance of diversity in the forest as well as providing successional and nutrient diversity" and niche development (Polster, 2012). Finally, the late successional species will seed themselves into the stabilized sites, introducing age class diversity to the forest.

The principles of bio-engineering that are most salient to the Schuster Slope project are:

- Extensive grading and earthwork in erosion prone area or slopes should be avoided
- Increased runoff should be handled with installed hydraulic conveyance facilities
- Runoff velocities should be kept as low as possible
- Soil moisture should be maintained as much as possible
- Native vegetation on the site should be saved and protected where possible
- If the vegetation needs to be cleared, this should be done in a small workable increments, keeping the duration of exposure as short as possible
- Cleared areas should be protected with mulches
- Erosion control measures should be applied as soon as possible
- The erosion control measures should be surveyed and maintained regularly

From Andreu et al., (2008)

In contrast to prior restoration efforts, the recommendations in this design do not seek to plant a late successional forest community. Although conifer trees growing on steep slopes is a common occurrence in PNW forests, to set the proper conditions for their growth and success on the project site, living cribwalls and cribwalls over brush mattresses are recommended solely at the early stages of stabilization (Figures 3 and 4). These living cribwalls will form terraces that will be the successional lynchpin for reestablishing the conditions to allow the Schuster Slopes forest to restore itself.

This approach is consistent with the recommendations for "ecotechnological" solutions from Norris et al., (2008) to properly use native live stake-able species to promote soil conservation and stabilization. The aim is to install stabilizing structures that also will grow branches and leaves to protect the soil from rainfall impact and concentrated erosion. The terraces and the vegetation that grow from the cribwalls will capture rock and soil falling downhill, adding more growth media for future plantings or windborne seeds to establish themselves. Finally, as the pioneer species that form the cribwalls decay, they will enhance the soils with carbon and organics for the more nutrient demanding secondary and late successional species. Working within the parameters of the city of Tacoma's Municipal code on work within critical areas, only native species are recommended for use in the fascine cribwalls and modified brush mattes.

While terracing the lower to mid slope portions of the driest cobble and gravel prone areas will be a laborious effort and vegetation succession is expected to stabilize to soil only to maximum root penetration depth, surficial slide processes could still occur as the vegetation terraces decline or fail shortly after installation, especially in the first year following installation (Norris et al., 2008; Lewis et al., 2001). As such, best management operations for this work includes beginning at the toe of the slope and work uphill from there to first stabilize the base of work area and to improve the efficacy of work crews as they move upslope. Contiguous structures will not be possible as is often seen along roadside stabilization sites (Photo 6) due to the intermittent presence of existing trees. Though soil amendments were recommended in the consultant Work Plan, such materials are not being recommended for the cribwall terraces. While Lewis et al., (2001) found these additions aided in early plant establishment in a drier climate bioengineering project, their addition had no correlated effect in the previous planting efforts on the site. In addition, access and labor constraints at this project site make such additions difficult and time consuming.

Photo 6. Typical roadside bioengineering work.

From Lewis et al., (2001). This image has been digitally enhanced.

Plant species will differ at the base of the slope where the work site extends into a wetland buffer and soils immediately adjacent to the sidewalk are perennially saturated (Map 3). Ideal live stake species for building fascine cribwalls at the base of the slope where the site extends into the wetland include: Sitka willow (*Salix sitchensis*), Black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), Red-twig dogwood (*Cornus sericea*), and Pacific Ninebark (*Physocarpus capitatus*). These species grow quickly from live stake cuttings and are classified by the U.S. Army Corps of Engineers as species commonly found in both wetlands and non-wetland systems. This adaptability will allow the native live stakes to thrive during the wet winter months and also persist during the dry summer months.

Moving upslope into mesic conditions, the planting palette will change to include willow species tolerant of drier conditions, specifically Scouler's willow (*Salix scouleriana*). This willow species in addition to Black cottonwood will form the basis for much of the bioengineering techniques and the bulk of the plant material. Scouler's willow, as known as Upland willow, is tolerant of drier growing conditions and as such it is the chosen species to form a majority of the structure of fascine cribwalls and living fence boards. The intent of planting this medium-size at maturity species is to allow dense root masses to form across the slope while not burdening the slopes with large growing species, initially. Cottonwood live stakes will serve as the vertical pins of the fascine cribwalls (Figure 3) to provide species diversity in the living stabilization technique as well as to keep material costs down. In accordance with best recommendations for live staking, plant materials should be soaked at minimum 24-hours to delay desiccation during the drier months (Hoag, 2007).

In the drier conditions upslope, modified brush layers are recommended as the primary treatment. This bioengineering technique consists of excavating a hole into the slope as with the fascine cribwall but long dry-soil-tolerant-species live branches are “packed” perpendicular to the hillside. Either a wooden fence board or Scouler’s willow poles can be installed parallel to the slope contours to retain backfill soil and rock (Figure 4). The most highly recommended species for branch packing in the PNW is Indian Plum (*Omleria cerasiformis*) with Beaked hazelnut (*Corylus cornuta*), Red-flowering currant (*Ribes sanguineum*), and Vine maple (*Acer circinatum*) are good options for intermixing if plant material of the preferred stock is lacking. The plant stock chosen for these conditions should be harvested from areas with similar site conditions to those where they are being installed to increase site-specific plant adaptations (Polster, 2006). All of the recommended species are shade-tolerant and are propagated via layering, where a branch is laid down against the soil and covered. Adventitious roots develop from these branches and spread the parent plant in a multi-stem shrub form. This growth habit is key to establishing spreading roots that will increase shear strength on the slope, protect soils from rainfall, and drop organic material on the rocky slopes.

As bioengineering stabilization progresses in re-establishing regenerative ecosystem processes and resetting the ecological trajectory of the Schuster Slopes, a critical dearth of native plant propagule sources will remain. At the same time, wind and wildlife will certainly continue to bring many of the cosmopolitan invasive species that can interfere will ecosystem recovery. As such, hand-seeding of native conifer trees, shrubs, and groundcovers that are deemed appropriate in the target ecosystem plant palette is recommended several years after site stabilization work (Figure 6). The seeds of these species are found in abundance in Tacoma's green spaces and the seed collection work is already a part of the Passive Open Space Program or are easily accessible and collected (Desirée Radice, city of Tacoma, personal communication, February 2019).

Figure 6. Select species for hand seeding

- Salal (*Gaultheria shallon*)
- Low Oregon grape (*Mahonia nervosa*)
- Indian Plum (*Oemleria cerasiformis*)
- Kinnickinick (*Arctostaphylos uva-ursi*)
- Douglas-fir (*Pseudotsuga menziesii*)
- Western hemlock (*Tsuga heterophylla*)
- Western Redcedar (*Thuja plicata*)
- Tall Oregon grape (*Mahonia aquifolium*)
- Evergreen huckleberry (*Vaccinium ovatum*)
- Red alder (*Alnus rubra*)
- Snowberry (*Symphoricarpos albus*) [to be live staked due to high viability]

Tree Removals

Tree felling is not recommended for this site; the LMP notes that every tree, even the invasive species, are holding soil through their root systems. Even limb thinning can cause destabilizing conditions as roots decompose in proportion to removed limbs. Nonetheless, significant benefits to the forest floor can result from careful hardwood thinning. The slow decomposition of logs in cool climates such as the Pacific Northwest can eventually lead to a substantive accumulation of coarse woody debris as selective thinning occurs and as the shrub and poplar species mature and decompose. Selective limb thinning for light penetration onto the forest floor should be very site specific and should be only be conducted away from the roadway by experienced chainsaw operators.

As thinning allows light to penetrate the canopy onto the live-wattle terraces, the decomposition and decay of logs can serve to build soil by adding organics, catch surficial rolling soil if placed parallel to the slope contours, and slow releasing moisture during the decomposition process (Harmon & Sexton, 1995). Research comparing the rates of decomposition of conifer trees to deciduous trees has shown that conifers decompose at a slower rate, fallen logs and snags generally that are not removed from forests have proven to be effective physical barriers and catchment places for falling rocks (Norris et al., 2008; Stokes, 2006). The addition of such logs to provide that protection is particularly important on the Schuster Slopes which sit between busy arterials.

With the glacial till soils being characteristically well draining and the lack of precipitation during the growing season, the summer time release of moisture from decaying wood has the potential to provide surface irrigation to the terraced live stakes and moisture for germinating seedlings. Further, Harmon and Sexton (1995) found logarithmic increases of carbon and nitrogen inputs into the forest floor at more advanced stages of log decomposition. Trees in urban forest greenspaces therefore provide greater benefits and services to the ecosystem in the later stages of their death, just as they provide greater services and benefits as larger mature trees.

Recommendations for Steep Slope Restoration

Successful steep slope ecosystem restoration is dependent on modeling best practices after natural disturbance site recovery processes. Observations from alpine slopes that experiences slides on occasion and mature forests that experience fires or high wind events provide examples about how to proceed in slope reforestation work. The best approach considers processes of forest plant succession and seeks to develop work plans in ways that assist natural recovery. A PNW mountain that experiences a slide is first colonized by lupines that thrive in full sun exposure and host nitrogen-fixing bacteria in their roots to provide that nutrient to the host plant (Halvorson et al., 1991). These early colonizers set the conditions for woody shrubs, maples, and aspen to move in as secondary successional species tolerant of full sun exposure, rocky-gravel soils, and potentially low carbon soils from a lack of decaying material. A PNW forest that has experienced a large disturbance such as a windthrow event will recover faster than a slide event because the forest community is in a secondary successional state: conifers are growing onsite, permanent shade has established, more organic material is present on the forest floor, and micro niches associated with these conditions are present. Even a catastrophic wind event is not a reset to barren soils conditions; the conifers that remain standing now have more access to sunlight and rainfall from reduced competition and the forest floor may be suddenly exposed to sunlight that will stimulate germination of conifer seeds. Fallen logs are now nurse logs that will hold moisture, serve as deep sources of organic material, and provide topographic heterogeneity for niche infilling (Polster, 2012).

Considering the Schuster Slope Project, process based recovery provides an alternative to the work conducted thus far. Whereas extensive erosion control material was brought onto the site to stabilize erosion, a succession based alternative is to use native plants that grow quickly in eroding soils as an erosion controlling method. Whereas late successional species were planted in two successive efforts to establish vegetation on steep slopes, planting pioneer species that adapted to the dry soils of the site slopes addresses the soil conditions that are inappropriate for late succession species. This type of restoration work is slower because it does not skip the successional steps but it is likely to be more successful because this type of effort works with the conditions currently onsite versus those that land managers hope will be present onsite after evergreens are established.

Conclusion

The history of managing steep slopes using vegetation has a long reach in the agrarian lives of humans the world over. Agriculture and forestry had destructive consequences on slopes as human settlement populations increased in size and so experimentation with soil stabilization likely began with the materials at hand: sticks, rocks, soil, and seeds. These techniques are in recorded history as far back as 28 B.C.E. and they have not lost their efficacy and the need for low-impact measures to restore forests and slopes also continues (Needham, 1971, p.331, as cited in Lewis et al., 2000).

When slopes are denuded of protective vegetation they are exposed to erosional factors that can cause minor erosion or exacerbate soil moving events. Though wind, intense rainfall, or prolonged soil saturation are the proximate causes for shallow landslides, a well-established vegetation root system serves as mitigating agent against slides by two mechanisms: a) uptake of water through the root system which creates a soil suctioning effect and b) a mechanical reinforcement of soil held between roots (Norris et al., 2008; Chirico et al., 2013). To that point, McIvor et al., (2011) note that higher densities of young poplars and willows are necessary at time of installation to provide soil protection depending on growth rate and exposure to storm events.

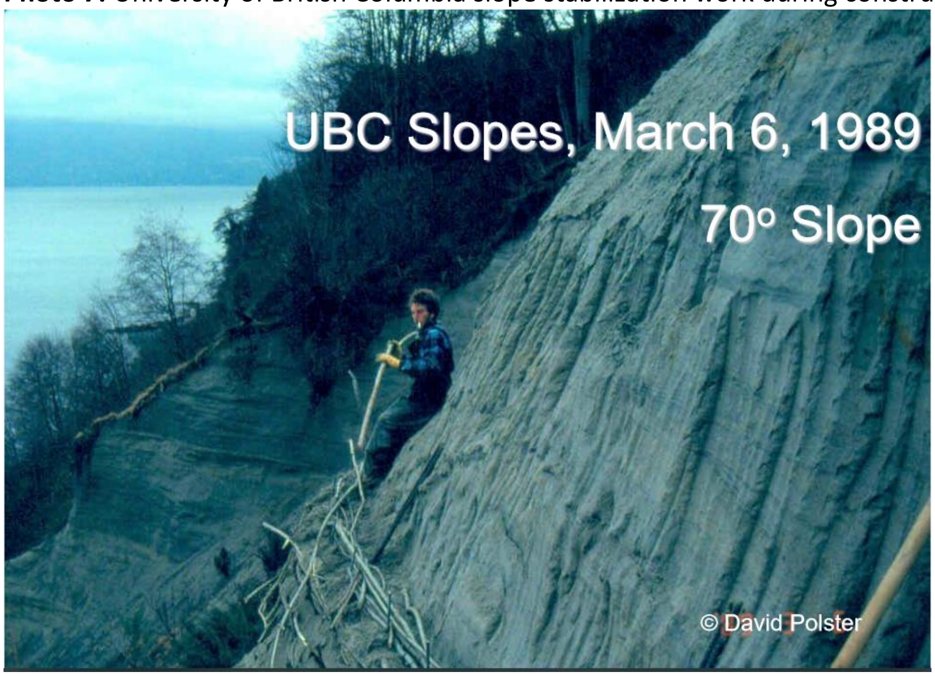
In the city of Tacoma Washington, the Passive Open Space Program has implemented a reforestation program on 31-acres of steeply sloped urban forest that have been mismanaged over the years. The comprehensive Landscape Management Plan sought to address human and ecological needs for a complex forest system. The LMP made recommendations for how to selectively prune trees for views while prohibiting whole tree removal, how best to manage invasive species that can prevent native species from maturing into a diverse plant community, and the Plan made many references to the importance of vegetation for mitigating geological hazards on slopes (Environmental Services, 2015). The subsequent Work Plan (GeoEngineers, 2015) was developed to comply with permit requirements for steep slope work. The Work Plan prescribed conventional erosion control techniques common to the construction industry. An overly complicated planting plan accompanied the erosion control techniques and after 3 years and thousands of dollars' worth of plant material and labor hours, minimal progress has been made in resetting the successional trajectory of a PNW forest. Plant establishment is low, no natural recruitment is occurring, invasive species competition remains high, and surface erosion continues.

The restoration work to date on the Schuster Slopes have failed to meet the city of Tacoma's goals for creating a self-sustaining forest. Although the work was implemented with the best intentions to establish a recommended forest plant community, the process for forest restoration on this site must go beyond planting conifer trees and evergreen shrubs. The implementation of the consultant's Work Plan recommendations in Treatment Plot 6 proved difficult for the works crews and yielded poor survivability results during monitoring activities. The sub-plots were not "ground-truthed" with markers delineating work areas. The plant-hole lining recommendations were overly complicated and labor intensive for a meager 23% plant survival rate.

The proposed treatments are intended to provide structural stability for a highly mobile site while giving fast-growing vegetation the opportunity to grow and protect the forest floor from intense and prolonged rains. Cribwall and live-stake bioengineering methods have been used to stabilize slopes by creating micro-terraces and establishing native pioneer species. These terraces and pioneer species will then bring the organics and macro nutrients necessary for longer-lived PNW species to establish themselves. Using natural material that can be collected locally by hand crews can reduce the materials cost for restoration work while demonstrating the importance of preserving native forests, wetlands, and riparian areas. Hand seeding native plants collected from those same sources can aid in the recovery process at greatly reduced time and labor costs.

While the bioengineering techniques recommended will be laborious and experimental, the techniques are not new to restoration work. Successful bioengineering slope stabilization projects are common in the PNW particularly in roadside stabilization. Sites with similar climate and constraints to those faced on the Schuster Slopes have been implemented by the Washington Department of Transportation in western Washington on sites with 2-3x the average precipitation (Lewis et al., 2001). Slope stabilization using living cribwall terraces has been successfully implemented on steeper slopes than the Schuster Project above the University of British Columbia Vancouver, Canada (Photos 7, 8, 9). In both cases, bioengineering techniques showed themselves to be sustainable long-term ecological solutions to human-induced erosional problems. In both of these examples, bioengineering accomplished the goals of protecting life and property while establishing or enhancing native forests. Ecological restoration is both an art and science and while vegetation alone cannot always stabilize slopes, incorporating nature into the recovery process has been and can continue to be a sustainable solution.

Photo 7. University of British Columbia slope stabilization work during construction.



Source: David Polster, used with permission. This image has been digitally enhanced.

Photo 8. University of British Columbia slope stabilization work. Treatment (green arrow) and non-treatment (red arrow) sections illustrated.

Source: David Polster, used with permission. This image has been digitally enhanced.

Photo 9. University of British Columbia slope stabilization after restoration.

Source: David Polster, used with permission. This image has been digitally enhanced.

References

Andreu, V., Khuder, H., Mickovski, S.B., Spanos, I.A., Norris, J.E., Dorren, L.K.A., Nicoll, B.C., Achim, A., Rubio, J.L., Jouneau, L., and Berger, F. 2008. "Ecotechnological solutions for unstable slopes: Ground bio- and – eco-engineering techniques and strategies". In *Slope Stability and Erosion Control: Ecotechnological Solutions*. Eds. J.E. Norris, A. Stokes, S.B. Mickovski, E. Cammeraat, R. van Beek, B.C. Nicoll, and A. Achim. Springer Science & Business Media, February 29, 2008.

Cammeraat, E., Van Beek, R., and Kooijman, A. 2007. "Vegetation succession and its consequences for slope stability in SE Spain". *Plant and Soil*. 278: 135-147.

Chirico, G.B, Borga, M., Tarolli, P., Rigon, R., and Preti, F. 2013. "Role of vegetation on slope stability under transient unsaturated conditions". *Procedia Environmental Studies*. (19): 932-941. DOI: 10.1016/j.proenv.2013.06.103.

Douglas, G.B., McIvor, I.R., Manderson, A.K., Koolaard, J.P., Todd M., Braaksma, S., and Gray, R.A.J. 2011. "Reducing shallow landslide occurrence in pastoral hill country using wide spaced trees". *Land Degradation and Development*. DOI: 10.1002/ldr.1106.

Environmental Services Department. 2015. "Schuster Slope Landscape Management Plan". City of Tacoma, WA. Accessed from https://cms.cityoftacoma.org/surfacewater/Schuster/FinalPlan/SchusterSlopeLMP_FINAL_09032015.pdf.

GeoEngineers. 2015. "Work Plan—Final Revision: Schuster Slope Management Area –Unit". Tacoma, Washington. Accessed from https://cms.cityoftacoma.org/SurfaceWater/Schuster/WorkPlan/SchusterMU1_WorkPlan_122315.pdf

Halvorson, J.J., Smith, J.L., and Franz, E.H. 1991. "Lupine influence on soil carbon, nitrogen and microbial activity in developing ecosystems at Mount St. Helens". *Oecologia*. 87(2): 162-170. doi.org/10.1007/BF00325253.

Harmon, M.E., and Sexton, J. 1995. "Water balance of conifer logs in early stages of decomposition". *Plant and Soil*. 172(1): 141-152. https://doi.org/10.1007/BF00020868.

Hoag, J.C. 2007. "How to plant willows and cottonwoods for riparian restoration". Technical Note, USDA, Natural Resource Conservation Service. Boise, Idaho.

Johannessen, J. 2015. "Assessing littoral sediment supply (feeder bluffs) and beach condition in King and southern Snohomish counties, Puget Sound, Washington". Coastal Geologic Services Inc., www.coastalgeo.com.

Lewis, L. 2000. "Soil bioengineering: An alternative for roadside management". Technical Paper. USDA, US Forest Service, Technology and Development Program. San Dimas, CA, September 2000. https://www.wsdot.wa.gov/publications/fulltext/Roadside/SoilBioEngAlternative.pdf. Accessed Oct, 22, 2019.

Lewis, L., Salisbury, S.L., & Hagen, S. 2001. "Soil bioengineering for upland slope stabilization". Research Report Washington Department of Transportation, Washington State Transportation Center. University of Washington Seattle, Washington.

MacDonald, K., Simpson, D., Paulsen, B., Cox, J., and Gendron, J. 1994. "Shoreline armoring effects on physical coastal processes in Puget Sound, Washington". Washington Department of Ecology, Coastal Erosion Management Studies. (5): 94-78.

McIvor, I., Douglas, G., Dymond, J., Eyles, G., and Marden, M. 2011 "Pastoral hill slope erosion in New Zealand and the role of poplar and willow trees in its reduction". *Soil Erosion Issues in Agriculture.* D. Godone and S. Stanchi, eds. Oct 21, 2011. doi:10.5772/926.

Menashe, E. 1993. "Vegetation management: A guide for Puget Sound bluff property owners". Shorelands and Environmental Assistance Program, Washington Department of Ecology. Olympia.

Passive Open Space Program. 2017. "Schuster Slope Activities and Monitoring Report 2016/2017". City of Tacoma, WA. Unpublished report.

Passive Open Space Program. 2018. "Schuster Slope Activities and Monitoring Report 2017/2018". City of Tacoma, WA. Unpublished report.

Pawlik, L., Samonil, P. "Soil creep: The driving factors, evidence and significance for biogeomorphic and pedogenic domains and systems – A critical literature review". *Earth-Science Reviews*, v 178, March 2018: 257-278.

Polster, D.F. 2006. "Soil bioengineering for riparian restoration". Paper presented at the Canadian Land Reclamation Association 2006 Conference, Ottawa, Canada, August 20-23.

Polster, D.F. 2011. "Effective reclamation: Understanding the ecology of recovery". Paper presented at the 2011 Mine Closure Conference and B.C. Technical and Research Committee on Reclamation, BC Mine Reclamation Symposium. Lake Louise, AB. September 18-21, 2011.

Polster, D.F. 2012. "A new paradigm for the restoration of drastically disturbed sites". Paper presented at the British Columbia Mine Reclamation Symposium, 2012.

Pruser, M. "How much is a great view worth?". Doughroller.net April 26, 2010. Accessed from https://www.doughroller.net/real-estate-investing/how-much-is-a-great-view-worth/.

Scurfield, G. 1973. "Reaction Wood: Its structure and function". *Science*. Vol 179 (4074): 647-655.

Straker, J. 1996. "Regeneration on Natural Landslides". Paper presented at the Coastal Forest Sites Rehabilitation Workshop. B.C. Forestry Continuing Studies Network. Nanaimo, B.C. October 31 - November 1, 1996.

Stokes A., Fitter A.H., and Coutts, M.P. 1995. "Responses of young trees to wind and shading: effects on root architecture". *Journal of Experimental Botany*. 46:1139-1146.

Stokes, A., Nicoll, B.C., Coutts, M.P., and Fitter, A.H. 1997. "Responses of young Sitka spruce clones to mechanical perturbation and nutrition: effects on biomass allocation, root development, and resistance to bending". *Canadian Journal of Forest Research* 27:1049-1057.

Stokes, A. 2006. "Selecting tree species for use in rock-fall protection forests". *Forest Snow and Landscape Research*. 80(1): 77-86.

Styczen, M.E. and Morgan, R.P.C. 1995. "Engineering properties of vegetation". In *Slope Stabilization and Erosion Control: A Bioengineering Approach*. Eds. R.P.C. Morgan and R.J. Rickson. London: E & FN Spon, 5-58.

Sustainable Human. 2014. "How Wolves Change Rivers". *Wolf Reintroduction Changes Ecosystem in Yellowstone.* February 14, 2019. Accessed from https://www.yellowstonepark.com/things-to-do/wolf-reintroduction-changes-ecosystem.

Tacoma Municipal Code, Title 13, *Land Use Regulatory Code*, accessed Oct 6th, 2019. https://cms.cityoftacoma.org/cityclerk/Files/MunicipalCode/Title13-LandUseRegulatoryCode.pdf.

Terwilliger, V.J., and Waldron, L.J. 1991. "Effects of root reinforcement on soil-slip patterns in the transverse ranges of Southern California". *American Geological Society Bulletin*. 103:775-785.

USDA, Forest Service, Technology & Development Program. September 2006. "Wilderness and Backcountry Site Restoration Guide". Therrell, L., Cole, D., Claassen, V., Ryan, C., and Davies, M.A.

Waldron, LJ. 1977. "The shear resistance of root permeated homogenous and stratified soil". *American Journal of Soil, Science, and Society*. 41:843-849.

Waldron, L.J. and Dakessian, S. 1981. "Soil reinforcement by roots: calculation of increased soil shear resistance from root properties". *Soil Science*. 132:427-435.

Waldron, L.J. and Dakessian, S. 1982. “Effect of grass, legume, and tree roots on soil shearing resistance”. *American Journal of Soil, Science, and Society*. 46:894-899.

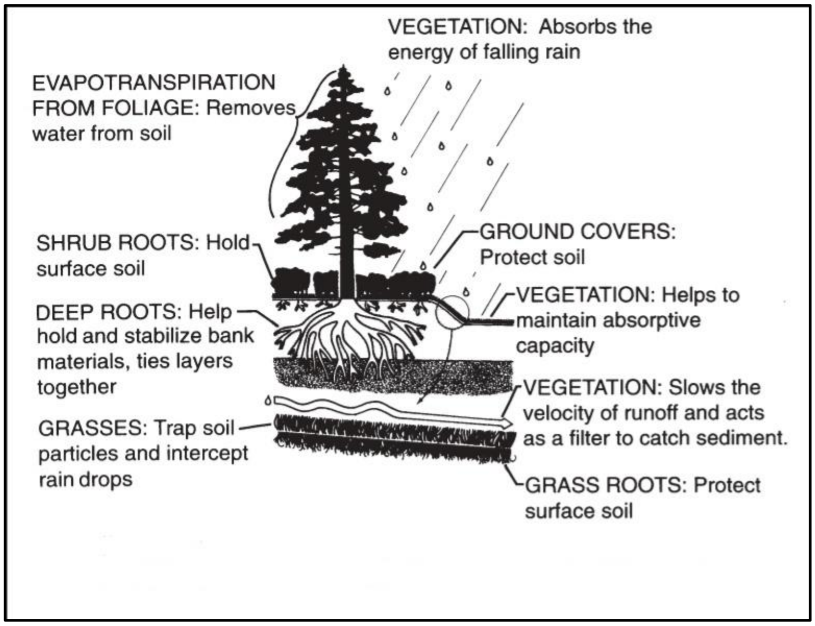
WDNR. 2011. “Ecological integrity assessments North Pacific dry-mesic and mesic-wet Douglas-fir - Western hemlock forests”. Washington State Department of Natural Resources, Natural heritage Program. February 24.

Wu, T.H. 1995. “Slope stabilization”. In *Slope Stabilization and Erosion Control: A Bioengineering Approach*. Eds. R.P.C. Morgan and R.J. Rickson. London: E & FN Spon, pp.221-264.

Ziemer, R.R. 1981. “The role of vegetation in the stability of forested slopes”. Proceedings of the International Union of Forestry Research Organizations, XVII World Congress, 6-17 September 1981, Kyoto, Japan (1): 297-308.

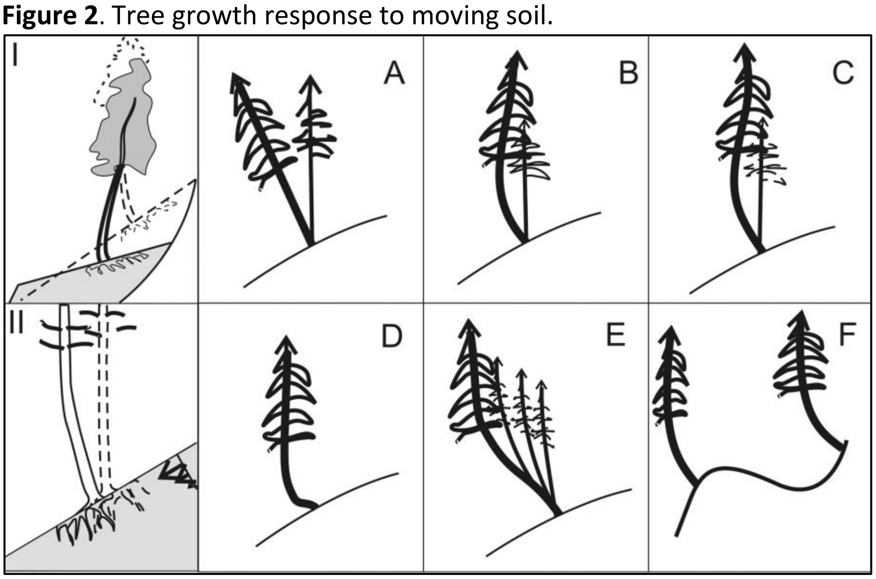
Appendix A. Figures

Figure 1. Effects of vegetation in minimizing erosion.



From Menashe (1993). This image has been digitally altered.

Figure 2. Tree growth response to moving soil.



From Andreu et al., (2007)

Figure 3. Fascine aka living-cribwall design. Live stakes are staked horizontally across the slope to retain soil and rocks. Stakes then can sprout adventitious roots and stabilize slopes with pioneering vegetation. Vertical stakes can be live stakes, natural wood stakes that will not grow from cuttings, or processed timber.

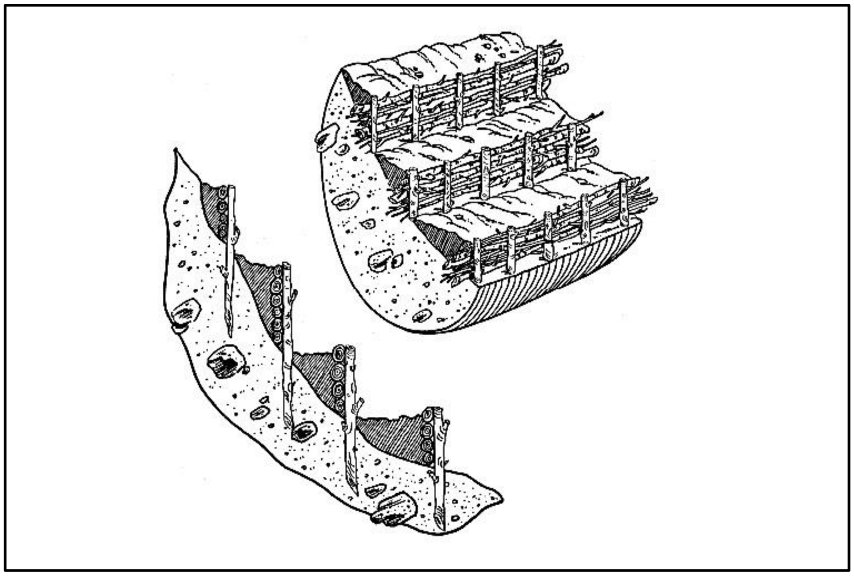
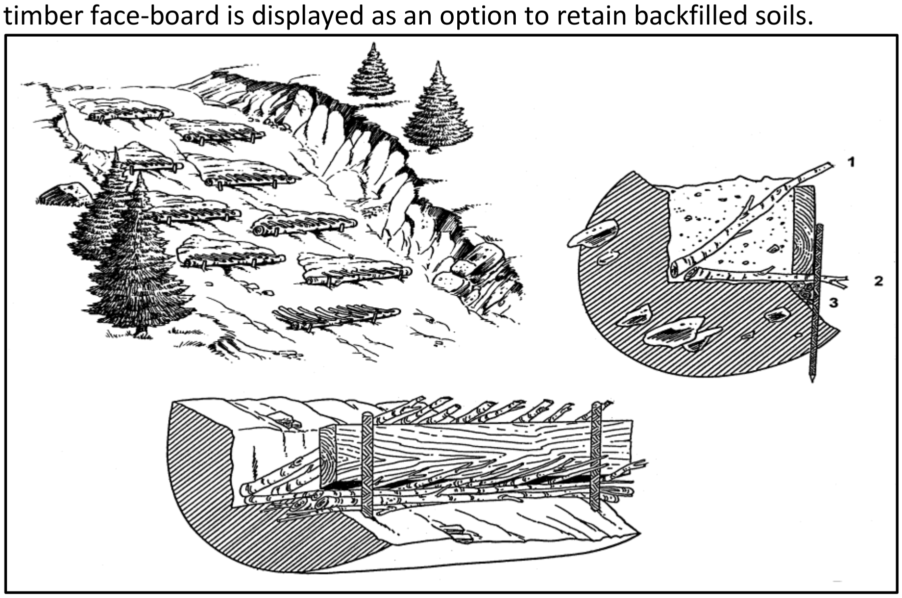
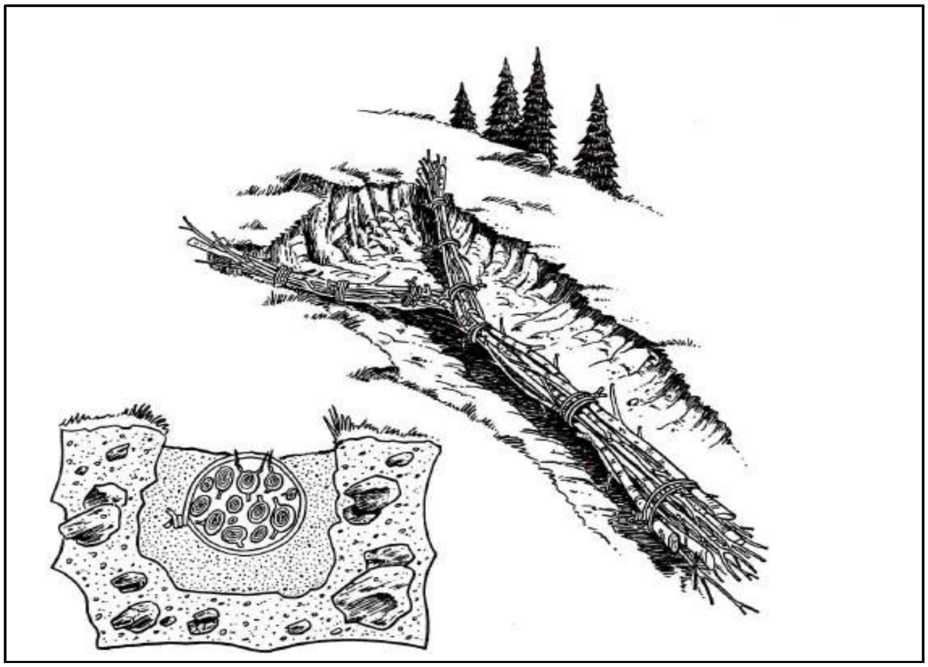


Figure 4. Offset modified brush layers with wooden fence board displayed. Brush layers are recommended for drier slopes where willow and cottonwood stakes may not be viable. Processed timber face-board is displayed as an option to retain backfilled soils.



From David Polster, polsterenvironmental.com, used with permission.

Figure 5. Live drain poles installation. Long bundles of moisture-tolerant cottonwoods and/or willows are bundled in a rill, gully, or other saturated area where soil stability is of concern. All stakes should be arranged to face uphill, tightly bound together with separate bundles in contact with each other, and covered 3 quarters of the bundle diameter with soil.



From David Polster, polsterenvironmental.com, used with permission

Figure 6. Select species for hand seeding

- Salal (*Gaultheria shallon*)
- Low Oregon grape (*Mahonia nervosa*)
- Indian Plum (*Oemleria cerasiformis*)
- Kinnickinick (*Arctostaphylos uva-ursi*)
- Douglas-fir (*Pseudotsuga menziesii*)
- Western hemlock (*Tsuga heterophylla*)
- Western Redcedar (*Thuja plicata*)
- Tall Oregon grape (*Mahonia aquifolium*)
- Evergreen huckleberry (*Vaccinium ovatum*)
- Red alder (*Alnus rubra*)
- Snowberry (*Symphoricarpos albus*) [to be live staked due to high viability]

Appendix B. Tables

Table 1. Desirable plant characteristics for functions of vegetation in preventing or reducing erosion.

Function	Desirable Plant Characteristics
Capture and restrain moving soil/rocks	Strong, multiple, and flexible stems; rapid stem growth; ability to re-sprout after damage; ready propagation from cuttings and root suckers
Cover and protect soil surface	Extensive, tight, and low canopy; dense, spreading, surface growth; fibrous root mat
Reinforce and support slope soils	Multiple, strong, deep roots; rapid root development; high root/shoot biomass ratio; good leaf transpiration potential
Improve ecosystem community	Shade and cover to moderate temperatures and improve moisture retention; soil humus development from litter; nitrogen fixation potential

Adapted from Gray and Sotir (1996), as cited in Stokes, (2008)

Table 2. Bioengineering techniques

Name	*Construction*	*Primary functions(s)*
1. Live stake	Sticks are cut from rootable plant stock and tamped directly into ground	Live plants reduce erosion and remove water by evapotranspiration. Plant roots reinforce soil
2. Live fascine (cribwall)	Sticks of live plant material are bound together and placed in a trench. They are anchored to the ground by live stakes (Figure 3)	Same as 1
3. Brush mattress	Live branches are placed close together on the surface to form a mattress	Same as 1. In addition, it provides immediate protection against surface rainfall impact.
4. Brushlayer, branchpacking	Live branches are placed in trenches or between layers of compacted fill (Figure 4)	Same as 1
5. Live pole drains	Live poles bound together end-to-end and anchored by live stakes (Figure 5)	Same as 1. In addition, drain excess moisture from seepage zones. Acting like living French drains.

Adapted from Wu (1995) and Polster (2006)

Table 3. Treatment Plot 6 Sub-plot treatments

Groundcover	absent				present			
Planting Fabric	none	straw	burlap	coir	none	straw	burlap	coir
Sub-TP								
1A	X							
2A							X	
2B						X		
3B				X				
3C	X							
1C						X		
1D							X	
3D			X					
2E	X							
1E								X
3F								X
2F		X						

From Passive Open Space Program (2017), used with permission.

Table 4. Monitoring results Management Unit 1 after first growing season.

Treatment Plot	Average Survival Rate (%)	Well-Performing Species	Conditions
1	16.7	Grand-fir (*Abies grandis*)	Dry to Moist Soil, Sand, Sun to Part-shade
2	142.9	Tall Oregon Grape (*Mahonia aquifolium*), Nootka rose (*Rosa nutkana*)	Dry to Moist Soil, Sand, Sun to Part-shade
3	140	Snowberry (Symphoricarpos albus), Vine maple (Acer circinatum), Shore pine (Pinus contorta)	Dry to Moist Soil, Sand, Sun to Part-shade
4	100	Cascara (Rhamnus purshiana)	Dry to Moist Soil, Sand, Sun to Part-shade
5	66.7	Swordfern (Polystichum munitum), Snowberry (Symphoricarpos albus)	Dry to Moist Soil, Sand-Gravel, Shade to Part-shade
6-1C	17.6	Snowberry (Symphoricarpos albus)	Dry to Moist Soil, Sand-Gravel, Shade to Part-shade
Average	80.7		

From Passive Open Space (2017). Recreated with permission.

Table 5. Estimated costs for erosion on materials, Management Unit

Type	Material/ Alternatives	Description	Unit Cost ($)		Units	Quantity	Cost Range ($)	
			Low	High			Low	High
Nets or Blankets	Jute	Made from Jute Fiber; 100% biodegradable	$0.20	$0.30	SF	63,000	$12,600.00	$18,900.00
	Coir	Made from coconut husk; 100% biodegradable	$0.20	$0.30	SF	63,000	$12,600.00	$18,900.00
Debris Containment	Silt Fencing	As described in BMP C223 Tacoma Stormwater Management Manual Vol. 2	-	$1.00	LF	1,200	-	$1,200.00
	Ecology Blocks	2'Wx2'Hx3'L concrete block	$35.00	$45.00	each	14	$490.00	$630.00
		2'Wx2'Hx6'L concrete block	$35.00	$45.00	each	7	$245.00	$315.00
	Traffic Barriers	120"L x 24"W x 34"H	$250.00	$846.00	each	5	$1,250.00	$4,230.00
Wattles	Straw	Straw bundled with biodegradable material	-	$1.00	LF	3,840	-	$3,840.00

From Passive Open Space (2018). Reprinted with permission.

Table 6. Management Unit 1 Year-2 monitoring results.

TP	Average Survival Rate (%) 2016/2017 to 2017/2018	Survival Rate (%) from Y0	Well performing species 2017/2018 only **Well performing Species 2016/2017 and 2017/2018** Well-Performing Species 2016/2017	Conditions
2*	50	71	**Tall Oregon Grape (*Mahonia aquifolium*)**, Nootka Rose (*Rosa nutkana*)	Dry to Moist Soil, Sand, Sun to Part-Shade
3*	64	90	**Snowberry (*Sympharicarpos albus*)**, Vine Maple (*Acer circinatum*) Shore Pine (*Pinus contorta*)	Dry to Moist Soil, Sand, Sun to Part-Shade
4*	100	200	**Snowberry (*Sympharicarpos albus*),** Cascara (*Rhamnus purshiana*)	Dry to Moist Soil, Sand, Sun to Part-Shade
5*	17	11	**Snowberry (*Sympharicarpos albus),*** Sword Fern (*Polystichum munitum*)	Dry to Moist Soil, Sand-Gravel, Shade to Part-Shade
6-1C*	33	6	**Snowberry (*Sympharicarpos albus),*** Pacific Wax Myrtle (*Myrica californica*)	Dry to Moist Soil, Sand-Gravel Shade to Part- Shade
6-1D	N/A	23	Snowberry (*Sympharicarpos albus)*	Dry to Moist Soil, Sand-Gravel, Shade to Part-Shade
6-2E	N/A	42	Sword Fern (*Polystichum munitum*)	Dry to Moist Soil, Sand-Gravel Shade to Part-Shade
6-3F	N/A	23	Nothing of note	Dry to Moist Soil, Sand-Gravel, Shade to Part-Shade
Average	53	58		

*The number of plants installed per monitoring location was estimated based upon the total number of plants installed per treatment plot, no baseline monitoring was performed.

From Passive Open Space (2018). Reprinted with permission.

Table 7. Replanting charts for Treatment Plot 6, 2017/2018

Treatment Plot 6 - Slope Face and Toe, Dry to Moist Soils, Shade to Part Shade				
Tree Layer	**45,273**			
Species	**Common Name**	**% Total**	**Spacing (Ft)**	**Quantity**
Abies grandis	Grand fir	50%	8	409
Rhamnus purshiana	Cascara	10%	8	82
Thuja plicata	Western red cedar	20%	8	164
Tsuga heterophylla	Western Hemlock	20%	8	164
TOTALS		**100%**		**819**
Shrub Layer	**45,273**			
Species	**Common Name**	**% Total**	**Spacing (Ft)**	**Quantity**
Acer circinatum	vine Maple	10%	6	145
Corylus cornuta	beaked hazelnut	10%	6	145
Holodiscus discolor	oceanspray	20%	6	290
Morella californica	California wax myrtle	30%	6	436
Oemleria cerasiformis	Indian plum	15%	6	218
Vaccinium ovatum	Evergreen huckleberry	15%	6	218
TOTALS		**100%**		**1452**
Groundcover Layer	**45,273**			
Species	**Common Name**	**% Total**	**Spacing (Ft)**	**Quantity**
Gaultheria shallon	salal	20%	4	654
Mahonia nervosa	dull Oregon grape	15%	4	491
polystichum munitum	sword fern	35%	4	1,144
Symphoricarpos albus	snowberry	30%	4	981
TOTALS		**100%**		**3270**

Treatment Plot 6 - Wetland/Streams, Moist to Wet Soils, Shade to Part Shade				
Tree Layer	**627**			
Species	**Common Name**	**% Total**	**Spacing (Ft)**	**Quantity**
Thuja plicata	Western red cedar	40%	8	5
Picea sitchensis	Sitka Spruce	40%	8	5
Rhamnus purshiana	cascara	20%	8	3
TOTALS		**100%**		**13**
Shrub Layer	**627**			
Species	**Common Name**	**% Total**	**Spacing (Ft)**	**Quantity**
Cornus sericea v. stolonifer	red-osier dogwood	25%	6	6
Oplopanax horridus	Devil's club	0%	6	0
Physocarpus capitatus	Pacific ninebark	25%	6	6
Rubus spectabilis	salmonberry	50%	6	11
TOTALS		**100%**		**23**
Groundcover Layer	**627**			
Species	**Common Name**	**% Total**	**Spacing (Ft)**	**Quantity**
Athyruim felix-femina	lady fern	0%	3	0
Carex obnupta	slough sedge	50%	3	40
Juncus effusus	soft rush	50%	3	40
TOTALS		**100%**		**80**

Source: Brandon Drucker, city of Tacoma, personal communication.

Appendix C. Maps

Map 1. Extent of last glacier through the Puget Sound area, approximately 15,000 years ago.

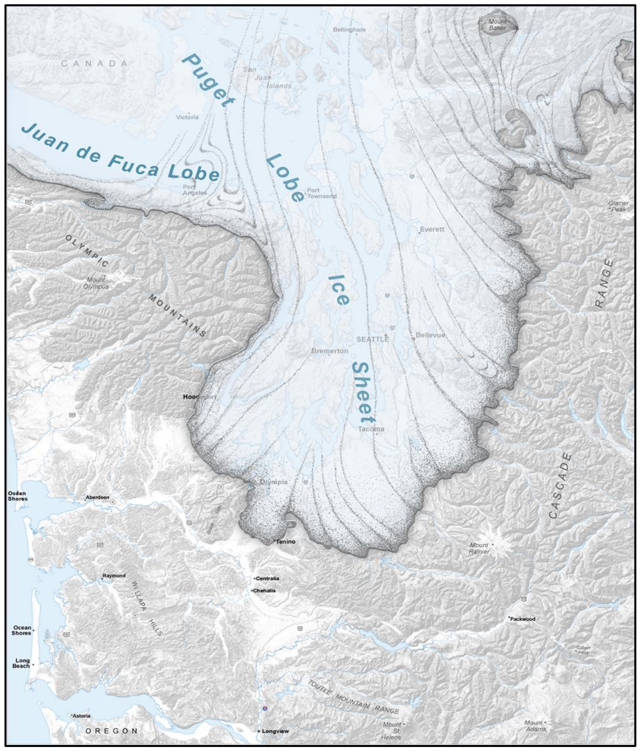
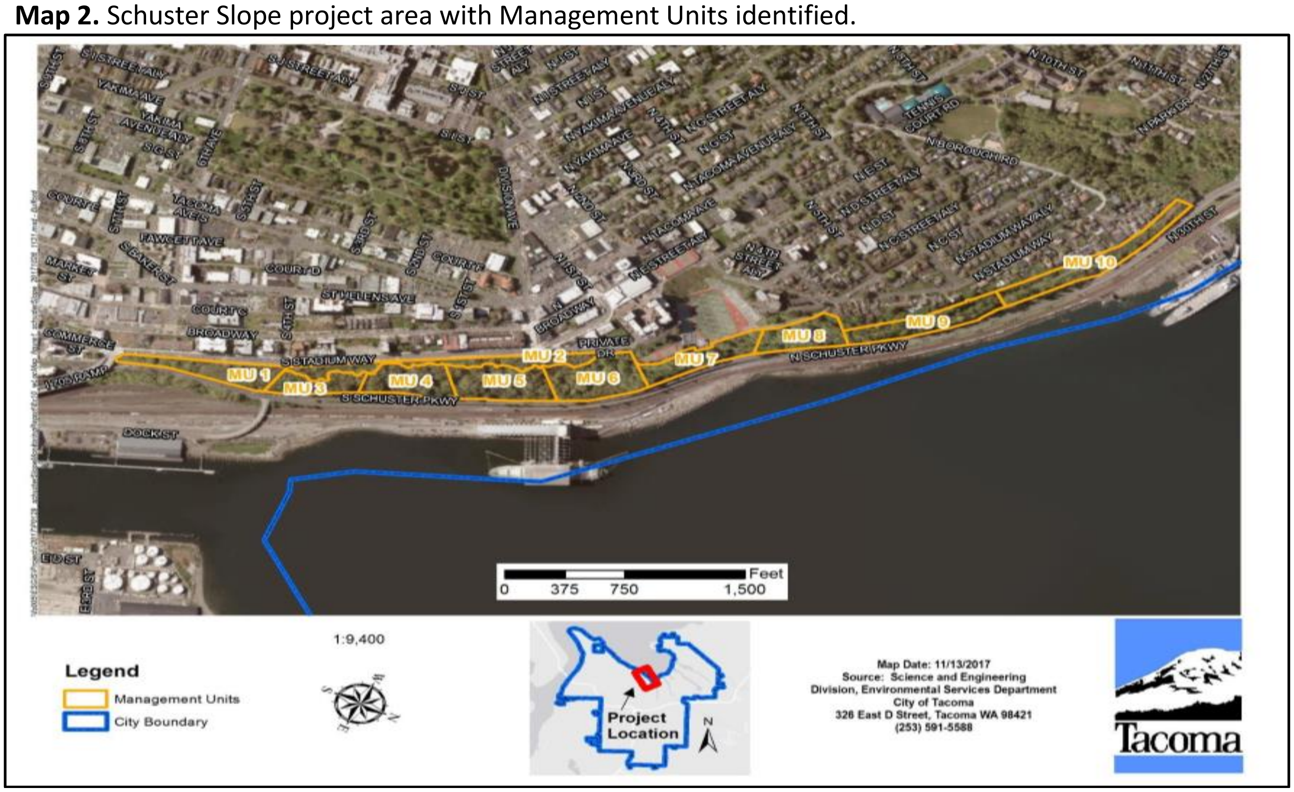


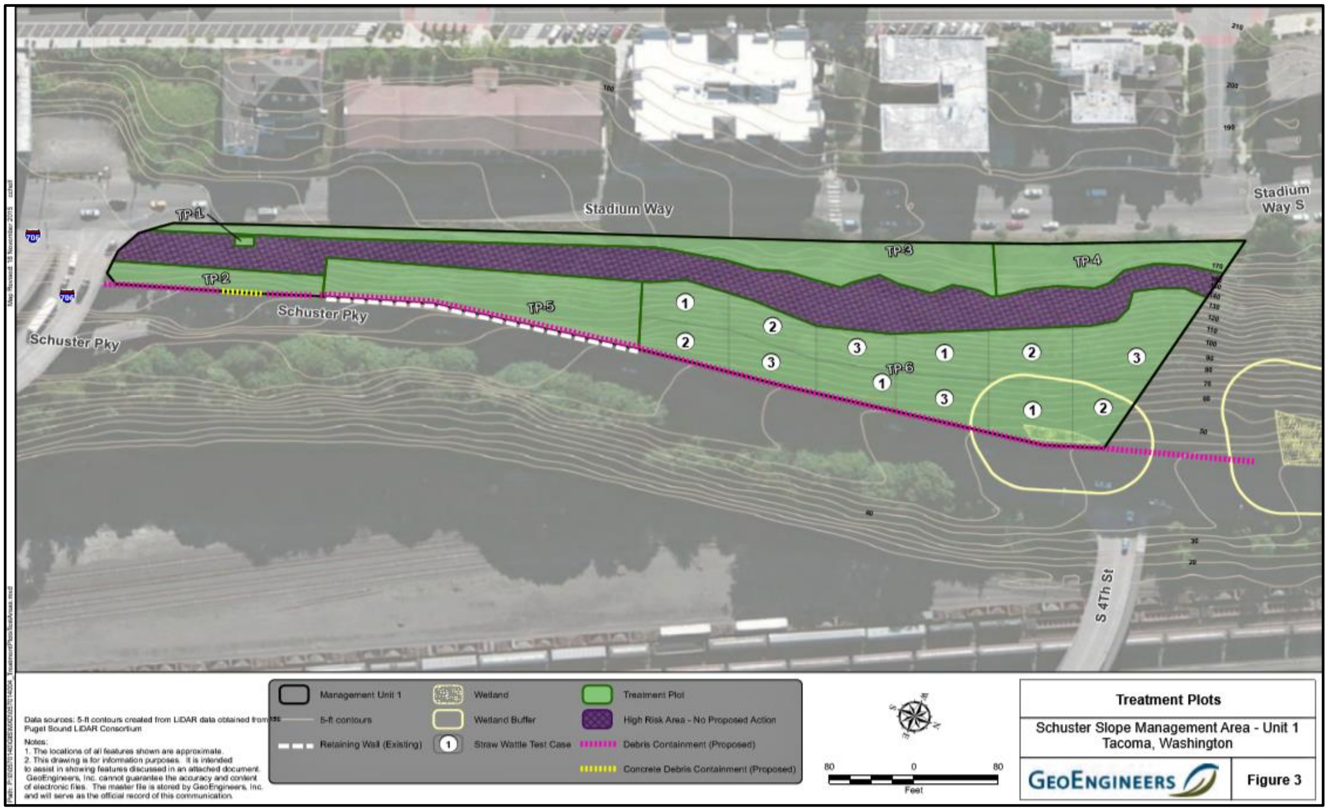
Photo source: https://www.dnr.wa.gov/programs-and-services/geology/explore-popular-geology/puget-sound-and-coastal-geology#puget-sound-geology

Map 2. Schuster Slope project area with Management Units identified.



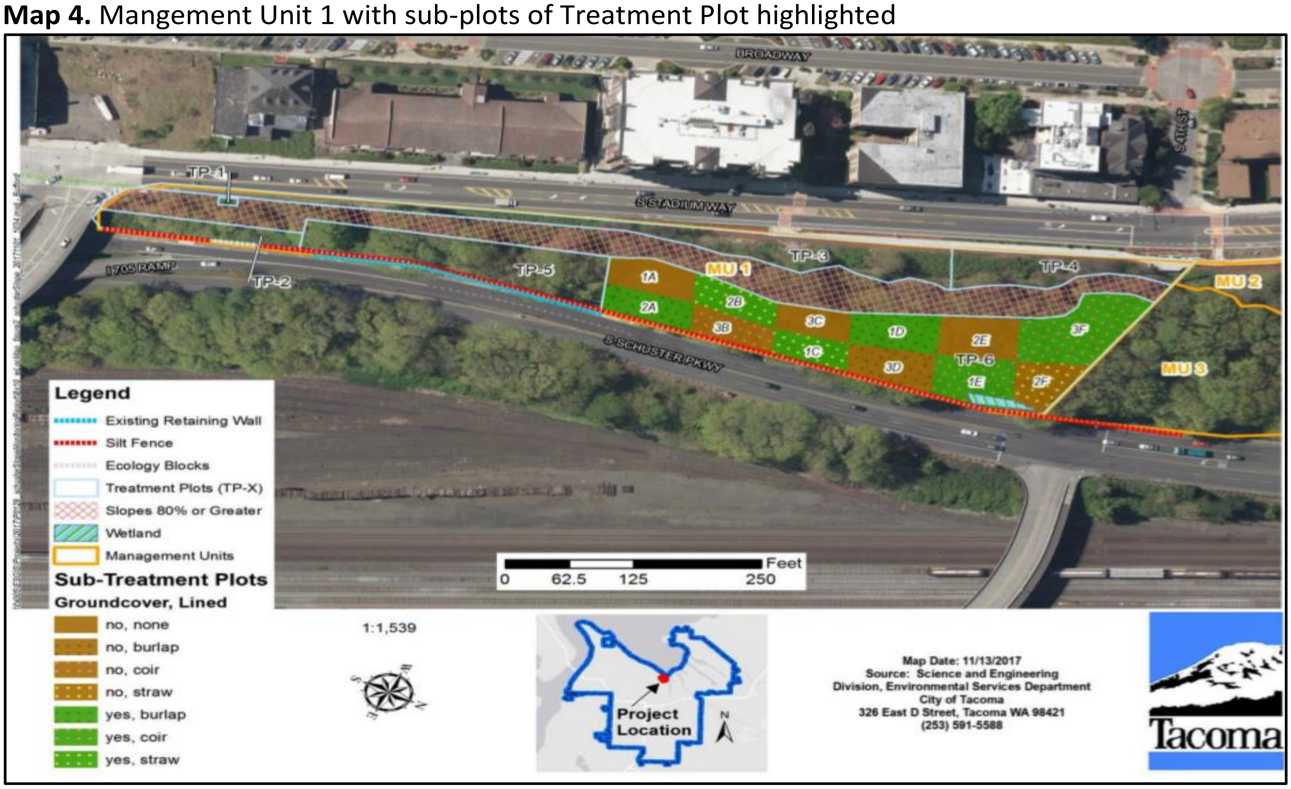
From Passive Open Space Program (2017). This image has been digitally enhanced.

Map 3. Management Unit 1 with Treatment Plots identified.



From GeoEngineers (2015). This image has been digitally enhanced.

Map 4. Mangement Unit 1 with sub-plots of Treatment Plot highlighted



From Environmental Services (2016). This image has been digitally enhanced.

Appendix D. Photos

Photo 1. Surficial slide on Schuster Slope near pedestrian walkway, January 2019.

Photo source Luis Yanez, 2019

Photo 2. Typical homeless encampment on Schuster Slope

Photo source: Luis Yanez 2019

Photo 3. Treatment Plot 6 understory. Note large cobble stone pervasive onsite.

Photo credit: Michael Carey, city of Tacoma, used with permission

Photo 4. Treatment Plot 6

Photo source: Brandon Drucker, 2019. This image has been digitally enhanced.

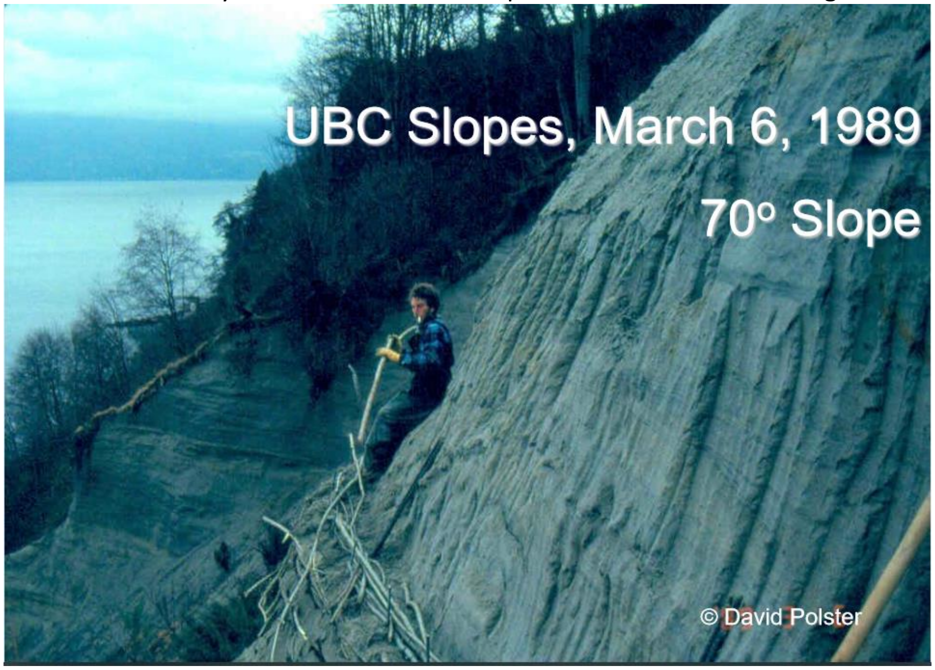
Photo 5. Western hemlock (*Tsuga heterophylla*) growing on an old stump.

Source: Ken Denniston, nwconifers.com, used with permission

Photo 6. Typical roadside bioengineering work.

From Lewis et al., (2001). This image has been digitally enhanced.

Photo 7. University of British Columbia slope stabilization work during construction.



Used with permission. This image has been digitally enhanced.

Photo 8. University of British Columbia slope stabilization work. Treatment (green arrow) and non-treatment (red arrow) sections illustrated.

Used with permission. This image has been digitally enhanced.

Photo 9. University of British Columbia slope stabilization after restoration.

Used with permission. This image has been digitally enhanced.

Appendix E. Installation Methods.

Detailed installation directions for live cribwalls, From Lewis (2000).

Willow fencing with brushlayering. USDA Forest Service

Willow Fencing Modified with Brushlayering

Advantages: These structures reduce slope angle, providing a stable platform for vegetation to establish. Willow fences trap rolling rocks and sliding debris and protects vegetation growing lower on the slope. Willow fences provide support for small shallow translational or rotational failures. Sites where fine textured soils can provide ample summer moisture, or where seepage of groundwater provides moisture, are suitable for willow/brushlayering fence installations. These structures can also be constructed on dryer sites, however, expect high willow mortality. In these situations, the willow shelf is considered a temporary planting platform. It is important, therefore, to establish deeper rooting shrubs and trees within the shelf. When the structure begins to decay, root systems of other plants will serve as the permanent feature.

Disadvantages: Significant quantity of plant material is required. Moist site conditions are required for the fence to sprout and grow.

Willow fencing with brushlayering is essentially a willow fence supported on a short brushlayer. Specifically, it is a short retaining wall built of living cuttings with a brushlayer base (figure 11). Willow fencing can also be used without base brushlayering (Polster, 1998).

Tools needed:

Hand pruners and clippers, pulaski or hazel hoe, McLeod rake, deadblow or rubber hammer, wood stakes or rebar.

Procedure:

Brushlayering

- Begin project at base of treatment area. Excavate 16 to 20 inch deep trenches along slope contour and for full width of treatment area. Spacing of trenches averages between 5 to 8 feet full measurement depending on site conditions. This technique can cause additional erosion during installation, therefore, it is important to construct project in phases and to avoid excavating more area than is necessary to install plant materials (figure 11).