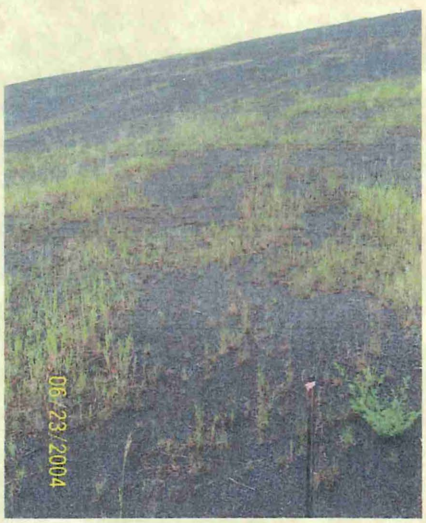
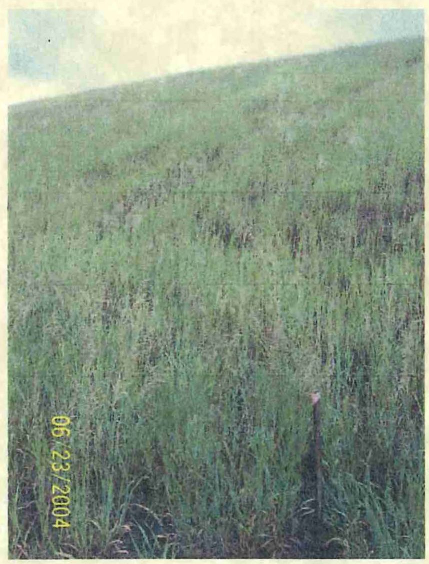
Use of Biosolids to Reclaim Coarse Taconite Tailings



Vegetation without biosolids



Vegetation with biosolids

Final Report
January 2005

Minnesota Department of Natural Resources
Division of Lands and Minerals
St. Paul, MN

Use of Biosolids to Reclaim Coarse Taconite Tailings

Final Report
January 2005

Paul Eger
David A. Antonson

Minnesota Department of Natural Resources
Division of Lands and Minerals
500 Lafayette Road
St. Paul, MN 55155-4045

Table of Contents

Table of Contents (continued)

Page

List of Tables

List of Figures

Table of Contents (continued)

List of Photos

List of Appendices

0. Executive Summary

Mining companies in Minnesota have been unable to meet the vegetation standard (90% cover) on the coarse fraction of taconite tailings despite repeated applications of both seed and inorganic fertilizer. Previous small scale demonstration and plot tests demonstrated that 90% cover could be established within three years with the addition of about 20 dry tons/acre of suitable organic amendments. Although biosolids applied at the agronomic rate improved vegetative results, it did not meet the three year cover standard of 90%. The standard was met after top dressing with additional biosolids at a rate of 100 lbs N/acre.

The primary objective of this study was to determine if there was an optimum rate for a one time application of biosolids that would improve vegetation without adversely impacting water quality. In order to determine an effective rate, a combination small plot and demonstration slope study was conducted.

The amendments applied were:

- Standard mineland reclamation control
- Biosolids to provide 100 lb. available Nitrogen ~ 3.1 dry tons/acre
- Biosolids to provide 200 lb. available Nitrogen ~ 6.2 dry tons/acre
- Biosolids to provide 400 lb. available Nitrogen ~ 12.4 dry tons/acre
- Biosolids to provide 200 lb. available Nitrogen ~ 6.2 dry tons/acre + paper mill residue from Stora Enso in Duluth ~ 28 dry tons/acre
- Biosolids to provide 400 lb available Nitrogen ~ 12.4 dry tons/acre + paper mill residue from Stora Enso in Duluth ~ 56 dry tons/acre

The small plots were seeded with 55 lbs/acre of a standard cool season reclamation seed mix and mulched with 2 tons/acre of hay in June of 2002.

Although there appeared to be reasonable germination in the small plots (bins), all the vegetation except a few isolated sweet clover plants disappeared in July. Although there was no definitive explanation for the disappearance of the vegetation, the late planting combined with predation by grasshoppers were believed to be responsible for the poor results. The plots were all reseeded in August. After two full growing seasons, percent cover on all of the amended plots was more than twice that on the standard mineland reclamation plots. Average percent cover on the 400 N + paper mill residue plot exceeded 90%, the three year cover standard.

The demonstration slopes were planted several weeks after the bins and the mulching was not completed until the middle of July. Despite late planting and delayed mulching, vegetation did grow on the bottom part of the slopes, but developed very slowly and no quantitative data was collected during the first growing season. After the third growing season, percent cover on the bottom portion of the amended plots was more than three times that on the standard mineland reclamation plot. Percent cover on the

400 N + paper mill residue plot exceeded 90%, the three year cover standard. Cover on the top portion of the slopes was sparse during the first two years, but began to fill in during 2004, although percent cover was still only about half that on the bottom slopes.

With the exception of nitrate, there were minimal water quality problems. With essentially no first year vegetation in any of the plots, the average nitrate values for all the treated plots were elevated. The average nitrate values exceeded the water quality standard of 10 mg/L in all plots except the control and the 200N biosolid + paper mill residue plots. Nitrate concentrations were generally lower in the bins treated with paper mill residue.

The total cost to reclaim the slope ranged from $960 per acre for the 100N biosolid application to $3140 for the 400 N + PMR treatment.

Based on water quality, vegetation, and cost, the optimum application of biosolids appears to be 200N. Although the nitrate concentrations were somewhat greater than the water quality standard, the concentration was only slightly greater than the average concentration from the 100N treatment for both years and the standard mineland reclamation treatment during the first year. After two growing seasons, the percent cover on the bins ranged from 71-85% and the cover on the lower slope of the demonstration slope was 72%. If conditions are near normal next year, the bins are expected to approach 90 % cover within 3 years, and vegetation on the slope should also improve. Although percent cover was higher with 400N, the average nitrate concentrations were about 3 times higher than the 200N treatment and 3-5 times above the water quality standard. In addition, the average sulfate concentration in the first year was slightly above the water quality standard. Although the addition of paper mill residue successfully controlled nitrate release and generally improved vegetation (the 400N +PMR was the only treatment to achieve the 90% cover standard in both the bins and demonstration slope), it would cost at least 6 times as much as the 200N application. The use of paper mill residue also released small amounts of mercury and cobalt.

Currently WLSSD pays for the transport and application of biosolids on mine lands, so mining companies can now meet their reclamation obligations at no additional cost. In the past, since the percent cover produced by standard reclamation did not meet reclamation standards, mining companies spent additional money either to refertilize or sometimes replant entire areas. If the entire area is replanted, reclamation costs double from around $750 /acre to about $1500/acre. Yet despite this increased effort and cost, percent cover on retreated tailings rarely exceeded 70% and did not meet the 90% cover standard. At a biosolids application of 200N, the total estimated cost to successfully reclaim an acre of coarse tailings is about 20% less than the previous practice of multiple standard mineland reclamation treatments which has not been successful.

1. INTRODUCTION

All mines in Minnesota are required to reclaim tailings basins, stockpiles and other disturbed areas after they are no longer in use. Current reclamation standards require that a 90% vegetative cover be established within 3 years (5 years for south and west facing slopes), and a self-sustaining vegetative community must exist within 10 years. Studies conducted by the Minnesota Department of Natural Resources (MN DNR) have shown that tailings have a high pH, and are infertile with little to no nitrogen, phosphorus or organic matter. Although fine grained tailings can be revegetated successfully by applying large amounts of inorganic fertilizer, seed and mulch, this approach has not worked for coarse tailings. Despite repeated applications of seed and fertilizer, percent cover on coarse tailings rarely exceeds 70%, and is typically around 50% (Dewar, personal communication). Studies conducted by the MN DNR and the former US Bureau of Mines, in conjunction with EVTAC, USX and National Steel demonstrated that the addition of organic materials can greatly improve vegetative success and meet reclamation standards (Eger et al, 1999). Some of these organic amendments are considered waste, and if they can be used successfully in mineland reclamation a beneficial reuse will be created. The amendments used in this study include material from paper manufacturing and wastewater treatment; paper mill residue and biosolids (Appendix 1).

In 2002, EVTAC, Western Lake Superior Sanitary District (WLSSD) and the MN DNR began a cooperative research program to determine the benefits of applying these organic amendments to tailings. Paper mill residue was provided by the Stora Enso plant in Duluth Minnesota and biosolids came from the WLSSD treatment plant, also in Duluth. These amendments were expected to improve vegetation by providing nutrients and moisture retention capacity.

In order to fully evaluate the use of these amendments, a small-scale plot study was combined with a full-scale demonstration project. A twelve acre portion of EVTAC's tailings dam was used for the full-scale demonstration area and 14 small bins were used to evaluate the effect of the organic amendments on water quality and vegetation.

2. OBJECTIVES

1. To determine the effect of increasing amounts of biosolids on coarse tailing vegetation and water quantity and quality.

2. To determine the effect of paper mill residue in combination with biosolids on coarse tailing vegetation and water quantity and quality.

3. To determine an optimum biosolid application for coarse taconite tailings

3. BACKGROUND

Previous studies demonstrated that organic amendments could be used successfully to reclaim coarse tailings (Melchert et al., 1994; Norland et al., 1993, 1995; and McCarthy et al., 1995). Most of these studies were done on small (2.5 by 4 meter), level plots, and only a few collected any water quality data.

In general, the results from these studies showed that organic additions on the order of 20 to 40 dry tons/acre were capable of improving vegetation to the point where percent cover would meet the 3-year reclamation standard of 90% cover (Eger et al., 1999). In 1997, the first full scale application of a variety of amendments was made at EVTAC (Eger et al., 2000). After three years, percent cover on all of the amended slopes was at least 50% higher than the cover produced by the standard mineland reclamation practice. Although none of the plots met the three-year cover standard of 90%, plots containing municipal solid waste compost and paper mill residue with biosolids had cover which was greater or equal to 85%. The vegetation on the biosolid plot that had received the equivalent of 100 lbs N (6 dry tons/acre), was only about 75%. One of the objectives of the current study was to examine the effect of higher addition rates of biosolids on vegetative success.

3.1. Biosolids

The US EPA defines biosolids as slow-release nitrogen fertilizers produced from treated wastewater. This material was previously called sewage sludge. Biosolids applied to agricultural areas have improved vegetation without adversely impacting water quality (www.biosolids.org, www.epa.gov/owm/mtb/biosolids). Minnesota has adapted biosolids application guidelines for application to agricultural soils, but there are currently no guidelines specific to mine lands, although the rules include a provision which provides for the application of higher rates of biosolids for land reclamation projects (MN PCA, 2000; Chapter 7041.1200, subpart 4; Appendix 14). In 1997, when the first demonstration project with biosolids was conducted, the agricultural guidelines were generally applied to the mining area. The rules for application to tailings are based on the 503 rules of the US EPA, which sets standards for pathogen destruction and acceptable metals content (US EPA, 1999).

Biosolids have been used extensively in coal mining areas (Pietz et al.,1989; Peterson et al., 1972; Sopper, 1993). Biosolids in combination with limestone have ameliorated the effects of acid soil conditions on plant growth (Voeller et al., 1998). While results varied depending on species, plants were generally more productive at the higher pH, and grew more rapidly where nutrients were present due to the addition of biosolids. Biomass increased when plots with biosolids were augmented with ammonium nitrate.

Since biosolids contain high concentrations of nitrogen, application rates are generally based on the amount of nitrogen that will be used by the plants during the growing season (agronomic rate). This approach assumes that all the applied available nitrogen will be used by the plants so that nitrogen release from the site will be minimized. Most biosolids contain sufficient amounts of plant available phosphorus for natural soils but may not provide enough for a low phosphorous, alkaline material like tailings (Appendix 6) Higher addition rates of biosolids have been tried in some reclamation projects. The optimal one-time application was reported to be 22 - 44 dry ton/acre (Daniels and Haering, 2000).

The biosolids used in this project came from the Western Lake Superior Sanitary District (WLSSD) wastewater treatment plant in Duluth, MN. Solids are separated from the incoming sewage and digested anaerobically. This process breaks down the organic material and reduces the amount of pathogens. Although the contact time, temperature and contaminant levels are consistent with Class A requirements, or exceptional quality biosolids, the flow through nature of the digesters makes it difficult to insure that every particle of material will be held for the required time at the required temperature (Hamel, personal communication, 2002). As a result, the biosolids are considered a Class B material. Digested sludge is dewatered to approximately 25 percent solids (75% moisture) by an Ashbook-Simon-Hartley belt press (Additional data on the process and biosolid data is provided in Appendix 1).

3.2. Paper Mill Residue

Paper mill residue is a waste produced from the paper making process and contains primarily wood fiber and clay. It is high in carbon (C), low in nitrogen (N), and is effective at retaining water. In extreme cases, C:N ratios have been as high as 270:1 (Campbell et al., 1995). In a plot study at EVTAC, using paper mill residue containing a de-inking waste, the C:N ratio was 123:1 (McCarthy et al., 1995). Paper residue from Stora Enso, Inc., formerly Consolidated Paper, was used in this study. This residue was also used in the 1997 study.

Stora Enso, Inc., has two facilities at its Duluth, MN location. Lake Superior Paper Industries (LSPI), which manufactures uncoated, supercalendared papers for the printing industry, and Superior Recycled Fiber Industries (SRFI), a de-inking mill, that recycles post-consumer office waste paper to produce a high quality pulp. Recycled paper is mixed with water and ground, and the ink is then removed (de-inking) to produce a recycled feedstock. This feedstock is then added into the paper making process to meet the required recycled fiber content. The residue from the paper production process is combined with the residue from the de-inking process and dewatered to produce a semi-solid material (about 50% solids). Stora Enso produces approximately 250 wet tons per day of residue. Prior to 1997, all of this material was landfilled, but now about 40 % is used as daily cover at the Canyon landfill in Canyon, MN and the excess is landfilled (Additional data on the process and residue data are provided in Appendix 1).

Previous studies with material similar to Stora Enso residue were conducted on small test plots at the EVTAC mine (McCarthy et al., 1995). Variables included the amount of residue (five rates), fertilizer (two rates), and native and standard seed mixes. Data from these plots is limited to 1, 2, and 7-year results. After two years, all the plots with fertilizer had higher percent cover, and for those plots with 10-20 dry tons/acre of paper mill residue, cover was between 85-90% (Eger et al., 1999). Suction lysimeters were used to collect water quality samples from the plots. Chloride and boron were elevated, but did not exceed drinking water standards (McCarthy et al., 1996). In the 1997 study, the specific conductance of the water collected from the plots that had received paper mill residue was about 20% higher than the control but there were no significant water quality problems (Eger et al., 2000).

4. METHODS

4.1. Introduction

The 2002 EVTAC experiment contained two components. The first component of the study was to investigate the effect of higher rates of biosolids on water quality. A set of fourteen tailing-filled bins, previously constructed for the 1997 organic amendment project, were used to study the impact of biosolids addition on vegetation and water quality. The tailings used in the 1997 study were removed and new liners and plumbing were installed. New tailings were then added to the bins. Since the bins were self-contained, water quality (surface runoff and infiltration) and vegetation growth could be monitored separately for each treatment (Figure 1; Photo 1).

The second component of the project was full scale demonstration plots. Six, two acre plots of each treatment were constructed on a newly sloped portion of the coarse tailings dam (Figure 2). Percent cover was measured on these plots in 2003 and 2004.

4.2. Materials

Fourteen bins, nine feet long by three wide by three feet deep with an open bottom were constructed in 1997 from 20 gage steel by EVTAC and placed on site with a crane. The front of each bin was equipped with a gutter to collect surface runoff. The bins were secured in place at a 3:1 slope (Photo 1, Figure 3). The Department of Natural Resources installed custom-made liners (ultraviolet resistant 40 mil low density polyethylene) and a plumbing system to collect infiltration and surface runoff (see photos in Appendix 7). A special tape (UV resistant 25 mil synthetic elastomeric tape) was provided by the manufacturer to tape seams produced during the installation, particularly in the collection gutter (More information on the liner and tape is provided in Appendix 13).

In the 1997 study the liner material was a 30 mil ultraviolet resistant polyvinyl chloride membrane (PVC). The polyethylene product was chosen for the project to comply with WLSSD's policy to minimize the use of PVC. The material was much more rigid than PVC and was difficult to bend and conform to the somewhat irregular bin dimensions. The supplier of the liner suggested that installation be delayed until air temperature exceeded 60 degrees, but even at these temperatures the material was stiff and hard to form to the bin. Since the temperatures in the Spring of 2002 were unseasonably cold, liner installation was postponed until June (Appendix 5) .

A foundation geotextile (9 oz.) was used to line the entire bin to protect the liner. A geonet drainage composite (Miradrain G-Series by TC Mirafi) was placed in the bottom of each bin over the liner to facilitate rapid drainage once the water infiltrated the tailings. The plumbing to collect the infiltration water consisted of a one-inch (0.10" slotted) schedule 40 PVC pipe wrapped with a geotextile sleeve which was placed at the bottom of each bin and plumbed out the front with PVC pipe to a collection apparatus. The surface runoff plumbing consisted of a ½" port in the bottom of the gutter which was plumbed with PVC pipe to a collection apparatus. A 3/16" slotted plastic mesh cylinder was placed in the outlet port to prevent plugging with mulch. The collection apparatus consisted of a 50 gallon plastic tank to collect the infiltration water and a 20 gallon plastic tank to collect the surface runoff. Each tank was equipped with a plastic spigot on the bottom to collect water quality samples.

Figure1. Plot layout (schematic).

North ↓

Plot #	
1	Biosolids (400 N)
2	Standard Mineland Reclamation
3	Biosolids (100 N)
4	Biosolids (400 N) & Paper Mill Residue
5	Control
6	Biosolids (200 N) & Paper Mill Residue
7	Biosolids (200 N)
8	Biosolids (400 N)
9	Control
10	Biosolids (200 N)
11	Biosolids (200 N) & Paper Mill Residue
12	Biosolids (400 N) & Paper Mill Residue
13	Standard Mineland Reclamation
14	Biosolids (100 N)

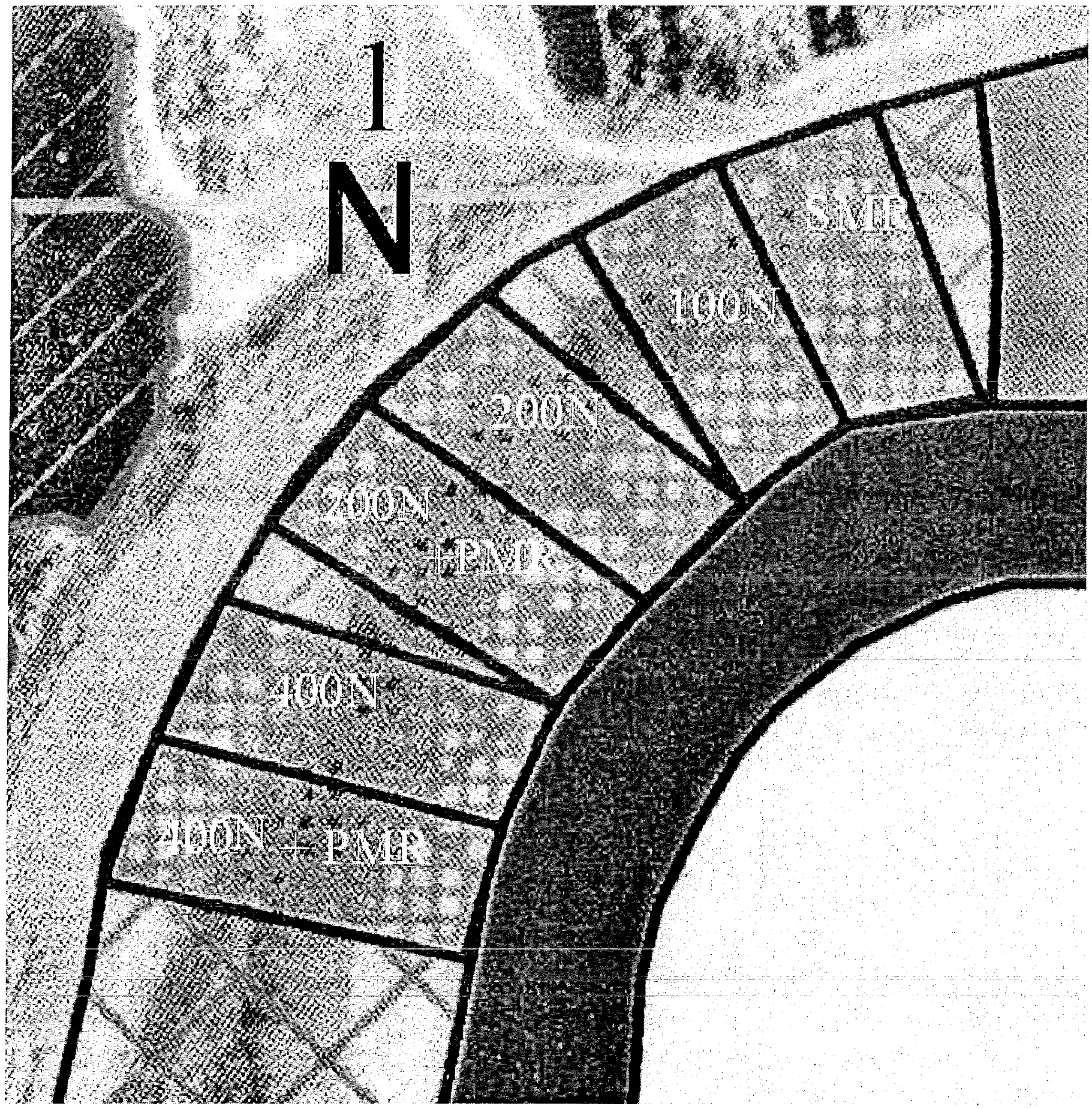


Figure 2. Demonstration Slope Layout, 2002.

Photo 1. Bins used in study, July 2002

The tailings were added to each bin to a depth of approximately 3 feet with a front-end loader and leveled by hand (photos, Appendix 7). The treatments were assigned using a randomized split block design (Figure 3, Table 1). The paper mill residue was obtained from Stora Enso Company's facility in Duluth, MN, about 100 km southeast of the site. The Class B municipal biosolids were generated at WLSSD's wastewater treatment plant, also in Duluth.

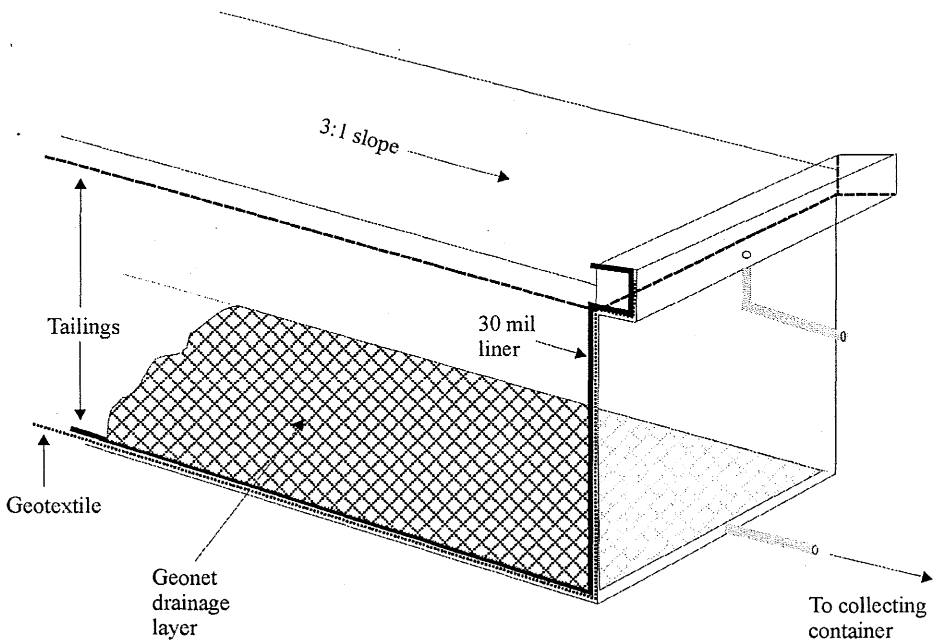
4.3. Treatments

Each treatment was applied in duplicate. Two bins were left as untreated bare tailing controls.

• Standard mineland reclamation control	
• Biosolids to provide 100 lb. available Nitrogen	3.1 dry tons/acre
• Biosolids to provide 200 lb. available Nitrogen	6.2 dry tons/acre
• Biosolids to provide 400 lb. available Nitrogen	12.4 dry tons/acre
• Biosolids to provide 200 lb. available Nitrogen	6.2 dry tons/acre
+ paper mill residue from Stora Enso in Duluth	28 dry tons/acre
• Biosolids to provide 400lb available Nitrogen	12.4 dry tons/acre
+ paper mill residue from Stora Enso in Duluth	56 dry tons/acre

The total dry tons was based on the assumption that the nitrogen content of the anaerobically digested WLSSD biosolids would be 9 lb N /wet ton and the average percent solids would be 28 %. An application of 11 wet tons per acre will supply about 100 lbs of available N per acre (Saunders, personal communication, 2002). The paper mill residue is typically about 40% moisture. The

Figure 3. Cross section of individual plots (schematic).



addition rate was based on data collected on the chemistry of the residue during the 1997 EVTAC study and information from the company on the relative consistency of the material (Gobin, personal communication, 2002). Addition rates were adjusted to provide a C:N ratio of 25:1 (Appendix 8). This ratio should facilitate break down of the paper residue while supplying nitrogen to the vegetation and minimizing the loss of nitrate from the site (Schmidt et al, 2001).

Table 1. Treatment and fertilizer application rates.

Treatment	Bins	Biosolids Application rate (dry tons/acre)	Paper Mill Residue Application rate (dry tons/acre)	Fertilizer (18-46-0) Application Rate (lbs/acre)	Mulch Application Rate (tons/acre)	Seed Application Rate (lbs/acre)
Control	5, 9	0	0	0	0	0
Standard mineland reclamation (SMR)	2, 13	0	0	500	2	55
Biosolids (100 N)	3, 14	3.2	0	0	2	55
Biosolids (200 N)	7, 10	6.4	0	0	2	55
Biosolids (400 N)	1, 8	12.8	0	0	2	55
Biosolids (200 N) + Paper mill residue	6, 11	6.4	28	0	2	55
Biosolids (400 N) + Paper mill residue	4, 12	12.8	56	0	2	55

4.4. Application

Reconditioning of the small bins was completed on June 13, 2002. On June 17, the biosolids and paper mill sludge were mixed into the plots receiving amendments. Based on the percent moisture of the biosolids and paper mill residue, these amendments were added volumetrically using 5 gallon buckets (Appendix 1, Table A1.3). They were spread on the surface of the tailings and then incorporated about 6 inches deep using a hoe. The surface was then raked evenly.

On June 19, 2002, the seed was hand broadcast at a rate of 55 lbs/acre and lightly raked to cover the seeds (see Table 2 for seed mix). Diammonium phosphate fertilizer (18-46-0) at the rate of 500 lbs/acre was broadcast over the two SMR plots and incorporated using the same technique as for the amendments. Straw mulch at the rate of 2 tons/acre was spread over the seeded plots and a netting was tacked over the mulch to hold it in place. Wooden stakes and twine secured the netting.

EVTAC sloped the demonstration area, located on the northwest of tailings basin 1, in April - May 2002. Biosolids were applied to the large scale demonstration plots in June 2002. The demonstration plots were hydroseeded in late June/early July. The seed mix was the same that was used for the bins. The plots were not mulched immediately as would have been the normal practice. Mulching began about 10 days after seeding (Additional detail is provided in Appendix 15).

Table 2. Standard mineland reclamation (SMR) seed mix used at EVTAC, 2002. Seed mix was obtained from Agassiz Seed and Supply in West Fargo, ND.

Common Name	Percent	Lbs/acre
Lincoln Smooth Bromegrass	19.43	10.7
Creeping Red Fescue	15.86	8.7
Perennial Ryegrass	14.69	8.1
Climax Timothy	11.96	6.6
Vernal Alfalfa	11.95	6.6
Norcen Birdsfoot Trefoil	11.94	6.6
Yellow Sweet Clover	11.93	6.6
Inert Ingredients	2.0	1.1
	Total:	55

NOTE: Also included are: 1) crop (0.09%)
2) weeds (0.09%)
3) noxious weeds (0.00%)

Seed mix was tested for percent accuracy in June 2002. All species had at least 80% germination.

4.5. Solid phase analyses

Biosolids and paper mill residue were moved from the top of the basin, where they had been delivered and stockpiled, to the area immediately adjacent to the bins. Five gallon samples of both biosolids and paper mill residue were collected from the material near the bins. After the samples were collected, the amendments were covered with plastic tarps to prevent a change in moisture content by drying and/or precipitation before applying the amendments to the bins. Wet weight of the five gallon pail samples for the biosolids and paper mill residue was determined (Appendix 1). Percent moisture on the biosolids and paper mill residue were run in triplicate at the MN DNR laboratory in Hibbing, MN. The samples were oven dried at 110 C°. A representative sample of the tailings, biosolids and paper mill residue was sent to Minnesota Valley Testing Laboratories (MVTL) in New Ulm, MN for soil fertility analyses.

4.6. Sampling

From spring through fall the site was visited approximately once a week with the timing and frequency of visits dependent on rainfall. Water entered the collection tanks through a PVC pipe which was plumbed into the top of the tanks. Each plastic tank was equipped with a lid, which prevented contamination from foreign materials such as dust. All samples were collected directly from the plastic spigot on the bottom of the tanks. After sampling the extra water was drained from the tank. This extra water was periodically used to clean the tanks to remove minor amounts of precipitates, suspended material or biological growth.

One 20 gallon (surface runoff) and one 50 gallon (infiltration) tank were calibrated (in liters) before installation. Flow volumes were measured by inserting a gauging stick into the top of the tank and recording the reading. The actual flow was then calculated using the calibration numbers for each size tank.

4.7. Water Quality

Input to the bins consisted entirely of precipitation. A total of ten infiltration samples were collected from June 24, 2002 through September 15, 2003. There was very little surface runoff from any of the bins but samples were collected and analyzed for nitrate on July 30 from bins 2, 9, and 14 and on August 2, from bins 5 and 9.

Six sample bottles were required for each sample. One bottle was for pH, specific conductance, and alkalinity analyses at the MN DNR laboratory in Hibbing, MN as well as fluoride and boron analyses at the Minnesota Department of Agriculture's (MDA) laboratory in St. Paul, MN. Sample pH was measured using an Orion SA 720 pH meter equipped with a Ross combination electrode (model 8165). Specific conductance was measured with a Myron L (model EP) conductivity meter. Alkalinity was measured using standard titration techniques (method 2320) in APHA et al. (1992). Fluoride and boron were filtered and boron was acidified with 0.2 mLs of Baker Instra-Analyzed nitric acid per 50 mL and shipped to MDA.

Boron was analyzed using an ICP/MS (Hewlett Packard HP4500 Series, model# G1820A), and the technology utilizes argon inductively coupled plasma with quadrapole separation. Fluoride was analyzed using the Ion Chromatographic Method (Wastewater Method 4500-SO_4B) with a Latchet QuickChem 8000.

Four bottles, one each for metals, sulfate and chloride, total phosphorous, and nutrients were collected, filtered if needed, preserved if needed and shipped the same day to WLSSD's laboratory for analyses. Metals, sulfate and chloride samples were filtered through a 0.45 micron Supor filter prior to acidification. Metal samples were acidified with 0.2 mLs of Baker Instra-Analyzed nitric acid per 50 mL. Nutrient samples were acidified with 1 mL of Baker Instra-Analyzed sulfuric acid per 500 mLs. Nutrient analysis was conducted by WLSSD and Era laboratories in Duluth. Methods and equipment are listed in Appendix 2, Table A2.19.

The remaining sample bottle was used to collect a low-level mercury sample. The sample was collected using EPA method 631 and sent to North Shore Analytical Inc. in Duluth, MN the same day for analyses (see attachment A2.2. for sampling method).

Quality assurance procedures are described in Appendix 9.

4.8. Vegetation

Due to the sparse vegetation no quantitative measurements of percent cover or biomass were made in 2002. Percent cover was estimated for the bins (Appendix 4). A decision was made to reseed the bins to establish a vegetative cover. On August 22 the mulch was removed, the bins were reseeded with 15 grams of the original seed mix and the mulch and netting was reapplied. No additional fertilizer or amendments were added. Vegetation measurements were made in August 2003 and 2004 for both the bins and the demonstration plots.

5. Results

5.1. Amendments

The average percent moisture content for the biosolids and paper mill residue was 40% and 25.9%, respectively. The pH for the biosolids was 6.8 and 8.0 for the paper mill residue; and both contained approximately 40% organic matter. Typical Kjeldahl nitrogen values for WLSSD biosolids are around 5% (50,000 mg/kg) with about 1% ammonia nitrogen (Appendix 1). The paper mill residue has much lower nitrogen values (on the order of 0.10 - 0.15%) and as a result has a much higher C:N ratio (greater than 150:1) than the biosolids (5.2:1) (Table 3).

Metals levels in the biosolids were generally about an order of magnitude below the requirements for exceptional quality sludge. Based on historical data for the paper mill residue, metal levels in the paper mill residue were lower than the biosolids and easily met land application limits (Table 4, Appendix 1).

The EVTAC tailings were alkaline, had a pH of 8.4, contained little organic matter, and only low levels of trace metals. The tailings had the texture of a coarse sand, with about 33% coarse sand, 40% medium sand, 22% fine sand, and 5% silt and clay (Eger et al., 1999). Additional information on the properties of EVTAC's coarse taconite tailings is included in Appendix 10.

5.2 Climate

Temperatures were generally above normal for the period of the study, while precipitation was slightly above normal for 2002 and less than normal in 2003 (Table 5). Dry, warm conditions prevailed during part of July, all of August and part of September 2003 and as a result no water quality samples were collected during that period.

Table 3. EVTAC organic amendments and tailings chemistry, soil fertility analyses.

Parameters[1]	Tailings	Biosolids	Paper mill residue
pH	8.4	6.8	8.0
% Organic Matter	0.2	40	41.4
Nitrate-N[2] (mg/kg)	2.0	113	1
Nitrogen, Kjeldahl (mg/kg)	42.6	20800	821
Nitrogen, Ammonia (mg/kg)	<8	6480	<8
Organic Carbon (mg/kg)	10900	248000	**124000** (257,000)
Total Nitrogen (mg/kg)	44.6	**20913** (47, 600)	822 (1400)
C:N Ratio	244:1	**12:1** (5.2:1)	151:1 (184:1)
Phosphorus (mg/kg) Bray 1: Olsen:	 5 2	 178 228	 8 26
Potassium	402	876	64
Calcium	612	6284	8750
Magnesium	202	1008	444
Sodium	15	216	53
Iron	45.2	393.6	92.0
Manganese	16.8	88.0	29.6
Copper	0.2	26.4	3.2
Zinc	1.5	99.2	23.2
Boron	0.8	14.4	6.4
Sulfate-S	8	676	513
	5.8	43.7	47.8

[1.] Metals are extractable values in this table. All values are measured in mg/kg, dry weight basis.
[2] This result reported on an as-received basis.
Calculated using Total N data from WLSSD

Note: Samples were analyzed by MVTL Laboratories, New Ulm, MN.

Bold indicates anomalous values
Three month average value (February - April, 2002: WLSSD) (Appendix 1)
Average of values from 1997 EVTAC study (Eger et al, 2000) and from 2001 UM study (Rosen et al, 2002)

Table 4. EVTAC organic amendments and tailings chemistry, total metals[1].

Parameters	Tailings[5]	Paper Mill Residue, Stora Enso[8]		Biosolids		Standards		
		1997[5] EVTAC Study	Concentration Range[6] (1998-99)	Three month average[7]	May[8] 2002	EQ Sludge[2]	Class 1[3] Compost	Land application of industrial byproducts[4]
Arsenic	<11	<2.2	<0.4-1.1	<5	<5	41	41	41
Cadmium	<2.5	<0.50	<0.18-.43	6.2	6.4	39	39	39
Chromium	<5.0	3.2	3.5-13	no data	no data	NL	NL	NL
Copper	<5.0	15	22-34	143	170	1500	1500	1500
Lead	<9.5	2.0	9-23	21	24	300	300	300
Mercury	0.03	0.02	<0.01-.15	0.54	0.70	17	5	5
Nickel	<5.0	1.1	<0.96-3.7	16	20	420	420	420
Selenium	<15	<3.0	<0.74-1.2	<5	<5	100	100	100
Zinc	<16	150	120-390	567	600	2800	2800	2800

[1] Metals are total values in this table. All values are measured in mg/kg, dry weight basis.
[2] EQ (Exceptional Quality) sludge limits, 40 CFR part 503, EPA, 1999.
[3] Class 1 compost, MN Rules Chapter 7035.2836 (MPCA, 1998). Solid Waste MN Rules 7041 (MPCA, 1998).
[4] These values are referred to as the pollutant concentrations in 40 CFR part 503 (EPA, 1999) and MN Rules Chapter 7041. These values were developed specifically for biosolids from the treatment of sewage. The value for mercury was taken from MN Rules Chapter 7035.2836 for compost utilization. (This information was obtained from www.state.mn.us/water/1a-report.html.
[5]Data from 1997 EVTAC study, no substantial changes were made to the tailings or the paper process so these values should provide a reasonable estimate of the total composition.
[6]Range is from additional data on the paper mill residue in Appendix 1 (period of record 2/98-8/99, n = 7).
[7]3 month average value February, March, April 2002; the three month average is used to plan application for the following month.
[8]May 02 value
NL = no limit listed

Table 5. Climatic data for the 2002 and 2003 field seasons.

	Temperature[1] (°F)					Precipitation[2] (inches)				
	Average		Normal	Departure[3]		Total		Normal	Departure[3]	
	2002	2003		2002	2003	2002	2003		2002	2003
January	14.10	5.30	4.10	10.00	1.20	0.22	0.11	0.71	-0.49	-0.60
February	19.20	6.30	10.30	8.90	-4.00	0.31	0.18	0.49	-0.16	-0.31
March	15.10	22.80	23.80	-8.70	-1.00	1.07	0.39	1.02	0.05	-0.63
April	36.80	39.00	38.90	-2.10	0.10	1.04	1.30	1.68	-0.64	-0.38
May	47.20	55.20	51.50	-4.30	3.70	1.27	1.81	2.62	-1.35	-0.81
June	64.40	62.50	60.30	4.10	2.20	6.86	2.69	3.85	3.01	-1.16
July	69.80	66.20	65.60	4.20	0.60	3.31	5.48	3.81	-0.51	1.67
August	65.60	68.60	62.70	2.90	5.90	5.24	2.92	3.59	1.65	-0.67
September	57.40	56.10	52.80	4.60	3.30	2.38	4.38	3.12	-0.74	1.26
October	32.20	44.00	42.20			2.69	1.68	2.24	0.45	-0.54
November	23.40	24.40	26.00	-2.60	-1.60	0.20	1.05	1.12	-0.92	-0.07
December	18.50	19.00	10.10	8.40	8.90	0.64	0.32	0.72	-0.08	-0.40
Average/Total						25.23	22.31	24.97	0.26	-2.66

[1] Temperature values were recorded at the Hibbing Airport, located approximately 25.7 km west of the plots.
[2] 2002 and 2003 precipitation values were measured at the DNR office in Eveleth, MN (Oct - April), which is located approximately 3 km northeast of the plots. Summer values (May - Sept) were measured on site at EVTAC.
[3] Departure is the monthly average (temperature) or total (precipitation) minus the 30-year average (1961-1990) for Hibbing, MN.

5.3. Flow

Flow data was collected from June 2002 through October 2003. Data collection was ended in October due to the onset of freezing conditions. Precipitation was measured on site from spring through fall. Winter and any missing data was obtained from the DNR forestry monitoring station, which was about 2 miles from the site.

5.3.1. Surface Runoff

Very little surface runoff was measured from any of the plots in 2002, and none occurred in 2003. On June 24, 2002, 4.1 inches of rain fell. Despite this extremely large event no surface runoff occurred for any of the bins. The only runoff occurred during a series of storms at the end of July and the beginning of August; the total volume of surface runoff ranged from 3 - 8 liters (Appendix 2).

5.3.2. Infiltration

In 2002, average yearly infiltration ranged from 650 liters for the control to 790 liters for the 400N biosolid application. In 2003, the minimum infiltration was about 435 liters. All the plots that had received the 400N biosolid application as well as the 200N biosolids with paper mill residue produced the minimum flow, while the highest infiltration was measured in the control and standard mineland reclamation plots (~ 600 liters).

Infiltration can be expressed in terms of water yield, which is defined as the ratio of the amount of outflow to the amount of inflow:

$$\text{yield} = [\text{volume of infiltration from plot} \div (\text{precipitation} \times \text{collection area of plot})] \times 100\%$$

The percent yield was much higher in 2002 than 2003. In 2002, total yield varied from 55% for the control to 66% for the 400N treatment. In 2003, the highest yield was 45% and was measured in the control and standard reclamation plots. Percent yield was lower in the plots with biosolids and ranged from 38 to 32% and tended to decrease as the amount of biosolids increased (Table 6).

In 2002, the difference in flow between the duplicate bins was generally within 5%, but there was a difference of about 15% for the bins with the 200N biosolid treatment (Appendix 3). In 2003, the difference between duplicates was generally higher but overall still ranged from 5-15%.

5.4. Water Quality

5.4.1. Surface water

Since the volume of surface water generated from the plots was insignificant, only nitrate was measured. Nitrate concentrations were very low, with all values below 0.1 mg/l.

5.4.2. Infiltration

5.4.2.1 pH

The pH was essentially the same for all plots, increased slightly between 2002 and 2003, and ranged from 8.20 in the 400N + PMR plots in 2002 to 8.53 in the control plots in 2003 (Table 7, Figure 4).

5.4.2.2 Major Cations/Anions

In general, specific conductance and the concentrations of the major cations (calcium and magnesium) and anions (sulfate and chloride) increased with increasing application of biosolids and decreased with time. The addition of paper mill residue increased concentrations by about 10% (Table 7, Figures 5-9, Appendix 2).

5.4.2.3. Trace Metals

The initial sample from all the plots was analyzed for a large group of parameters. All trace metal concentrations were low with most being at or near the detection limit. Molybdenum was present in all plots, with concentrations ranging from 0.012 mg/L in the control to 0.007 mg/L in the 400N + PMR plot.

Low levels of copper, nickel, cobalt and zinc were present in the initial samples from the plots with paper mill residue. Concentrations increased with the amount of residue and decreased with time. Only cobalt remained detectable throughout 2002. By the end of 2002, cobalt was at the detection limit and was not detected in any of the samples collected in 2003 (Appendix 2).

A limited number of low level mercury samples were collected. Mercury concentrations were all quite low and were lower in the second sample collected in the fall than in the initial sample collected shortly after the bins were completed. Concentrations tended to increase with biosolid and paper mill residue additions. Average initial concentrations ranged from 2.6 ng/L in the control to 12.2 ng/L in the 400N + paper mill residue plots. Average concentrations decreased to 0.6 ng/L in the 100N plot to 2.2 ng/L in the 400N biosolids plots (Table 8).

5.4.2.4. Nutrients

Total phosphorous was generally low with most concentrations at or near the detection limit. Small amounts were measured in the initial sample with concentrations ranging from 0.01 mg/L in the controls to 0.07 in one of the standard reclamation plots. This may be an anomalous result since the concentration was only 0.01 mg/L in the duplicate bin.

Total Kjeldahl nitrogen which measures both nitrogen in organic compounds and ammonia was low in all plots, ranging from less than the detection limit in the control to a maximum of 2.5 mg/L in the initial sample from one of the 400N + PMR plots. Concentrations decreased with time but remained

Table 6. Flow totals for infiltration bins; 2002, 2003

Treatment	Plot #	Average Infiltration (L)				Yield, %[2]			
		2002 (Total)	2002 Growing[1] Season	2003 (Total)	2003 Growing Season	Total		Growing Season	
						2002	2003	2002	2003
Control	5 9	650	581	600	463	55	*45*	*59*	44
SMR	2 13	688	620	605	466	58	45	63	45
Biosolids 100N	3 14	678	613	515	378	57	38	63	36
Biosolids 200N	7 10	744	671	499	354	62	37	69	34
Biosolids 400N	1 8	787	708	436	285	66	32	72	27
200N + PMR	6 11	741	669	435	300	62	32	68	29
Biosolids 400N + PMR	4 12	738	668	439	303	62	33	68	29

[1] Growing season is typically from May to September; in 2002, bins did not get set up until June 17, so annual and growing season starts with 6-18.

[2] Yield = $\frac{\text{infiltration}}{\text{volume of input from precipitation}} \times 100\% = \frac{\text{measured outflow}}{\text{total plot x collecting area of plot}} \times 100\%$

2002 Input total (6/18-12/31) = 1192L
Growing season (6/18 to 9/30) = 979L

2003 Input (L) total = 1348L
Growing season = 1044L

Table 7. Water quality results (average concentration per treatment) of infiltration. pH is standard units and concentrations are in ppm. EVTAC 2002 water quality bin study.
Page 1 of 2

Amendment	Control	Standard Mainland Reclamation	Biosolids (100N)	Biosolids (200 N)	Biosolids (400 N)	Biosolids (200 N) + Paper mill residue	Biosolids (400 N) + Paper mill residue	Surface Water Standards[A]	Drinking Water Standards [B]
pH	8.39	8.32	8.34	8.37	8.28	8.32	8.20	6.5 to 9.0	6.5 - 8.5 (S)
Specific Conductance	610	729	793	810	1155	876	1147		
Calcium	16.0	19.7	21.4	19.0	30.9	23.1	33.2		
Magnesium	84.8	105	106	108	153	114	145		
Chloride	0.55	0.9	6.6	9.9	26.6	16.0	28.9	230	250 (S)
Sulfate	84.4	91.7	134	159	262	194	260		250 (S)
Arsenic	0.002[D]	0.002[D]	0.002[D]	0.002[D]	0.002[D]	0.002[D]	0.003[C]	0.053	0.05
Copper	0.0025[D]	0.0025[D]	0.005[C]	0.003[C]	0.0025[D]	0.007[C]	0.010[C]	0.015-0.023	1(S)
Zinc	0.010[D]	0.011[D]	0.009[C]	0.010[D]	0.010[D]	0.010[D]	0.014[C]	0.191-0.343	5(S)
Cobalt	0.001[D]	0.001[D]	0.001[D]	0.001[D]	0.001[D]	0.007	0.016	0.005	
Total Kjeldahl Nitrogen	0.10[D]	0.19	0.24	0.31	0.60	0.72	1.06		
Nitrate-Nitrogen	1.8	14.5	13.7	17.2	48.5	7.5	10.2		10
Total Phosphorous	0.009	0.017	0.01	0.009	0.01	0.01	0.013		

[A] Surface water quality criteria (chronic standard) for 2B waters (aquatic life and recreation, non-drinking water). Standards for the trace metals are a function of water hardness. A range of 200 mg/L to 400 mg/L was used to compute chronic toxicity values for Cu and Zn. Metals that do not currently have a standard were left blank. Reference: Minnesota Rules, 1999, Chapter 7050.0222, Waters of the State (http://www.revisor.leg.state.mn.us/arule/7050/0222.htm).
[B] US EPA Office of Ground Water and Drinking Water. Current Drinking Water Standard: National Primary and Secondary (S) Drinking Water Regulation(revised September 11, 1998), http://www.epa.gov/OGWDW/wot/appa.html.
[C] Half the detection limit was used to calculate the average.
[D] Value represents an average of half the detection limit value.

Table 7. Water quality results (average concentration per treatment) of infiltration. pH is standard units and concentrations are in ppm. EVTAC 2003 water quality bin study.
Page 2 of 2

Amendment	Control	Standard Mineland Reclamation	Biosolids (100N)	Biosolids (200 N)	Biosolids (400 N)	Biosolids (200 N) + Paper mill residue	Biosolids (400 N) + Paper mill residue	Surface Water Standards [A]	Drinking Water Standards [B]
pH	8.53	8.49	8.46	8.48	8.49	8.50	8.40	6.5 to 9.0	6.5 - 8.5 (S)
Specific Conductance	811	774	863	875	1045	924	1113		
Calcium	11.2	13.8	13.1	12.8	13.1	13.0	17.4		
Magnesium	91.5	92.9	107	100	102	106	110		
Chloride	0.38	0.38	0.38	0.38	0.44	0.69	0.73	230	250 (S)
Sulfate	94.8	102	166	129	155	128	178		250 (S)
Arsenic	0.0017[D]	0.001[D]	0.0017[D]	0.0019[D]	0.0017[C]	0.0012[D]	0.0017[C]	0.053	0.05
Copper	0.001[D]	0.001[D]	0.001[D]	0.001[D]	0.001[D]	0.0025[D]	0.0025[D]	0.015-0.023	1(S)
Zinc	0.006[D]	0.01[C]	0.008[C]	0.008[C]	0.009[C]	0.008[C]	0.009[C]	0.191-0.343	5(S)
Cobalt	0.001[D]	0.001[D]	0.001[D]	0.001[D]	0.001[D]	0.001[D]	0.001[D]	0.005	
Total Kjeldahl Nitrogen	0.10[D]	0.15	0.10[C]	0.15[C]	0.10[D]	0.45	0.55		
Nitrate-Nitrogen	3.78	6.5	10.9	12.5	32.1	11.1	19.7		10
Total Phosphorous	0.005[D]	0.0063[C]	0.0075[C]	0.005[D]	0.005[D]	0.0075[C]	0.0075[C]		

[A] Surface water quality criteria (chronic standard) for 2B waters (aquatic life and recreation, non-drinking water). Standards for the trace metals are a function of water hardness. A range of 200 mg/L to 400 mg/L was used to compute chronic toxicity values for Cu and Zn. Metals that do not currently have a standard were left blank. Reference: Minnesota Rules, 1999, Chapter 7050.0222, Waters of the State (http://www.revisor.leg.state.mn.us/arule/7050/0222.htm).
[B] US EPA Office of Ground Water and Drinking Water. Current Drinking Water Standard: National Primary and Secondary (S) Drinking Water Regulation(revised September 11, 1998), http://www.epa.gov/OGWDW/wot/appa.html.
[C] Half the detection limit was used to calculate the average.
[D] Value represents an average of half the detection limit values.

Figure 4. Box plot summary, average by treatment, pH

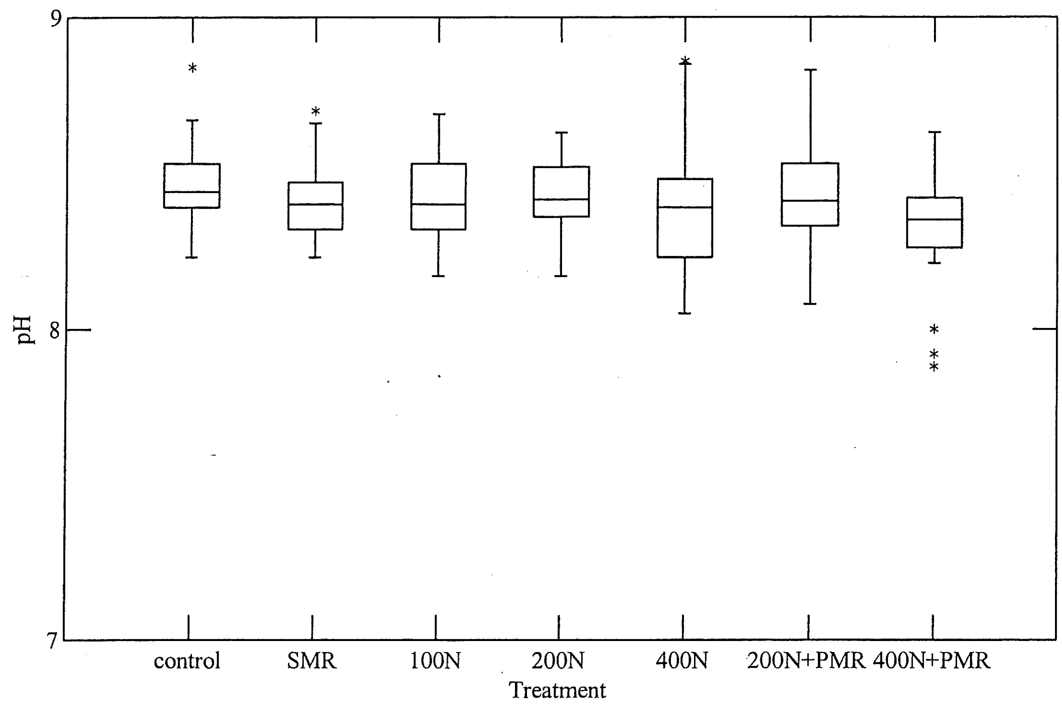


Figure 5. Box plot summary, average by treatment, specific conductance

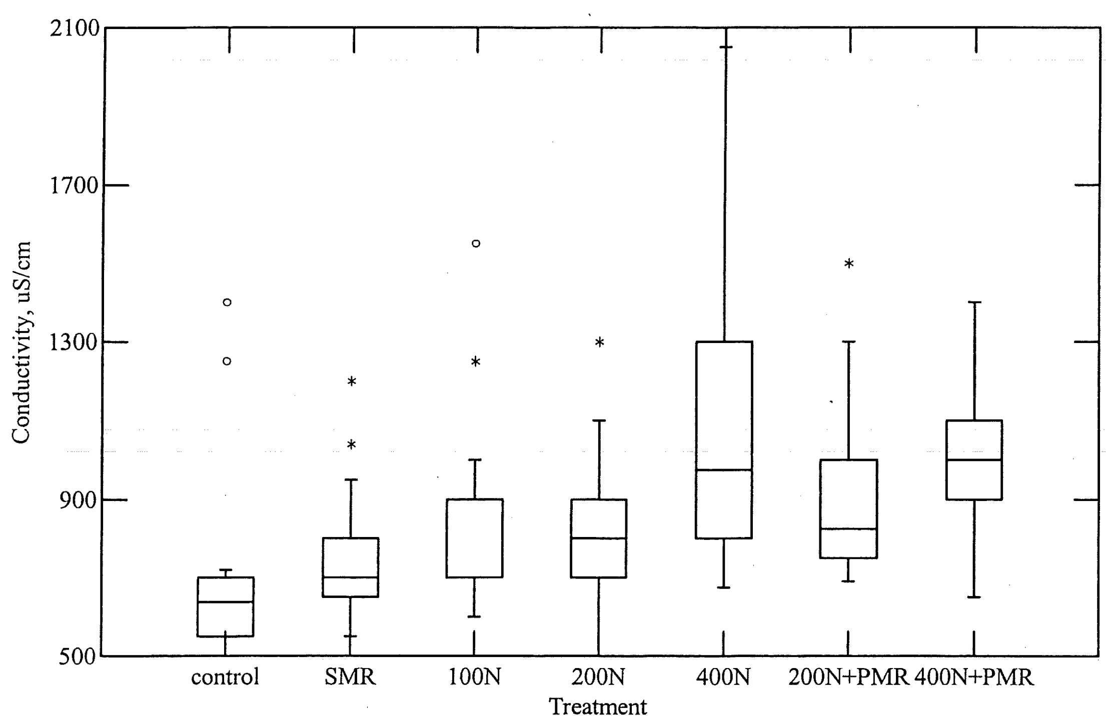


Figure 6. Box plot summary, average by treatment, calcium

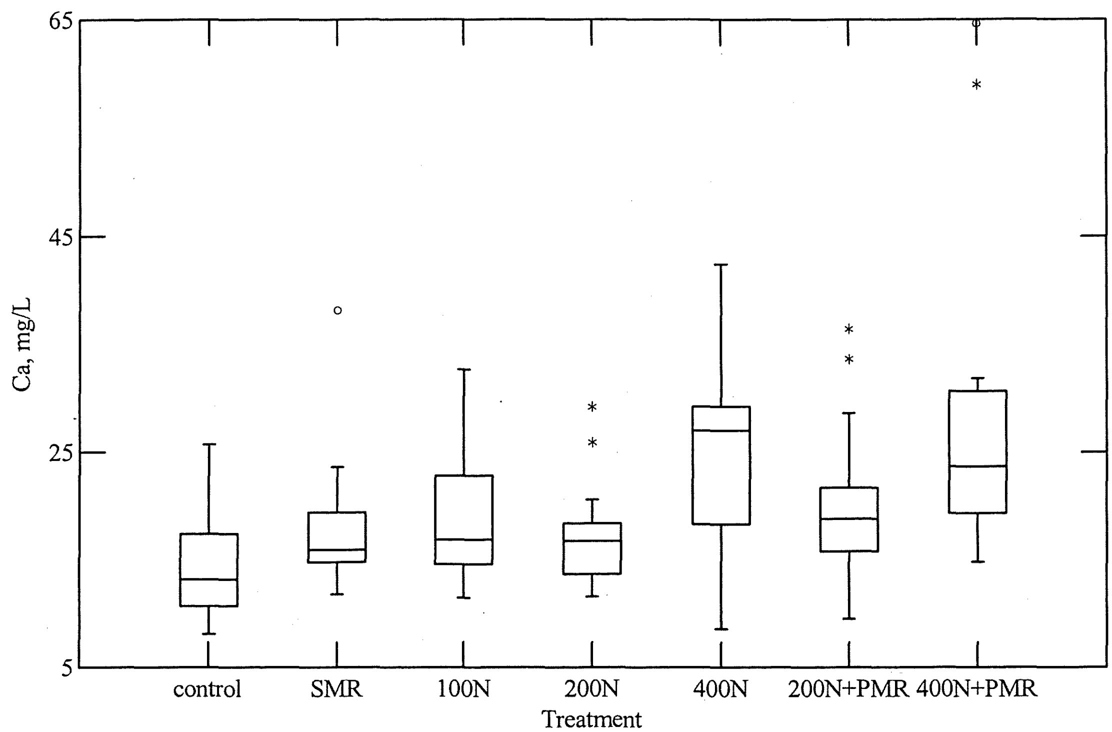


Figure 7. Box plot summary, average by treatment, magnesium

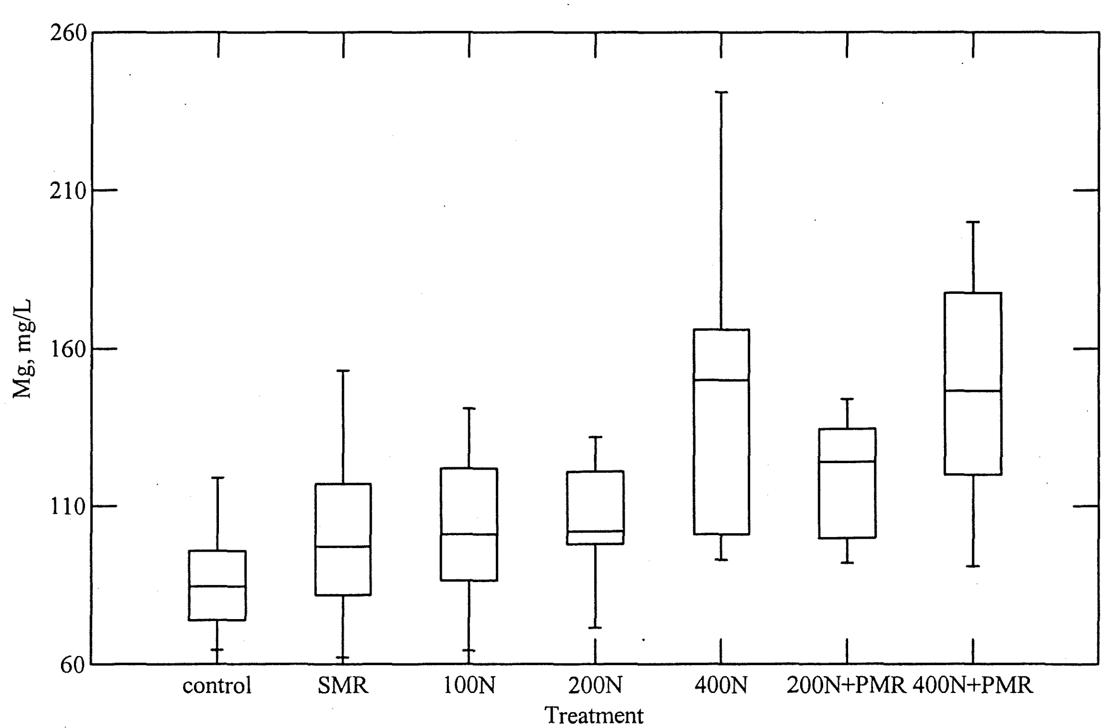


Figure 8. Box plot summary, average by treatment, sulfate (Dotted line indicates water quality standard = 250 mg/L).

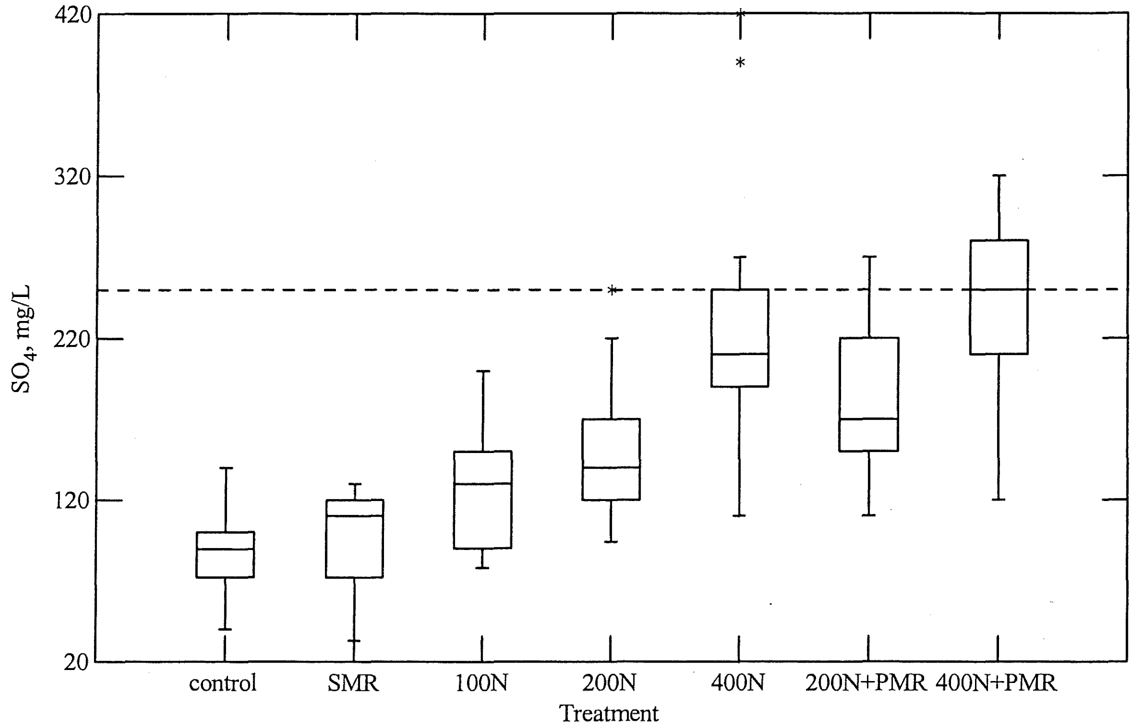
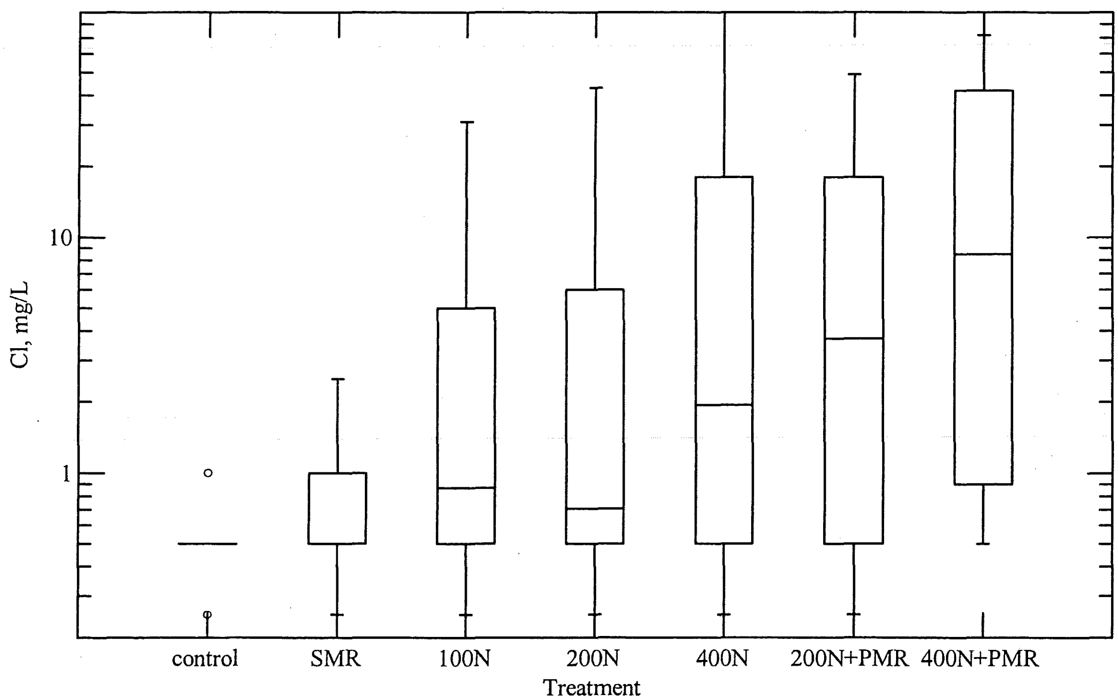


Figure 9. Box plot summary, average by treatment, chloride



detectable at low concentrations in the plots with paper mill residue (Table 7, Figure 10).

Nitrate concentrations were lowest in the control plots and increased with the rate of biosolid application. Over the entire study the average nitrate concentration increased from 2.8 mg/L in the control plots to 40 mg/L in the 400 N plots. The addition of paper mill residue significantly reduced nitrate concentrations. Average concentrations for both the 200 N and 400 N treatments with paper mill residue were 9.3 mg/L compared to 15 mg/L and 40 mg/L for the comparable biosolid applications.

Nitrate concentrations varied with time but there was no consistent pattern. Although average nitrate concentrations decreased in the plots with biosolids and standard reclamation, they increased in the control and plots with paper mill residue (Table 7, Figure 11). Variation between duplicate plots generally varied from about 10 - 20% for the control, standard mineland reclamation, and 400N plots to about a factor of 2 in some of the biosolid plots (Appendix 2).

Table 8. Mercury concentrations, infiltration samples, 2002

Treatment	Bins	Summer samples (6/24) ng/L	Average	Fall samples (10/7) ng/L	Average
Control	5, 9	2.2, 2.9	2.6	1.3, no sample	1.3
Standard Mineland Reclamation (SMR	2, 13	3.5, 4.5	4.0	1, 1.5	1.2
Biosolids (100 N)	3, 14	4.9, 4.9	4.9	0.7, 0.6	0.6
Biosolids (200 N)	7, 10	5.9, 7.3	6.6	0.7, 1.4	1.0
Biosolids (400 N)	1, 8	6.3, 7.8	7.0	0.8, 3.7	2.2
Biosolids (200 N) + Paper mill residue	6, 11	7.4, 8.8	8.1	1.3, 1.3	1.3
Biosolids (400 N) + Paper mill residue	4, 12	11.3, 13.2	12.2	1.5, 1.6	1.6

5.4.2.5 Nitrate mass release

The total mass of nitrate-nitrogen that left the bins was calculated by multiplying the concentration of the sample by the collected volume. For periods of flow without a sample, an average concentration calculated from the preceding and following samples was used. The percent of flow that was sampled ranged from 65-73% in 2002 and from 53-57% in 2003.

Figure 10. Box plot summary, average by treatment, nitrate (Dotted line indicates water quality standard, 10 mg/L)

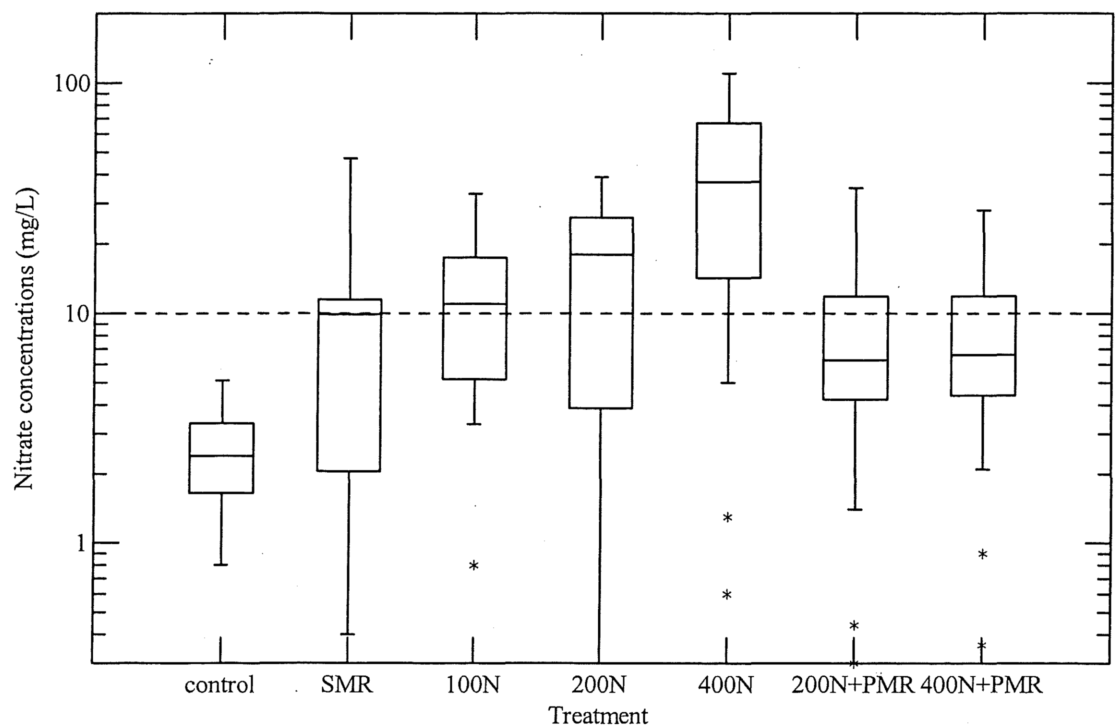
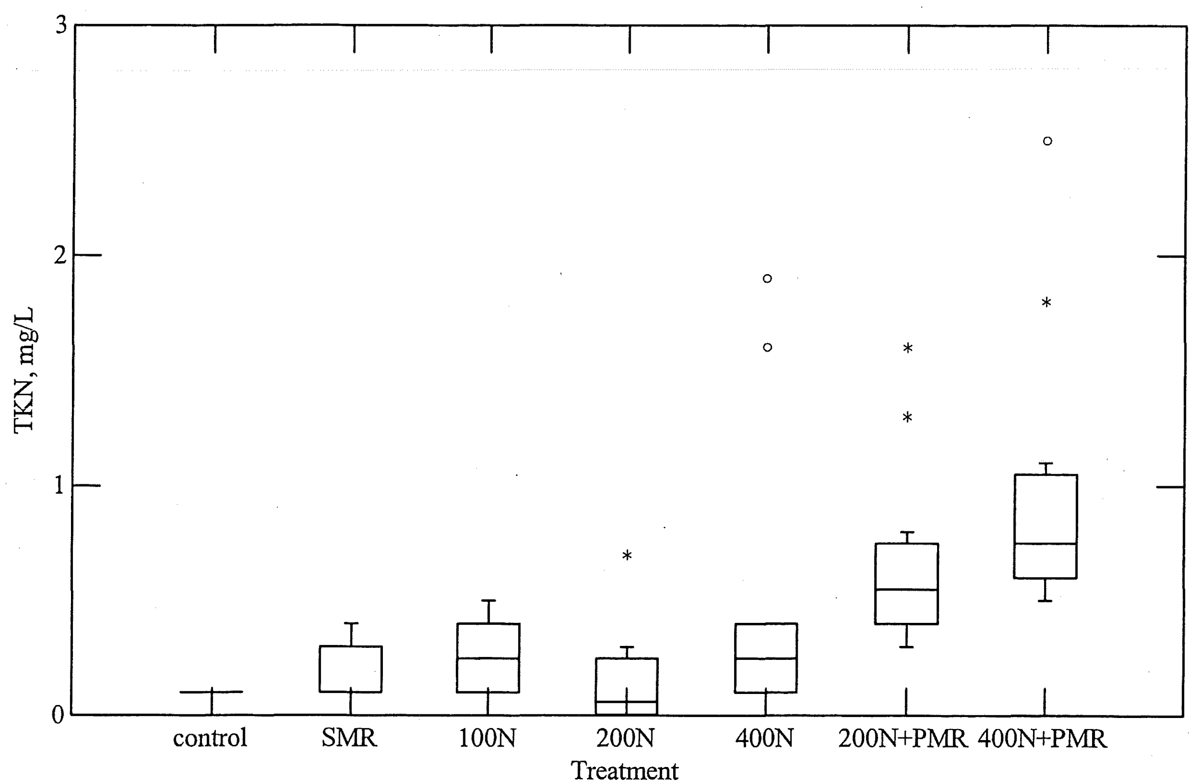


Figure 11. Box plot summary, average by treatment, Total Kjeldahl Nitrogen (TKN)



The nitrate-nitrogen release from the control plots was subtracted from the total release for each treatment to give the net nitrate release. The net release ranged from 6 grams to 47 grams and was lowest in the plots with paper mill residue and highest in the 400 N plots (Table 9). Mass release increased with increasing application of biosolids. The percent of applied nitrogen that was released ranged from 7.3% for the 400 N +PMR plots to 41.8% for the 400 N treatment. Mass release for the 100 N plots was essentially the same as the standard reclamation treatment and was only about 40% greater in the 200 N plots. The release in the plots with paper mill residue were 20 to 40 % lower than the standard mineland reclamation treatment (Table 9).

Table 9. Total nitrate - N release for each treatment (mass in grams)

Amendment	Nitrogen [3] added	$N\text{-}NO_3$ release 2002	Net release treatment - control (2002)	$N\text{-}NO_3$ release 2003	Net release treatment - control (2003)	Total net release	Percent of applied N
Control	0	1.1		2.0			
Standard Mineland Reclamation	25.3	10.0	8.9	2.9	0.9	9.8	38.7
Biosolids (100 N)	28.1	9.5	8.4	3.9	1.9	10.3	36.7
Biosolids (200 N)	56.2	12.7	11.6	4.4	2.4	14.0	24.9
Biosolids (400 N)	112.4	38.5	37.4	11.6	9.6	47.0	41.8
Biosolids (200 N) + paper mill residue	56.2[1]	5.4	4.3	3.7	1.7	6.0	0.7
Biosolids (400 N) + paper mill residue	112.4[1]	8.1	7.0	3.2 [2]	1.2	8.2	7.3

[1] Nitrogen from biosolids only.
[2] An anomalous nitrate value of 110 mg/L for bin 4 was replaced with an average(19.5mg/L) of 10/7/02 and 4/22/03 nitrate values.(See Appendix 2)
[3] Data from WLSSD was used to calculate the nitrogen added to each plot that received biosolids.

5.5. Vegetation

5.5.1. Bins

The bins were seeded on June 19, 2002 and by July 5 vegetation was observed on all seeded bins (Appendix 4). However on July 22, the vegetation was essentially gone, with only some isolated sweet clover plants remaining (photos, Appendix 7). The exact reason for the loss of vegetation was not known, but one possible explanation was that the loss was due to the large population of grasshoppers observed in the area. This explanation was consistent with reported information that grasshoppers tend to avoid sweet clover. The bins were reseeded on August 22, 2002, so cover measured in 2003 would be considered first year cover.

Percent cover and biomass were higher on the bins that received biosolids and percent cover generally increased with increasing application of biosolids (Table 10). For the treatments without paper mill residue, the cover did not change substantially between 2003 and 2004. The percent cover on the plots with paper mill residue increased substantially from 56% in 2003 to 83 and 91% in 2004.

In 2004, average overall cover decreased in the following order:

400N + PMR > 400N > 200N + PMR > 200N > 100N >> SMR >> Control

In general the percent cover measurement on the duplicate bins were similar, with the exception of the 100N treatment in 2004. The cover on bin 3 decreased from 63% in 2003 to only 48% in 2004, while the cover on the duplicate bin was 74% for both years. The cover on all the other bins treated with biosolids had cover in excess of 70% and four of the bins had cover between 89-93%, essentially meeting the 3 year cover requirement of 90% after only two years (Appendix 4). Photo 2 shows the vegetation in June of 2004. Appendix 7 contains additional photos of the vegetation in the bins.

Photo 2. Vegetation on bins, 6-23-04

5.5.2. Demonstration Slopes

Vegetation established very slowly on the slopes. During 2002, the first growing season, no vegetation was observed on the lower slopes until the end of July and the upper slopes remained bare for the entire growing season. Due to the sparse vegetation, no quantitative measurements of percent cover were made in 2002. By fall 2002, vegetation had started to grow on the lower portion of the slope but the upper slope was still generally bare throughout 2003.

Table 10. Vegetation results, Bins 2003, 2004. Average percent cover and biomass per treatment.

Treatment	Bins	Percent Cover		Biomass (kg/ha)	
		2003	2004	2003	2004
Control	5, 9	1	0.4	.76	5
Standard mineland reclamation (SMR)	2, 13	26	28	376	348
Biosolids (100N)	3, 14	68	61	949	1491
Biosolids (200N)	7, 10	68	78	1521	1758
Biosolids (200N) + Paper mill residue	6, 11	56	83	1726	1505
Biosolids (400N)	1, 8	85	86	2402	1949
Biosolids (400N) + Paper mill residue	4, 12	56	**91**	2882	2946

Bold; percent cover meets 3 year reclamation standard (90% cover)

5.5.2.1. Lower slopes

In 2003, percent cover on the bottom of the amended plots ranged from 41 to 62% and was about 1.5 to 2.5 times greater than the standard mineland reclamation (Table 11). In 2004, cover on the amended plots increased with increasing biosolid application rate and ranged from 62 to 94 % or about 4 to 6 times higher than standard reclamation. Only the 400N + PMR plot met the three year reclamation standard of 90% (Photo 3, Appendix 7).

5.5.2.2. Upper Slopes

In 2003, vegetation was so sparse that only estimates of percent cover were made. Cover increased in 2004 with about 40-50% cover in plots treated with biosolid applications of 200N or higher. Percent cover on the 100 N and SMR plots was only about 15%.

Table 11. Percent cover Demonstration Slope 2003 and 2004.

Treatment	Upper Slope		Lower Slope	
	2003	2004	2003	2004
Standard Mineland Reclamation (SMR)	0-10*	5-25*	25	5-25*
Biosolids (100 N)	15-20*	13	41	62
Biosolids (200 N)	10-15*	44	54	72
Biosolids (200 N) + Paper mill residue	20-25*	46	41	67
Biosolids (400 N)	NM	48	41	82
Biosolids (400 N) + Paper mill residue	NM	47	62	**94**

* whole plot estimate due to lack of cover. **Bold;** percent cover meets 3 year reclamation standard (90% cover)

5.6. Costs

Costs for this project were figured on a standard cost per ton developed by WLSSD ($19 /ton) (Appendix 15). These costs probably underestimate the total cost for the project, particularly for the higher application rates, where additional time was required to apply and incorporate the amendments. Total costs varied from $750 per acre for standard mineland reclamation to $3140 for the 400 N + PMR treatment (Table 12).

Table 12. Costs, demonstration plots, EVTAC, 2002

Plot	Biosolids applied tons per acre		Paper mill residue (PMR) tons per acre		Total amendment tons per acre		Cost $/acre	
	wet weight	dry[1] weight	wet weight	dry[2] weight	wet weight	dry weight	Amendment[3]	Total[4]
SMR[5]	0		0		0		0	750
100N	11.1	3.1	0	0	11.1	3.1	210	960
200N	22.1	6.2	0	0	22.1	6.2	420	1170
400N	44.3	12.4	0	0	44.3	12.4	840	1590
200N + PMR	22.1	6.2	62.9	28	107.2	34.2	1195	1945
400N + PMR	44.3	12.4	125.8	56	170.1	68.4	2390	3140

1 Moisture 28%, based on 3 month running average, WLSSD, February to April

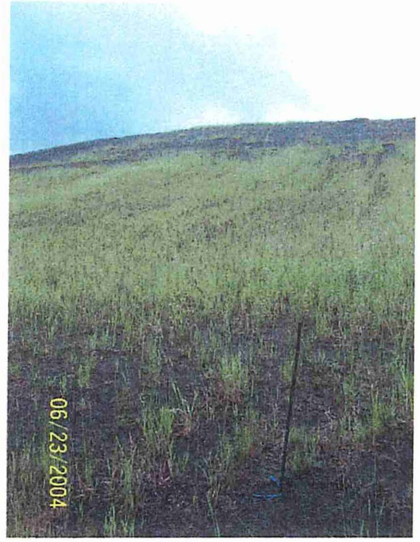
2 Moisture 44.5%

3 Costs are based on WLSSD's standard cost to haul and apply amendments, $19/ wet ton (Appendix 15).

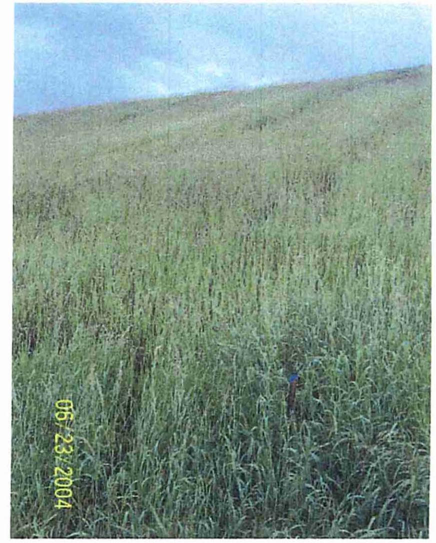
4 Costs include fertilizer, seed and mulch based on costs paid by EVTAC for this project (previous estimate: $500/acre, represents cost for flat portions of basin, higher cost for slopes).

5 standard mineland reclamation; inorganic fertilizer, seed, mulch.

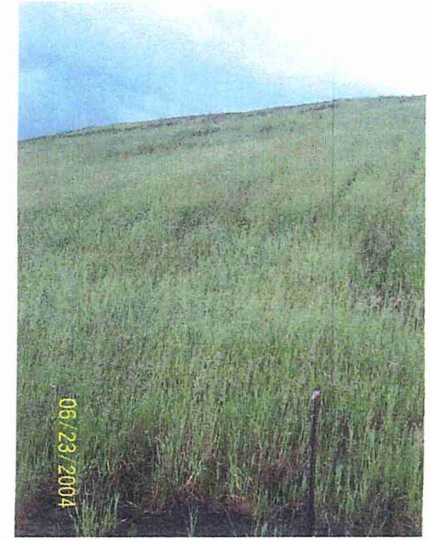
Plot 6, SMR



Plot 5, 100N



Plot 3, 200N



Plot 2, 400N

Plot 4
200N +PMR

Plot 1,
400N + PMR

Photo 3. Vegetation on demonstration slopes, 6/23/04.

6. DISCUSSION

The application of biosolids has substantially improved vegetative success on coarse taconite tailings. In the 1997 study at EVTAC, applying the agronomic rate of biosolids (~ 90 lbs N/acre) produced vegetation with a three year percent cover of 75 %, almost double the percent cover achieved with standard reclamation (39%) (Table A6.2, Appendix 6). However, an additional top dressing of biosolids (100 lbs N/acre) was required to improve the cover so that the reclamation cover standard of 90% was met. The application of biosolids at 100N on coarse tailings at US Steel produced a similar three year cover of about 78% (Jagunich, personal communication, 2004). The goal of the present study was to determine if there was an optimum application of biosolids that would produce vegetative cover that would meet the reclamation standard without adverse impacts on water quality.

Typically biosolids are applied at a rate that will balance the available nitrogen in the biosolids with the requirements of the plants being grown at the site (defined as the agronomic rate). Ideally all the nitrogen from the biosolids will be used by the vegetation so that none will migrate from the site. The agronomic rate for the type of species in the standard seed mixes developed for mineland reclamation is on the order of 100 lbs N/acre. Biosolids can be produced by several different processes but are most commonly classified by the type of digestion process, either aerobic or anaerobic. Depending on the type of biosolids and the total amount of nitrogen, 3 - 6 dry tons per acre of biosolids provide 100 lbs of available N/acre.

In addition to nitrogen, other major plant nutrients include phosphorus and potassium. While tailings contain adequate potassium, they are deficient in phosphorus and previous experience and research was used to develop the current fertilizer recommendation of 100 lbs P per acre. For agricultural soils, the recommended rate for low phosphorus soils is on the order of 15 lbs per acre, but the alkaline nature and chemical composition of the tailings limit phosphorus availability. At an application of 100 lbs N/acre the anaerobic biosolids from WLSSD provides about 42 lbs P/acre. Limited data from a study at US Steel suggest that this level of phosphorus is adequate, since additional phosphorus did not improve percent cover(Appendix 6).

Literature references suggested that the optimum one time application of biosolids for minelands was on the order of 22-44 dry ton/acre (Daniels and Haering, 2000). Applying the WLSSD biosolids at this rate would be the equivalent of applying on the order of 800 lbs N per acre, or about 8 times the agronomic rate. With this much excess nitrogen, migration of nitrogen from the site would be unavoidable. Since vegetation had been established with lower applications of biosolids in previous studies, the range of application was limited to 100- 400 lbs N (Additional discussion and rationale is discussed in Appendix 16).

Based on the water quality results from previous studies and the low trace metal content of both the biosolids and the paper mill residue, no substantial water quality impacts, except for nitrogen were expected. Although this was generally true, some elevated levels of cobalt, mercury and sulfate were observed. Cobalt appeared to be related to the paper mill residue and low levels were released throughout 2002. Currently there is no groundwater standard for cobalt and much of the cobalt would be adsorbed if the infiltrating water moved through additional tailings before reaching the water table. Mercury concentrations increased with increasing application of biosolids and paper mill residue, but all concentrations, with the exception of the 400N +PMR, were lower than the typical concentration of mercury in rainfall (~10 ng/L). Taconite tailings have been shown to effectively remove mercury, so it is unlikely that there would be any substantial mercury migration as long as the infiltrating water contacted additional tailings prior to leaving the site.

Sulfate was associated with the biosolids application and increased with increasing biosolids. In 2002, the average sulfate concentration in the plots that had received the 400 N biosolids was about 260 mg/l, which was slightly higher than the MPCA secondary drinking water standard of 250 mg/l. In 2003, the average concentration dropped to about 165 mg/l, well below the standard. Since sulfate is generally a conservative parameter, it tends to move with the water and will migrate off site with little change in concentration other than dilution.

The primary water quality concern with biosolid application is the leaching of nitrogen, in the form of nitrate from the site. Nitrogen is a critical plant nutrient but can only be used by plants if present in an inorganic form (either nitrate or ammonia). The nitrogen in biosolids is primarily present in the organic form and must be mineralized before it can be utilized by the plants. Standard equations are used to determine the amount of nitrogen in biosolids that will be plant available and to determine the total amount of biosolids that can be added to a site (Appendix 14).

Biosolids also provide organic matter to the tailings which improves moisture retention and cation exchange capacity. Previous studies have demonstrated that applications of about 20 dry tons per acre of various other organic amendments is a cost effective rate, which is about the minimum value recommended for biosolids by Daniels and Haering (2000). Vegetation improved at higher application rates, but the small increase in percent cover did not justify the higher cost. Biosolid applications have been restricted to lower rates due to concerns with nitrate leaching. However, biosolid rules do permit applications at higher than agronomic rates to reclamation sites, particularly for a one time treatment (Minnesota Rules 7041.1200, Subp. 4).

Vegetation improved with increasing application of biosolids but so did the concentration of nitrate in the water draining from the tailings. Nitrate is a conservative parameter in groundwater systems so that little removal occurs once the nitrate has moved below the root zone. Since nitrate effects the ability of blood to carry oxygen, a standard of 10 mg/l has been established to protect drinking water. In 2002, the average nitrate concentration for all biosolid applications exceeded 10 mg/l, but so did the standard mineland reclamation treatment. Concentrations were much higher than observed in the 1997 study, when the maximum nitrate value was 10.8 mg/l in a sample from one of the biosolid bins. Average nitrate values over the course of the study were about a factor of 4 lower than in this study and ranged form 2.9 for standard mineland reclamation to 3.2 mg/l for the biosolids plots.

One possible explanation for the higher nitrate concentrations in this study was the lack of vegetation during the first growing season. Both fertilizer and biosolids were applied assuming that vegetation would be present to use the available nitrogen. Colder than normal temperatures in the spring of 2002 delayed the construction of the bins due to the inflexibility of the low density polyethylene liner. The bins were not seeded until mid-June, which is later than normal but still within the acceptable time period for spring planting in northern Minnesota (Dewar, personal communication). Vegetation began to grow in the beginning of July but was essentially gone by the end of July except for a few isolated sweet clover plants. Although there was no definitive explanation for the disappearance of the vegetation, the large number of grasshoppers observed in the area could have destroyed the vegetation. Grasshoppers tend to avoid sweet clover, so the survival of the sweet clover plants was consistent with grasshopper damage. With essentially no vegetation in the plots, all the nitrogen that mineralized would be mobile and could drain from the plot.

Another factor that could contribute to lower concentration values in the initial study were higher flows from the bins. Precipitation in 1998 and 1999 was above normal (50% above average in 1999), and as a result the total flow from the bins in the original study was much higher. Flows from the control and standard mineland reclamation bins were about 2200 liters or almost a factor of 2 higher than the total flows from the same treatments in this study. Higher flows tend to lower the concentrations in the drainage.

One approach to minimize the movement of excess nitrogen from biosolid applications is to add a high carbon organic material, such as paper mill residue, to the site. Nitrogen is required to breakdown the high carbon material and as a result the total amount of nitrate that leaves the site is reduced. In general, if the C:N ratio is greater than 30: 1, the available nitrogen is used by the microorganisms that break down the organic material and there is not enough nitrogen for plant growth. If the ratio is below 20:1, most of the nitrogen is available to plants and excess nitrogen can migrate from the site. If the ratio is between 20-30:1, nitrogen is used to break down the organic material but some of the nitrogen in the amendment is released to the vegetation (Donahue et al., 1977). Research by Schmidt et al (2001) found that the optimum C:N ratio to minimize nitrogen transport in disturbed soils was 28:1.

Although other high carbon additives such as wood chips and sawdust were available, paper mill residue was used in this study since it is a waste product that is under utilized, and has improved vegetation in previous studies. The amount of residue was determined to give a C:N ratio of about 25:1 (Appendix 8). The plots treated with paper mill residue had the lowest nitrate release and the best percent cover was in the 400N + PMR treatments, which was the only treatment to meet the 3 year reclamation cover standard.

A problem with the paper mill residue, particularly at the highest loading rate, was the time required to apply and incorporate the material on the slope. At the highest application rate, 400N+PMR, two applications of biosolids was required and the slope had to be disced three times to incorporate the large amount of paper mill residue. Even after discing the slope three times, the incorporation of the paper mill residue was not completely uniform (see photographs in Appendix 7).

Optimum rate of biosolid addition

The primary objective of this study was to determine if there was an optimum rate of biosolid addition; a rate that would improve vegetation without adversely impacting water quality. Based on the data from this study, it appears that a biosolid application of 200 N would be the optimum rate. Although the nitrate concentrations are somewhat greater than the water quality standard, it was only slightly greater than the average concentration from the 100N treatment for both years and the standard mineland reclamation treatment during the first year. After two growing seasons, the percent cover on the bins ranged from 71-85% and the cover on the lower slope of the demonstration plot was 72%. If conditions are near normal next year, the bins are expected to approach 90 % cover within 3 years, and vegetation on the slope should also improve. Although percent cover was

6. DISCUSSION (cont.)

higher with 400N, the average nitrate concentrations were about 3 times higher than the 200N treatment and 3-5 times above the standard. In addition, the average sulfate concentration in the first year was slightly above the water quality standard. Although the addition of paper mill residue successfully controlled nitrate release and generally improved vegetation (the 400N +PMR was the only treatment to achieve the 90% cover standard in both the bins and demonstration slope), applying this large amount of material would cost at least 6 times as much as applying biosolids at the 200N rate. The use of paper mill residue also released small amounts of mercury and cobalt.

Reapplying biosolids (top dressing) may also be an alternative method to improve vegetation and meet the reclamation standard. In this approach, biosolids are spread on existing vegetation, but not incorporated. A plot originally treated with 90 lbs N/acre of biosolids was dressed with biosolids at 100 lbs N/acre. Percent cover on treated portion increased from 75 to 90% while percent cover on the untreated portion of the plot was only 72%. Although top dressing generally improved vegetation on other plots, reapplication did not produce 90% cover in most treatments (Eger et al, 2004, Appendix 6). Applying nitrogen in increments by top dressing should help reduce nitrate movement through the tailings, but it increases the potential to release constituents to surface water runoff. However, the coarse tailings generated little to no surface flow, so no substantial release of constituents would be expected. The second application of biosolids increased the overall cost of reclamation and driving on the vegetated slopes was reported to be more difficult than on the original unreclaimed tailings.

7. Conclusion

A biosolids application of 200N appears to be an optimum application rate for establishing successful vegetation on coarse taconite tailings without adversely impacting water quality. Two year percent cover averaged 78% on the bins and was 72% on the demonstration slope. Although nitrate values in the 200N were above the nitrate standard, nitrate also exceeded the standard by about the same amount in both the 100N and in the standard mineland reclamation plot. Nitrate concentrations were much higher in the current study than in the 1997 study, probably due primarily to the loss of first year vegetation and lower rainfall. With more typical first year vegetative growth, nitrate concentrations should be lower than measured in this study, and would cause only minimal impact to the immediate groundwater.

Currently WLSSD transports and applies biosolids on mine lands at no cost to the mining company, so mining companies do not have to spend any additional money to meet their reclamation obligations. In the past, since the percent cover produced by standard reclamation did not meet reclamation standards, mining companies spent additional money either to refertilize or sometimes to replant entire areas. If the entire area is replanted, reclamation costs on the coarse tailings slopes double from about $750 /acre to $1500/acre. Yet despite this increased effort and cost, percent cover on the retreated coarse tailings rarely exceeded 70%, and did not meet the 90% cover standard. At a biosolids application of 200N, the total estimated cost to successfully reclaim an acre of coarse tailings is about 20% less than the previous practice of multiple standard mineland reclamation treatments which has not been successful.

8. ACKNOWLEDGMENTS

As with most research projects, many people have contributed to the success of this study. Funding was provided by Western Lake Superior Sanitary District (WLSSD) and the MNDNR Minerals Environmental Cooperative Research Program. WLSSD transported and applied all the amendments. EVTAC Mining sloped the large scale demonstration plots, constructed the metal framework for the bins, and loaded the tailings into the bins. We would like to especially thank Kathy Hamel, Tim Tuominen, and Mark Saunders with WLSSD and Brad Anderson of EVTAC Mining for their assistance in initiating, coordinating, supporting and following the project. Special thanks goes to David Antonson for his help in supervising the data collection but also for his assistance in the construction of the plots. Doug Rosnau, John Folman and Pat Geiselman reconditioned the bins and assisted in the amendment application and seeding. Steve Dewar and Anne Jaguních coordinated the amendment addition, planting and mulching and were responsible for the vegetation data collection phases of the study. John Folman was responsible for sample collection and analyses as well as producing tables and figures for the report.

9. REFERENCES

American Public Health Association (APHA), American Water Works Association, Water Environment Federation. 1992. Standard methods for the examination of water and wastewater, 18th edition. American Public Health Association, Washington, D.C.

Campbell, A.G.; X. Zhang; and R. Tripepi. 1995. Composting and evaluating a pulp and paper sludge for use as a soil amendment/mulch. Compost Science and Utilization. p 85-89.

Daniels, W. Lee and Kathryn C. Haering 2000. Protocols for use of biosolids and co-amendments for mined land reclamation. Mining, Forest and Land Restoration Symposium, July 17-19, Golden, CO.

Dewar, Steve. 2002. Minnesota Department of Natural Resources. Personal communication.

Dickinson, Samuel K. 1986. Use of Papermill/Biosolids and Composted Sludge in Mineland Reclamation. Annual Meeting for the Society for Surface Mining and Reclamation, Jackson, MS, March 17-20.

Eger, P.; K. A. Lapakko. 1981. The leaching and reclamation of low-grade mineralized stockpiles. P. 157-166. In Proc. 1981 Symposium on Surface Mining Hydrology, Sedimentology and Reclamation. Lexington, KY.

Eger, P; A. Johnson, S. Dewar, B. Anderson, P. Churak. 2004. Thinking outside the box – new ways to close old tailing basins. Mining Engineering, January p. 45-51.

Eger, P.; K. A. Lapakko; and P. G. Chamberlain. 1984. Mixed disposal of waste rock and tailings to reduce trace metal release from waste rock. P. 49-56. In Proc. 1984 Symposium on Surface Mining Hydrology, Sedimentology and Reclamation. Lexington, KY.

Eger, P.; G. Melchert; and S. Dewar. 1999. Waste for wastelands - reclaiming taconite tailings basins with organic amendments. In Mining and Reclamation for the next Millennium. Vol. 1 Proc. 16th National Meeting ASSMR, Scottsdale, AZ, August 13 - 19, 1999. p.132 - 145.

9. References (cont.)

Eger, P., Johnson, A., Melchert, G., Crozier, M.. 2000. Use of organic amendments to reclaim coarse taconite tailings. MN Dept. Nat. Resour., Div. of Lands and Minerals. St. Paul, MN. 38 p. plus appendices.

Gobin, Diane 2002. Stora Enso, personal communication

Hamel, Kathy 2002. Western Lake Superior Sanitary District, personal communication.

Jagunich, Anne. 2004. Minnesota Department of Natural Resources, personal communication.

McCarthy, B.J.; D. Monson Geerts; K.W. Johnson; and T.J. Malterer. 1995. Mineland Reclamation Using Office Waste Paper De-Inking Residue. National Meeting of the American Society for Surface Mining and Reclamation, Gillette, Wyoming.

McCarthy, B.J. and S.D. Monson Geerts. 1996. The beneficial use of biosolids from the city of Grand Rapids: a preliminary assessment of its impact on shallow soil water. Natural Resources Research Institute, Duluth, MN.

Melchert, G.D.; A.P. Eger; Z. Kassa; and S.W. Dewar. 1994. Reclaiming coarse taconite tailing with municipal solid waste compost. National Meeting of the American Society for Surface Mining and Reclamation, Pittsburgh, Pennsylvania, April 24-29, 1994.

Minnesota Pollution Control Agency. 1998. Mn Rules Chapter 7035.2836. Solid Waste. http://www.revisor.leg.state.mn.us/arule/7035/2836.html

Minnesota Pollution Control Agency. 1999. MN Rules Chapter 7050.0222: Specific Standards of Quality and Purity for Class 2 Waters of the State; Aquatic life and recreation. http://www.revisor.leg.state.mn.us/arule/7050/0222.html

Minnesota Pollution Control Agency. 2000. MN Rules Chapter 7041.1100: Sewage Sludge Management. http://www.revisor.leg.state.mn.us/arule/7041/1100.html

Norland, M.R.; D.L. Veith; and S.W. Dewar. 1993. Standing Crop Biomass and Cover on Amended Coarse Taconite Iron Ore Tailing. National Meeting of the American Society for Surface Mining and Reclamation, Spokane, WA.

Norland, M.R.; D.L. Veith; and S.W. Dewar. 1995. Revegetation of coarse taconite iron ore tailing using municipal solid waste compost. Journal of Hazardous Materials, 41:123-134.

Peterson, J.R. and J. Goschwind, 1972. Leachate quality from acidic mine spoil with liquid digested sludge. Journal of Environmental Quality, 1:410-412.

Pietz, R.I, C.R. Carlson; J.R. Peterson; D.R. Zenz; and C. Lue-Hing. 1989. Application of biosolids and other amendments to coal refuse material: III. Effects on Percolate Water Composition. Journal of Environmental Quality, 18:174-179.

9. References (cont.)

Raelson, J.V. and G.W. McKee. 1982. Measurement of plant cover to evaluate revegetation success. Agronomy Series 67, Department if Agronomy, Penn State university, 45p.

Rosen, Carl and others. 2002. Final Report to the LCMR on the Co-application of Waste Products to Agricultural and Mine Lands. University of Minnesota, Department of Soil, Water and Climate.

Saunders, Mark, 2002. Western Lake Superior Sanitary District, personnel communication**

Schmidt, J.M., Daniels, W.L., Li, R.S., and D. McFaden. Determining optimal sawdust/biosolids mixtures to manage nitrate leaching in reclaimed disturbed soils. 2001 proceedings of ASSMR, Vol. 2, June 3-7, 2001, Albuquerque, NM.

Sopper, W.E. 1993. Municipal sludge used in land reclamation. Lewis Publishers, Boca Raton, FL.

United States Environmental Protection Agency. 1998. Office of Groundwater and Drinking Water. Current Drinking Water Standards: National primary and secondary drinking water regulations. http://www.epa.gov/OGWDW/wot/appa.html

United States Environmental Protection Agency. 1999. Title 40 : Protection of Environment; Part 503.13 : Standards for the use or Disposal of Sewage Sludge (40CFR503.13). http://www.access.gpo.gov/nara/cfrwaisidx_99/40cfr503_99.html

Voeller, P.J., B.A. Zamora; and J. Harsh. 1998. Growth response of native shrubs to acid mine spoil land to proposed soil amendments. Plant and Soil. 198:209-217.