BUNKER HILL, ID: ECOLOGICAL RESTORATION

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ABSTRACT

The Bunker Hill Superfund site in Idaho is the second largest in the nation. From smelting operations, soils on the mountainsides became severely acidic and contaminated with high concentrations of metals. Erosion from these hillsides, as well as an estimated 70 million tonnes of mine tailings were purposely dumped into the river; potentially depositing up to 700 million tonnes of contaminated sediment to the river.

USDA, U of Washington, U of Idaho, and the Northwest Biosolids Management Association members installed Phases I and II of this demonstration in spring and fall 1997, consisting of surface application of "supermulch" to tailings and steep, eroded hillsides. Biosolids from King County, Everett, Tacoma and Cowlitz County, WA, and Post Falls, Hayden, and Coeur d'Alêne, ID were mixed with wood ash from Washington Water Power, Louisiana Pacific or Kimberly-Clark. Plant establishment has been dramatic, as well as there being reestablishment of soil microbial communities and evidence of wildlife usage, suggesting that these treatments are highly successful in revegetation and erosion control.

INTRODUCTION

The Bunker Hill Superfund site in the Coeur d'Alêne River Basin is the second largest Superfund site in the nation. This area had been the nation's largest and richest mining district, with mining and smelting of Zn and Pb during the period 1916 until the early 1980's. Smelting of Zn and Pb sulfide ores resulted in aerial deposition of high concentrations of Pb, Zn, Cd, and As as well as sulfur compounds. The subsequent decrease in soil pH, coupled with the elevated concentrations of metals resulted in phytotoxicity to existing vegetation. Without a vegetative cover, mountain soils became highly susceptible to erosion and a substantial portion of the surface layer has washed into the Coeur d'Alêne River Basin. In areas of high erosion, soil samples from the affected mountainsides now contain total Zn < 800 mg/kg and total Pb <300 mg/kg, in contrast to earlier surface soil concentrations of up to 29,000 mg/kg Zn (Ragaini et al. 1977). In other areas, not so highly eroded, soil samples remain with total Zn over 4000 mg/kg and total Pb over 2500 mg/kg, while mine tailings and chat have measured concentrations of over 24,000 mg/kg Zn and 5000 mg/kg Pb.

Even prior to being designated as a Superfund site, several attempts to restore the effected areas had been undertaken. The construction of terraces (Hansen and Mitchell 1978) as well as the addition of agronomic rates of limestone and fertilizers were not sufficient to establish a vegetative cover in a number of efforts. Grass survival is generally limited to 2 growing seasons following hydroseeding. Revegetation In addition to metals, erosion removed many of the macro and micro nutrients necessary for plant growth. Soil physical properties were also impacted. Without a surface organic horizon, the soil water holding capacity has been reduced.

The Bunker Hill Superfund site is a highly visible site; success in restoration is both environmentally and politically of paramount importance. Application of remediation mixtures (such as biosolids and wood ash) to the surface of these soils addresses the problems at this site. Amorphous oxide minerals that are precipitated during wastewater treatment process are able to tightly bind trace metals and thereby limit metal phytoavailability, leachability and bioavailability. Wood ash has a high calcium carbonate equivalent that will can raise soil pH and make the soil calcareous. Research has shown that application of a liming material in combination with an biodegradable organic matter-rich product such as biosolids results in the formation of soluble Ca compounds that correct soil pH in subsurface soils (Brown et al. 1997). Biosolids in combination with wood ash provides high levels of N, P, and K, balanced levels of Ca and Mg, in addition to the plant-required micronutrients. Biosolids also provide organic matter that both improves soil tilth and provides a substrate for soil microbes; and the organic matter holds nitrogen which can be mineralized over time to support development of a balanced vegetated system. Surface application of the biosolids/ash mixture creates a new soil horizon that is capable of supporting plant growth.

USDA was asked to assist Region 10 EPA in demonstrating the effectiveness of this approach. A team of scientists and residuals managers (USDA, U. of Washington, U. of Idaho, the Northwest Biosolids Management Association, and Washington Water Power) installed spring and fall demonstration and research plots in 1997 using the tailor-made remediation treatments. Biosolids from King County, Everett, Tacoma and Cowlitz County, WA, and Post Falls, Hayden, and Coeur d'Alêne, ID were mixed with wood ash from Washington Water Power, Louisiana Pacific or Kimberly-Clark. This paper discusses preliminary results from the spring and fall installations.

RESEARCH AND DEMONSTRATION OBJECTIVES

The overall goal of the research and demonstration efforts at Bunker Hill is to investigate methods for establishment of stable, long-term vegetated and healthy ecosystems. Due to the success of many disturbed soil reclamation efforts throughout the country using organic residuals, we strongly believed that a combination of biosolids, wood ash and other organic amendments could be an effective tool in long-term revegetation and restoration at Bunker Hill. However, in light of past failed attempts using conventional methods to restore these denuded lands, we recognized the value of a carefully planned investigation to determine the best method for use in these unique environmental conditions. Thus, we approach this project in phases, ultimately developing a prescription with the highest possible chances of success; an approach which could be applied at disturbed metal contaminated sites anywhere. We have the following objectives:

- To develop soil amendment methods to reduce erosion.
- To determine long-term plant establishment techniques.
- To achieve reduction of metal phytoavailability and bioavailability.
- To develop application technique efficacy.
- To develop techniques that enhance nutrient and organic matter conservation and cycling.
- To document ecosystem restoration and remediation of toxic effects of contaminated soils by use of a combination of organic residuals and by-products such as ash or flyash.

PHASE I: INSTALLATION OF DEMONSTRATION PLOTS

Dewatered biosolids from King County and Everett, WA were tested along with material from Post Falls, Hayden, and Coeur d'Alêne, ID. Each source of biosolids was mixed with a 1:1 blend of wood ash from Washington Water Power and Louisiana Pacific. Biosolids from King County and Everett were applied at 55 and 110 dry Mg/ha. Biosolids from the Idaho WWTP's were mixed and applied at a rate of 110 dry Mg/ha. Ash was applied at a constant rate of 220 wet Mg/ha to provide 50 Mg/ha calcium carbonate equivalent. In addition, logyard wood waste from Crown Pacific was added at a fixed volume ratio of 1:5. Materials and soils characteristics are presented in Table 1. Treatments were mixed on a volume basis using a front end loader. It is possible to determine the accuracy of the mixing by analysis of samples taken from each plot (Table 3).

A seeding mixture of grasses and legumes was added to the biosolids/ash amendment mixture immediately prior to surface application at a rate of 30 kg/ha. The mixture used met the specifications outlined by EPA Region 10 in their attempt to restore native vegetation to the site. Seeds were hand scattered over each treatment mix before loading into the application vehicle.

Table 1. Characteristics of the materials used in the field trial of biosolids, wood ash, and logyard waste at the Bunker Hill, ID site.

	Zn	Cd	Pb	pH	Carbon	Nitrogen
	------ mg/kg ----				---- % ----	
Biosolids						
High N	915	3.5	141	8.1	29	4.4
High N (2)	326	1.8	29	7.8	34	5.7
High N (3)	612	2.1	54	8.1	32	4.9
Low N	1652	21.5	380	6.5	26	2.8
Wood Ash						
Ash 1	534	4.9	69	12.8	23	0.1
Ash 2	284	1.9	40	8.4	13	0.1
Logyard Waste	85.5	0.5	15	7.2	8.8	0.2

The experiment was set up on a tailings site directly off 1-90 using a Completely Randomized Design with 3 replications. The site was on a slope with limited vegetation on the top of the slope directly adjacent to the roadway. The majority of the plot area was devoid of vegetation. The surface of the soil was covered by large rocks. Four soil samples on a grid were taken from each plot and analyzed separately. Results of the analysis (Table 2) suggest that the soils on the 1-90 plots are a mixture of mine tailings and overburden that had been moved to this location from elsewhere on the property.

Table 2. Characteristics of the soils in the field trial at the Bunker Hill, ID site (±SD).

	Zn	Cd	Pb	pH	Carbon	Nitrogen
	------ mg/kg -------- % ----					
I-90 plots						
Plot 1	6000±6700	12±2	3200±2400	6.5±0.6	0.83±.74	0.033±.025
Plot 2	12000±2600	21±10	2100±900	6.9±0.5	0.52±.26	0.018±.005
Plot 3	10800±6300	17±6	3200±2400	7.0±0.3	0.41±.27	0.020±.008
Plot 4	14700±6300	21±4	4900±2200	6.3±1.0	0.48±.13	0.018±.010
Plot 5	11100±7200	9±3	2100±1500	6.4±0.4	0.40±.18	0.020±.014
Plot 6	11700±7100	11±3	2400±1500	6.7±0.4	0.44±.21	0.018±.015
Plot 7	5500±6300	7±3	4500±3600	4.6±1.7	0.16±.10	0.020±.000
Plot 8	9400±7100	28±18	3400±3000	6.1±1.1	0.35±.18	0.020±.008
Plot 9	10200±6400	18±14	3600±2200	6.0±0.4	0.46±.10	0.028±.010
Plot 10	7900±7000	16±5	1500±1100	6.7±0.4	0.35±.10	0.018±.010
Plot 11	7800±5900	19±11	2133±1400	6.6±0.2	0.39±.28	0.018±.010
Plot 12	9000±4800	22±11	2600±2000	6.9±0.3	0.42±.06	0.020±.008
Hillside plots						
0-15 cm	1300±1000	21±13	700±600	4.4±0.1	3.7±2.3	0.14±.06
0-2.5 cm	3000±1500	44±19	2000±800	4.4±0.2	12.0±10.8	0.31±.16
2.5-15 cm	1000±600	21±10	700±700	4.3±0.1	4.2±3.1	0.17±.02

Table 3. Characteristics of the treatments (biosolids applied at 2 rates, mixed with wood ash and wood waste applied at a constant rate) used in the replicated field trial (±SD).

	Zn	Cd	Pb	pH	Carbon	Nitrogen	Solids	Depth
	------ mg/kg ----				-------- % --------			(cm)
Low N								
25 Mg ha	1809±409	6.1±0.7	265±95	8.4±0.4	17±2	0.5±0.1	60±5	4.1±2.5
50 Mg ha	1143±182	9.0±0.6	217±17	7.6±0.1	20±2	1.1±0.2	49±7	6.1±2.3
High N								
25 Mg ha	1213±438	2.7±0.1	102±15	8.7±0.2	19±3	1.0±0.2	45±3	4.6±1.8
50 Mg ha	873±103	2.7±0.1	228±34	8.5±0.1	21±4	1.8±0.6	37±3	8.1±2.3
High N (2&3)								
50 Mg ha	554±20	2.6±0.1	168±30	8.4±0.1	24±1	2.2±0.3	30±4	5.8±1.8

All treatments were applied using an Aerospread on a Rottne chassis. This application vehicle is ideally suited to the surface application of the semi-solid biosolids/ash mixture. The machine has sufficient traction to access the existing terraces and can accurately distribute the mixture for up to 65 m in either direction from the roadway. Another problem at Bunker Hill is that the slopes often exceed 50%. The combination of fly ash and biosolids formed a product with very high adhesive properties. This enabled the mixture to remain on the hillsides while simultaneously permitting seedling emergence and increasing water permeability. During installation of the plots, a severe storm accompanied by a tornado watch did not cause any erosion of the applied amendments, including those on very steep slopes. From our observations, it appeared that pedestrian traffic was unaware of our operations other than immediately during applications, indicating that odor was not a problem.

In addition to this experiment, a single plot was installed in the area immediately adjacent to the Bitterroot revegetation trial on the hillsides directly above the site of the Zn smelter. This plot will provide a direct comparison of the remediation technologies. Soil and plant samples were taken from the vicinity of the plot area (Tables 2 and 4). Metal concentrations in these soils were high enough to inhibit plant growth. The Zn concentrations in the white pine needles and grass are above phytotoxic levels, while Mg and Ca are both below deficiency levels. The high C concentrations of these soil samples, coupled with the high metal concentrations, suggest that level of microbial activity at this site has been reduced due to metal toxicity. An active microbial population would have used the soil C as an energy source and thereby reduced the total C concentrations in the soil.

Table 4. Elemental concentrations in plants collected from Hillside site at the Bunker Hill, ID site (June 1, 1997, prior to treatment).

	Zn	Cd	Cu	P	K	Ca	Fe	Mg	Mn
	(mg/kg)								
Grass	310	1.5	14	1700	23000	920	154	430	170
Elderberry leaf	38	0.4	15	3200	23000	5900	68	1700	37
White pine needle	370	3.9	6	1100	3700	1400	290	630	490

INTERIM RESULTS

Germination and growth of grasses was noted on a site visit, 12 days after establishment of test plots. A second visit, 30 days after treatment application showed extensive germination on the Everett biosolids amended treatments with some germination visible on all other treatments. The second visit did not include an inspection of the plot on the hillside. A third visit, on July 14th noted continued growth on the Everett Plots, and germination on the hillside plot. In addition, excess biosolids/ash mix that had been sprayed onto a previously hydroseeded slope has caused lush growth on that slope.

The most recent visit on August 1 showed almost complete coverage on the Everett plots, including both grasses and legumes. The Hillside site also showed significant, though less complete, establishment of grasses. Other plots have relatively little plant establishment. It is likely that these observed differences in treatments are results of either the effect of temporary ammonia toxicity, or the different stabilities of the biosolids tested. Both the King County and Idaho biosolids have high ammonium concentrations, and, following mixture with ash, will have high rates of ammonia evolving. Also, these biosolids presumably experience a rapid degradation of organic material immediately after application. This generates acetic acid that can inhibit seed germination. This is a short term effect does not have any long-term implications on the potential usefulness of these biosolids. Due to the lower N content and more stable organic matter, both of these effects were presumably minor in the Everett treatments, allowing for germination and good plant growth.

Plant samples collected during the August site visit were analyzed for macro and micro nutrients; results shown in Table 5. There has been a significant reduction of Zn concentration in the grass of all the treated plots compared to the control, but the most dramatic effect was the increased concentration of P and K in all grass in the treated plots compared to control.

Table 5. Elemental concentrations in plants collected from Phase I plots (8/97).

	Zn	Cd	Cu	P	K
	---- mg/kg----			-- g/kg --	
Control	215	0.4	3.9	590	10
Low N biosolids					
Low rate	102	1.4	11.6	3620	47
High rate	150	2.3	11.4	3800	38
High N biosolids					
Low rate	118	1.2	16.1	3600	34
High rate	108	0.6	9.9	6830	26
High N (2&3) biosolids					
High rate	59	0.9	13.8	6110	25

The plots were reseeded in mid September. Observations in mid October of emerging plants suggest that full germination will be achieved by spring 1998. The adhesive properties of the biosolids/ash mixture suggest that delayed germination will not have any adverse affect on the long-term effectiveness of the soil amendments for reducing erosion.

Preliminary microbial assessments indicate the contaminated soils at Bunker Hill are almost devoid of microbial activity. However, two months after our treatments were installed, both the treatments and the soil six inches below the treatments show good and highly diverse microbial populations.

We will continue to monitor these plots for vegetation establishment and growth, plant uptake of metals, changes in soil chemistry, the status of the N and C added in the treatments, and effect on microbial activity. In Spring 1998 we will plant white pine seedlings and follow their survival and growth characteristics.

PHASE II INSTALLATION

A second phase of this research was installed October 1997, as a series of smaller plots with specific research objectives. These were designed to investigate the best prescription and the effect of different organic amendment sources for large-scale restoration efforts at Bunker Hill. The primary objectives for this phase are:

- To determine the effectiveness of different locally available residuals
- To compare ratios of different amendments
- To determine the most effective seeding time
- To predict long-term fate of restoration efforts

Both low and high N biosolids were used for this phase, in addition to wood ashe, one pulp and paper sludge, and logyard waste. We are interested in the least amount of materials that will give us long-term restoration and good throwing characteristics. All "supermulch" treatments received ash at similar rates. Also, from what we learned from Phase I, we are investigating the length of time required before seeding. Measurements during this phase will be more intensive that during Phase I, including vegetation evaluations, the fate of metals, carbon and nitrogen, and soil microbial assessments. Germination was relatively good throughout the plots by spring 1998, with the "supermulch" treatments > conventional hydromulch treatments > control. There was very little problem with ammonia toxicity in these plots, probably due to the lower temperatures during application.

Recent sampling in July 1998 included both soils and vegetation; most of which is in the process of being analyzed. Figure 1 shows the average biomass measurements from Phase II plots. Vegetation was almost non-existent from the controls, and little available from plots treated with conventional hydroseeding techniques. In contrast, all "supermulch" amendments showed relatively good biomass production. There appears to be a rate effect from use of the low N biosolids (greater growth at higher application rates), while there is either no difference, or even a reduction in biomass production with the high N biosolids with increased application rate. However, as these are preliminary results, long-term effects will only be evident in future years. Addition of logyard waste neither increased nor decreased biomass, while logyard waste with ash resulted in similar biomass production to the low N biosolids.

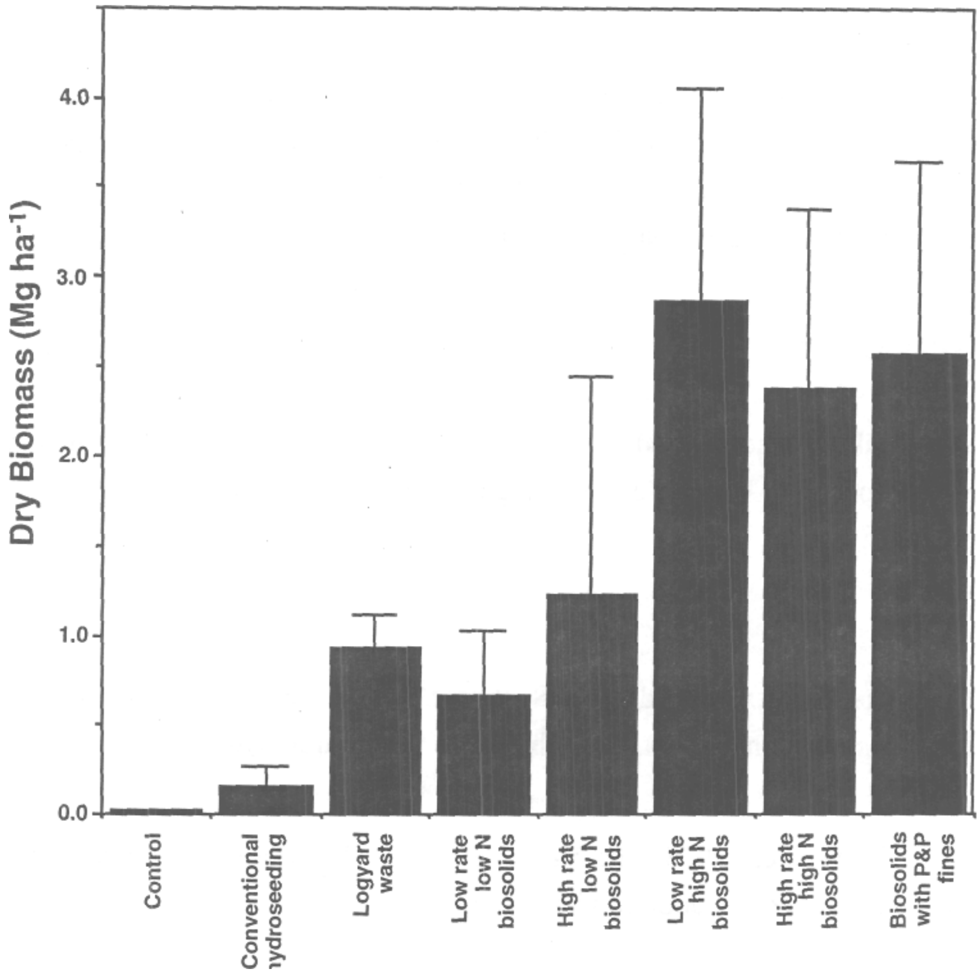

Figure 1. Biomass measurements from Phase II plots.

PRELIMINARY CONCLUSIONS

Results so far from Phases I and II indicate that application of a mixture of biosolids and ash is highly successful in revegetation and erosion control for long-term restoration. A vigorous combination of grasses and legumes on the plots indicate a self-sustaining vegetative cover. The mixture appears to be highly adhesive. There has been no movement of material from the plots by several erosive weather events.

Although early seeding on plots applied with biosolids containing high N had poor germination due to ammonia toxicity, reseeding efforts have been extraordinarily successful. Plant measurements indicate that "supermulch" treatments can result in biomass far exceeding control soils, and over an order of magnitude greater than conventional hydroseeding techniques.

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