

THE BUNKER HILL HILLSIDES: A CASE STUDY IN THE USE OF ADAPTIVE MANAGEMENT IN EARLY SUCCESSIONAL RESTORATION ON THE NATION'S LARGEST SUPERFUND SITE¹

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Abstract. Active hillsides restoration included development and installation of site prescriptions using adaptive management and monitoring of results. Initial prescriptions for hillsides restoration and their implementation were based on a combination of site characterization and demonstration studies. Prescriptions were modified over time as the results of past activities became evident. Hillsides have responded well to prescriptions and successional processes appear to have been re-initiated. Adaptive management induced prescription modifications including changing liming materials to improve performance, increasing seeding rate to improve initial plant canopy cover, adjusting seed mix composition to remove poorly germinating species and adding herbaceous species with exceptional establishment and growth performance, increasing shrub sizes to improve establishment, and selecting tackifiers that reflected actual site performance of the products. Target plant covers were 50 percent or greater and overall plant canopy cover from 1998 and 1999 operational hydroseeding averaged over 61 percent after two growing seasons. Red top, bluegrass, sheep fescue, Idaho fescue, and timothy dominate the seeded communities. Plant and mulch cover is approximately 10 percent higher on east-facing slopes compared to west-facing slopes. Areas of low cover are often composed of rock pavement surfaces. New seedlings are emerging and volunteer plant species are appearing on the slopes. Turbidity of surface water emanating from the hillside watersheds has dropped substantially from past years. Instantaneous comparisons between background turbidity at the mouths of Government and Deadwood creeks indicate that State of Idaho water quality standards are being met in most cases. Early successional processes appear to be emerging on the hills with assistance provided by wildlife.

Additional keywords: monitoring, surface water quality, plant cover, remediation

¹Paper was presented at the 2003 National Meeting of the American Society of Mining and Reclamation and The 9th Billings Land Reclamation Symposium, Billings MT, June 3-6, 2003. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2003 pp 1472-1500

DOI: 10.21000/JASMR03011472

Introduction

A primary question restoration ecologists pose is, “How can we accelerate ecosystem succession – both in form and function – in our projects?” A second and equally valid question is, “How do we cost-effectively implement solutions to Question No. 1?” Restoration solutions for project goals must be cost-effective for the restoration paradigm to gain wide acceptance. Projects are often faced with balancing the speed of ecosystem restoration against the often higher cost of implementing the accelerating technology. To best do so, we must identify ways to work with nature to achieve cost-effective success. We must also be willing to balance uncertainties through on-site experience and adapting management decisions to actual ecosystem responses to restorative inputs.

The southern hillsides of Bunker Hill are located in the towns of Kellogg and Smeltonville, Idaho. They are a difficult restoration challenge. Over 400 denuded hectares of more or less contiguous landscape lies on steep slopes that can extend to over 560 meters in length (Figure 1). The project area occupies lower elevations in six different watersheds: Deadwood Gulch, Portal Gulch, Magnet Gulch, Government Gulch, Grouse Gulch and Page Gulch. The entire hillside environment is highly eroded and moisture-limited. The hills are acidic (average $pH = 4.9$) with scattered pockets of heavy metal contamination, especially near the footprints of the now-removed smelting and refining facilities. The pre-treatment plant cover was restricted to a few water collecting surfaces such as draws and small hillside convexities.

This paper is part of a series describing the early restoration of the Bunker Hill hillsides. A companion paper discusses the history of the site and the establishment of goals, objectives, and performance standards for the project (White et al., 2003). A second paper summarizes work that characterized soil properties and limiting factors on this expansive site (White and Mengel, in preparation) while another paper reviews amendment testing that occurred prior to developing site prescriptions (Mengel et al., in preparation).

This paper discusses the use of adaptive management in achieving success in early successional restoration. Included in the following discussion are the design context and criteria (CH2M HILL 1999), the soil amendment, revegetation prescriptions, and the technology that was used along with some early results of these revegetation efforts (CH2M HILL, 2001; CH2M HILL, 2002). It includes a brief review of the post-application monitoring program and



Figure 1. Pre-treatment hillsides environment in Government Gulch. Note construction of terrace benches spaced approximately 30 m apart. Steep slopes, exceeding 30 degrees (58 percent) and extending to over 500 meters in many places, dominate the site. Combined with extensive soil erosion, acidic reaction, and even steeper cut and fill slopes, the hillsides landscape is a difficult restoration challenge (photo taken in 1997).

concludes with a discussion of ancillary benefits from our work and the role that early successional restoration projects play in the understanding of ecosystem restoration.

The Context of Hillsides Revegetation

The ultimate goal for the Bunker Hill hillsides is to return them to a coniferous forest ecosystem similar to that found elsewhere in northern Idaho. However, retention of soil resources is a first priority in restoration projects of this type and of critical importance to meeting the directives of Superfund projects. Loss of soil results in reduced site productivity and a concomitant narrowing of potentially successful restoration trajectories. The high degree to which soil resources had previously been depleted on the hillsides (Figure 1) dictated a critical need to focus on this initial target.

In the short-term, therefore, the hillsides project focused on reduction of erosion and sedimentation in order to reduce pollution of the South Fork of the Coeur d'Alene River. To date, our work has used soil amendment and seed mix applications combined with a limited use of check dam structures. Decisions made to this end occurred within the context of both project goals and objectives as well as project constraints (White et al., 2003; White and Mengel, in preparation; Mengel et al., in preparation). Throughout the project, we employed adaptive management to guide decision making. Adaptive management gave us flexibility to engage other approaches in areas where performance was not satisfactory.

While site nutrient and physical conditions set the stage for revegetation decisions, other constraints establish a context for the project which controls the size of the decision matrix. The most important constraints were site access, shipping, and sustenance of prior restoration activities. The following discussion details these constraints and how this limitation affected the decision-making process.

Lack of Site Access

Road access to the hillsides is only available for some lower-elevation slopes. Elsewhere access consists of relatively narrow terrace benches that are more or less uniformly spaced (Figure 1). Inter-terrace passages between most of these benches, which are designed for soil stabilization purposes, do not exist. The narrow benches can extend for hundreds of meters at a stretch without areas that are wide and/or safe enough within which to turn around.

Decision Impact. Because of poor access, aerial applications were considered more feasible for revegetation of most of the hillsides. This decision alone affected subsequent judgments regarding material quantities and handling.

Shipping

A substantive contributor to hillside project expenses was the cost of shipping revegetation materials. Thousands of tons of restoration materials would be needed to meet project objectives. However, Kellogg, Idaho lies many miles from major metropolitan areas. Shipping options to the site are limited to truck-based transportation. As a result, shipping costs for

revegetation materials were proportionately higher than those for otherwise similar projects in areas closer to distribution centers.

Decision Impact. Reduction in the quantity of application materials became a high priority for the project since it would reduce project costs proportionately and improve the economic feasibility of the work.

Sustaining Prior Work

Over two million coniferous seedlings were planted throughout the Bunker Hill Superfund Site in previous years. Although many of the seedlings were struggling to survive on the hillsides, one objective of the project was to allow the forest to eventually dominate the landscape.

Decision Impact. To reduce impacts to prior tree planting efforts, species selected for revegetation were chosen, in part, to minimize competition to the developing forest. Consequently, we focused on establishment of native bunchgrass species, although sod-formers were also used for specific areas.

Developing Design Criteria: Soil Stabilization Versus Soil Process Rehabilitation

Soil stabilization with seed, mulch, and physical structures helps reduce sediment discharge over the short-term. Techniques used to limit erosion and sediment discharge all rely on reducing the energy of water. Minimizing erosion and sediment discharge from the hillsides relies primarily on the production of plant biomass (along with limited use of check dams). Plant cover intercepts rain drops and slows runoff velocities. Expanding root systems anchor underlying soils. Moreover, strategic placement of plants and/or structures effectively reduces sediment transport.

Long-term sediment discharge, soil erosion control, and sustainability goals, however, rely on re-establishment of sustainable plant-soil relationships similar to those of the surrounding landscape. For long-term ecosystem development the soils of the hillsides must be able to naturally supply nutrients at levels that fall within the natural range of variability of the

surrounding landscape. Soils accrue these capabilities as organic matter and nutrient pools expand and when nutrient cycling processes are at levels that are sufficient to meet plant needs. The degree to which ecosystem restoration is achieved at the site level can often rely substantially upon the degree to which such processes approach background levels. Until soil processes are re-established at levels sufficient to sustain plant growth and ecosystem development, other amendments applications may be needed.

The hillsides are acidic, moisture-limited, and low in certain nutrient supplies. Accordingly, restoration of hillside soils begins first with introduction of organic matter and lime. Inoculation of some target woody species with fungal mycorrhizal species may also assist with both the short- and long-term re-establishment of these processes.

Development of Site Prescriptions

The restoration team faced a daunting task: revegetate over 400 contiguous hectares of steep, remote mountain slopes primarily by aerial application methods while limiting the amount of materials applied per hectare and ensuring that the previous substantial investment in tree planting was not wasted along the way.

Soil amendment and plant species selections dominated hillside revegetation decisions. Demonstration plot studies identified some plant species that grew well and others whose performance was poor (Mengel et al., in preparation). This allowed us to select plant species that were at least early good performers on our site. Generally poor top growth of the planted conifers created doubt about their long-term sustainability on the site. As such, we decided to plant additional species of trees and shrubs to increase biodiversity in these strata and to enhance the potential for long-term succession to a forested landscape.

Reducing the acidity of the hillsides was clearly an important consideration (White and Mengel, in preparation). As *pH* increases, the availability of certain soil nutrients improves while the availability of certain micronutrients and metals decreases. Common soil processes, such as nitrification, are inhibited at low *pH* (Alexander, 1965) and a reduction in acidity would likely accelerate re-establishment of some soil processes.

Importantly, since the project was managed adaptively, we acquired new performance information each year through monitoring (see below) that allowed us to modify the kinds and

rates of soil amendments as well as species and proportions of species found within seed mixes. By doing so, our goal was to enhance the performance of subsequent year's treatments. As such, no single prescription was developed that was implemented throughout the entire 425 ha area.

Herbaceous Species Selection

Because of the existing condition of the hillsides and project constraints noted above, we knew that it would be difficult for the hillsides revegetation team to produce much beyond early successional development during the project lifetime. Consequently, our design focus was to stimulate natural successional processes that would lead to the development of forested ecosystems over the long term. We sought to quickly stabilize the "sediment superhighway" -- water collecting surfaces through which water concentrates and carries sediment into the creeks. These areas included gullies and flat terrace benches. Through stabilization of the sediment superhighway, we hypothesized that the hillsides would reap the benefits associated with greater moisture storage and reduced erosion. As water storage improved in these areas, vegetation would gradually expand into convex and flat slopes, similarly reducing desiccation from wind and further enhancing soil water storage.

In addition to bunch grasses and legumes, we also included quickly growing grass species adapted to somewhat wetter soils to take advantage of conditions along terrace benches and convexities (Table 1). As a result, not all species used on this project were native species. While restoration projects normally rely upon extensive use of native plant species, we felt justified in departing from their exclusive use because of the critical need to conserve soil resources. Non-natives used on the project include sod-forming grasses (for stabilization) and legumes (for N additions). As the target forested community develops, we expect shading from the forest to gradually result in the replacement of grasses and forbs (both native and non-native) with understory shrubs and trees. Use of native bunchgrasses was expected to provide the hills with stabilization through root growth while having openings in above-ground growth through which tree seedlings could gain access to sunlight.

Woody Species Selection

Tree seedlings planted in past efforts included western white pine, western larch, Douglas-fir, ponderosa pine, and lodgepole pine. No hardwood species or shrub species were planted nor

Table 1. Herbaceous Plant Species used on the Bunker Hill Hillsides Early Successional Restoration Program

Common name	Scientific name
Slender wheatgrass	<i>Elymus trachycaulus ssp. trachycaulus</i> var. Revenue
Idaho fescue	<i>Festuca idahoensis</i> var. Joseph
Sheep fescue	<i>Festuca ovina</i> var. Covar
Mountain brome	<i>Bromus marginatus</i> var. Bromar
Meadow brome	<i>Bromus biebersteinii</i> var. Paddock
White Yarrow	<i>Achillea millefolium</i>
Blue flax	<i>Linum lewisii</i> var. Appar
Rocky Mountain penstemon	<i>Penstemon strictus</i>
Alfalfa*	<i>Medicago sativa</i> var. Alfagraze
Redtop*	<i>Agrostis alba</i>
Canada bluegrass*	<i>Poa compressa</i>
Big bluegrass	<i>Poa ampla</i> var. Sherman
Canby bluegrass	<i>Poa canbyi</i> var. Canbar
Cicer milkvetch*	<i>Astragalus cicer</i>
Lupine	<i>Lupinus perennis</i>

* Not native to northern Idaho

were any N-fixing species installed. As a result, we decided to enhance both overstory and understory diversity and further improve soils by introducing additional native and non-native hardwood species.

We chose plant species for their ability to sustain themselves on harsh sites as well as their ability to fix N. As a result, non-native black locust was planted on portions of the hills along with two species of native ceanothus and mountain alder (Table 2). All three species fix N and we expect their importance to gradually yield to conifer species over time. Other planted species included wild rose, serviceberry, maple, and aspen.

Planting of all woody species was done within concave-sloping areas to help increase the available moisture to these plants. Aspen was largely restricted to water collecting benches and downslope from groundwater seeps. We used island plantings throughout the site to “inoculate” woody species and ultimately produce a better distributed seed bank than could be achieved through large block plantings (Scherer and Everett, 1998). This approach relies upon migration of new propagules (seeds, rhizomes, stolons) outward from planting areas to gradually expand cover from these species.

Table 2. Tree and shrub species planted on the Bunker Hill hillsides during the 2001-2002 planting seasons¹

Common Name	Scientific Name
Snowbrush Ceanothus	<i>Ceanothus velutinus</i>
Red Stem Ceanothus	<i>Ceanothus sanguineus</i>
Black locust*	<i>Robinia pseudoacacia</i>
Rocky mountain maple	<i>Acer glabrum</i>
Quaking aspen	<i>Populus tremuloides</i>
Saskatoon Serviceberry	<i>Amelanchier alnifolia</i>
Woods Rose	<i>Rosa woodsii</i>
Mountain alder	<i>Alnus incana</i>

¹ In addition to these species, five species of conifers were planted on the hillsides in the past including western white pine, western larch, Douglas-fir, ponderosa pine, and lodgepole pine.

* Not native to northern Idaho.

Amelioration of Soil Chemical Constraints

Soil *pH*, N, phosphorus (P), and potassium (K) levels were identified as soil-chemical limiting factors on the hillsides (White and Mengel, in preparation). Therefore, prescriptions focused on adding lime to the hillsides followed up with additions of K fertilizer as part of a complete fertilization prescription. In addition to inorganic-K, organic-K fertilizers were also included in the prescription.

Liming materials. Seed mix application (Table 1) was preceded by application of liming materials. In 1998, we used pelletized lime, but found that slope steepness resulted in rapid migration of the pellets off of the hills and onto the terrace benches. The net effect was high *pH* on the benches and reduced effect elsewhere.

We subsequently applied lime hydraulically for a more uniform application. We also used lime with a higher percentage of hydroxides. Lime moves slowly through the soil profile and alkaline amendments are routinely incorporated into the surface to speed up overall soil reaction. Yet, lack of access and slope angle would not allow this to occur on the hillsides. While surface additions of lime can gradually increase soil *pH*, our inability to mix the lime into the steep slopes meant that application of lime would require an extensive period of time to achieve the desired effects.

To improve liming value, we selected materials that could more quickly leach into the soil profile. The liming material applied was composed of approximately 18 percent hydroxides and 82 percent carbonates (115 percent calcium carbonate equivalent). A small amount of mulch and

tackifier was added to the mix to help retain it on the slope prior to seeding. Once seedling emergence occurred, the plants would retard downslope migration of the lime. Four years after application, the liming materials remain visible in many areas of the site, suggesting that the mulch and tackifier did their job. Liming materials were generally applied at least one growing season in advance of seeding activities.

Liming rates varied based on soil testing results. Rates ranged from 0 mt per ha to 17.6 mt per ha. Areas with liming requirements of 10 mt per ha or greater were limed in two smaller applications staged two years apart. Since we were not able to incorporate, two applications provided additional time for soil reaction and reduced the potential for creating excessively high alkalinity at the soil surface with its potentially negative effects on newly germinated seedlings.

Fertilizer materials. We also used both organic and inorganic fertilizers, mulch, and different types of tackifier on the project. Rates and types of fertilizer used varied during the course of the project. Earlier hillside studies did not uncover significant differences between plant biomass response to inorganic and organic fertilizers. Not surprisingly, however, we observed a more rapid and shorter-lived plant response to inorganic fertilizer in comparison to organic nutrient sources (Mengel et al., in preparation).

Both inorganic and organic fertilizer sources have advantages and disadvantages. The project needed rapid plant response to ensure that seedlings would not be washed off the slope and to provide some initial site anchoring. Yet the project would also benefit from the long-term nutrient delivery characteristics of organic products. Consequently, in an effort to gain both benefits, we simultaneously applied smaller amounts of each type. We believed this would result in initial rapid anchoring followed by several additional years of nutrient enhancement as organic sources slowly mineralized. We felt the downside risk of this approach was more rapid mineralization of the organic fertilizer products and perhaps a shorter lived overall benefit. Nevertheless, we were willing to assume that risk to ensure the seedlings remained on the slope.

Tackifier materials. Selection of the proper tackifier was critical on this project. Obviously, revegetation of steep slopes requires that products adhere to the slope for the time necessary for germination and early rooting. We conducted informal studies of tackifier to this end in 1998 (unpublished data). Ultimately, we applied different tackifiers based primarily upon slope angle. In general, when average slopes exceeded about 27 degrees (50 percent) we used polymer tackifiers, and guar-based products were used on shallower slopes.

Implementation

Application Technology

Seeding activities occurred in 1998, 1999, 2000, and 2001. TriState Hydroseeding, Inc. of Kingston, ID implemented the revegetation program. Three primary work items were: 1) application of lime, 2) application of hydroseed mixtures, and 3) planting of trees and shrubs. TriState applied lime and hydroseed mixtures primarily from the air using Sikorski helicopters (Figure 2). This aircraft has an approximate payload of 10 tons. In combination with a proprietary mixing and pumping unit developed by TriState Hydroseeding, Inc., the helicopter arrived at the staging area, acquired and delivered its payload, and returned to the staging area for another load, on average, in approximately 3 minutes. Each sortie resulted in the application of materials across approximately 0.13 ha. Thus, the high hourly cost of the aircraft was offset by its high productivity (Figure 2).

Monitoring

Monitoring is guided by revegetation goals, objectives, and performance standards (White et al. 2003). Annual plant cover monitoring is triggered when a seeded area is approximately two years old. For example, annual monitoring began in 2000 on areas seeded in 1998. Monitoring in 2001 measured areas seeded in 1999 as well as those seeded in 1998, and so forth. Thus, the results presented herein summarize cover, regeneration capability, and other parameters acquired during 2001 from two- or three-year old communities (Tables 3 and 4). Metrics acquired during monitoring and the rationale for their selection are summarized in White et al. (2003). In contrast, surface water quality was measured on a continuous basis beginning in 2000.

Methods

Plant Cover. We combined aerial photo interpretation with ground truthing to estimate the amount and distribution of plant cover in seeded areas. Cover was placed into one of four cover classes: Class 1 (0 to 24 percent cover), Class 2 (25 to 49 percent), Class 3 (50 to 74 percent), and Class 4 (75 to 100 percent). We measured regeneration (using either fixed diameter plots or strip transects depending upon existing cover) including plant cover by species, seed production,



Figure 2. Steep slopes and poor access resulted in the use of aerial application techniques on the hillsides. Sikorski helicopters were used to apply most of the hillsides prescriptions. Although per hour costs are high, application rates were much higher than with other air frames and per hectare application costs were effective. Note hydroseed materials on background slopes.

incidence of volunteer species, spreading by rhizomes or stolons, and other regeneration measures. We also noted presence or absence of noxious weeds and overall plant vigor.

Surface Water Quality. Surface water quality monitoring currently uses five stations as part of a pilot hydrology monitoring program. Parameters measured are air temperature, precipitation, turbidity, flow, and total suspended solids (TSS). Hourly air temperature and precipitation are measured at the project site. We have been monitoring various combinations of flow, turbidity, and TSS at four locations in Government Gulch and one location in Deadwood Gulch. We have been using American Sigma 950 flow meters coupled with ultrasonic, velocity, and bubbler transducers. We also use a submerged area velocity probe at two stations. Turbidity monitoring is done with a Model 6920 sonde manufactured by YSI Incorporated.

Tree planting activities concluded in 2002 and monitoring of tree planting activities is scheduled to begin in 2003.

Vegetation Results

Areas seeded in 1998. Three-year results for areas seeded in 1998 are encouraging (Figure 3; Table 3). Eighty-eight percent of the hillsides area seeded in 1998 has met or exceeded revegetation cover goals. The greatest cover falls within Class 3. Overall, 62 percent of the seeded area (55.4 ha) contains Class 3 cover levels and another 26 percent (22.8 ha) has over 75 percent cover (Class 4). Meanwhile, 12 percent of the land area seeded in 1998 (10.8 ha) has less than 50 percent cover, 5.5 ha of which is Class 1. Thus, a total of 78.2 ha (88 percent) of the total land area seeded in 1998 contained 50 percent or greater cover by the early summer of 2001. This represents a 4 percent increase from levels found in 2000.

In contrast, areas containing less than 25 percent cover (Class 1) increased by approximately 0.8 ha. We have found that many areas containing low cover are dominated by pavement-like surfaces of large rocks interspersed with vegetation in the interstices. Although rocky, these areas nonetheless appear stable. Many other low cover areas are composed of loose, dry talus.

Trend Analysis. Using the project GIS, we compared plant cover measured during 2000 (areas seeded in 1998) to that measured during 2001 and described polygons where differences arose. This results in a geographically referenced estimate of trends in vegetative cover for these areas (Figure 4)¹. Most of the seeded area has stable cover levels. Where cover class changes have occurred, east-facing slopes appear to be improving in cover, while west-facing slopes appear to be decreasing in plant cover. Approximately 12.5 ha of cover measured in 2001 shifted upward compared to similar measures in 2000. East-facing slopes of Government Gulch showed improvements in this regard, as did large areas on east-facing slopes of Deadwood Gulch. In general, Government Gulch east-facing slopes increased to Class 4, and Deadwood Gulch east-facing slopes increased from either Class 1 to Class 2 or Class 3 to Class 4. Steep cut-slopes have low cover values irrespective of gulch or aspect (Figure 3).

¹ Readers should note that only areas seeded in 1998 have been measured twice and are thus currently available for trend analysis. Subsequent monitoring in future years will result in multiple measures of new areas (those seeded in 1999, those seeded in 2000 and so forth) and allow trend analysis to be extended to them. Readers should also note that cover class changes discussed herein allow us to pinpoint areas for additional inspections prior to making decisions regarding any future management inputs.



Figure 3. Early results of revegetation in Government Gulch several years after treatment application are promising. Vegetation concentrates in concavities and flatter slopes and gradually migrates to drier convex areas. The vertical faces of cut slopes make it difficult to stick restoration materials to them and so they remain largely unvegetated. Fill slopes are also problematic, but less so than cut slopes. Elsewhere, seeded vegetation is growing vigorously and previously planted trees are responding well. Photo also illustrates check dam installation in a major gully.

In contrast, about 4.6 ha on the west-facing slope of Government Gulch decreased an average of one cover class between 2000 and 2001. Much of this area decreased from Class 4 to Class 3 and so, despite a drop in cover class, a substantial amount of plant cover remains on the site. Moving south along the hillsides facing toward the old industrial stacks location, however, more and more area shows a downward trend from Class 2 to Class 1 (Figure 4).

We expected that establishment on this particular site could be problematic because of generally higher metals content, combined with the site-specific lack of fine soil particles and a substantial loss of native topsoil. In response to this possibility, an agronomic rate of biosolids was applied in the direct vicinity of the former smelter stacks in the fall of 2001. Nevertheless, while most of the area continues to exceed 50 percent cover, this decrease suggests that additional fertilizer or other inputs should be considered along these slopes in the future

Areas Seeded in 1999

We seeded a total of 148.4 ha of the hillsides in 1999. After about 2 years, most of the plant cover is distributed among Class 2, 3, and 4 cover (Table 3). Only 2 ha of this area (1 percent) falls into Class 1 and has less than 25 percent cover. The remaining 99 percent of the area (146.5 ha) has greater than 25 percent cover, with 63 percent (94.2 ha) having greater than 50 percent cover.

On a percentage basis, less of the area seeded in 1999 exceeds 50 percent cover than those areas seeded in 1998 (63 percent versus 84 percent, respectively). Several reasons explain the

Areas Seeded in 1998		
Cover Class	Hectares	Percent of Total
Class 1 – 0 to 24 percent (poor)	5.5	6.2
Class 2 – 25 to 49 percent (fair)	5.3	5.9
Class 3 – 50 to 74 percent (good)	55.4	62.3
Class 4 – 75 to 100 percent (excellent)	22.8	25.6
Total	89.0	100
Areas Seeded in 1999		
Class 1 – 0 to 24 percent	2.1	1.5
Class 2 – 25 to 49 percent	52.1	35.1
Class 3 – 50 to 74 percent	56.6	38.1
Class 4 – 75 to 100 percent	37.6	25.3
Total	148.4	100

differences in performance. In 1998, most of the revegetation work was done along flat terrace benches and in gullies as part of the initial check dam installation. Both terraces and gullies collect water more so than the surrounding steep slopes. On a percentage basis, then, 1998 seeding areas would be expected to have better moisture relations than the more steeply sloping 1999 areas. In addition, 1998 work primarily occurred on the relatively mild east-facing slopes. In contrast, much of the revegetation work in 1999 occurred in the harsher conditions found on west-facing slopes. Another reason for the difference is that the 1998 seeding used higher percentages of redtop to quickly stabilize the gullies that were treated during that time. It is

expected that this quickly-establishing sod-former, in contrast to the slower-to-establish native bunchgrasses, contributed to the higher percent covers found in 2000. Nevertheless, a substantial majority of the plant cover from the 1999 seeding is good to excellent after two growing seasons (Table 3).

Overall Plant Cover

In large part (with some exceptions noted below), plant cover on areas seeded in 1998 and 1999 met performance goals (Figure 3; Tables 3 and 4). The overall condition of 2-year or older vegetation on the hillsides is illustrated by combining data from 1998-seeded and 1999-seeded polygons (Table 3). In combination, approximately 27 percent of the area seeded in 1998 and 1999 has less than 50 percent cover, with the remaining 63 percent achieving project performance standards. Of the 64.8 ha not meeting project standards, most the area contained at least 25 percent cover, with only 7.7 ha (3 percent of the total treated area) containing less than this amount of cover.

Table 4. Overall Plant Cover Class Distributions Found in 2001

Cover Class	Areas	Percent of Total
Class 1 – 0 to 24 percent	7.6	3.2
Class 2 – 25 to 49 percent	57.3	24.2
Class 3 – 50 to 74 percent	112.0	47.2
Class 4 – 75 to 100 percent	60.4	25.4
Total	237.3	100

Plant Cover Sustainability

One important measure of the health of the hillsides is their ability to support production and germination of seed and other measures of sustainability. Earlier monitoring work visually suggested that regeneration was present across much of the hillsides landscape. In 2001, we initiated formal measurement of this critical phenomenon using fixed-radius circular and strip plots (Figure 5). Almost all plots measured in 2001 contained indicators of regeneration -- far exceeding the monitoring goal of 50 percent of sample units showing such indicators. Seed bank

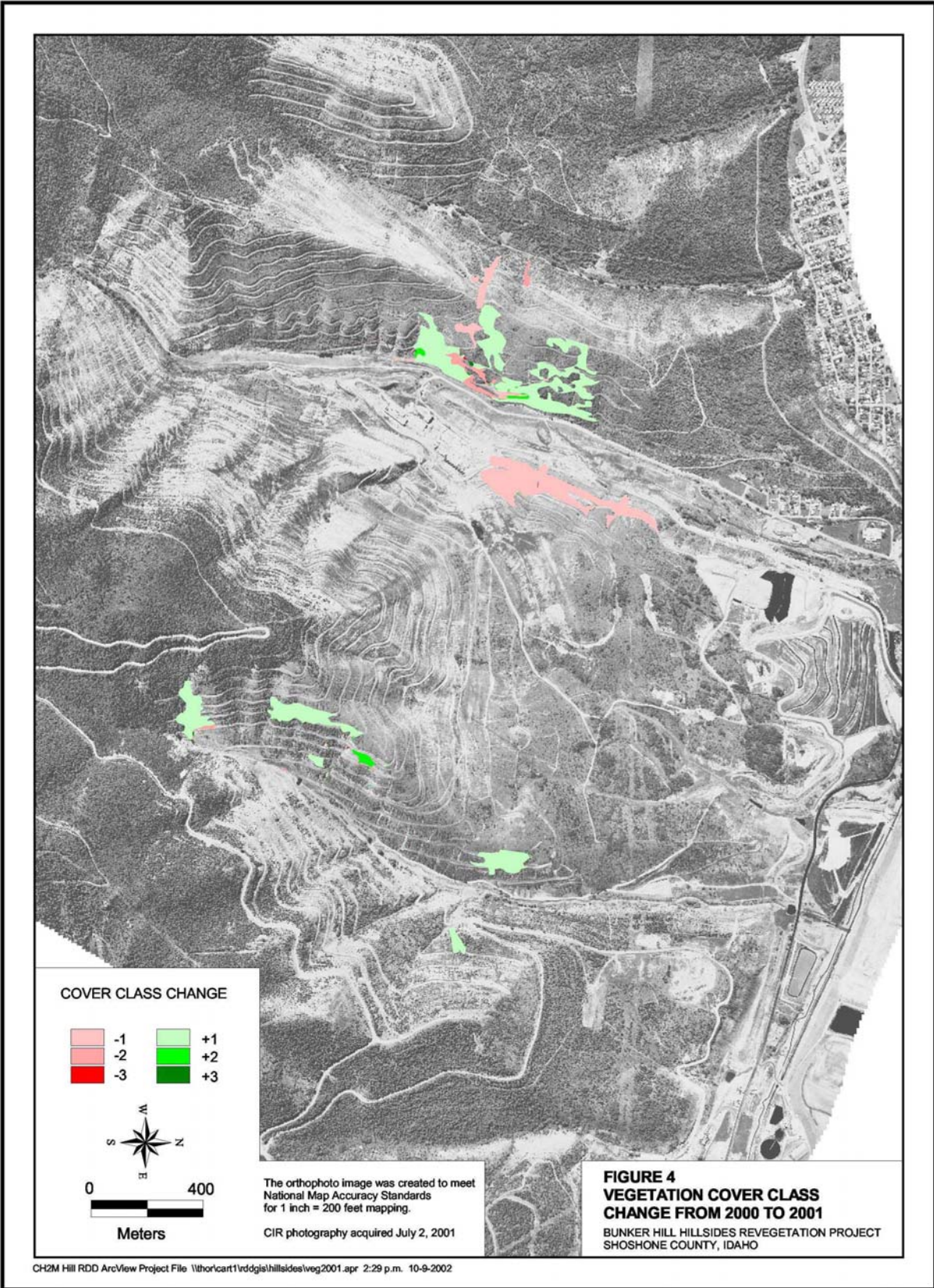




Figure 5. Fixed radius plots were established in low-cover areas and located by measuring distance and bearing from hillside landmarks and acquiring latitude-longitude coordinates using hand-held GPS. Readers should note that summer droughts produce annual die-back of vegetation bracketed by more vigorous growth during cooler portions of the growing season in the spring and fall. Note growth responses to soil amendments by western white pine saplings in the background.

development is proceeding well on all gulches. Asexual reproduction through stolons and rhizomes is present on over 90 percent of all plots. Volunteer species are invading the hillsides as well (Figure 6). Regeneration is currently expected to sustain existing herbaceous stands. Control of noxious weeds along travel corridors has been a part of general site management. Perhaps as a result, noxious weeds were found on only about 2 percent of the fixed-radius plots measured and less than 4 percent of the strip plots during a recent survey. For hillsides vegetation to ultimately progress to a forested community, significant soil building activity and early successional plant community development must take place. As these processes mature,



Figure 6. Deadwood High Elevation Alder Volunteer. Volunteer species continue to invade post-treatment hillsides. Here, an alder (*Alnus* sp.) seedling emerges from a largely rocky substrate along east aspects of Deadwood Gulch. Other volunteer species include ceanothus, fireweed, mountain snowberry, Rocky Mountain maple, Oregon grape, alder, gooseberry, raspberry, pachistima, and several coniferous species whose seed has migrated from higher slopes onto lower benches now more supportive of plant growth.

other plant species are expected to emerge to occupy specific niches that become available for mid- and late-successional species.

Currently, the hillsides are dominated by a number of early successional herbaceous species such as yarrow, sheep fescue, mountain brome, penstemon, and Idaho fescue. All of these species were part of the original seed mix. Other species present include mullein (*Mullein thapsus*), prickly lettuce (*Lactuca serriola*), fireweed (both *Epilobium angustifolium* and *Epilobium brachycarpum*), mustard (*Brassica* spp.), and clovers (*Trifolium* spp.). Some species

such as fireweed are associated with colonization following disturbance. Others such as clover contribute additional N to the soil through N-fixation.

Evidence of a progression toward later successional species was measured on 81 percent of all plots in 2001. Woody species are invading the hillsides. Overstory and understory species, including trees and shrubs, are present. In some areas, colonization by woody vegetation exceeds that of herbaceous species. Early seral stage species are most prevalent, including Douglas-fir, Engelmann spruce, and western larch. Common understory species include mountain snowberry, Rocky Mountain maple, Oregon grape, alder, gooseberry, raspberry, and pachistima. Other species that may form monospecific overstory or understory stands include willow, black cottonwood, quaking aspen, ceanothus, hawthorn, and birch.

The rapid expansion of seeded species and the evidence of regeneration suggest that the emergence of ecological processes needed to build nutrient and carbon pools on the hillsides has begun at least in places. Where this occurs, over the long-term, these processes are expected to convert the droughty, nutrient and carbon deficient hillsides into sites more representative of coniferous habitat types in northern Idaho. The high incidence of successional species in places where no species invaded for many decades is another indication that microsite conditions are more suitable to plant growth than in the past. Of particular interest is the appearance of more hydrophilic species such as birch, willow, aspen, and cottonwood, suggesting at least an early improvement in the water-holding capacity of the soils.

Surface Water Quality Results

Ameliorating the physical and chemical constraints to establishing a sustainable plant cover on the hillsides landscape is part of project objectives (White et al., 2003). In most areas of the hillsides, this objective recognizes limitations in surface soil moisture with subsequent impacts on establishment and vigor of vegetation. Moreover, this objective also recognizes that soil losses through erosion result in both physical and chemical limitations to the establishment of functioning ecosystems through the export of nutrients and other resources important to this end.

As vegetation develops, more runoff will be captured, soil temperatures will lower, and soil moisture supplies will improve. A gradually improving soil moisture regime should, in turn, improve vegetative growth until other limitations to plant growth are encountered. Improved growth results in even more surface roughness further slowing runoff and yielding better

moisture retention and plant productivity. The end result of this mutually reinforcing process is that hydroperiods of hillsides watersheds will shift from “flashy” runoff characteristics to lower amplitude hydroperiods more dominated by groundwater discharge and support of higher and more uniform base flows emanating from the watershed.

Reduction of water energy also reduces the erosive power of flowing water. Reduced water energy, therefore, should produce a reduction in soil losses through water erosion and should retain more of what soil fertility is left on the landscape. For purposes of this project, turbidity was used as an indicator of relative soil loss emanating from each hillside watershed. We also acquired periodic sampling of total suspended solids (TSS). While turbidity is not a quantitative measure of soil loss nor as accurate as TSS for estimating it, our ability to measure turbidity continuously provides us with a much richer data set to evaluate relative changes in water quality over time. Moreover, recent analysis suggests a surprisingly good correlation between these two variables for our site (r^2 from 0.50 to 0.97).

2001 Water Year Results and Comparisons to 2000 Runoff

The most complete hydrologic data set available to the project at the time of this writing was turbidity and this information is provided herein. Figure 7 displays the most up-to-date information on surface water turbidity. The figure compares storm peak intensity versus maximum hourly average turbidity for the 2000 and 2001 water years.

Two important results of hillsides vegetation are apparent. First, a substantial reduction in turbidity occurred from year 2000 to year 2001 for any level of storm intensity. Second, as storm intensity increases, the reduction in turbidity between the two water years also increases. The differences are most evident in downstream areas that are affected by runoff from previously denuded hillsides.

The difference in turbidity between the two water years is least evident, and probably not statistically significant, at reference station GG-1 (Government Gulch-1), where surface water turbidity is measured as the stream enters the hillside environment. The lack of difference at the GG-1 reference station, coupled with substantial differences elsewhere in the watershed, suggests that differences between the two water years were not the result of environmental factors ancillary to work occurring within the Government Gulch watershed, but resulted instead

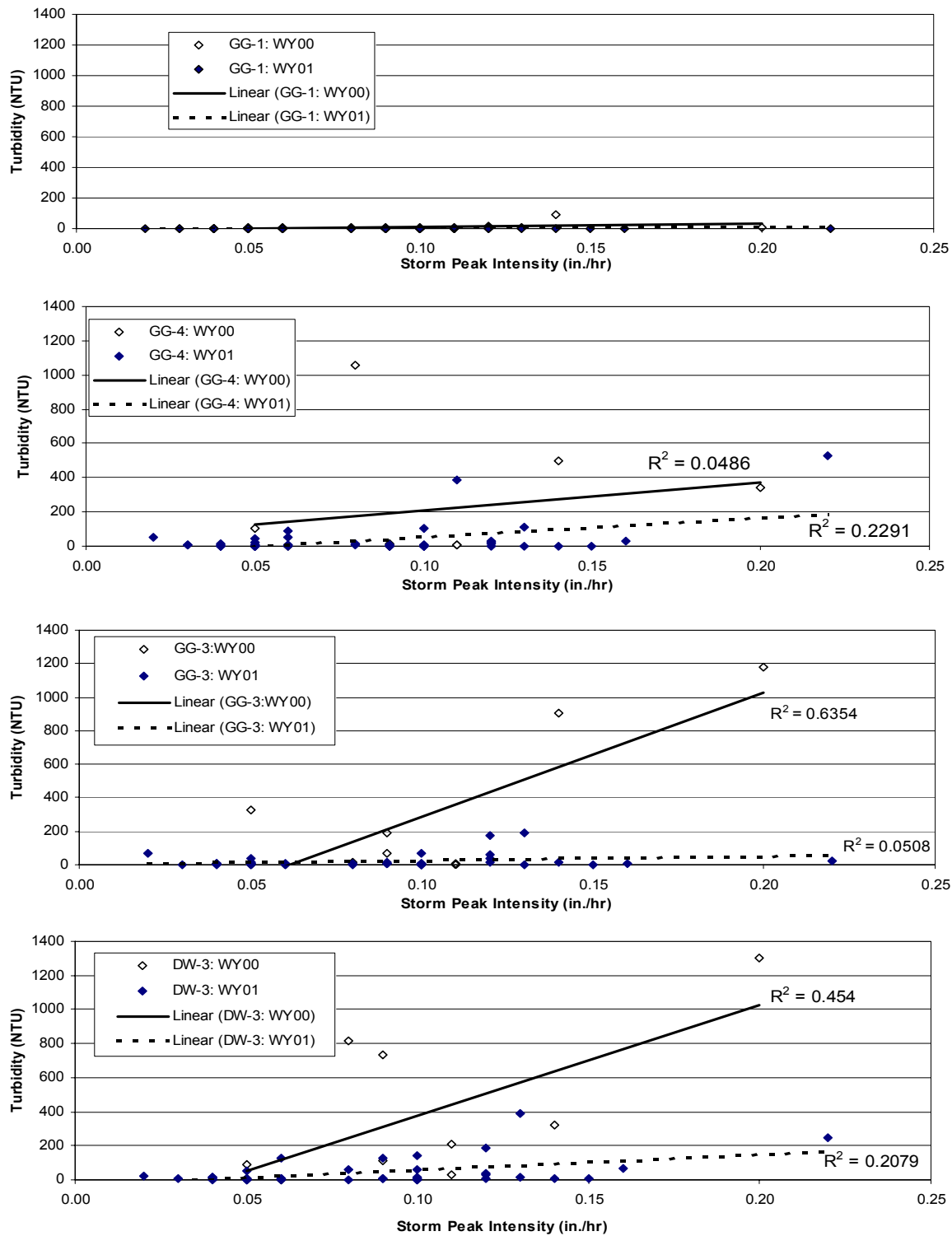


Figure 7. Storm peak intensity versus maximum hourly average turbidity. GG-1 = Government Gulch reference station; GG-3 = mouth of Government Gulch; GG-4 = Government Gulch interior station; DW-3 = mouth of Deadwood Gulch.

from changes in watershed conditions between the GG-1 reference station and the mouth of Government Gulch.

The turbidity differences between 2000 and 2001 become progressively greater as turbidity is measured farther and farther downstream (compare differences from GG-1 to GG-4 to GG-3). This is to be expected because as one moves downstream from GG-1 to GG-3, more of the previously denuded landscape contributes to a turbidity reading, and the opportunity for greater turbidity increases accordingly. Only one station is currently established within Deadwood Gulch (at its mouth), but changes in turbidity between water years appear consistent with those found in Government Gulch.

At the mouth of both Government Gulch Creek and Deadwood Gulch Creek, turbidity levels measured during high-intensity precipitation events decreased from approximately 1,000 Nephelometric turbidity units (NTUs) in water year 2000 to less than 125 NTUs in 2001 on average. Government Gulch turbidity levels under the highest peak precipitation events in 2001 decreased to less than 50 NTUs.

We compared the simultaneous differences between background levels of turbidity and the turbidity of the creeks at different portions of the watershed. More than 99 percent of all measurements differed from background levels by less than 50 NTUs. The one exception occurred during the spring runoff at GG-3. In this instance, creek turbidities exceeded background by less than 2 percent of the readings. The State of Idaho water quality standard for cold water biota states that “turbidity, below any applicable mixing zone...shall not exceed background turbidity by more than fifty (50) NTU instantaneously or more than twenty-five (25) NTU for more than ten (10) consecutive days.” Thus, in the vast majority of cases over the course of 2001, the hillsides delivered water that met or exceeded turbidity water quality standards for the State of Idaho.

Conclusions and Discussion

Overall, the current performance of the vegetative cover resulting from the 1998 and 1999 hydroseeding events is very promising. Of the 237 ha evaluated in August 2001, 63 percent (172.4 ha) contain greater than 50 percent cover. This good-to-excellent cover resides on all watersheds and on all aspects. The remaining 27 percent (64.3 ha) has not yet reached the

50 percent cover Class 3 or greater. Of this total, only about 7.7 ha contain less than 25 percent cover, with the remaining 56.7 ha having between 25 and 49 percent cover. Almost all of the 7.7 ha that reside in the lowest cover class occur in areas where metals deposition would be expected to be high—adjacent to and across the valley from the former zinc stacks in Government Gulch and adjacent to the former Arizona mine dump in upper Deadwood Gulch. As mentioned previously, while the west-facing foothill slope north of the former stacks retains substantial plant cover, it shows signs of a downward trend. These areas should remain a priority for observation in future years to monitor trends and make decisions about subsequent treatment.

Much remains to be learned on this project. A great deal of the Class 2 cover land resides on west-facing slopes where overall soil temperatures are higher and corresponding available soil moisture is lower. Thus, it is not altogether surprising to see that these areas are slower to develop than elsewhere on the site. In addition, the surface of much of the lower cover class ground is composed of non-soil, rock fragments that may preclude development of vegetation, although the rock itself does not represent a significant source of sediment to the basin. Again, trends that emerge in these areas will be important to the understanding of the need for maintenance actions on them.

Response of previously planted trees to soil amendments has been very encouraging. Prior to our work, western white pine planted on the site from five to ten years previously were largely stunted. Annual height increment has accelerated substantially in comparison to years prior to treatment (Figure 5). Foliage color suggests ample N supplies. Other woody species native to north Idaho are volunteering in previously denuded areas. These include emerging seedlings of Douglas-fir, Rocky mountain maple, black cottonwood, willow, Engelmann spruce, grand fir, quaking aspen, gooseberry, raspberry, elderberry, and others.

Additional trees and shrubs were extensively planted along terrace benches in 2001. In addition to installing trees and shrubs to improve biodiversity and to accelerate successional processes, planting along terrace benches will serve to screen some of the exposed cut slopes and gradually improve the overall aesthetics of the hillsides environment. Elk browse was expected to constrain successful establishment of woody species on the hillsides. Unfortunately, visual observations during the planting work in the fall of 2001 verified these concerns.

Measures of regeneration currently suggest that herbaceous cover will be sustainable to the degree that N-fixation and nutrient cycling can support plant growth. Seed production is

occurring for all species of grass and forbs. Trees throughout the hillsides show accelerated growth compared to past years. Other grass and forb species are expanding through growth of rhizomes, stolons, or other vegetative structures. In places, grass and forb cover is so dense that it will limit any immediate opportunities for germination and vigorous growth of new herbaceous seedlings. However, seed production in these instances (as well as elsewhere on the hillsides) recharge soil seed banks and can provide new seed for future germination in the event that fire or other disturbance events remove the existing herbaceous cover.

The hillsides should continue to be monitored for trends in cover by noxious plants, which currently occur at fairly low levels. Presence and composition of noxious weeds were noted throughout the hillsides during monitoring and in the vast majority of cases, they were not present. Most of the current population of noxious weeds occurs in high elevations of Deadwood Gulch, immediately downslope of Murphy Point along the Silver Mountain Road. The roadsides of this area were infested with spotted knapweed and meadow hawkweed. Despite weed control efforts along the road that removed these pests in 2000, colonies have found their way onto the upper Deadwood slopes. Additional control measures are dictated at least in the area as a result.

Although habitat values and aesthetics remain important elements of the project, the quality of surface water emanating from hillsides influences the entire Coeur d'Alene River basin. Surface water hydrology data suggest that the revegetation efforts are substantially reducing the amount of sediment entering the basin from the hillsides. At all rainfall intensity levels, turbidity of surface water has decreased substantially between 2000 and 2001. Instantaneous comparisons between background turbidity at the mouths of Government and Deadwood Creeks indicate that State of Idaho water quality standards are being met in most cases. Decisions about the need for additional management input to increase plant cover should be balanced by the surface water quality emanating from the hillsides.

Over the next 2 years, information on the remaining hillsides watershed area will be entered sequentially into the performance data base and will allow us to begin to understand the relationship between watershed performance and vegetative cover. This information will not only be important for purposes of this project, but should contribute to the establishment of performance metrics elsewhere within the Coeur d'Alene basin.

Giving Nature a Helping Hand – and Vice-Versa

Perhaps the most rewarding aspect of the hillsides project is witnessing the renewal of the hills through natural processes and sources of propagules. Ecosystem restoration on projects like Bunker Hill help reveal the range of early successional processes and the often complementary interactions that each change engenders within the landscape. Amendment applications almost immediately generated substantial above-ground growth responses from pine seedlings and saplings. Pine saplings growing in height by centimeters a year in the past are now growing by decimeters a year (Figure 8). This has also resulted in observable changes to the aesthetics of the hillsides as tree emerge onto the viewshed. They can now easily be seen from the valley floor, a distance of over a kilometer.

Better tree growth produces several additional changes that ultimately contribute to healing of this landscape. Larger canopies throw more shade on the hillside, reducing soil temperatures and water evaporation. Higher amounts of litter deposition mulches the soil and produces cooler, moister conditions and opportunities for additional biomass production from the trees as well as surrounding species. It also creates microhabitat refuge for small mammals. As their numbers increase this, in turn, stimulates predation from raptors and transfer of new propagules from outside the site. This further accelerates succession and does so at no cost to the project.

While elk have heavily browsed planted woody vegetation, overall elk use of the hillsides has played an important positive role in facilitating recovery of the hills. For example, we have observed that use of the new hillside habitat by wildlife accelerates certain successional processes along several routes. Prior to revegetation work on the hills, signs of elk or other wildlife were relatively scarce. This was not surprising owing to the lack of food or cover found there at the time. Following a single season of demonstration plot growth in 1997, elk scat were found throughout the demonstration area. Along with it came nutrients and seed. New species such as fireweed, not seen on the hillsides for many decades prior to our work, is now established and at least partially owes its initial presence to importation by elk. Each elk hoof print creates a small depression on sloped areas that collects water and becomes an improved microsite for additional plant growth. Thus, use of the renewed hills by elk and other mammals is a mutually beneficial relationship: the elk benefit from the nutritive value of the vegetation and increased cover while the site benefits through importation of organic fertilizer, seed, and microsite enhancement.

What we have found on the hills to date is an increasing number of volunteer species along with some less desirable weedy species as well. Beneficial species include elderberry, cottonwood, and willow. Near some mature forested vegetation on the higher elevations of Deadwood Gulch, we are also seeing natural regeneration of western hemlock, larch, and white pine as they migrate downslope into areas now more conducive to growth than in the past. None of these species was planted initially in these areas, but subsequent to our revegetation efforts seedlings are becoming more and more common. As the early N levels resulting from the treatment begin to subside, legume species such as alfalfa are beginning to assert dominance within the herb community. Similarly, lupine is gaining in importance.

Conversely, noxious weeds are occupying some portions of the hillsides landscape, albeit in currently small amounts. More than half of the noxious weeds noted in the strip plot survey occurred in high elevation Deadwood Gulch, immediately downslope from a dirt road that had previously been heavily infested with spotted knapweed and meadow hawkweed. These are serious pests and our noxious weed management program may have to expand into these areas to limit their spread. We are continuing to monitor the noxious weed population of the hillsides and making management recommendations related to it.

Opportunities for Study of Early Successional Restoration

Definitions of restoration over the years have sought to describe the place where restoration lives within modern thought. As the art and science of ecosystem restoration matures, restoration ecologists will continue to define meaningful contexts within which to discuss their work. Current definitions and concepts are broader than in the past and, depending upon the circumstances of specific projects, now include rehabilitation and reclamation projects similar to the work on the hillsides (SER 2002). Goals and objectives for the project were the result of consensus-building workshops among project stakeholders (White et al. 2003). Short-term project goals for the hillsides focus on functional attributes (sediment retention) and, in the long term, structural recovery (conifer forest). Reference systems surround the degraded site and can be used to establish trajectories in growth, species composition, and other ecosystem components of the native forested landscape. Although we have used non-native species on the hills, they have helped stabilize the site and add N to it. We expect all of these species to gradually diminish in importance as the native conifer forest matures.

The Bunker Hill hillsides offers opportunities for understanding the wide range of variability within which restorative processes act. Our work has attempted to reestablish basic ecosystem processes on a site which lacked them for decades. It has required significant management adaptation and active intervention on a highly degraded and relatively remote site. Results to date are very encouraging. To what degree these processes will continue to function and to what extent the hillside trajectory toward a forested ecosystem is sustained remains uncertain and additional interventions may be necessary. Nevertheless, measurement of early successional development under such conditions has much to offer other revegetation efforts in the Coeur d'Alene basin as well as the restoration community in general. That the area has been subjected to extreme degradation over many decades offers opportunities for study of restoration at this earliest stage of landscape recovery.

Acknowledgements

The authors gratefully acknowledge the following people whose expertise and dedication to solving the environmental problems at Bunker Hill have been critical to the success of the hillsides effort. They include the Project Team members: Richard Fink and Elizabeth Dierich (US Army Corps of Engineers), Michael Thomas, and Nicholas Zilka (State of Idaho Department of Environmental Quality), William Hudson (DJN, Inc.), Dr. Edward DePuit (Washington State University), and Dave Fortier (US Bureau of Land Management). Also critical to the success of the work were Patrick Brunner, Sean Sheldrake, and Lowell Tuttle (USEPA), Mark Ohlstrom, Miriam Ramsey, Michael Mahoney and Donna Street (USACE), Robert Hanson (IDEQ). Project support included significant contributions from Mike Stephan, Doug Holsten, Joan Stoupa and Brenda Osterhaug of CH2M HILL, Inc. and many others too numerous to mention.

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