USE OF PERFORMANCE STANDARDS AND ADAPTIVE MANAGEMENT TO GUIDE REMEDIATION AT THE BUNKER HILL SITE, IDAHO[1]

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Abstract. Adaptive management follows a general model of study, prescribe, monitor, and refine management approaches. The original Record of Decision concerning remediation activities at the smelter-affected Bunker Hill site in northern Idaho contained little guidance on how to evaluate the success of remediation. Therefore, the Bunker Hill project team convened a series of three workshops in 1998 and 1999 to develop remediation guidance statements including goals, objectives, and performance standards. Project purpose and goals defined broadly based visions for the project. Objectives identified specific approaches to achieving the purpose and goals, assuming all work would be conducted under the umbrella of adaptive management. Performance standards were developed for each objective to measure its success. Owing to significant uncertainty regarding performance of site soils at varying levels of plant cover, performance standards were considered interim until monitoring could measure parameters of site performance. Site remediation activities are now essentially complete and monitoring has been ongoing since 1998. An interagency project team workshop was convened in 2004 to evaluate site performance and to validate or invalidate the ability of the interim performance standards (IPSs) to clearly reflect the project's objectives. Based on the workshop and site performance, proposed final performance standards (FPSs) were developed at the workshop. This paper presents the evolution of the performance standards and how monitoring results were used to validate or modify those standards. The role and importance of goal setting and their evolution in remediation projects are presented in the context of actual project performance.

Additional Key Words: monitoring, smelter-affected soils, restoration goals, restoration objectives, remediation planning

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Introduction

The Bunker Hill Mining and Metallurgical Complex Superfund Site is located in Shoshone County in northern Idaho. The Site lies in the Silver Valley of the South Fork of the Coeur d'Alene River (SFCDR). Figure 1 is a site map identifying the key features of the Bunker Hill Site. The Silver Valley is a steep mountain valley that trends from east to west. It has an average elevation of approximately 685 meters above mean sea level (MSL) at the base of the valley and extends to approximately 1,372 meters MSL in the higher areas. Interstate 90 bisects the Site east to west and parallels the SFCDR. The Site has been impacted by over 100 years of mining and 65 years of smelting activities. Those activities resulted in widespread contamination of the Site with metals. Contamination of soils, surface and groundwater, and air has occurred to varying degrees. Detailed descriptions of the physical and cultural settings of the Site can be found in the 1991 and 1992 Records of Decision (RODs) (EPA, 1991; EPA, 1992).

Commercial mining for lead, zinc, silver, and other metals first began in the Coeur d'Alene mining district in 1883. Over the following decades, the Silver Valley became one of the most important centers of metals mining and processing in the U.S. At one point, industrial output associated with the Bunker Hill Mine alone peaked at over 2,268,000 kilograms of processed ore per day.

Mining waste accumulated in and adjacent to downstream surface waters and along railroad lines as a result of spillage of ore and concentrates from railroad cars during transport. It was also used as fill material for construction of roads, railroads, and structures, and was transported as airborne dust. Over time, groundwater became heavily contaminated with metallic compounds with potentially detrimental human health effects: lead, cadmium, mercury, arsenic, and others. The vegetation of surrounding hillsides was gradually denuded from logging, fires, deposition of air-borne metals, and acidification by sulfur compounds.

Smelter operations ceased in 1981, but limited mining and milling operations continued onsite from 1988 to 1991. In 1983, the federal government listed the area on its National Priority List (Superfund). EPA and with the State of Idaho (Idaho Division of Environmental Quality, or IDEQ) took control of the Site in 1995 following the 1992 bankruptcy of one of the Site's Potentially Responsible Parties (PRPs) and the subsequent bankruptcy of the Site's major PRP in 1994. EPA and IDEQ took on implementation of the remaining remedial actions, including the Hillsides as part of that action.

Hillsides Remediation Planning Process

A series of consensus-based workshops (two in 1998 and one in 1999) were convened to refine the purpose, goals, objectives, and interim performance standards (IPSs) of hillsides remedial actions to address the general guidance provided in the ROD (CH2M HILL, 1999). Participants included the EPA, the U.S. Army Corps of Engineers (USACE), the Bureau of Land Management (BLM), the IDEQ, and CH2M HILL. The first workshop task was to develop a purpose statement to guide revegetation of the hillsides. The purpose statement developed during the workshop is as follows:

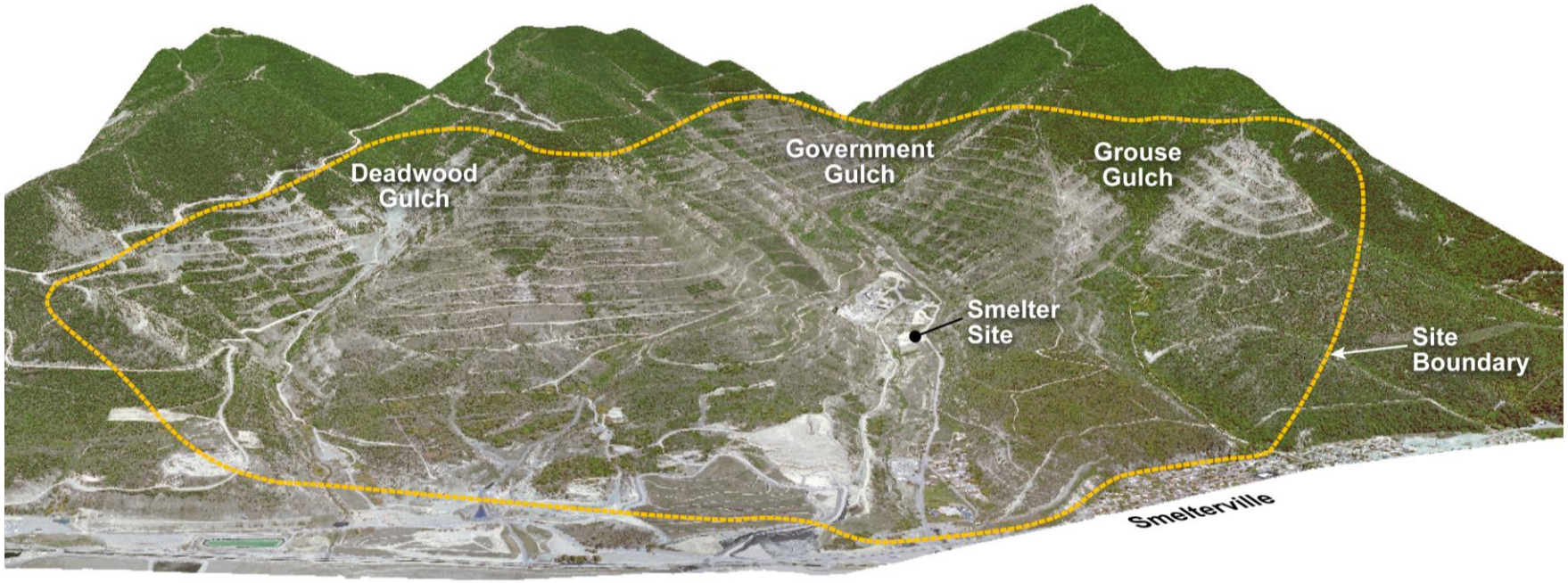

Figure 1. 3-D View of Bunker Hill Hillside Site Looking South.

Table 1. Objectives, interim performance standards, monitoring methods, and contingencies for evaluating performance of the Hillside's revegetation.

Objective	Interim Performance Standard	Monitoring Method	Contingency
1. Establish herbaceous cover on sites with less than 50 percent cover with priority to areas with high contaminant levels and/or sites with less than 25 percent cover.	1. Herbaceous plant canopy cover of regeneration species shall exceed 50 percent within each planting area designated in each Task Order Specification within two (2) full growing seasons after installation.	**1. Monitor Percent Vegetation Cover on Hillsides** ***Plot Size:*** 5-acre management unit blocks ***Sampling Method:*** Use photo interpretation to estimate areal percent cover in all treated management units. Use color ortho photos flown annually in June (2 years after first construction season); low elevation (approx. 1000-2000') and high-resolution (approximately 1"=300'). Calibrate interpretations with random 100-ft transects on a 10 percent subset of treated management units. ***Sampling Frequency:*** Once per treated management unit at end of 2 full growing seasons after installation. ***Sampling Density:*** Estimate percent cover on all treated management units.	Any management unit with less than 50 percent cover within two (2) full growing seasons will be evaluated further to determine the appropriate course of action including, but not limited to, reseeding, addition of soil amendments, lime, or fertilizer, or additional monitoring to determine rate of cover expansion. Included in this latter category are trend analysis of plant cover, correlation of plant cover to water quality performance, and re-evaluation of the plant cover performance standard.
2. Establish check dams in gullies and terraces.	2. Check dams, built and installed as specified, shall be constructed in all major gullies and adjacent to major gullies on terraces.	**2A. Monitor Check Dam Installation** ***Sampling Method*:** Site inspection. Check dams shall be inspected to ensure that they have been built and installed as specified (refer to Task Order Specifications). ***Sampling Frequency*:** Once immediately after check dams are installed but before COR approval is issued to contractor. ***Sampling Density*:** Representative of designated check dams.	Any check dam exhibiting short-circuiting of water shall be repaired as soon as possible. Monitoring shall continue within each gully-check dam system until Objective 3 (as measured by Performance Standard #3 below) is achieved for that gully.

Table 1, continued

Objective	Interim Performance Standard	Monitoring Method	Contingency
		2B. Monitor Check Dam Performance ***Sampling Method*:** Site inspection of check dams to collect baseline information immediately after check dam installation. Use narrative descriptions or still photos. The inspection shall determine if each check dam is retarding or retaining water flow by ensuring that water is not bypassing or "short-circuiting" each check dam. Mark erosion locations with graduated rebar to assess erosion rate. ***Sampling Frequency*:** Each check dam shall be inspected at least once per year following precipitation events (including rain, rain-on-snow, and specific snow-melt events) sufficient to cause sheet erosion runoff from the barren hillsides. ***Sampling Density*:** Visit all check dams.	
3. Establish herbaceous and woody vegetation in gullies and terraces.	3. Vegetation cover of regeneration species shall exceed 70 percent of each major gully bottom and terrace within two (2) full growing seasons after completion of installation.	**3. Monitor Percent Vegetation Cover in Gullies and on Terraces** ***Plot Size*:** 100-ft transects ***Sampling Method*:** Use aerial photo interpretation (as described in #1 above), and site inspection to calibrate areal percent cover estimates and verify inconclusive interpretations. ***Sampling Frequency*:** Monitor once per designated planting area, at end of 2 full growing seasons after installation. ***Sampling Density*:** One transect per check dam terrace and all major gullies in designated planting areas. Major gullies are those having log and pole and/or ecology block structures installed in them.	Any transect with less than 70 percent cover will be evaluated further to determine the appropriate course of action including, but not limited to, reseeding, addition of soil amendments, lime, or fertilizer, or additional monitoring to determine rate of cover expansion.

Table 1, continued

Objective	Interim Performance Standard	Monitoring Method	Contingency
4. Ameliorate soil physical and chemical constraints to watershed function and plant growth.	4A. Within five (5) years after completion of plant establishment projects, the following ratios of runoff volume to precipitation shall decrease: Runoff volume to precipitation (per annual monitoring period) Hourly runoff volume to hourly rainfall intensity	**4A. Monitor Runoff** ***Sampling Method:*** • Identify and delineate sub-watersheds where revegetation and check dams are planned and runoff monitoring is to occur. • Calculate runoff for each sub-watershed to properly size flume. • Evaluate streamflow data already collected on Government Gulch, Deadwood Gulch, and other streams to help predict response. • To continuously measure annual streamflow, install up to 10 trapezoidal flumes with flow meter in designated sub-watersheds where treatments will be applied (for example, plantings, check dams). • To measure precipitation, air temperature, and wind speed, install at least one weather station. • Correlate hydroperiod performance with specific precipitation and/or snowmelt events ***Sampling Frequency:*** Continuous monitoring turbidity and flow shall be initiated immediately following installation of check dams and plantings in designated sub-watersheds. ***Sampling Density:*** Single gage at downstream extent of designated sub-watersheds on valley bottom.	Sub-watersheds where average annual peak and duration of runoff emanating from the hillsides do not decrease within 5 years (after completion of plant establishment projects) will be evaluated further to determine the appropriate course of action including, but not limited to, reseeding, addition of soil amendments, lime, or fertilizer, or the performance standard will be reviewed for its reasonableness and adjusted accordingly.

Table 1, continued

Objective	Interim Performance Standard	Monitoring Method	Contingency
	4B. Water quality of discharges is within Bunker Hill project targets for heavy metals, and turbidity decreases within five (5) years after completion of plant establishment projects.	**4B. Monitor Water Quality for Metals** ***Sampling Method:*** Use grab samples to collect samples. Submit samples to analytical lab for analysis of lead, zinc, cadmium, and arsenic. ***Sampling Frequency:*** Sample quarterly as part of site-wide monitoring program. ***Sampling Density:*** Single point at flume discharge point in streams and gullies associated with areas that have been revegetated. **4C. Monitor Sediment Accretion Behind Check Dams** ***Sampling Method:*** Immediately after check dam installation, install 2-ft graduated rebar stake behind 100 check dams (50 terrace check dams; all toe-of-gully check dams; 30 gully check dams). Use site inspection to measure sediment accretion behind check dams. Placement of rebar on terrace check dams should occur only on last dam before discharge of each terrace into gully. Estimate length and width of sediment wedge and size of contributing drainage area. Use rebar to stake perimeter of alluvial fans at the toe of each gully. ***Sampling Frequency:*** Each check dam with a rebar stake shall be inspected at least once per year (preferably at same time as other check dam evaluations; see Objective #2). ***Sampling Density:*** 100 check dams (represent approximately 10 percent subsample).	Any water quality monitoring location not meeting Bunker Hill project targets for heavy metals will be evaluated further to determine the appropriate course of action.

Table 1, continued

Objective	Interim Performance Standard	Monitoring Method	Contingency
5. Reduce runoff from terraces.	5A. Water shall not flow from the terraces into major gullies with sufficient energy to initiate sediment transport and down-cutting, but shall instead be retained or retarded until it infiltrates, evaporates, or slowly discharges onto the hillsides. 5B. The check dams shall also not result in any terrace being breached due to operation of the check dams. This shall apply to the vicinity of check dams only and until such time as vegetation becomes established and stops sediment movement.	**5A/5B. Monitor Check Dams** Refer to monitoring methods under Item #2 above.	Locations where water from terraces is causing erosion or check dams causing terrace breaching shall be repaired immediately. Monitoring shall continue within each terrace-check dam system until Objective 3 (as measured by Performance Standard #3) is achieved for that gully.
6. Establish self-regenerating species and, where needed, soil-building species.	6. Evidence of regeneration of site species must be present within three (3) years following execution of a given Task Order. Evidence of regeneration shall be present in at least 50 percent of sample units. Plant cover of regenerating species shall not show a downward trend over time.	**6. Monitor Vegetation For Sustainability** ***Plot Size*:** Radius = 2 meter fixed plots. ***Sampling Method*:** Site inspection using fixed circular plots to determine presence of regeneration. Evidence of potential for regeneration includes but is not limited to one or more of the following: 1. Seed production of on-site plant species and presence of newly germinated seed. The presence of newly germinated seed must be linked to on-site seed production from existing plant species to ensure that newly germinated seed did not arise from previous seeding operations and/or invasion from off-site noxious species.	Any management unit lacking evidence of self-regenerating species within three (3) years will be evaluated further to determine the appropriate course of action including, but not limited to, reseeding, addition of soil amendments, lime, or fertilizer, or additional monitoring to determine regeneration potential.

Table 1, continued

Objective	Interim Performance Standard	Monitoring Method	Contingency
		2. Expansion of cover by vegetative production of new shoot growth from rhizomes or other underground structures. 3. Evidence of sprouting from damaged or cut stems of woody species. ***Sampling Frequency*:** Monitoring to occur once at end of 3 full growing seasons after installation. ***Sampling Density*:** One transect per acre in designated planting areas.	
7. Minimize colonization of noxious weeds.	7. Comply with State of Idaho Noxious Weed regulations.	**7. Monitor For Noxious Weeds** ***Sampling Method*:** Site inspection to determine presence of noxious weeds as listed in the State of Idaho Noxious Weed regulations. This data will be collected during existing vegetation monitoring protocols. Where found, the extent and location of noxious weeds shall be noted on map and findings reported as soon as possible. ***Sampling Frequency*:** Same as Performance Standard #1: monitoring to occur once at end of 2 full growing seasons after installation.	Any transects not complying with Idaho's Noxious Weed regulations will be evaluated further to determine the appropriate course of action including, but not limited to, chemical, mechanical, or biological treatment, or additional monitoring to determine rate and extent of noxious weed colonization.
8. Manage the Bunker Hill hillsides using adaptive management techniques.	8. Use information derived from the Monitoring Program in an iterative fashion to determine the effectiveness, utility, and validity of each of the performance standards in the project.	8. The Project Team shall convene at least every two years to review the results of the monitoring program and to either accept the results of the program and establish Final Performance Standards and/or to modify one or more of the Interim Performance Standards to meet the needs of the hillsides watersheds. All Goals, Objectives, and Performance Standards shall be reviewed at the meeting and project performance discussed as measured by the monitoring program. Possible design solutions for problem areas will also be discussed at these meetings.	

Improve the condition and safety of the human and natural environments, which have been impaired by actual or threatened releases of hazardous substances from this site in the Silver Valley, Idaho, through the implementation of selected response actions for the hillsides.

The goals set for the project to achieve the project's purpose include:

- Improve watershed function by reducing runoff, erosion, and transport of pollutants within and from the site.
- Establish adapted plant communities capable of natural regeneration and providing ecological and/or societal values.

The objectives, IPSs, and monitoring plan to achieve the purpose of the project were also generated during the workshops and are shown in Table 1. These guidance statements formed the basis for long-term monitoring of hillside performance, which provided the data for adaptive management. The IPSs were used to guide monitoring of hillside performance, because of the significant uncertainty about the specific relationships between plant cover on hillside soils and various watershed functions. As the hillsides were revegetated, monitoring work was expected to reveal these relationships more clearly. As such, the IPSs were developed with the expectation that final performance standards (FPSs) would be developed as site remediation activities matured and the environment of the hillsides stabilized.

A fourth workshop was held in 2004 to evaluate the IPSs and determine where changes were needed. This workshop included representatives from the EPA, IDEQ, BLM, and USACE, and was led by CH2M HILL. The workshop participants examined each IPS (including the goals and objectives underlying each IPS) to determine whether, on the basis of existing monitoring information, the IPS was relevant to actual hillside performance. In other words, we evaluated the relevance of a given IPS to existing conditions and its ability to measure success under those circumstances. This lead to a rejection of some IPSs, because of the fact that they were not really measuring the success of a given objective—or that we were simply unable to successfully measure it. Modifications were made accordingly and FPSs proposed. Table 2 summarizes changes made to the IPSs and the proposed FPSs.

To ensure that the hillsides work meets the requirements of the ROD and overall project goals, a monitoring program began in 2000. The Hillsides Monitoring Program includes measures of surface water quality and vegetation and comprehensive reviews of this work are contained in CH2M HILL (2001, 2002, 2003, and 2004). Surface water quality monitoring has included total suspended solids (TSS), flow, and turbidity in the Deadwood and Government drainages. Measures of these parameters in Grouse Gulch began in the fall of 2004. Monitoring results are discussed below in context of development of the FPSs.

Proposed Final Performance Standards

As discussed above, monitoring results were used to modify the IPSs into proposed FSPs. The FPSs are needed to provide site managers with the tools needed to evaluate and guide long-term operation and management activities. Monitoring has facilitated the development of FSPs that reflect current site conditions. This section describes the FSP development process.

Table 2. Summary Interim Performance Standards (IPSs) and Proposed Final Performance Standards and Recommended Contingency Actions on the Bunker Hill Hillsides and 2003 Monitoring Results Specific to Objectives (modifications shown in **bold**)

IPS	Preliminary FPS	Reason
1. Herbaceous plant canopy cover of regeneration species shall exceed 50% within each planting area designated in each Task Order Specification within two (2) full growing seasons after installation.	Herbaceous plant canopy cover of regeneration species shall exceed 50% within **the Project Area. Plant cover may be less than 50% in those areas with <u>low potential</u> for erosion and discharge of sediment to surface waters.**	Monitoring work to date has shown good to excellent development of plant cover in most areas. Low cover areas often occur on specific landscape features. As such, this performance standard will be assigned only to those areas with the potential to further degrade the environment through continued discharge of sediment to hillside watersheds.
2. Check dams, built and installed as specified, shall be constructed in all major gullies and adjacent to major gullies on terraces.	Check dams, or alternative stabilization approaches shall be constructed and maintained in all gullies and terraces **that are actively discharging sediment.**	Only some of the "major gullies" were actively discharging sediment from them and all check dams were installed as specified within active gullies.
3. Vegetation cover of regeneration species shall exceed 70% of each major gully bottom and terrace within two (2) full growing seasons after completion of installation.	Vegetation cover of regeneration species shall exceed 70% of each major gully bottom and terrace within two (2) full growing seasons after completion of installation. **(NO CHANGE)**	This IPS language is retained as the Preliminary FPS because the vegetation standard is being met and sediment discharge is being reduced as desired.
4A. Within five (5) years after completion of plant establishment projects, the following ratios of runoff volume to precipitation shall decrease: Runoff volume to precipitation (per annual monitoring period) Hourly runoff volume to hourly rainfall intensity	**None**	Ratio of runoff volume to precipitation volume (per annual monitoring period) is being discontinued as a result of data gaps and confoundment of attempted analyses.

Table 2, continued

IPS	Preliminary FPS	Reason
4B. Water Quality Of Discharges is within Bunker Hill project targets for heavy metals, and turbidity decreases within five (5) years after completion of plant establishment projects.	4. **Turbidity of surface waters** decreases within five (5) years after completion of plant establishment projects.	Heavy metal monitoring of surface waters specifically as part of the hillsides project has not occurred. Turbidity monitoring has occurred in both Deadwood and Government Gulch and Grouse Gulch turbidity measures are to begin in fall 2004.
5A. Water shall not flow from the terraces into major gullies with sufficient energy to initiate sediment transport and down-cutting, but shall instead be retained or retarded until it infiltrates, evaporates, or slowly discharges onto the hillsides.	Water shall not flow from the terraces into major gullies with sufficient energy to initiate sediment transport and down-cutting, but shall instead be retained or retarded until it infiltrates, evaporates, or slowly discharges onto the hillsides. **(NO CHANGE)**	Data obtained to date suggests that this performance standard has been met.
5B. The check dams shall also not result in any terrace breach resulting from operation of the check dams. This shall apply to the vicinity of check dams only and until vegetation becomes established and stops sediment movement.	Operation of the check dams shall not result in any terrace breaching.	Minor breaching has occurred and been identified over the last two years.
6. Evidence of regeneration of site species must be present within three (3) years following execution of a given Task Order. Evidence of regeneration shall be present in at least 50% of sample units. Plant cover of regenerating species shall not show a downward trend over time.	Evidence of regeneration species must be present in at least 50% of sample units. Plant cover of regenerating species shall not show a downward trend over time.	Planted species are naturally regenerating and herbaceous and woody volunteer species are slowly invading the hillsides.
7. Comply with State of Idaho noxious weed regulations.	Comply with State of Idaho noxious weed regulations. **(NO CHANGE)**	Noxious weed control is ongoing in the hillsides area.

Table 2, continued

IPS	Preliminary FPS	Reason
8. Use information derived from the Monitoring Program in an iterative fashion to determine the effectiveness, utility, and validity of each of the performance standards in the project.	Use information derived from the Monitoring Program in an iterative fashion to determine the effectiveness, utility, and validity of each of the **management practices and** performance standards in the project. **This information will provide direction and feedback to development and the revisions of the O&M Plan.**	At this point in time, it appears that adaptive management has resulted in a project that has met most performance standards set for it.

Objective 1 - Herbaceous Cover

An initial standard of 50 percent cover was established under the expectation that revegetation would be successful and relatively uniform over each area. We believed this level of cover would be necessary to prevent off-site movement of potentially contaminated soil through erosion. After 5-years of monitoring, only 19.7 percent of the site falls below this standard, of which over three-quarters of that area exceeds 25 percent cover. Only 21.5 hectares (ha) of the total 440.7 ha have less than 25 percent cover. These low cover areas include over-steepened to vertical cut slopes and some fill slopes adjacent to terrace benches, areas of dry-ravel, and areas of rock pavement that have low potential for erosion. It is doubtful that these areas can be revegetated cost-effectively and, importantly, that lack of vegetation on them will result in further degradation of the basin environment. Therefore the proposed FPS allows managers flexibility in maintaining vegetation on sites where vegetative cover is low, but have low erosion potential.

Objective 2—Check Dam Establishment

The initial standard called for check dams to be established in all gullies and along terraces. Subsequent work showed that only certain gullies and terraces actually discharge sediments. Monitoring showed that check dams were established as specified in all active gullies, but water was being short-circuited around some check dams. Language was added to facilitate continued maintenance of the check dams, but to also allow maintenance to cease where sediment discharge is no longer a problem.

Objective 3—Vegetation Establishment in Gullies and Terraces

The IPS for this objective was not changed as monitoring is showing that the vegetation goal is being achieved. Stream turbidity monitoring suggests that sediment is being retained and therefore this standard should not be changed.

Objective 4—Ameliorate Soil Physical and Chemical Restraints to Watershed Function and Plant Growth

4A—Runoff Volume to Precipitation Ratio. Data gaps and confoundment of attempted analyses has resulted in this IPS being discontinued. Specific problems include 1) flow and precipitation data gaps significantly influence the relationship of annual runoff volume to precipitation, 2) for a given precipitation event, runoff volume can vary due to inter-event time, evaporation, and/or basin wetness, further complicated by rain-on-snow events, and 3) variability in the relationship between rainfall and runoff volume complicates extracting a meaningful cause and effect relationship from a trend analysis of this ratio.

Despite difficulties in measurement of this objective, removing constraints to better watershed function and plant growth remains important to the success of the overall project. In this regard, the project has made valuable contributions. Soil amendments including alkaline materials for long-term pH amelioration and organic and inorganic fertilizers for improving nutrient availability have been added to the hillsides. These amendments act to remove initial chemical constraints to plant growth and, in turn, watershed function. Nutrient cycling is a

process that is essential to long-term sustainability of hillside ecosystems and the presence of at least several species of reproducing fungi were identified during a recent site visit, suggesting that this process is starting to re-establish. Finally, check dams have been capturing sediment and reducing its impact on watershed function as well since the beginning of the project. Consequently, plant community development measured for Objective 1, regeneration/ sustainability indicators measured for Objective 6, and check dam performance measured for Objective 5 can suitably replace the measures of success as stated in IPS 4A. Removing this specific standard is not expected to result in failure to meet the desired needs of Objective 4.

4B—Water Quality of Hillsides Runoff and Discharge. This ISP has been modified because continuous heavy metal monitoring of surface waters in the Hillsides project has not occurred. However, event-based monitoring of heavy metals has been done as part of site-wide monitoring work, but not at intensity sufficient to define whether this IPS was achieved or not. These data nevertheless generally suggest that surface water metals levels have decreased at the mouth of Government Gulch since the initiation of remedial activities, perhaps as a result in turbidity reductions (see below). Nevertheless, the data are insufficient to measure the reason for metals reductions (hillsides revegetation versus other remediation work). The heavy metal requirement is removed within the FPS and information from the site-wide monitoring program is expected to support metals issues within these watersheds.

This IPS has been met with respect to turbidity in both Deadwood and Government Gulch, but not yet shown in Grouse Gulch, where turbidity measurements are to begin in fall 2004. Some of the key turbidity findings that support this statement include:

- The range of monthly, maximum, and daily-average turbidities were lower in water year (WY) 2003 than in WY 2002 at all monitoring stations. Precipitation event statistics and overall precipitation volume were very similar in the two water years, with the exception of less precipitation in the fall of 2002 (WY 2003).
- Turbidity associated with precipitation events from June through September at all monitoring stations has continued to decrease since WY 2000.
- During WY 2003, the ratios of turbidity to storm volume were the lowest for all monitoring stations for all water years since monitoring began, with the exception of one value at one station.
- During WY 2003, instantaneous turbidity value readings rarely exceeded background conditions by more than 50 nephelometric turbidity units (NTUs) in Lower Government Gulch and Lower Deadwood Gulch - one and two percent of the time, respectively. For all five stations during the summer season (a time period when rainfall events are the dominant erosive process), less than one percent of all the readings exceeded background turbidity by more than 50 NTUs.
- For all monitoring stations and all seasons, readings never exceeded background turbidity by more than 25 NTUs for more than 10 consecutive days.

Objective 5—Reduce Runoff From Terraces

5A—Reduce Erosion and Sediment Transport. Turbidity measurements can be used a surrogate to indicate that this ISP is being achieved. The ISP is proposed as the FSP.

5B—No Terrace Breaching Around Check Dams. Efforts continue to maintain the check dams, however, delays to repair have resulted in their function potentially being compromised. Simplification of the IPS for this objective is suggested to facilitate timely repair and ensure sustainability of this remedy.

Objective 6—Establish Self-Regenerating Species and, Where Needed, Soil-Building Species

Data was collected from 80 plots in low-cover areas (less than 50 percent canopy cover) and 234 plots in high cover areas. Evidence of regeneration was present in 100 percent of the plots with the exception of one area with 67 percent of the plots having regeneration. Additional evidence that succession is progressing includes volunteer (not planted) species and accelerated growth of planted species. Seven herbaceous and four woody species were found as volunteers or were showing accelerated growth during monitoring. The proposed FPS has the time criteria removed from the IPS, because self-regeneration and other successional processes are prevalent across the hillsides.

Objective 7—Comply with the State of Idaho Noxious Weed Regulations

Weed control activities are ongoing where it is possible to access the weed site with vehicles necessary for transport of herbicides and/or mechanically-removed plants. This includes areas immediately adjacent to and within short walking distance of any roads. Treatment in these areas helps reduce the presence of noxious weeds along a primary vector for transmittal of these pests within the site and elsewhere in the basin. Horses are now being used to transport herbicides and/or plants in limited access, steep areas. Weeds are being actively treated and therefore the IPS is proposed as the FPS.

Objective 8—Manage the Bunker Hill Hillsides Using Adaptive Management Techniques

Adaptive management has been used throughout this project to adjust prescriptions in a manner that reflected past performance on the hillsides and to essentially improve overall performance with each succeeding year. Examples include:

- Switched from pelletized lime to a hydrated product after one year. The pellets did not adequately cover the site and tended to roll down the steep slopes and/or pile up behind rocks and other obstructions.
- Eliminated blanket flower, vetch, regreen, and lupine from the seed mix after monitoring showed that they were not establishing on the site.
- Refined the use of different tackifiers based on a study established at the site. We used more co-polymer and guar tackifiers and less plantago-based products, due to performance. Co-polymer and guar appeared to have superior holding power on the steep hillside slopes.

- Refined the tree and shrub species to be planted and adjusted seedling container size to meet the needs of the site. Of particular importance was using a larger seedling container to take advantage of the benefits provided by a larger root mass.

The success of adaptive management resulted in no need to propose major changes to this IPS. Additions to the IPS for this objective are suggested to ensure that the success continues and adaptive management is anticipated to guide future operation and maintenance (O&M) of the hillsides.

Conclusions

Monitoring has shown that establishing consensus-based objectives, goals, and measures of success (IPSs) have resulted in a successful remediation program on the Bunker Hill Hillsides. Using adaptive management to adjust the remediation design to match changing site needs and new information has improved overall site performance. The identification of FPSs will allow the remediation program to transition smoothly into the O&M phase of the site. The overall long-term vision of eventual establishment of a restored, forested ecosystem appears to be realistic, as successional processes proceed and the site recovers from historic impacts.

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