Biosolids use in Landfill Topsoil Fabrication Demonstration – 2018 Final Report

City of Winnipeg – Brady Road Resource Management Facility

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Prepared for:

Manitoba Sustainable Development
Environmental Approvals – Municipal and Industrial Section
2nd Floor, 123 Main Street
Winnipeg, MB
Canada, R3C 1A5

Prepared by:

SYLVIS Environmental
427 Seventh Street
New Westminster, BC
Canada, V3M 3L2
Phone: 1.800.778.1377
Fax: 604.777.9791
www.SYLVIS.com

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LIST OF ABBREVIATIONS

General abbreviations used in this document:

BGM – Biosolids Growing Medium
BRRMF – Brady Road Resource Management Facility
CCME – Canadian Council of Ministers of the Environment
LFG – Landfill gas
MSD – Manitoba Sustainable Development
OMRR – British Columbia Organic Matter Recycling Regulation
WWTP – Wastewater Treatment Plant

Unit abbreviations used in this document:

cm – centimetre
dw – dry weight
g – gram
ha – hectare
kg – kilogram
km – kilometer
L – litre
m – metre
m^3 – cubic metre
mg – milligram
t – tonne
µg – microgram
ww – wet weight

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1 INTRODUCTION

The City of Winnipeg (the City) is in the process of investigating alternative management options for its municipal biosolids in order to meet the objectives for beneficial use outlined in the City's Biosolids Master Plan. Projects examining re-establishment of beneficial use include:

- a compost pilot project in which up to 20% of the annual biosolids production can be composted and used on-site; and,
- an agricultural land application pilot project.

The remaining biosolids are being buried in landfill using a 'trench-and-backfill' system. This scenario is not a beneficial use of the biosolids, and also poses significant operational challenges for the landfill.

In order to address the need for additional beneficial use options, the City is working with SYLVIS, undertaking a pilot project to investigate a third option; the use of biosolids and other locally available residuals to fabricate a topsoil-like growing medium for final cover on the City's closed and historic landfill cells, including those at the Brady Road Resource Management Facility (BRRMF). If successful, the use of biosolids in this manner may be expanded to additional City landfills, systematically commencing with sites which are closed and retain a leachate management system, to allow for ongoing demonstration of the concept at an operational scale, while also monitoring any potential impacts to the leachate or site water balance. Growing medium fabrication not only provides beneficial use options for biosolids and other residuals, but can also reduce the cost to the City of topsoil importation for landfill closure without sacrificing reclamation quality or productivity of the reclaimed landscape.

The City received approval to conduct this demonstration from Manitoba Sustainable Development (MSD) as a notice of alteration in accordance with Section 14 of the *Environment Act*, dated February 6th, 2017. A detailed description of the proposed demonstration can be found in SYLVIS (2016) and a summary of the growing medium fabrication operations can be found in SYLVIS (2017). This report summarizes the second year of monitoring at the site.

1.1 Project Objectives

The goal of this project is to fabricate and place a demonstration quantity of fabricated growing medium containing biosolids and other regionally available residual materials on a portion of a closed area of the BRRMF, and following placement, to seed the areas, and monitor them for a full year.

- The fabrication will demonstrate that the manufacture of biosolids growing medium with regionally available residual materials is possible, and that operations can be feasibly conducted under cold winter conditions.
- The placement will demonstrate that the biosolids growing medium may be successfully placed in an operationally appropriate scenario on a closed portion of the active landfill.

- The seeding and germination will demonstrate that the medium is suitable for the germination and established growth of vegetation under normal climatic conditions, and may provide an improved growing medium over other available covers.

The monitoring will assess the quality of fabricated growing medium as an alternative to topsoil, as well as the potential of the demonstration for environmental impact from nutrient migration due to runoff or other phenomena. For the purposes of this demonstration, the biosolids growing medium will be referred to as “fabricated soil” throughout this report.

This project aims to provide MSD with “proof of concept” of the safe and effective use of biosolids in this manner under controlled conditions on a landfill cap, adding an additional long-term beneficial use option for the City’s biosolids.

A bench-scale study, conducted in the fall of 2016, developed test blends that met applicable regulatory criteria and were able to support germination. The full report of this assessment is included in the project proposal (SYLVIS, 2016). A modified version of one of these blends was selected to be tested at different placement thicknesses and compared to a control plot using existing landfill closure practices.

The experimental design and monitoring plan were developed with the following key guiding questions to evaluate the operational-scale use of biosolids fabricated soil for landfill closure:

- Can biosolids fabricated soil be feasibly fabricated at the landfill in winter conditions?
- Can biosolids fabricated soil be used to achieve similar reclamation success compared to current practices?
- Can biosolids fabricated soil be placed up to depths of one meter without adverse impacts to downstream surface water and soils?

2 OPERATIONAL OVERVIEW

The following is a summary of operational activities related to the demonstration. A more detailed account of operational activities is included in the project Interim Report (SYLVIS, 2017).

2.1 Soil Fabrication

Growing medium fabrication occurred between February 27th and March 22nd, 2017. A total of 5,000 cubic metres of soil was fabricated during this period, which included approximately 800 tonnes of biosolids diverted from landfill burial (Photograph 1 through Photograph 3, Appendix Three).

2.2 Soil Placement

The fabricated soil was placed in the treatment blocks as shown in Figure 1, Appendix Two on May 2nd, 2017 (Photograph 4, Appendix Three). The treatment plots were designed to assess the effect of cover depth and to compare the fabricated growing medium to a cover of compost. Each treatment was placed in a uniform layer at the specified depth overlaying the existing cap:

- T1 – 0.9 m of fabricated soil
- T2 – 0.6 m of fabricated soil
- T3 – 0.3 m of fabricated soil
- Control – 0.3 m of Compost (leaf and yard waste and biosolids compost)

The locations of the treatment plots were placed in order to accommodate the installation of landfill gas (LFG) infrastructure, which was completed later in the summer. Buffer zones approximately 15 m in width were left between each treatment plot. Once the installation of the LFG system was complete, these buffer zones received the same final cover as the control areas (0.3 m of compost).

2.3 Seeding

Seeding occurred on May 4th, 2017. Due to drought in Winnipeg in the spring of 2017, there was very little germination in any plots. The plots were seeded again on June 13th, 2017 in anticipation of a rain event. Grass establishment in the first growing season was sparse, but growing, despite the dry conditions. Following the completion of the LFG system, the demonstration plots and buffer areas were hydroseeded again in October 2017. No additional seeding on the plots was needed in 2018.

3 MONITORING

3.1 Soil Monitoring

A composite sample, consisting of 8 discrete subsamples of the fabricated soil was collected in March 2017, upon completion of soil mixing operations. This sample represented the baseline conditions of the fabricated soil.

Composite soil samples, consisting of 24 subsamples each, were collected from 0-15 cm depths within each of the plots. Samples were collected prior to soil placement, in May 2017, to assess any background conditions. Following soil placement and seeding, samples were collected on three different occasions: September 2017, June 2018, and October 2018.

The soil samples were submitted to an accredited laboratory and analyzed for physical and chemical parameters, including total and available nutrients, organic matter, pH, electrical conductivity, moisture, and trace elements.

The Canadian Council of Ministers of Environment (CCME) Soil Quality Guidelines, Industrial Application, were used as a comparison standard for trace elements concentration within the plots. The quality parameters for biosolids growing medium within the *British Columbia Organic Matter Recycling Regulation* (OMRR) (B.C. Reg. 18/2002) were used for comparison purposes only, to assess the overall quality of the fabricated soil.

The results of the soil monitoring are reported in Table 1 through Table 5, Appendix One.

3.2 Vegetation Monitoring

Ten randomly selected 0.5 x 0.5 m quadrats were chosen for vegetation monitoring within each treatment plot. A visual inspection, which consisted of the average percentage of foliage cover, native species and weeds found on each quadrat, was conducted at the end of the second growing season, in September 2018. The mean total percent cover and percent non-native weeds for each treatment plot are reported in Table 6, Appendix One. Aerial images of the treatment plots during the second growing season are presented in Figure 2 and Figure 3, Appendix Two.

A single factor ANOVA ($\alpha=0.05$, $n=10$) was used to determine if there was a significant difference in total cover or percent non-native weeds between the treatment depths. A Student's *t*-test ($\alpha=0.05$, $n=10$) was used to determine if there was a significant difference in total cover or percent non-native weeds between each fabricated soil plot and the control plot.

3.3 Water Monitoring

Due to drought conditions in 2017, and the high water holding capacity of the final cover, sufficient runoff water for sampling could only be collected on one occasion during this trial. Samples of runoff were collected from below each of the plots on July 12th, 2017 and analyzed for dissolved nitrogen and phosphorous. The Manitoba Water Quality Standards, Objectives and Guidelines were used as a comparison standard. The results of the water monitoring are reported in Table 7, Appendix One.

4 MONITORING RESULTS AND DISCUSSION

4.1 Overall Soil Quality

The trace element concentrations met CCME Soil Quality Guidelines for industrial lands in all fabricated soil samples, and meet the necessary criteria to be used within a landfill site. In order to assess the soil quality more closely, we took the additional step of comparing the soil trace elements against the more stringent agricultural guidelines. Of the 126 assessed samples (9 samples and 14 criteria per sample), only four measurements exceeded these criteria – three for copper and one for zinc. Zinc exceeded the agricultural soil quality guideline of 200 mg/kg in one sample, with a value of 207 mg/kg. Copper exceeded the agricultural soil quality guideline of 63 mg/kg in three out of nine samples, with values of 68, 81.6, and 67.3 mg/kg. The average concentrations of zinc and copper within each treatment plot were all below the agricultural criteria.

The high copper and zinc in the fabricated soils are both primarily due to copper and zinc concentrations in the biosolids. The average zinc concentration reported for Canadian biosolids is 970 mg/kg (CCME, 2009), whereas City of Winnipeg biosolids tend to be higher, with an average of 1,164 mg/kg reported for between 2014 and 2016. The copper concentrations in City of Winnipeg biosolids are comparable to other Canadian municipalities, with 559 mg/kg as the national average, and 578 mg/kg in City of Winnipeg biosolids.

The OMRR is a British Columbia regulation that enables the unrestricted sale and distribution of biosolids growing medium. Within the context of this demonstration, it is used strictly as a benchmark. Initial samples of fabricated soil at the BRRMF exceeded the OMRR quality parameters set as benchmarks for organic matter, total Kjeldahl nitrogen (TKN), and total zinc (Table 1 and Table 2, Appendix One). It is worthwhile to note that biosolids growing media that do not meet the OMRR BGM parameters are frequently used throughout British Columbia, under a Land Application Plan prepared by a qualified professional, which is how this trial and future biosolids soil fabrication projects by the City of Winnipeg are intended to be undertaken.

The OMRR zinc criteria of 150 mg/kg is more stringent than the CCME Guidelines for agricultural soils of 200 mg/kg, and would only apply to unrestricted use of a fabricated growing medium. All other quality parameters met the OMRR criteria. Following placement, 3 out of 9 samples exceeded 150 mg/kg zinc (Table 5, Appendix One).

After a fabricated soil is placed and seeded, a minimum C:N ratio of 15 is no longer critical, as the growing biomass should take up the available nitrogen, and prevent losses to the environment. Following placement, the fabricated soils had a C:N ratio below 15 in five out of nine samples, but the C:N ratio was consistent with the standard treatment of compost in the control samples (Table 5, Appendix One).

4.2 Effect of Treatment Depth

The soil quality and vegetation cover results do not indicate any differences between the fabricated soil treatment depths after the second growing season. Initial observations of vegetation during the first growing season suggested that the 0.3 m treatment may have had more non-native weeds than the 0.6 and 0.9 m treatments. This observation was not confirmed by the vegetation survey at the end of the second growing season. The average percent cover was 67.5%, 63%, and 68% in the 0.9 m, 0.6 m, and 0.3 m treatments, respectively (Table 6, Appendix One). The proportional cover in the fabricated soil plots due to non-native species was exceptionally low in all three fabricated soil plots. The average percentage of non-native weeds as a proportion of total cover was 1.5%, 4.5%, and 1.5%, in the same respective treatments. The percent cover and percent non-native species between the three fabricated soil plots were not significantly different.

4.3 Fabricated Soil Compared to Compost

The samples from the control plot generally had higher concentrations of available nutrients, total organic carbon, total nitrogen, and total organic matter than the fabricated soils. The total Kjeldahl nitrogen (TKN) was about two times higher in the compost than the fabricated soils, ranging from 0.67 – 1.6% and from 0.22 – 0.57%, respectively. Within the compost, total organic carbon (TOC) ranged from 10.5 to 14 %, and organic matter ranged from 15 – 24%. In the fabricated soils, TOC and organic matter were consistently lower, ranging from 3.7 – 7.9% and 5.1 – 11.4 %, respectively. The carbon to nitrogen ratio (C:N) was slightly higher in the fabricated soils, ranging between 9.0 – 19.5, compared to 8.8 – 15.7 in the compost.

Available ammonium in the compost plot ranged from 4.4 – 13.3 mg/kg. The fabricated soils had a much wider range of available ammonium, from < 2.0 mg/kg – 702 mg/kg. Available nitrate ranged from 10.43 – 21.9 mg/kg in the compost, and from 4.0 – 27.9 mg/kg in the fabricated soils. The concentrations of total and available nutrients in both the fabricated soil and the compost were all higher than those found in typical agricultural soils.

The compost plots generally had a higher pH and higher electrical conductivity than the fabricated soils. In the compost plots, pH ranged from 7.63 – 7.99, and electrical conductivity ranged from 4.65 – 7.64 dS/m. In the fabricated soils, the pH was 6.64 – 7.93 and the electrical conductivity was 4.05 – 6.30 dS/m

The saturation percentage, which represents the water holding capacity of the soil, was higher in the compost compared to the fabricated soil plots, but the moisture content between the treatments was generally the same. The water holding capacity in compost is entirely due to its organic matter content, while the water holding capacity in the fabricated soils is a combination of organic matter and the mineral texture and structure, so although the two materials have different physical mechanisms for water retention, they retain water more or less evenly under the conditions for this demonstration. Any differences in vegetation cover between the control and the fabricated soil plots are likely not driven by differences in moisture content.

Overall, most trace elements had comparable concentrations between the fabricated soil plots and the compost plot. The fabricated soils had slightly higher concentrations of chromium, lead, uranium, and zinc than the compost. The trace element with the greatest difference between the treatment types was copper, which ranged from 20-39.2 mg/kg in the compost, and from 45 – 81.6 mg/kg in the fabricated soils.

There was a significant difference ($P< 0.05$) in total percent cover and percent non-native species between the control plot and the fabricated soil plots. The control plot had significantly lower mean total cover (48.5%) and significantly higher non-native species (60.5%) compared to the fabricated soils, which had an average of 66%, and 2.5%, across all three treatment depths, for total cover and non-native species, respectively.

4.4 Trends in Soil Quality over Time

Some trends over time were identified across all of the treatment plots. The TKN in the fabricated soil has decreased over time, from 0.62% immediately upon fabrication, to an average of 0.35% at the end of the second growing season. Much of this drop in nitrogen is likely due to ammonia volatilization following soil placement. Available soil ammonium dropped from an initial concentration of 572 mg/kg, to 2.7 mg/kg after the first growing season. The soil ammonium has fluctuated up and down in the second growing season, as the organic nitrogen is mineralized and then taken up by the growing vegetation and soil biota. Soil nitrate has increased over time, as might be expected when aerobic soil processes oxidize ammonium into nitrate. The steady decline in total soil nitrogen between the first and second growing is seasons is expected as soil nitrogen is mineralized and taken up by the growing vegetation.

The C:N ratio appeared to consistently increase over time in both the compost and the fabricated soils. This trend in C:N ratio was controlled by different trends in TOC and TKN within the compost and fabricated soils. TKN decreased over time in both the compost and fabricated soils, but the decline was much sharper in the compost. The TOC appeared to increase slightly over time in the fabricated soils, but decreased over time in the compost.

Electrical conductivity generally decreased over time in all treatment types, as would be expected due to plant uptake of soluble nutrients, and movement of other soluble ions down the soil profile.

Several trace elements exhibited a trend of increased concentration over time in both the fabricated soil and the compost: arsenic, barium, cobalt, lead, nickel, thallium, tin, and vanadium. Most of these trace elements tend to be immobile in soil due to interactions with clay particles and organic matter, thus it would be expected for soil concentrations of these elements to increase over time to a steady state, as the organic matter in the soil decomposes to a steady state concentration.

4.5 Water Monitoring

Orthophosphate was below 1 mg/L in surface water collected below all plots, which is the province-wide standard for phosphorous in Manitoba. This indicates that dissolved phosphorous is not moving off the fabricated soil in surface water runoff in any significant quantities. Nitrogen concentrations and forms varied between the surface water samples collected below the different plots, but there was no clear pattern between the plots. Nitrate exceeded surface water quality standards for aquatic life from below the control and 0.3 m plots.

No additional surface water samples could be collected since the spring of 2017, which is indicative of the ability of the fabricated soils to infiltrate and hold water, preventing any significant surface runoff.

5 CONCLUSIONS

To date, this soil fabrication demonstration has proven to be an operationally effective beneficial use option for biosolids management for the City of Winnipeg, and provides a safe and effective vegetated cover for landfill closure at the BRRMF.

The performance of the fabricated soil far outdid the compost in terms of total cover and suppression of non-native weeds. The trace element concentrations in the fabricated soils met the regulatory guidelines for industrial areas, and were typically comparable to concentrations within the compost. There was no indication of movement of dissolved phosphorus into surface water, and the movement of nitrate was comparable to that from the standard cover of compost. Furthermore, the water holding capacity of the fabricated soils and compost cover prevented surface runoff from occurring under the conditions experienced during this demonstration.

Available nutrient concentrations were lower in the fabricated soil compared to compost, but were still high enough to support vigorous vegetative growth.

The City of Winnipeg looks forward to working with MSD to apply the lessons learned from this pilot demonstration to other closed landfill sites, including the current pilot at Summit Landfill, leading towards a diverse, long-term beneficial use program for biosolids management, beneficial re-use of other residuals, and improved reclamation outcomes for the City’s closed landfills.

REFERENCES

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APPENDIX ONE – TABLES

Table 1: Fabricated soil physical and chemical properties prior to placement at the BRRMF demonstration site[a]. Bold values indicate that one or more regulatory criteria were not met.

Constituent	Sample 1	Regulatory Limits (BC OMRR)[b]	Units
	3-Mar-2017		
Aggregate Organic Constituents			
Loss on Ignition	30.2	-	%
Available Nutrients			
Nitrate - N	10	-	µg/g
Phosphorus - available	340	-	µg/g
Potassium - available	1,530	-	µg/g
Sulfate - S - available	460	-	mg/kg
Copper - available	7.0	-	mg/kg
Iron - available	532	-	mg/kg
Manganese - available	43.8	-	mg/kg
Zinc - available	32.3	-	mg/kg
Calcium - available	3,820	-	mg/kg
Magnesium - Available	1,460	-	mg/kg
Sodium - Available	261	-	mg/kg
Ammonium - N (dry basis)	572	-	µg/g
Classification			
Cation Exchange Capacity	47	-	meq/100g
Organic Matter - Calculated	**22.0**	15	%
Total Organic Carbon	11.0	-	%
Total Nitrogen - TKN	**0.616**	0.600	%
C:N Ratio	17.86	15 (minimum)	-
Physical and Aggregate Properties4			
Moisture - wet weight	2.8	-	%
Texture	Clay	-	-
Sand (50 um - 2 mm)	36.7	-	% by weight
Silt (2 um - 50 um)	22.0	-	% by weight
Clay (<2 um)	41.3	-	% by weight
Bulk Density	0.77	-	kg/L
Wet Bulk Density	0.79	-	kg/L
Soil Acidity			
pH (1:2 Soil:Water)	7.7	-	pH
Electrical Conductivity (1:2 Soil:Water)	1.50	-	dS/m

[a] Samples collected on Mar 3rd, 2017 by SYLVIS and analyzed by Exova Laboratories under Report No. 2173186.

[b] Limits obtained from the *British Columbia Organic Matter Recycling Regulation* (OMRR) for biosolids growing medium.

Table 2: Fabricated soil trace element concentrations, prior to placement at the BRRMF demonstration site[(a)]. Bold values indicate that one or more regulatory criteria were not met.

Constituent	Sample 1 3-Mar-2017	Regulatory Limits (BC OMRR)[(b)]	Units
Total Metals			
Antimony	1.9	-	µg/g
Arsenic	4.5	13	µg/g
Barium	134	-	µg/g
Beryllium	0.522	-	µg/g
Cadmium	0.4	1.5	µg/g
Chromium	50.4	100	µg/g
Cobalt	6.34	34	µg/g
Copper	80.3	150	µg/g
Lead	9.56	150	µg/g
Manganese	275	-	µg/g
Mercury	0.0716	0.8	µg/g
Molybdenum	2.1	5	µg/g
Nickel	22.9	62	µg/g
Phosphorus	3,010	-	µg/g
Selenium	0.75	14	µg/g
Silver	1.0	-	µg/g
Strontium	64.5	-	µg/g
Thallium	< 0.5	-	µg/g
Tin	4.1	-	µg/g
Vanadium	62.3	-	µg/g
Zinc	**207**	150	µg/g

(a) Samples collected on Mar 3rd, 2017 by SYLVIS and analyzed by Exova Laboratories under Report No. 2173186.

(b) Limits obtained from the *British Columbia Organic Matter Recycling Regulation* (OMRR) for biosolids growing medium.

Table 3: Background physical and chemical properties collected below each treatment plot at the BRRMF demonstration site(a).

Constituent	Control	T1	T2	T3	Units
Soil Placement Depth	0.3	0.9	0.6	0.3	m
Nutrients					
Available Ammonia	< 2.0	< 2.0	< 2.0	< 2.0	mg/kg
Available Nitrogen	< 2.0	< 2.0	3.4	< 2.0	mg/kg
Available Phosphorus	9.1	< 1.0	< 1.0	1.2	mg/kg
Available Potassium	450	410	430	520	mg/kg
Available Sulphur	460	380	540	780	mg/kg
Inorganics					
Total Organic Carbon	1.1	0.83	0.68	0.66	%
Organic Matter	2.0	1.4	1.2	1.1	%
Total Kjeldahl Nitrogen	1,900	1,200	960	1,100	mg/kg
C:N Ratio	5.8	6.9	7.1	6.0	
Physical Properties					
Moisture	31	26	30	34	%
Soluble Parameters					
Soluble Conductivity	3.3	3.0	3.0	4.0	dS/m
Soluble pH	7.56	7.65	7.68	7.60	pH
Saturation %	84	77	100	110	%

(a) Samples collected on May 30th, 2017 by the City of Winnipeg and analyzed by Maxxam Analytical in Report R2392878.

Table 4: Background soil trace element concentrations collected below each treatment plots at the BRRMF demonstration site(a).

Constituent	**Control**	**T1**	**T2**	**T3**	**Soil Quality Guidelines(b)**				**Units**
Soil Placement Depth	0.3 m	0.9 m	0.6 m	0.3 m	**Agricultural**	**Residential /Parkland**	**Commercial**	**Industrial**	
Total Metals									
Antimony	< 0.50	< 0.50	< 0.50	< 0.50	20	20	40	40	mg/kg
Arsenic	5.7	5.4	6.3	7.8	12	12	12	12	mg/kg
Barium	160	150	160	170	750	500	2,000	2,000	mg/kg
Beryllium	0.49	0.49	0.64	0.71	4	4	8	8	mg/kg
Cadmium	0.12	0.13	0.14	0.19	1.4	10	22	22	mg/kg
Chromium	31	30	38	34	64	64	87	87	mg/kg
Cobalt	9.3	8.8	11	12	40	50	300	300	mg/kg
Copper	22	24	26	29	63	63	91	91	mg/kg
Lead	9.6	13	16	12	70	140	260	600	mg/kg
Molybdenum	0.82	0.68	0.98	1.1	5	10	40	40	mg/kg
Nickel	28	27	34	34	45	45	89	89	mg/kg
Selenium	< 0.50	< 0.50	< 0.50	0.76	1	1	2.9	2.9	mg/kg
Silver	< 0.20	< 0.20	< 0.20	< 0.20	20	20	40	40	mg/kg
Thallium	0.16	0.15	0.18	0.20	1	1	1	1	mg/kg
Tin	< 1.0	2.2	< 1.0	< 1.0	5	50	300	300	mg/kg
Uranium	1.1	1.1	1.2	1.6	23	23	33	300	mg/kg
Vanadium	45	44	53	53	130	130	130	130	mg/kg
Zinc	60	66	68	76	200	200	360	360	mg/kg

(a) Samples collected by the City of Winnipeg and analyzed by Maxxam Analytical in Report R2392878.

(b) Limits obtained from the Canadian Council of Ministers of the Environment (CCME) Soil Quality Guidelines for the production of environmental and human health, industrial application.

Table 5: Soil physical and chemical characteristics, and trace element concentrations within each treatment plot, following placement at the BRRMF demonstration site[(a)]. Bold values indicate that one or more regulatory criteria were not met.

Constituent	Control (0.3 m compost)			T1 (0.9 m)			T2 (0.6 m)			T3 (0.3 m)			Soil Quality Guidelines[(b)] Agricultural	Soil Quality Guidelines[(b)] Industrial	Units
	Sep-17	Jun-18	Oct-18	Sep-17	Jun-18	Oct-18	Sep-17	Jun-18	Oct-18	Sep-17	Jun-18	Oct-18			
Nutrients															
Available Ammonium	4.4	13.3	7.3	< 2.0	702	236	< 2.0	194	137	4.0	20.60	15.7	-	-	mg/kg
Available Nitrate	12	87.4	4.0	21	4.0	25.4	9.6	14.7	27.9	4.7	12.60	12.5	-	-	mg/kg
Available Phosphate	790	320	313	27	96	75.7	29	34.6	70.6	21	63.2	50.3	-	-	mg/kg
Available Potassium	7,800	2,610	1,940	750	920	930	800	672	709	970	548	529	-	-	mg/kg
Available Sulfate	380	791	677	850	885	509	970	453	724	660	859	252	-	-	mg/kg
Inorganics															
Total Organic Carbon	14	12.4	10.5	3.7	7.37	7.88	4.6	4.45	6.27	5.2	5.09	4.28	-	-	%
Organic Matter	24	15.4	15.1	6.3	11.4	11.2	8.0	7.4	9.7	9.0	7.8	5.1	-	-	%
Total Kjeldahl Nitrogen	1.6	0.99	0.67	0.41	0.57	0.46	0.43	0.25	0.37	0.50	0.28	0.222	-	-	%
C:N Ratio	8.75	12.5	15.67	9.0	12.93	17.1	10.7	7.08	16.95	10.4	18.18	19.45	-	-	
Physical Properties															
Moisture	33	30.7	31.3	22	35.9	33.5	25	35.0	36.8	26	21.5	26.2	-	-	%
Soluble Parameters															
Soluble Conductivity	7.0	7.64	4.65	6.3	5.98	4.51	6.2	4.05	4.68	5.6	5.57	4.31	-	-	dS/m
Soluble pH	7.99	7.63	7.99	7.48	7.12	7.83	7.43	7.41	7.93	7.53	6.64	7.90	-	-	pH
Saturation %	150	130	111	90	109	106	92	99.0	104	92	100	91.0	-	-	%
Total Metals															
Antimony	< 1.0	0.44	0.51	0.51	0.64	0.85	0.57	0.60	0.77	0.68	0.66	0.63	20	40	mg/kg
Arsenic	< 2.0	6.33	8.47	5.5	9.08	7.17	5.8	7.98	7.55	5.8	7.39	7.81	12	12	mg/kg
Barium	41	175	236	130	181	189	140	167	194	150	173	195	750	2,000	mg/kg
Beryllium	< 0.80	0.74	0.88	0.60	0.98	0.60	0.57	0.87	0.81	0.60	0.79	0.74	4	8	mg/kg
Cadmium	0.40	0.306	0.295	0.28	0.330	0.421	0.34	0.308	0.373	0.40	0.399	0.376	1.4	22	mg/kg
Chromium	23	35.0	34.0	38	45.6	46.5	39	43.8	44.8	47	43.7	38.1	64	87	mg/kg
Cobalt	1.0	10.9	11.5	8.3	12.2	9.48	8.6	11.3	12.0	8.1	11.3	10.6	40	300	mg/kg
Copper	20	39.2	36.6	45	53.5	**81.6**	56	51.9	**67.3**	**68**	57.5	50.2	63	91	mg/kg
Lead	6.7	14.7	14.1	12	15.8	18.0	14	15.1	15.7	15	15.5	20.3	70	600	mg/kg
Molybdenum	< 0.80	1.05	1.62	1.4	1.67	2.30	1.6	1.41	2.10	2.0	1.70	1.60	5	40	mg/kg
Nickel	11	28.9	34.2	27	38.3	30.5	28	33.7	35.0	29	34.2	34.2	45	89	mg/kg
Selenium	< 1.0	< 0.50	< 0.50	0.60	0.79	0.64	0.63	< 0.50	0.53	0.75	< 0.50	< 0.50	1	2.9	mg/kg
Silver	< 0.40	0.24	0.18	0.46	0.43	1.07	0.61	0.45	0.63	0.80	0.54	0.41	20	40	mg/kg
Thallium	< 0.20	0.21	0.26	0.20	0.28	0.21	0.19	0.26	0.25	0.19	0.25	0.24	1	1	mg/kg
Tin	< 2.0	< 5.0	< 5.0	2.2	< 5.0	< 5	2.6	< 5.0	< 5.0	3.6	< 5.0	< 5.0	5	300	mg/kg
Uranium	0.44	1.48	1.75	1.5	2.44	2.34	1.8	1.86	2.32	2.0	2.08	1.73	23	300	mg/kg
Vanadium	5.8	46.6	50.1	40	60.7	42.9	38	59.8	53.4	42	54.1	48.3	130	130	mg/kg
Zinc	56	108	92	110	143	**207**	140	129	167	180	146	130	200	410	mg/kg

[(a)] Samples collected by the City of Winnipeg and reported in: Maxxam Analytical Report R2449334, R2392878, and ALS Analytical Report L2115629, L2177997.

[(b)] Limits obtained from the Canadian Council of Ministers of the Environment (CCME) Soil Quality Guidelines for the production of environmental and human health.

Table 6: Average total percent cover, and average percent native species and non-native weeds as a percentage of total cover, within each treatment plot at the BRRMF demonstration site, September 2018.

Constituent	Control	T1	T2	T3	Units
Soil Placement Depth	0.3 m	0.9 m	0.6 m	0.3 m	
Average Cover					
Foliage	48.5 ± 10.5	67.5 ± 15.5	63 ± 15.5	68 ± 17.8	% cover
Native species	39.5 ± 17.9	98.5 ± 3.4	94.5 ± 7.9	97.5 ± 7.9	% of total cover
Non-native weeds	60.5 ± 17.9	1.5 ± 3.4	4.5 ± 5.5	1.5 ± 4.7	% of total cover

Note: Average based on visual inspection of ten randomly selected 0.5 m x 0.5 m quadrat plots per treatment area, ± standard deviation.

Table 7: Chemical properties of runoff water collected below each treatment plot at the BRRMF demonstration site[a]. Bold values indicate that one or more regulatory criteria were not met.

Constituents	Control (compost)	T1	T2	T3	Water Quality Guidelines[b]	Units
Soil Placement Depth	0.3 m	0.9 m	0.6 m	0.3 m		
Calculated Parameters						
Dissolved Nitrate (NO_3)	28	36	0.68	< 0.22	-	mg/L
Nitrate plus Nitrite (N)	6.7	9.4	0.15	< 0.071	-	mg/L
Dissolved Nitrite (NO_2)	1.2	4.0	< 0.16	< 0.16	-	mg/L
Nutrients						
Dissolved Ammonia (NO_3)	0.69	1.7	19	29	-	mg/L
Orthophosphate (P)	0.60	0.23	0.15	0.76	-	mg/L
Total Kjeldahl Nitrogen	46	16	38	92	-	mg/L
Dissolved Nitrite (N)	**0.37**	**1.2**	< 0.050	< 0.050	0.06	mg/L
Dissolved Nitrate (N)	6.3	8.2	0.15	< 0.050	13	mg/L

[a] Samples collected on July 12th, 2017 by the City of Winnipeg and analyzed by Maxxam Analytical in Report R2415298.

[b] Limits obtained from the Manitoba Tier III numerical water quality guidelines – Manitoba Water Quality Standards, Objectives, and Guidelines, 2011.

APPENDIX TWO – FIGURES

Figure 1: Fabricated soil placement treatment areas at the BRRMF demonstration (Imagery date August 24, 2015).

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Figure 2: Drone photograph of BRRMF demonstration areas during the second growing season: June 5, 2018.

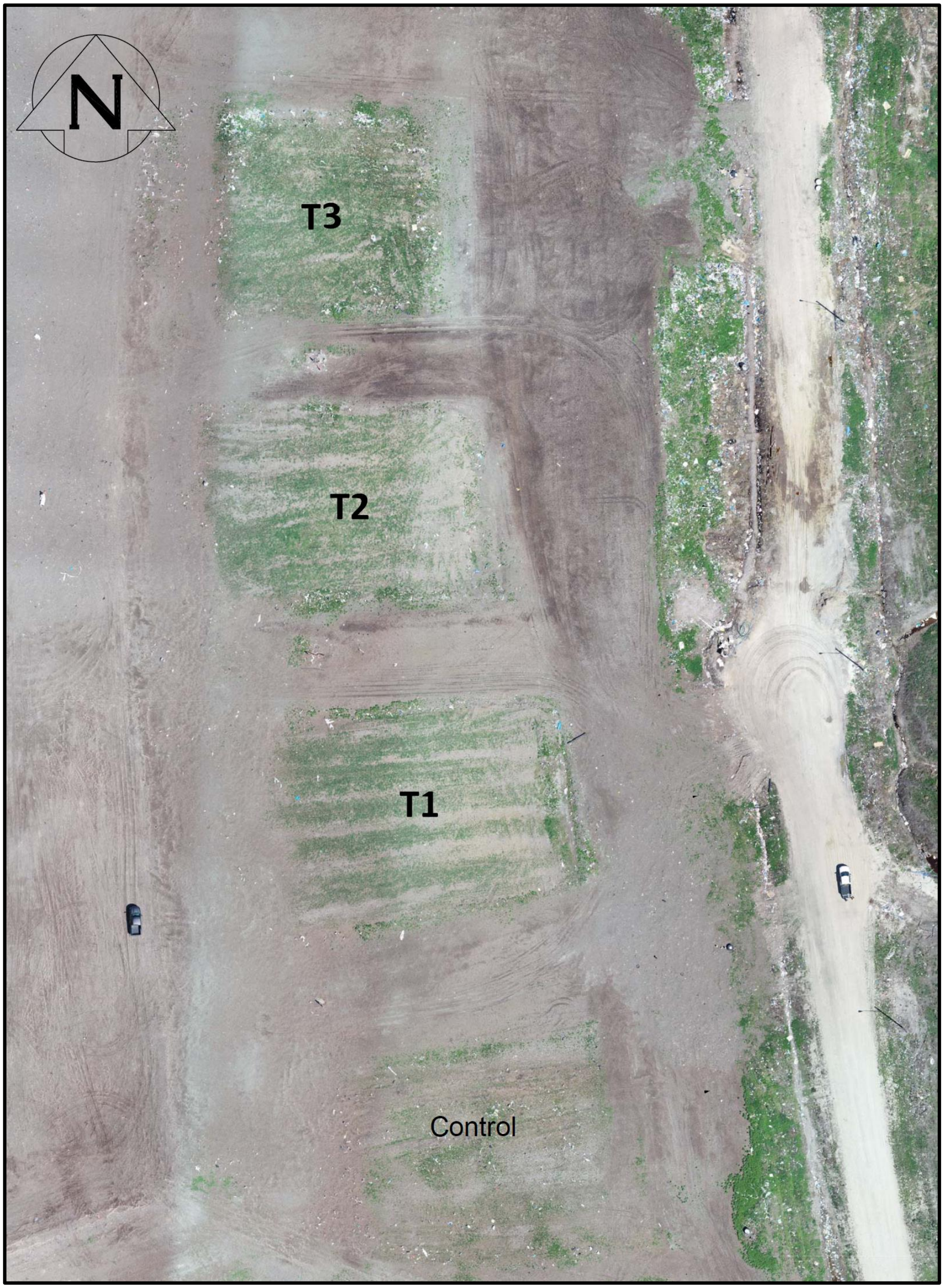
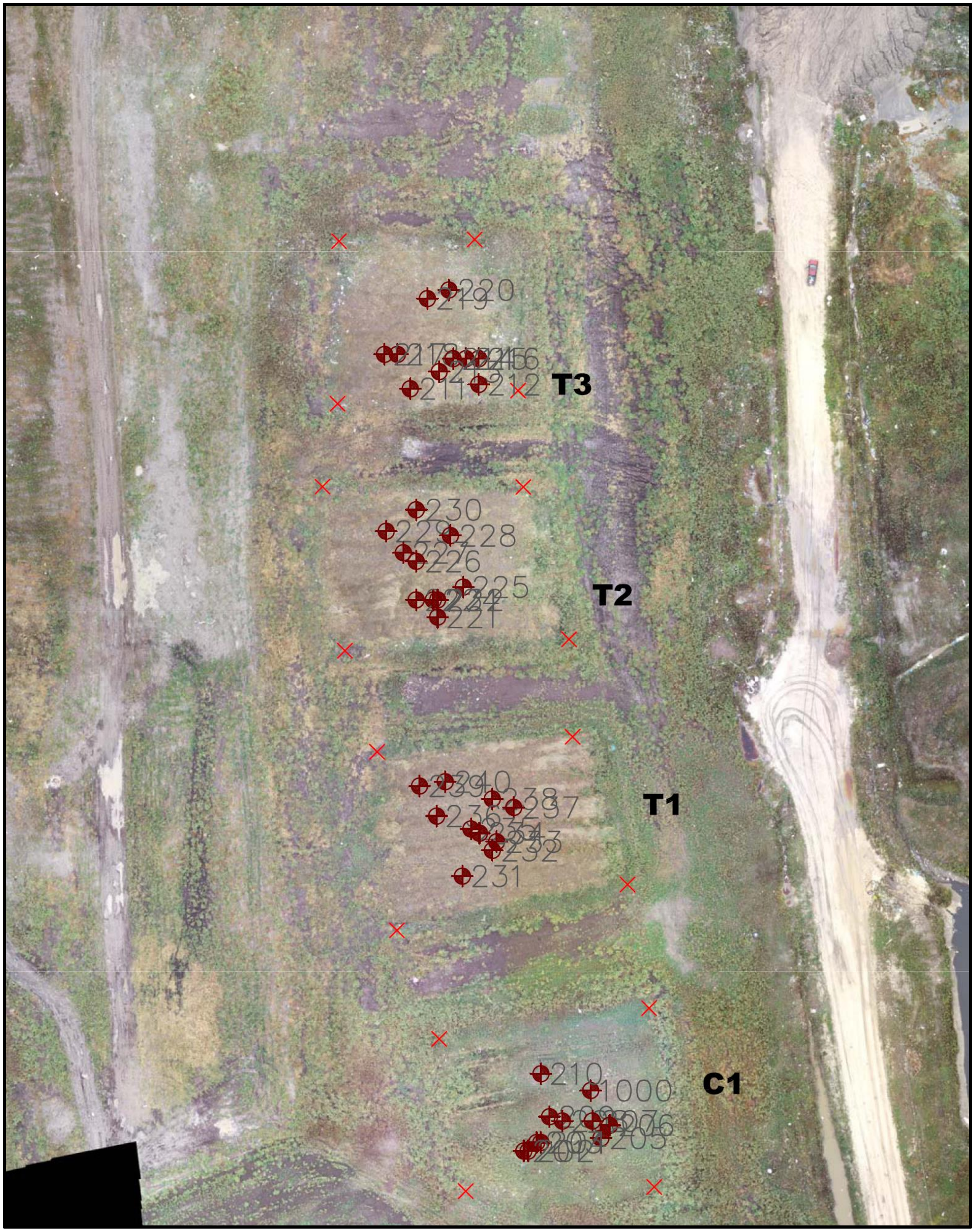


Figure 3: Drone photograph of BRRMF demonstration areas during the second growing season: July 2, 2018.

Figure 4: Drone photograph of BRRMF demonstration areas showing the locations of the vegetation survey: September 14, 2018.



APPENDIX THREE – PHOTOGRAPHS

Photograph 1: An excavator fitted with a hammer mill implement grinds frozen clay to a consistency suitable for soil mixing (February, 2017).

Photograph 2: A front-end loader mixes the feedstocks together at the appropriate ratios (February, 2017).

Photograph 3: The blended feedstocks receive a final pass through the hammer mill implement to finish the fabricated soil (February, 2017).

Photograph 4: The demonstration plots at the BRRMF immediately following fabricated soil placement (May, 2017).

Photograph 5: The demonstration plots at the BRRMF after a second seeding (July, 2017).

Photograph 6: The demonstration plots at the BRRMF at the end of the second growing season (October, 2018).