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ENVIRONMENTAL EFFECTS OF COPPER MINE TAILINGS RECLAMATION WITH BIOSOLIDS

Karin Renken[1]
Craig C. Peddle [2]
Sie-Tan Chieng[3]

[1]University of B.C., Bio-Resource Engineering; 76A 2357 Main Mall, Vancouver, B.C. V6T 1Z4
[2]Greater Vancouver Regional Dist, Sewerage & Drainage Dept.; 4330 Kingsway, Burnaby, B.C. V5H 4G8
[3]University of B.C., Bio-Resource Engineering

ABSTRACT

Anaerobically digested biosolids (treated sewage sludge) were applied to Copper mine tailings (pH 8.0) in Princeton, B.C. to determine how well biosolids could achieve land reclamation on a site prone to wind erosion in a semi-arid climate (350 mm mean annual precipitation). In October 1992, biosolids at 62, 77 (two plots), and 179 Mg/ha were applied to four 0.5 ha plots with manure spreaders. In 1993, vegetation established on all sites without irrigation which reduced wind erosion. The 77 Mg/ha treatment led to the best vegetation quality and yield in the first growing season. Yield increased from 300 kg/ha (Control) to 5500 kg/ha (77 Mg/ha).

In October 1993, additional biosolids were applied to the 62 and one of the 77 Mg/ha plots to test if it is beneficial to apply biosolids in two applications rather than one larger application. Yields in 1994 were generally lower than in 1993 reflecting lower precipitation. Alfalfa established well on all sites and was the dominant legume while brome and fescue were dominant grasses. Vegetation samples showed no micronutrient or metal toxicity problems.

Notable trends in both growing seasons included: foliar Mo concentrations were lower; foliar Cu:Mo ratios were higher; cattle and deer grazing did not hamper growth; soil pH decreased whereas concentrations of Total P, Bray-P, TKN-N, NH_3-N, NO_3-N, Fe, and Hg increased with increasing application rates. Nitrate below 60 cm was negligible for all plots except the 179 Mg/ha and split application plots in 1994. N leaching losses were below 4-8% of applied TKN-N. Metal concentrations were below the CCME criteria for agricultural and residential soils except for Cu. Well water samples met the Canadian Drinking Water Guidelines.

INTRODUCTION

The revegetation of mine spoils can only be achieved with difficulty. The major difficulty in mine reclamation lies in the establishment of a nitrogen mineralization cycle. Mine tailings are generally low in organic matter which contributes to the soil characteristics of low nitrogen content, low moisture retention, low infiltration rate, and high bulk density all of which hamper plant establishment and growth (Hall and Vigerust, 1983). Low nitrogen content and low organic matter are correlated since the majority of nitrogen in soils is in organic form (Salisbury and Ross, 1992).

Conventional mine reclamation techniques involve regrading of tailings where appropriate which may be followed by deep cultivation and/or spreading of overburden before the application of inorganic fertilizer and a mixture of grass and legume seeds. Mulch may also be added to the soil surface to add moisture holding capacity and to provide wind protection. Common practise in B.C. has been to fertilize and seed tailings directly without overburden or mulch, but with repeated fertilizer applications. Stroo and Jencks (1982) found mine spoils reclaimed with fertilizer, seed, and mulch were initially productive, but that little nitrogen tended to remain in the soil which made repeated refertilization and reseeding necessary to achieve plant establishment. Studies have shown that periodic maintenance fertilizations seem to be necessary until the ecosystem has accumulated at least 1000 kg N/ha (Hall and Vigerust, 1983).

Another mine reclamation technique uses biosolids (municipal sewage sludge) instead of inorganic fertilizer to facilitate plant establishment and growth. The organic matter in biosolids contains nutrients, especially nitrogen and phosphorus, and microorganisms and their metabolites. Biosolids have the ability to complex metals and nutrients, and are a longer term source of nutrients than inorganic fertilizers as most nitrogen in biosolids is in organic form which is not available for plant use until it is mineralized. Microbial processes like mineralization and biosynthesis are particularly enhanced in the rhizosphere after biosolids application both of which improve mineral nutrition and enhance plant growth (Tomati et al., 1984). Biosolids can act as a mulch as well. Sopper (1993) summarized over 75 research projects that investigated the effects of biosolids utilization in mine spoil reclamation and found that a self-sustaining ecosystem can be established quickly.

This paper discusses the Princeton Tailings Demonstration Project in which anaerobically digested biosolids produced at the Annacis Island Wastewater Treatment Plant (Delta, B.C.) were applied to Granby tailings (Copper mine tailings) in Princeton. The project was conducted and financed by the Greater Vancouver Regional District - Residuals Management Group under permit AR-11578 issued by the B.C. Ministry of Environment, Lands, and Parks.

The demonstration sites are approximately 5 km southeast of Princeton, B.C. Princeton is located in a semi-arid climatic zone with a mean annual precipitation of 350 mm, a mean annual temperature of 5°C (-41°C to 38°C), and 104 frost free days. The main tailings ponds consist of loose silts and clays (Si, SiC, SiL, and SiCL) with a soil pH around 8.0 (alkaline).

METHODS AND MATERIALS

Plot Treatments

In total, twelve (12) different treatments of tailings plots were monitored between the first application of biosolids in October 1992 and October 1994. The biosolids application took place in two phases. In the first phase, biosolids were applied to six tailings plots of which four are discussed in this paper as they were studied in more detail. The biosolids were applied with hydraulic ram manure spreaders at application rates of 62, 77 (two plots), and 179 Mg/ha (55000, 69000, and 160000 Ib/acre respectively). Subsequently, the biosolids were incorporated with a 20 cm (8") farm disk, and the demonstration sites were seeded with a no-till, seed-drill seeder and rolled to minimize seed loss through wind erosion. A nurse crop seed mix was seeded at 30 kg/ha and a reclamation seed mix was seeded at 65 kg/ha. Characteristics of the biosolids and the seed mix are given in Tables 1 and 2 while Phase I treatments are depicted in Figure 1 and application rates are listed in Table 3.

TABLE 1. Biosolids Characteristics

Element:		PHASE I Annacis Land-dried Dewatered Biosolids Oct-92		PHASE I Annacis Stored Dewatered Biosolids Oct-92		PHASE II Annacis Freshly Dewatered Biosolids Oct-93
Total Kjeldahl N (mg/kg)	~	11000		33785		37200
% Moisture		31		74.9		72.8
Nitrate/Nitrite-N (mg/kg)		101		5		-
Ammonia-N (mg/kg) - extracted		241		12072		5150
Ammonia-N (mg/kg) - distilled		266		16733		6260
Arsenic (mg/kg)	<	12	<	17.0		4.7
Cadmium (mg/kg)		1		5.0		1.8
Chromium (mg/kg)		40		50.0		66.0
Cobalt (mg/kg)		5.0		4.1	<	3.6
Copper (mg/kg)		219		1050		902
Lead (mg/kg)		88		190		123
Mercury (mg/kg)		3		6.7		4.8
Molybdenum (mg/kg)	<	4		6.6		5.5
Nickel (mg/kg)		31		37		24
Selenium (mg/kg)		1		6.0		3.5
Zinc (mg/kg)		193		915		708

TABLE 2. Seed Mix used in the Princeton Demonstration Project

Reclamation Mix:

20%	BOREAL Creeping Red Fescue	*Festuca rubra*
15%	Hard Fescue	*Festuca ovina var. duriuscula (L.) Koch*
10%	CARLTON Bromegrass	*Bromus inermis*
10%	STREAMBANK Wheatgrass	*Agropyron riparium Scribn. & Smith*
10%	FAIRWAY Crested Wheatgrass	*Agropyron cristatum (L.) Gaertn.*
5%	Canada Bluegrass	*Poa compressa L.*
5%	ALMA Timothy	*Phleum pratense L.*
10%	RANGELANDER Alfalfa	*Medicago sativo L.*
5%	White Clover	*Trifolium repens L.*
5%	SC Red Clover	*Trifolium pratense L.*
5%	CICER Milkvetch	*Astragalus cicer L.*

Nurse Crop Seed Mix:

67%	Fall Rye	*Secale cereale*
33%	Hairy Vetch	*Vicia vil/osa*

Table 3. Phase I Biosolids Treatments

Location		Plot size (ha)	Application Rate (Mg/ha)	Biosolids type
Plot 2a	Tailings without vegetation	0.5	77	Stored dewatered
Plot 2b	Tailings without vegetation	0.5	62	41 Mg/ha Stored dew. & 21 Mg/ha Land-dried
Plot 3a	Tailings without vegetation	0.5	179	Stored dewatered
Plot 3b	Tailings without vegetation	0.5	77	Stored dewatered

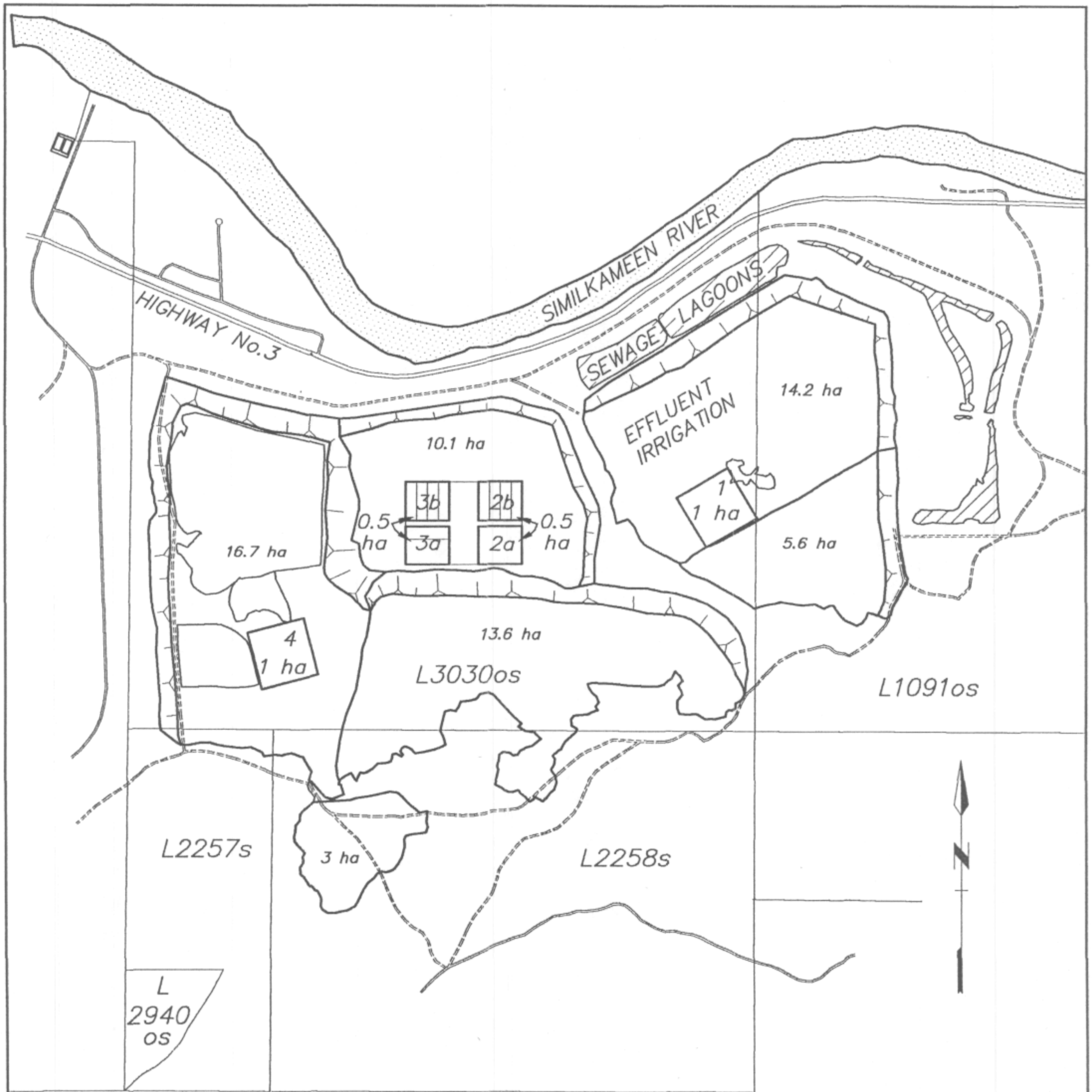


FIGURE 1. SITE PLAN
PRINCETON MINE TAILINGS
RECLAMATION PROJECT

In the second phase, additional biosolids were applied to portions of plots 2b and 3b, and the southern 2/3 portion of plot 3a (3aTS) was rotovated and reseeded in October 1993. The split applications were intended to test whether it is beneficial to apply biosolids in two applications rather than in one larger application, especially regarding mineral nitrogen in soil. Before additional biosolids were applied with manure spreaders, vegetation was cut, baled, and removed. After the application of biosolids, half of the areas which received additional biosolids (labelled 2bTS and 3bTS) were rotovated and seeded with the same seed mix used in the previous year but accidentally at double the rate. In October 1993, plot 3aTS was rotovated and reseeded primarily to improve germination and growing conditions as a 2 to 10 cm thick layer of biosolids left on the soil surface after the first year disking and rolling operations was believed to have hindered seed germination and seedling growth in the first growing season. Phase II application rates and treatments are shown in Figure 2.

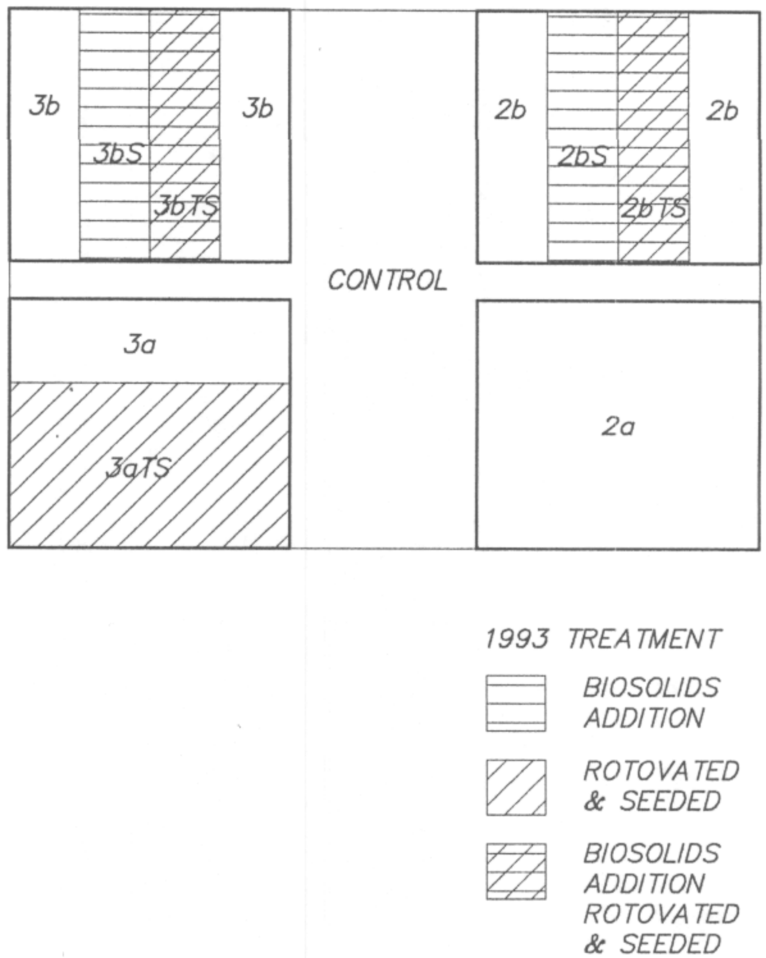
Soil Samples and Data Collection

In Phase I, soil samples were collected prior to, 6 and 12 months after biosolids application from the 0-15, 15-30, 30-60, 60-90, 90-120, and 120-150 cm soil profiles. All composite soil samples were analyzed for the parameters: Total Kjeldahl Nitrogen (TKN), nitrate, ammonia, and Total Phosphorus. In addition, composite soil samples from sites 2a and 3a were analyzed for the elements: Arsenic (As), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Selenium (Se), and Zinc (Zn). Soil fertility was also assessed for all 0-15 cm soil samples. Soil fertility analyses included the parameters: pH, EC, ammonia, nitrate, Bray-P, potassium (K), Calcium (Ca) Magnesium (Mg), Boron (B), Cu, Zn, Iron (Fe), Manganese (Mn), sulfate, organic matter, and CEC.

In Phase II, composite soil samples were collected in April and September 1994 from the 0-15, 15-30, and 30-45 cm profiles. In addition, composite soil samples were collected from the 45-60, 60-90, 90-120, and 120-150 cm profiles from tailings sites 3a, 3aTS, 3b, 3bS, and 3bTS. All samples were analyzed for TKN, ammonia, and nitrate, and all 0-15 cm samples were analyzed for soil fertility parameters. In addition, metal analyses were conducted on the 0-15 cm samples collected from sites 3aTS, 3b, 3bS, and 3bTS in April 1994 and on all 0-15 cm samples collected in September 1994.

In the soil analyses, the below 2 mm fractions were analyzed for: TKN by sulfuric acid digestion; ammonium and nitrate by potassium chloride extraction; exchangeable K, Ca, and Mg by ammonium acetate extraction; available P by Bray-P extraction; sulfate by calcium chloride extraction and turbidimetrical determination; available Zn, Fe, Cu, and Mn by DTPA-TEA extraction; B by hot water extraction; organic matter by total carbon determination (org. matter = TC*1.78); Hg by cold vapor atomic absorption; Se by hydride atomic absorption; and all other metals by aqua regia digestion and ICP analysis. Digestions or extraction were followed by a colorimetric determination of concentration for TKN-N, nitrate, ammonia, Bray-P, and B; or by atomic absorption spectrophotometry (A.A.S) for exchangeable K, Ca, and Mg, and available Zn, Fe, Cu, and Mn.

Representative samples from each plot might not have always been collected since lower nutrient and organic matter levels were measured than had been expected. We suspect the sampling probe had a tendency to part the biosolids on the soil surface rather than core them, leading to lower results. An increase in the core diameter for samples from the zone of biosolids incorporation might improve this situation.



2a	77 dt/ha
2b	62 dt/ha
2bS	62 + 52 dt/ha
2bTS	62 + 52 dt/ha
3a	179 dt/ha
3aTS	179 dt/ha
3b	77 dt/ha
3bS	77 + 106 dt/ha
3bTS	77 + 106 dt/ha

FIGURE 2.
PRINCETON MINE TAILINGS
RECLAMATION PROJECT

SCALE 1: 2,000
SF–2068 SK.20

Vegetation Samples and Data Collection

In Phase I, vegetation samples were collected in July and September 1993 of which the September samples were statistically compared. In September 1993, vegetation was collected from five discrete, predetermined locations per treatment (pattern '5' on a die). The vegetation was cut from 0.25 m^2 areas about 4-5 cm above the ground. However, only one of the samples from plot 3a yielded enough vegetation for analysis. The samples were analyzed for TKN, nitrate, ammonia, yield, As, Cd, Cr, Cu, Pb, Hg, Mo, Ni, Se, and Zn. From the control area, three discrete samples were collected which were analyzed separately for TKN and nitrate and were composited for metal and yield analyses. Species within the discrete vegetation samples were not analyzed separately.

In Phase II, vegetation samples were collected, evaluated, and reported by Gould Gizikoff (1994). In the September 1994 sampling program, composite samples of the dominant legume and one or two dominant grasses per treatment were analyzed. At least 3 subsamples per treatment were clipped from 1 m areas.

Before analysis, plant samples were dried (60°C), milled, and passed through a 1 mm sieve. The below 1 mm fraction was analyzed for TKN by sulfuric acid digestion; nitrate by potassium chloride extraction; Fe by hydrochloric acid extraction; Hg by cold vapor atomic absorption; Se by hydride atomic absorption; and all other parameters by nitric/perchloric acid digestion. Digestions or extractions were followed by colorimetric determination of concentration for TKN, nitrate, P, and B; by A.A.S. for Ca, Mg, Fe, Cu, Zn, and Mn; and by flame spectroscopy for K and Na.

Water Samples and Data Collection

Well water samples were collected in the first phase from wells in the Princeton Memorial Park (downgradient) and the Cemetery (upgradient) prior to and 1, 6, and 12 months after the application of biosolids except for the Cemetery samples. No water sample could be collected from the Cemetery one month after application due to frozen pipes.

RESULTS AN DISCUSSION

The demonstration project was very successful. Nitrification was easily established on all plots as indicated by the nearly complete conversion of ammonia to nitrate over the first growing season. Vegetation was established within one growing season on all sites. Growth on the tailings was early to start in the spring and continued well into the fall after surrounding vegetation had turned brown. Vegetation was very lush for a non-irrigated site, likely due to a combination of moisture holding capacity of the biosolids, improved nutrient status, and moisture content of the tailings. Over the last two growing seasons, there has been vigorous growth, especially of alfalfa, a nitrogen fixing legume. Compared to the sparse natural revegetation over the past 40 years, the vegetation establishment has been remarkable.

Soil Fertility

Ammonia, nitrate, Bray-P, available Fe and Ca, and organic matter tended to increase whereas pH tended to decrease with increasing application rates. Plant available Cu in the tailings tended to increase following biosolids application. The concentration of ammonia tended to be high in the early spring and low in the fall whereas nitrate concentrations tended to be low in the early spring and high in the fall. Nitrate leaching below 60 cm was negligible for plots 2a (77 Mg/ha), 2b (62 Mg/ha), and 3b (77 Mg/ha) and was below 4-8% of applied TKN-N for plots 3a (179 Mg/ha) and 3aTS (179 Mg/ha + rotovation) and the split application plots in 1994. Nitrate leaching in this range still constitutes good fertilizer efficiency.

On the split application plots, the mineral N levels increased over the growing season indicating that plant uptake, volatilization, and denitrification were not keeping pace with mineralization and possible fixation. This increase was even more pronounced on the rotovated plots. According to these results, it appears to be better to apply one larger biosolids application rather than two smaller applications likely because of higher denitrification and volatilization losses in the first year after application for a higher one-time application. For details, refer to Table 4. Rotovating appears to have increased the mineralization rate significantly. This effect should be taken into account in the design of future projects for which intensive incorporation of biosolids is proposed.

Vegetation

In the first growing season, the treatment of Granby tailings with 77 Mg/ha of stored dewatered biosolids led to the best vegetation quality and yield (5500 kg/ha). A statistical comparison of discrete vegetation samples collected from the 0, 62, and 77 Mg/ha sites determined that Total N and nitrate concentrations, Cu:Mo ratios, and yields increased with increasing application rates, and that Mo, Cu and Cr decreased with increasing application rates. Refer to Table 5 for details. The beneficial trend towards lower Mo concentrations in foliage is possibly a result of increased nitrification resulting in lowered soil pH and reduced Mo availability to plants and/or adsorption of Mo onto organic matter. The Cu concentration likely decreased due to less air-borne tailings resulting in less tailings adhering to the surface of vegetation. Statistically, vegetation yields for the control and the 179 Mg/ha sites were comparable. In the first growing season, fall rye, brome, timothy, crested wheatgrass, fescues, alfalfa, and hairy vetch grew of which fall rye was visibly the most prominent. Deer grazing in 1993 did not hamper vegetation growth.

In the second growing season, the identification of the 'best' treatment is difficult since some of the plots were in their first growing season and some were in their second growing season, and since alfalfa establishes slowly. No micronutrient or metal toxicity problems for plant health or cattle consumption were identified in the second growing season, and again there appeared to be a beneficial trend towards lower Mo levels in foliage. Alfalfa, brome, and fescue were the dominant species on all tailings plots except on site 3aTS, and on the seeded and unseeded control sites. On plot 3aTS russian thistle *(Salsola kali)* was dominant (88%) and on the seeded control plot alfalfa *(Medicago sativd)* and brome *(Bromus inermis)* were dominant whereas on the unseeded control plot, not enough grasses or legumes grew for analysis. In general, alfalfa cover was lowest on plots rotovated in the fall of 1993.

In the second growing season, plot 3a had the highest yield (5050 kg/ha; 179 Mg/ha; 2nd season) followed by plot 2bTS (4680 kg/ha; 62+52 Mg/ha; 1st season). The lowest yields by far were measured for the seeded and unseeded control sites (188 and 81 kg/ha respectively). The lowest yield on a treatment site was measured for plot 2b (1790 kg/ha; 62 Mg/ha; 2nd season). Biomass production in 1994 was generally lower than in 1993 except for plot 3a. Lower seasonal rainfall in 1994 and cattle and deer grazing in 1993/1994 were likely contributing factors to lower yields. The rainfall in the first and second growing seasons were 230 and 120 mm respectively.

TABLE 4. Mineral N below 60 cm as Percentage of Applied TKN-N

Plot	Appl. Rate (Mg/ha)	Pre Oct. '92	Post - 1 Apr. '93	Post - 2 Sept. '93	Post - 3 Apr. '94	Post - 4 Sept. '94
2b	62	0.25%	0.35%	0.38%		
2a	77	0.16%	0.20%	0.33%		
3b	77	0.09%	0.28%	0.25%	2.72%	7.82%
3a	179	0.04%	0.14%	0.39%	2.91%	4.19%

	Post - 2 Sept. '93	Post - 3 Apr. '94	Post - 4 Sept. '94	Post - 3 Apr. '94	Post - 4 Sept. '94
Plot	3b	3bS		3bTS	
Application Rate (Mg/ha)	77	77 + 106		77 + 106	
% of TKN applied	0.3%	2.4%	2.5%	2.8%	6.4%
Plot	3a	3a		3aTS	
Application Rate (Mg/ha)	179	179		179	
% of TKN applied	0.4%	2.9%	4.2%	4.9%	4.6%

TABLE 5. Phase I Foliage Quality

Element / Appl. rate:	_0 Mg/ha		_62 Mg/ha		_77 Mg/ha		_179 Mg/ha	
Chromium, mg/kg	3.0	a	1.8	b	1.8	b	not compared	
Copper, mg/kg	68	a	23	b	21	b	not compared	
Molybdenum, mg/kg	24	a	5.7	b	4.4	b	not compared	
NO3-N, %	0.003	b	0.010	ab	0.039	a	not compared	
Total N, %	1.5	ab	1.2	b	2.0	a	not compared	
Yield, dt/ha	0.2	b	4.3	a	5.5	a	0.6	b

Notes:
The Duncan multiple range test at the 0.05 level of probability was used to determine signifcantly different means.

Over the two growing seasons, vegetation on plots with low application rates established quicker than on plots with high application rates, however, vegetation on the plot with highest application rate (179 Mg/ha) did much better in the second growing season than vegetation on plots with lower application rates.

Total Metals

Of the metals tested in 1993, only the 0-15 cm Hg concentration changed significantly. The Hg concentration increased with increasing application rates, but increases were below the Level of Quantification. In 1993 and 1994, all soil metal concentrations were below the lowest of the CCME criteria for agricultural or residential soils except for Copper which was reduced but remained above the industrial criterion.

Water Samples

All water samples met the Canadian Drinking Water Guidelines (1989).

CONCLUSION

The positive environmental effects of biosolids application to Copper mine tailings in Princeton, B.C. were major: accelerated reclamation, reduced wind erosion, improved vegetation quality, increased yield, and improved soil fertility, and the negative effects were minor: nitrate below 60 cm for high application rates (< 4-8% of applied TKN-N) and increased but not quantifiable Hg concentrations in the 0-15 cm profile. After two growing seasons, the vegetation appears to be well established and self-sustaining. For further information on the demonstration projects, contact the authors or refer to project progress reports issued by the GVRD Residuals Management Group to the B.C. Ministry of Environment.

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