Metro Plant Solids Management Improvements Facility Plan

Prepared for

Metropolitan Council Environmental Services

METROPOLITAN COUNCIL

July 2018

Draft

Metro WWTP Solids Management Improvements Facility Plan

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

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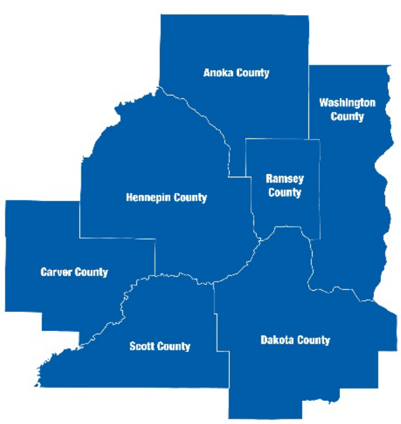

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Executive Summary

Purpose and Objectives

The purpose of this Facility Plan is to present the plan for the Metropolitan Council Environmental Services (MCES) to add solids treatment facilities at the Metropolitan Wastewater Treatment Plant (Metro Plant) and to document the basis for the recommended plan. Several tasks associated with this planning effort are addressed, including:

* Evaluation of current solids production
* Projection of future solids production
* Assessment of existing solids treatment facilities
* Development and evaluation of alternatives
* Selection and development of the recommended plan

Statement of Need

The Metro Plant needs additional solids treatment capacity to preserve existing wastewater treatment plant infrastructure and to serve regional growth in an efficient, reliable, and environmentally responsible manner.

Anticipated future renewal work within the existing incineration system will require that each of the Metro Plant's three incinerators be taken out of service for a period greater than 6 months. System capacity with only two incinerators available for extended periods during construction of the renewal work is insufficient, requiring MCES to landfill excess solids. Without the proposed project, the estimated amount of solids that would be landfilled is 10 percent to 20 percent of the total wastewater solids production, which would require an estimated additional total landfill volume of 2.9 million cubic yards through the end of the planning period (2050).

Population and employment in the Metro Plant service area are anticipated to grow by 25 percent (500,000 residential equivalents) from 2020 to 2050. The corresponding wastewater solids loading increase is 60 dry tons per day (dtpd), from 240 dtpd in 2020 to 300 dtpd in 2050.

The estimated additional capacity needed to extend sustainable solids treatment service at the Metro Plant through the end of the planning period is 75 dtpd, which includes growth and renewal needs.

Evaluation of Alternatives

A wide range of alternatives was narrowed down to the following four alternatives, which maximize the use of the existing incinerators:

> **Alternative 1: Fourth Incinerator.** Add a fourth incinerator, the same size as the existing incinerators (125 dtpd), with associated centrifuges, energy recovery and air pollution control.
>
> **Alternative 2: Digest and Incinerate.** Add an anaerobic digestion complex to digest a portion of the solids. Digested solids would be incinerated in the existing incineration system. The digester complex is sized at 150 dtpd to reduce loading to the incinerators by 75 dtpd.

Alternative 3: Digest, Dry, and Sell. Add an anaerobic digester complex and dryer facilities (75 dtpd) to produce a biosolids product that can be sold as a fertilizer. Dried solids would be pelletized for offsite use by others.

Alternative 4: Digest and Land Apply. Add an anaerobic digester complex and land application facilities (75 dtpd) to produce biosolids that can be used as a soil amendment.

These selected alternatives were configured to provide an additional minimum of 75 dtpd of solids treatment capacity to meet growth and renewal needs. The evaluation considered cost, sustainability, community impacts, and other non-monetary factors.

All alternatives include renewal projects associated with the maintaining the existing capacity.

Recommended Plan

This Facility Plan recommends the construction of the Alternative 1: Fourth Incinerator, which adds a new incinerator parallel to the existing three units. Due to the size of the Metro Plant and its location relative to land application sites, adding a fourth incinerator costs 50 percent less than the next lowest cost alternative to construct, operate, and maintain. It is the most sustainable alternative and has the lowest community impact. The fourth incinerator provides for continuity with existing Metro Plant operations and increases the reliability of the entire regional wastewater treatment system owned and operated by MCES.

The recommended alternative will be constructed in a 22,000-square-foot addition to the Solids Management Building, which houses the existing incinerators. The construction of the Fourth Incinerator (2021 to 2024) would be followed by renewal of the existing incineration facilities (2025 to 2027). At time of this renewal, the existing incinerators will be 20 years old.

The estimated total cost is $180 million in 2018 dollars.

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1.0 Introduction and Facility Management Conditions

1.1 Background and Purpose

The Metropolitan Wastewater Treatment Plant (Metro Plant) has incinerated wastewater solids since its original construction in 1938. In 2005, six multiple hearth incinerators were abandoned, and a new solids management building was constructed to house three fluid bed incinerators. MCES deferred construction of facilities at the Metro Plant for land application of an alkaline stabilized solids product that would have provided additional processing capacity at that time (2005).

MCES has occasionally landfilled sludge during extended incinerator shut downs at the Metro Plant. The Metro Plant needs additional solids processing capacity to preserve existing wastewater treatment plant infrastructure and to serve regional population growth in a sustainable manner. This Metro Plant Solids Management Facility Plan includes renewal of existing incineration facilities at the Metro Plant following construction of the additional capacity needed to perform the renewal work. Additional solids treatment capacity at the Metro Plant would provide emergency backup for solids processing from other MCES plants and, thereby, improve total system reliability.

The purpose of this document is to present the Facility Plan in a manner that meets the funding requirements of the Minnesota Public Facilities Authority. The planning period is through the year 2050.

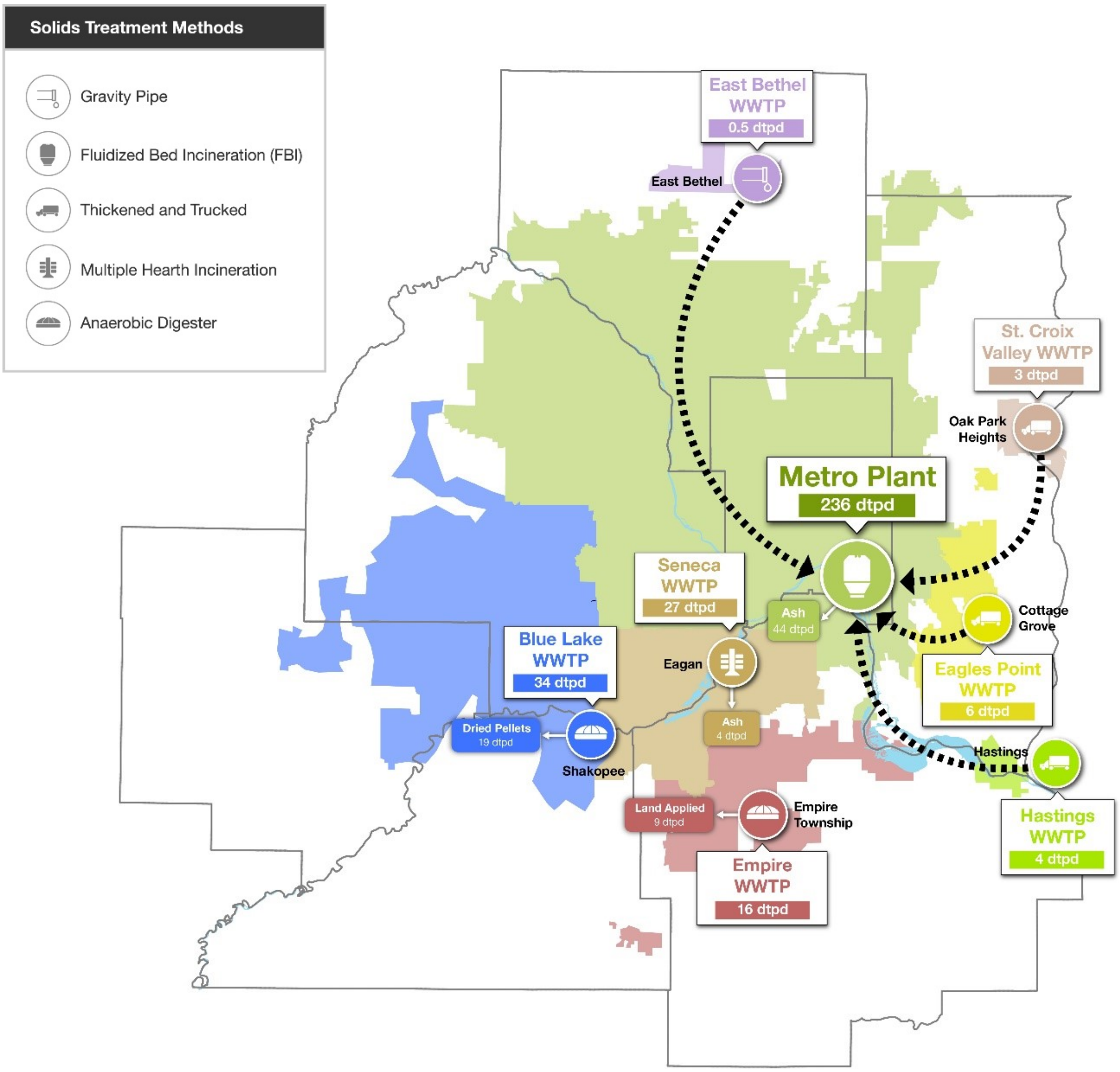

Figure 1. Wastewater and Wastewater Solids Treatment Provided by Metropolitan Council Environmental Services for Minnesota's Twin Cities Region

1.2 Service Area

The wastewater treatment service area for each of eight wastewater treatment plants owned and operated by the Metropolitan Council Environmental Services (MCES) and the solids treatment method employed at each plant are shown in Figure 1.

The Metro Plant located in St. Paul, Minnesota, treats 180 million gallons of wastewater every day for 66 communities (70 percent of the region). The Metro Plant treats wastewater solids for its own service area plus it receives and treats solids from four other plants; Eagles Point, East Bethel, Hastings, and St. Croix Valley. A total of 850 wet tons (including moisture), or 240 dry tons (excluding moisture), of wastewater solids are treated at the Metro Plant every day for 73 communities (75 percent of the region).

The Metro Plant also receives wastewater scum from all the other MCES wastewater treatment plants, except the Seneca Wastewater Treatment Plant. Wastewater scum is floating material skimmed from the liquid surface of process tanks.

As summarized in Table 1, population and employment in the Metro Plant service area are anticipated to grow by 25 percent (500,000 residential equivalents) from 2020 to 2050. The corresponding wastewater solids loading increase is 60 dtpd, from 240 dtpd in 2020 to 300 dtpd in 2050 (Table 2).

Table 1. Projected Population Growth for the Metro Plant Service Area[1]

Year	Residents	Employment	Equivalent Residents	Total Equivalent Residents
2010	1,770,000	1,067,000	267,000	2,040,000
2020	1,910,000	1,177,000	294,000	2,200,000
2040	2,190,000	1,367,000	342,000	2,530,000
2050	2,330,000	1,450,000	363,000	2,700,000

[1] 2014 Water Resources Policy Plan, Metropolitan Council Environmental Services.

1.3 Current and Projected Wastewater Solids Production and End Use

Actual and projected solids quantities treated at the Metro Plant and solids quantities exported from the plant are summarized in Table 2.

1.3.1 Wastewater Solids

The quantity of solids requiring treatment at the Metro Plant, which includes residential, commercial, and industrial components, as well as solids produced within the plant by wastewater treatment processes, has been steady over the last 11 years, with small fluctuations around the average of 234 dtpd.

Table 2. Metro Plant Wastewater Solids, Historical Data (2007-2017) and Projections

Year	Load to Solids Treatment (dtpd)[1]	Scum (dtpd)	Ash (dtpd)	Sludge To Loadout and Landfill (wet tons)[3]
2007	235	--[2]	48	4706
2008	241	--[2]	45	0
2009	234	--[2]	43	0
2010	235	--[2]	44	551
2011	240	--[2]	38	0
2012	225	2	37	4,050
2013	231	2	27	38,287[4]
2014	229	2	44	56,477[4]
2015	232	2	41	10,202[4]
2016	230	2	38	21,544
2017	236	2	41	2,920

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Year	Load to Solids Treatment (dtpd)[1]	Scum (dtpd)	Ash (dtpd)	Sludge To Loadout and Landfill (wet tons)[3]
Average	**234**	**2**	**42**	**--**
2020[5]	240	2	43	--
2050[5]	300	2	54	--

[1] Solids load based on flow measured at the cake pump discharge and solids concentration measured at the centrifuge discharge.

[2] Prior to July 2011, scum was processed with the other wastewater solids and is included in the values presented in "Solids Processed". Since July 2011 scum has been processed separately from other solids and is not included in the values presented in "Solids Processed."

[3] Includes wastewater solids, moisture, and ash and lime additives

[4] Sludge loaded out to landfill during the 2013-2015 Solids Processing Improvements Project. Each incinerator was shut down twice (for a total of 19 weeks each) to complete renewal work.

[5] Wastewater solids projections are based on 25% population growth (2020-2050): (0.25x240)/30 = 2 dtpd/yr

Industrial wastewater solids loading into the plant has decreased, residential and commercial components have increased, indicating population growth. Organic loading into the plant has increased, which also indicates population growth. (Soluble wastewater organic compounds produce solids within the plant by the wastewater treatment process.) Historical data depicting these trends are included in Appendix A.

Wastewater solids are projected to increase at the same rate as population and employment growth in the service area, 25 percent over 30 years.

This plan provides for a reliable, long-term average solids processing capacity of 300 dtpd and a peak month design value of 345 dtpd, based on an actual average 30-day peaking factor of 1.15. Appendix B contains a tabulation of solids processing peaking factors for the Metro Plant.

1.3.2 Scum

The Metro Plant currently treats about 2 dtpd of scum, which is floating material collected from the liquid surface of process tanks, and includes scum trucked in from the other wastewater treatment plants, except the Seneca Wastewater Treatment Plant. Scum is treated separately from the settleable wastewater solids and is not reported with wastewater solids quantities described in Section 1.3.1. Scum is concentrated by draining in dumpsters and then landfilled.

MCES is evaluating options to process scum with the other solids, which would add to system capacity requirements.

1.3.3 Ash

Incineration eliminates 95 percent of the Metro Plant waste material that would otherwise have to be hauled offsite (solids and water); the remaining residue, or ash, is collected at the bottom of the incinerator flue gas treatment train. The Metro Plant produces about 40 dtpd of ash, which is currently landfilled or used as a bulking agent during sludge loadout and landfill. From 1989 to 2004, MCES reused Metro Plant ash in cement and other construction products. This practice was discontinued due to the potential to re-volatilize mercury in the ash during cement manufacturing. Ash is currently landfilled without additional treatment.

In 2001, MCES implemented a mercury reduction program that involved an industrial pretreatment campaign, mainly with local dentists. This program reduced mercury loading to the Metro Plant by 70 percent (Appendix A). In 2005, MCES implemented wastewater biological phosphorus removal at the Metro Plant, a process that concentrated phosphorus in the solids. Phosphorus, a non-renewable nutrient required for plant growth, ultimately ended up in the ash.

The result of these two programs, mercury reduction and biological phosphorus removal, is that Metro Plant ash is 27 percent phosphorus and has very low metals content, leading MCES to re-evaluate alternatives for the beneficial use of Metro Plant ash.

As part of this planning effort, a trial greenhouse study of the growth of lettuce and corn using ash as a fertilizer was conducted by the University of Minnesota, and results indicated that Metro Plant ash is potentially a suitable phosphorus fertilizer. The trial greenhouse study report is provided in Appendix C. Subsequently, MCES initiated a 3-year field crop study of the growth of corn and soybeans using Metro Plant ash as a fertilizer, which will be completed by the University of Minnesota in 2019.

Photo 1. Corn and lettuce grown during a trial study conducted by the University of Minnesota found Metro Plant ash to be a potentially suitable phosphorus fertilizer.

Ash nutrient data are summarized in Table 3. For comparison to other commercial fertilizers, Metro Plant ash has an N-P-K ratio of 0:14:2 with an estimated value of $125 per ton.[1]

Ash metals data are summarized in Table 4. Metro Plant ash meets metal concentrations for fertilizers published by the Association of American Plant Food Control Officials and it is below ceiling limits established by the United States Environmental Protection Agency (EPA) for land application of biosolids, for all metals. Metro Plant ash meets EPA's standards for exceptional quality biosolids for all metals except copper. Although the regulations do not apply to ash used as a fertilizer, biosolids regulations provide a reference for acceptable levels of metals for reuse of ash.

Toxicity Characteristic Leachate Procedure (TCLP) tests indicates Metro Plant ash is below toxicity thresholds for arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver.

[1] Comparable value based on June 2018 market rates for commercial grade fertilizers from www.dtnpf.com

Table 3. Fertilizer Constituents of Metro Plant Ash

Constituent	Average (%)[1]
Total Phosphorus, as P2O5	27.73
Available Phosphorus, as P2O5	17.22
Total Potassium, as K2O	3.81
Available Potassium, as K2O	2.27
Boron (B)	0.00
Calcium (Ca)	11.34
Copper (Cu)	11.34
Iron (Fe)	3.20
Magnesium (Mg)	2.89
Manganese (Mn)	0.81
Sulfur (S)	0.61
Zinc (Zn)	0.22

[1] All items based on 32 tests from 2017-2018

Table 4. Metro Ash Metals Content and Comparison to Reference Standards

Constituent	Average (mg/kg)[1]	AAPFCO Heavy Metal Rule (mg/kg)[2]	EPA EQ Biosolids (mg/kg)	EPA Ceiling Biosolids (mg/kg)
Arsenic	91	182	41	75
Cadmium	10	140	39	85
Cobalt	13	1904	-	-
Chromium	216	-	1200	3000
Copper	2143	-	1500	4300
Lead	296	854	300	840
Mercury	3	14	17	57
Molybdenum	48	588	-	75
Nickel	130	3500	420	420
Selenium	12	364	36	100
Zinc	2198	5880	2800	7500

[1] Based on 32 tests through 2017-2018
[2] Based on average available Phosphorus, as P2O5 of 14%.

1.3.4 Sludge Loadout and Landfill

Because it is expensive and environmentally unsustainable, sludge loadout and landfill is used at the Metro Plant only when needed incineration capacity is unavailable[2]. Sludge loadout and landfill costs $220 more per dry ton of solids processed than incineration costs.

As shown in Table 5, sludge loadout and landfill increases the amount of material that must be hauled offsite by 25 fold. To meet Minnesota landfill requirements, lime must be added to the sludge to adjust the sludge's pH level. Ash is added as a bulking agent to make the sludge more transportable.

Table 5. Metro Plant Solids Exports, Incineration versus Sludge Loadout and Landfill

	Incineration	Sludge Loadout and Landfill
Dewatered cake	1.0 parts solid	1.0 parts water
	2.6 parts water	2.6 parts water
Added materials	--	1.3 parts ash
		0.9 parts lime kiln dust
Solids export	0.2 parts ash	5.8 parts sludge

A significant amount of loadout is required when incinerators are taken out of service to perform renewal work (Table 5). More sludge loadout and landfill will be required as equipment continues to age, and more extensive renewal work is needed. The existing incinerators will be 20 years old in 2025.

1.4 Previous Facility Plan

The 1998 Facility Plan for constructing the existing three fluidized bed incinerators (FBIs) included a provision for 94 dtpd of additional treatment (plus one spare) in the form of alkaline stabilization and land application. Alkaline and ash addition facilities were installed, but construction of the curing and storage facilities required to implement land application was deferred while optimizing the operation of the new incineration technology at the Metro Plant.

In 2011, MCES investigated implementing the land application program and found that a number of these facilities had been prematurely abandoned due to higher than anticipated operation and maintenance costs and limited acceptance of the product for land application.

MCES focused on achieving maximum efficiencies with the existing FBI system. MCES also initiated studies to determine the most sustainable alternative to alkaline stabilization and land application, which resulted in this Facility Plan.

[2] Part of the Council's Wastewater Sustainability Policy: "Stabilize and reduce the volume of biosolids through thermal processing or anaerobic digestion, and utilize the remaining solids as fertilizer and soil conditioner."

2.0 Permits

The following is a list of currently-effective Metro Plant permits and licenses:

- Air Quality (Title V) Permit, Minnesota Pollution Control Agency (MPCA)
- Groundwater Permit, Minnesota Department of Health
- Groundwater Appropriations Permit, Minnesota Department of Natural Resources
- Hazardous Waste License, Ramsey County
- Water Quality
    - National Pollution Discharge Elimination System (NPDES) Permit, MPCA
    - Total Phosphorous Permit, MPCA

This section focuses on the Title V permit because this permit regulates incineration and related equipment.

The current Title V Air Emissions Permit regulates emissions from sources at the Metro Plant, including incineration and operation of emergency generators, boilers, secondary treatment, and ash and materials handling. The original Title V of the Clean Air Act Air Emissions Permit was issued on March 13, 2001, and included the requirements codified at 40 Code of Federal Regulations (CFR) Part 503, Standards for the Use or Disposal of Sewage Sludge (1993). This permit was amended three times, as presented in Table 6. The last reissuance was February 25, 2010.

Table 6. Metro Plant Title V of the Clean Air Act Air Emissions Permit History

Permit Number and Issuance Date	Action Authorized
12300053-001 (March 13, 2001)	Part 70 Total Facility Permit issued
12300053-002 (November 15, 2002)	Authorized construction and operation of Solids Processing Facility (Solids Management Building)
12300053-003 (Not Issued)	No action
12300053-004 (June 28, 2004)	Authorized operation for fabric filters to be used instead of electrostatic precipitators, clarified the completion of the Operation and Maintenance Manual, allowed for flexible operation of the alkaline stabilization and three-stage odor scrubber, clarified operational limits of the incinerators, amended the PM10 emissions standard, and eliminated emission units for nonexistent or insignificant activities
12300053-005 (February 5, 2007)	Authorized the use of two 2,000 kilowatt temporary generators for effluent pumping during floods
12300053-006 (February 25, 2010)	Minnesota Pollution Control Agency (MPCA) reissued permit
Renewal application of permit 12300053-006 was sent to MPCA. (August 26, 2014)	No action
MPCA received application for minor modification – generator replacement. (August 18, 2017)	No action

The current Title V of the Clean Air Act Air Emissions Permit is being reviewed by the Minnesota Pollution Control Agency (MPCA) for reissuance. When re-issued, it is assumed that the Title V of the Clean Air Act Air Emissions Permit will incorporate additional incinerator emissions limits and operating and reporting requirements meeting the EPA regulations codified at 40 CFR Part 60, Standards of Performance for New Stationary Sources; including Subparts LLL, LLLL, and MMMM. As part of these regulations, there are New Source Performance Standards (NSPS) for sewage sludge using Maximum Achievable Control Technology (MACT) for Existing Fluid Bed Incinerators[1] or New Fluid Bed Incinerators.[2] Until reissuance of the permit, the Metro Plant incinerators are operating under the Federal Implementation Plan as of March 21, 2016.[3]

2.1 EPA Sewage Sludge NSPS Rule (MACT Rule 2016)

The new rules (81 Federal Register 26040) included requirements for reporting and operating and the rules set new lower emission limits for nine criteria pollutants: cadmium (Cd), polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs), carbon monoxide (CO), hydrogen chloride (HCl), mercury (Hg), nitrogen oxides (NO_X), lead (Pb), particulate matter (PM), and sulfur dioxide (SO_2). Stack testing conducted in 2016 demonstrated that incinerator emissions were below MACT Standards for existing Fluid Bed Incinerators (constructed prior to October 14, 2010) as required by EPA. The supplemental engineering tests conducted in 2017 and 2018 for this facility demonstrated that incinerator emissions were below MACT Standards for new Fluid Bed Incinerators (constructed after October 14, 2010).

Table 7. Metro Plant Performance

Pollutant	Units (corrected to 7% dry Oxygen)	2015-2016 Emission Result (average of six tests)	% of Existing Limit	2017-2018 Emission Result (average of five tests)	% of New Limit (most recent tests 2017-2018)
Cadmium (Cd)	mg/dscm	2.7E-04	17%	7.6E-05	7%
PCDDs/PCDFs (TEQ)	ng/dscm	7.6E-06	0%	-	0%
Carbon Monoxide (CO)	ppmvd	19.5	30%	6.4	24%
Hydrogen Chloride (HCl)	ppmvd	8.5E-02	17%	-	35%
Mercury (Hg)	mg/dscm	8.7E-04	2%	1.8E-04	18%
Nitrogen Oxide (NOx)	ppmvd	20.2	13%	12.9	43%
Lead (Pb)	mg/dscm	9.3E-04	13%	2.6E-04	41%
Particulate Matter (PM)	mg/dscm	1.8	10%	-	18%
Sulfur Dioxide (SO_2)	ppmvd	3.0	20%	1.04	20%

[1] 40 CFR Part 60 Subpart MMMM, for Existing Sewage Sludge Incinerators (constructed before October 14, 2010).
[2] 40 CFR Part 60 Subpart LLLL, for New Sewage Sludge Incinerators (constructed after October 14, 2010).
[3] Federal Implementation Plan 40 CFR 62 Subpart LLL.

2.2 Permitted Incineration Capacity

- **Annual Total Each Unit**: 38,325 dry tons (12-month rolling average)
- **24-Hour Maximum Each Unit**: 130 dtpd
- **24-Hour Maximum Three Units**: 315 dtpd

3.0 Overview of Existing Solids Treatment Facilities

Figure 2 is a Metro Plant site map depicting plant process areas, which includes the following active solids treatment facilities:

* Flotation thickening
* Sludge storage tanks (SSTs)
* Solids Management Building (SMB)
    - Scum concentration dumpsters
    - Dewatering centrifuges
    - Cake bins and cake feed pumps
    - Polymer system
    - Incinerator trains
    - Steam turbines
    - Ash conveyance equipment
    - Sludge loadout
    - Odor control system
* Ash loadout and storage

Incinerator trains include the incinerators, flue gas heat recovery and air pollution control equipment, and stacks (located outside, adjacent to the SMB). A generalized solids process schematic is shown in Figure 3.

Design data for existing solids treatment facilities are included in Appendix E.

3.1 Gravity Thickening

Gravity thickening was installed in 1969. The gravity thickening area of the Metro Plant contains six process tanks to thicken primary solids that enter the plant with the wastewater from 1 percent to 6 percent solids. The gravity thickener building houses electrical and building mechanical equipment.

The gravity thickening tanks were covered in 2007, and a biofilter for odor control was installed.

Renewal work is currently under construction (2018) and includes roof replacement, concrete and mechanical repairs, and replacement of the biofilter with a trickling filter.

3.2 Flotation Thickening

Flotation thickening was installed in 1979. The flotation thickening area of the Metro Plant contains 16 covered process tanks; 12 tanks thicken waste activated sludge that is generated within the plant by the wastewater treatment process from 1 percent to 4 percent solids. Renewal work completed in 2018 that replaced the motors, restored metal components within the tanks, and decommissioned four tanks.

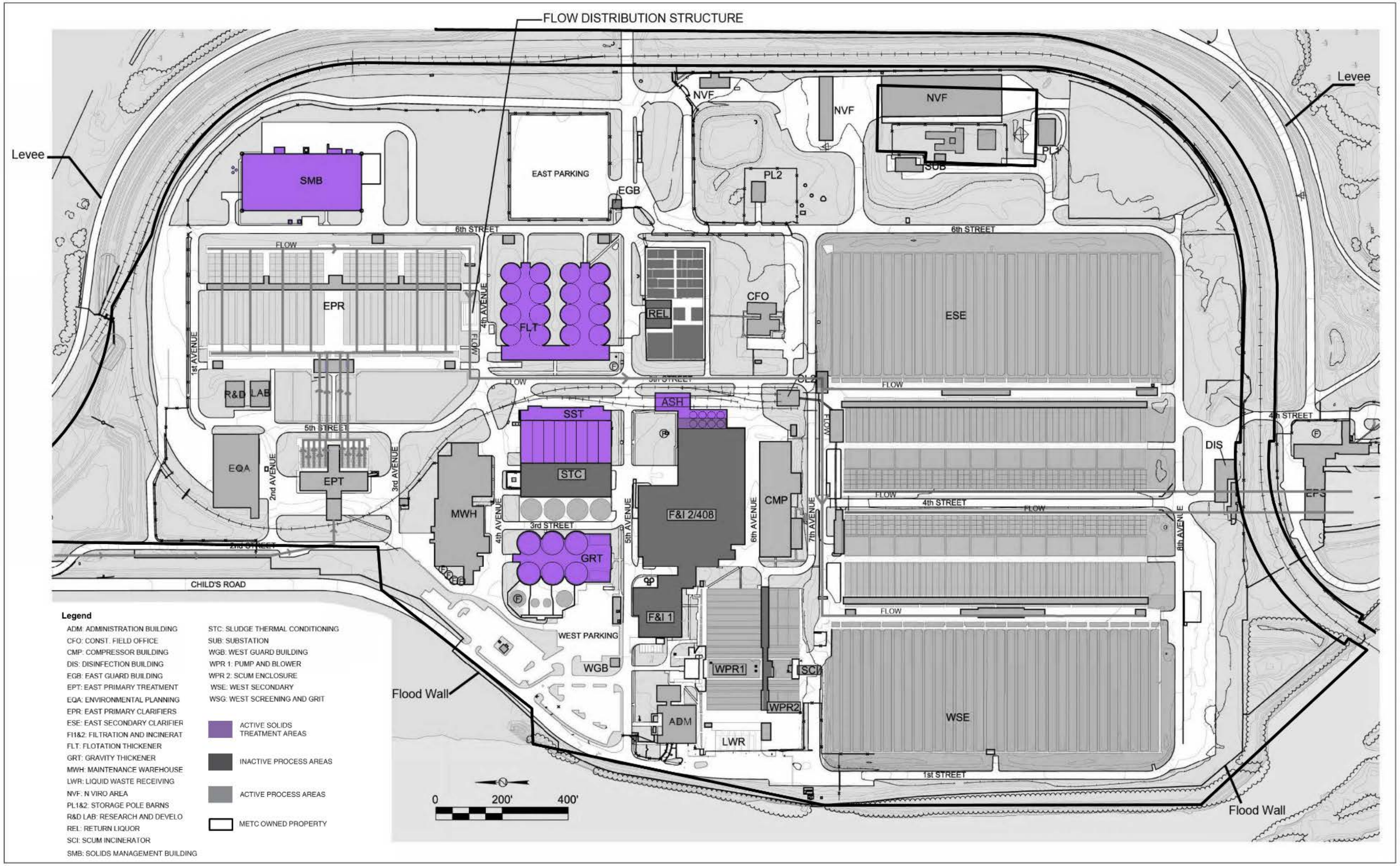


Figure 2. Metro Plant Site Plan

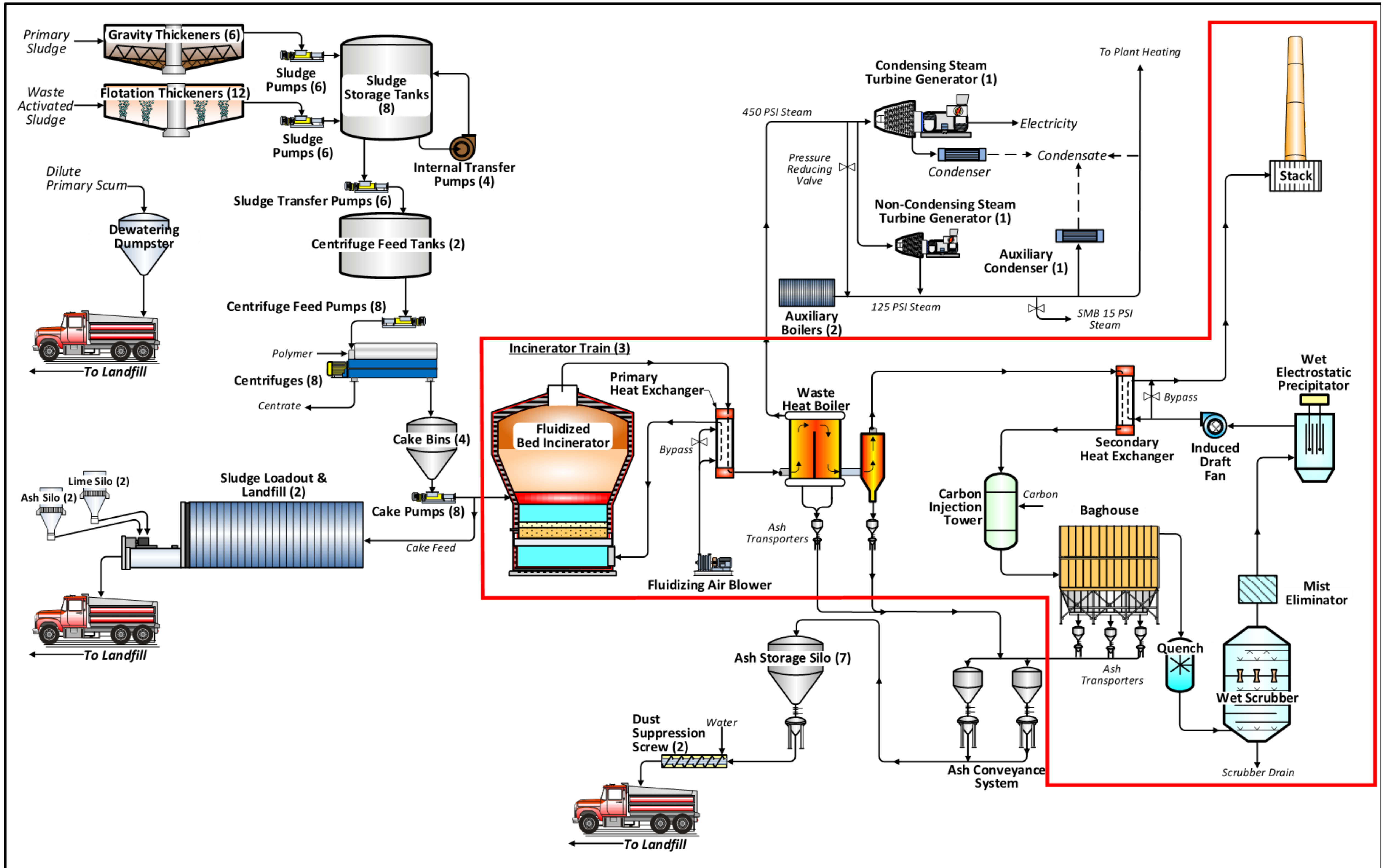


Figure 3. Metro Plant Solids Treatment Process Schematic

3.3 Sludge Storage Tanks (SST)

Eight, 750,000-gallon SSTs began operation in 1980. SST 1 through SST 4 on the north side of the Metro Plant store flotation thickened sludge and are not mixed. SST 5 through SST 8 on the south side of the Metro Plant store gravity thickened sludge and are air mixed.

In 2014, concrete surfaces within the SSTs were rehabilitated and access hatches were replaced.

Ten SST pumps are located alongside the SSTs, below grade in the Metro Plant tunnel network. Six newer progressing cavity pumps, two pumps installed in 1997 and four pumps installed in 2004, are used to transfer sludge from the SST to the centrifuge feed tanks located in the SMB. Four older pumps (two centrifugal pumps and two piston pumps installed in 1980) are used to transfer sludge from any given tank in preparation for maintenance to an alternate tank.

One centrifugal pump and one piston pump are used, in sequence, to transfer sludge between tanks. One set of these pumps serves SST 1 through SST 4, and one set serves SST 5 through SST 8. Four older pumps (two centrifugal pumps and two piston pumps installed in 1980) are used to empty the bottom 5 feet of sludge in any given tank in preparation for maintenance in that tank.

3.4 Solids Management Building (SMB)

The SMB began operation in 2005. It houses scum concentration dumpsters, dewatering centrifuges, a polymer system, cake bins and cake feed pumps, incinerators, heat recovery equipment, air pollution control equipment, ash conveyance systems, and sludge loadout equipment.

SMB floor plans are included in Appendix G.

The Solids Processing Improvements Project, which recovered incineration capacity and service availability of the SMB incineration system, was completed in 2015. Design of the Metro Plant SMB Baghouse/Scrubber/Miscellaneous Improvements Project was initiated in 2018 to renew the ash collection and handling system. A list of modifications to the SMB facilities is provided in Appendix F.

3.4.1 Scum Concentration Dumpsters

Two scum concentration dumpsters that drain water from the scum have been temporarily located in one of the sludge loadout bays. MCES intends to relocate this facility or blend scum into the existing solids treatment process so that it is ultimately incinerated, depending on results of demonstration testing.

3.4.2 Dewatering Centrifuges

Eight dewatering centrifuges concentrate combined gravity and flotation thickened sludge from 5 percent to 28 percent solids. The sludges are combined in two, 50,000-gallon centrifuge feed tanks, operated in a batch mode. The centrifuge feed tanks and eight centrifuge feed pumps are in the basement of SMB.

One centrifuge was installed in 1996 in F&I2. This centrifuge was relocated to the SMB with its construction in 2002 to 2004, and six additional centrifuges were installed at that time. The eighth centrifuge was installed in 2008.

3.4.3 Polymer System

Original construction of the SMB included a polymer system that conditions feed sludge for centrifuge dewatering. Polymer is added to the centrifuge feed piping.

3.4.4 Cake Bins and Cake Feed Pumps

A system of four cake bins and eight cake pumps were installed in the SMB with its construction in 2002 to 2004. As shown in Figure 3, these systems can feed alternate incineration or sludge loadout and landfill trains from any of the eight dewatering centrifuges.

3.4.5 Incinerator Trains

The Metro Plant has three parallel incinerator trains that were installed with the construction of SMB in 2002 to 2004. Each train consists of a fluid bed incinerator, heat recovery equipment, air pollution control equipment, and a stack as shown in Figure 3.

Figure 4 provides a brief description and treatment objective of each component in the incinerator train.

3.4.6 Turbine Generators and Auxiliary Boilers

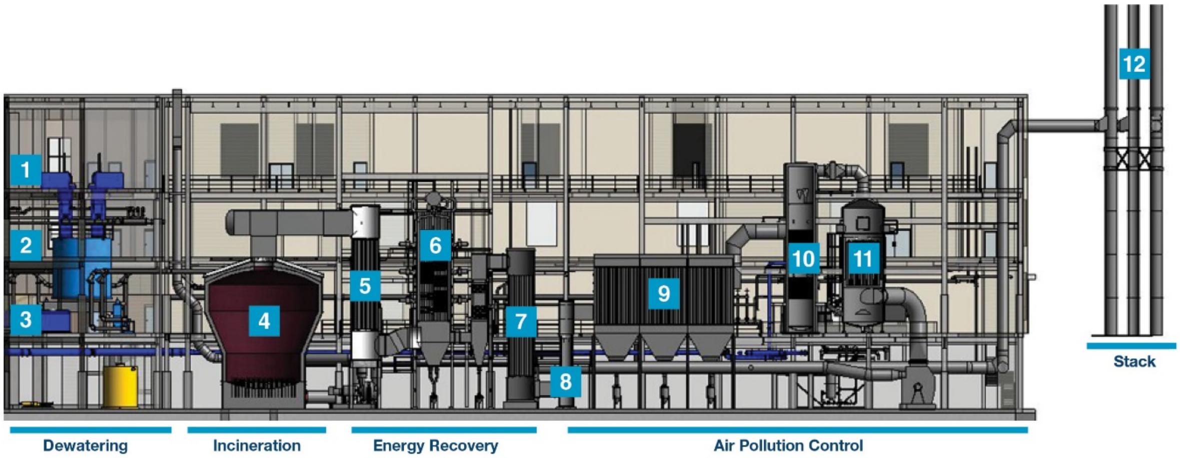
High-pressure steam (450 pounds per square inch [psi]) from the waste heat boilers (WHBs) is used in the winter to heat the plant and used in the summer to produce electricity in the 4.75-megawatt condensing steam turbine generator. This generator and the auxiliary condenser were installed with construction of the SMB. The auxiliary condenser condenses excess steam and is sized to handle all steam from the WHBs in the event of a turbine shutdown.

One smaller, non-condensing steam turbine generator (0.75 megawatts) was added in 2013 to recover energy that would otherwise be lost at the steam pressure reducing station.

Two auxiliary boilers provide 150 psi steam to supplement the steam distribution system, as needed.

3.4.7 Ash Collection and Conveyance from Solids Management Building

The Metro Plant has a dense phase ash conveyance system, which was installed with the original construction of the SMB. One ash conveyance system for each incinerator collects ash from the bottom of the WHBs and the baghouses and sends that ash to two intermediate storage bins located in the SMB. Two parallel ash conveyance systems transport ash 1,500 feet from the storage bins to ash storage and loadout at the east end of the previous incineration building.



1 DEWATERING CENTRIFUGE

Thickened sludge is pumped into a dewatering centrifuge which spins at 2,600 rpm to increase solids concentration from 5% to 28% to a consistency similar to moist soil.

2 CAKE BIN

Dewatered "cake" falls into a cake bin. A sliding frame and an extraction screw conveyor feeds cake into the cake pump.

3 CAKE PUMP

A hydraulically powered piston pump feeds cake through pipes to the fluidized bed incinerator.

4 FLUID BED INCINERATOR

The cake combusts at a temperature of 1,375°F in a bubbling sand bed. Combustion reduces the volume of cake by 95% and eliminates bacteria. The fluid bed incinerators are operated within specified temperature ranges to meet nitrogen oxide standards. Complete combustion minimizes carbon monoxide.

REMOVES: NOx CO

5 PRIMARY HEAT EXCHANGER

Hot flue gas leaving the incinerator is recovered to preheat the fluidizing air entering the bottom of the incinerator.

6 WASTE HEAT BOILER

The waste heat boiler recovers heat from the flue gas by converting water pumped through hundreds of metal tubes into steam.

7 SECONDARY HEAT EXCHANGER

The secondary heat exchanger recovers heat from the flue gas to evaporate water vapor in the stack, which removes any visible plume.

8 CARBON TOWER

Carbon is injected into the flue gas to remove mercury.

REMOVES: Hg

9 BAGHOUSE

The baghouse uses 816 filter bags to remove particulates which include injected carbon and heavy metals. The particles collected on the outside of the bags fall to bottom in the form of ash.

REMOVES: TSP Cd Hg Pb

10 WET SCRUBBER

Water is sprayed into the wet scrubber to cool the flue gas and remove remaining particulates. Caustic is added to neutralize acid gases.

REMOVES: TSP SO_2 NOx Cd Hg HCl Pb PCDD/PCDF

11 WET ELECTROSTATIC PRECIPITATOR

Electrically charged metal rods remove any remaining very fine particulates and heavy metals from the flue gas.

REMOVES: TSP Cd Hg Pb

12 STACK

Emissions leaving the stacks are clean, odorless, colorless, and have no visible plume.

Figure 4. The Metro Plant Incinerator, Energy Recovery, and Air Pollution Control Equipment

3.4.8 Sludge Loadout

Two sludge loadout trains—each consisting of one intermediate storage bin for lime kiln dust, one intermediate storage bin for ash, and one pug mill—are located in the SMB. These facilities are used to stabilize solids prior to landfill disposal when loadings exceed available storage and incinerator capacity.

During sludge loadout, ash and lime kiln dust is transported 1,500 feet from the large storage silos to four, 10-ton capacity day bins located in the SMB. Sludge cake from the SMB is pumped to cake hoppers. Augers transport the ash, lime, and cake into a mixer that blends the admixture to a chute that drops into a truck parked in one of two bays of the loadout garage.

3.5 Ash Loadout and Storage

Ash is transported from the SMB approximately 1,500 feet to six of seven large storage silos (one silo is reserved for lime kiln dust); each silo stores 600 tons of material.

Commissioned in 1983, the eight concrete ash silos receive about 40 tons per day of ash from the SMB. Ash from storage silos 1 through 7 is conveyed to the ash truck loadout garage where water is added to moisten the ash for dust control. Stored ash from storage silos 2, 4, and 6 can also be routed to the alkaline sludge loadout along with lime kiln dust from storage silo 8.

4.0 Assessment of Existing Solids Treatment Facilities

Solids Treatment Facilities were compared against current and intended future requirements for capacity, condition, and level of service. Level of service requirements include permit compliance, reliability, flexibility, operability, and maintainability.

Project scope items identified by this assessment and included in this Facility Plan are marked with an "∗."

4.1 Sludge Thickening

Condition, capacity, and level of service requirements for the gravity and flotation thickening processes, which have been addressed under other programs, are considered adequate for this Facility Plan.

4.2 Sludge Storage

The following condition and level of service deficiency will be addressed by sludge storage pumping improvements included in this Facility Plan:

∗ Six SST pumps are nearing the end of their service life and need to be replaced: two centrifugal pumps, two piston pumps, and two progressing cavity pumps.

Two replacement progressing cavity pumps, sized the same as the existing two progressing cavity pumps, will provide firm capacity for sludge storage transfer through the planning period.

4.2.1 Sludge Storage Tanks

Capacity, condition, and level of service of the SSTs are considered adequate through the planning period. Sludge storage capacity provides between 14 and 21 days of storage with two incinerators operating (one incinerator train out of service).

Air mixing of gravity thickened sludge in SST 5 through SST 8 is prone to diffuser fouling and filling of the air piping with sludge. Currently, mixing air is delivered by blowers through rubber duck-bill type check valves. Mixing improvements are included in the design phase of another project separate from this Facility Plan.

4.2.2 Sludge Storage Tank Pumps

Capacity of the SST pumping systems is sufficient to transfer solids between tanks and to transport solids to the SMB through the planning period. Six SST pumps are nearing the end of their service life: two centrifugal pumps, two piston pumps (installed in 1980), and two progressing cavity pumps (installed in 1997). One of the progressing cavity pumps is currently inoperable.

Due to poor suction piping configuration, the bottom 5 feet of SST volume (150,000 gallons total volume) cannot be emptied with any of the six progressing cavity pumps used for transferring sludge to SMB. Therefore, this volume is not available for storage during normal operation, and other pumps are needed to empty a storage tank for maintenance.

Transfer of sludge between SSTs for maintenance purposes is provided by one centrifugal pump and one piston pump for SST 1 through SST 4, and by one centrifugal pump and one piston pump for SST 5 through SST 8. The centrifugal pumps provide quick draw down to less than 1 foot; the piston pumps are slower, but completely empty a given SST.

4.3 Solids Management Building

4.3.1 Scum Concentration Dumpsters

MCES plans to incinerate scum, which has a heating value of 15,000 BTUs. Scum incineration will increase the sustainability of Metro Plant solids processing, and it will increase the amount of energy recovered at the SMB. Scum processing modifications will be implemented in another project, separate from this Facility Plan.

4.3.2 Sludge Feed Equipment

Capacity of existing sludge feed equipment is sufficient to dewater solids and to deliver dewatered solids to the existing incineration system. The recommended alternative for increasing solids processing capacity (see Section 7) requires additional sludge feed equipment, as selected for the recommended alternative to connect to the existing system.

Polymer storage and blending tanks are sufficient to meet existing and future requirements.

The following are capacity, condition, and level of service deficiencies in the sludge feed equipment that will be addressed by this Facility Plan:

- Additional sludge feed equipment is needed to connect the recommended alternative to the existing system for increasing solids treatment capacity.
- Existing cake bins need to be restored and, based on evaluation during preliminary design, the extraction screws will be replaced with larger ones.
- Additional cake pump capacity is needed to improve reliable service.

Figure 5 shows available routing of sludge through the existing sludge feed equipment.

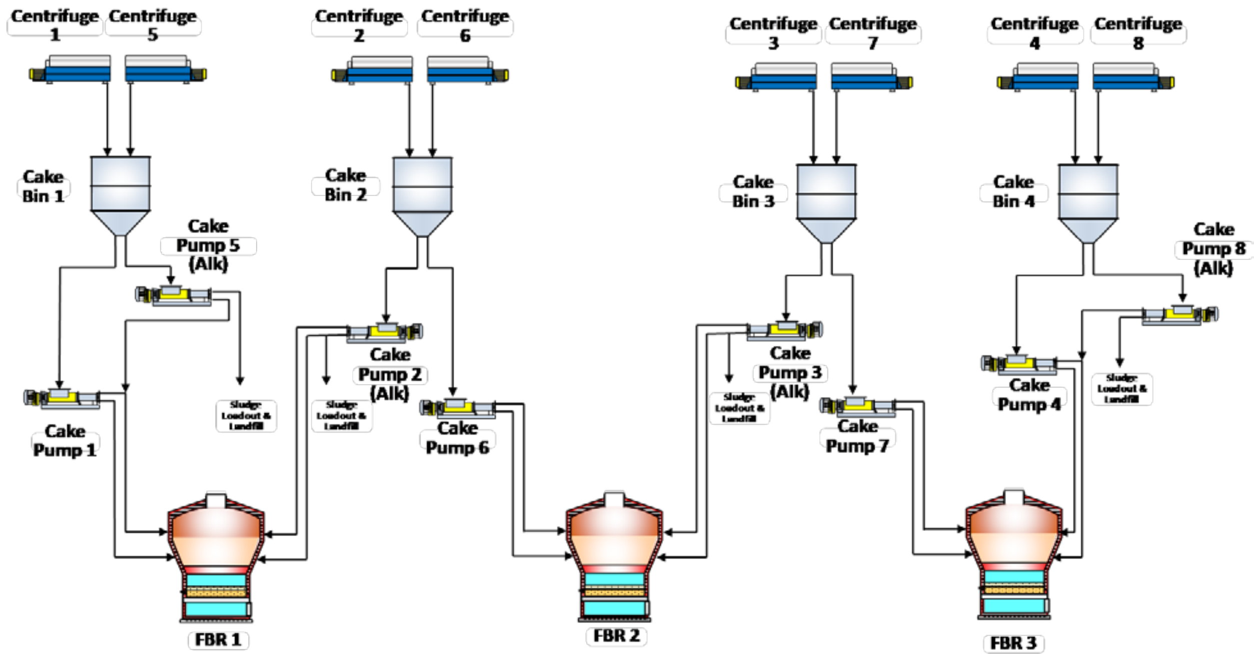


Figure 5. Metro Plant Solids Routing Options from the Centrifuges to the Incinerator

Centrifuges require ongoing maintenance within expected parameters. The time to repair one centrifuge can be long (occasionally more than 12 months), and SMB has two spare rotating assemblies to reduce the mean time for repair.

The cake bins have experienced corrosion and have been reskinned with stainless steel and painted patches. Extraction screws are worn and need to be replaced with higher-capacity units; extraction screws occasionally limit incinerator feed.

The existing system lacks flexibility to feed dewatered sludge from a given centrifuge to all incinerators. For example, dewatered sludge discharged from two centrifuges into cake bin 4 cannot be routed to Incinerator 1 (see Figure 5). Two cake pumps are required to feed each incinerator. Incinerators 1 and 3 each have a standby cake pump; Incinerator 2 does not. The result is that the right combination of six operating centrifuges and six operating feed pumps are needed to fully feed three online incinerators.

Additional cake pump discharge piping to improve system flexibility is currently being designed and implemented in another project, separate from this Facility Plan. This Facility Plan provides for increasing the capacity of each pump with an original equipment manufacturer (OEM) standard retrofit kit so that only one pump is required to feed each incinerator, which will further improve system flexibility.

4.3.3 Incinerator Train

The reliable capacity of one incinerator train in good condition is 90 dtpd,[1] and the reliable system capacity of three incinerator trains is 270 dtpd. Reliable system capacity is sufficient to

[1] Based on MCES experience at the Metro Plant:

Maximum capacity per train = 125 dtpd during optimum operating conditions

Average maximum capacity per train = 106 dtpd averaged over varying operating conditions treat current peak month solids loadings. However, additional solids treatment capacity is needed to perform the renewal work included in this Facility Plan and to process future solids loadings in a sustainable manner.

Two to three incinerator trains operate continuously to manage sludge inventory in the SSTs. Typically, one incinerator train can be down for a period of approximately 2 weeks before storage capacity is exceeded. MCES schedules two, 2-week preventative maintenance shutdowns per year for each incinerator train. In the event of extended shutdowns, due to the failure of any component of the train or for planned renewal work,[2] excess sludge is loaded out to a landfill to prevent sludge overflow at the SSTs. On occasion, MCES has curtailed preventative maintenance to avoid landfilling.

As equipment ages, it becomes less reliable causing an increase in the number of unplanned shutdowns and a corresponding decrease in system service availability. The net effect is reduced reliable system capacity. At any given time, a portion of the service availability can be recovered through renewal and replacement of system components.

The 2015 Solids Processing Improvements Project recovered reliable system capacity (system service availability increased from 0.75 to 0.85). During renewal, MCES landfilled 105,000 wet tons of sludge (5 percent of production).

As a part of this planning effort, MCES performed a Monte Carlo risk analysis to evaluate the risk of deferring additional solids treatment capacity through the planning period. This risk analysis used historic Metro Plant data, including planned and unplanned outages, variability in solids loading, and variability in SST level. The computer model applied future solids increases of 2 dtpd per year and scheduled renewal periods of 90 days per incinerator every 10 years to predict impacts on sludge storage and loadout requirements.

Results of the Monte Carlo risk analysis, which are included in Appendix H, are summarized as follows:

1. Sludge loadout will increase to 12 percent of annual solids loading by the end of the planning period and it will reach 15 percent during renewal periods. The estimated additional total landfill volume that would be required, without the fourth incinerator, is 2.9 million cubic yards.
2. Sludge storage will be full 1 to 2 times per year; 2.5 times during renewal periods

These risk values, which are anticipated to be higher for more extensive renewals, are not mitigated by modelled increased system reliability input (that is, service availability greater than 0.85). Curtailing maintenance is more effective than increasing system reliability at controlling inventory in the sludge storage tanks during non-renewal years, but this practice is not recommended because it shortens equipment service life and increases the risk of permit non-compliance. Curtailing maintenance is not effective for controlling inventory during renewal

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Reliable capacity per train = average maximum capacity x SERVICE AVAILABILITY

= 106 dtpd x 0.85

= 90 dtpd

Note: A service availability factor of 85 percent accounts for down time needed to perform maintenance, 41 days of planned maintenance plus 21 days of unplanned maintenance (54 days/365 days = 0.85).

[2] During the 2014 renewal project.

periods. Future requirements for landfilling Metro Plant solids, as determined using the Monte Carlo type risk analyses, do not meet the MCES level of service objectives for sustainability, asset preservation, or customer service.

The following are capacity, condition, and level of service deficiencies in the existing incinerator train that will be addressed by this Facility Plan. The reliable capacity of the incineration system is insufficient to perform renewal work and to serve regional growth in a sustainable manner.

Fluid Bed Incinerators

- The incinerator air distribution system needs to be renewed for three incinerators. The expansion joints need to be rehabilitated and damaged and plugged tuyeres need to be replaced. A new tuyere layout is proposed to address the most problematic outer rows of tuyeres.
- The refractory and shell need to be restored in targeted areas.
- The water sprays need to be rehabilitated using better materials.
- The overfire air system needs to be restored.
- The burners should be replaced with low NOx type burners and heat-up control.

Fluidizing Air Blowers and Flue Gas Duct

- The discharge check valves need to be replaced with improved design for longer service life.
- Hydraulic improvements, for example, baffles, should be implemented to mitigate duct erosion, based on hydraulic analysis during preliminary design, and expansion joints may need to be replaced.

Primary Heat Exchangers (pHEX) Renewal

- The pHEXs need to be renewed due to their 10-year expected service life.

Waste Heat Boilers Renewal

- Tubes should be replaced or shielded based on thickness measurements taken near the time of construction.
- Tube supports need to be re-designed to mitigate erosion and to accommodate increased steam production.

Baghouse Renewal

- The baghouse hoppers, which have been temporarily patched, need permanent repair, or replacement (to be determined based on an alternatives evaluation during preliminary design).

Wet Electrostatic Precipitator (ESP) Electrical Upgrades

- The mist eliminator needs to be upgraded with a larger and/or different type unit to achieve target wet ESP operating voltages.

4.3.3.1 Fluid Bed Incinerator

The FBI is shown, with the pHEX, in Figure 6. The incinerator unit is connected to the pHEX through the crossover duct.

The capacity of each FBI is 91,000,000 million BTUs per hour. This capacity corresponds to 130 dtpd throughput of sludge with a specific volatile solids content and water content, for a short duration and when the incinerator is in like-new condition.[3] The capacity of the FBIs is a function of fuel quality, physical limitations, and thermodynamics. The fuel quality anticipated in the original design had fewer volatile solids than the actual loads currently being received. The water content of the feed is based on the sludge blend ratio of gravity and flotation thickened sludges.

Typical FBI bed temperature ranges from 1,350 degrees Fahrenheit (°F) to 1,375 °F. The pHEX inlet temperature the crossover duct is maintained below 1,600 °F to limit the pHEX exit temperature to 1,325 °F, which is the outlet nameplate rating. Cooling water sprays at the top of the incinerator suppress the temperature in the crossover duct as needed. Elevated temperatures above about 1,600 °F in the bed or in the crossover duct will melt the ash into hard rock (known as slagging) and cause an incinerator shut down.

The structural joint around the metal plate is damaged and leaks sand into the plate expansion chamber. If the plate is unable to move freely within the expansion chamber, the plate might shift or catastrophically fail. Strain gauges installed on each incinerator during the 2015 Solids Processing Improvements Project are used during startups to measure plate expansion, and thus far, no shifts have been detected.

About 65 of 1,300 tuyeres in each reactor are plugged. Up to 130 tuyeres (10 percent) can be plugged without impacting fluidization, if the plugs distributed evenly across the plate.[4] The tuyere damage that has occurred in the Metro Plant incinerator is concentrated in areas close to the incinerator walls and appears to be related to differential expansion between the metal plate and the plate’s refractory cap. A new layout that removes the outer row and replaces the next two inner rows with higher-flow bubble caps has been proposed by the incinerator design engineer, Brian Copeland. Renewal of the incinerator air distribution system, including the structural joint around the metal plate and tuyeres, will require an extended shutdown, greater than 9 to 12 months.

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[3] During construction, each new incinerator was demonstrated at 130 dtpd, hence the maximum permit limit.

[4] Brian Copeland, incinerator design engineer

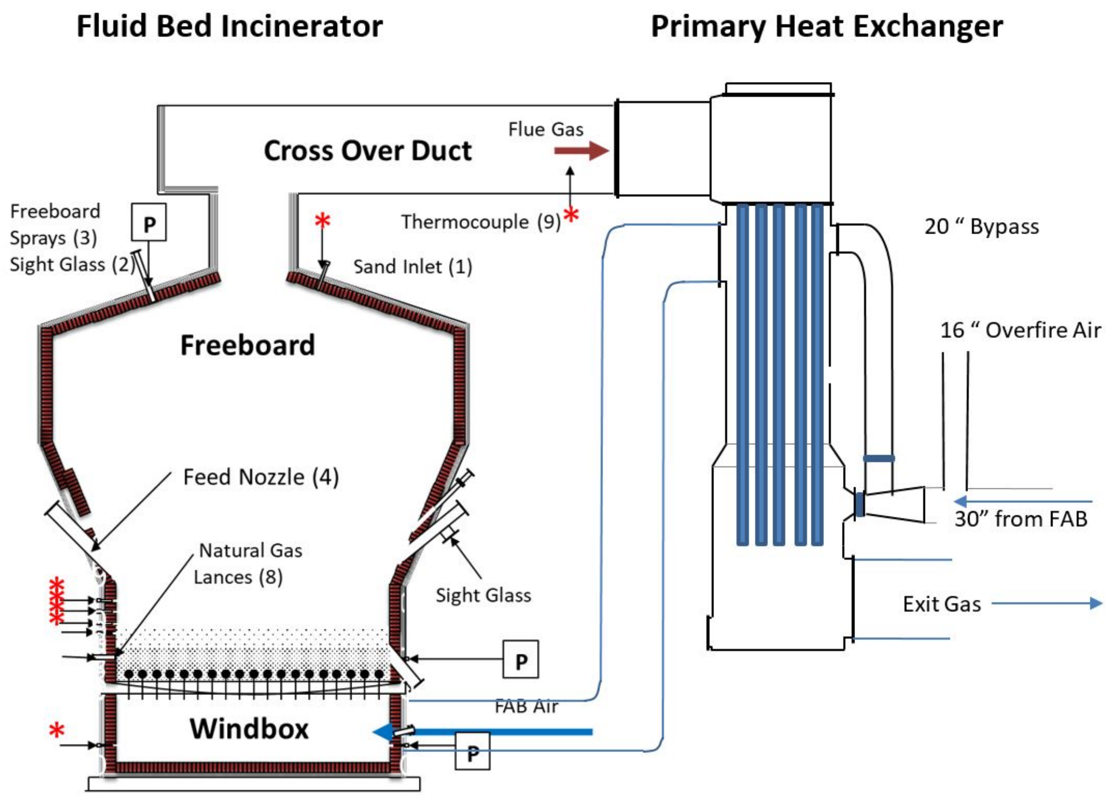


Figure 6. Fluid Bed Incinerator and Primary Heat Exchanger

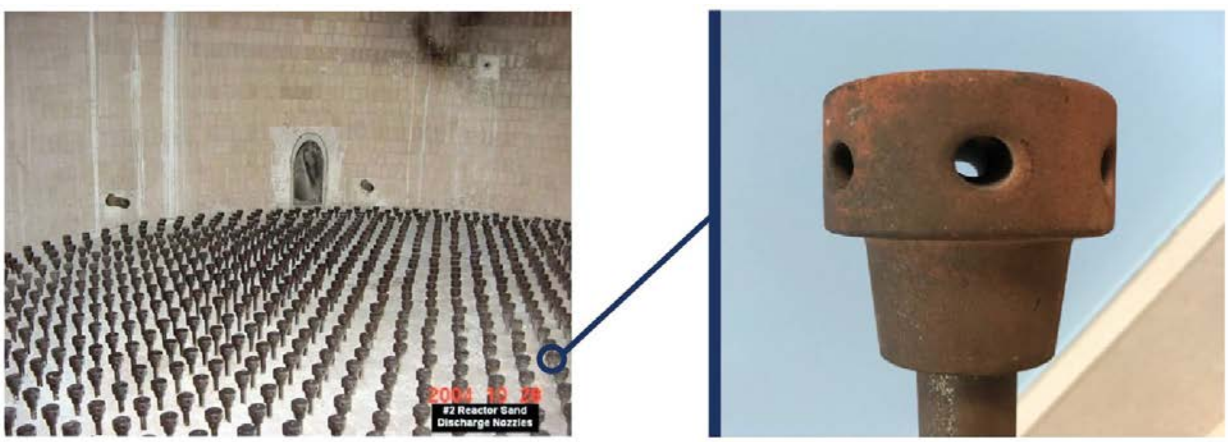


Photo 2. 1,339 tuyeres, which are 1-inch-diameter pipes with bubble caps, deliver combustion and fluidizing air to the incinerator

Water sprays require excessive maintenance to keep them in proper working order; due to extreme temperatures and the corrosive environment in the freeboard area, the nozzles are prone to falling off and the water jackets frequently leak.

The pre-heat burners used for startup are near end of service life and need to be replaced. Low NOx type burners would reduce the plant's Potential to Emit (PTE) level for NOx.

The cake feed ports were originally designed as an over bed feeding system with steam and compressed air addition at the entry point to facilitate distribution of the cake feed. These facilitators were difficult to keep in operation and have been abandoned. Follow-up testing of the feed system shows that adequate distribution is achieved by the over bed feeding without the use of supplemental systems.

The overfire air system, which was installed with the 2015 Solids Processing Improvements Project, is plugged with ash. The overfire air system re-directs some of the fluidizing air from the bottom of the bed to the top of the bed and is designed to increase the capacity of burning wet sludge. Although this feature has been found to be ineffective, overfire air should be restored to provide operation flexibility in controlling NO_X emissions.

4.3.3.2 Fluidizing Air Blower, Induced Draft Fan, and Flue Gas Ducts

The duct system that carries flue gas through the heat recovery and air pollution control equipment for each incinerator train is a push-pull system; a Fluidizing Air Blower and an Induced Draft Fan work together to maintain a zero-pressure set point at the top of the incinerator. The capacity of the Fluidizing Air Blower is 20,000 cubic feet per minute, which is sufficient to fluidize the bed and to provide excess oxygen for the combustion process. The capacity of the Induced Draft Fan is 23,000 cubic feet per minute at 100” w.c., which is sufficient to pull flue gas through to the stack. Replacement of the Induced Draft Fan motors in the 2015 Solids Processing Improvements Project allowed the fans to operate consistently below the motor service factor.

The check valves on the Fluidizing Air Blower discharge piping prematurely failed and have been removed. These check valves need to be replaced and re-designed for a longer service life.

The harsh environment created by flue gas and maldistribution of ash in the flue gas stream has caused corrosion and erosion issues at various locations within the heat recovery and air pollution control equipment (as discussed under those sections) and within the duct segments between equipment (discussed herein).

Leaks in the flue gas duct have been attributed to erosion of the expansion joints and localized corrosion of the carbon steel duct at cold spots. Because the duct is operated at negative pressure, any holes draw air from the environment and rob induced draft fan capacity. As rule of thumb, air in-leakage of greater than 25 percent of the total flow should be corrected. Leak mitigation improvements implemented in the 2015 Solids Processing Improvements Project reduced air in-leakage, as determined from oxygen measurements, from 50 percent to 20 percent.

The carbon steel crossover duct experienced severe corrosion and was replaced with stainless steel in the 2015 Solids Processing Improvements Project. Corrosion was caused by a failure of the insulation and coating system. As the hot acid gases moved through cracks in the refractory, the acids cooled and condensed, which corroded the duct. The expansion joints that were replaced throughout in the 2015 Solids Processing Improvements Project are anticipated to need another renewal by the time of construction (based on a condition assessment and alternatives evaluation during preliminary design.)

4.3.3.3 Primary Heat Exchanger

The capacity of the pHEX is aligned with the capacity of the incinerator.

The pHEXs were replaced during the 2015 Solids Processing Improvements Project. Upon inspection of those units, cracks between the heat exchanger pipes and the tube sheet were found that would have eventually caused the tubes to fall out of the tube sheet (as has been experienced at other facilities). Because the expected service life of the pHEX is 10 years, these units should be renewed under this Facility Plan.

Photo 3. Cracking in the primary heat exchanger tubes at the tube sheet will cause the tubes to fall out of the tube sheet.

4.3.3.4 Waste Heat Boiler

The WHB system includes one unit that houses two banks of water tubes, called super heaters and five banks of water tubes, called evaporators; the second unit houses two banks of water tubes, collectively called the economizer. These WHB components are shown in Figure 7.

The WHB produces approximately 30,000 pounds of steam per hour at a pressure of 450 psi and is sufficient for normal operating conditions.

Occasionally, when processing dry sludge, operators must reduce incinerator feed to reduce the inlet temperature to the WHB. Re-evaluation of the steam system for actual operating conditions by the original equipment manufacturer indicates that the WHB can be re-rated if superheater supports are re-designed.

WHB leaks are the biggest factor in the loss of run time for the incinerator trains. The unpredictability of the leaks and efforts to quickly mitigate leaks to avoid landfilling places significant pressure on operating staff. A summary of the shutdowns resulting in WHB tube leaks is shown in Figure 8.

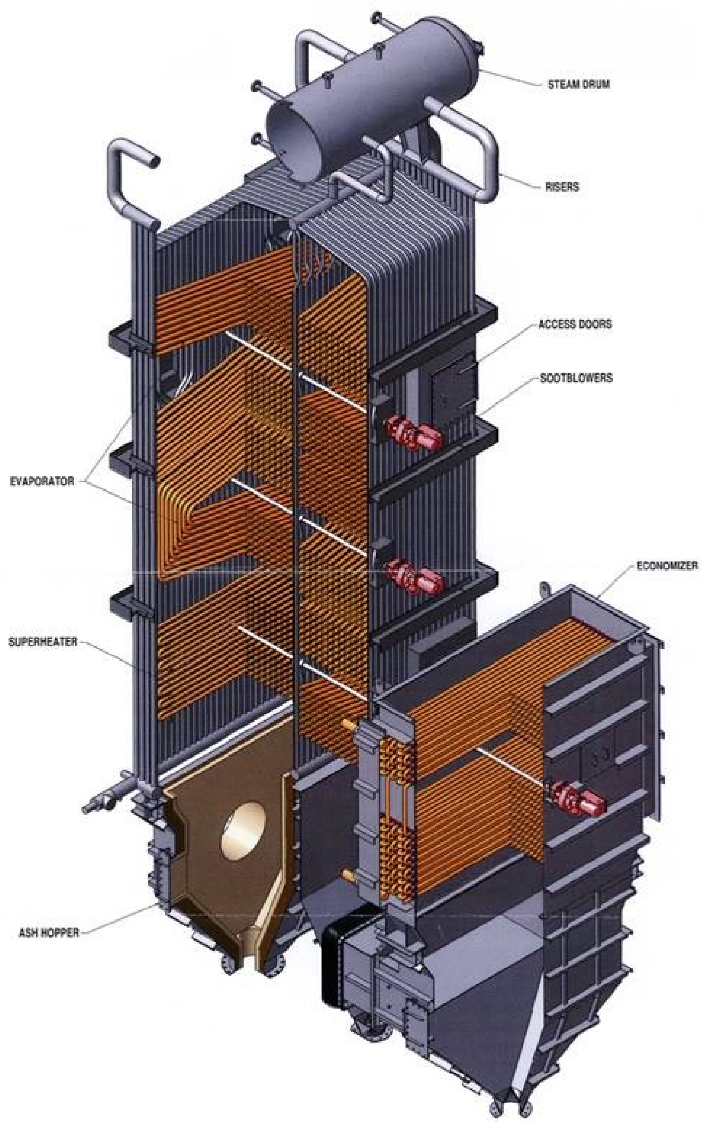


Figure 7**. Waste Heat Boiler Components**

The WHB experienced leaks during commissioning that were attributed to fabrication defects, and subsequent boiler leaks (prior to the failure of the economizer in incinerator train 2) were considered acceptable because the annual cost of repair was a small percentage of the capital cost for a new WHB. As a part of this planning effort, MCES began mapping WHB leaks and collected samples of damaged tubes for evaluation. Whole banks of tubes were targeted (based on leak history) for replacement during the 2015 Solids Processing Improvements Project to complete forensic analyses on the existing tubes. MCES also completed a hydraulic analysis.

Following the 2015 Solids Processing Improvements Project, MCES implemented a continuous renewal strategy consisting of tube replacement and shielding. The boiler tube repair and replacement schedules are presented in Table 8. This strategy and the 2015 Solids Processing

Improvements Project have reduced the number of days down due to boiler leaks from 109 days in 2012 to 46 days in 2017, which is considered acceptable.

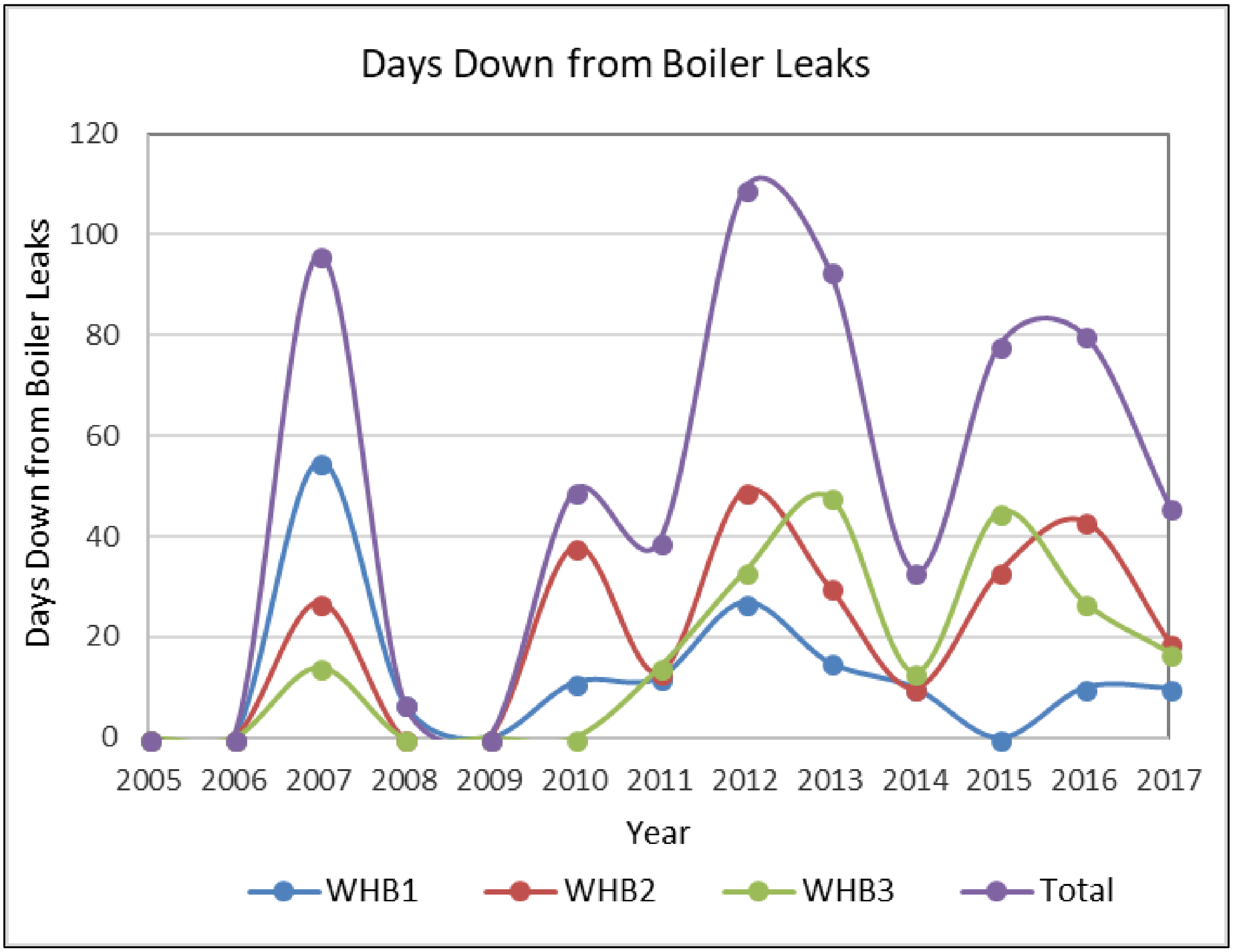


Figure 8. History of Incinerator Shutdowns Due to Waste Heat Boiler Leaks

Table 8. Boiler Tube Repair and Replacement Schedules

	Preventative Repair Criteria	
2" Evaporator UT Measurement	**1-1/4" Superheater and Economizer UT Measurement**	**Repair**
0.15 – 0.12 inches	0.16 – 0.13 inches	Install tube shield
0.12 – 0.08 inches	0.13 – 0.09 inches	Pad weld and install tube shield
0.08 inches or less	0.09 inches or less	Replace tube segment and install tube shield
0.17 – 0.11 inches	0.12 – 0.08 inches	Pad weld
0.11 inches or less	0.08 inches or less	Replace tube segment and install tube shield
	Boiler Tube Replacement Frequency	
Superheater Bundle	11 – 22	2
Evaporator Harp	5 – 10	3
Evaporator Bundle	15 – 30	10
Economizer Bundle	25 – 50	2

4.3.3.4.1 WHB Inlet Duct

Connecting ducts between the WHB and the pHEX have exhibited erosion damage, which has been repaired and baffles have been installed to straighten out the velocity and particle distribution in the gas flow.

4.3.3.4.2 WHB Superheaters and Evaporators

Leaks occur at discontinuities, for example, tube supports, access doors, which create highly erosive eddies. Leaks also occur at tubes closest to the waterwall, at bends, and connections to the waterwall. Computer analysis of the particle velocity distribution confirms that a greater number of particles are hugging the waterwall and velocities are higher near the waterwalls.

During the 2015 Solids Processing Improvements Project, MCES observed that most of the tubes have 70 percent or more of their wall thickness (a corrosion/erosion allowance), and some tubes next to the WHB walls, where most of the leaks have occurred had been flattened on one side next to the waterwall by erosion.

4.3.3.4.3 WHB Economizer

In 2014, during construction of the renewal project, the economizer in incinerator train 2 experienced catastrophic failure. In response, MCES authorized a change order to the construction contract that replaced all economizers and incorporated design improvements.

The economizer removed from incinerator train 2 weighed about 10 tons more than it weighed upon installation. Ash had filled chambers between the tube sheets and the outer housing, and a growth of hardened ash had blocked about half of the cross-sectional area, which doubled the velocities through the unit. Forensic examination of one of the tubes determined that abrasion between the tube and the tube sheet caused leaks in that area. The tubes were not fixed to the tube sheet to allow for thermal expansion and contraction.

Economizers were constructed with shell material that was too thin. Prior to the 2015 Solids Processing Improvements Project, MCES had to install additional access doors to address premature erosion of tubes along the walls of the units (the outer tubes were coated). While in operation, the economizer housing puffed rhythmically in and out about 2 inches from center.

The new economizers have one less row of tubes (to reduce overall velocity), higher wall thickness (to increase rigidity), and extra thickness of the tubes through the tube sheet.

Photo 4. Forensic examination determined that abrasion between the tube and the tube sheet had caused failures in this area (economizer, incinerator train 2).

4.3.3.5 Secondary Heat Exchanger

The capacity, condition, and level of service of the secondary heat exchanger are sufficient to remove visible water vapor from the stack plume.

The secondary heat exchanger (sHEX) experienced erosion at the pipe inlets, which has been addressed by the installation of abrasion pipe inserts.

The 2015 Solids Processing Improvements Project installed a secondary heat exchanger bypass that diverts a portion of the hot flue gas from the WHB directly to the baghouse. The bypass allows the baghouse to be operated at higher temperatures above 330°F (the dew point temperature of sulfuric acid) to prevent condensation of acid gases inside the baghouse.

4.3.3.6 Baghouse

The capacity of the baghouse is aligned with the particulate loads it receives.

Baghouse condition has been difficult to maintain due to erosion and corrosion. The baghouse was originally designed with a bypass to allow the use of fuel oil for incinerator start up. Fuel oil generates soot, which needs to bypass the baghouse to prevent soot blinding of the bags. These bypasses were severely corroded and would not shut off completely during normal operation, resulting in ash carryover to the scrubber. Although the scrubber removed ash, the scrubber water recycled ash (mercury-laden carbon contained with the ash in the flue gas) back to secondary treatment and elevated effluent mercury concentrations. Because MCES uses natural gas instead of fuel oil for startup, in 2015 Solids Processing Improvements Project these bypasses were removed, rather than rehabilitated, to reduce the amount of ash carryover into the scrubber.

To address severe corrosion observed on the baghouse covers, the original carbon steel covers with insulation lining on the inside were replaced with stainless steel, externally-insulated covers. As noted under Section 4.3.3.5, a secondary heat exchanger bypass has been installed to elevate temperatures inside the baghouse to prevent corrosion caused by acid gas condensation.

Erosion has been observed inside the baghouse. If bags are missing or torn, ash impinges on the cleaning apparatus, eroding away the apparatus over a 2-year operating period.

Currently, there are holes in all baghouse hoppers (due to erosion) that have been temporarily patched. Rehabilitation (or replacement) of the hoppers, which are constructed of 1/4-inch welded steel plates, will require an extended shutdown of the incinerator train, anticipated to be between three and six months. Each baghouse is 12 feet wide by 37 feet long and 30 feet tall with three hoppers.

Baghouse reliability is needed to prevent mercury-laden carbon contained in the flue gas from entering the wet scrubber and recycling back with the scrubber water through secondary treatment. Mercury can build up in the secondary treatment system to cause exceedance of permitted effluent limits. The cloth filter bags must be monitored and replaced when damaged. MCES' current maintenance strategy, which involves dye testing the bags during preventative maintenance and monitoring mercury in the scrubber water recycle, has been effective in controlling effluent mercury. The baghouse can operate with one chamber out of service with no increase in solids loadings to the scrubber.

4.3.3.7 Wet Scrubber

The wet scrubber is the ring-jet type and has three sections. The first section is a once-through cooling section, the second section is a recirculating acid gas removal section with caustic addition, and the third section is an impingement water spray section where particulates are removed. Capacity and condition of the wet scrubber are sufficient.

Caustic addition has been optimized so that the minimum amount of chemical is needed to control sulfur dioxide emissions.

The scrubber uses plant effluent water for cooling, particulate removal and caustic dilution. To increase cooling, MCES increased the quench from 175 gallons to 225 gpm. Additional cooling was accomplished at the packed tower by increasing the size of the seven nozzles from 3/4-inch to 1 inch. These modifications effectively removed more condensable particulates.[5] Additional scrubber modifications to further increase the removal of condensable particulates are currently being designed and implemented in a project, separate from this Facility Plan.

[5] Flue gas cooling increases with cooler water and higher water flow rates. Condensable particulates decrease with lower flue gas temperature.

4.3.3.8 Wet Electrostatic Precipitator and Mist Eliminator

Capacity and condition of the wet electrostatic precipitator (wet ESP) are sufficient. MCES has recently (2017) upgraded the controls in accordance with the manufacturer's recommendation.

Performance of the wet ESP is sufficient to meet existing permit limits. However, desired optimization efforts have been limited by low operating voltages (typically less than 30,000 volts). The target operating voltage is 50,000 volts or more.

Engineering emissions tests conducted for this Facility Plan suggest that 1) lower emissions levels for particulates (specifically PM2.5)[6] and lead can be achieved with higher operating voltage in the wet ESP and 2) higher operating voltage can be achieved by reducing the water vapor at the inlet to the wet ESP.

Wet ESP performance is limited by the mist eliminator and should be replaced with a larger or different type unit that removes more water vapor so the wet ESP performance can be optimized.

4.3.4 Boiler Makeup Water System

The capacity, condition, and level of service of the boiler makeup water system are sufficient for the existing system. Additional capacity will be needed, as required to align with the recommended alternative for increasing solids processing capacity.

4.3.5 Carbon Storage and Delivery System

Capacity and condition of the carbon storage and delivery system are sufficient.

Operation has experienced plugging at the inlet of the storage tank. Because the reliability of this system is critical for the operation of all three incinerator trains, the following is a level of service deficiency in the carbon storage and delivery system that will be addressed by this Facility Plan:

- An additional carbon storage tank with manual load-in is needed to improve system reliability.

4.3.6 Steam Turbines and Auxiliary Boilers

Capacity and level of service for the steam turbines and the auxiliary boilers are sufficient through the planning period. The steam heat and electric power generation system provide the flexibility to optimize energy use, based the purchase prices of natural gas and electricity.

The following potential condition deficiency of the steam turbines will be addressed by this plan:

- The steam turbines will be replaced, pending a condition assessment during design.

The condition of the auxiliary boilers is considered adequate.

The future condition of the steam turbines at the time of renewal construction is questionable. The expected service life of a steam turbine is around 20 years, and the maintenance requirements are increasing for the condensing steam turbine. The turbine rotor was repaired in 2009 due to high vibration and moisture entering the steam supply. The generator rotor was

[6] PM 2.5 is a subset of total particulates that have a diameter equal to or less than 2.5 microns.

rewound in 2015 due to high vibration. A new generator rotor was ordered in 2018 due to continued vibration issues.

4.3.7 Ash Collection and Conveyance from Solids Management Building

Capacity and condition of ash collection and conveyance from SMB are sufficient. The following is level of service deficiency that will be addressed by this Facility Plan:

- Dense phase transport of ash from the WHB and baghouse needs to be replaced with a vacuum type system to mitigate ash deposition on equipment and structures within SMB.

Although it would be advantageous to replace the other segments of dense phase transport system between the SMB and FI2/408 with a vacuum type system, the distance of the other segments is beyond the capability of vacuum transport.

The dense phase ash transport to the storage silos is continuous, and it requires frequent maintenance and testing to maintain its reliability. Because it directly affects incineration capacity, ash collection and conveyance from SMB is well maintained. Control valves, air booster stations, and pipe sections and fittings are programmatically replaced.

The dense phase transport system often plugs around the air booster stations. Frequent small erosion leaks from control valves and piping, dispense material that accumulates as an unsightly dust layer on the operating floor, equipment and internal building structures within a wide area. This creates a housekeeping burden that could be alleviated with a vacuum transport system.

A vacuum transport system is vulnerable to erosion leaks, but air would leak into the hole rather than out of it.

4.3.8 Sludge Loadout and Landfill

Capacity, condition, and level of service of the sludge loadout and landfill system are insufficient to reliably backup one incinerator train through the planning period. The deficiencies described herein are being designed and implemented in a current project, separate from this Facility Plan, to address reliability needs until additional solids processing capacity can be constructed.

System design capacity of 188 dtpd is limited to 93 dtpd. Only one train can be operated at a time. The transport rate of lime kiln dust to the SMB is the current limiting factor.

Even though it is the same design used for transporting ash from SMB to the storage silos, dense phase ash transport of ash and lime kiln dust from the storage silos to SMB has been more difficult for MCES to maintain because of its infrequent use. The return ash and lime kiln ash transport systems required significant cost to commission for use during the 2015 Solids Processing Improvements Project.

4.3.9 Solids Management Building HVAC

Capacity, condition and level of service for the SMB HVAC system are sufficient for existing conditions. The recommended alternative for increasing solids treatment capacity may require addition HVAC equipment in SMB.

The following capacity deficiency will be addressed by SMB HVAC Improvements:

- Expand SMB HVAC system as needed to accommodate the alternative recommended for increasing solids treatment capacity.

4.4 Ash Loadout and Storage

Capacity, condition and level of service for ash loadout and storage are considered adequate. The following level of service deficiency may be addressed by **Ash Loadout and Storage Improvements**, based on future needs:

- Miscellaneous instrumentation and control modifications may be needed to facilitate the ash beneficial use program (to be determined during design).

Similar problems with the dense phase ash system occur between the storage silos and the loadout garage, as reported under Section 4.3.7 above. Parts are programmatically replaced, and remote monitoring cameras are used to identify leaks in unstaffed areas.

Miscellaneous control improvements for remote monitoring and/or remote control of equipment at the loadout bays from the SMB operator control room in SMB would support the ash beneficial use program. These improvements, if any, will be determined during design

4.5 Solids Management Building Effluent Water Service

Three effluent water pumps in the Metro Plant tunnels provide effluent water service to the SMB. Condition and level of service of the effluent water service are sufficient through the end of the planning period. Two to three effluent pumps run continuously. The following capacity deficiency in the SMB effluent water service will be addressed by this Facility Plan:

- Additional effluent water flow will be needed in the SMB, depending on the recommended alternative for additional solids processing capacity.

5.0 Alternatives Development

Many alternatives for adding solids processing capacity at the Metro Plant were initially listed for consideration. Some of the alternatives were dismissed for further evaluation because they were obviously more expensive or were not technically sound. For example, MCES dismissed the alternative of alkaline stabilization and land application for the Metro Plant because it was deemed a failed technology.

The initial list of alternatives was narrowed down to the four discussed herein, which maximize the use of the existing incinerators. The four alternatives were further developed conceptually for this evaluation. The alternatives were sized to increase average solids processing capacity by 75 dtpd, which is the difference between the projected average solids load at the end of the planning period (300 dtpd) and an existing system incineration capacity of 225 dtpd.[1]

[1] Incineration system capacity of 225 dtpd corresponds to a low service availability factor of 0.70, experienced prior to the 2015 Solids Processing Improvements Project.

5.1 Alternative 1: Fourth Incinerator

Alternative 1 includes construction of a fourth incinerator train in an expansion of the existing SMB.

The capacity of this alternative is 90 dtpd, which exceeds the required capacity and matches the existing three incineration trains. Improvements currently under construction at the three existing units would be included in the Alternative 1 design. Additional steam turbine capacity would be installed to provide additional energy recovery. The ash product is very high in phosphorus, a fertilizer, which can be recycled for agricultural benefit.

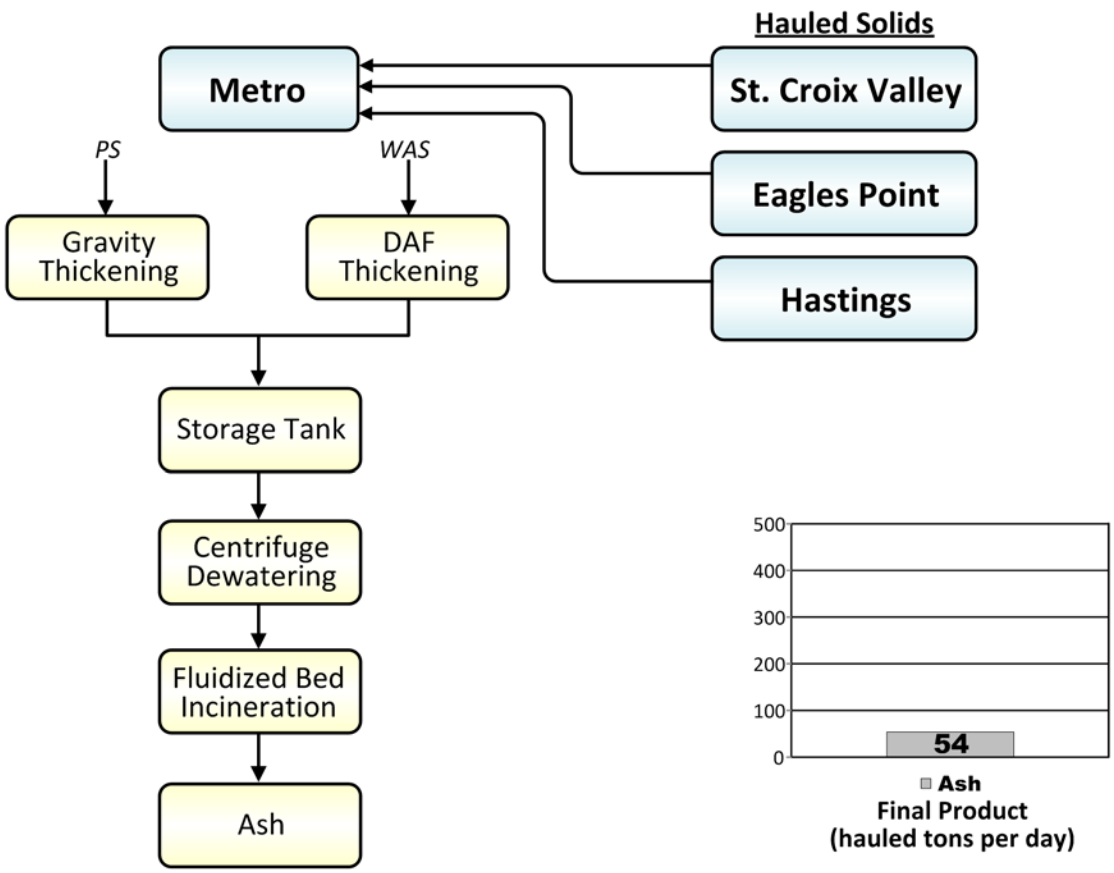


Figure 9. Alternative 1 – Fourth Incinerator

5.2 Alternative 2: Digest and Incinerate

Alternative 2 includes the construction of an anaerobic digestion complex in the space next to the SMB to digest a portion of the solids (150 dtpd). Digested solids would be dewatered and fed to the existing incineration process. Assuming 50 percent solids destruction in the digestion process, loading to the incinerators would be reduced by 75 dtpd (150 x 0.5 = 75).

The digestion complex would be provided with combined heat and power (CHP) engine recovery system, fueled by digester gas.

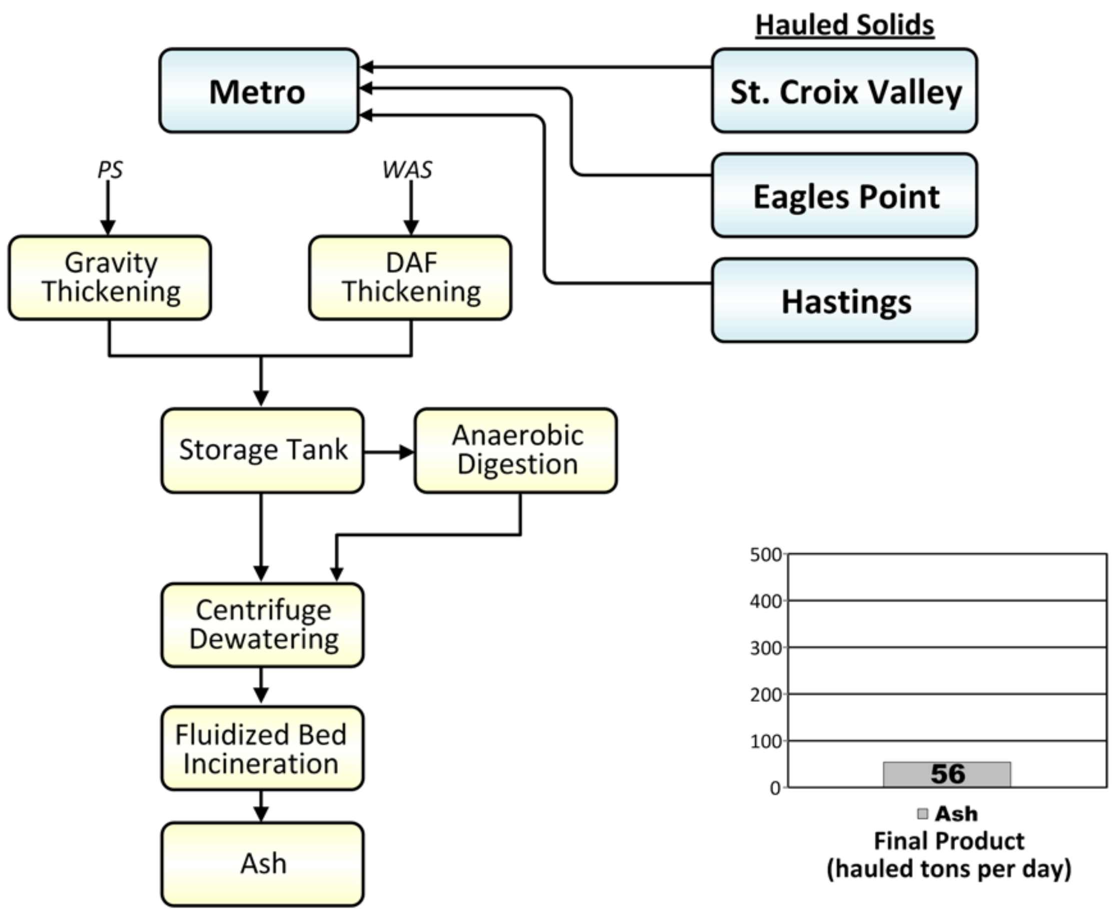


Figure 10. Alternative 2 – Digest and Incinerate

5.3 Alternative 3: Digest, Dry, and Sell

Alternative 3 includes the construction of a digestion complex to digest a portion of the solids (75 dtpd). Assuming 50 percent solids destruction in the digesters, 40 dtpd of digested solids would be dried and pelletized. Pellets would be sold as a fertilizer.

Digester gas would be used as fuel for the drying facilities.

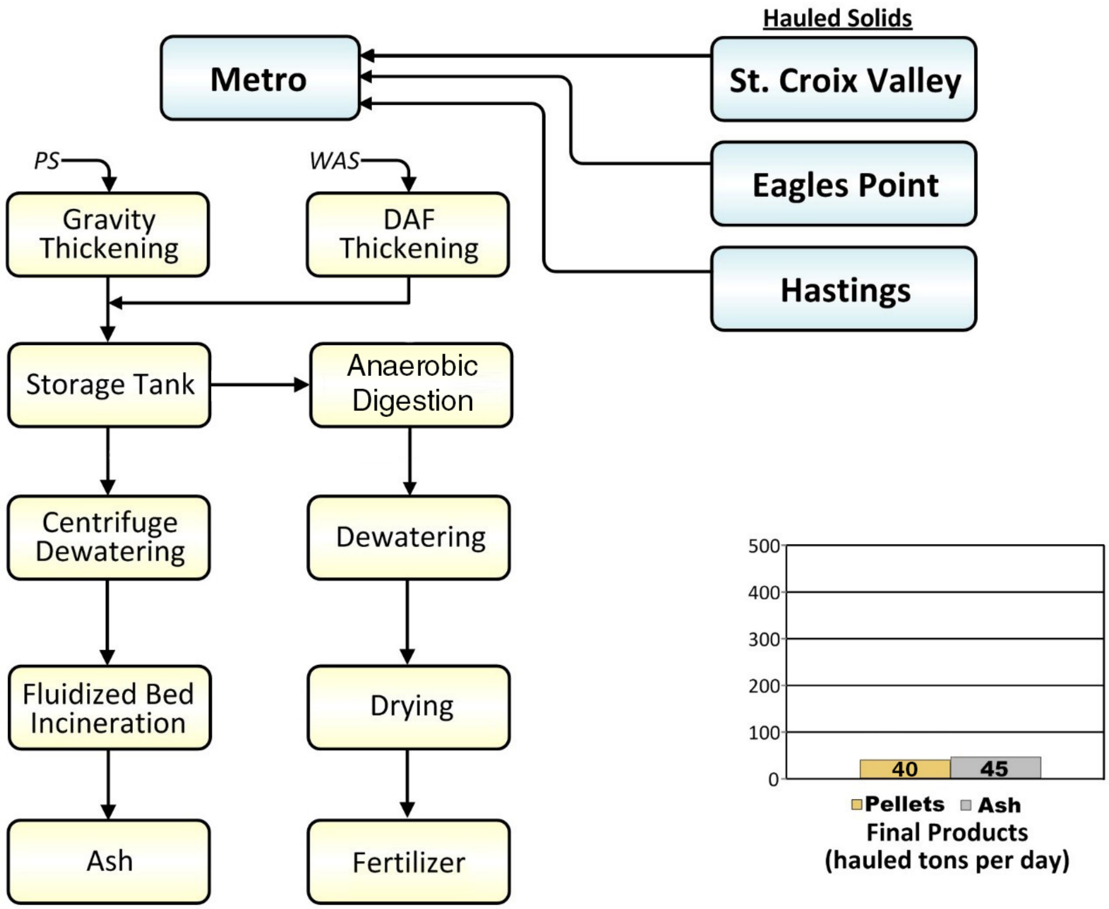


Figure 11. Alternative 3 – Digest, Dry, and Sell

5.4 Alternative 4: Digest and Land Apply

Alternative 4 includes the construction of an anaerobic digestion complex to digest a portion of the solids (75 dtpd). Digested solids would be dewatered and then land applied for soil amendment.

Assuming 50 percent solids destruction in the digesters, 40 dtpd of digested solids would be dewatered and stored onsite for seasonal land application. Seasonal land application is limited to spring and fall which concentrates the loading (i.e., 40 dtpd x (365 days/90 days) = 160).

The digestion complex would be provided with a combined heat and power (CHP) engine recovery system, fueled by digester gas.

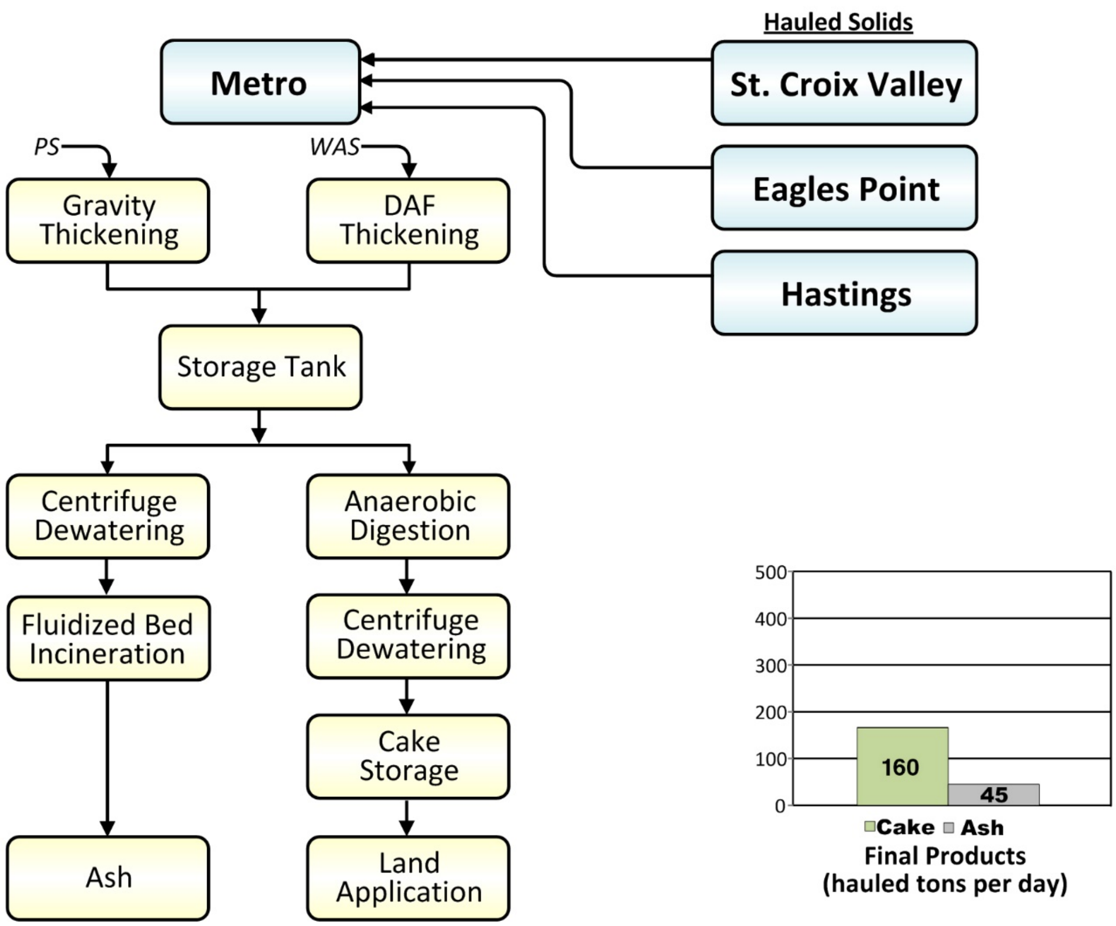


Figure 12. Alternative 4 – Digest and Land Apply

6.0 Evaluation of Alternatives

This evaluation includes economic considerations, sustainability, community impacts, and other non-monetary factors. A set of renewal projects for the existing incinerators 1, 2, and 3, which would be common to each of the alternatives are described in Section 7.

6.1 Present Worth Analysis

The 20-year net present worth of capital, operating, and maintenance costs for each alternative was estimated and referenced to the 2010 existing condition. Capital costs are based on the project scopes summarized in Table 9. Table 10 compares the net present worth of each alternative relative to existing (2010) operating and maintenance costs. The detailed cost data are included in Appendix I.

Table 9. Project Scope Summary for Alternatives

Alternative 1: Fourth Incinerator	Alternative 2: Digest/Incinerate	Alternative 3: Digest, Dry, Sell	Alternative 4: Digest, Land Apply Cake
Centrifuges and cake pump, fourth incinerator with WHB and steam turbine	Digesters, CHP	Digesters, dryer, pellet storage	Digesters, CHP, cake storage, and odor control

The Fourth Incinerator is the most cost-effective alternative to meet the region's wastewater needs. Adding a fourth incinerator costs 50 percent less than the lowest digestion alternative to construct, operate, and maintain.

Alternative 1: Fourth Incinerator is a net producer of electricity and, compared to the other alternatives, it has excellent energy recovery. Alternative 4: Digest and Land Apply is the biggest net producer of electricity, but it is the highest cost alternative, $200M more in present worth of capital and operating and maintenance costs. This alternative also significantly increases ash and solids handling requirements by $2M per year.

The net energy produced by the second incineration alternative, Alternative 2: Digest and Incinerate, is reduced by an increase in the supplemental fuel required to incinerate solids with reduced volatile content (destroyed by digestion). Alternative 3: Digest, Dry and Sell produces less electricity than any other alternative and requires supplemental natural gas due to the fuel requirement for drying.

Table 10. Alternatives Cost Comparison Summary

Cost Components	Existing Condition (2010)	Recommended Alternative: Alternative 1: Fourth Incinerator	Alternative 2: Digest/ Incinerate	Alternative 3: Digest, Dry, Sell	Alternative 4: Digest, Land Apply Cake
Capital					
Preliminary Construction Estimates	$ -	$75,000,000	$125,000,000	$130,000,000	$176,000,000
Engineering (20%)	$ -	$15,000,000	$25,000,000	$26,000,000	$35,000,000
Contingency Value (50%)	$ -	$37,000,000	$63,000,000	$65,000,000	$88,000,000
Total Near-Term Capital Costs (subtotal)	$ -	**$127,000,000**	**$213,000,000**	**$221,000,000**	**$299,000,000**
Present Worth of Salvage Value[1]	$ -	**$(28,000,000)**	**$(44,000,000)**	**$(2,000,000)**	**$(51,000,000)**
Present Worth of Replacements[1]	$ -	**$ -**	**$ -**	**$-**	**$-**
Present Worth of Capital[1]	$ -	**$99,000,000**	**$168,600,000**	**$189,000,000**	**$248,000,000**
Operating and Maintenance (O&M)	**Annual Cost**	**Alt 1: Incremental Annual Cost**	**Alt 2: Incremental Annual Cost**	**Alt 3: Incremental Annual Cost**	**Alt 4: Incremental Annual Cost**
Ash & Solids Handling[2]	280,000	25,000	32,000	(30,000)	1,960,000
Electricity[3]	1,100,000	(200,000)	(1,900,000)	800,000	(900,000)
Natural Gas	(1,370,000)			260,000	
Incinerator Auxiliary Fuel (No. 2 fuel oil)			1,810,000		
Net Energy	(270,000)	(200,000)	(90,000)	1,060,000	(900,000)
Chemicals	2,440,000	250,000	1,170,000	420,000	710,000
Labor	6,990,000	360,000	1,420,000	2,610,000	1,660,000
Additional Maintenance		500,000	870,000	650,000	600,000
Annual O&M Subtotal	$9,440,000	$940,000	$3,400,000	$4,710,000	$4,030,000
Present Worth of O&M[1]	180,000,000	$18,000,000	$65,000,000	$90,000,000	$77,000,000
Present Worth of Capital and O&M		**$117,000,000**	**$234,000,000**	**279,000,000**	**325,000,000**

[1] Note: 20-year Net Preset Worth (nominal discount rate = 4%, escalation rate = 3.5%). Includes 20% growth through the planning period.
[2] Transportation and landfill of ash and/or transportation and land application of solids product.
[3] Electricity cost after credit for power produced by steam turbine or combined heat and power engine generator systems.

6.2 Evaluation of Non-Monetary Factors

Alternative 1: Fourth Incinerator is the most sustainable alternative to meet the region's wastewater needs. It will have the lowest community impact. Alternative 1: Fourth Incinerator provides for continuity with existing facility operating requirements will increase the reliability of the region's wastewater treatment system.

Non-monetary factors are those factors that cannot be quantified in terms of financial measurements as they relate to considerations based on individual perceptions and beliefs or they relate to considerations whose value are not well enough understood to have developed a consensus for measurement of the factors. The non-monetary factors considered for this evaluation are listed in Table 11.

Scoring of the alternatives with respect to non-monetary factors is not conducive to selection of the appropriate alternative. Converting a factor to a score is an accounting approach, which may prevent an in-depth discussion with customers about these issues. It is more important to engage the community in a dialogue about the balancing of competing issues.

Table 11. Summary of Non-Monetary Evaluation Factors

Sustainability	Community Impact	Reliability
• Air emissions: volatile organic carbon, NOx, and carbon monoxide • Energy recovery and consumption • Greenhouse gas emissions: Carbon dioxide, methane, and nitrous oxide • Fate of residuals • Water quality discharges to all receiving waters	• Standard of living (Impacts on the economy of the region by spending more of the region's financial capital to construct higher cost alternatives • Truck hauling, safety • Odors • Offsite land requirements	• Continue the Council's ability to provide reliable treatment to levels lower than the permit levels • The reduction of risk of outages or process upsets and the negative • The flexibility to adapt to future changes

6.2.1 Sustainability

6.2.1.1 Air Quality

Air emissions from Alternative 1 are lower than the other alternatives due to the controlled combustion conditions and advanced air pollution control equipment in the incinerator trains. Air emissions for Alternative 3 would be slightly higher, but comparable to Alternative 1 because the dryer would have similarly robust emissions control equipment. Emissions from the gas engine generator included in Alternative 2 and Alternative 4 causes these alternatives to rank lower in terms of air quality.

6.2.1.2 Energy Recovery

Alternative 1 has excellent energy recovery, compared to the other alternatives. The heat recovery system on the incinerators generates a 1.5 megawatt surplus of electrical power or the equivalent of steam heat from the operation. Alternative 1 energy production reduces reliance on external utility capacity, resulting in a delayed need for electrical energy production capacity construction by the power utility. Reducing power demand lowers the amount of greenhouse gas and other emissions associated with the production of power in the region.

Alternative 4 would produce about the same amount energy as Alternative 1, and it would consume less energy. However, this alternative is the highest cost alternative, $200 million more in present worth of capital and operating and maintenance costs.

Alternative 2 produces the most digester gas to fuel a CHP system, but the electricity production is offset by the need for supplemental fuel in the combustion process; volatile solids reduction by the digestion process lowers the fuel value of the incinerator feed solids. In theory, biogas could be used as a supplemental fuel, but fuel oil is preferred over biogas because it combusts more completely in the bed rather than the freeboard. The alternative analysis assumes that biogas will be used for power generation (CHP).

Alternative 3 produces biogas, but experiences with other systems indicate that the biogas will be consumed by the drying process with no net energy surplus. In addition, the dryer diverts feedstock from the incineration process, reducing the output of the steam turbine generator system, such that the solids system is no longer energy self-sufficient.

6.2.1.3 Greenhouse Gas Emissions

Table 12 lists greenhouse gas (GHG) emissions estimates for the Metro Plant solids treatment alternatives. The listed values are such a small fraction of other sources in the Twin Cities region and in the State of MN, that the alternatives were considered equivalent with respect to GHG emissions.

Table 12. Greenhouse Gas Emissions Estimates for Alternatives

Alternative	Tons/yr as CO2	Equivalent Number of Cars[1]
Alternative 1: Fourth Incinerator	66,000	13,000
Alternative 2: Digest and Incinerate	52,000	10,000
Alternative 3: Digest, Dry and Sell	66,000	13,000
Alternative 4: Digest and Land Apply	43,000	8,000

[1] The average car is driven 11,400 miles per year and gets 21.6 mile per gallon (mpg) fuel efficiency. The GHG emission per average car is 6.6 tons per year CO2 equivalent.

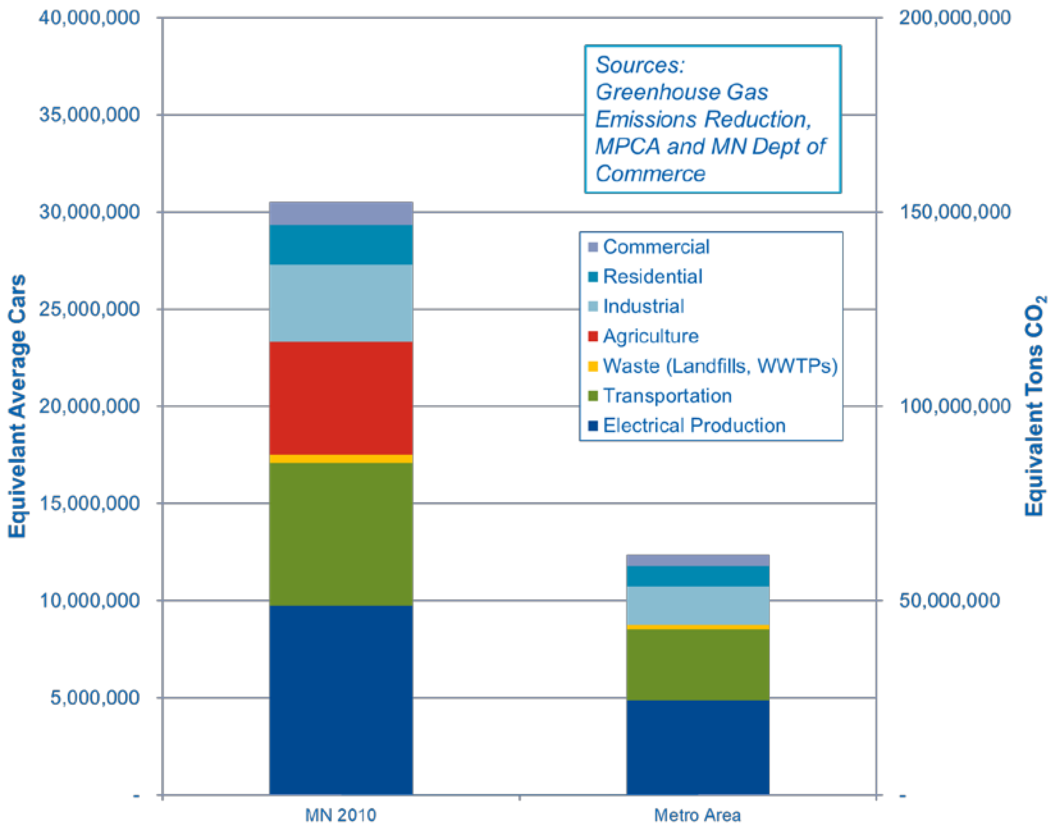


Figure 13. Greenhouse Gas Emissions in MN (2010) and the Metro Area, by Source[1]

6.2.1.4 Fate of Residuals

Phosphorus recovery was considered the most important.

Nitrogen is a renewable nutrient, but phosphorus is not. It takes millions of years to form phosphate rock in the Earth's crust. Due to the potential to beneficially use Metro Plant ash as phosphorus fertilizer, the incineration alternatives (Alternatives 1 and 2) are considered equal to the other fertilizer and land application Alternatives 3 and 4 in terms of nutrient recovery.

In addition, due to the short cycle of agriculture, carbon sequestration was found not to be a delineating factor in comparing the fate of residuals.

6.2.2 Community Impact

6.2.2.1 Financial Stewardship

Financial stewardship has the consequence of raising the standard of living for users and making the region more competitive for economic development. Alternative 1 has the lowest life cycle cost, compared to the other alternatives, which benefits the region by maintaining low user charges.

[1] The average car is driven 11,400 miles per year and gets 21.6 mile per gallon (mpg) fuel efficiency. The GHG emission per average car is 6.6 tons per year CO2 equivalent.

6.2.2.2 Truck Hauling

Because incineration reduces the amount of material that must be handled for export offsite by 95 percent, the incineration alternatives (Alternatives 1 and 2) have the lowest traffic impact. The amount of ash is the same for these two alternatives.

Compared to 54 tpd ash production for Alternatives 1 and 2 at future conditions, Alternative 3 produces 78 tons per day and Alternative 4 produces 200 wet tons per day. Note that land application is restricted to a few weeks in the spring and a few weeks in the fall, which concentrates the hauled traffic load during these seasons.

Truck traffic between the plant and industrial or other application sites, would likely be over major transportation corridors, but ultimately might be on residential or rural roads. Increased safety risks and solids spill risk are directly related to increased truck traffic.

6.2.2.3 Odor

All alternatives would be provided with odor control facilities so that the Metro Plant would not generate additional odors within the community. Alternative 4 may release odors during hauling and land application.

6.2.2.4 Offsite Land

Alternative 1 requires the least amount of land to construct within the existing plant property boundaries, and it has minimum offsite impact hauling.

6.2.3 Reliability

6.2.3.1 Process Failure Risk

The Metro Plant has successfully used incineration technology to treat solids since 1938 and adding a fourth incinerator (Alternative 1) would not pose additional process risk.

All digestion alternatives place a biological process with its associated heating and energy recovery systems would add to the complexity of the facility and may have more risk for process failure. Alternative 3 has additional process and safety risks associated with the thermal drying system.

6.2.3.2 Liquid Stream Impacts

Alternative 1 would have less impact on secondary treatment than the digestion alternatives that generate a recycle with very high levels of ammonia and phosphorus. Digestion process recycle streams would increase requirements for liquid treatment.

6.2.3.3 Land Application Management

Land application programs require significant resources for management and oversight of regulatory requirements, public relations, and logistics.

6.2.3.4 Future Flexibility

Alternative 1 provides the most flexibility in providing increases in future capacity. This alternative has more reserve capacity than the other alternatives.

This reserve capacity improves the reliability of the region’s wastewater treatment system because it could backup solids treatment process at the other MCES plants.

Increased capacity for the digestion alternatives to provide future flexibility would not be cost-effective.

7.0 Recommended Plan

Alternative 1: Fourth Incinerator is the recommended alternative for adding needed solids treatment capacity at the Metro Plant. It is the lowest cost, most sustainable alternative, and it has the lowest impact on surrounding communities. The recommended plan is to construct and commission the fourth incinerator train, then complete needed renewal work in incinerator trains 1, 2, and 3.

7.1 Fourth Incinerator and Auxiliary Systems

The current concept is to add the fourth incinerator train on the east side of the SMB. The fourth incinerator will be similar to those in the existing trains and will be integrated with the existing system.

Figure 14 is a process schematic and Figure 15 is a plan view of the proposed facilities.

7.1.1 Incinerator Cake Feed System

The dewatering portion of SMB would be expanded with the addition of Cake Bin 5, two centrifuges, and two cake pumps. The cake pumps will be sized so that either pump can feed the fourth incinerator at full capacity.

7.1.2 Cake Receiving

Cake receiving will allow dewatered solids to be hauled in from other MCES wastewater treatment plants. The proposed cake receiving facility will include one below-grade cake load-in bin with a hydraulically actuated cover, and one hydraulic piston transfer pump designed to transfer cake to any of the five cake bins.

Cake receiving is envisioned to be constructed adjacent to the existing loadout garage in a building extension, with a basement level tied into the existing SMB basement. The cake load-in bin, cake pump, hydraulic power units, and pipeline lubrication pumps will be in the basement a. Access to cake receiving will be through two overhead doors. Odor control will be provided for the building and basement.

Figure 15 shows preliminary layouts for the Cake Receiving Facility.

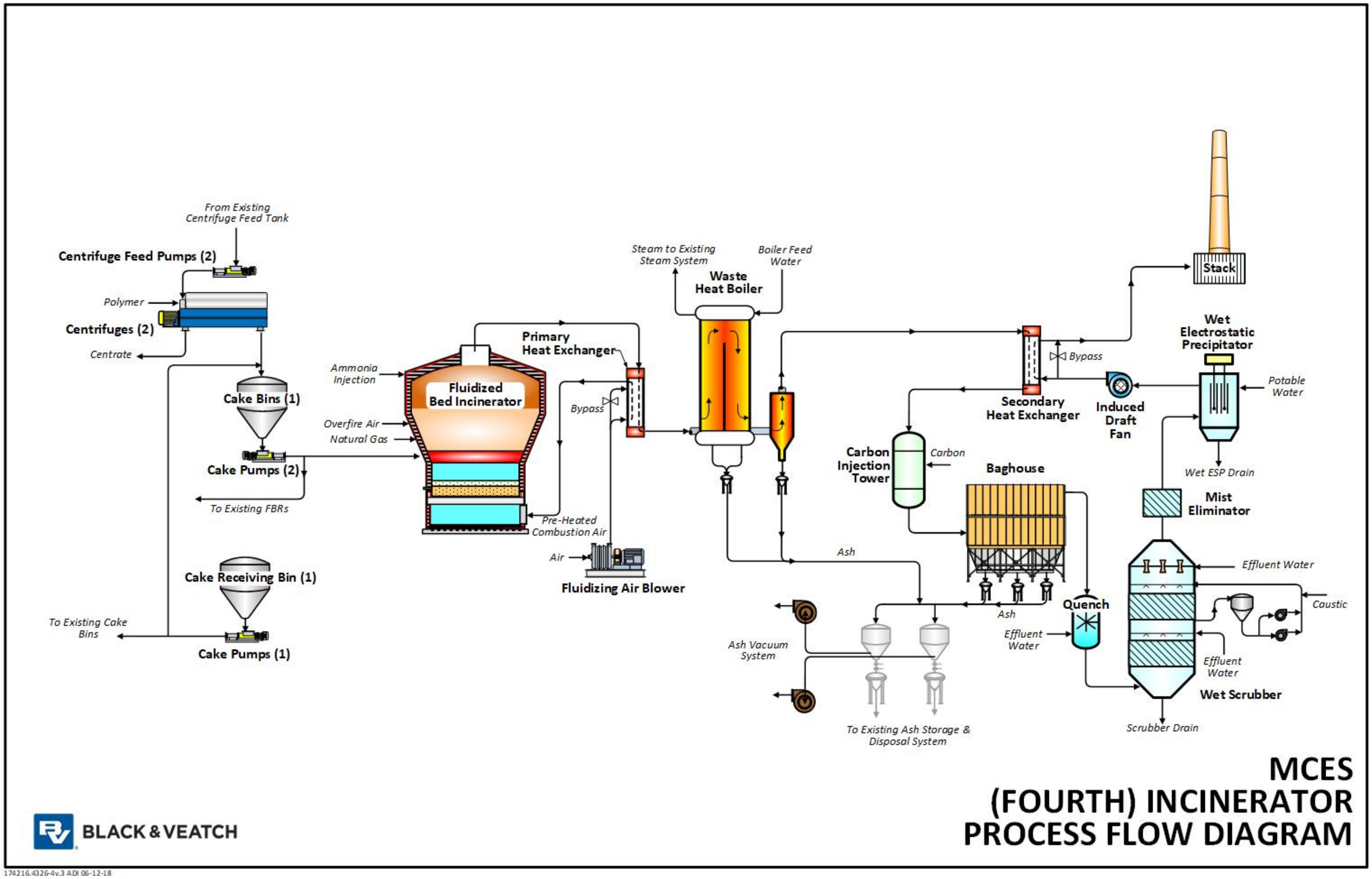


Figure 14. Recommended Plan Fourth Incinerator Process Flow

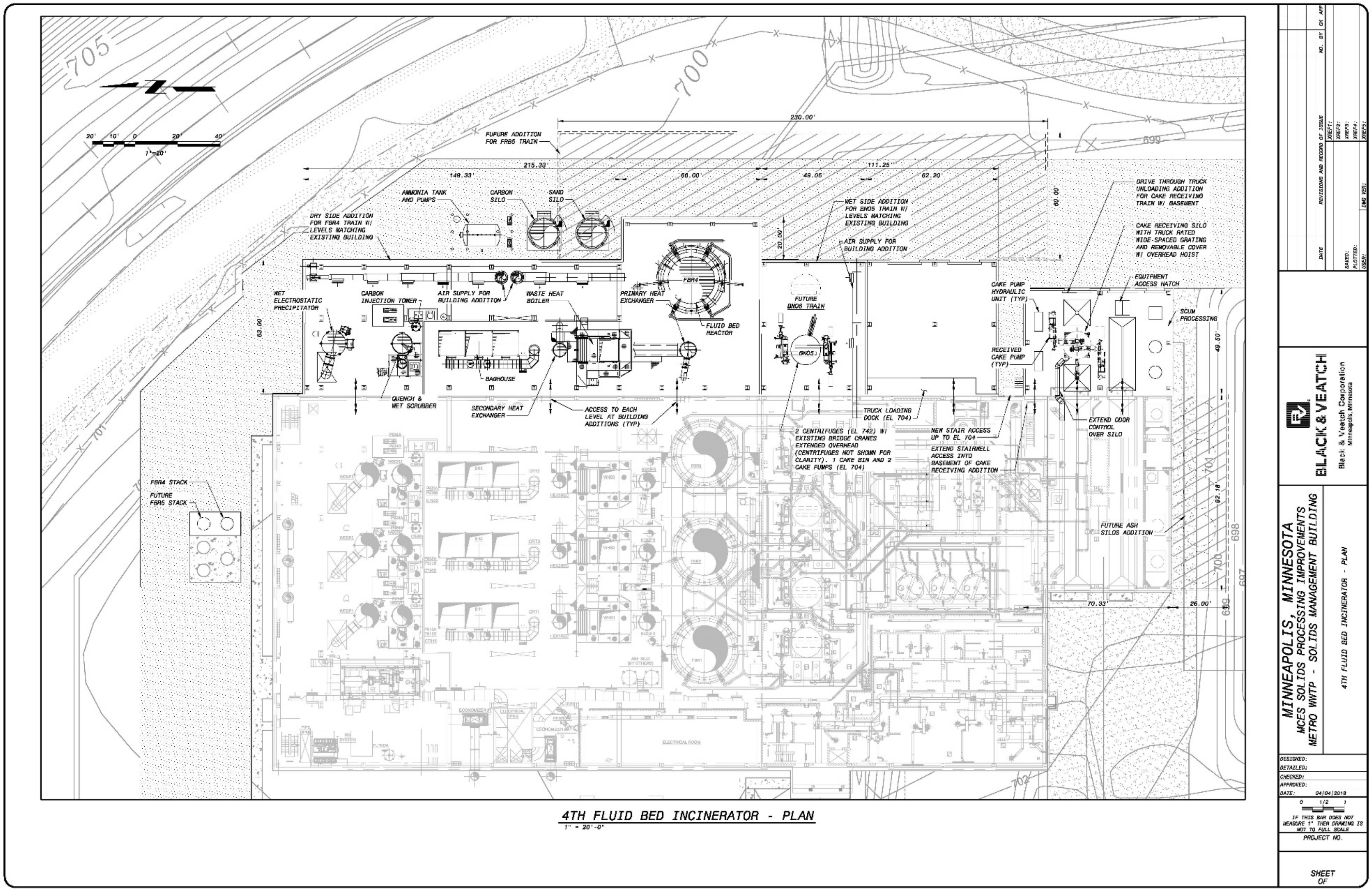


Figure 15. Metro Plant Fourth Incinerator Concept Plan

7.1.3 Incinerator

The proposed fourth incinerator is the fluidized bed type, sized to treat a minimum of 120 dtpd of dewatered cake. The incinerator vessel will consist of three zones: hot windbox, sand bed, and freeboard. Preheated fluidizing air will be directed into the windbox and distributed to the bed through tuyeres in a metal plate or refractory arch.

A fluidizing air blower will provide combustion/fluidizing air, and an induced draft fan will assist in drawing flue gas through energy recovery and air pollution control equipment and exhausting all flue gas from the stack.

Dewatered cake will be pumped into the incinerator through multiple injection nozzles. Auxiliary fuel injection lances (fuel oil or natural gas) will provide supplemental fuel.

Ancillary systems such as purge air blowers, compressed air, emergency roof spray water, and pre-heat burners will also be provided. The pre-heat burner will be the low-NOx type.

7.1.4 Air Pollution Control

The new air pollution control system will include similar technologies to match the approach of existing systems with selected upgrades as required to consistently meet the 40 CFR Part 60, Subpart LLLL emission requirements for new fluid bed incinerators.

The NOx emission requirement may require design enhancements to provide compliance. Current optimization testing (for example, overfire air) may negate the need for additional treatment for NOx. If required, an ammonia injection system will be included during design to reduce NOx emissions. Ammonia injection facilities include aqua ammonia chemical storage and handling equipment located east of the new building addition. Each incinerator train will have a dedicated ammonia metering pump.

The new system will have a baghouse to remove particulates and metals. Powdered Activated Carbon injected upstream of the baghouse will remove mercury to acceptable levels. The carbon silo will be relocated to serve all four incinerator trains, and a second carbon storage tank with manual load-in will be added to improve reliability.

A wet scrubber will be provided with caustic injection and effluent water sprays to meet sulfur dioxide (SO_2) and hydrogen chloride (HCl) limits and to remove particulates that pass through the baghouse. An additional effluent pump will be provided to meet increased effluent water demands.

A wet electrostatic precipitator will be provided as a polishing device for particulates, Cadmium (Cd), and Lead (Pb).

7.1.5 Energy Recovery

The heat recovery system will include a pHEX, a WHB, and a secondary heat exchanger.

The WHB will be the water tube type and will include an economizer. It will be designed to integrate with the existing steam heat and steam turbine system. Alternate configurations for improved maintenance access and lower flow velocities around the tubes will be evaluated during design.

The pHEX will transfer heat from the incinerator exhaust gases to the fluidizing/combustion air to minimize auxiliary fuel demand, and the secondary heat exchanger will provide plume suppression for the stack discharge. Both primary and secondary heat exchangers will be provided with bypass ductwork and dampers to optimize heat recovery to the incinerator and provide temperature control respectively.

7.1.6 Ash Handling and Storage

A new vacuum type ash handling system will be provided for all four incinerators to collect and convey incinerator fly ash from the WHBs and the baghouse and to the existing ash storage bins in the SMB.

Miscellaneous modifications to ash loadout in FI2/408 may be incorporated as required to implement the beneficial use of incinerator ash program.

7.2 Cost Estimate

Table 13 provides the opinion of probable cost summary for the fourth incinerator. The scope for this work is described in Section 7.1.

Table 14 provides the opinion of probable cost summary for renewal of incinerators 1, 2, and 3. The scope for this work is described in Section 4.

Detailed cost estimates are included in Appendix I.

Table 13. Opinion of Probable Cost Summary, Fourth Incinerator

Item	Cost
Mobilization, Bonds, Insurance	$7,700,000
Demolition/Relocation	$250,000
Site Work	$1,450,000
Incinerator Building Addition	$6,050,000
Incinerator Feed System	$5,770,000
Cake Receiving	$1,910,000
Incinerator and Fans	$26,000,000
Energy Recovery Equipment	$8,100,000
Air Pollution Control Equipment	$11,300,000
Other Equipment and Systems	$3,640,000
Plumbing and HVAC	$9,620,000
Electrical, Instrumentation, and Controls	$14,430,000
Subtotal	**$96,220,000**
Contingency	$28,870,000
Design Engineering	$12,510,000
Construction Engineering and Inspection	$12,510,000
Fourth Incinerator Project Cost	**$150,110,000**

Table 14. Opinion of Probable Cost Summary; Renewal of Incinerators 1, 2, and 3

Item	Cost
Mobilization and Bonds	$1,550,000
Sludge Storage Pumping Improvements	$230,000
Sludge Feed Equipment Improvements	$2,400,000
Incinerator Rehabilitation	$3,400,000
Fluidizing Air Blowers, Induced Draft Fans and Duct Modifications	$610,000
Primary Heat Exchangers Renewal	$2,250,000
Waste Heat Boilers Renewal	$1,500,000
Baghouse Renewal	$1,130,000
Mist Eliminator Upgrade	$300,000
Wet Electrostatic Precipitator Electrical Upgrades	$450,000
Turbine Generators and Auxiliary Boilers	$3,580,000
Electrical, Instrumentation and Controls	$1,930,000
Subtotal	**$19,330,000**
Contingency	$5,800,000
Design Engineering & Construction Inspection	$5,020,000
Total Renewal Cost	**$30,150,000**

7.3 Implementation Plan and Schedule

Implementing the project will require a variety of phases including formal approval of the Facility Plan, preliminary engineering detailed engineering, permitting, construction, and commissioning. A preliminary schedule including these various activities is listed below:

Table 15. Proposed Plan Schedule

Project Activity	Date
Public Outreach	April 2018 – June 2018
Public Hearing	August 30, 2018
Design and Permitting	2019 – 2021
Construct Fourth Incinerator	2021 – 2024
Renew Incinerators 1, 2, and 3	2025 – 2027

7.3.1 Permit Considerations

The fourth incinerator will require a major amendment for a minor modification to the existing air permit. MCES has voluntarily completed an Environmental Assessment Worksheet (EAW), which is included in Appendix K, and will follow with an application for the major amendment as a separate submittal to the MPCA. Ultimately, MPCA would issue a combined construction and operating permit.

EPA uses ambient air quality standards to classify geographical areas as either attainment or non-attainment for seven criteria pollutants (CO, SO_2, PM10, PM2.5, NO_x, ozone, Pb). The Metro Plant is in an attainment area. However, part of St. Paul, including the Metro Plant site is designated a PM10 Maintenance Area, which means that MPCA is taking special precautions to assure that the area remains in attainment for PM10.

Metro Plant's location in an attainment area dictates that the applicable air permitting procedure is governed by Prevention of Significant Deterioration (PSD) thresholds for emissions of the criteria pollutants. The overall site and new sources within the site are subject to PSD thresholds. Major thresholds for the site are 250 tons per year (tons/year) of potential to emit (PTE) of each criteria pollutant, except PM10. The site's designation as a PM10 Maintenance Area reduces the major threshold for PM10 to 100 tons/year.

The Metro Plant's NO_x PTE was listed as 318 tons/year in the plant's current 2010 Title V of the Clean Air Act Air Emissions Permit. Hence, the Metro Plant is rated as a major PSD source for NO_x. All other criteria pollutant PTEs are listed within major thresholds and the special maintenance area threshold. Actual emissions of NO_x were listed as 157 tons/year, in the 2010 Title V of the Clean Air Act Air Emissions Permit.

The Title V of the Clean Air Act Air Emissions Permit also includes limits that restrict the site to minor status for Hazardous Air Pollutants (Pb, Cd, Hg, and HCL). The permit is renewed every 5 years.

Metro Plant's NO_x PTE calculation is based on NO_x emissions from packaged boilers and emergency generators as well as from combustion of sludge in the existing FBIs. The PTE value reflecting existing conditions, as would be stated in the Title V of the Clean Air Act Air Emissions Permit renewal application, is approximately 340 tons/year. The NO_x PTE from sludge incineration is based on the new MACT 129 emissions rule governing existing sewage sludge incinerators. That rule became effective in 2016. The NO_x concentration in incinerator emissions from existing FBIs (40 CFR 60 Subpart MMMM) will be 150 ppmvd adjusted to 7 percent oxygen. An important consideration regarding the new emissions rule is that allowable NO_x emissions from new FBIs (40 CFR 60 Subpart LLLL) are five times more stringent than from existing FBIs, that is, 30 ppmvd at 7 percent oxygen.

The sensitivity of the Metro Plant site NO_x PTE to emissions from its incinerators is illustrated in Figure 16. The total site NO_x PTE is 340 tons/year assuming the existing three FBIs are compliant with Subpart MMMM and 161 tons/year if they were to be compliant with Subpart LLLL. Thus, it is very likely that the site could be reclassified as minor PSD source. Certainly, the plant would continue to perform as a minor source, even if it continued to be classified major.

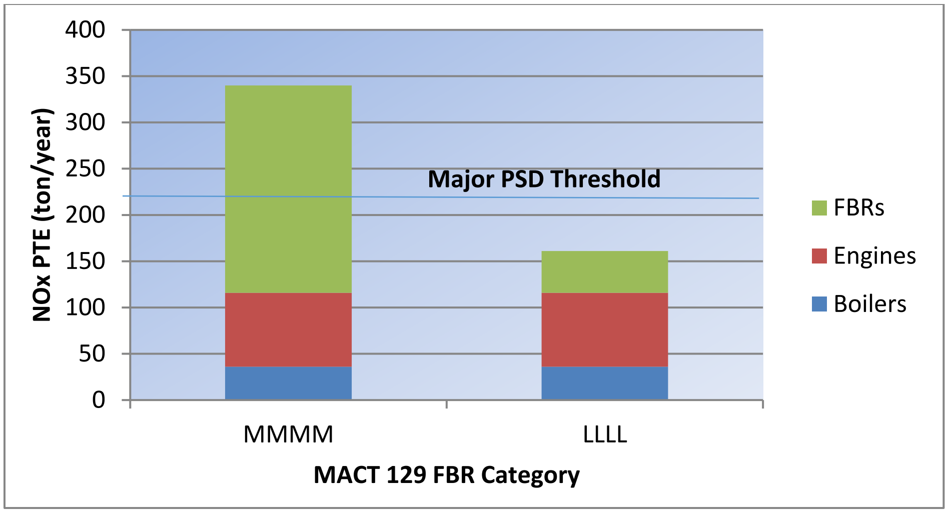


Figure 16. Site NO_x Sensitivity to FBI PTE

The added incinerator emissions source would be accounted for in the application for the Major Minnesota Air Permit Amendment. PM10 air dispersion modeling results would be submitted with the application. PSD review of the new source could conceivably be addressed through either of two options:

Accepting NO_x emission limits on the existing incinerators to establish minor PSD source status for the site as a whole, including the proposed equipment. This would be feasible considering the results of controlled performance tests wherein emissions from the existing FBIs were well within the Subpart MMMM NO_x limitation.

Or, remaining a PSD major source and (a) staying below the PSD significant air emissions increase thresholds, (b) proposing emission limits on the fourth FBI for PM (PM, PM10 and PM2.5) and possibly VOCs, and (c) factoring in new source compliance requirements, as of 2016, with 40 CFR 60 Subpart LLLL emission limits for NO_x, SO_2 and CO. PM includes filterable PM, but does not contain condensable PM. Condensable PM is included within PM10 and PM2.5, but is not regulated under 40 CFR 60 Subpart LLLL. Therefore, total PM10 and PM2.5 emission limits for a fourth FBI could be proposed by MCES, as would be similar to the levels listed in the permit for the three existing FBIs.

These options are based on the assumptions that (a) the proposed capacity for the fourth FBI will be 130 tons/day (same as the three existing FBIs), (b) that no other new air emission sources will be installed at the same time that the fourth FBI is installed, and (c) that actual PM emissions from the ash handling system, after the fourth FBI is placed into service, will increase less than 50% from the most recently reported levels. An additional scenario of installing one generator engine of a 2 MW size burning either propane or diesel within three years of the installation of the fourth FBI may require lowering any proposed emission limits for the fourth FBI. However, it is likely that PSD could be addressed through either of the two options identified above.

The primary advantage of establishing minor source status for the Metro Plant site is fewer compliance requirements. For example, the installation of new air emission sources on PSD minor source sites only need to be reviewed for potential site emission increases, not for both potential and actual emission increases. The PSD major source criteria were established by

EPA to identify those sources where more stringent requirements are needed. Reclassification as a minor source would serve to recognize that there are currently no such concerns at Metro Plant and that the fourth FBI would not cause the NOx major threshold to be exceeded.

The disadvantage of establishing PSD minor source status for the site may be restriction of total allowable NOx emissions to more than the project-by-project restrictions that are established for PSD major sources. The major source threshold for NOx with new projects is 40 ton/year. Reverting to major site status could affect all plant NOx sources, not only new sources under consideration. Also, PSD minor source status is typically established in a separate permit application, which would extend the schedule for air permitting of the fourth FBI.

After considering the air permitting alternatives for the new fourth incinerator at the Metro Plant, MCES is committed to retaining the plant’s existing PSD major status, keeping any increases in air emissions from the new incinerator below the regulatory thresholds for PSD applicability, and accepting a limit on PM. New source performance standards of 40 CFR Part 60 Subpart LLLL would cause this approach to be feasible. There is no significant advantage to MCES or its customers to seek minor site reclassification. Continuing as a major site allows for plant expansion projects in the future without the burden of reconsidering all plant sources of NO_x. The next step would be to submit the protocol for PM10 dispersion modeling. The results of that modeling would be submitted with the Application for a Minor Modification to the Existing Air Permit.

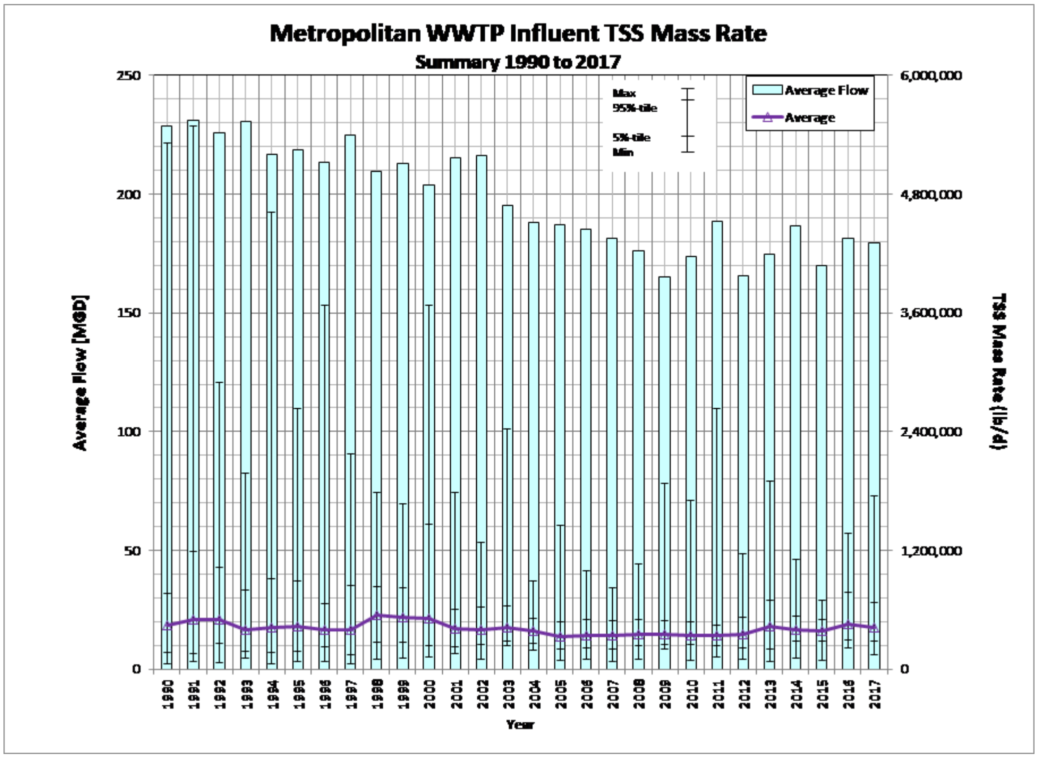
7.3.2 Project Delivery Methods

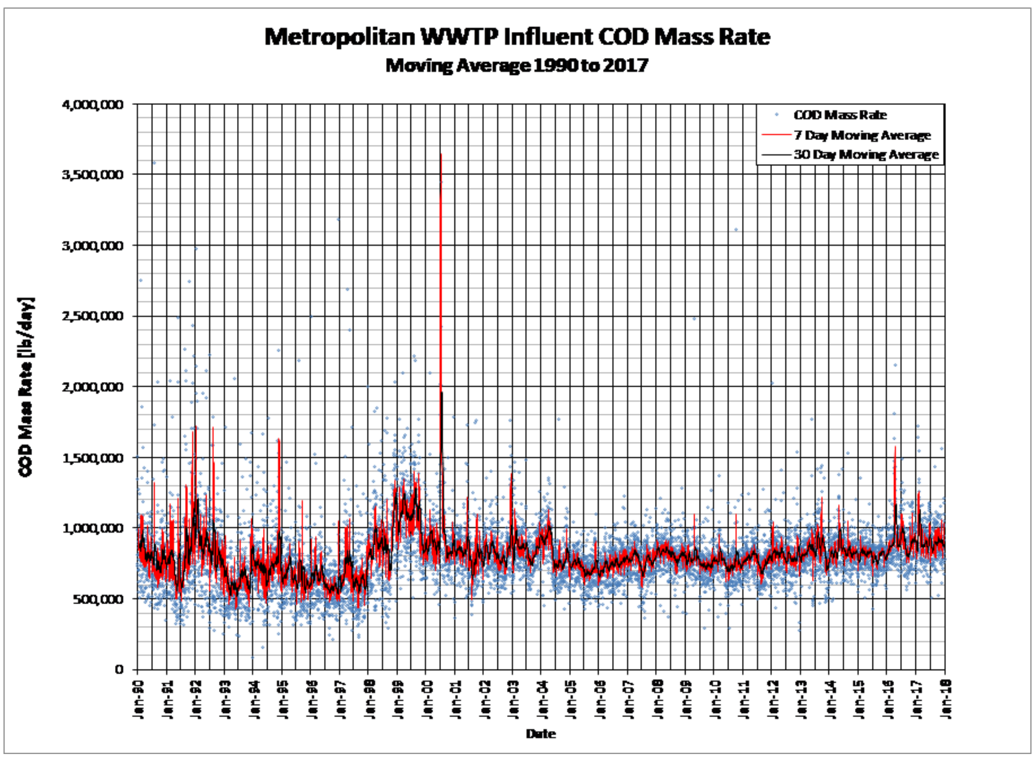
The original incineration project was constructed using a design build approach for the reactors, air pollution control trains, and energy recovery. The building and utility systems were constructed using conventional design-bid-build methods. Foundation work (pile installation) was constructed in a preliminary phase.

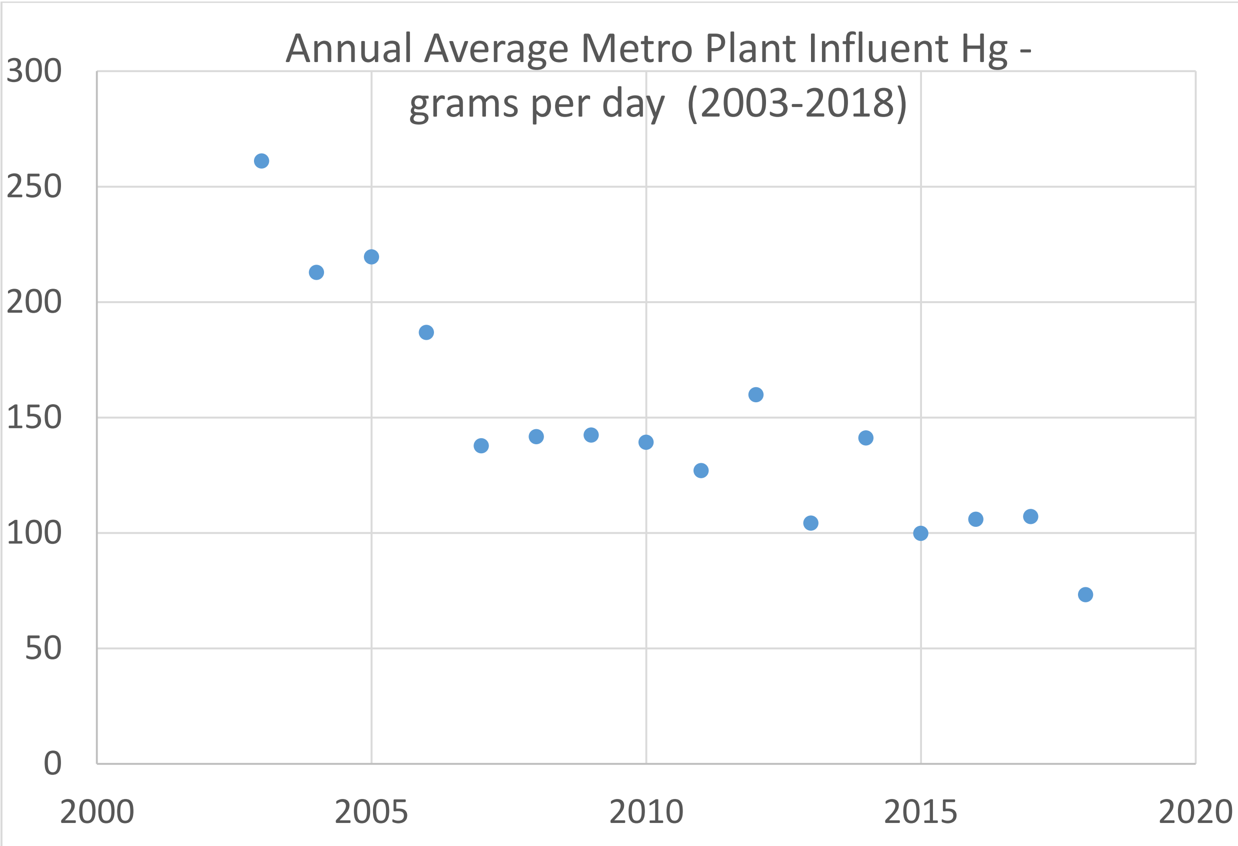
Due to consolidation and bankruptcy, there are currently a very limited number of qualified firms in the specialized area of sewage sludge incineration, resulting in limited competition and price leverage. Furthermore, few if any design firms can provide detailed design services for a full incineration system and need to rely on experienced incineration equipment vendors.

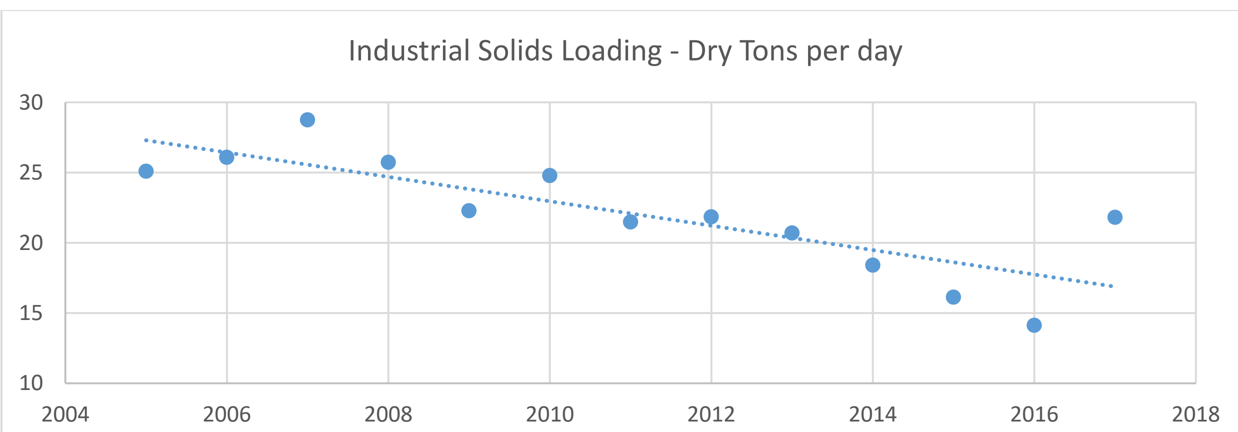
Selection of an equipment vendor and installation package through an evaluated design-build proposal or multiple proposal process is recommended for the fourth incinerator project. The performance criteria and minimum requirements need to be addressed as part of a detailed request for proposal process that would include statements of interest, proposer prequalification and evaluated proposals based on project criteria and proposals received.

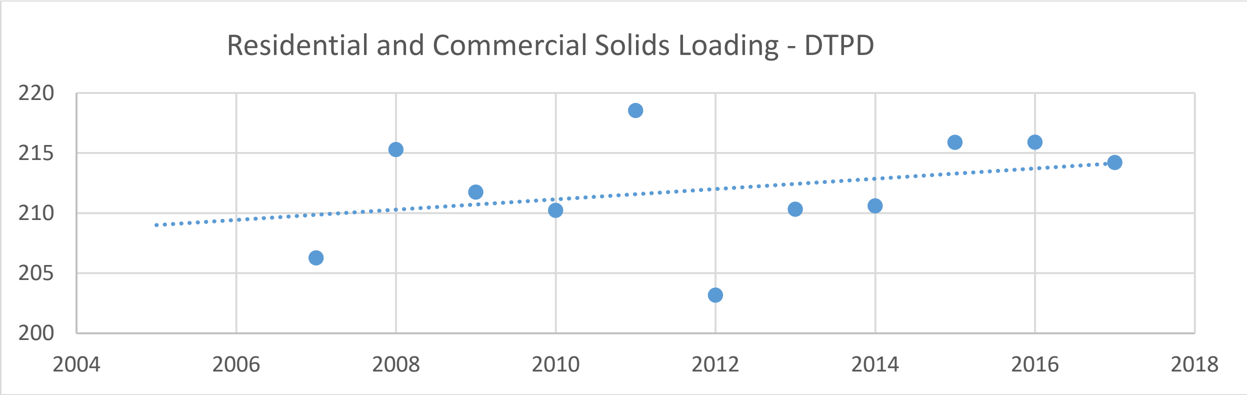
Appendix A. Metro Plant Influent Flow and Load Data



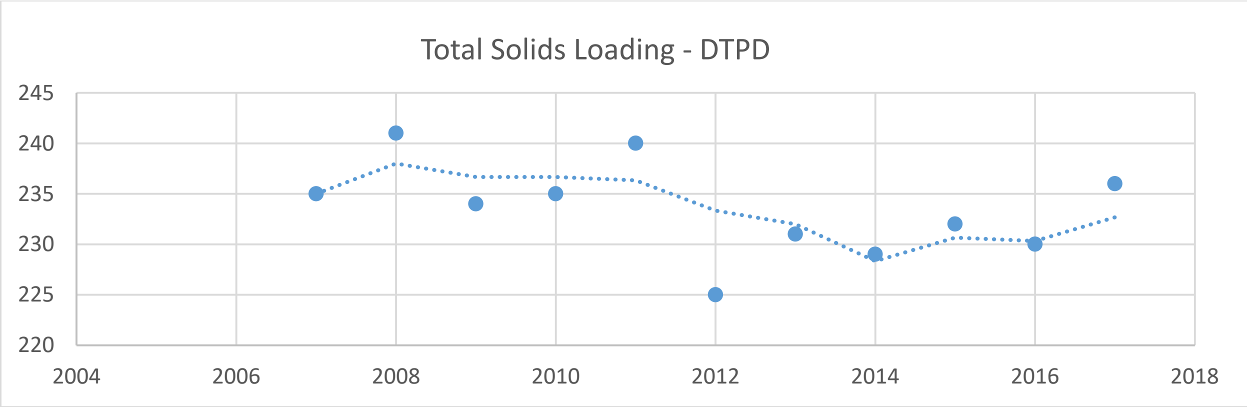



Annual Average Metro Plant Influent Hg - grams per day (2003-2018)
300
250
200
150
100
50
0
2000
2005
2010
2015
2020


Industrial Solids Loading - Dry Tons per day
30
25
20
15
10
2004
2006
2008
2010
2012
2014
2016
2018



Residential and Commercial Solids Loading - DTPD
220
215
210
205
200
2004
2006
2008
2010
2012
2014
2016
2018



Total Solids Loading - DTPD
245
240
235
230
225
220
2004
2006
2008
2010
2012
2014
2016
2018

Appendix B. Tabulation of Metro Plant 30-day Peaking Factors for Solids Treatment

Metro Plant Total Solids Processed, Average Daily and Peak 30-Day Mass Load Values

Year	Input Total Solids Processed (dtpd)[1]	Input 30-day Peak Solids Processed (dtpd)	30-day Peaking Factor
2007	235	264	1.12
2008	241	274	1.14
2009	234	261	1.12
2010	235	271	1.15
2011	240	286	1.19
2012	225	254	1.13
2013	231	293	1.27
2014	229	256	1.12
2015	232	266	1.15
2016	230	259	1.13
2017	236	273	1.16
Average	**234**	**269**	**1.15**
2020[2]	240	276	1.15
2050[2]	300	345	1.15

1. 2014 Water Resources Policy Plan, Metropolitan Council Environmental Services
2. Population equivalent for business growth is estimated as 25 percent of the employment increase, that is, 0.25 x (1,366,990 – 1,067,250) = 75,000 people

Appendix C. Feasibility Study: Beneficial Use of Metro Plant Ash as Phosphorus Fertilizer

Corn and Lettuce Growth Responses and Elemental Uptake in Soils Amended with Sewage Sludge Incinerator Ash

Final Report Submitted to Brown and Caldwell
September 9, 2014

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The effects of ash from incinerated sludge on plant growth and soil and plant chemical composition were examined for corn (*Zea mays* L., HL R208) and lettuce (*Lactuca sativa* L., cv. Valmaine) grown in a greenhouse. Pots were filled with 2500 dry grams of Esterville sandy loam soil fertilized with triple super phosphate (TSP), sludge ash, pelletized biosolids, or struvite, to phosphate application rates equivalent to 50, 100, or 200 lbs/Ac, with a control treatment receiving no supplemental phosphorus. Urea and potassium chloride were added as necessary to achieve equivalent application rates of nitrogen and potassium for all treatments. Plants were grown from seed, thinned to two plants per pot at 14 or 18 days post planting, and harvested at 60 days post planting. Plant shoot biomass was determined at harvest, as were the concentrations of 28 elements in the soil and in the shoot tissue. Uptake of these elements into the above ground tissue was calculated. Based on growth responses and phosphorus uptake, sludge ash was found to be an acceptable phosphorus source relative to the other sources tested, while pelletized biosolids were found to be less effective in this regard. At the rates applied, neither amendment had an effect on soil pH or soil salinity. Sludge ash and pelletized biosolids produced higher plant-available soil copper and zinc concentrations than TSP or struvite. These differences were generally not observed for total soil concentrations, except that sludge ash and pelletized biosolids produced higher total soil copper concentrations than TSP for corn. Above ground tissue concentrations of these elements tended to be elevated in ash- and pellet-fertilized plants of both crop species, but remained well below toxicity levels for plants and levels of concern for human consumption. Sludge ash and biosolids pellets had elevated mercury concentrations compared to TSP and struvite, but this had no effect on soil or tissue mercury concentrations or plant uptake of mercury. Neither sludge ash nor biosolids pellets produced unsafe concentrations of other heavy metals in either soils or plant tissues. Based on these results, the sludge ash and pelletized biosolids tested in this study are potentially usable as phosphorus fertilizer sources for crops. While results from this greenhouse study are promising, longer-term studies are necessary to evaluate effects on crop responses and soil chemical properties under field conditions.

Introduction

The bulk of sewage sludge in the Twin Cities metropolitan area is incinerated and the resulting ash discarded into landfills. Previous research has shown that ash from incinerated sludge is a viable P source for crop production, but the high concentrations of heavy metals such as Hg, Cd, Pb, etc., in the evaluated ash raised environmental and safety concerns. The sludge ash that is currently produced has much lower metal concentrations than that used in previous studies. It is therefore appropriate to re-evaluate the use of ash from incinerated sludge as a P source for crops.

While most sludge in the Twin Cities is incinerated, a smaller amount is heat-dried and made into pellets. The pelletized product may also be a viable N and P source. Additionally, struvite (NH_4MgPO_4) is a compound formed in wastewater processing and may also be useful as a potential P source.

The overall objective of this study was to assess the value of ash from incinerated Twin-Cities sludge as a P source for crops, relative to pelletized biosolids, struvite and triple super phosphate fertilizer (TSP). Specific objectives included the following: 1) chemically characterize each amendment, 2) compare the effects of the amendments on corn and lettuce growth and biomass production, 3) evaluate the effects of the amendments on selected soil chemical properties after harvest, and 4) determine the effects of the amendments on above ground plant elemental composition and uptake.

Materials and methods

Corn (*Zea mays* L.) and lettuce (*Lactuca sativa* L.) were grown in a greenhouse at the University of Minnesota, St. Paul, MN. Each treatment was replicated four times in a randomized complete block design. There were thirteen treatments, including a control treatment receiving no supplemental P and twelve treatments receiving P_2O_5 at one of three rates (equivalent to 50, 100, or 200 lbs P_2O_5/Ac) from one of four sources (sludge ash, pelletized biosolids, struvite, and triple superphosphate fertilizer - TSP), with urea and KCl applied as needed to achieve equivalent application rates of N (250 lb N/Ac) and K (100 lb K_2O/Ac) in all treatments. The soil used was a dried, mixed, and sieved Esterville sandy loam. Soil characteristics are presented in Table 1. Concentrations of elements in the soil and in each amendment based on a microwave digestion procedure (EPA Method 3051) and inductively coupled plasma (ICP) analysis are presented in Table 2.

Corn (HL R208, a Hyland Roundup-ready grain line) and lettuce (cv. Valmaine) were planted on December 12, 2013, in six-inch square pots containing 2,500 dry grams of soil plus treatment-appropriate fertilizers and amendments (Table 3). Corn seeds were planted 3/4" deep, 6 seeds per pot, and lettuce seeds were planted 3/8" deep, 9 seeds per pot. The plants were thinned to 2 plants per pot on December 26 (corn), and December 30 (lettuce). The number of plants in each pot immediately prior to thinning was noted to assess germination and survival over 14 days (both corn and lettuce) or 18 days (lettuce only).

Plants were watered daily as needed to maintain soil moisture. They were fertilized with the equivalent of 55.1 lbs/Ac NH_4NO_3 and 241.9 lbs/Ac $Ca(NO_3)_2$, divided among four equal applications, on January 3, 8, and 21 and February 5, 2014, for corn, and on January 6, 8, 14, and 28, 2014, for lettuce. The plants were photographed on February 7 (lettuce) and 11 (corn) for visual comparison of plants grown in different treatments.

The plants were harvested on February 11, 2014. Plants of both species were cut at the base, weighed, and rinsed with distilled water to remove soil. In addition, for corn, the width of the stalks at 1/2" above the first node and the height to the top of the whorl were determined. Plant tissues were dried at 60 ˚C, weighed, ground to pass through a 2 mm sieve with a Wiley mill, and the sent to the University of Minnesota Soil Testing and Research Analytical Laboratories (UMSTRAL. St. Paul, MN), where elemental concentrations were determined by both microwave wet digestion (EPA 3051) and dry combustion, followed by inductively coupled plasma (ICP) analysis for all elements except mercury. Both microwave digestion and dry combustion procedures were used because each method proved superior to the other in recovering certain elements from the plant tissues. Data from wet digestion are presented unless dry combustion produced statistically significantly higher recovery (Wilcoxon signed-rank test). Data on dry weight and element concentrations were used to calculate uptake amounts of each element by the plants in each pot. Total mercury was determined using EPA Method 1631: Revision E. For this method, Hg was detected using cold vapor atomic fluorescence spectroscopy (CVAFS) with a Brooks Rand Model III CVAFS detector.

The soil from each pot was dried at 35^{o}C, ground, and sent to UMSTRAL to obtain measurements of pH, electrical conductivity, organic matter content, and nutrient availability, and to determine elemental composition by microwave digestion and ICP analysis. In addition, microwave-digested soil was analyzed on a second, dual-filtered ICP machine because the measured concentrations of some elements were erratic on the first machine.

Data were analyzed using the GLM procedure in SAS 9.3. Each dependent variable was analyzed as a function of (1) treatment and replicate and (2) P source, rate, source*rate, and replicate. Significant differences between groups for each main effect were determined using a Waller-Duncan k-ratio t-test (k ratio = 50; $\alpha \approx 0.10$). Linear and quadratic rate effects were also investigated using contrasts in the second GLM for each variable.

Results and discussion

Plant health

Results for plant stand are presented in Table 4. At least 92% of planted corn seeds germinated and survived to 14 days post-planting in each treatment. Germination was much lower for lettuce. Between 39% and 78% of seeds in each treatment produced living seedlings by 14 days after planting, and 41 – 81% had done so by 18 days. It is unclear why the plant stand of the lettuce was low for some pots. Plant stand did not vary significantly among the treatments, nor with application rate or P source, for either crop. Photographs of the plants taken on February 7 for lettuce and February 11 for corn revealed no clear visible differences among treatments or signs of phytotoxicity.

Plant available concentrations of elements in soil, soil pH, organic matter and electrical conductivity after harvest

Corn

Post-harvest soil properties for each treatment are presented in Table 5. The treatments receiving sludge ash had greater Bray and Olsen P concentrations than those receiving biosolids pellets, but lower concentrations than those receiving struvite. They also had lower Olsen P than the treatments receiving TSP. Because the Bray P test uses an acid extractant, some of the insoluble P in the ash is dissolved during the extraction. The Olsen P test uses $NaHCO_3$ as the extractant, which does not extract insoluble P, resulting in a greater difference in measured P between soils supplemented with sludge ash versus TSP at the same rate of P_2O_5/Ac than seen with the Bray P test.

Available soil P after harvest increased with increasing application rate. This relationship of soil P to application rate was evident among the treatments receiving each P source except for the pelletized biosolids, for which the two variables showed no apparent relationship. As a result, the source-by-rate interaction effect was significant.

The treatments receiving struvite had a higher mean soil Mg concentration than those receiving any other P source, reflecting the higher amount of Mg applied with this source. Across all sources, soil Mg concentration was higher at 200 lbs P_2O_5/Ac than at 100 lbs P_2O_5/Ac, with an intermediate mean concentration in the 50 lbs P_2O_5/Ac treatments.

The treatments receiving pelletized biosolids or sludge ash had higher mean available soil Cu and Zn concentrations than those receiving TSP or struvite, and the sludge ash treatments had a higher mean soil Zn concentration than those receiving pelletized biosolids. Mean soil Cu and Zn concentrations both increased with increasing P_2O_5 application rate. The positive relationship between soil Cu and Zn concentrations and application rate was only evident among the treatments receiving sludge ash or pelletized biosolids, and not among those receiving TSP or struvite, resulting in significant source-by-rate interaction effects on the concentrations of both elements.

Lettuce

Post-harvest soil properties for each treatment are presented in Table 6. The treatments receiving sludge ash had higher Bray and Olsen P than those receiving pelletized biosolids, but lower Bray and Olsen P than those receiving struvite. The Bray vs. Olsen effect for ash vs. fertilizer observed with corn was not significant for lettuce, but the trends were the same, with Olsen P lower on average with ash than fertilizer and Bray P similar between the two sources. Soil P increased with application rate. The effect of application rate on soil P concentration was markedly stronger for P sources with higher mean P concentrations, resulting in a significant source-by-rate interaction effect.

The treatments receiving struvite had a higher mean post-harvest available Mg concentration than those receiving any other treatment.

The treatments receiving sludge ash or pelletized biosolids had higher mean available soil Cu and Zn concentrations than those receiving TSP or struvite, and the treatments receiving pelletized biosolids had a higher mean soil Cu concentration than those receiving sludge ash. Soil Cu and Zn concentrations increased with application rate. Similar to the corn results, the effect of application rate on Cu and Zn concentration was much more pronounced among the treatments receiving sludge ash or pelletized biosolids than those receiving TSP or struvite, resulting in significant source-by-rate effects for both elements.

For both crops, sludge ash and pelletized biosolids had higher Cu and Zn concentrations than TSP or struvite (Table 2). Fertilization with sludge ash or pelletized biosolids produced higher soil concentrations of Cu and Zn than fertilization with TSP or struvite, based on DTPA extraction (Tables 5 and 6). Concentrations of both metals increased with application rate when sludge ash or biosolids pellets were applied, but showed little or no response to rate when TSP or struvite was used. Although neither element was present in high enough soil concentration to cause concern in any treatment, it is possible that consistent use of sludge ash or biosolids pellets as P sources over many years could result in greater-than-desirable Cu or Zn soil concentrations.

Previous research has indicated that the effects of using sludge ash as a P source may include increases in soil pH due to liming (which may or may not be desirable) and phytotoxicity due to the high salt content. We found no effect with sludge ash or pelletized biosolids on soil pH at any application rate. At the rates applied, electrical conductivity (E.C.) was never high enough to be harmful to crops. For lettuce, soil in the pots receiving pelletized biosolids had a higher mean E.C. than those receiving TSP or struvite. However, overall, E.C. decreased with increasing application rate, and no fertilized treatment had significantly higher E.C. than the unfertilized control treatment. There is no evidence from our results that fertilizing with the sludge ash used in this study has any effect on soil salinity, though fertilization with pelletized biosolids over many years may result in elevated salt levels relative to using other sources.

Total concentrations of elements in soil after harvest, microwave digest extraction

<u>Corn</u>

Post-harvest soil concentrations of nutrient elements are shown in Table 7.

The treatments receiving sludge ash had a higher mean post-harvest soil P concentration than those receiving pelletized biosolids. The treatments receiving 50 lbs P_2O_5/Ac had a lower mean concentration than those receiving 200 lbs P_2O_5/Ac.

The treatments receiving sludge ash or pelletized biosolids had higher mean soil Cu concentrations than those receiving TSP.

Post-harvest soil concentrations of non-nutrient elements are shown in Table 8.

Treatments receiving sludge ash and struvite had higher mean Cr soil concentrations than those receiving pelletized biosolids and higher Ni concentrations than those receiving TSP or biosolids pellets. Treatments receiving sludge ash had a lower mean Na concentration than those receiving TSP or pelletized biosolids.

Lettuce

Post-harvest soil concentrations of nutrient elements are shown in Table 9.

The treatments receiving pelletized biosolids had a lower mean post-harvest P concentration than those receiving struvite or sludge ash. Soil P concentration increased with application rate; the treatments receiving 200 lbs P_2O_5/Ac had a higher mean concentration than those receiving 50 or 100 lbs P_2O_5/Ac.

The mean Mo concentration was highest in the treatments receiving 50 lbs P_2O_5/Ac and lowest in those receiving 100 lbs P_2O_5/Ac; the treatments receiving 200 lbs P_2O_5/Ac had an intermediate soil Mo concentration that was significantly lower than that of the treatments receiving 50 lbs P_2O_5/Ac.

The treatments receiving 200 lbs P_2O_5/Ac had a higher mean post-harvest soil Zn concentration than those receiving 50 or 100 lbs P_2O_5/Ac.

Post-harvest soil concentrations of non-nutrient elements are shown in Table 10.

The treatments receiving TSP or pelletized biosolids had higher mean Na concentrations than those receiving struvite.

Concentrations of both Cr and V increased with increasing P_2O_5 application rate.

The effect of fertilization treatment on total soil P was small, though sometimes statistically significant. Even at the highest application rate, the amount of P added with the amendments was only 15% of the total of P in the soil.

The potential concerns about using sludge ash as a P source include contamination of soils with heavy metals. In the corn planting, treatments receiving sludge ash had higher soil Cr and Ni concentrations than those receiving biosolids pellets (both metals) or TSP (Ni only). However, no treatment had a significantly higher concentration of either metal than the zero-P control treatment. These results do not indicate a short-term concern about Cr or Ni soil contamination from the sludge ash used in this study, but a cumulative effect from multiple years of use of sludge ash as a P source is possible.

Contamination with Hg is a particular concern with sludge ash, based on previous studies. We found higher Hg concentrations in sludge ash than the other amendments (Table 2) but soil Hg concentration was not affected by treatment for either crop, and there was no trend toward higher soil Hg concentration in treatments receiving sludge ash. Because the Hg could not be accounted for in the plants (see below), these results indicate that the low Hg amounts added with the sludge ash are within experimental error of the analytical methods used. Soil Hg contamination is not likely to be an issue with the sludge ash at the rates used in this study.

The potentially concerning results for plant-available Cu and Zn concentrations found with DTPA extraction were not reflected in the microwave digestion with ICP analysis, except that the treatments receiving sludge ash or biosolids pellets had higher soil Cu concentrations than those receiving TSP among pots containing corn plants.

Another potential concern with using sludge ash and biosolids pellets is their effect on soil salinity. Treatments receiving sludge ash had a lower soil mean Na concentration than those receiving TSP for both crops, though the difference was only statistically significant for corn. Based on these results, the use of sludge ash as a P source poses no greater threat of elevated soil Na concentration than the use of conventional P sources. Biosolids pellets generally produced higher soil Na concentrations than struvite, but similar concentrations to TSP, suggesting that this amendment also poses little risk of producing elevated soil Na concentrations.

Plant size and biomass at harvest

Results for corn shoot height to the top of the whorl, diameter ½ inch above the first node, and biomass are shown in Table 11. The treatments receiving 50 lbs P_2O_5/Ac had lower dry weight and percent dry matter than those receiving 100 or 200 lbs P_2O_5/Ac. Mean percent dry matter was lower for the treatments receiving pelletized biosolids than for those receiving TSP or sludge ash. Corn height and diameter were not affected by treatment.

Results for lettuce shoot biomass are shown in Table 12. The treatments receiving 50 lbs P_2O_5/Ac had lower fresh and dry biomass than those receiving 100 or 200 lbs P_2O_5/Ac. TSP and struvite produced greater fresh and dry biomass than pelletized biosolids. The treatments receiving struvite also produced a greater mean dry biomass than those receiving sludge ash.

In general, plant biomass of both species increased with increasing P rate. The effect was more pronounced in lettuce than corn, which reflects the higher P demand for lettuce. The response to P fertilizer relative to the control (no P applied) was not as pronounced as expected due to the fact that soil test P was already in the medium to high range. Had a soil with lower soil test P used, the response would have been greater. However, finding agriculturally useful soils with very low P is difficult because most agricultural soils have a long history of P fertilizer and/or manure applications. Even though the soil test P was not as low as desired, the results clearly show a benefit to P application for all P sources and that the ash in particular is an effective P source. Dried, pelletized biosolids yielded a lower mean fresh and dry biomass of lettuce than TSP or struvite, and may therefore require higher rates to achieve a similar P response.

The two crops exhibited different growth responses to supplemental P: increased dry matter concentration for corn and increased size for lettuce. Corn showed no biomass response above 100 lbs P_2O_5/Ac, while the biomass response of lettuce spanned the tested application rate range, confirming the higher demand for P by lettuce than for corn.

Concentrations of elements in plant tissues after harvest

Corn

Corn shoot tissue concentrations of nutrient elements are shown in Table 13.

The treatments receiving TSP had a lower mean tissue P concentration, and those receiving struvite had a higher concentration, than those receiving sludge ash or biosolids pellets. Tissue P concentration increased linearly with P_2O_5 application rate. The source-by-rate interaction effect was significant. The treatments receiving struvite showed a large effect of application rate between 100 and 200 lbs P_2O_5/Ac, while those receiving pelletized biosolids showed a much weaker response over that range.

The treatments receiving pelletized biosolids had a higher mean tissue N concentration than those receiving TSP or struvite. The treatments receiving struvite had a higher mean Mg concentration than those receiving sludge ash. The treatments receiving pelletized biosolids had a higher mean tissue Cu concentration than those receiving TSP or struvite. The treatments receiving sludge ash had a higher mean tissue Fe concentration than those receiving pelletized biosolids or struvite. The treatments receiving TSP had a higher mean Mn concentration than the treatments receiving sludge ash or pelletized biosolids. The treatments receiving sludge ash had a higher mean Zn concentration than those receiving pelletized biosolids, which had a higher mean than the ones receiving TSP or struvite.

The treatments receiving 50 lbs P_2O_5/Ac had higher mean tissue K and Cu concentrations than those receiving 100 or 200 lbs P_2O_5/Ac. The treatments receiving sludge ash had a higher mean Zn concentration than those receiving pelletized biosolids, which had a higher mean than those receiving TSP or struvite. The treatments receiving 100 lbs P_2O_5/Ac had a higher mean tissue Zn concentration than those receiving 200 lbs P_2O_5/Ac, with those receiving 50 lbs P_2O_5/Ac intermediate between the two.

There was a significant source-by-rate interaction effect on tissue Zn concentration. Among the treatments receiving sludge ash, those receiving 100 lbs P_2O_5/Ac had much higher Zn concentrations than those receiving the other application rates, while treatments receiving the other amendments either showed decreasing Zn concentration with increasing P_2O_5 application rate (TSP and struvite) or no apparent rate effect (pelletized biosolids).

Each of the significant results for tissue Zn concentration reflected very high Zn concentrations (26.7 and 26.2 μg/g) in two of the four replicates of the treatment receiving 100 lbs P_2O_5/Ac as sludge ash (treatment 6). Further research is required to validate these results.

Corn shoot tissue concentrations of non-nutrient elements are shown in Table 14.

The treatments receiving TSP or struvite had higher mean tissue Pb concentrations than those receiving sludge ash or pelletized biosolids. The treatments receiving sludge ash had a higher mean tissue Ti concentration than the treatments receiving any other P source, consistent with the high Ti concentration observed in sludge ash itself (Table 2). Tissue Ba concentration decreased with increasing application rate over all P sources.

<u>Lettuce</u>

Lettuce shoot tissue concentrations of nutrient elements are shown in Table 15.

Tissue P concentration showed only marginal responses to P source and application rate. This suggests that, for lettuce, the main response to P deficiency was reduced growth. By reducing growth, internal P concentration can be maintained.

The treatments receiving pelletized biosolids had a higher mean tissue N concentration than those receiving TSP or struvite. The treatments receiving sludge ash or pelletized biosolids had greater mean tissue S and Cu concentrations than those receiving TSP or struvite. The treatments receiving sludge ash or TSP had higher mean tissue Mn concentrations than those receiving pelletized biosolids. The treatments receiving sludge ash had a greater mean tissue Zn concentration than those receiving P from any other source.

The concentrations of N, K, S, and Cu in lettuce plant tissues decreased, while the concentration of B increased, with increasing application rate.

There was a significant source-by-rate interaction effect on tissue Zn concentration, which decreased with application rate among treatments receiving TSP or struvite, but increased with rate among the treatments receiving sludge ash and pelletized biosolids.

Lettuce shoot tissue concentrations of non-nutrient elements are shown in Table 16.

The treatments receiving TSP or struvite had greater mean tissue Cd concentrations than those receiving pelletized biosolids. The treatments receiving TSP had a greater mean Ni concentration than those receiving sludge ash.

Tissue concentrations of Ba, Sr, and V were negatively related to P_2O_5 application rate.

Tissue Na concentration generally increased with application rate among treatments receiving sludge ash or pelletized biosolids, but not among those receiving TSP or struvite, resulting a significant source-by-rate interaction effect.

Tissue Hg concentration was not related to treatment in either crop, and there was no trend toward elevated Hg concentration in treatments receiving ash sludge.

The effects of sludge ash and biosolids pellets on available soil Cu and Zn were generally reflected in the concentrations of these metals in plant tissues. However, no treatment had significantly higher tissue Cu or Zn concentrations than the control, and in no treatment were tissue Cu or Zn concentrations high enough to cause phytotoxicity or raise concerns about toxicity to humans. It remains to be seen whether tissue concentrations will increase over time if sludge ash is used as a P source over multiple seasons.

Uptake of elements into plant tissues

<u>Corn</u>

Uptake of nutrient elements into corn shoots is shown in Table 17.

The treatments receiving struvite had a higher mean uptake of P than those receiving P from any other source, and the ones receiving sludge ash had a higher mean P uptake than those receiving TSP. Plant P uptake increased linearly with application rate. The response to application rate was stronger for sources with higher mean P uptake, resulting in a significant source-by-rate interaction effect.

The treatments receiving TSP or struvite had higher mean uptake of Ca than those receiving pelletized biosolids, and higher mean uptake of Mg than those receiving pelletized biosolids or sludge ash. The treatments receiving sludge ash or pelletized biosolids had higher mean uptake of Cu than those receiving struvite, and those receiving pelletized biosolids also had a higher mean Cu uptake than those receiving TSP. The treatments receiving sludge ash had a higher mean uptake of Fe than those receiving pelletized biosolids or struvite. The treatments receiving TSP had a higher mean uptake of Mn than those receiving sludge ash or pelletized biosolids. The treatments receiving sludge ash had a higher mean uptake of Zn than those receiving P from any other source.

Plant uptake of Ca, Mg, Mn, and Fe increased with application rate. Uptake of Zn among treatments receiving 100 lbs P_2O_5/Ac was greater than at 200 lbs P_2O_5/Ac and not significantly greater than at 50 lbs P_2O_5/ac.

The treatments receiving 50 lbs P_2O_5/Ac had much higher uptake of Mo than those receiving 100 or 200 lbs P_2O_5/Ac among the treatments receiving sludge ash or struvite, but much lower uptake among the treatments receiving TSP or biosolids pellets, resulting in a significant source-by-rate effect. There was also a significant source-by-rate effect for Zn uptake, which decreased with application rate among treatments receiving TSP or struvite and peaked notably at 100 lbs P_2O_5/Ac for treatments receiving sludge ash.

As was true for tissue Zn concentration, the results for Zn uptake are strongly influenced by two replicates (out of four) with very high tissue Zn concentrations and Zn uptake from the treatment receiving 100 lbs P_2O_5/Ac as sludge ash (treatment 6). Further research is required to validate these results.

Uptake of non-nutrient elements into corn shoots is shown in Table 18.

The treatments receiving TSP or struvite had higher Ba uptake than those receiving pelletized biosolids, and higher Pb uptake than those receiving sludge ash or pelletized biosolids. The treatments receiving sludge ash had significantly higher uptake of Ti than the treatments receiving P from any other source, reflecting the high Ti concentration of sludge ash (Table 2).

<u>Lettuce</u>

Uptake of nutrient elements into lettuce shoots is shown in Table 19.

Plants from the treatments receiving struvite took up more P, on average, than plants from the treatments receiving pelletized biosolids. Overall, lettuce P uptake increased with application rate. However, the different P sources yielded different P uptake responses to P_2O_5 application rate, with TSP and sludge ash producing decelerating increases with rate, struvite producing an accelerating increase, and pellets yielding linear increases. These differences in response resulted in a significant source by rate interaction.

Plants receiving pelletized biosolids took up less Ca, Mg, and B than plants receiving P from all other sources, less Mn than plants receiving TSP or struvite, and less Zn than those receiving sludge ash. Plants receiving sludge ash took up less Mn than those receiving TSP. The amount of each of these elements taken up increased with increasing application rate, except for Zn, which displayed an insignificant trend in that direction. Uptake of N, K, S, Cu, and Mo also increased with increasing application rate.

Uptake of B, Cu, K and Zn showed significant source-by-rate effects. B uptake increased with application rate for all four P sources, but the relationship either accelerated (struvite), decelerated (TSP and sludge ash), or increased linearly (pelletized biosolids) with increasing application rate. Uptake of Cu, K, and Zn all showed similar variations in response to application rate among P sources to each other. Uptake of these elements decreased with increasing application rate among treatments receiving TSP, increased among those receiving sludge ash or biosolids pellets, and showed no directional response to rate among treatments receiving struvite.

Non-nutrient elements: Uptake of non-nutrient elements into lettuce shoots is shown in Table 20. Plants receiving pelletized biosolids took up less Ba and Sr than plants receiving any other P source. They also took up less Cd than plants receiving TSP or struvite, while plants receiving sludge ash took up an intermediate amount of Cd. Plants receiving sludge ash or pelletized biosolids took up less Ni than plants receiving TSP, and less Si than plants receiving TSP or struvite. Uptake of Ba, Cd, Na, Si, and Sr increased with increasing P_2O_5 application rate, while uptake of Cr peaked at 100 lbs P_2O_5/Ac.

As was true of soil and tissue Hg concentration, uptake of Hg into above-ground tissues was not related to treatment in either crop, and there was no trend toward elevated Hg uptake in treatments receiving sludge ash.

Conclusions

The sludge ash and struvite examined in this study were adequate sources of P_2O_5, while the pelletized biosolids was slightly less effective in this role. In general, all P sources tested tended to increase plant biomass with increasing application rate, with greater responses by lettuce than by corn. At the rates used based on P fertilizer requirements, neither product significantly increased soil pH or E.C., and neither produced dangerous concentrations of metals or Na in the soil or in plant tissues. Relative to the unfertilized control and fertilization with TSP or struvite, fertilization with sludge ash or pelletized biosolids resulted in elevated soil concentrations in Cu and Zn, as measured by DTPA extraction (plant available) but usually not by microwave extraction (total), the exception being higher total soil Cu concentrations for sludge ash and pelletized biosolids than for TSP in corn. These elevated Cu and Zn concentrations were reflected in tissue concentrations and uptake, but in no treatment were tissue concentrations significantly greater than in the control, nor were they high enough to present a health concern for human consumers. Sludge ash and, to a smaller degree, pellets, had higher Hg concentrations than TSP or struvite, but this had no effect on Hg concentrations in soil or tissues or on Hg uptake into tissues. While results from the greenhouse studies are promising, longer-term studies are necessary to evaluated ash effects on crop responses and soil chemical properties under field conditions

Table 1. Selected properties of Esterville sandy loam soil

Macronutrients							Micronutrients						Soil properties		
Bray P	NO_3-N	NH_4OAc K	Exchangeable NH_4OAc K	SO_4-S	Exchangeable NH_4OAc Ca	Exchangeable NH_4OAc Mg	Hot-H_2O B	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Zn	Exchangeable NH_4OAc Na	pH	1:1 slurry E.C.	O.M.
(ppm)														(mmhos/cm)	(%)
17.7	8.9	84.5	74.9	6.5	2068	400	0.55	0.64	47.2	14.5	1.95	14.98	6.7	0.20	4.2

Table 2. Concentrations of selected elements, determined by microwave digestion and ICP analysis, in Esterville sandy loam and each soil amendment. NT = not tested.

Element	Esterville sandy loam	TSP	Sludge ash	Pelletized biosolids	Struvite
Abundant elements - concentrations in g / kg					
Aluminum	10.2	1.5	26.7	4.1	0.9
Calcium	3.5	182.9	109.3	35.7	13.6
Iron	13.4	1.8	21.5	28.2	22.4
Magnesium	2.4	6.7	30.2	10.6	136.7
Manganese	0.99	0.02	10.79	2.24	2.27
Phosphorus	0.6	225.0	118.5	33.3	162.4
Potassium	1.0	1.6	25.6	3.0	0.7
Silicon	1.46	3.18	1.07	2.16	0.74
Sodium	0.11	4.72	6.03	2.44	0.24
Sulfur	0.08	12.37	1.68	2.39	0.26
Trace elements - concentrations in mg / kg					
Antimony	<0.010	NT	<0.010	<0.010	<0.010
Arsenic	7.7	13.5	28.0	12.8	9.6
Barium	141	65	1244	534	64
Beryllium	1.79	2.01	2.75	3.04	2.32
Boron	19.8	45.0	73.0	50.9	31.4
Cadmium	0.54	15.43	5.95	2.00	0.98
Chromium	16	350	130	34	3
Cobalt	5.6	1.0	15.0	2.0	0.2
Copper	10	65	1936	921	48
Lead	8	5	107	21	12
Lithium	7.80	1.85	8.76	3.30	0.05
Mercury	0.082	0.008	2.513	0.415	0.160
Molybdenum	0.7	1.4	56.0	22.7	1.4
Nickel	12.9	32.8	88.1	28.5	3.6
Platinum	<0.010	NT	<0.010	1.963	<0.010
Selenium	0.6	NT	12.8	4.5	2.2
Silver	<0.010	NT	13.5	1.6	<0.010
Strontium	102	808	459	326	215
Thallium	<0.010	NT	<0.010	<0.010	<0.010
Tin	<0.010	NT	29.1	12.3	1.0
Titanium	228	77	1601	58	25
Zinc	46	417	2717	1095	59
Zirconium	5.8	NT	6.2	21.7	4.8

Table 3. Amounts of each amendment (dry wt), and of each fertilizer used to correct N and K to a consistent rate, applied to 2,500 g soil (dry wt) per pot for each treatment.

Treatment			Tested amendments				Fertilizers to correct N & K	
Treatment #	**P rate (lbs P_2O_5 / Ac)**	**P source**	TSP	Sludge ash	Pelletized biosolids	Struvite	Urea	Potassium chloride
			g / pot (2,500 dry g soil)					
1	0	None	0	0	0	0	0.195	0.208
2	50	TSP	0.139	0	0	0	0.195	0.208
3	100	TSP	0.278	0	0	0	0.195	0.208
4	200	TSP	0.555	0	0	0	0.195	0.208
5	50	Sludge ash	0	0.465	0	0	0.195	0.193
6	100	Sludge ash	0	0.930	0	0	0.194	0.178
7	200	Sludge ash	0	1.861	0	0	0.192	0.147
8	50	Pelletized biosolids	0	0	0.796	0	0.165	0.204
9	100	Pelletized biosolids	0	0	1.592	0	0.135	0.201
10	200	Pelletized biosolids	0	0	3.184	0	0.075	0.193
11	50	Struvite	0	0	0	0.363	0.159	0.208
12	100	Struvite	0	0	0	0.726	0.123	0.208
13	200	Struvite	0	0	0	1.451	0.051	0.208

Table 4. Plant percent stand 14 or 18 days after planting (December 12, 2013).

Treatment			Stand (%)		
			Corn	**Lettuce**	
Treatment #	**P rate (lbs P_2O_5 / Ac)**	**P source**	**26-Dec**	**26-Dec**	**30-Dec**
1	0	None	100	53	53
2	50	TSP	92	61	64
3	100	TSP	100	64	64
4	200	TSP	96	59	67
5	50	Sludge ash	92	61	73
6	100	Sludge ash	96	58	61
7	200	Sludge ash	92	39	41
8	50	Pelletized biosolids	92	47	70
9	100	Pelletized biosolids	100	59	72
10	200	Pelletized biosolids	96	64	70
11	50	Struvite	100	78	81
12	100	Struvite	92	53	75
13	200	Struvite	100	61	67
Overall treatment effect		Treatment significance[1]	NS	NS	NS
		Treatment LSD (0.1)	--	--	--
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	NS	NS	NS
		P source[1]	NS	NS	NS
		P source * rate[1]	NS	NS	NS
Contrasts against application rate for fertilized treatments		Rate linear[1]	NS	NS	NS
		Rate quadratic[1]	NS	NS	NS

[1]NS: $P \geq 0.10$; ++: $0.05 \leq P < 0.10$; *: $0.01 \leq P < 0.05$; **: $P < 0.01$

Table 5. Selected post-harvest properties of soil in each treatment for corn

Treatment #	P rate (lbs P_2O_5 / Ac)	P source	Bray P	Olsen P	K	Ca	Mg	B	Cu	Fe	Mn	Zn	pH	1:1 slurry E.C. (mmhos/cm)	O.M. (%)
Treatment			Available macronutrients (ppm)					Available micronutrients (ppm)					Soil properties		
1	0	None	13.3	6.7	70.7	2308	408	0.49	0.91	58.1	22.1	2.35	6.4	0.43	4.0
2	50	TSP	19.3	10.5	64.8	2351	413	0.51	0.92	55.6	20.0	2.38	6.4	0.40	4.2
3	100	TSP	20.5	12.3	67.0	2302	399	0.48	0.95	57.1	20.4	2.42	6.4	0.43	4.1
4	200	TSP	34.3	19.8	72.3	2334	405	0.47	0.93	57.9	20.8	2.47	6.4	0.40	3.9
5	50	Sludge ash	16.8	8.8	70.5	2241	398	0.47	1.04	57.3	20.6	2.65	6.4	0.43	4.1
6	100	Sludge ash	22.5	10.8	72.5	2274	403	0.43	1.02	57.1	20.1	2.69	6.4	0.40	4.1
7	200	Sludge ash	31.0	14.0	72.0	2299	413	0.50	1.14	57.7	20.2	3.19	6.4	0.43	4.0
8	50	Pelletized biosolids	17.8	10.5	70.3	2247	399	0.44	0.97	57.1	20.5	2.44	6.4	0.40	4.1
9	100	Pelletized biosolids	15.8	9.0	73.0	2269	397	0.47	1.08	57.8	21.0	2.60	6.4	0.43	4.1
10	200	Pelletized biosolids	19.0	10.0	69.0	2310	406	0.50	1.32	57.6	20.6	2.80	6.4	0.43	4.2
11	50	Struvite	21.0	11.8	71.5	2284	417	0.43	0.96	57.9	21.0	2.43	6.5	0.43	4.1
12	100	Struvite	27.5	15.5	74.8	2301	417	0.45	0.93	57.5	20.5	2.38	6.4	0.43	4.0
13	200	Struvite	49.0	29.3	67.8	2257	437	0.47	0.89	55.1	18.5	2.34	6.4	0.40	4.1
Overall treatment effect		Treatment significance[1]	**	**	NS	NS	**	NS	**	NS	NS	**	NS	NS	NS
		Treatment LSD (0.1)	3.0	2.2	--	--	18	--	0.12	--	--	0.16	--	--	--
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	**	**	NS	NS	++	NS	*	NS	NS	**	NS	NS	NS
		P source[1]	**	**	NS	NS	**	NS	**	NS	NS	**	NS	NS	NS
		P source * rate[1]	**	**	NS	NS	NS	NS	**	NS	NS	**	NS	NS	NS
Contrasts against application rate for fertilized treatments		Rate linear[1]	**	**	NS	NS	*	NS	**	NS	NS	**	NS	NS	NS
		Rate quadratic[1]	*	++	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]NS: $P \geq 0.10$; ++: $0.05 \leq P < 0.10$; *: $0.01 \leq P < 0.05$; **: $P < 0.01$

Table 6. Selected post-harvest properties of soil in each treatment for lettuce.

Treatment #	P rate (lbs P_2O_5 / Ac)	P source	Bray P	Olsen P	K	Ca	Mg	B	Cu	Fe	Mn	Zn	pH	1:1 slurry E.C. (mmhos/cm)	O.M. (%)
Treatment			Available macronutrients (ppm)					Available micronutrients (ppm)					Soil properties		
1	0	None	17.5	9.8	81.8	2370	439	0.59	0.91	56.5	20.6	2.37	6.3	0.68	4.1
2	50	TSP	22.8	12.3	79.8	2352	434	0.58	0.93	57.5	21.4	2.32	6.4	0.53	4.0
3	100	TSP	29.0	15.3	78.5	2330	428	0.47	0.95	58.0	22.3	2.27	6.3	0.55	4.1
4	200	TSP	32.5	18.5	74.3	2287	417	0.54	0.96	58.1	22.0	2.33	6.3	0.48	4.0
5	50	Sludge ash	24.0	12.5	84.5	2350	438	0.59	0.97	56.8	20.6	2.57	6.3	0.70	4.1
6	100	Sludge ash	26.0	12.8	76.0	2276	422	0.57	1.01	55.6	19.8	2.61	6.3	0.53	4.2
7	200	Sludge ash	37.8	17.3	72.5	2246	420	0.59	1.12	57.6	21.3	3.09	6.4	0.53	4.1
8	50	Pelletized biosolids	20.8	11.0	82.8	2330	434	0.60	1.05	56.7	20.7	2.45	6.3	0.78	4.1
9	100	Pelletized biosolids	24.0	12.0	80.3	2344	435	0.64	1.11	56.9	20.5	2.75	6.3	0.65	4.1
10	200	Pelletized biosolids	25.5	14.8	79.0	2341	433	0.58	1.29	58.9	21.1	2.81	6.3	0.63	4.2
11	50	Struvite	27.3	14.3	75.8	2330	444	0.61	0.92	56.8	20.6	2.28	6.4	0.65	4.1
12	100	Struvite	35.5	18.5	79.0	2260	436	0.54	0.92	56.7	20.7	2.26	6.3	0.55	4.1
13	200	Struvite	55.0	31.8	75.5	2317	466	0.53	0.93	58.2	19.9	2.26	6.3	0.45	4.1
Overall treatment effect		Treatment significance[1]	**	**	NS	NS	**	NS	**	NS	NS	**	NS	*	NS
		Treatment LSD (0.1)	4.3	2.9	--	--	19	--	0.05	--	--	0.18	--	0.19	--
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	**	**	NS	NS	NS	NS	**	++	++	**	NS	*	NS
		P source[1]	**	**	NS	NS	**	NS	**	NS	NS	**	NS	*	NS
		P source * rate[1]	**	**	NS	NS	++	NS	**	NS	NS	**	NS	NS	NS
Contrasts against application rate for fertilized treatments		Rate linear[1]	**	**	*	NS	NS	NS	**	*	NS	**	NS	**	NS
		Rate quadratic[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]NS: $P \geq 0.10$; ++: $0.05 \leq P < 0.10$; *: $0.01 \leq P < 0.05$; **: $P < 0.01$

Table 7. Concentrations of nutrient elements in post-harvest soil of corn plant pots, determined by microwave digestion and ICP analysis.

Treatment			Macronutrients (µg / dry gram soil)					Micronutrients (µg / dry gram soil)					
Treatment #	P rate (lbs P_2O_5 / ac)	P source	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Mo	Zn
1	0	None	630	1117	4287	2498	429	35.8	8.47	16494	912	0.252	52.0
2	50	TSP	647	1012	4579	2547	437	32.4	7.84	15024	867	0.568	49.2
3	100	TSP	642	1137	4469	2523	433	34.8	8.16	15857	909	0.241	52.1
4	200	TSP	650	1100	4670	2537	425	34.6	8.11	15591	859	0.048	51.9
5	50	Sludge ash	627	1056	4324	2475	425	33.0	8.39	15384	845	0.015	50.5
6	100	Sludge ash	662	1115	4483	2519	432	34.8	9.19	15810	822	0.367	52.6
7	200	Sludge ash	683	1041	4118	2429	421	34.9	8.83	15850	845	0.103	52.6
8	50	Pelletized biosolids	628	1029	4489	2517	434	34.3	9.02	15458	897	0.193	52.0
9	100	Pelletized biosolids	613	1065	4229	2475	435	33.5	8.15	15190	826	0.125	51.4
10	200	Pelletized biosolids	636	1035	4342	2454	439	33.2	8.68	15632	898	0.444	51.1
11	50	Struvite	643	1203	4475	2595	432	34.1	8.16	15477	821	0.010	52.4
12	100	Struvite	635	1086	4296	2585	431	34.2	8.45	15626	836	0.063	52.0
13	200	Struvite	664	1085	4210	2472	424	34.5	8.46	16061	835	0.439	50.6
Overall treatment effect		Treatment significance[1]	++	NS	NS	NS	NS	NS	++	NS	NS	NS	NS
		Treatment LSD (0.1)	44	--	--	--	--	--	0.92	--	--	--	--
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	++	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		P source[1]	++	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
		P source * rate[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
Contrasts against application rate for fertilized treatments		Rate linear[1]	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		Rate quadratic[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]NS: $P \geq 0.10$; ++: $0.05 \leq P < 0.10$; *: $0.01 \leq P < 0.05$; **: $P < 0.01$

Table 8. Concentrations of non-nutrient elements in post-harvest soil of corn plant pots, determined by microwave digestion and ICP analysis.

Treatment			Elements (µg / g dry soil)															
Treatment #	P rate (lbs P_2O_5 / ac)	P source	Al	As	Ba	Be	Cd	Co	Cr	Hg	Li	Na	Ni	Pb	Si	Sr	Ti	V
1	0	None	12627	3.62	154	0.705	0.155	7.96	16.0	0.007	9.66	225	15.6	12.2	1483	16.0	252	22.0
2	50	TSP	11967	3.55	153	0.685	0.139	7.56	14.3	0.002	9.16	240	14.6	11.8	1491	15.4	222	20.0
3	100	TSP	13170	3.88	161	0.694	0.159	7.84	16.1	0.004	9.95	242	15.5	12.1	1393	16.6	256	22.0
4	200	TSP	12714	3.57	147	0.675	0.160	7.94	15.3	0.009	9.71	247	14.3	12.2	1411	16.2	254	21.9
5	50	Sludge ash	12306	3.62	146	0.687	0.141	7.88	15.8	0.004	9.06	225	15.8	11.5	1430	15.5	226	21.1
6	100	Sludge ash	12968	3.68	151	0.677	0.177	7.78	18.8	0.005	9.61	241	16.3	12.3	1435	16.0	247	21.9
7	200	Sludge ash	12036	3.40	144	0.678	0.136	7.67	16.8	0.002	9.12	224	15.5	11.9	1438	15.4	231	21.4
8	50	Pelletized biosolids	12025	3.54	150	0.687	0.170	7.85	13.6	0.006	9.01	248	14.3	12.4	1474	15.3	224	20.5
9	100	Pelletized biosolids	12307	3.43	148	0.702	0.140	7.62	14.3	0.003	9.30	235	14.1	12.2	1474	15.5	233	20.7
10	200	Pelletized biosolids	12084	3.56	152	0.690	0.160	7.71	14.1	0.004	8.88	249	14.5	12.0	1469	15.2	222	20.6
11	50	Struvite	13597	3.49	153	0.709	0.183	7.69	17.2	0.001	10.24	244	15.2	11.8	1440	17.2	255	22.9
12	100	Struvite	12934	3.57	147	0.687	0.151	7.91	16.1	0.004	9.62	237	15.1	12.3	1415	16.0	250	21.7
13	200	Struvite	12535	3.69	147	0.681	0.155	7.93	15.9	0.002	9.60	223	15.7	12.1	1415	15.8	238	21.6
Overall treatment effect		Treatment significance[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
		Treatment LSD (0.1)	--	--	--	--	--	--	--	--	--	19	--	--	--	--	--	--
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		P source[1]	NS	NS	NS	NS	NS	NS	**	NS	NS	*	**	NS	++	NS	NS	NS
		P source * rate[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
Contrasts against application rate for fertilized treatments		Rate linear[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		Rate quadratic[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	++	NS	NS	NS	NS

[1]NS: $P \geq 0.10$; ++: $0.05 \leq P < 0.10$; *: $0.01 \leq P < 0.05$; **: $P < 0.01$

Table 9. Concentrations of nutrient elements in post-harvest soil of lettuce plant pots, determined by microwave digestion and ICP analysis.

Treatment			Macronutrients (µg / dry gram soil)					Micronutrients (µg / dry gram soil)					
Treatment #	P rate (lbs P_2O_5 / ac)	P source	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Mo	Zn
1	0	None	617	1022	4318	2468	412	32.5	7.98	14998	855	0.947	49.2
2	50	TSP	628	1046	4441	2497	410	34.2	8.48	15636	881	1.383	50.9
3	100	TSP	637	1039	4360	2419	413	32.5	8.13	14923	861	0.174	50.0
4	200	TSP	677	1201	4541	2596	435	36.5	8.35	16670	892	0.124	54.3
5	50	Sludge ash	656	1086	4537	2476	422	32.5	8.37	15094	836	0.686	51.1
6	100	Sludge ash	644	1025	4384	2456	422	32.4	8.71	14932	860	0.231	50.6
7	200	Sludge ash	705	1091	4292	2524	421	33.3	9.06	15693	902	0.673	53.6
8	50	Pelletized biosolids	610	1092	4466	2515	405	34.5	8.50	15391	929	0.769	50.6
9	100	Pelletized biosolids	636	1161	4419	2521	420	34.7	8.77	15258	800	0.327	51.4
10	200	Pelletized biosolids	640	1091	4300	2462	417	33.9	8.32	15098	839	0.560	51.7
11	50	Struvite	644	1063	4326	2465	419	33.4	7.95	15368	870	0.782	50.3
12	100	Struvite	656	1139	4272	2555	410	34.9	8.79	16355	850	0.112	51.1
13	200	Struvite	690	1111	4368	2581	417	34.6	8.08	15584	862	0.703	51.4
Overall treatment effect		Treatment significance[1]	**	NS	NS	NS	NS	NS	NS	NS	NS	*	*
		Treatment LSD (0.1)	27	--	--	--	--	--	--	--	--	0.727	2.5
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	**	NS	NS	NS	NS	NS	NS	NS	NS	**	**
		P source[1]	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		P source * rate[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts against application rate for fertilized treatments		Rate linear[1]	**	NS	NS	NS	++	NS	NS	NS	NS	NS	**
		Rate quadratic[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS

[1]NS: $P \geq 0.10$; ++: $0.05 \leq P < 0.10$; *: $0.01 \leq P < 0.05$; **: $P < 0.01$

Table 10. Concentrations of non-nutrient elements in post-harvest soil of lettuce plant pots, determined by microwave digestion and ICP analysis.

Treatment			Elements															
Treatment #	P rate (lbs P_2O_5 / ac)	P source	Al	As	Ba	Be	Cd	Co	Cr	Hg	Li	Na	Ni	Pb	Si	Sr	Ti	V
			µg / g dry soil															
1	0	None	11766	3.46	152	0.681	0.130	7.72	14.5	0.010	8.45	138	14.2	11.90	1466	14.6	213	20.0
2	50	TSP	12128	3.55	155	0.691	0.172	7.88	15.1	0.006	8.84	147	15.7	12.50	1448	15.0	222	20.2
3	100	TSP	12017	3.41	155	0.673	0.176	7.73	15.0	0.011	8.73	130	15.1	11.65	1459	15.2	226	20.2
4	200	TSP	13807	3.65	167	0.703	0.152	8.05	17.2	0.010	10.08	152	14.9	12.30	1410	17.1	261	23.8
5	50	Sludge ash	12307	3.60	158	0.684	0.134	7.71	17.2	0.003	8.76	139	15.9	11.90	1473	15.4	232	20.5
6	100	Sludge ash	12065	3.57	152	0.673	0.149	7.64	15.6	0.006	8.57	134	15.2	12.05	1500	14.9	222	20.1
7	200	Sludge ash	12537	3.57	158	0.718	0.191	8.01	18.0	0.007	9.10	135	16.7	12.15	1445	16.1	239	21.9
8	50	Pelletized biosolids	12253	3.51	158	0.670	0.130	7.58	14.2	0.008	8.93	144	15.2	12.05	1460	15.6	235	20.9
9	100	Pelletized biosolids	13081	3.50	151	0.703	0.147	7.60	15.5	0.007	9.47	147	14.0	11.98	1458	16.1	250	21.6
10	200	Pelletized biosolids	12521	3.76	158	0.685	0.197	7.54	14.6	0.006	9.31	136	14.8	12.10	1441	15.7	237	21.1
11	50	Struvite	12270	3.56	161	0.689	0.153	7.62	14.0	0.006	8.81	133	14.5	11.85	1450	15.4	219	20.9
12	100	Struvite	12888	3.79	157	0.679	0.138	8.05	16.4	0.007	9.47	127	15.9	11.77	1433	15.9	264	22.4
13	200	Struvite	12828	3.60	156	0.699	0.157	7.79	17.5	0.006	9.42	123	15.2	11.95	1413	15.8	250	21.3
Overall treatment effect		Treatment significance[1]	NS	NS	NS	NS	++	NS	*	NS	NS	*	*	NS	NS	++	*	*
		Treatment LSD (0.1)	--	--	--	--	0.053	--	2.8	--	--	17	1.5	--	--	1.5	32	2.2
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	NS	NS	NS	NS	++	NS	*	NS	++	NS	NS	NS	++	++	++	*
		P source[1]	NS	NS	NS	NS	NS	NS	++	NS	NS	**	++	NS	NS	NS	NS	NS
		P source * rate[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	++	NS	NS	NS	++	++
Contrasts against application rate for fertilized treatments		Rate linear[1]	*	NS	NS	++	*	NS	*	NS	*	NS	NS	NS	*	*	*	*
		Rate quadratic[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]NS: $P \geq 0.10$; ++: $0.05 \leq P < 0.10$; *: $0.01 \leq P < 0.05$; **: $P < 0.01$

Table 11. Linear dimensions and biomass of corn shoots in each treatment.

Treatment #	P rate (lbs P_2O_5 / Ac)	P source	Height	Diameter	Fresh weight	Dry weight	Dry matter
			----(cm)----		----(g)----		(%)
1	0	None	127	0.89	187.0	29.0	15.5
2	50	TSP	127	0.86	171.8	28.4	16.5
3	100	TSP	130	0.88	181.6	30.7	16.9
4	200	TSP	131	0.88	184.3	30.7	16.6
5	50	Sludge ash	123	0.86	182.4	29.3	16.0
6	100	Sludge ash	128	0.86	176.6	29.3	16.7
7	200	Sludge ash	129	0.86	184.2	30.7	16.7
8	50	Pelletized biosolids	127	0.87	177.1	27.8	15.7
9	100	Pelletized biosolids	131	0.88	185.9	29.4	15.8
10	200	Pelletized biosolids	120	0.86	178.8	28.9	16.2
11	50	Struvite	129	0.86	176.2	27.4	15.6
12	100	Struvite	129	0.86	185.2	31.3	16.9
13	200	Struvite	126	0.88	187.9	31.4	16.7
Overall treatment effect		Treatment significance[1]	NS	NS	NS	*	**
		Treatment LSD (0.1)	--	--	--	2.7	0.9
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	NS	NS	NS	**	*
		P source[1]	NS	NS	NS	NS	*
		P source * rate[1]	NS	NS	NS	NS	NS
Contrasts against application rate for fertilized treatments		Rate linear[1]	NS	NS	NS	**	*
		Rate quadratic[1]	NS	NS	NS	*	*

[1]NS: $P \geq 0.10$; ++: $0.05 \leq P < 0.10$; *: $0.01 \leq P < 0.05$; **: $P < 0.01$

Table 12. Biomass of lettuce shoots in each treatment.

Treatment #	P rate (lbs P_2O_5 / Ac)	P source	Fresh weight	Dry weight	Dry matter
			----(g)----		(%)
1	0	None	79.4	7.0	8.8
2	50	TSP	93.1	8.3	8.9
3	100	TSP	104.5	9.3	8.9
4	200	TSP	110.6	10.1	9.1
5	50	Sludge ash	67.7	5.9	8.8
6	100	Sludge ash	106.0	9.0	8.5
7	200	Sludge ash	110.4	9.6	8.7
8	50	Pelletized biosolids	66.8	6.0	8.9
9	100	Pelletized biosolids	85.3	7.2	8.5
10	200	Pelletized biosolids	98.3	8.0	8.2
11	50	Struvite	92.5	8.1	8.6
12	100	Struvite	95.9	8.8	9.2
13	200	Struvite	131.0	11.6	8.9
Overall treatment effect		Treatment significance[1]	**	**	NS
		Treatment LSD (0.1)	22.8	1.9	--
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	**	**	NS
		P source[1]	*	**	NS
		P source * rate[1]	NS	NS	NS
Contrasts against application rate for fertilized treatments		Rate linear[1]	**	**	NS
		Rate quadratic[1]	NS	NS	NS

[1]NS: $P \geq 0.10$; ++: $0.05 \leq P < 0.10$; *: $0.01 \leq P < 0.05$; **: $P < 0.01$

Table 13. Concentrations of nutrient elements in corn plant shoot tissues, determined by microwave digestion or dry combustion and ICP analysis.

Treatment #	P rate (lbs P_2O_5 / ac)	P source	P	N	K	Ca	Mg	S	B	Cu	Fe	Mn	Mo	Zn
--Treatment--			--Macronutrients-- mg / g dry weight						--Micronutrients-- µg / g dry weight					
1	0	None	1.20	8.59	14.3	2.80	3.85	0.63	5.31	2.07	20.8	17.7	3.4	14.3
2	50	TSP	1.26	8.61	14.4	3.11	4.13	0.65	8.98	2.56	21.6	22.7	5.3	12.4
3	100	TSP	1.34	8.91	14.2	3.13	4.20	0.65	9.37	1.97	23.0	25.5	8.6	10.7
4	200	TSP	1.55	8.25	12.8	3.01	4.27	0.60	8.73	2.23	22.3	23.0	8.2	9.8
5	50	Sludge ash	1.38	8.59	14.1	2.80	3.86	0.64	8.44	3.06	21.9	19.5	10.3	13.5
6	100	Sludge ash	1.50	8.84	13.5	2.89	4.02	0.64	8.02	2.38	24.7	19.0	5.3	19.3
7	200	Sludge ash	1.72	8.79	13.8	3.10	4.08	0.66	9.43	2.40	33.4	21.9	4.7	12.4
8	50	Pelletized biosolids	1.38	9.20	14.4	2.99	4.15	0.65	7.83	2.59	20.9	18.9	6.1	12.9
9	100	Pelletized biosolids	1.50	9.10	14.0	2.81	3.92	0.65	8.72	2.87	20.5	19.0	7.6	13.6
10	200	Pelletized biosolids	1.59	9.28	14.4	2.88	4.23	0.69	8.96	2.94	23.4	20.8	7.8	13.3
11	50	Struvite	1.58	9.19	14.7	3.06	4.21	0.69	7.40	2.69	21.2	21.1	11.5	12.6
12	100	Struvite	1.69	8.31	13.0	2.95	4.32	0.66	9.13	2.21	21.4	21.6	6.2	11.7
13	200	Struvite	2.14	8.13	12.6	2.95	4.51	0.62	8.23	1.59	20.5	21.0	5.7	9.5
Overall treatment effect		Treatment significance[1]	**	++	**	NS	*	NS	NS	**	++	**	NS	**
		Treatment LSD (0.1)	0.10	0.84	1.1	--	0.37	--	--	0.69	7.6	3.2	--	2.5
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	**	NS	**	NS	++	NS	NS	*	NS	NS	NS	**
		P source[1]	**	*	++	NS	**	NS	NS	**	*	**	NS	**
		P source * rate[1]	**	NS	++	NS	NS	NS	NS	++	NS	NS	++	**
Contrasts against application rate for fertilized treatments		Rate linear[1]	**	NS	**	NS	*	NS	NS	*	++	NS	NS	*
		Rate quadratic[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*

[1]NS: P ≥ 0.10; ++: 0.05 ≤ P < 0.10; *: 0.01 ≤ P < 0.05; **: P < 0.01

Table 14. Concentrations of non-nutrient elements in corn plant shoot tissues, determined by microwave digestion or dry combustion and ICP analysis.

Treatment #	P rate (lbs P_2O_5 / ac)	P source	Al	As	Ba	Be	Cd	Co	Cr	Hg	Li	Na	Ni	Pb	Si	Sr	Ti	V
--Treatment--			--Elements-- µg / g dry matter															
1	0	None	12.7	0.849	11.7	0.018	0.020	0.059	0.697	0.007	0.087	37.1	0.430	0.423	1600	6.09	2.87	0.315
2	50	TSP	7.0	1.782	11.7	0.013	0.042	0.017	0.719	0.002	0.013	72.2	0.348	0.749	1683	6.36	0.09	0.253
3	100	TSP	18.3	0.198	12.0	0.006	0.001	0.044	0.677	0.004	0.061	57.3	0.359	0.965	1765	6.41	0.08	0.276
4	200	TSP	10.8	1.490	11.5	0.014	0.105	0.020	0.797	0.009	0.037	51.7	0.516	0.821	1714	6.26	0.72	0.288
5	50	Sludge ash	16.0	0.287	11.4	0.014	0.015	0.008	0.750	0.004	0.072	40.9	0.405	0.426	1558	6.07	3.60	0.265
6	100	Sludge ash	9.7	0.895	10.6	0.011	0.043	0.027	0.849	0.005	0.024	31.1	0.578	0.495	1750	5.98	1.87	0.265
7	200	Sludge ash	19.3	0.491	10.9	0.005	0.032	0.019	0.829	0.002	0.020	39.4	0.467	0.236	1723	6.34	0.56	0.287
8	50	Pelletized biosolids	10.1	0.165	12.0	0.011	0.031	0.022	0.692	0.006	0.028	45.9	0.421	0.279	1634	6.43	0.23	0.284
9	100	Pelletized biosolids	9.8	1.408	10.7	0.006	0.097	0.007	0.678	0.003	0.025	30.4	0.415	0.260	1685	5.85	0.50	0.247
10	200	Pelletized biosolids	10.5	0.405	10.1	0.014	0.275	0.000	0.776	0.004	0.049	51.1	0.335	0.391	1655	5.97	0.24	0.305
11	50	Struvite	5.9	1.297	12.0	0.005	0.057	0.000	0.704	0.001	0.016	59.9	0.532	1.758	1700	6.67	0.03	0.301
12	100	Struvite	6.5	2.155	11.3	0.009	0.142	0.026	0.762	0.004	0.009	62.7	0.200	0.691	1730	5.93	0.04	0.301
13	200	Struvite	6.8	1.922	11.3	0.007	0.044	0.000	0.631	0.002	0.025	78.6	0.546	1.010	1650	6.17	0.05	0.307
Overall treatment effect		Treatment significance[1]	NS	NS	++	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
		Treatment LSD (0.1)	--	--	1.4	--	--	--	--	--	--	--	--	0.762	--	--	--	--
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	++	NS	NS
		P source[1]	NS	NS	++	NS	NS	NS	NS	NS	NS	++	NS	**	NS	NS	*	NS
		P source * rate[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts against application rate for fertilized treatments		Rate linear[1]	NS	NS	*	NS	++	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		Rate quadratic[1]	NS	NS	NS	NS	NS	++	NS	NS	NS	NS	NS	NS	++	*	NS	NS

[1]NS: P ≥ 0.10; ++: 0.05 ≤ P < 0.10; *: 0.01 ≤ P < 0.05; **: P < 0.01

Table 15. Concentrations of nutrient elements in lettuce plant shoot tissues, determined by microwave digestion or dry combustion and ICP analysis.

Treatment #	P rate (lbs P_2O_5 / ac)	P source	P	N	K	Ca	Mg	S	B	Cu	Fe	Mn	Mo	Zn
Treatment			Macronutrients (mg / g dry weight)						Micronutrients (µg / g dry weight)					
1	0	None	2.66	29.4	36.1	12.9	7.86	2.61	19.6	10.0	68.3	105	5.9	50.5
2	50	TSP	2.57	27.1	33.4	13.8	7.63	2.47	18.8	9.4	74.5	116	8.2	46.8
3	100	TSP	2.51	26.7	28.7	13.1	7.35	2.25	19.3	7.8	72.6	120	9.1	43.7
4	200	TSP	2.32	23.6	22.9	12.0	6.81	1.83	17.2	6.0	48.0	104	9.0	30.6
5	50	Sludge ash	2.80	31.1	42.6	17.9	8.28	2.84	17.9	11.6	105.0	108	15.8	49.7
6	100	Sludge ash	3.03	27.6	31.4	13.2	8.33	2.53	20.6	10.2	68.7	102	9.0	55.6
7	200	Sludge ash	3.08	25.0	32.1	13.4	8.26	2.34	22.4	9.4	70.5	105	11.1	54.0
8	50	Pelletized biosolids	2.55	29.0	37.8	16.3	7.23	2.57	14.8	10.6	81.4	83	6.5	35.7
9	100	Pelletized biosolids	2.67	28.7	33.5	14.0	7.15	2.45	17.0	10.6	74.6	90	3.8	44.6
10	200	Pelletized biosolids	3.42	29.7	35.5	13.8	8.27	2.66	19.5	11.8	74.3	85	9.1	47.9
11	50	Struvite	2.99	28.3	37.0	14.6	8.20	2.58	19.7	9.4	70.8	108	7.6	50.3
12	100	Struvite	2.35	26.4	27.8	12.4	6.51	2.16	16.4	7.1	54.3	91	6.6	37.6
13	200	Struvite	3.13	22.5	23.7	13.0	7.82	1.84	20.7	6.8	70.1	104	10.1	33.3
Overall treatment effect		Treatment significance[1]	*	**	**	NS	NS	**	++	**	NS	NS	NS	**
		Treatment LSD (0.1)	0.65	3.0	9.0	--	--	0.34	4.6	2.1	--	--	--	11.2
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	++	**	**	*	NS	**	NS	*	NS	NS	NS	NS
		P source[1]	++	**	*	NS	NS	**	++	**	NS	**	NS	**
		P source * rate[1]	NS	++	NS	NS	NS	++	NS	NS	NS	NS	NS	*
Contrasts against application rate for fertilized treatments		Rate linear[1]	++	**	**	++	NS	**	*	**	++	NS	NS	NS
		Rate quadratic[1]	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]NS: P ≥ 0.10; ++: 0.05 ≤ P < 0.10; *: 0.01 ≤ P < 0.05; **: P < 0.01

Table 16. Concentrations of non-nutrient elements in lettuce plant shoot tissues, determined by microwave digestion or dry combustion and ICP analysis.

Treatment #	P rate (lbs P_2O_5 / ac)	P source	Al	As	Ba	Be	Cd	Co	Cr	Hg	Li	Na	Ni	Pb	Si	Sr	Ti	V
Treatment			Elements (µg / g dry matter)									mg / g	µg / g dry matter					
1	0	None	28.3	0.529	31.3	0.000	0.729	0.013	0.314	0.010	0.073	13.2	0.709	0.609	588	24.1	0.557	0.482
2	50	TSP	39.6	0.625	32.0	0.000	0.816	0.020	0.302	0.006	0.070	12.3	1.104	0.454	614	25.3	0.450	0.539
3	100	TSP	35.9	0.764	27.2	0.001	0.818	0.071	0.573	0.011	0.090	11.5	0.800	0.583	537	23.6	0.435	0.437
4	200	TSP	17.4	0.461	25.9	0.000	0.807	0.020	0.294	0.010	0.050	12.1	0.889	0.366	503	22.7	0.377	0.428
5	50	Sludge ash	73.4	0.956	43.7	0.000	0.634	0.000	0.522	0.003	0.101	11.5	0.466	0.367	573	33.8	1.183	0.526
6	100	Sludge ash	26.1	0.070	29.4	0.000	0.772	0.000	0.326	0.006	0.073	16.0	0.447	0.740	501	24.6	0.320	0.447
7	200	Sludge ash	35.1	0.583	28.4	0.000	0.667	0.008	0.317	0.007	0.075	14.7	0.414	0.288	584	23.8	0.485	0.415
8	50	Pelletized biosolids	52.2	0.131	37.1	0.000	0.520	0.000	0.516	0.008	0.083	9.3	0.709	0.185	438	30.6	2.302	0.552
9	100	Pelletized biosolids	74.1	0.388	32.8	0.001	0.712	0.010	0.649	0.007	0.057	11.7	0.941	0.638	456	27.6	0.342	0.504
10	200	Pelletized biosolids	28.3	0.412	26.8	0.001	0.576	0.023	0.364	0.006	0.031	16.0	0.338	0.333	578	24.7	0.152	0.361
11	50	Struvite	31.6	0.598	35.8	0.001	0.741	0.054	0.334	0.006	0.081	14.3	0.723	0.391	528	27.1	0.367	0.415
12	100	Struvite	23.2	0.351	30.2	0.001	0.714	0.000	0.450	0.007	0.100	10.5	0.608	0.530	489	23.4	0.053	0.405
13	200	Struvite	45.3	0.021	29.7	0.000	0.894	0.045	0.335	0.006	0.087	13.0	0.641	0.485	558	23.2	0.907	0.415
Overall treatment effect		Treatment significance[1]	NS	NS	NS	NS	++	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
		Treatment LSD (0.1)	--	--	--	--	0.242	--	--	--	--	3.7	--	--	--	--	--	--
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	NS	NS	**	NS	NS	NS	NS	NS	NS	++	NS	NS	NS	*	NS	*
		P source[1]	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	++	NS	NS	NS	NS	NS
		P source * rate[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
Contrasts against application rate for fertilized treatments		Rate linear[1]	NS	NS	**	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	*	NS	*
		Rate quadratic[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	++	NS	NS	NS	NS

[1]NS: P ≥ 0.10; ++: 0.05 ≤ P < 0.10; *: 0.01 ≤ P < 0.05; **: P < 0.01

Table 17. Uptake of nutrient elements into corn plant shoot tissues (2 plants/pot).

Treatment			Macronutrients						Micronutrients					
Treatment #	P rate (lbs P_2O_5 / ac)	P source	P	N	K	Ca	Mg	S	B	Cu	Fe	Mn	Mo	Zn
			mg / pot						µg / pot					
1	0	None	34.8	249	413	81.0	112	18.2	154	60.5	603	513	102	413
2	50	TSP	35.7	244	408	88.0	117	18.3	253	71.5	612	644	149	351
3	100	TSP	40.9	272	432	95.4	128	19.8	287	60.0	701	791	254	330
4	200	TSP	47.7	252	392	92.1	131	18.5	268	67.5	682	702	246	300
5	50	Sludge ash	40.0	250	407	80.9	112	18.8	244	88.6	644	572	278	394
6	100	Sludge ash	44.1	259	396	84.8	118	18.8	235	69.6	722	558	155	568
7	200	Sludge ash	53.0	270	423	95.1	125	20.3	288	73.9	1018	670	143	381
8	50	Pelletized biosolids	38.3	255	400	83.0	115	18.1	217	71.5	582	526	170	357
9	100	Pelletized biosolids	44.2	267	411	82.3	115	19.1	256	83.3	602	558	221	399
10	200	Pelletized biosolids	45.9	267	412	83.0	122	19.8	259	83.6	678	603	223	383
11	50	Struvite	43.6	251	403	83.6	115	18.9	204	73.2	583	576	306	346
12	100	Struvite	53.0	260	406	91.8	135	20.6	285	68.2	668	674	195	366
13	200	Struvite	67.3	255	395	92.5	141	19.5	258	50.1	644	656	181	296
Overall treatment effect		Treatment significance[1]	**	++	NS	**	**	NS	++	*	*	**	NS	**
		Treatment LSD (0.1)	4.5	21	--	9.1	9	--	74	18.4	218	94	--	77
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	**	*	NS	*	**	NS	++	NS	*	*	NS	**
		P source[1]	**	NS	NS	*	**	NS	NS	**	*	**	NS	**
		P source * rate[1]	*	NS	NS	NS	NS	NS	NS	++	NS	NS	*	*
Contrasts against application rate for fertilized treatments		Rate linear[1]	**	++	NS	*	**	NS	++	NS	**	*	NS	NS
		Rate quadratic[1]	NS	*	NS	NS	++	NS	NS	NS	NS	NS	NS	**

[1]NS: $P \geq 0.10$; ++: $0.05 \leq P < 0.10$; *: $0.01 \leq P < 0.05$; **: $P < 0.01$

Table 18. Uptake of non-nutrient elements into corn plant shoot tissues (2 plants/pot).

Treatment			Elements															
Treatment #	P rate (lbs P_2O_5 / ac)	P source	Al	As	Ba	Be	Cd	Co	Cr	Hg	Li	Na	Ni	Pb	Si	Sr	Ti	V
			µg / pot									mg / pot	µg / pot		mg / pot	µg / pot		
1	0	None	370	26.3	338	0.537	0.561	1.714	20.6	0.205	2.500	1.07	12.4	12.6	50.0	177	88.6	9.14
2	50	TSP	197	52.0	330	0.364	1.145	0.431	20.5	0.054	0.357	1.98	10.0	21.7	46.9	179	2.5	7.20
3	100	TSP	553	6.2	367	0.181	0.018	1.232	20.4	0.120	1.977	1.66	10.9	29.1	54.1	196	2.9	8.32
4	200	TSP	327	46.7	351	0.427	3.069	0.636	24.5	0.258	1.133	1.58	15.9	24.8	52.5	192	22.5	8.86
5	50	Sludge ash	472	9.0	336	0.451	0.443	0.236	22.5	0.131	1.841	1.22	12.3	13.0	45.3	175	115.1	7.85
6	100	Sludge ash	284	26.0	311	0.329	1.249	0.801	24.8	0.161	0.718	0.91	16.9	14.4	51.3	175	53.8	7.76
7	200	Sludge ash	564	15.2	334	0.146	1.000	0.533	25.2	0.075	0.627	1.21	14.1	7.4	52.7	194	16.1	8.76
8	50	Pelletized biosolids	284	4.6	332	0.311	0.870	0.574	19.2	0.175	0.748	1.26	11.6	7.7	45.3	178	6.9	7.87
9	100	Pelletized biosolids	284	39.9	315	0.188	2.765	0.203	20.1	0.083	0.734	0.90	12.4	7.6	49.4	171	15.0	7.23
10	200	Pelletized biosolids	301	12.2	295	0.402	7.398	0.000	22.4	0.112	1.355	1.56	9.6	12.6	47.8	172	6.9	8.83
11	50	Struvite	163	31.9	330	0.127	1.361	0.000	19.7	0.043	0.368	1.65	14.4	49.0	46.7	182	0.9	8.31
12	100	Struvite	202	69.3	353	0.268	4.635	0.866	24.0	0.118	0.261	2.00	6.2	21.2	54.3	185	1.1	9.28
13	200	Struvite	213	59.9	355	0.218	1.359	0.000	19.9	0.064	0.748	2.45	17.1	31.6	52.2	193	1.5	9.60
Overall treatment effect		Treatment significance[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	++	NS	NS	NS
		Treatment LSD (0.1)	--	--	--	--	--	--	--	--	--	--	--	23.0	8.2	--	--	--
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	++
		P source[1]	NS	NS	*	NS	NS	NS	NS	NS	NS	++	NS	**	NS	++	*	NS
		P source * rate[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts against application rate for fertilized treatments		Rate linear[1]	NS	NS	NS	NS	++	NS	NS	NS	NS	NS	NS	NS	*	++	NS	*
		Rate quadratic[1]	NS	NS	NS	NS	NS	++	NS	NS	NS	NS	NS	NS	**	NS	NS	NS

[1]NS: $P \geq 0.10$; ++: $0.05 \leq P < 0.10$; *: $0.01 \leq P < 0.05$; **: $P < 0.01$

Table 19. Uptake of nutrient elements into lettuce plant shoot tissues (2 plants/pot).

Treatment #	P rate (lbs P_2O_5 / ac)	P source	P	N	K	Ca	Mg	S	B	Cu	Fe	Mn	Mo	Zn
			Macronutrients (mg / pot)						Micronutrients (µg / pot)					
1	0	None	17.9	203	243	87	52.9	18.1	140	71.0	475	732	48.1	354
2	50	TSP	21.0	222	273	113	63.1	20.3	155	77.7	596	973	68.4	388
3	100	TSP	23.6	246	267	123	68.7	21.0	183	74.2	695	1143	85.6	417
4	200	TSP	23.5	234	228	122	68.9	18.3	176	61.8	482	1061	92.7	312
5	50	Sludge ash	15.9	181	225	93	46.1	16.1	102	62.8	582	585	66.7	289
6	100	Sludge ash	27.2	246	281	120	75.2	22.7	187	91.9	618	928	83.5	502
7	200	Sludge ash	28.9	240	295	126	77.4	22.2	215	88.4	679	999	99.2	520
8	50	Pelletized biosolids	14.5	164	194	81	40.0	14.2	89	57.1	388	471	51.9	211
9	100	Pelletized biosolids	19.1	203	224	91	49.7	16.9	121	74.7	475	648	25.8	328
10	200	Pelletized biosolids	27.0	237	280	110	65.3	21.0	155	93.6	586	681	68.0	383
11	50	Struvite	22.4	217	253	103	61.6	19.8	156	69.8	530	836	43.4	394
12	100	Struvite	20.9	229	236	107	56.9	18.6	147	61.9	467	796	60.8	332
13	200	Struvite	35.8	259	272	149	89.3	21.1	238	77.3	784	1186	112.1	383
Overall treatment effect		Treatment significance[1]	**	++	++	**	**	NS	**	++	NS	**	NS	*
		Treatment LSD (0.1)	6.0	64	67	21	16.0	--	44	26.7	--	259	--	147
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	**	**	NS	**	**	++	**	++	NS	**	NS	++
		P source[1]	*	NS	NS	**	**	NS	**	NS	NS	**	NS	*
		P source * rate[1]	*	NS	*	NS	++	NS	*	*	NS	NS	NS	*
Contrasts against application rate for fertilized treatments		Rate linear[1]	**	**	*	**	**	*	**	*	NS	**	*	++
		Rate quadratic[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]NS: $P \geq 0.10$; ++: $0.05 \leq P < 0.10$; *: $0.01 \leq P < 0.05$; **: $P < 0.01$

Table 20. Uptake of non-nutrient elements into lettuce plant shoot tissues (2 plants/pot).

Treatment #	P rate (lbs P_2O_5 / ac)	P source	Al	As	Ba	Be	Cd	Co	Cr	Hg	Li	Na	Ni	Pb	Si	Sr	Ti	V
			µg / pot									mg / pot	µg / pot		mg / pot	µg / pot		
1	0	None	207	3.31	212	0.000	4.73	0.092	2.07	0.072	0.603	89	5.22	4.44	4.76	163	3.84	3.35
2	50	TSP	308	4.28	261	0.000	6.73	0.162	2.45	0.051	0.620	101	8.97	4.01	5.04	206	3.35	4.43
3	100	TSP	349	7.65	256	0.013	7.75	0.711	5.68	0.106	0.856	107	7.69	4.70	5.03	221	4.28	4.11
4	200	TSP	171	4.06	262	0.000	8.34	0.150	3.00	0.099	0.474	121	9.73	3.80	5.12	230	2.88	4.34
5	50	Sludge ash	411	5.54	228	0.000	3.67	0.000	2.92	0.016	0.784	71	2.65	2.90	2.61	174	7.15	3.05
6	100	Sludge ash	231	0.66	264	0.000	7.00	0.000	2.94	0.053	0.694	144	4.06	6.13	4.45	221	2.97	3.99
7	200	Sludge ash	353	5.72	269	0.000	6.41	0.092	3.03	0.074	0.651	138	4.01	2.53	5.68	225	5.10	3.99
8	50	Pelletized biosolids	208	0.99	183	0.000	2.94	0.000	2.28	0.063	0.635	61	3.70	0.44	2.68	151	15.29	3.17
9	100	Pelletized biosolids	580	2.40	213	0.004	4.28	0.030	4.59	0.063	0.328	89	8.33	4.66	2.99	179	1.31	3.60
10	200	Pelletized biosolids	221	3.05	212	0.011	4.61	0.175	2.93	0.051	0.274	126	2.85	2.74	4.61	196	1.16	2.81
11	50	Struvite	251	4.31	254	0.011	5.77	0.508	2.48	0.051	0.773	112	6.85	2.66	3.77	191	2.42	3.40
12	100	Struvite	195	3.65	258	0.013	6.33	0.000	3.69	0.062	0.926	94	5.09	4.65	4.63	200	0.40	3.50
13	200	Struvite	498	0.26	342	0.000	10.19	0.512	3.82	0.072	0.992	148	7.43	5.76	6.37	265	9.75	4.75
Overall treatment effect		Treatment significance[1]	NS	NS	**	NS	**	NS	NS	NS	NS	**	NS	NS	**	**	NS	NS
		Treatment LSD (0.1)	--	--	40	--	2.09	--	--	--	--	41	++	--	1.73	37	--	--
P_2O_5 application rate and source effects among fertilized treatments		P rate[1]	NS	NS	**	NS	**	NS	++	NS	NS	**	NS	NS	**	**	NS	NS
		P source[1]	NS	NS	**	NS	**	NS	NS	NS	NS	NS	*	NS	*	**	NS	NS
		P source * rate[1]	NS	NS	++	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts against application rate for fertilized treatments		Rate linear[1]	NS	NS	**	NS	**	NS	NS	NS	NS	**	NS	NS	**	**	NS	NS
		Rate quadratic[1]	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	++	NS	NS	NS	NS

[1]NS: $P \geq 0.10$; ++: $0.05 \leq P < 0.10$; *: $0.01 \leq P < 0.05$; **: $P < 0.01$

Appendix D. Metro Plant Emissions Data for Fluid Bed Incinerators 1, 2, and 3

Test (1)	Start Date	End Date	Feed Rate	MACT Parameters											Existing Permit Parameters (2)									
				Cd	dioxins/ furans TEQ (3)	dioxins/ furans TMB(3)	CO	HCl	Hg	NOx	Pb	TSP (PM)	SO_2	PM 2.5	Filterable Particulate Matter	Filterable Particulate Material	PM-10	Pb	Hg	Hg Combined	Metal HAPS	Volatile HAPS	HCl	N2O
		Units ⇨	dtph	mg/ dscm	ng/ dscm	ng/ dscm	ppmvd	ppmvd	mg/ dscm	ppmvd	mg/ dscm	mg/ dscm	ppmvd	lb/hr (2.0 mg blank correction)	lb/ ton	lb/ hr	lb/ hr	lb/ ton	lb/ ton	gms/ 24hr	lbs/ ton	lbs/ ton	lbs/ ton	ppmvd
EPA Final MACT Limits for Fluid Bed Reactors (FBRs) 02/21/2011															**Existing Air Permit**									
Existing FBRs				**0.0016**	**0.1000**	**1.2**	**64**	**0.51**	**0.0370**	**150**	**0.0074**	**18**	**15**		1.30	2.57	2.01	0.00097	0.0036	3200	0.065	0.034	0.1	
NEW FBRs				0.0011	0.0044	0.013	27	0.24	0.0010	30	0.00062	9.6	5.3	0.55										
Metro FBR1																								
C	04/22/08	04/22/08	3.7																0.00000627	0.24				
C	01/29/08	01/29/08	4.2															0.0000547	0.0000129	1.97	0.00129			
C	03/11/08	03/11/08	4.4												0.063	0.28						0.0139	0.005	
C	09/16/08	09/16/08	4.2																0.0000146	0.7				
C	12/16/08	12/16/08	4.9														0.55							
C	12/18/08	12/18/08	4.0																0.0000058	0.5				
C	02/10/09	02/10/09	4.0															0.000021	0.0000372	1.73	0.00116			
C	03/24/09	03/24/09	4.4												0.02	0.09						0.0098	0.004	
C	03/31/09	03/31/09	4.3														0.47							
C	04/28/09	04/28/09	4.4																0.00000488	0.47				
C	09/09/09	09/09/09	3.8																0.00000446	0.6				
C	10/29/09	10/29/09	4.2																0.00000943	0.62				
I	02/08/10	02/09/10	3.8		0.03		0.4			28.5			0											
C	03/02/10	03/02/10	4.1												0.03	0.12						0.0096	0.004	
D	03/02/10	03/02/10	4.10	0.00039				0.17	0.0007		0.0020	2.4												
C	03/09/10	03/09/10	4.5														0.52							
C	03/30/10	03/30/10	3.5															0.0000348	0.0000118		0.000742			
C	04/06/10	04/06/10	3.0																0.0000135					
C	11/29/11	11/29/11	5.0												0.03	0.14						0.0091	0.001	
C	12/06/11	12/06/11	4.7														0.57							
C	12/13/11	12/13/11	4.5															0.00000856	0.0000109		0.000245			
C	03/31/15	04/01/15	**4.50**	**0.0002**	**0.00004**	**0.029**	**33.8**	**0.016**	**0.0027**	**28.5**	**0.0006**	**2.47**	**1.9**											
C	04/20/16	04/20/16	**4.60**	**0.0003**	**0.00000**	**0.00670**	**16.4**	**0.040**	**0.00025**	**28.0**	**0.0018**	**1.73**	**5.4**											

Test (1)	Start Date	End Date	Feed Rate	MACT Parameters											Existing Permit Parameters (2)									
				Cd	**dioxins/ furans TEQ (3)**	**dioxins/ furans TMB(3)**	**CO**	**HCl**	**Hg**	**NOx**	**Pb**	**TSP (PM)**	**SO_2**	**PM 2.5**	**Filterable Particulate Matter**	**Filterable Particulate Material**	**PM-10**	**Pb**	**Hg**	**Hg Combined**	**Metal HAPS**	**Volatile HAPS**	**HCl**	**N2O**
		Units ⇨	dtph	mg/ dscm	ng/ dscm	ng/ dscm	ppmvd	ppmvd	mg/ dscm	ppmvd	mg/ dscm	mg/ dscm	ppmvd	lb/hr (2.0 mg blank	lb/ ton	lb/ hr	lb/ hr	lb/ ton	lb/ ton	gms/ 24hr	lbs/ ton	lbs/ ton	lbs/ ton	ppmvd
EPA Final MACT Limits for Fluid Bed Reactors (FBRs) 02/21/2011															**Existing Air Permit**									
Existing FBRs				**0.0016**	**0.1000**	**1.2**	**64**	**0.51**	**0.0370**	**150**	**0.0074**	**18**	**15**		1.30	2.57	2.01	0.00097	0.0036	3200	0.065	0.034	0.1	
NEW FBRs				0.0011	0.0044	0.013	27	0.24	0.0010	30	0.00062	9.6	5.3											
Metro FBR2																								
C	01/03/08	01/03/08	4.1														0.29							
C	02/05/08	02/05/08	4.1																0.0000313	1.97				
C	04/15/08	04/15/08	3.8																0.0000313	1.3				
C	09/23/08	09/23/08	3.2																0.00000171	0.7				
C	10/07/08	10/07/08	4.5												0.06	0.26						0.0048	0.006	
C	10/14/08	10/14/08	4.5														3.75							
C	11/18/08	11/18/08	3.0															0.000044	0.00000669		0.0146			
C	12/04/08	12/04/08	4.6				2.6			16.7							0.87							
C	02/18/09	02/18/09	3.2																0.000000451	1.73				
C	04/21/09	04/21/09	3.1																0.0000025	0.47				
C	09/15/09	09/15/09	4.1																0.0000074	0.6				
C	10/13/09	10/13/09	3.5															0.0000547	0.0000224	0.62	0.000845			
D	10/13/09	10/13/09		0.0006					0.0013		0.0001													
D	12/01/09	12/01/09						0.14																
C	12/01/09	12/01/09	4.2												0.02	0.08						0.0107	0.004	
C	12/08/09	12/08/09	4.2														0.67							
I	02/09/10	02/10/10	3.60	0.00075	0.0300		1.5			13.4			0											
C	12/07/10	12/07/10	4.3														0.90							
C	12/09/10	12/09/10	4.8												0.02	0.10								
D	12/09/10	12/09/10										1.25												
C	03/24/15	03/25/15	**4.50**	**0.0002**	**0.00001**	**0.018**	**21.3**	**0.020**	**<0.0007**	**24.9**	**0.0008**	**2.07**	**<2.0**											
C	08/31/16	09/01/16		**0.0006**	**0.00000**	**0.003**	**6.6**	**0.044**	**0.0002**	**13.8**	**0.0007**	**1.84**	**5.0**											
E																								

Test (1)	Start Date	End Date	Feed Rate	MACT Parameters											Existing Permit Parameters (2)									
				Cd	dioxins/ furans TEQ (3)	dioxins/ furans TMB(3)	CO	HCl	Hg	NOx	Pb	TSP (PM)	SO_2		Filterable Particulate Matter	Filterable Particulate Material	PM-10	Pb	Hg	Hg Combined	Metal HAPS	Volatile HAPS	HCl	N2O
		Units ⇨	dtph	mg/ dscm	ng/ dscm	ng/ dscm	ppmvd	ppmvd	mg/ dscm	ppmvd	mg/ dscm	mg/ dscm	ppmvd		lb/ ton	lb/ hr	lb/ hr	lb/ ton	lb/ ton	gms/ 24hr	lbs/ ton	lbs/ ton	lbs/ ton	ppmvd
EPA Final MACT Limits for Fluid Bed Reactors (FBRs) 02/21/2011															**Existing Air Permit**									
Existing FBRs				**0.0016**	**0.1000**	**1.2**	**64**	**0.51**	**0.0370**	**150**	**0.0074**	**18**	**15**		1.30	2.57	2.01	0.00097	0.0036	3200	0.065	0.034	0.1	
NEW FBRs				0.0011	0.0044	0.013	27	0.24	0.0010	30	0.00062	9.6	5.3											
Metro FBR3																								
D	12/09/04	12/09/04			0.0630																			
C	04/09/08	04/09/08	3.9															0.0000689	0.00000477	0.19	0.000935			
C	02/12/08	02/12/08	4.0																0.00000105	1.97				
C	09/09/08	09/09/08	3.3																0.0000011	0.7				
C	09/09/08	09/09/08	3.3																0.00000067	0.43				
C	10/28/08	10/28/08	4.7												0.06	0.29						0.0108	0.005	
C	11/04/08	11/04/08	3.9																0.000001					
C	12/09/08	12/09/08	4.6														0.48							
C	02/24/09	02/24/09	3.5																0.00000144	1.73				
C	04/14/09	04/14/09	2.7															0.0000133	0.00000483	0.47	0.000743			
C	10/20/09	10/20/09	2.9																0.00000316	0.62				
C	11/10/09	11/10/09	3.9												0.02	0.07						0.0108	0.004	
D	11/10/09	11/10/09						0.16				1.1												
I	02/11/09	02/12/09	3.40	0.00097			1.3			2.26E+01			0											
C	12/15/09	12/15/09	4.0														0.75							
D	02/11/10	02/11/10					1.3			22.56			0											
C	04/15/10	04/15/10	4.3												0.03	0.11							0.008	
C	12/14/10	12/14/10	4.4														1.05							
C	03/26/15	03/27/15	**4.3**	**0.0002**	**0.000001**	**0.020**	**29.5**	**0.348**	**0.0011**	**13.1**	**0.0006**	**1.93**	**<2.4**											
C	04/22/16	04/23/16		**0.0001**	**0.000000**	**0.000**	**7.4**	**0.040**	**0.00024**	**12.9**	**0.0011**	**0.47**	**1.2**											
E	Dec-17	PM 2.5 Test 1	**4.7**											**0.36**										
E	Dec-17	PM 2.5 Test 2	**4.5**											**0.26**										
E	Dec-17	MACT Test 1	**4.7**	**0.000074**			**6.2**		0.00018	**10.8**	**0.0004**		**1.1**											
E	Dec-17	MACT Test 2	**4.6**	**0.000072**			**6.6**		0.00018	**11.8**	**0.0005**		**1.0**											
E	Apr-18	PM 2.5 Test 1	**4.7**											**0.24**										
E	Apr-18	PM 2.5 Test 2	**4.5**											**0.16**										
E	Apr-18	PM 2.5 Test 3												**0.32**										
E	Apr-18	Metals Test 1	**4.5**	**0.000072**			**8.8**		0.00018	**14.4**	**0.00013**		**1.0**											
E	Apr-18	Metals Test 2	**4.5**	**0.000090**			**4.9**		0.00018	**13.9**	**0.00016**		**1.1**											
E	Apr-18	Metals Test 3	**4.6**	**0.000072**			**5.5**		0.00018	**13.9**	**0.00012**		**1.0**											

Appendix E. Metro Plant Facilities Design Data

Item	Unit	Design	Year Installed
Solids Management Building			
Centrifuges			2005 (7), 2008 (1)
Type		Decanter (High Solids)	
Number		8	
Capacity, each	dtpd	70	
Loading	dtph	2.5	
Centrifuge Feed Tanks			2005
Type		Rectangular	
Number		2	
Capacity, each	gallons	60,000	
Centrifuge Feed Pumps			2005 (7), 2008 (1)
Type		Progressing Cavity	
Number		8	
Capacity, each	gpm	340	
Centrifuge Feed Grinders			2005
Type		Heavy-Duty, In-Line	
Number		8	
Capacity, each	gpm	340	
Centrifuge Feed Tank Air Compressors			2005
Type		Positive Displacement	
Number		2	
Capacity, each	scfm	1000	
Cake Pumps			2005
Type		Hydraulic Piston	
Number		8	
Capacity, each	gpm	60	
Cake Pipeline Lubrication Pumps			2005
Type		Metering Diaphragm	
Number		16	
Capacity, each	gph	180 @ 1,000 psi	
Cake Bin			2005
Type		Steel	
Number		4	
Capacity, each	ft^3	2,290	
Polymer Storage Tanks			2005
Type		Fiberglass	
Number		4	
Capacity, each	gallons	12,000	
Polymer Mix Tanks			2005
Type		Fiberglass	
Number		3	
Capacity, each	gallons	4,800	
Polymer Feed Tanks			2005
Type		Fiberglass	
Number		4	
Capacity, each	gallons	4,800	
Polymer Transfer Pumps			2005
Type		Progressing Cavity	
Number		3	
Capacity, each	gpm	40	
Polymer Feed Pumps			2005
Type		Progressing Cavity	
Number		8	
Capacity, each	gpm	20	
Fluidized Bed Incinerators			2005

Item	Unit	Design	Year Installed
Type		Fluidized Sand	
Number		3	
Capacity, each	dtpd	105	
Precooler			2005
Type		Shell and Tube	
Number		6	
Capacity, each	gpm	600	
Heat Recovery Units			2005
Type		Shell and Tube	
Number		4	
Capacity, each	ft^3/min	75,000	

Appendix F. Solids Management Building Modifications Included in Recent Projects

Solids Management Building Modifications Included in Recent Solids Management Building Projects

Component	Metro Plant Solids Processing Improvements (construction completed 2015)	Metro Plant SMB Baghouse/Scrubber/ Miscellaneous Improvements (design initiated 2018)	Others
Centrifuges			Installed eighth centrifuge (CF6) in 2008
Cake Bins & Cake Pumps			Repaired and coated internal surface of corroded cake bins
Incinerator	Add overfire air – redirect a portion of the combustion air to the incinerator freeboard to reduce the use of cooling water sprays	Renew air distribution in one incinerator with new design – demonstrate effectiveness of proposed design	With NOx emission concentrations cut in half between 2005 and 2013 (from 48 ppm to 24 ppm) by reducing bed temperatures, the ammonia system was decommissioned in July, 2014. Ran silica sand from 2015-2017. After experiencing high sand loss rates at times, switched back to olivine sand in 2017.
Fluidizing Air Blower	Replace inlet valves on fluidizing air blowers – decrease size to improve control		A new motor for the FBR1 fluidizing air blower was provided in 2015 after the 2014 feed sludge tank overflow incident.
Flue Gas Duct	Replace crossover duct – upgrade to stainless steel material to mitigate premature corrosion damage Replace expansion joints - mitigate air leaks into the flue gas train[1]		
Primary Heat Exchanger	Replace primary heat exchangers – avoid pending failure caused by thermal cracking of tubes at the tube sheet		Reskinned inlet and outlet tees 2011-2011.

Component	Metro Plant Solids Processing Improvements (construction completed 2015)	Metro Plant SMB Baghouse/Scrubber/ Miscellaneous Improvements (design initiated 2018)	Others
Waste Heat Boiler	Replace economizer sections all boilers - avoid pending failure caused by erosion and cementitious buildup on tubes. Included design modifications to improve flow distribution and mitigate tube abrasion at the tube sheets. Replace selected waste heat boiler sections – complete forensics to identify issues	Replace baghouse inlet duct supports – correct observed sagging Replace waste heat boiler tube sections – address known high wear areas Replace ash transporters and valves – address abrasion issues	
Steam Turbine G7			Major overhauls in 2006, 2009 (reblade stages 1,2,3,8) and 2014 (T&T valve and bent rotor) Replace HVAC system – increase cooling capacity
Noncondensing Steam Turbine G9			Installed and started in February 2003.
Auxiliary Condenser		Replace auxiliary condenser – avoid pending failure	Replaced in July 2010 after 28 of the 210 tubes were plugged due to leakage.
Boiler Feedwater system			Replaced RO membranes 2007, 2009, 2011, 2017.
Baghouse	Replace Baghouse Covers – includes re-design of insulation and seal and upgraded stainless steel alloy material to mitigate corrosion. Add bypass to secondary heat exchanger – allows operation of baghouse at higher temperature to mitigate corrosion Removed bypass valves to mitigate leakage in 2014	Rehabilitate baghouse hoppers - permanently repair areas that have been temporarily patched Replace ash transporters and valves – address abrasion issues	Installed epoxy coating on corroded carbon steel covers in 2006. Complete bag changeout 2007, 2011, and 2015. Reskinned lower BH access doors 2009 Reskinned upper plenums 2013.
Scrubber		Modify scrubber – optimize scrubber performance	Installed larger packed tower nozzles.
Wet Electrostatic Precipitator	Disconnected purge air blower and installed orifice plates to reduce purge air flow into the flue gas train.		Replace control panel 2015. Installed filters on purge air pipe 2018.

Component	Metro Plant Solids Processing Improvements (construction completed 2015)	Metro Plant SMB Baghouse/Scrubber/ Miscellaneous Improvements (design initiated 2018)	Others
Induced Draft Fan	Replace Induced Draft Fan Motors – increases size to maintain operation within the motor service factor Install internal sprays – prevent chemical buildup		
Secondary heat exchanger			Installed abrasion pipe inserts in outer tube rows of HEXSEC starting in 2006. Continued to check upper tubes during shutdown.
Process Areas Vacuum Systems		Replace SMB vacuum system – increase capacity Reroute F&I2/408 vacuum system bag filter vent – reduce plugging of vent pipes	
Digital Control System			Changed PLCs from ABB Conductor software to Modicon Quantum software 2013.
Carbon system			Changed gearboxes from 15:1 to 60:1 gear ration in 2005. Maximum carbon rate decrease to 6 pph. Changed back to 15: 1 gearbox in 2012 to restore 12 pph carbon maximum flow rate.
Odor Control		Renew – ensure continued service	
Wet Scrubber			Installed extra 6 inches of pall ring stainless steel packing in packed tower in 2009.
Backup service for natural gas		Add propane system – replace old fuel oil system	

1. This and modifications to the carbon injection and the wet electrostatic precipitator reduced air in-leakage from 30% to < 5% of the flue gas flow.

Appendix G. Metro Plant Solids Management Building Floor Plan

Solids Management Building Basement 684.00'

Solids Management Building First Floor 704.00'

Solids Management Building Second Floor 724.00'

Solids Management Building Third Floor 742.00'

Appendix H. Risk Evaluation: Deferring Additional Solids Processing Capacity at the Metro Plant

1

SMB Risk Project

Nov 6, 2017 Update
Jan 22, 2018 Minor Corrections and *Added Material on Sensitivity to Renewal Maintenance*

George Sprouse, Process Engineering Manager

v1.2018_01_22_1400

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- Updates
  - Inputs
    - Starting projection year average annual = 2016 value
    - Sludge storage fill tank level to access contingency condition counting = 170.8 (per discussion with Mike M and Peter)
  - **Simulation Addition – Logic to Curtail (end) a PM upon the Number of Failed Units**
    - Now includes a logic input that, if the number of failed units gets above an input criteria, then any unit in PM will be immediately put back into service
    - The amount of PM remaining is captured and reported as planned PM not performed
    - With this addition that is more close to actual conditions, number of units on-line and sludge to landfill more closely match observed info
  - Past info corrections
    - Corrected table and revised cumulative probability plots to match original graphs (included graphs at end)
  - ***Jan 22, 2018 Added two runs with shorter renewal maintenance times and corrected some legends***
- New Item
  - Attempted additional method to work towards also putting info in a relatable framework

3

Input Updates – Solids Production For Projection Period

INPUTS

Scenario Designation: 3 Units, UM avg failure p = 0.0162

System Processing Requirements

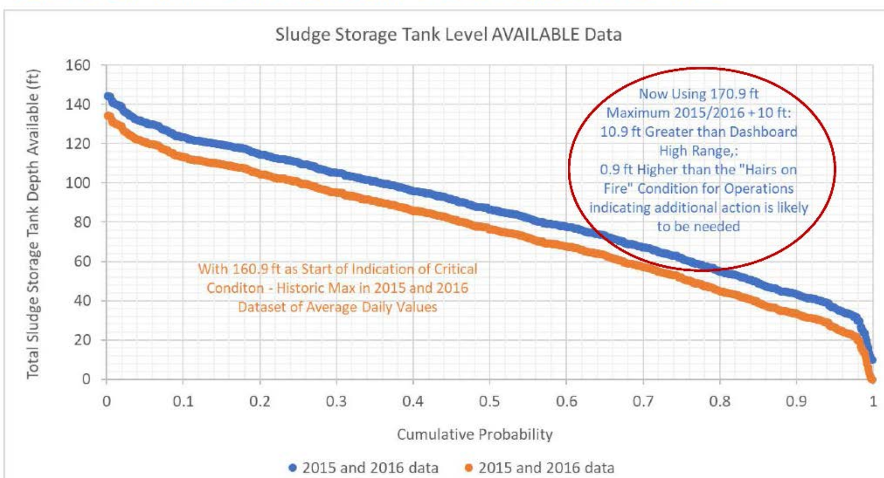
Start Year:		2010
First Projection Year:		2017
First Projection Year Average Annual Solids Production [dtpd]:	(2016 value used for first projection year)	230.00
Increase in Average Annual Solids Production for Future Years [dtpd/yr]:		1.80
Future Year Maximum Month Peaking Factor		1.15

The Resulting Monthly Solids Production Factors using the Max Month Input Factor From Warping the Past Average Curve

Month	Days in Month	Day of the Year Start	Day of the Year End	M/A factor not wt'ed	M/A factor wt'ed
Jan	31	1	31	0.938	0.938
Feb	28	32	59	1.044	1.044
Mar	31	60	90	1.018	1.018
Apr	30	91	120	1.059	1.059
May	31	121	151	1.103	1.103
Jun	30	152	181	1.150	1.150
July	31	182	212	1.028	1.028
Aug	31	213	243	0.892	0.892
Sep	30	244	273	0.911	0.911
Oct	31	274	304	0.946	0.946
Nov	30	305	334	0.972	0.972
Dec	31	335	365	0.946	0.946
Sum:	365		Avg:	1.001	1.001
			Wt Avg:	1	1

4

Input Updates – SST Fill Level used in critical condition ID



Input – Capacity Characteristics

5

Treatment Train Characteristics

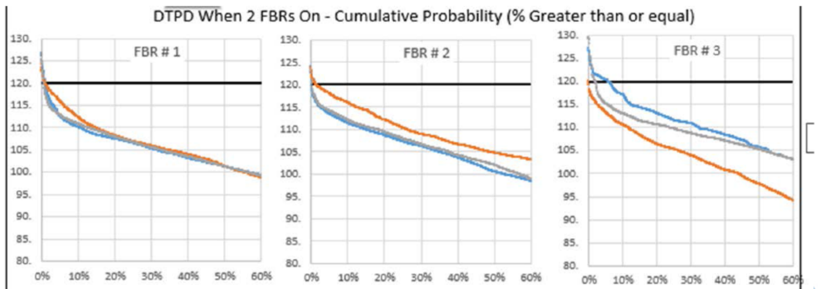
FBR Units Characteristics

Number of FBR Units (min = 1, max = 8 in current programming)	3
FBR Unit Capacity [dtpd]:	110 *

Alkaline Addition System Characteristics

Alkaline Addition System Capacity [dtpd]:	90 *

Capacity While Operating



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Input – Capacity Characteristics Additional Info - CORRECTED

6

Corrected

Item	FBR 1: For All Data with 2 FBRs Running	FBR 1: For Data With Sludge to Loadout Also Running	FBR 1: For Data Without Sludge to Loadout Running	FBR 2: For All Data with 2 FBRs Running	FBR 2: For Data With Sludge to Loadout Also Running	FBR 2: For Data Without Sludge to Loadout Running	FBR 3: For All Data with 2 FBRs Running	FBR 3: For Data With Sludge to Loadout Also Running	FBR 3: For Data Without Sludge to Loadout Running
2014									
Count	150	101	49	213	128	85	185	121	64
50 %-tile	101.7	101.6	102.7	103.2	104.0	101.2	105.2	106.1	103.9
75 %-tile	106.5	106.7	106.5	108.6	109.2	106.8	110.0	111.0	108.0
90 %-tile	109.2	109.3	108.7	113.2	114.3	111.7	114.0	114.4	112.2
95 %-tile	111.5	111.4	112.7	115.4	116.3	113.9	116.7	116.7	117.1
2015									
Count	155	46	109	154	29	125	111	23	88
50 %-tile	100.1	103.4	99.6	102.9	96.2	103.8	101.0	100.4	102.1
75 %-tile	105.6	108.0	103.1	107.5	104.6	108.0	111.8	108.2	113.2
90 %-tile	109.9	115.7	108.5	112.1	108.4	112.3	116.0	112.8	116.1
95 %-tile	113.9	116.0	110.9	113.3	111.3	113.6	116.9	115.2	117.6
2016									
Count	200	70	130	106	32	74	148	46	102
50 %-tile	104.3	104.4	104.2	106.3	106.2	106.4	102.6	99.4	104.6
75 %-tile	108.0	106.9	108.5	111.4	113.6	111.1	110.0	105.0	111.3
90 %-tile	112.1	111.3	113.3	116.4	118.6	115.9	113.4	111.9	114.5
95 %-tile	114.2	112.6	115.0	119.2	122.0	118.8	114.9	113.1	115.1
2017 to Oct 25									
Count	97	15	82	79	2	77	106	17	89
50 %-tile	103.6	103.6	103.5	100.4	98.6	100.4	105.6	105.3	105.6
75 %-tile	107.3	105.0	107.6	106.7	Note 1	106.8	109.7	109.5	109.9
90 %-tile	109.9	108.5	110.0	111.1	Note 1	111.1	114.5	112.1	114.6
95 %-tile	111.4	Note 1	111.6	113.4	Note 1	113.4	115.1	Note 1	115.2

FBR Mass Flow Rate (dtph) During Periods with 2 FBRs Running

Note 1. Excel function returned an error. It is likely there were too few data points for the Excel to calculate the cumulative probability by its method.

See pages at end for reformatted cumulative probability graphs

Using full processing day screening criteria of:
-FBR daily average >= 10 wtph (~67 dtpd)
-Sludge to Landfill daily average >= 0.2 dtph (4.8 dtpd)

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PM Curtailment in the Real World

7

Status Tracking Project FBR History for 5/9/16 to 9/15/17 - Scheduled Outage Data								
FBR	First Tracking Project Recorded Day with "F" Status	Last Tracking Project Recorded Day with "F" Status	Estimated First Day Off-Line Based on Feed Data (critiera < 6 wpth for day)	Estimated Last Day Off-Line Based on Feed Data (critiera < 6 wpth for day)	Estimated Duration Based on FBR Feed Data	Minimum Potential Duration (including weekend) - Project Recorded Days	Minimum Duration Days with Observations (weekends not included, consistent with sampling approach) - Project Recorded Days	Note
1	6/10/2016	6/10/2016	6/9/2016	6/9/2016	1	1	1	All day building shut down.
1	7/25/2016	8/10/2016	7/22/2016	8/11/2016	21	17	12	FBR 1 maintenance shut down
1	11/18/2016	11/18/2016	short - did not flag in daily feed			1	1	all day building shut down for electrical PM.
1	12/19/2016	12/20/2016	12/17/2016	12/20/2016	4	2	2	FBR 1 down for PMs but not completed **cut short due to WHB 2 Tube leak**
1	1/30/2017	2/10/2017	1/28/2017	2/10/2017	14	12	10	FBR 1 maintenance shut down and c alibrations
1	8/17/2017	8/18/2017	8/5/2017	8/20/2017	16	2	2	No note
1	8/30/2017	8/30/2017	8/29/2017	8/29/2017	1	1	1	SMB Shutdown
Sum					57	36	29	
2	6/10/2016	6/10/2016	6/9/2016	6/9/2016	1	1	1	All day building shut down.
2	9/6/2016	10/6/2016	9/4/2016	10/5/2016	32	31	18	FBR 2 maintenance shut down
2	11/18/2016	11/18/2016	short - did not flag in daily feed			1	1	all day building shut down for electrical PM.
2	4/17/2017	5/5/2017	4/15/2017	5/5/2017	21	19	15	FBR 2 maintenance shut down
2	7/19/2017	7/19/2017	7/18/2017	7/18/2017	1	1	1	#1 WHB tube leak, #2,#3 down for electrical PMs. **A day with all FBRs down for some period including one in forced outage**
2	8/30/2017	8/30/2017	8/30/2017	8/30/2017	1	1	1	SMB Shutdown
Sum					56	54	37	
3	6/8/2016	6/10/2016	6/8/2016	6/10/2016	3	3	3	BH 3 Mod 3 Plugged since May limiting capacity. Taken down to correct issue.
3	10/20/2016	10/20/2016	10/19/2016	10/19/2016	1	1	1	Electrical PM Maintenance on FBR 3 train
3	11/4/2016	11/4/2016	11/4/2016	11/5/2016	2	1	1	FBR 3 could have been started, but remained down due to electrical PM -- **Electrical PM tacked on to the end of a forced shutdown**
3	11/18/2016	11/18/2016	short - did not flag in daily feed			1	1	all day building shut down for electrical PM.
3	12/2/2016	12/8/2016	12/2/2016	12/8/2016	7	7	5	FBR 3 tube leakrepaired afternoon of 12/2, now down entirely for PM. **PM tacked on to a forced outage.**
3	6/12/2017	6/22/2017	6/10/2017	6/25/2017	16	11	9	Tracking project didn't capture data for the next week - use FBR Feed data for this case
3	7/19/2017	7/19/2017	7/18/2017	7/18/2017	1	1	1	#1 WHB tube leak, #2,#3 down for electrical PMs. **A day with all FBS down for some period with one in forced outage**
3	8/30/2017	8/30/2017			1	1	1	SMB Shutdown
Sum					31	26	22	

Number 3 does not appear to have received 2 of the programmed long duration planned maintenance shut downs during this >1 year period

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Input – Maintenance and Renewal Characteristics – Now With PM Curtailment Option

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FBR Unit's Maintenance Characteristics		
Maximum Allowed Number of FBR Units in PM/RM	1	
FBR Unit's Unplanned Maintenance		
Probability of Failure when operating:		Input Results in
At the Start of the Renewed Period	0.01530	3.42
At the End of the Renewed Period	0.01530	Events per unit
Unplanned Maintenance Duration [calendar d]:	7	per year in 2016
Calendar Day Window in which the UM will be converted to PM [calendar d]:	30	
FBR Unit's Planned Maintenance		Input Results in
Operating Days Between Planned Maintenance, if operating will not force taking off line and PM [operating d]:	122	2.03
Maximum Operating Days Between Planned Maintenance, will force taking out of operation and PM [operating d]:	210	Events per unit
Planned Maintenance Duration [d]:		per year in 2016
At the Start of the Renewed Period	21	Input Results in
At the End of the Renewed Period	21	13.328
Calendar Day Window in which the PM will be converted to RM [calendar d]:	50	Event days duration
Number of Units (>=) in UM to cause all PMs to be curtailed and units in PM to be converted to available:	1	per unit per year in 2016

```
' start - if number in UM is >= limit, place units in PM to available and capture the amount of curtailed PM

        units_in_um_w = 0

        For i = 1 To n_unit

            units_in_um_w = units_in_um_w + unit_status(i, 6)

        Next i

        If units_in_um_w >= pm_curtail_no_in_um Then

            For i = 1 To n_unit

                If unit_status(i, 8) = 1 Then

                    der_pm_day_sum = der_pm_day_sum + (pm_dur_start - unit_status(i, 9))

                    unit_status(i, 4) = 1
                    unit_status(i, 5) = -1
                    unit_status(i, 8) = 0
                    unit_status(i, 9) = 0

                End If

            Next i

        End If

' end - if number in UM is >= limit, place units in PM to available and capture the amount of curtailed PM
```

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Failure Rate Input for Comparisons

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Status Tracking Project FBR History Data From 5/9/16 to 9/15/17 – Overall Brief Summary							
Item	FBR 1	FBR 2	FBR 3	Total	Total Expressed Per 3 Units	Total - 2 and 3	Total Expressed Per 2 Units
Unplanned Maintenance							
Total Number of Days Without Feed per Year	2.95	34.68	30.25	67.88	22.63	64.93	32.47
Total Number of Events per Year	0.74	4.43	5.17	10.33	3.44	9.59	4.80
Net Days Without Feed per Event	4.00	7.83	5.86	-	6.57	-	6.77
Planned Maintenance						Total - 1 and 2	Total Expressed Per
Total Number of Days Without Feed per Year	42.06	41.32	22.87	106.25	35.42	83.38	41.69
Actual Total Number of Events per Year	5.17	4.43	5.90	15.50	5.17	9.59	4.80
Number of Major Events Per Year to Distribute Over	2.00	2.00	2.00	2.00	2.00	4.00	2.00
Net Days per Major Event for Risk Evaluation	21.03	20.66	11.44	53.13	17.71	41.69	20.85
Failure Rate					Low PM for 3		
Days Operating per year (365 -UM-PM)	319.99	289.00	311.87		306.95		290.84
Operating Days Availble per year (365-PM)	322.94	323.68	342.13		329.58		323.31
Failure Rate - Time to Failure Basis (events/operating day)	0.0023	0.0153	0.0166		0.0112		0.0165
Failure Rate - Time Between Failure Basis (events/day)	0.0023	0.0137	0.0151		0.0104		0.0148

Median

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PM Curtailment - Simulated

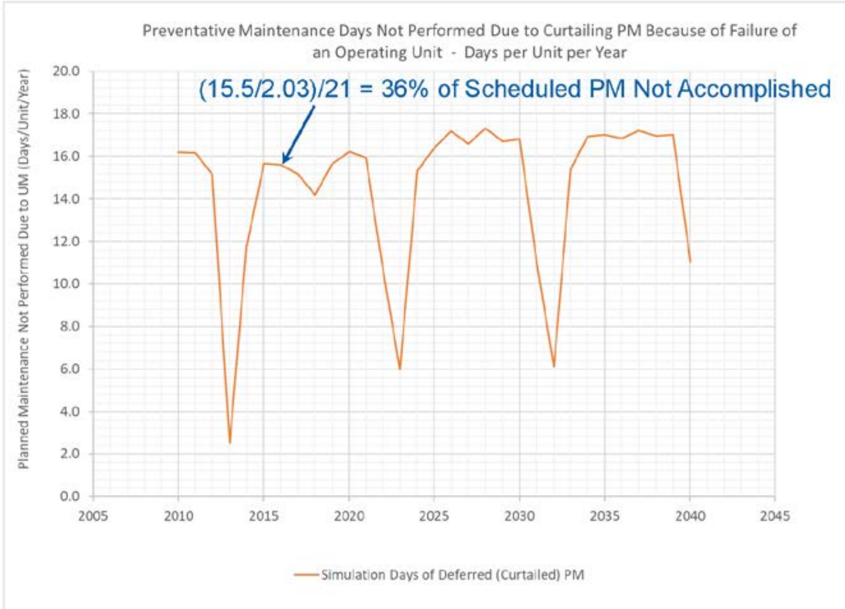
10

Treatment Train Characteristics		
FBR Units Characteristics		
Number of FBR Units (min = 1, max = 8 in current programming)	3	
FBR Unit Capacity [dtpd]:	110	
Alkaline Addition System Characteristics		
Alkaline Addition System Capacity [dtpd]:	90	
FBR Unit's Maintenance Characteristics		
Maximum Allowed Number of FBR Units in PM/RM	1	
FBR Unit's Unplanned Maintenance		
Probability of Failure when operating:		Input Results in
At the Start of the Renewed Period	0.01530	3.42
At the End of the Renewed Period	0.01530	Events per unit
Unplanned Maintenance Duration [calendar d]:	7	per year in 2016
Calendar Day Window in which the UM will be converted to PM [calendar d]:	30	
FBR Unit's Planned Maintenance		Input Results in
Operating Days Between Planned Maintenance, if operating will not force taking off line and PM [operating d]:	122	2.03
Maximum Operating Days Between Planned Maintenance, will force taking out of operation and PM [operating d]:	210	Events per unit
Planned Maintenance Duration [d]:		per year in 2016
At the Start of the Renewed Period	21	Input Results in
At the End of the Renewed Period	21	13.328
Calendar Day Window in which the PM will be converted to RM [calendar d]:	50	Event days duration
Number of Units (>=) in UM to cause all PMs to be curtailed and units in PM to be converted to available:	1	per unit per year in 2016
FBR Renewal Maintenance		
Operating Days Between Renewal Mainteance, if operating will not force taking off line and RM [operating d]:	2,700	
Maximum Operating Days Between Renewal Mainteance, will force taking out of operation and RM [operating d]:	3,200	
Renewal Mainteance Duration [d]:	90	
The Operating Days added to the normal PM need following a RM [operating d]:	80	

METROPOLITAN COUNCIL

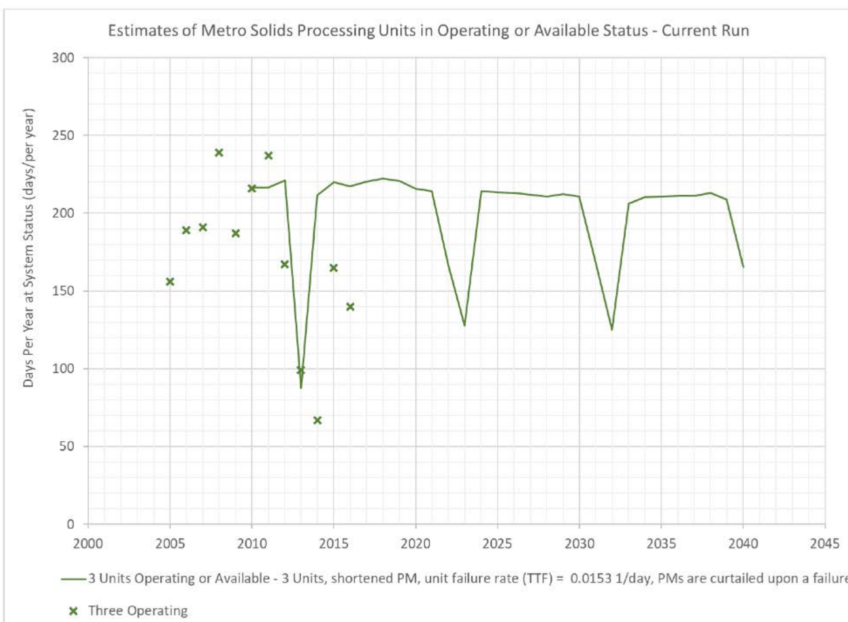
PM Curtailment – Simulated

11



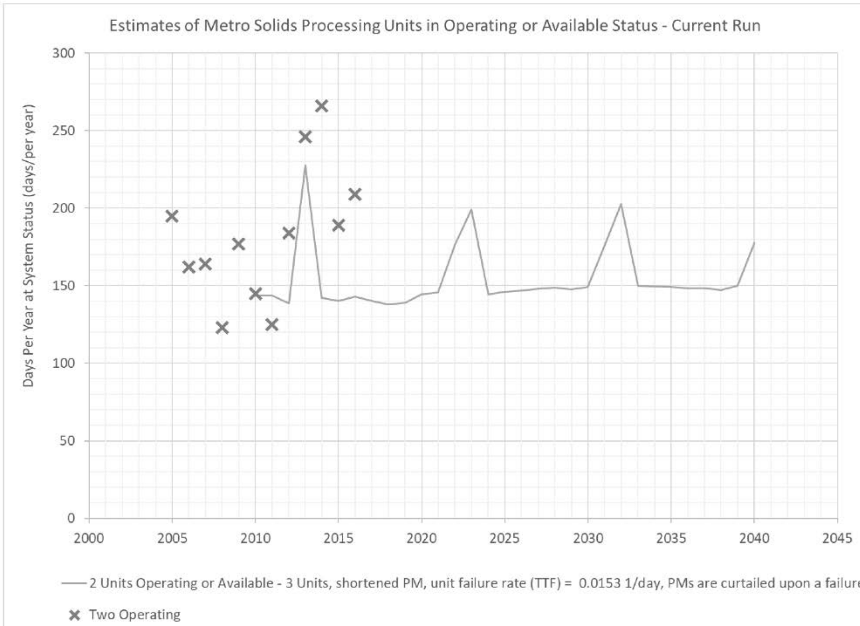
PM Curtailment – Simulated - 3

12



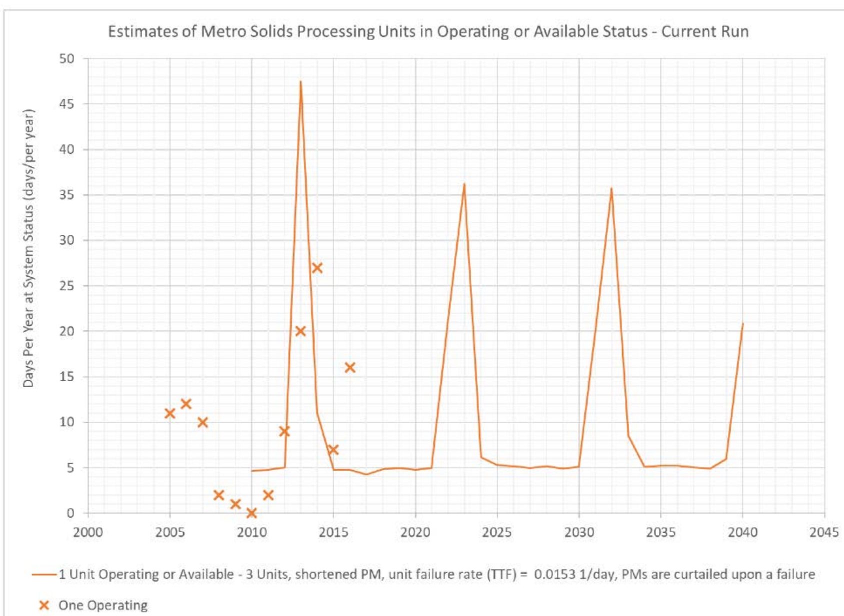
PM Curtailment – Simulated - 2

13



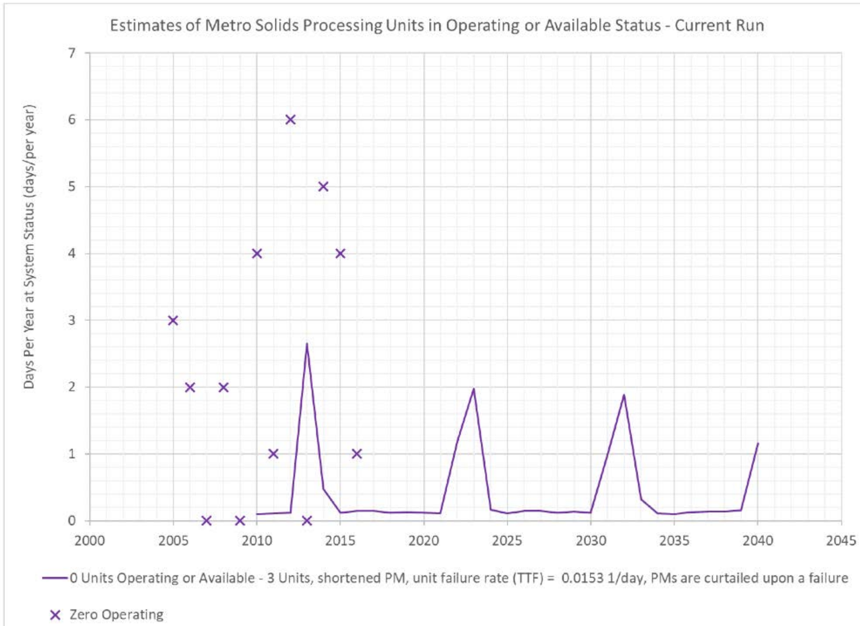
PM Curtailment – Simulated - 1

14



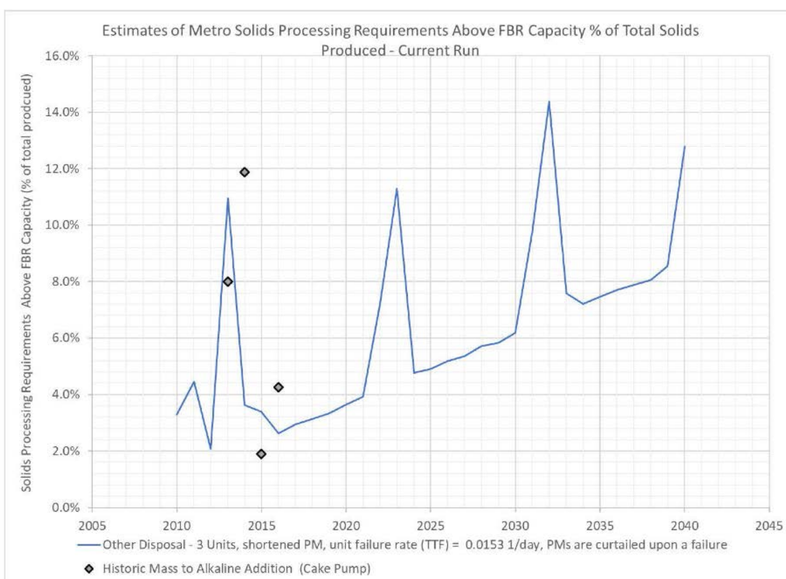
PM Curtailment – Simulated - 0

15



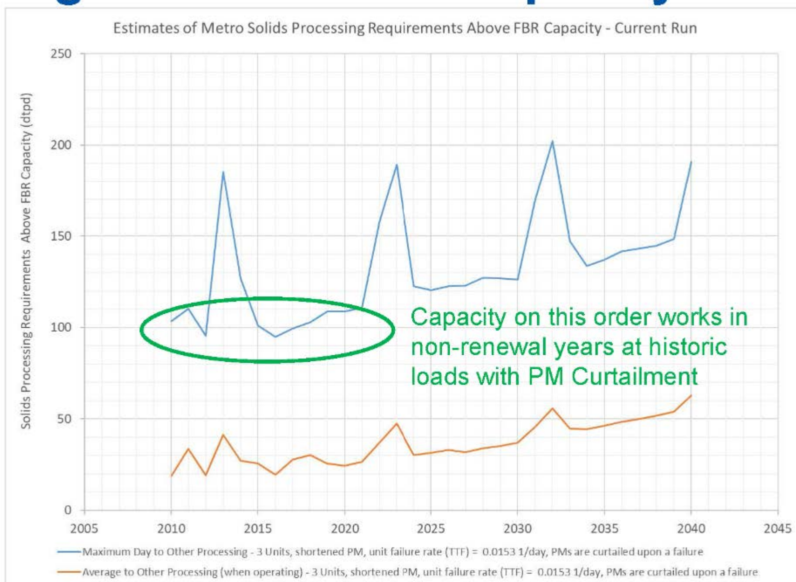
PM Curtailment – Simulated – Sludge to Landfill

16



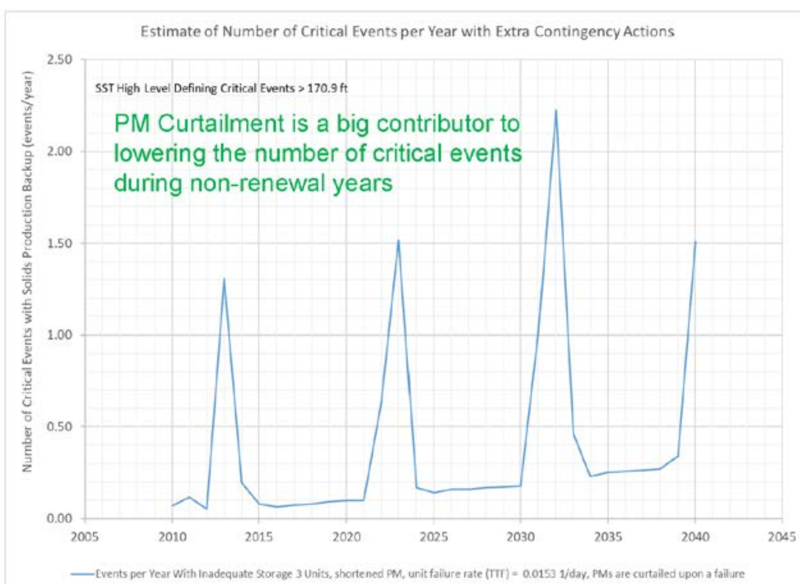
PM Curtailment – Simulated – Sludge to Landfill – Capacity Used

17



PM Curtailment – Simulated – Critical Conditions

18



Simulation Runs - PM Curtailment

Treatment Train Characteristics		
FBR Units Characteristics		
Number of FBR Units (min = 1, max = 8 in current programming)	3	
FBR Unit Capacity [dtpd]:	110	
Alkaline Addition System Characteristics		
Alkaline Addition System Capacity [dtpd]:	90	
FBR Unit's Maintenance Characteristics		
Maximum Allowed Number of FBR Units in PM/RM	1	
FBR Unit's Unplanned Maintenance		
Probability of Failure when operating:		Input Results in
At the Start of the Renewed Period	0.01530	3.42
At the End of the Renewed Period	0.01530	Events per unit
Unplanned Maintenance Duration [calendar d]:	7	per year in 2016
Calendar Day Window in which the UM will be converted to PM [calendar d]:	30	
FBR Unit's Planned Maintenance		Input Results in
Operating Days Between Planned Maintenance, if operating will not force taking off line and PM [operating d]:	122	2.03
Maximum Operating Days Between Planned Maintenance, will force taking out of operation and PM [operating d]:	210	Events per unit
Planned Maintenance Duration [d]:		per year in 2016
At the Start of the Renewed Period	21	Input Results in
At the End of the Renewed Period	21	13.328
Calendar Day Window in which the PM will be converted to RM [calendar d]:	50	Event days duration
Number of Units (>=) in UM to cause all PMs to be curtailed and units in PM to be converted to available:	1	per unit per year in 2016
FBR Renewal Maintenance		
Operating Days Between Renewal Mainteance, if operating will not force taking off line and RM [operating d]:	2,700	
Maximum Operating Days Between Renewal Mainteance, will force taking out of operation and RM [operating d]:	3,200	
Renewal Mainteance Duration [d]:	90	
The Operating Days added to the normal PM need following a RM [operating d]:	80	

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Sim Runs - Without PM Curtailment - 3

Treatment Train Characteristics		
FBR Units Characteristics		
Number of FBR Units (min = 1, max = 8 in current programming)	3	
FBR Unit Capacity [dtpd]:	110	
Alkaline Addition System Characteristics		
Alkaline Addition System Capacity [dtpd]:	90	
FBR Unit's Maintenance Characteristics		
Maximum Allowed Number of FBR Units in PM/RM	1	
FBR Unit's Unplanned Maintenance		
Probability of Failure when operating:		Input Results in
At the Start of the Renewed Period	0.01530	3.38
At the End of the Renewed Period	0.01530	Events per unit
Unplanned Maintenance Duration [calendar d]:	7	per year in 2016
Calendar Day Window in which the UM will be converted to PM [calendar d]:	30	
FBR Unit's Planned Maintenance		Input Results in
Operating Days Between Planned Maintenance, if operating will not force taking off line and PM [operating d]:	122	1.90
Maximum Operating Days Between Planned Maintenance, will force taking out of operation and PM [operating d]:	210	Events per unit
Planned Maintenance Duration [d]:		per year in 2016
At the Start of the Renewed Period	21	Input Results in
At the End of the Renewed Period	21	21.000
Calendar Day Window in which the PM will be converted to RM [calendar d]:	50	Event days duration
Number of Units (>=) in UM to cause all PMs to be curtailed and units in PM to be converted to available:	8	per unit per year in 2016
FBR Renewal Maintenance		
Operating Days Between Renewal Mainteance, if operating will not force taking off line and RM [operating d]:	2,700	
Maximum Operating Days Between Renewal Mainteance, will force taking out of operation and RM [operating d]:	3,200	
Renewal Mainteance Duration [d]:	90	
The Operating Days added to the normal PM need following a RM [operating d]:	80	

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Sim Runs - Without PM Curtailment - 4

21

Treatment Train Characteristics		
FBR Units Characteristics		
Number of FBR Units (min = 1, max = 8 in current programming)	4	
FBR Unit Capacity [dtpd]:	110	
Alkaline Addition System Characteristics		
Alkaline Addition System Capacity [dtpd]:	90	
FBR Unit's Maintenance Characteristics		
Maximum Allowed Number of FBR Units in PM/RM	1	
FBR Unit's Unplanned Maintenance		
Probability of Failure when operating:		Input Results in
At the Start of the Renewed Period	0.01530	3.01
At the End of the Renewed Period	0.01530	Events per unit
Unplanned Maintenance Duration [calendar d]:	7	per year in 2016
Calendar Day Window in which the UM will be converted to PM [calendar d]:	30	
FBR Unit's Planned Maintenance		Input Results in
Operating Days Between Planned Maintenance, if operating will not force taking off line and PM [operating d]:	122	1.61
Maximum Operating Days Between Planned Maintenance, will force taking out of operation and PM [operating d]:	210	Events per unit
Planned Maintenance Duration [d]:		per year in 2016
At the Start of the Renewed Period	21	Input Results in
At the End of the Renewed Period	21	21.000
Calendar Day Window in which the PM will be converted to RM [calendar d]:	[illegible]	Event days duration
Number of Units (>=) in UM to cause all PMs to be curtailed and units in PM to be converted to available:	8	per unit per year in 2016
FBR Renewal Maintenance		
Operating Days Between Renewal Mainteance, if operating will not force taking off line and RM [operating d]:	2,700	
Maximum Operating Days Between Renewal Mainteance, will force taking out of operation and RM [operating d]:	3,200	
Renewal Mainteance Duration [d]:	90	
The Operating Days added to the normal PM need following a RM [operating d]:	80	

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Sim Runs - Without PM Curtailment – 3 and 75% of current failure rate

22

FBR Units Characteristics		
Number of FBR Units (min = 1, max = 8 in current programming)	3	
FBR Unit Capacity [dtpd]:	110	
Alkaline Addition System Characteristics		
Alkaline Addition System Capacity [dtpd]:	90	
FBR Unit's Maintenance Characteristics		
Maximum Allowed Number of FBR Units in PM/RM	1	
FBR Unit's Unplanned Maintenance		
Probability of Failure when operating:		Input Results in
At the Start of the Renewed Period	0.01163	2.33
At the End of the Renewed Period	0.01163	Events per unit
Unplanned Maintenance Duration [calendar d]:	7	per year in 2016
Calendar Day Window in which the UM will be converted to PM [calendar d]:	30	
FBR Unit's Planned Maintenance		Input Results in
Operating Days Between Planned Maintenance, if operating will not force taking off line and PM [operating d]:	110	1.92
Maximum Operating Days Between Planned Maintenance, will force taking out of operation and PM [operating d]:	210	Events per unit
Planned Maintenance Duration [d]:		per year in 2016
At the Start of the Renewed Period	21	Input Results in
At the End of the Renewed Period	21	21.000
Calendar Day Window in which the PM will be converted to RM [calendar d]:	[illegible]	Event days duration
Number of Units (>=) in UM to cause all PMs to be curtailed and units in PM to be converted to available:	8	per unit per year in 2016
FBR Renewal Maintenance		
Operating Days Between Renewal Mainteance, if operating will not force taking off line and RM [operating d]:	2,700	
Maximum Operating Days Between Renewal Mainteance, will force taking out of operation and RM [operating d]:	3,200	
Renewal Mainteance Duration [d]:	90	
The Operating Days added to the normal PM need following a RM [operating d]:	80	

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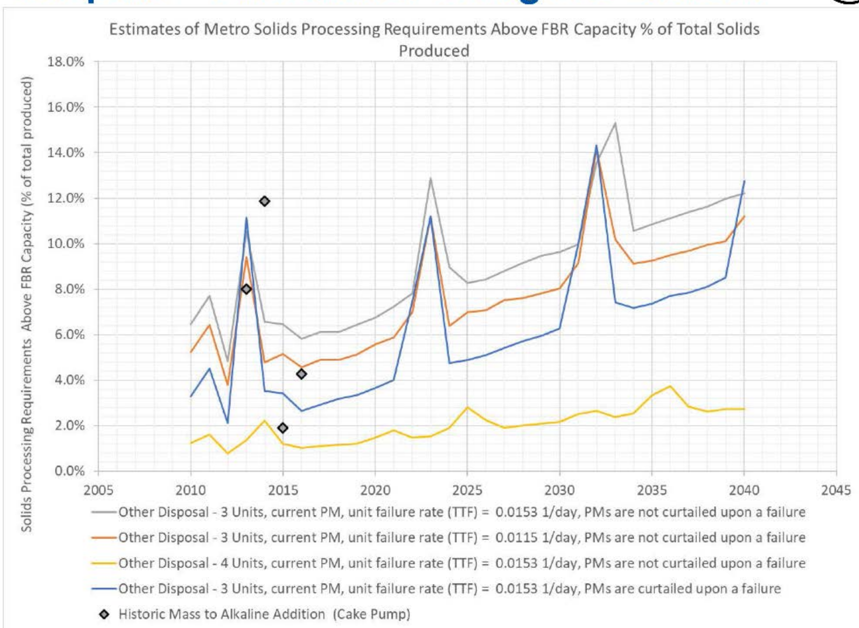
Outputs – Amount of Sludge to Landfill

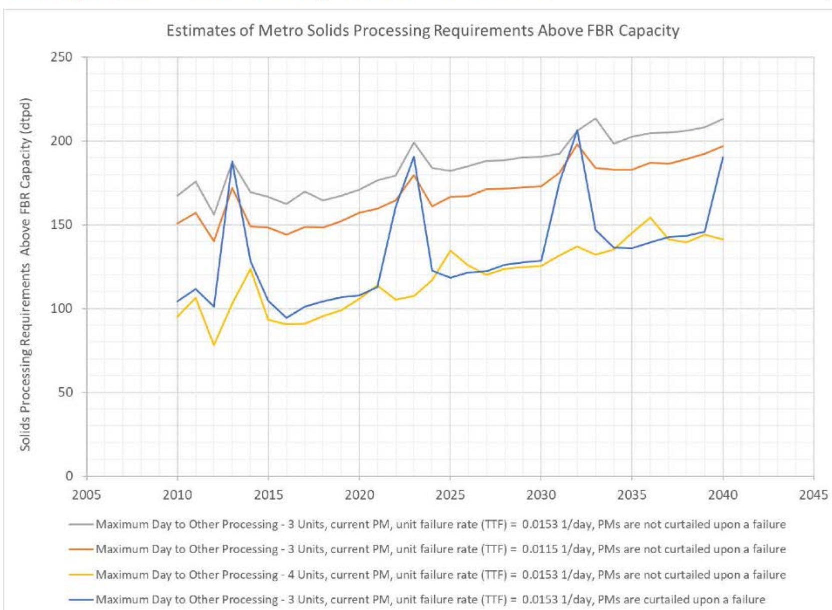
23



METROPOLITAN COUNCIL

Outputs – Max Day Above FBRs

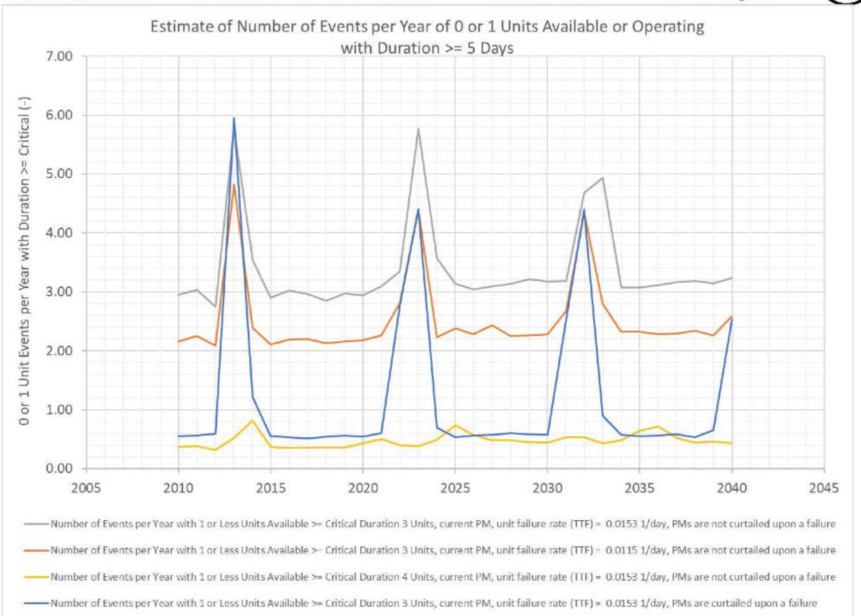
24



METROPOLITAN COUNCIL

Outputs – Critical Events – Events >= 5 Days

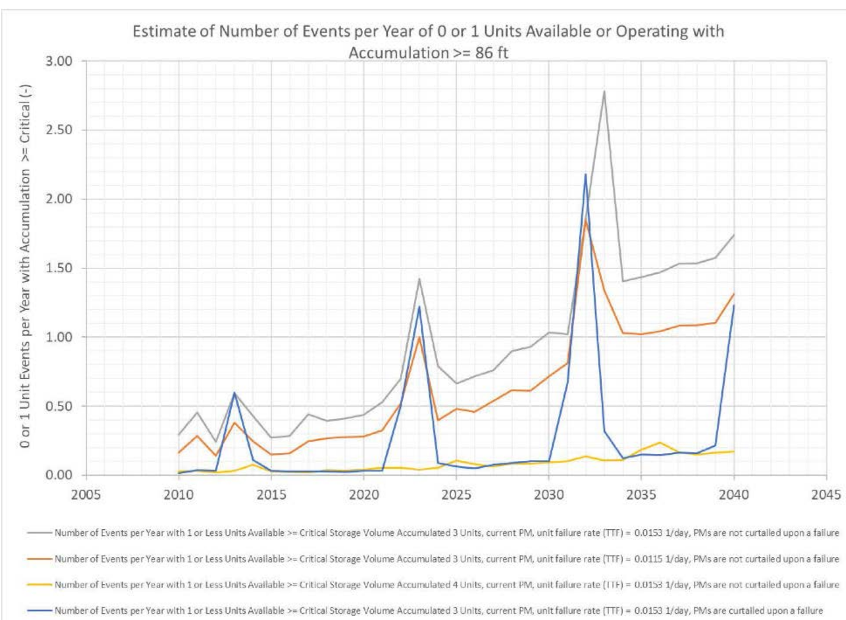
25



METROPOLITAN COUNCIL

Outputs – Events Requiring Over 86 ft of SST

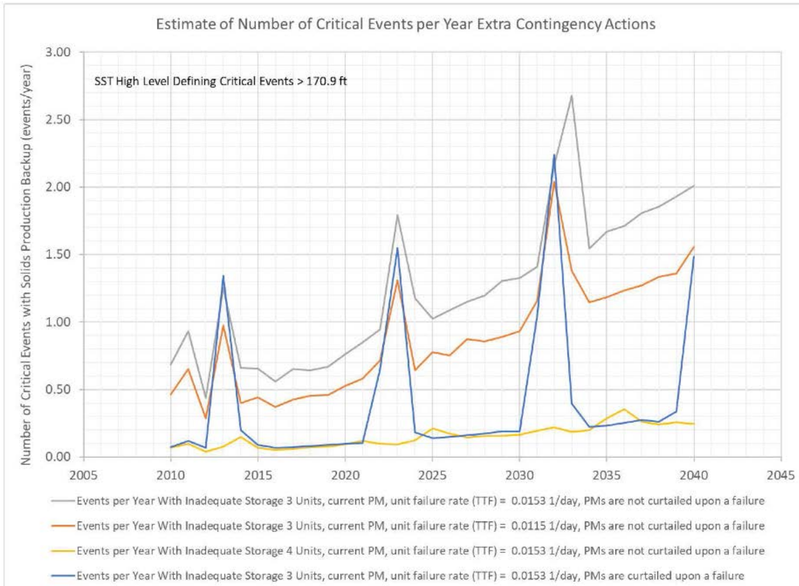
26



METROPOLITAN COUNCIL

Outputs – Events Requiring Extra Contingency Action

27



METROPOLITAN COUNCIL

Curtailment vs. Shorter PM

28

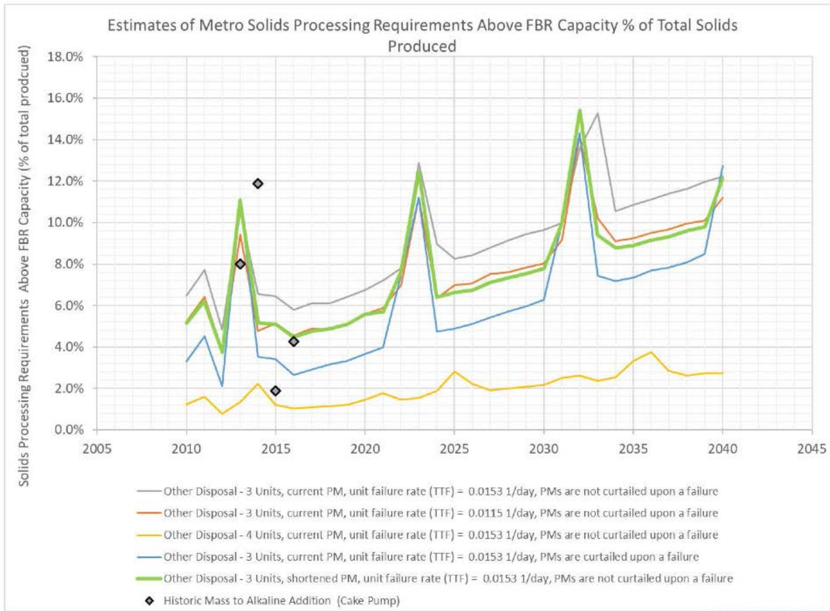
- What if PM is shortened to the days that resulted from curtailment but curtailment isn't practiced?

Treatment Train Characteristics		
FBR Units Characteristics		
Number of FBR Units (min = 1, max = 8 in current programming)	3	
FBR Unit Capacity [dtpd]:	110	
Alkaline Addition System Characteristics		
Alkaline Addition System Capacity [dtpd]:	90	
FBR Unit's Maintenance Characteristics		
Maximum Allowed Number of FBR Units in PM/RM	1	
FBR Unit's Unplanned Maintenance		
Probability of Failure when operating:		Input Results in
At the Start of the Renewed Period	0.01530	3.37
At the End of the Renewed Period	0.01530	Events per unit
Unplanned Maintenance Duration [calendar d]:	7	per year in 2016
Calendar Day Window in which the UM will be converted to PM [calendar d]:	30	
FBR Unit's Planned Maintenance		Input Results in
Operating Days Between Planned Maintenance, if operating will not force taking off line and PM [operating d]:	122	2.04
Maximum Operating Days Between Planned Maintenance, will force taking out of operation and PM [operating d]:	210	Events per unit
Planned Maintenance Duration [d]:		per year in 2016
At the Start of the Renewed Period	14	Input Results in
At the End of the Renewed Period	14	14.000
Calendar Day Window in which the PM will be converted to RM [calendar d]:	50	Event days duration
Number of Units (>=) in UM to cause all PMs to be curtailed and units in PM to be converted to available:	8	per unit per year in 2016
FBR Renewal Maintenance		
Operating Days Between Renewal Mainteance, if operating will not force taking off line and RM [operating d]:	2,700	
Maximum Operating Days Between Renewal Mainteance, will force taking out of operation and RM [operating d]:	3,200	
Renewal Mainteance Duration [d]:	90	
The Operating Days added to the normal PM need following a RM [operating d]:	80	

METROPOLITAN COUNCIL

Outputs – Amount of Sludge to Landfill

29



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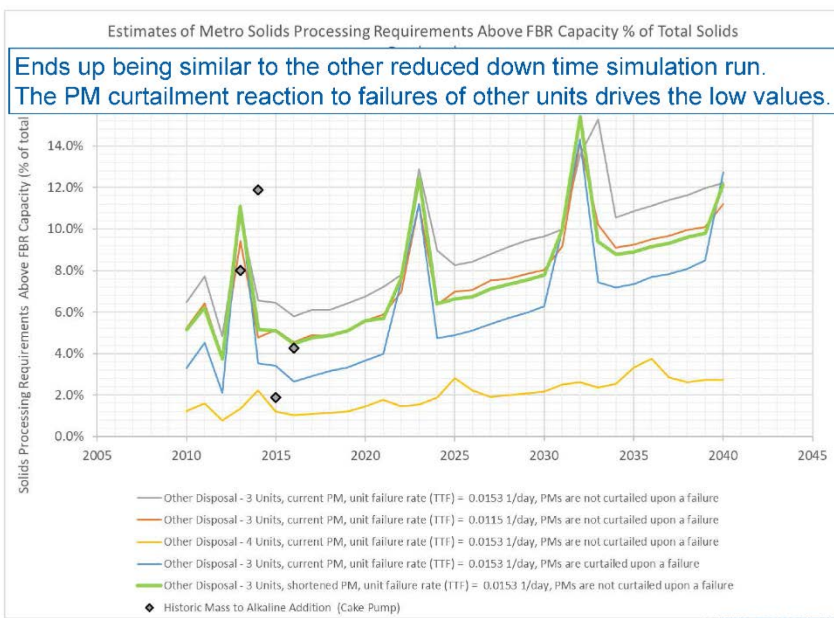
Outputs – Amount of Sludge to Landfill

30

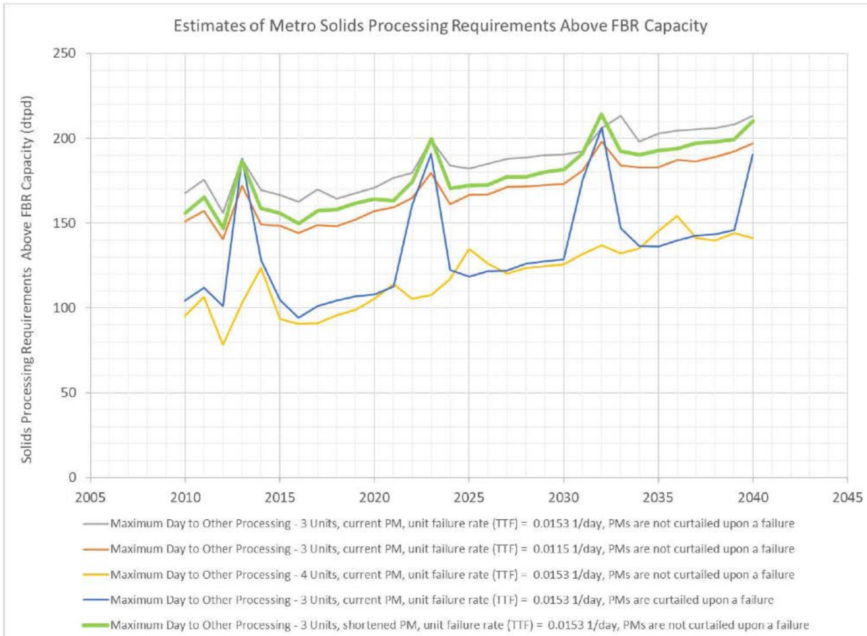
Ends up being similar to the other reduced down time simulation run.
The PM curtailment reaction to failures of other units drives the low values.



METROPOLITAN COUNCIL

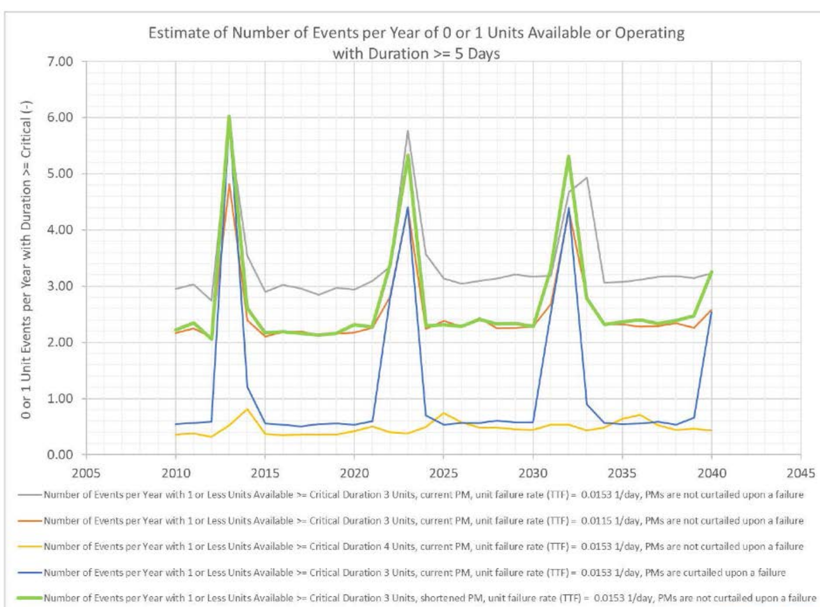
Outputs – Max Day Above FBRs

31



Outputs – Critical Events – Events >= 5 Days

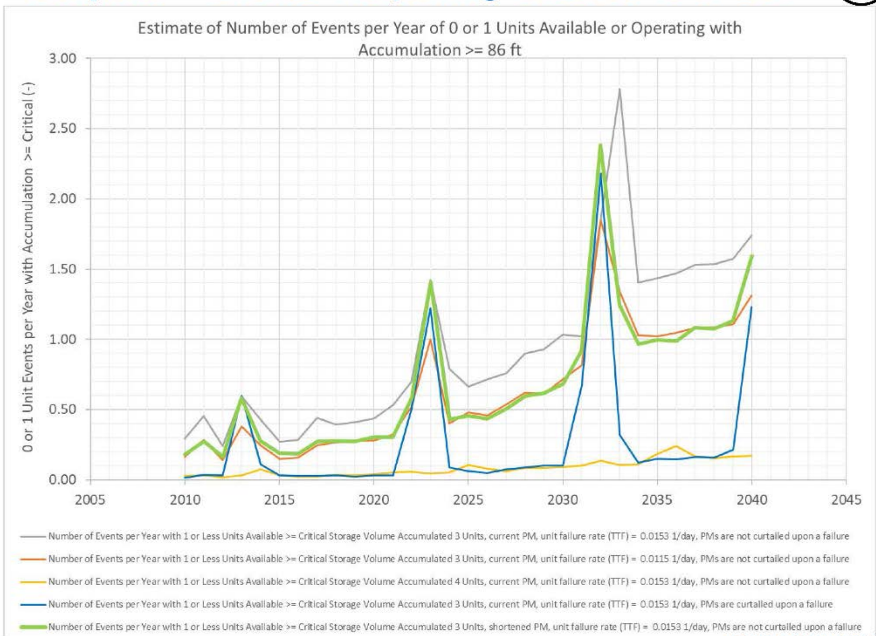
32



METROPOLITAN COUNCIL

Outputs – Events Requiring Over 86 ft of SST

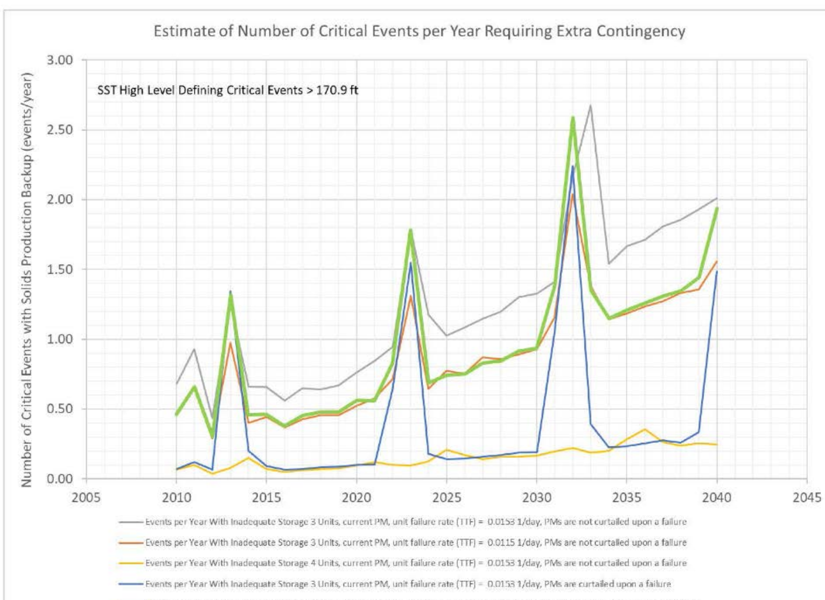
33



METROPOLITAN COUNCIL

Outputs – Events Requiring Extra Contingency Action

34



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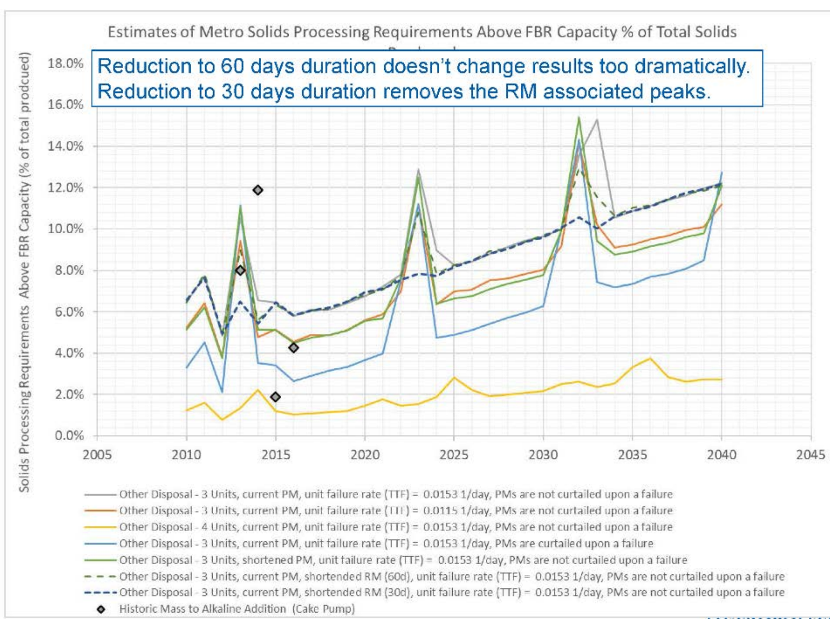
Jan 2018 Runs with Shorter Renewal Periods (base = 90 d)

FBR Renewal Maintenance	
Operating Days Between Renewal Mainteance, if operating will not force taking off line and RM [operating d]:	2,700
Maximum Operating Days Between Renewal Mainteance, will force taking out of operation and RM [operating d]:	3,200
Renewal Mainteance Duration [d]:	60
The Operating Days added to the normal PM need following a RM [operating d]:	[illegible]

FBR Renewal Maintenance	
Operating Days Between Renewal Mainteance, if operating will not force taking off line and RM [operating d]:	2,700
Maximum Operating Days Between Renewal Mainteance, will force taking out of operation and RM [operating d]:	3,200
Renewal Mainteance Duration [d]:	30
The Operating Days added to the normal PM need following a RM [operating d]:	[illegible]

METROPOLITAN COUNCIL

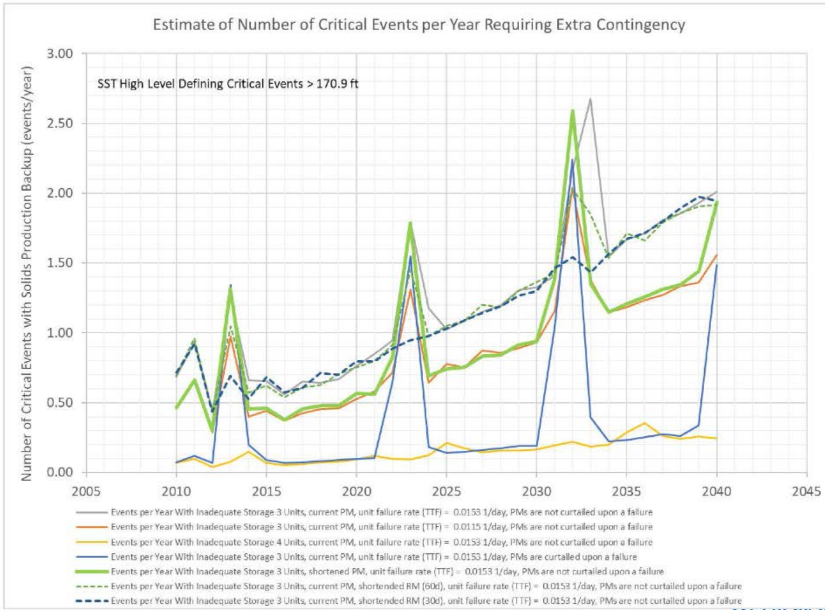
Outputs – Amount of Sludge to Landfill



METROPOLITAN COUNCIL

Outputs – Events Requiring Extra Contingency Action

37



METROPOLITAN COUNCIL

38

Parallel Calcs in a More Standard Framework

Status Tracking Project FBR History Data From 5/9/16 to 9/15/17 – Overall Brief Summary

Item	FBR 1	FBR 2	FBR 3	Total	Total Expressed Per 3 Units	Total - 2 and 3	Total Expressed Per 2 Units
Unplanned Maintenance							
Total Number of Days Without Feed per Year	2.95	34.68	30.25	67.88	22.63	64.93	32.47
Total Number of Events per Year	0.74	4.43	5.17	10.33	3.44	9.59	4.80
Net Days Without Feed per Event	4.00	7.83	5.86	-	6.57	-	6.77
Planned Maintenance						Total - 1 and 2	Total Expressed Per
Total Number of Days Without Feed per Year	42.06	41.32	22.87	106.25	35.42	83.38	41.69
Actual Total Number of Events per Year	5.17	4.43	5.90	15.50	5.17	9.59	4.80
Number of Major Events Per Year to Distribute Over	2.00	2.00	2.00	2.00	2.00	4.00	2.00
Net Days per Major Event for Risk Evaluation	21.03	20.66	11.44	53.13	17.71	41.69	20.85
Failure Rate					Low PM for 3		
Days Operating per year (365 -UM-PM)	319.99	289.00	311.87		306.95		290.84
Operating Days Availble per year (365-PM)	322.94	323.68	342.13		329.58		323.31
Failure Rate - Time to Failure Basis (events/operating day)	0.0023	0.0153	0.0166		0.0112		0.0165
Failure Rate - Time Between Failure Basis (events/day)	0.0023	0.0137	0.0151		0.0104		0.0148

Item	FBR 1	FBR 2	FBR 3
Failure Rate - Time Between Failure Basis (events/day)	0.00228487	0.01367798	0.01509723
Operating Days Availble per year (365-PM)	322.94	323.68	342.13
Operating Days Availble per year (365-PM) Per 2 Periods	161.47	161.84	171.06

Use 162 days even spacing and 21 days per PM event (2)

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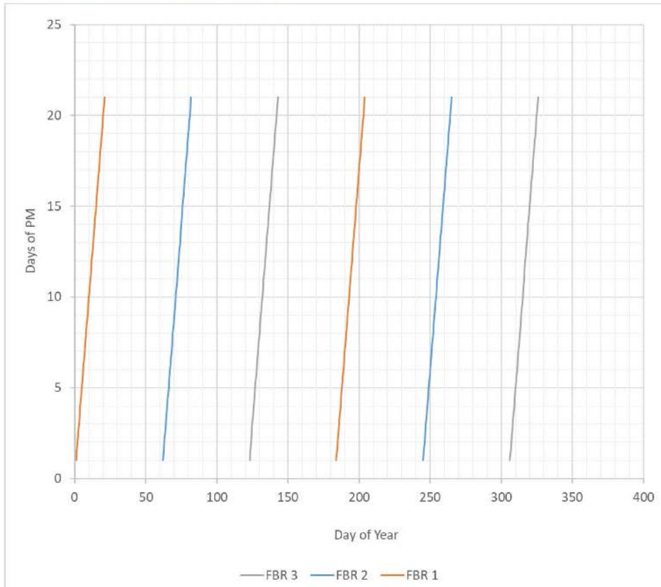
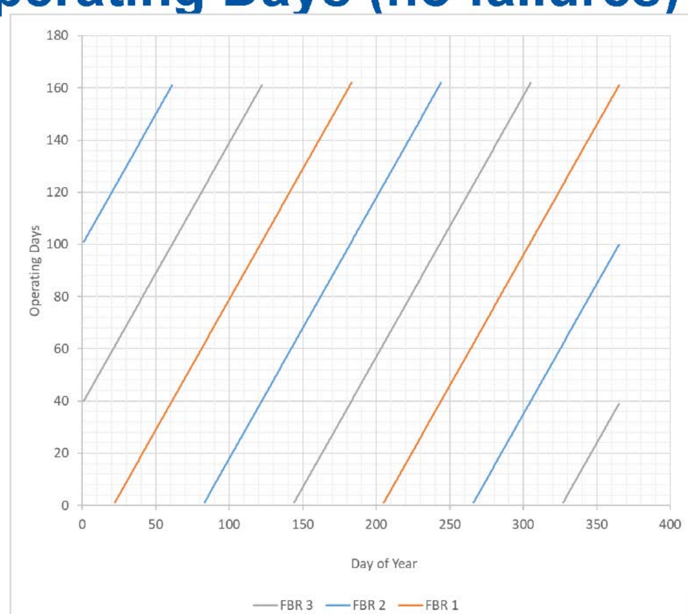
PM Schedule

39



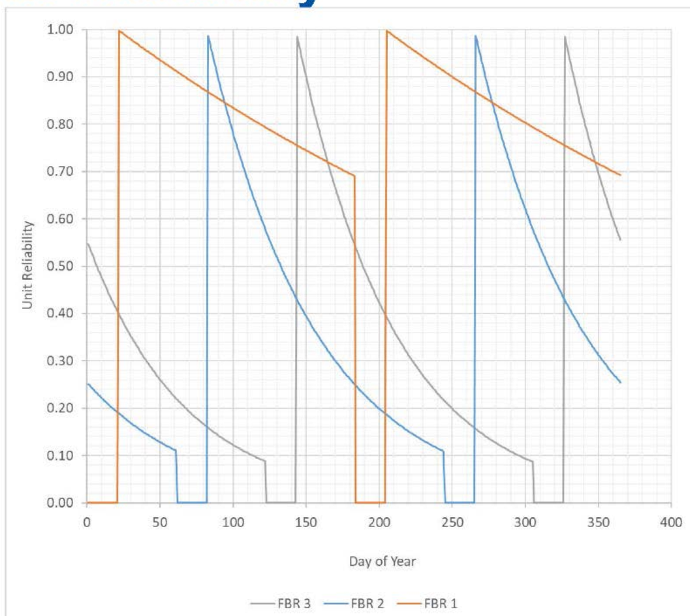
Operating Days (no failures)

40



Unit Reliability

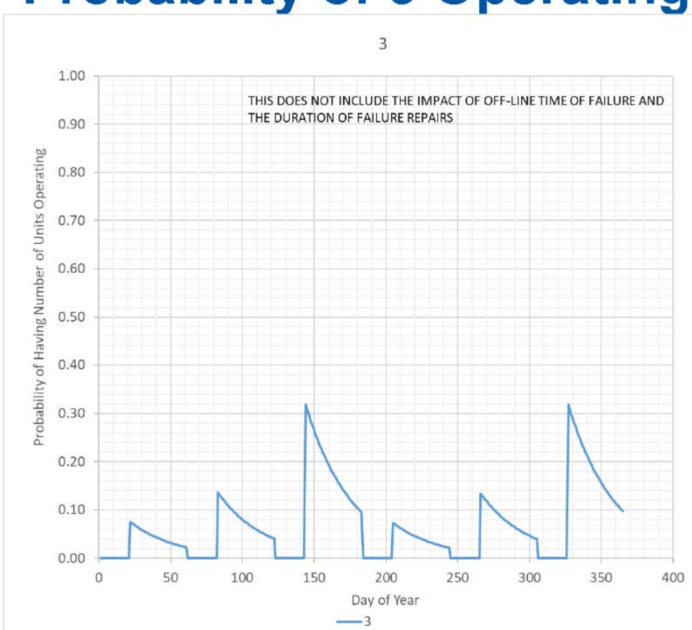
41



METROPOLITAN COUNCIL

Probability of 3 Operating

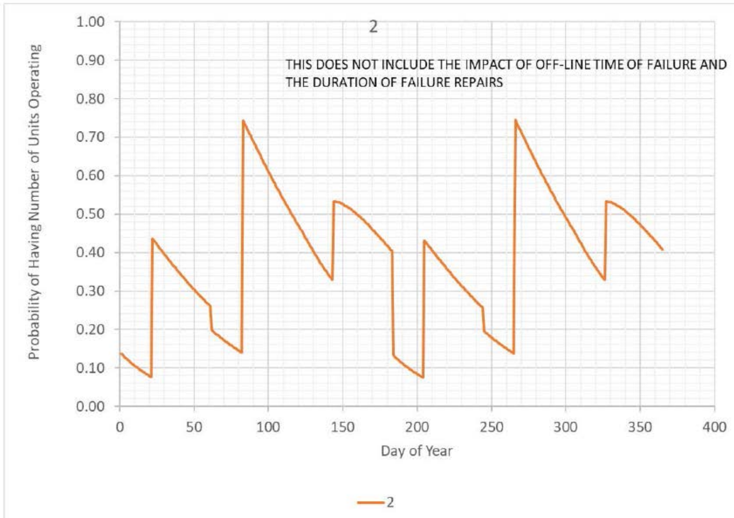
42



METROPOLITAN COUNCIL

Probability of 2 Operating

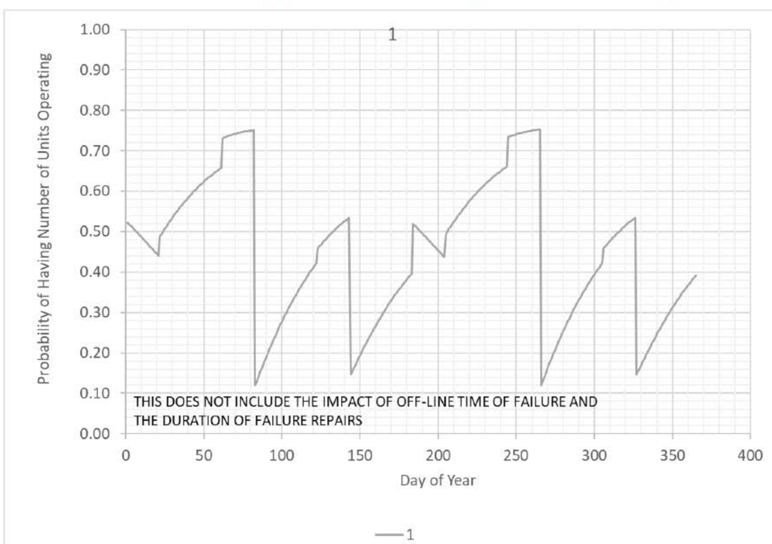
43



METROPOLITAN COUNCIL

Probability of 1 Operating

44



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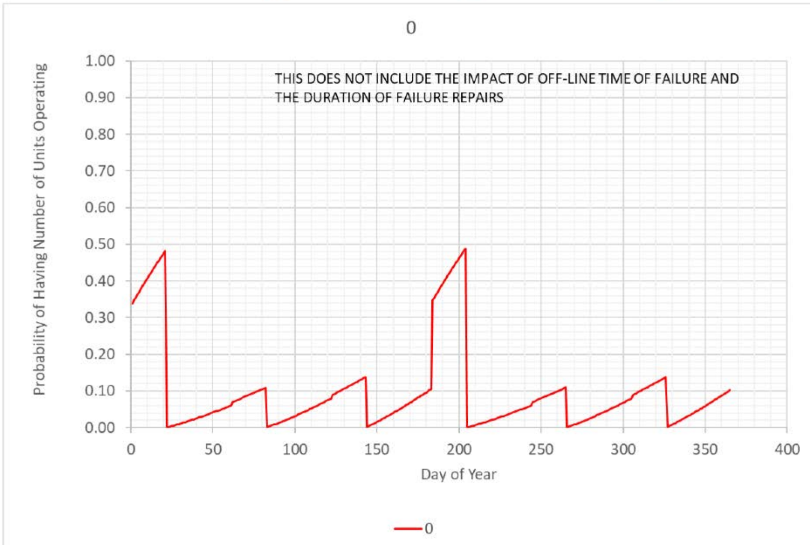
Probability of 0 Operating

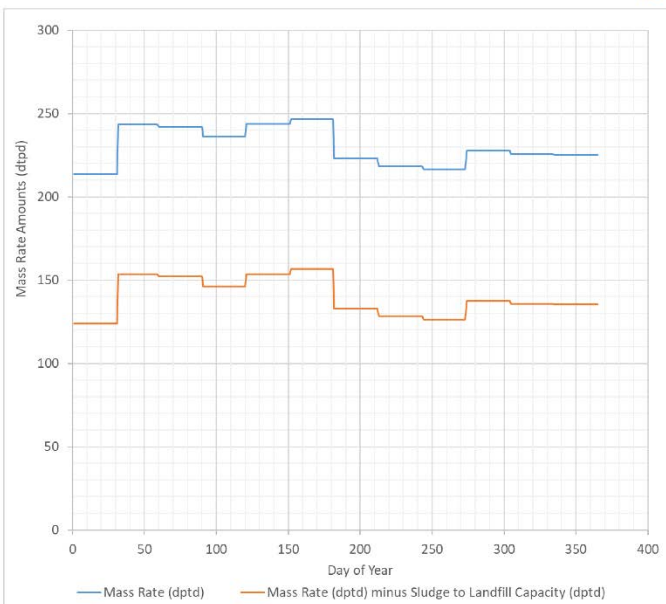
45



METROPOLITAN COUNCIL

Mass Rates – 2016 Monthly Values

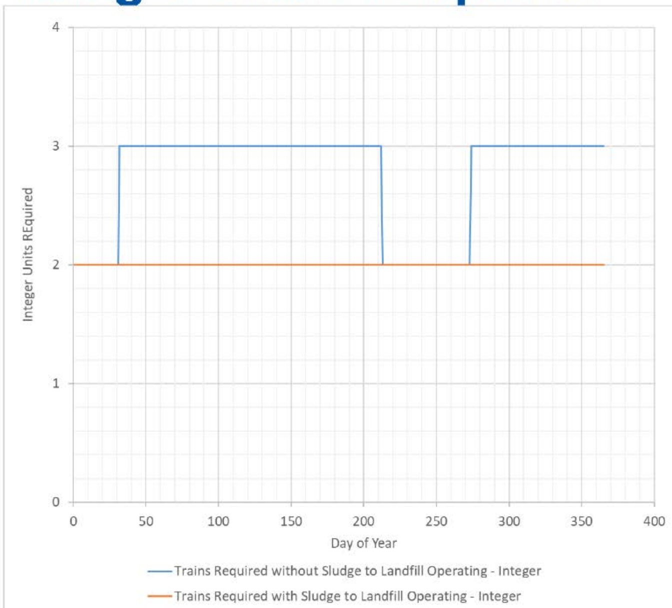
46



METROPOLITAN COUNCIL

Integer Units Required

47



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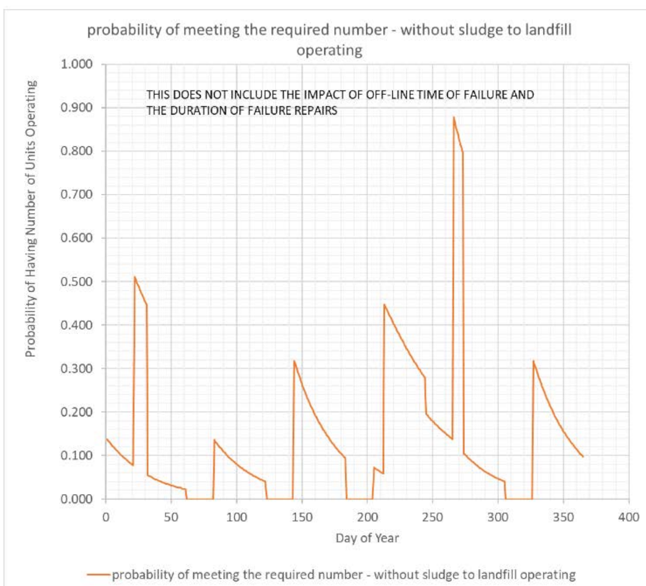
Probability of Having Required Units

48



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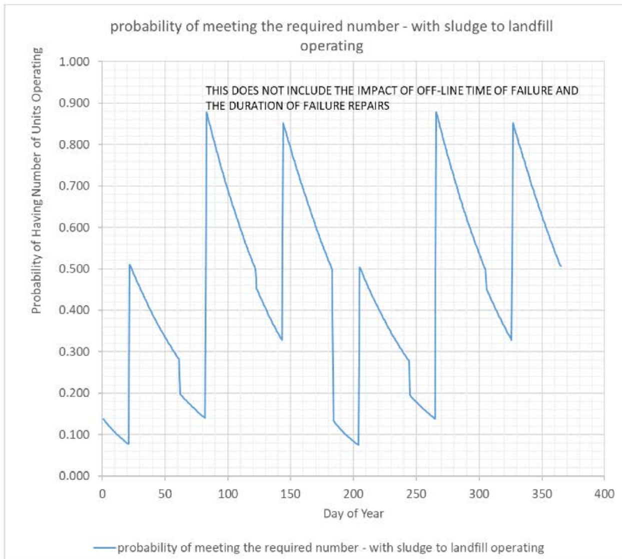
Probability of Having Required Units

49



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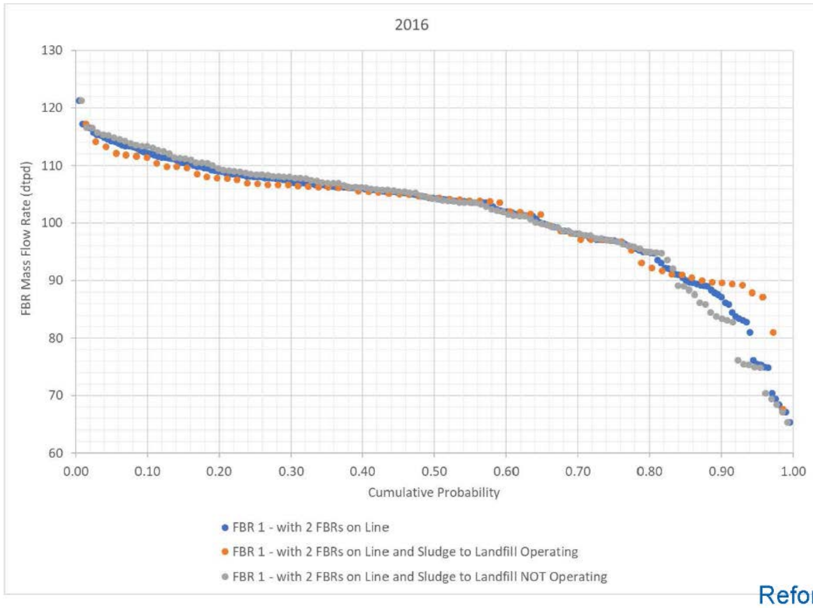
50

Reformatted 2 FBR On-line Cumulative Probability Graphs

Input – Capacity Characteristics Additional Info – 2016 FBR 1

51



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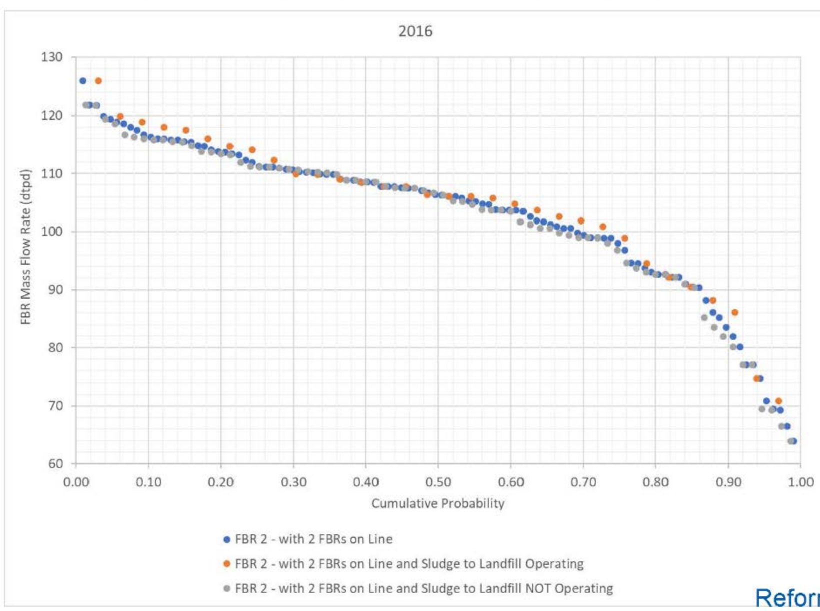
Input – Capacity Characteristics Additional Info – 2016 FBR 2

52



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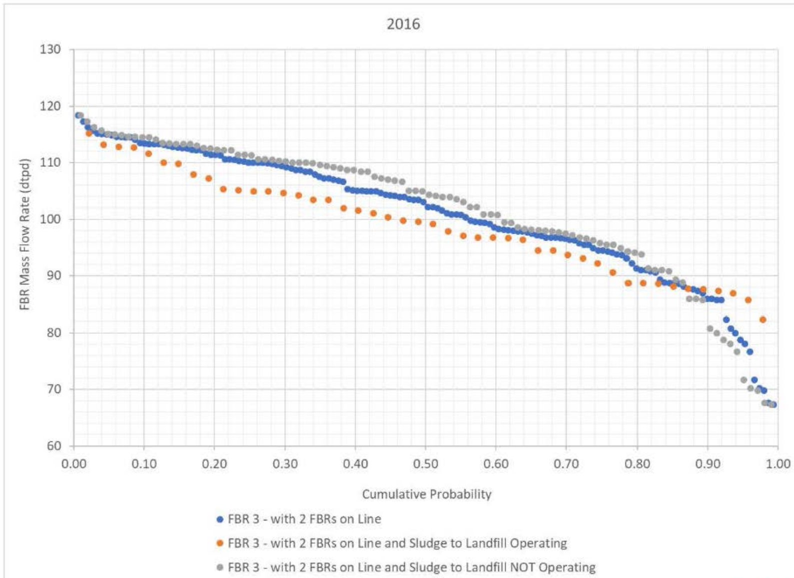
Input – Capacity Characteristics Additional Info – 2016 FBR 3

53



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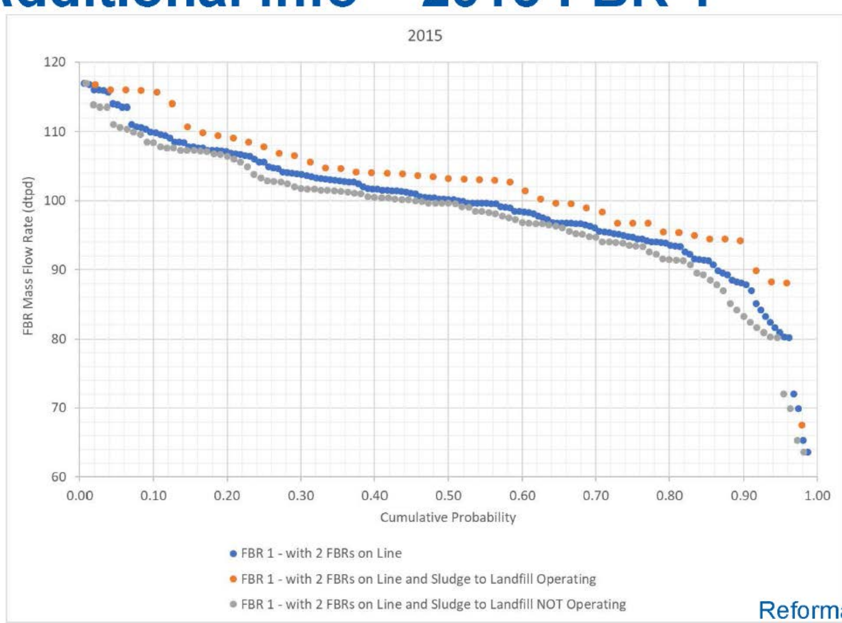
Input – Capacity Characteristics Additional Info – 2015 FBR 1

54



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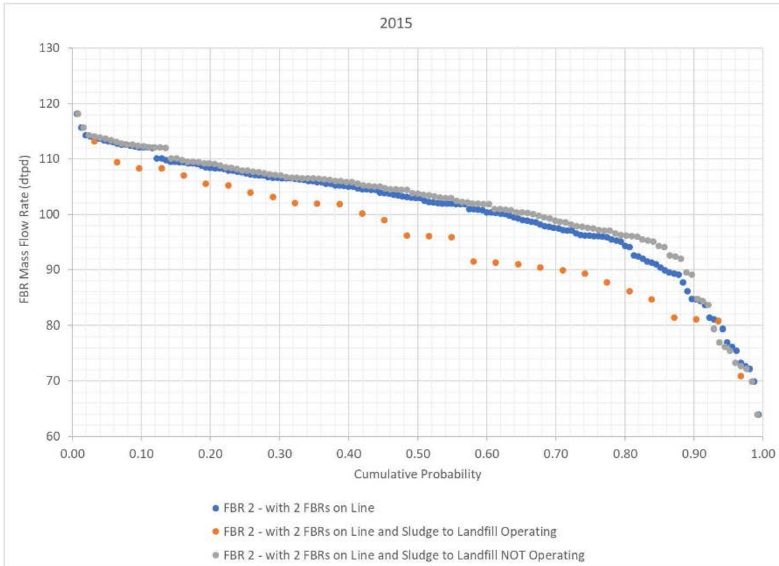
Input – Capacity Characteristics Additional Info – 2015 FBR 2

55



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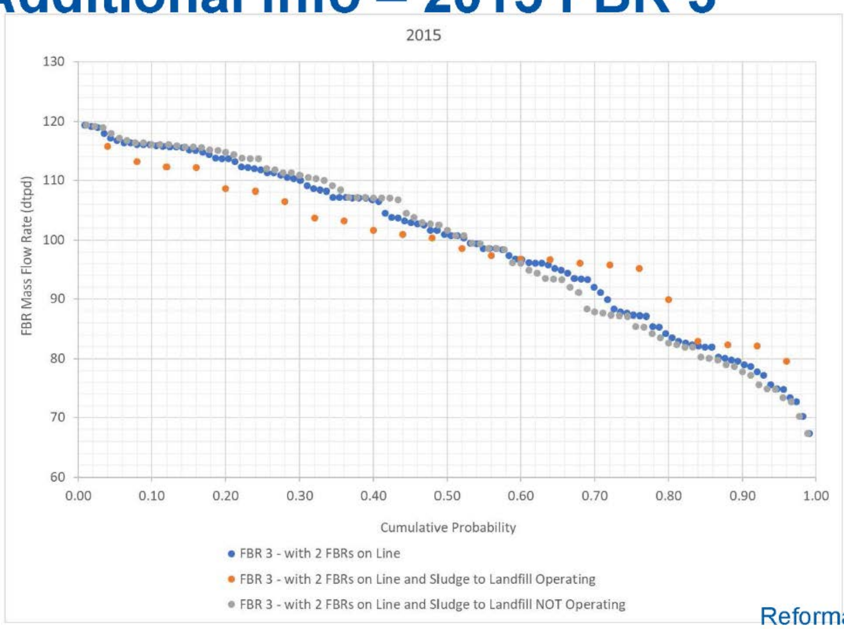
Input – Capacity Characteristics Additional Info – 2015 FBR 3

56



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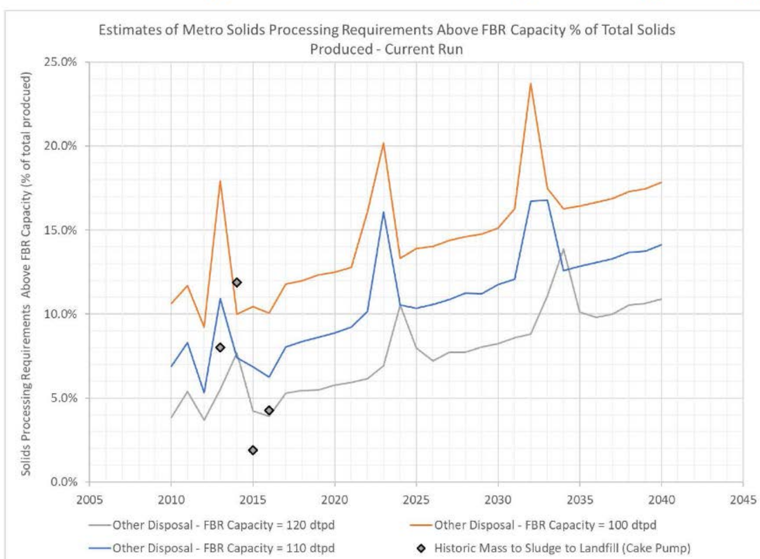
57

Supplemental Info and Slides from Past Weeks

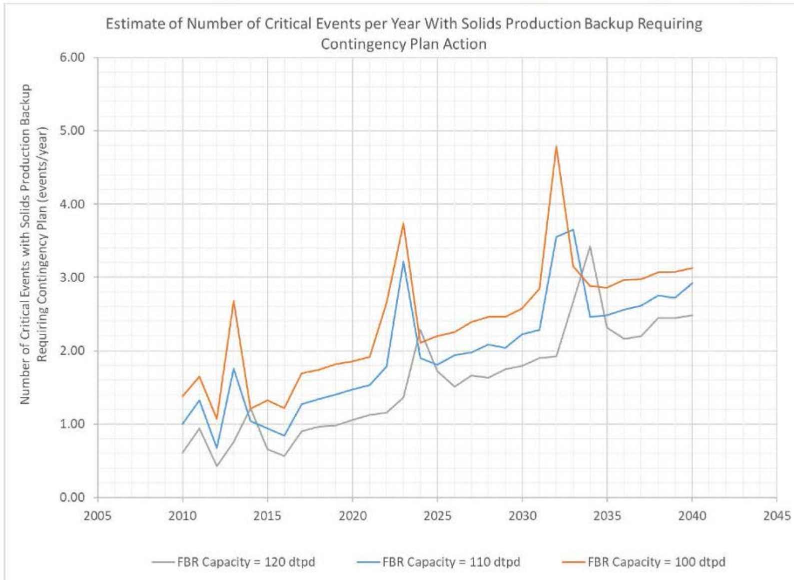
58

Input – Capacity Characteristics Sensitivity to FBR Capacity Input



Input – Capacity Characteristics
Sensitivity to FBR Capacity Input

59



All with Alkaline Addition System for Sludge to Landfill at 90 dpth

Input – Maintenance and Renewal
Characteristics – System Status

60

Year	Days per Year at Different Numbers of FBRs Operating - Using Criteria of <7.00 wtph Daily Average as Off-Line					Percentage of Days at Different Numbers of FBRs Operating - Using Criteria of <7.00 wtph Daily Average as Off-Line				
	Three Operating	Two Operating	One Operating	Zero Operating	Total	Three Operating	Two Operating	One Operating	Zero Operating	Total
2005	156	195	11	3	365	42.7%	53.4%	3.0%	0.8%	100.0%
2006	189	162	12	2	365	51.8%	44.4%	3.3%	0.5%	100.0%
2007	191	164	10	0	365	52.3%	44.9%	2.7%	0.0%	100.0%
2008	239	123	2	2	366	65.3%	33.6%	0.5%	0.5%	100.0%
2009	187	177	1	0	365	51.2%	48.5%	0.3%	0.0%	100.0%
2010	216	145	0	4	365	59.2%	39.7%	0.0%	1.1%	100.0%
2011	237	125	2	1	365	64.9%	34.2%	0.5%	0.3%	100.0%
2012	167	184	9	6	366	45.6%	50.3%	2.5%	1.6%	100.0%
2013	99	246	20	0	365	27.1%	67.4%	5.5%	0.0%	100.0%
2014	67	266	27	5	365	18.4%	72.9%	7.4%	1.4%	100.0%
2015	165	189	7	4	365	45.2%	51.8%	1.9%	1.1%	100.0%
2016	140	209	16	1	366	38.3%	57.1%	4.4%	0.3%	100.0%
2017	157	100	0	2	259	60.6%	38.6%	0.0%	0.8%	100.0%

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When did the critical conditions happen?

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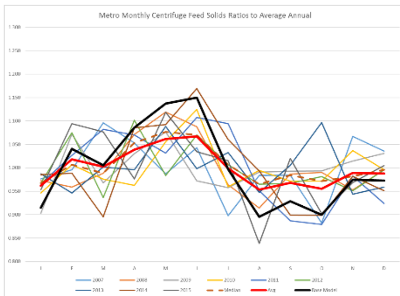
Have we been lucky? Yes, Probably.

Luck may be the residue of intent.



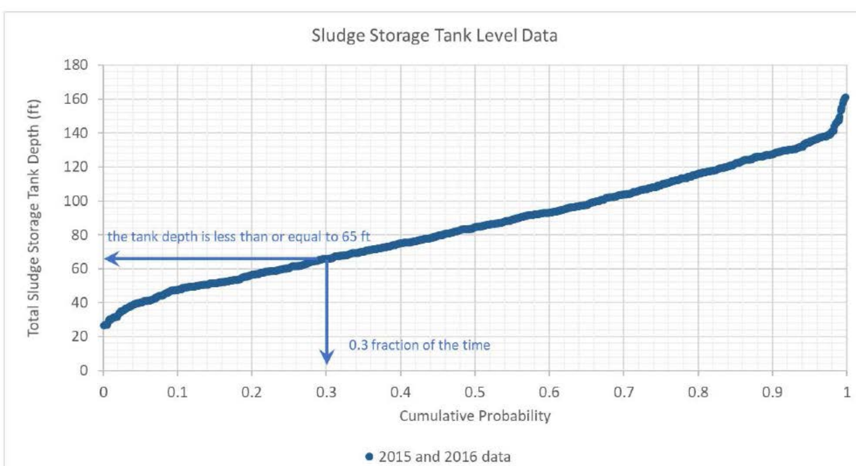
Start	End	Number On-Line	Duration (days)	Month	Month Loading Factor
10/1/2006	10/7/2006	1	7	Oct	nd
10/15/2007	10/18/2007	1	7	Oct	nd
1/9/2014	1/14/2014	1	6	Jan	0.98
8/3/2016	8/8/2016	1	6	Aug	0.95
7/19/2006	7/23/2006	1	5	Jul	nd
12/14/2012	12/18/2012	1	5	Dec	0.98
2/8/2014	2/12/2014	1	5	Feb	0.99
4/14/2013	4/17/2013	1	4	Apr	1.03
4/29/2013	5/2/2013	1	4	Apr - May	1.07
6/23/2013	6/26/2013	1	4	Jun	1.04
12/3/2013	12/6/2013	1	4	Dec	0.96
11/12/2015	11/15/2015	1	4	Nov	1.02
2/29/2016	3/3/2016	1	4	Feb - Mar	1.06
6/28/2005	6/30/2005	0	3	Jun	nd
3/28/2012	3/30/2012	1	3	Mar	0.96
7/30/2013	8/1/2013	1	3	Jul - Aug	0.98
8/16/2014	8/18/2014	1	3	Aug	0.98
10/28/2014	10/30/2014	1	3	Oct	0.94
11/5/2014	11/7/2014	1	3	Nov	0.96
12/20/2015	12/22/2015	1	3	Dec	1.01
12/18/2016	12/20/2016	1	3	Dec	0.98
10/24/2012	10/25/2012	0	2	Nov	1.00
11/7/2012	11/8/2012	0	2	Nov	0.95
3/25/2014	3/26/2014	0	2	Mar	0.93
1/19/2005	1/20/2005	1	2	Jan	nd
11/24/2005	11/25/2005	1	2	Nov	nd
3/29/2014	3/30/2014	1	2	Mar	0.93
11/13/2014	11/14/2014	1	2	Nov	0.96
8/10/2016	8/11/2016	1	2	Aug	0.95

Using full processing day screening criteria of:
-FBR daily average >= 7 wtph (~47 dtpd)

Output – Methods of Conveying Risk

62

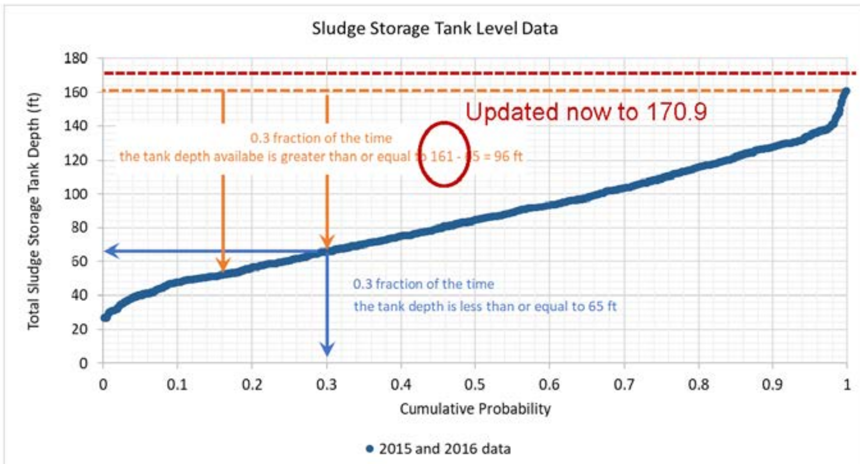
- 3. Total Number of Critical Events Requiring More Storage Volume than is Available



Output – Methods of Conveying Risk

63

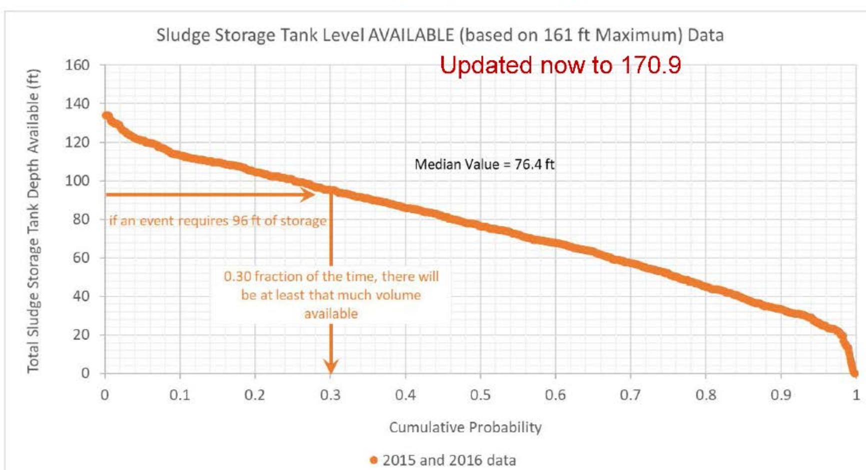
- 3. Total Number of Critical Events Requiring More Storage Volume than is Available



Output – Methods of Conveying Risk

64

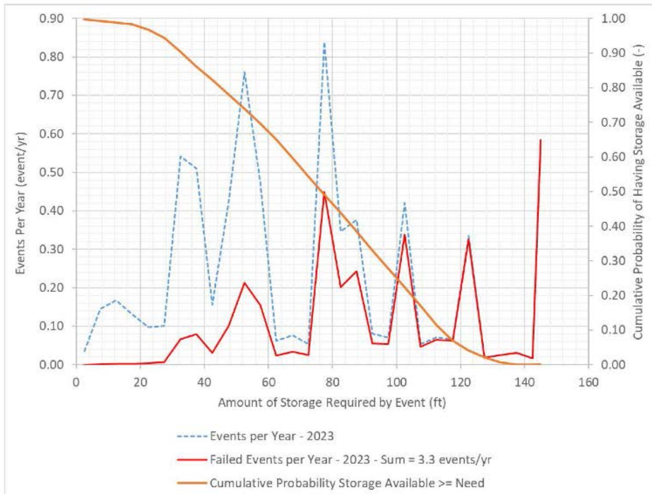
- 3. Total Number of Critical Events Requiring More Storage Volume than is Available



Output – Methods of Conveying Risk

65

- 3. Total Number of Critical Events Requiring More Storage Volume than is Available



Method

66

- A daily simulation, multi-trial approach
  - Visual basic macro in Excel that generates a day by day simulation from input conditions for a given period
  - Follows a logic flow pattern to establish status of units, with a random process applied to unplanned maintenance
  - Captures information on the status of units, the solids processed by the trains and to landfill, and the critical events related to risk
  - Due to the probability method used to address unplanned maintenance, repeats and averages the results for a lot of runs for the period (i.e. uses a Monte Carlo like method)

General flow diagram provided and code accessible

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Limitations

- Simplification of real conditions
  - Only one mass rate capacity input for an Incineration Train. Each FBR is treated the same.
  - One mass rate capacity for Sludge to Landfill.
    - Doesn't have different treated rates under different conditions.
    - Focus is on critical conditions when processing rate will be at upper limit.
  - Combine all planned maintenance into the two major events per train per year
- Follows logic input rigidly
  - ~~Doesn't use flexibility, judgement, and compromise to alleviate the impact of unfavorable conditions~~

Now does include curtailment of a PM upon failure

- Comparison versus prediction

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Input – Solids Production For Historic Periods

Historic Data Inputs

Annual Mass Rate

Year	Mass Rate (Cake Pump) - dtpd
2010	235
2011	240
2012	225
2013	231
2014	229
2015	232
2016	230

Rate factor = Monthly Avg/Annual Avg

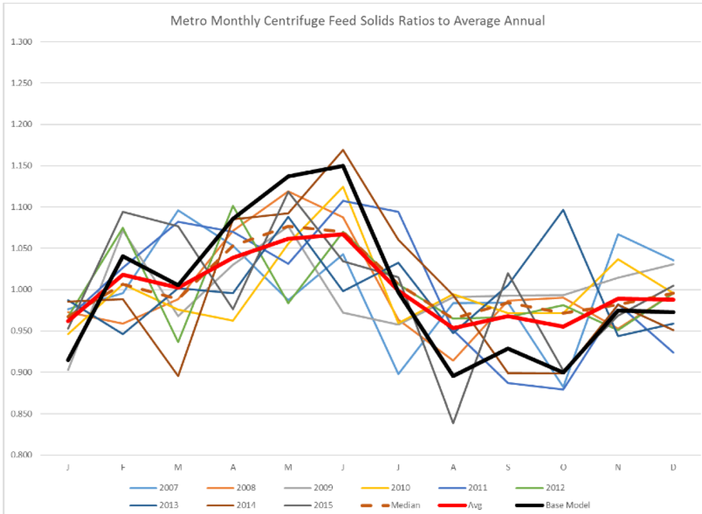
Monthly Rate Factors

Month	Year						
	2010	2011	2012	2013	2014	2015	2016
Jan	0.962	0.974	0.973	0.973	0.984	0.929	0.929
Feb	1.011	1.030	1.074	0.939	0.994	1.088	1.059
Mar	0.985	1.093	0.962	0.985	0.933	1.070	1.052
Apr	0.970	1.067	1.107	1.029	1.085	0.978	1.027
May	1.053	1.038	0.986	1.108	1.097	1.116	1.059
Jun	1.118	1.111	1.095	1.035	1.165	1.069	1.072
July	0.963	1.091	1.010	1.028	1.047	1.016	0.969
Aug	0.987	0.959	0.899	0.930	0.976	0.819	0.949
Sep	0.937	0.871	0.970	0.976	0.912	0.999	0.941
Oct	0.975	0.871	1.004	1.084	0.937	0.902	0.989
Nov	1.024	0.990	0.950	0.947	0.964	1.019	0.981
Dec	1.016	0.909	0.980	0.961	0.908	1.006	0.979

Input - Monthly Variation Projection Period

69

- Based on historic pattern of centrifuge feed solids rate
- Peak month factor is the adjustable input, pattern is modified to maintain annual average = 1



Input – Converting Mass Rate to Volume Rate and SST Use

70

Input Needed to Convert for Dewatered Cake to SST Volume and Calculated Values:	
Centrifuge Solids Capture Efficiency [-]:	0.93
Sludge Storage - Average Solids Concentration [% TS]:	5
Sludge Storage - Sludge Bulk Density [lb/gal]:	8.33
Surface Area per Sludge Storage Tank (sq ft):	4050
Unit Conversion gal/cu ft [gal/cu ft]:	7.4805

30 ft x135 ft = 4050 ft^2

Background Info for Input Consideration

71

SMB Systems Availability/Reliability Tracking Pilot (5/9/16 - 10/17/17)

System	%R	%A	%S	%F	Total
Centrifuges	54.8%	21.6%	3.6%	20.0%	100.0%
Cake Bins	88.6%	9.3%	2.1%	0.0%	100.0%
Cake Pumps	52.2%	36.7%	9.6%	1.6%	100.0%
FBRs	82.1%	0.0%	11.9%	6.0%	100.0%

Status Definitions:
- A - Available, has run less than 12 hours in past 24
- R - Running, has run more than 12 hours in past 24
- S - Scheduled Outage, taken down within past 24 hours
- F - Forced Outage, taken down within past 24 hours

A = Standby
R = Running
S = Scheduled Outage = PM
F = Forced Outrage = UM

System Definitions:
- Centrifuges - Suction line from feed tank through CF to cake bin
- Cake Bin - Bin plus sliding frame (pushes cake to extraction screws)
- Cake Pump - Extraction screws to FBR input
- FBR - FBR through APC equipment train

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Background Info for Input Consideration

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Status Tracking Project FBR History Data From 5/9/16 to 9/15/17 – Overall Brief Summary

Item	FBR 1	FBR 2	FBR 3	Total	Total Expressed Per 3 Units	Total - 2 and 3	Total Expressed Per 2 Units
Unplanned Maintenance							
Total Number of Days Without Feed per Year	2.95	34.68	30.25	67.88	22.63	64.93	32.47
Total Number of Events per Year	0.74	4.43	5.17	10.33	3.44	9.59	4.80
Net Days Without Feed per Event	4.00	7.83	5.86	-	6.57	-	6.77
Planned Maintenance						Total - 1 and 2	Total Expressed Per 2 Units
Total Number of Days Without Feed per Year	42.06	41.32	22.87	106.25	35.42	83.38	41.69
Actual Total Number of Events per Year	5.17	4.43	5.90	15.50	5.17	9.59	4.80
Number of Major Events Per Year to Distribute Over	2.00	2.00	2.00	2.00	2.00	4.00	2.00
Net Days per Major Event for Risk Evaluation	21.03	20.66	11.44	53.13	17.71	41.69	20.85

FBR 3 did not have 2 major PMs during this period

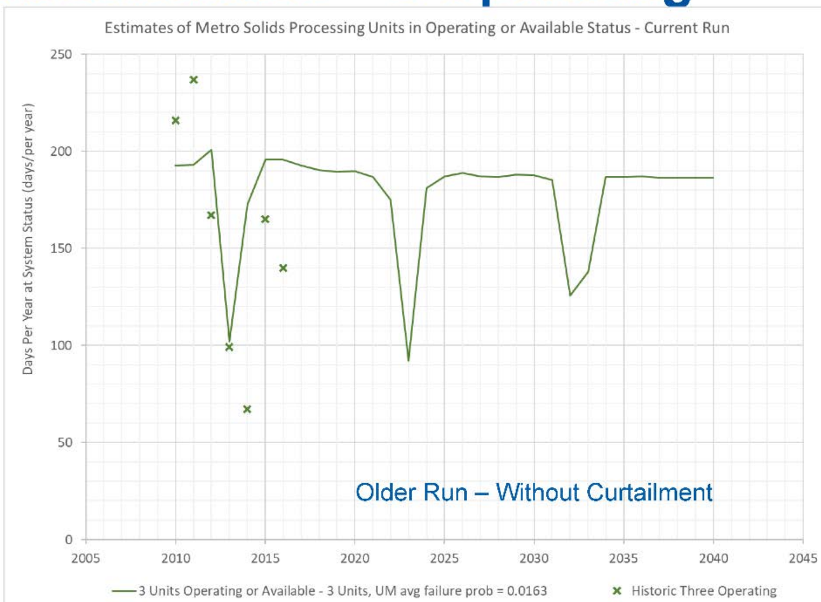
3.44 events per unit per year at ~ 7 day round duration

For simulation 2 major PM events per unit per year ~ 21 day round duration

Additional details in separate documents
- *Development of this info*
- *Long term historic trend with background info*

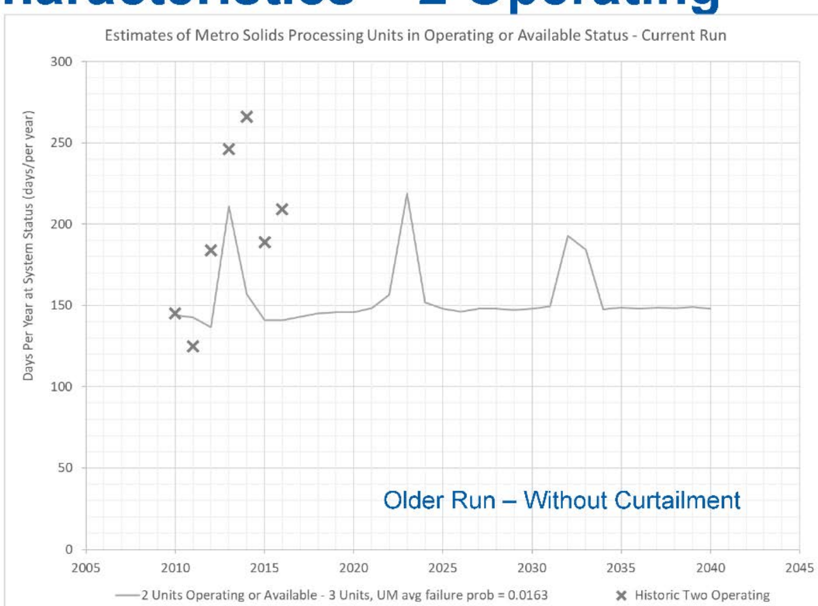
Input – Maintenance and Renewal Characteristics – 3 Operating

73



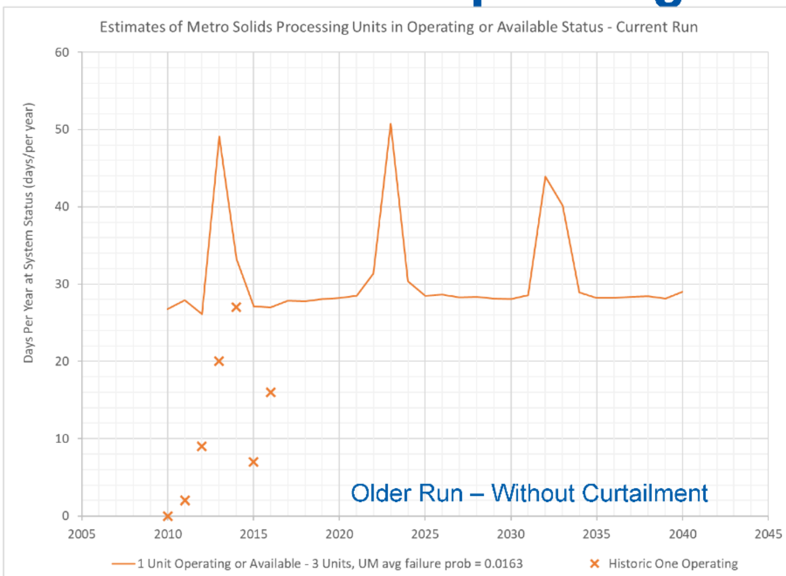
Input – Maintenance and Renewal Characteristics – 2 Operating

74



Input – Maintenance and Renewal Characteristics – 1 Operating

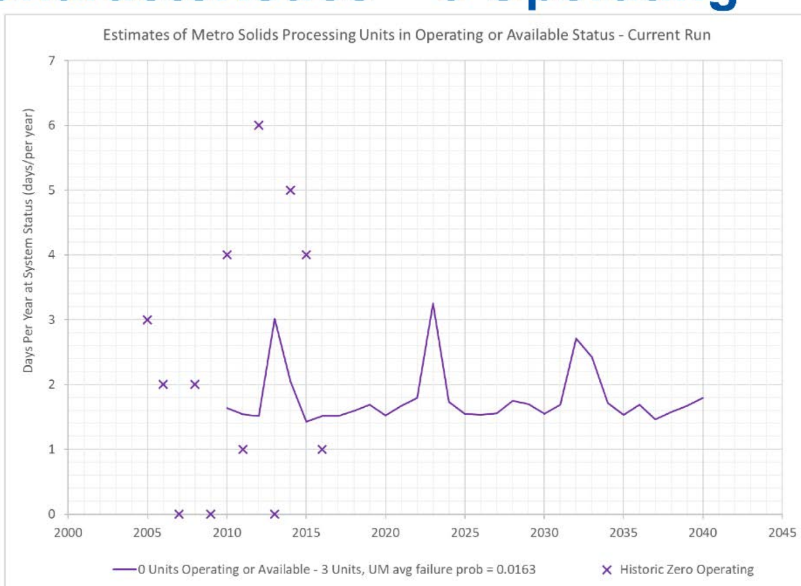
75



Note: See Limitations Discussion and Other Graphs

Input – Maintenance and Renewal Characteristics – 0 Operating

76



Output – Methods of Conveying Risk Events

77

- **1. Contingency Plan, Number of Critical Events Exceeding a Duration**
  - “The incident we are planning for is a situation where SMBU has only one or zero reactor trains available for five to seven days.”
  - Count these incidents per year (used 5 days)

- **2.** ***Number of Critical Events Exceeding a Specific Storage Volume Needed Value***
  - *For the critical condition (one or zero reactor trains available) events, how many exceed a critical value of storage usage*
  - *Count Events >= 76 ft of storage required (the median amount available for 2015-2016)*

- **3. Total Number of Critical Events Requiring More Storage Volume than is Available** (Number of Events with Solids Production Backup)
  - Put the Critical Events into the bins by the amount of storage they need
  - Use an estimate of the probability of having the necessary storage capacity to generate how many events in each bin will fail to have the necessary storage
  - Sum the failed events over all the bins to arrive at an estimate of the total number of events that will backup solids and require the contingency plan to be used

Appendix I. Alternatives Evaluation Cost Data

20-year Present Worth Comparison with 20% Growth through Planning Period

		M3-A	M3-B	M3-C	M3-D	M3-E	M3-F
4% Nominal discount rate							
3.50% Escalation rate							
			74 dtpd VSR	74 dtpd	74 dtpd	74 dtpd	74 dtpd
		4th Incinerator	PS/WAS Digest/Incinerate	PS/WAS Digest, Dry, Sell	PS/WAS Digest, LA Cake	Lime Stabilize, Store, LA	Dry Raw PS/WAS
Capital Cost Data							
Preliminary Construction Estimates		$ 74,588,000	$ 125,037,694	$ 129,722,980	$ 175,994,372	$ 145,810,384	$ 105,455,414
Engineering (20%)		$ 14,917,600	$ 25,007,539	$ 25,944,596	$ 35,198,874	$ 29,162,077	$ 21,091,083
Contingency Value (50%)		$ 37,294,000	$ 62,518,847	$ 64,861,490	$ 87,997,186	$ 72,905,192	$ 52,727,707
Total Near Term Capital Costs:		**$ 126,799,588**	**$ 212,564,066**	**$ 220,529,052**	**$ 299,190,418**	**$ 247,877,636**	**$ 179,274,187**
PW of Salvage Value		**$ (28,050,000)**	**$ (43,960,000)**	**$ (31,850,000)**	**$ (51,260,000)**	**$ (31,550,000)**	**$ (8,950,000)**
PW of Replacements		**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
PW of Capital with Salvage and Replacements		$ 98,700,000	$ 168,600,000	$ 188,700,000	$ 247,900,000	$ 216,300,000	$ 170,300,000
Operations and Maintenance Cost Data	**2010 Annual Costs**	**Incremental Change In Annual Costs**					
Ash & Sludge Handling	280,000	25,000	32,000	(30,000)	1,957,000	5,780,000	(30,000)
Produced Electricity	(1,800,000)	(400,000)	(1,800,000)	800,000	(500,000)	1,000,000	1,000,000
Consumed Electricity	2,900,000	200,000	(100,000)	-	(400,000)	-	(300,000)
Outside Feedstocks	$0	$0	$0	$0	$0	$0	$0
Natural Gas	(1,370,000)	-	-	260,000	-	-	2,120,000
Incinerator Auxiliary Fuel (No. 2 FO)		-	1,810,000	-	-	-	-
Chemicals	2,440,000	250,000	1,170,000	420,000	710,000	3,250,000	130,000
Labor Cost	6,992,208	360,000	1,420,000	2,610,000	1,660,000	1,070,000	1,780,000
Miscellaneous Additional Maintenance Costs	-	500,000	870,000	650,000	600,000	250,000	800,000
Total Annual Cost	$ 9,442,208	$ 935,000	$ 3,402,000	$ 4,710,000	$ 4,027,000	$ 11,350,000	$ 5,500,000
Present Worth of Annual Costs	$ 180,000,000	$ 18,000,000	$ 65,000,000	$ 90,000,000	$ 77,000,000	$ 216,000,000	$ 105,000,000
Present Worth of Capital and Operating Costs		**$ 117,000,000**	**$ 234,000,000**	**$ 279,000,000**	**$ 325,000,000**	**$ 433,000,000**	**$ 276,000,000**
Future Nitrogen Nutrient Limit	Addl. Cap Cost	-	$ 9,000,000	$ 4,500,000	$ 4,500,000	-	-
	Addl. Op Cost	-	41,100,000.0	$ 20,600,000	$ 20,600,000	-	-
Total Additional Present Worth		**None**	**$ 50,100,000**	**$ 25,100,000**	**$ 25,100,000**	**None**	**None**
Digested Solids Dewatering - Sensitivity Scenarios		-					
Total Additional Present Worth	20% TS	**None**	**$ 16,100,000**	$ 4,400,000	**$ 3,800,000**	**None**	**None**
Total Additional Present Worth	24% TS	**None**	**$ (16,100,000)**	**$ (3,900,000)**	**$ (3,200,000)**	**None**	**None**
Land Application Cost - Sensitivity Scenarios		-					
Total Additional Present Worth	$25/wet ton	**None**	**None**	**None**	**$ (9,000,000)**	**$ (33,000,000)**	**None**
Total Additional Present Worth	$45/wet ton	**None**	**None**	**None**	**$ 10,000,000**	**$ 33,000,000**	**None**

Table below calculates a salvage value based on values from the Capital Cost and Replacement tables.						

Salvage Value

			M3-A	M3-B	M3-C	M3-D
	Estimating Unit	**Useful Life**	**4th Incinerator**	**PS/WAS Digest/Incinerate**	**PS/WAS Digest, Dry, Sell**	**PS/WAS Digest, LA Cake**
Metro						
Add' Sludge Receiving / Blending	$/dtpd	25	-	-	-	-
Digesters	$/gal	40	-	(32,950,000)	(24,720,000)	(24,720,000)
Digester Piles	sf	40	-	(5,980,000)	(1,990,000)	(1,990,000)
Dryer	$/dtpd	20	-	-	-	-
Pellet Storage/Transport to Loadout	Lump Sum	20	-	-	-	-
Biogas CHP Heat Recovery Unit with Gas Conditioning	$/kW	20	-	-	-	-
Dewatering Capacity Increase	$/dtpd	30	(3,860,000)	-	(1,730,000)	(1,730,000)
Biosolids Storage, Load-out and Odor Control	$/sf	30	-	-	-	(19,920,000)
Biosolids Storage Odor Control	$/cfm	20	-	-	-	-
Cambi Equipment Cost	$/dtpd WAS	25	-	-	-	-
Sidestream Treatment	$/dtpd WAS	25	-	(4,520,000)	(2,390,000)	(2,390,000)
Incineration Train, nominal 120 dtpd	$/dtpd	30	(19,620,000)	-	-	-
Heat Recovery Boiler	$/dtpd	20	-	-	-	-
Steam Turbine	$/dtpd	25	(380,000)	-	-	-
Demolition and Building Modifications	$/sf	40	-	(510,000)	(1,020,000)	(510,000)
Building	$/sf	40	(4,190,000)	-	-	-
			(28,050,000)	(43,960,000)	(31,850,000)	(51,260,000)

Replacement Cost Factor	1
Base Year	2012
End of Planning	2032
Operating Life During Planning Period	20
Discount	4.00%
Inflation	3.50%

Quantities shown in table below denote the sizing of component process based on their estimating unit - dtpd, kW, gal, etc.

Unit Quantities used for Capital Cost Estimating

		M3-A	M3-B	M3-C	M3-D
	Estimating Unit	4th Incinerator	PS/WAS Digest/Incinerate	PS/WAS Digest, Dry, Sell	PS/WAS Digest, LA Cake
Metro					
Add' Sludge Receiving / Blending	$/dtpd				
Digesters	$/gal	-	16,128,000	12,096,000	12,096,000
Digester Piles	sf	-	105,281	35,094	35,094
Dryer	$/dtpd	-	-	70	-
Pellet Storage	Lump Sum	-	-	1	-
Biogas CHP Heat Recovery Unit with Gas Conditioning	$/MW	-	3.1	-	2.4
Dewatering Capacity Increase	$/dtpd	120	-	54	54
Biosolids Storage, Load-out and Odor Control	$/sf	-	-	-	280,094
Biosolids Storage Odor Control	$/cfm				420,141
Cambi Equipment Cost	$/dtpd WAS	-	-	-	-
Sidestream Treatment	$/dtpd WAS	-	79	42	42
Incineration Train, nominal 120 dtpd	$/dtpd	120	-	-	-
Heat Recovery Boiler	$/dtpd	120	-	-	-
Steam Turbine	$/dtpd	120	-	-	-
Demolition and Building Modifications	$/sf	-	7,500	15,000	7,500
Building	$/sf	15,375	-	-	-

MCES Solids Unit Processes - Conceptual Cost Estimates

	Size	Proposed Plant	Representative Unit Cost	Unit	Project Construction Cost	per dtpd at unit process	$/dtpd	Source	Comments
Sludge Transfer and Receiving									
Cake Load-out Modifications		Seneca, Empire			$750,000		Lump Sum		Enlarge, update existing cake load-out facilities. Modest odor control upgrades. Modify Empire building for over-the-road truck dimensions. Modify Nviro load-out for Seneca.
Cake Load-out		Blue Lake			$500,000		Lump Sum		
Foreign Biosolids Cake Receiving		Metro, Blue Lake, Seneca			$5,000,000	50	$100,000	DC Water	
Liquid Sludge Receiving, Pumping		Rosemount			$2,800,000	152	$18,421	MCES Metro	Gravity thickener pump complex. Double for structures.
FOG or Industrial Waste Receiving	Medium	Metro, Blue Lake, Consolidated			$2,000,000		NA	BV HRSD wksht	
Thickening and Dewatering									
Thickening		Medium Plants			$2,720,000	50	$54,400	BL dewatering facility	Assume 20% of BL dewatering facility cost for GBTs and primary sludge screening.
Dewatering		Medium Plants			$10,880,000	50	$217,600	BL dewatering facility	Includes feed pumps and polymer. Subtract 20% for GBTs and primary sludge screening. Empire dewatering building, around 175,000 per dtpd, includes GBTs and relocated BFPs.
Dewatering		Metro			$60,000,000	450	$106,400	DC Water	Pre-dewatering for Cambi, entire dewatering facility. (Still checking on SMB centrifuge costs)
Sludge Conditioning									
Thermal Hydrolysis Process - WAS	Large	Metro			$18,000,000	111	$162,162	Cambi Quote	$12 M Quote from CAMBI plus 50% for sludge screening, etc. BV HRSD used $125,000 per dt
Sidestream Treatment									
Nutrient Recovery	Medium	Metro, Empire			$9,400,000	30	$313,333	Madison	WAS P-release tanks, filtrate wells and handling, struvite harvesting process and building. Madison Nine Springs is a 40 mgd plant, 30 WAS dtpd assumed.
Stabilization									
Anaerobic Digestion	Small	Seneca	$5.50	gal				Various BC Projects	
Anaerobic Digestion	Medium	Consolidated (Metro+2)	$5.00	gal				Various BC Projects	Blue Lake - $25.5 million, 3 tanks, 1.67 MG each, $5 per MG, 58 dtpd
Anaerobic Digestion	Large	Metro	$4.50	gal				Various BC Projects	
Pile supports for Metro PS Digestion		Metro	$125	sf					
Fluid Bed Incineration	Medium	Seneca or Rosemount			$36,000,000	72	$500,000	BV	Single train, no heat recovery
Fluid Bed Incineration	Large	Metro			$65,244,500	120	$540,000	BV HRSD Wksht, CR similar	Single train. No heat recovery
Drying (Simple Paddle Type)	Medium Lg	Metro WAS			$16,600,000	59	$281,000	CR, 19% TS	Komline Sanderson paddle dryer based on 2008 quote for CR, times 2.0 for installation and inflation. Connection to existing steam.
Drying (Rotary Type)	Medium	Blue Lake/Seneca/Emp			$30,000,000	43	$698,000	Winston-Salem	$32 million includes a centrifuge and pipeline
Drying (Belt Type)	Medium	Blue Lake/Seneca/Emp			$20,100,000	14	$1,436,000	Western Wake	$26.8 M BC estimate for Western Wake Krueger dryer with dewatering, pellet incineration, liquid waste receiving.
Pellet Storage	Medium				$1,000,000	50	Lump Sum	Dynamic Air Proposal for CR	Eight 3300 cf silos, pneumatic transfer system, 50% for installation
Solids Storage									
Land Application Enhancements		Empire			$5,000,000	9	$555,556		500 acres at $10,000 per acre, rough estimate based on Empire digested solids quantity
Odor Control		Metro	$ 50.00	cfm					
Cake Storage Enclosed Building		Metro	$ 235.00	sf					Cost from Butch Mathews based on WLSSD building design type
Covered Cake Storage	Small	Empire			$3,200,000	25	$128,000	Iowa City	Fabric roof, concrete bays, 180 days storage, 7-8 ft deep, 23% TS, based on digested sludge quantity
Energy Production									
Hot Oil Heat Recovery Unit and Organic Rankine Cycle Engine	Medium	Consolidated (Metro+2)			$11,680,000	120	$97,000		CR Estimate, includes hot oil system, some bldg expansion
IC Engine with HW Heat Recovery	Medium	Consolidated (Metro+2)	$3,000	kW				Various BC projects	Includes gas treatment, compressors, new CHP bldg, elec
Waste Heat Boiler		Metro			$2,000,000	144	$13,889	CR Estimate	6 dtph, boiler only - reuse existing RO, deaerator, boiler feed
Steam Turbine		Metro			$2,500,000	144	$17,361	CR Estimate	Utilize existing condenser water system
Gas Combustion Turbine with Steam Heat Recovery	Large	Metro	$4,300	kW	$80,000,000			DC Water	Includes gas conditioning, compressors, HRSG, buildings
Gas Combustion Turbine with Steam Heat Recovery, no Gas Treatment	Large	Metro	$2,300	kW	$32,000,000			MMSD	Includes compressors, new CHP bldg, elec, NG mixing, long gas pipeline
Buildings									
Process Building		Several	$600	sf					High bay building with piles, etc
Repurposing of Existing Building		Cambi, WAS drying	$150	sf					

Metro Digestion Alternatives - Preliminary Assumptions

M3-B Nominal Incinerator Capacity 120 dtpd - Offload 74 Metro+Seneca tons via digestion (100 dtpd with peaking and growth), (199 dtpd from centrifuge to incineration)

	Total Solids	Primary Solids In	%VS - PS	WAS Solids In	%VS - WAS	%TS (digester inlet)	Solids Inflow	Water Inflow	Flow	Max Month HRT	VSR - PS	VSR - WAS	Equiv. VSR for 50/50 Blend	VS Destroyed	Solids to Centrifuge	Tank size	Digestion Cap Cost - Prelim Estimate	Cake
	dtpd	dtpd		dtpd		%	lb/hr	lb/hr	gpm	days	%	%		dtpd	dtpd	gal		%TS
Mesophillic - 20 day	263	81	82%	59	75%	5%	11,667	221,667	466	20	67%	35%	51%	60	203	16,000,000	$ 72,000,000	25
Mesophillic - 15 day	263	81	82%	59	75%	5%	11,667	221,667	466	15	64%	30%	47%	56	207	12,000,000	$ 54,000,000	23
Thermophillic	263	81	82%	59	75%	5%	11,667	221,667	466	12	72%	43%	58%	67	196	10,000,000	$ 45,000,000	23
TPAD	263	81	82%	59	75%	5%	11,667	221,667	466	15	72%	50%	61%	70	193	12,000,000	$ 54,000,000	28

M3-C, M3-D Digested Solids to Dryer or Land Application (not Incinerated) - Offload 74 dtpd (100dtpd with 20% growth and 12% peaking)

	Total Solids	Primary Solids In	%VS - PS	WAS Solids In	%VS - WAS	%TS (digester inlet)	Solids Inflow	Water Inflow	Flow	Max Month HRT	VSR - PS	VSR - WAS	Equiv. VSR for 50/50 Blend	VS Destroyed	Solids to Dryer	Tank size	Digestion Cap Cost - Prelim Estimate	Cake
	dtpd	dtpd		dtpd		%	lb/hr	lb/hr	gpm	days	%	%		dtpd	dtpd	gal		%TS
Mesophillic - 20 day	263	43	82%	31	75%	5%	6,167	117,167	246	20	67%	35%	51%	32	42	9,000,000	$ 40,500,000	25
Mesophillic - 15 day	263	43	82%	31	75%	5%	6,167	117,167	246	15	64%	30%	47%	29	45	6,000,000	$ 27,000,000	23
Thermophillic	263	43	82%	31	75%	5%	6,167	117,167	246	12	72%	43%	58%	35	39	5,000,000	$ 22,500,000	23
TPAD	263	69	82%	31	75%	5%	8,382	159,260	335	15	72%	50%	61%	53	48	9,000,000	$ 40,500,000	28

Peaking Factor	1.2	
Growth Factor	1	2030

Literature References

Ohanian et al, Anaerobic Digester Evolution at the Los Angeles Hyperion Plant, 2006

	Full Scale Thermophilic Data (CBTAD)			
Thermo Temp	128	F	53	C
HRT	11	days		
VSR	60%			
Gas Production	12.5	cf/lb VSd		

Wilson et al, Comprehensive Enhanced Digestion Evaluations at Blue Plains Advanced Wastewater Treatment Plant, 2009

	TAD 10	TAD 15	MAD 15	MAD 20	TPAD	TH-MAD	
Thermo Temp	55	49			55		degrees C
HRT	10	15	15	20	5/10	15	days
VSR	48%	58	45-59	52-61	67	68	

Quantities shown in table below denote annual average values.

Pellet Sales and Hauling (Ash, Cake Solids, Pipelines)

	Unit	Current	M3-A 4th Incinerator	M3-B PS/WAS Digest/Incinerate	M3-C PS/WAS Digest, Dry, Sell	M3-D PS/WAS Digest, LA Cake
Metro						
Ash	tpd	49.1	54.4	55.7	44.6	44.6
Ash Haul	trucks per day	2.2	2.5	2.5	2.0	2.0
Cake	wtpd					156
Cake Haul	trucks per day	0				7
Pellets	tpd	0	-		40.1	-
Pellet Haul	trucks per day	0	-	-	1.8	-

METRO ONLY

Ash						
Annual Total	tpd	49.09	54.37	55.69	44.63	44.63
Annual Ash Disposal (Cost)	$	275,288	304,881	312,278	250,282	250,282
Pellets						
Annual Total	tpd	-	-	-	40.1	-
Annual Pellet Sales	$	$ -	$ -	$ -	$ (40)	$ -
Solids Hauling						
Annual Total	$	0	0	0	0	0
Land Application						
Annual Total	$	$ -	$ -	$ -	$ -	$ 1,987,075
Total	$	275,000	305,000	312,000	250,000	2,237,000

Assumptions

$	15.36	Per ton ash disposal cost
	52.4	dtpd ash, Metro 2010 average
$	293,844	Metro 2010 ash disposal cost
$	30,000	Seneca 2010 ash disposal cost
	$1.00	Revenue from dried pellets, $/ton
	$15.00	Land Application Cost, $/wet ton
	$125.02	2011 Cost per dry ton
	$13.75	2011 Cost per wet ton
	20	years, BCE duration

56	lb/cf sludge cake
898	cf haul truck volume
25.144	wet ton per truck load
35	$/wet ton land applied - Metro Program
22	wet ton/truckload

Quantities shown in table below denote annual average values.

Energy Balance

	Unit	2010 plus NonCond Turbine	M3-A 4th Incinerator	M3-B PS/WAS Digest/ Incinerate	M3-C PS/WAS Digest, Dry, Sell	M3-D PS/WAS Digest, LA Cake
Metro						
Steam Turbine Power Production (Condensing and Non-Condensing)	MW	2.9	3.5	1.4	1.6	1.2
Steam Export (Net of FBI Process Steam)	MW	4.5	4.5	4.5	4.5	4.5
Auxiliary Fuel	MW	-	-	(2.8)	-	-
Gas Turbine Power Production	MW	-	-	4.4	-	2.4
Gas Turbine Steam Export	MW	-	-	-	-	-
Natural Gas Consumption for Aux Boiler and FBR Bed Heating	MW	(1.4)	(1.4)	(1.4)	(1.4)	(1.4)
Natural Gas Consumption for Dryer	MW	-	-	-	(0.8)	-
SMB and Digester Power Consumption (Dewatering Excluded)	MW	(4.7)	(5.0)	(4.5)	(4.6)	(4.0)
		1.3	1.6	1.7	(0.7)	2.7

Metro Steam Export	SMB	Aux Boiler
Steam to process	30,000	
Deaerator, Soot Blowers, Condenser	15,000	
Exported Steam	15,000	
	1027	
	15.405	5
	0.2931	0.2931
	4.5	**1.4**

	2010 plus Non-Condensing Turbine			4th Incinerator		
	kWh/year	MMBtu/year	Average kW			
ID Fans	10,040,250		1,146	2,317	From Metro Plant Energy Monitoring TM, Project No. 133797, Jan 9, 2012, Fig 10	
Fluidizing Air Blowers	8,295,881		947		ID Fan and FAB kW per train as a function of feed rate:	
Centrifuges	8,184,097		934	1,028	kW=3.317*dtpd+485.94	
Effluent Pumps (Scrubber, Condenser Water)	5,228,337		597	657		
Cake Pumps	3,339,946		381	419		
Heat Recovery Units (FBR HVAC)	2,352,586		269	269		
SMB Compressors	2,295,323		262	262		
Centrifuge Feed Pumps	1,823,254		208	229		
Turbine Cooling Recirculaiton Pumps	1,015,761		116	128		
Centrifuge Feed Tank Blower	293,234		33	37		
20% Miscellaneous Item Estimate	8,573,734		979	979		
Total Electrical Consumption	51,442,403		5,872	6,323		
Backcheck Cost at 0.07/kWh	$ 3,600,968					
Actual 2011 Cost net of turbine credit)	$ 3,661,771					
Electrical Consumption			5,872	6,323		
Condensing Steam Turbine Production			(2,500)	(3,466)	2012 average through October	2.25
Non-condensing Steam Turbine Production	3,700,000		(400)	-		
NG Purchase (2011 $ at $8/MMBTU)		42,676	1,400	1,400		
NG Credit for steam export		204,196	(4,515)	(4,515)		
SMB Net Energy			(143)	(258)		
Net Energy w/o Dewatering			(1,319)	(1,551)		
Dewatering kW				1,293	kW	
				1.3	MW	

Quantities shown in table below denote annual average values.

Chemicals

	Unit	2010	M3-A 4th Incinerator	M3-B PS/WAS Digest/Incinerate	M3-C PS/WAS Digest, Dry, Sell	M3-D PS/WAS Digest, LA Cake
Metro						
Polymer	$	2,039,212	2,241,233	2,710,419	2,535,929	2,535,929
Biogas Treatment Media, Chemicals	$	-	-	582,102	-	316,674
Lime	$					
Imported Ash	$					
Nutrient Harvesting	$					
Incineration Chemicals	$	403,600	443,807	321,959	326,870	299,554
Total		2,442,812	2,685,040	3,614,480	2,862,798	3,152,157

Assumptions - Polymer

Metro	
$ 2,549,500	provided by Metro 2010 polymer cost
9.00	Polymer dose, lb per dry ton with scum in centrifuge feed
7.20	Polymer dose, lb per dry ton without scum in centrifuge feed
$26.56	2010 calculated polymer cost per ton of dry sludge entering into centrifuges (with scum)
$2.95	Polymer cost per pound
$130,000.00	Estimated Annual Cost from Don Esping Empire Ostara Report - 1.6 FTE less $45,000 in fertilizer revenue
8	Empire raw WAS dtpd
$16,455.70	$/yr/dtpd WAS - ADD ONE FTE TO LABOR - CHEMICALS ARE MINIMAL
Increase in polymer dose with digestion	
2	Meso Digestion
1.5	Partial Digestion (less than 33%)
1.1	Cambi Digestion
0.8	PS Only
Polymer dose for dewatering with WAS drying	
15	lb/dry ton

Assumptions - Other Chemicals

$ 403,600	2010 Metro
263.00	dtpd
$ 1,534.60	Annual Chemical Cost per incinerated dtpd

Quantities shown in table below denote annual average values.

Miscellaneous Changes to Current Maintenance - Materials and Outside Services

		M3-A	M3-B	M3-C	M3-D
	Unit	4th Incinerator	PS/WAS Digest/Incinerate	PS/WAS Digest, Dry, Sell	PS/WAS Digest, LA Cake
Metro					
Gas Treatment	$		200,000		200,000
Gas Turbine Maintenance	$		465,273		252,906
Digester Maintenance	$		200,000	150,000	150,000
FBI Maintenance	$	500,000			
Dryer/Alk Stab Maintenance	$			500,000	
		$ 500,000	$ 865,273	$ 650,000	$ 602,906

	Assumptions
	Metro
	$ 200,000
	$ 840,000
	2010 Metro costs below not included since cost analysis is based on increases or decreases, not absolute costs
	$ 50,000
	$ 338,000
	$ 1,039,400

Appendix J. Capital Cost Estimate for the Metro Plant Fourth Incinerator

Opinion of Probable Cost: Fourth Incinerator (Sheet 2/3)

ITEM	QUANTITY	UNIT	UNIT COST	TOTAL COST
Mobilization, Bonds, Insurance				**$7,697,970**
Mobilization and Bonds	1	%	8.0%	$7,697,970
Demolition				**$250,000**
Relocate Ammonia Tank, Pumps & Carbon Silo	1	LS	$250,000	$250,000
Site Work				**$1,452,000**
Grading / Roads / Excavation / Piles	22,000	SQ FT	$66	$1,452,000
Building Addition				**$6,050,000**
Incinerator Building Addition	22,000	SQ FT	$275	$6,050,000
Dewatering & Cake Pumping				**$5,770,000**
Centrifuges	2	EA	$1,100,000	$2,200,000
Cake Bin	1	EA	$700,000	$700,000
Cake Pumps	2	EA	$700,000	$1,400,000
Polymer Pumps	2	EA	$40,000	$80,000
Centrifuge Feed Pumps	2	EA	$50,000	$100,000
Installation		%	30%	$1,290,000
Incineration				**$26,000,000**
Incinerator	1	EA	$20,000,000	$20,000,000
Installation		%	30%	$6,000,000
Energy Recovery				**$8,099,000**
WH Boiler	1	EA	$2,300,000	$2,300,000
WH Boiler Ash System	1	EA	$250,000	$250,000
Primary Heat Exchanger	1	EA	$750,000	$750,000
Secondary Heat Exchanger	1	EA	$500,000	$500,000
De-superheater	4	EA	$125,000	$500,000
De-aerator	1	EA	$350,000	$350,000
De-aerator Transfer Pumps	2	EA	$25,000	$50,000
Reverse Osmosis System	1	EA	$250,000	$250,000
Boiler Feed Pumps	2	EA	$40,000	$80,000
Steam Piping	1	EA	$500,000	$500,000
Steam Specialties	1	EA	$400,000	$400,000
Chemical Systems for Condensate Cleaning	1	EA	$300,000	$300,000
Installation		%	30%	$1,869,000

Opinion of Probable Cost: Fourth Incinerator (Sheet 2/3)

ITEM	QUANTITY	UNIT	UNIT COST	TOTAL COST
Air Pollution Control Equipment				**$11,295,000**
PAC Injection	1	EA	$200,000	$200,000
Carbon Tower	1	EA	$1,000,000	$1,000,000
Baghouse	1	EA	$1,500,000	$1,500,000
Chemical Injection	1	EA	$400,000	$400,000
Wet ESP	1	EA	$1,000,000	$1,000,000
Scrubber	1	EA	$1,500,000	$1,500,000
Low Temp Duct	300	LF	$2,000	$600,000
CEMS	2	EA	$300,000	$600,000
Sodium Hydroxide System	1	EA	$350,000	$350,000
Vacuum Ash Conveyance System	1	LS	$2,000,000	$2,000,000
Installation		%	30%	$2,145,000
Cake Receiving				**$1,914,500**
Cake Bin	1	EA	$420,000	$420,000
Cake Pumps	1	EA	$315,000	$315,000
Lubrication Pumps	1	EA	$32,500	$32,500
Cake Piping	600	LF	$500	$300,000
Cake Valves	12	EA	$25,000	$300,000
Installation		%	40%	$547,000
Other Equipment & Systems				**$3,640,000**
ID Fan	1	EA	$300,000	$300,000
Effluent Water Pumping	1	EA	$925,000	$925,000
Non-Potable Water Supply Piping	1	EA	$100,000	$100,000
Potable Water Supply Piping	1	EA	$75,000	$75,000
Non-Potable Water Strainers	1	EA	$50,000	$50,000
Grating Floors and Structures	1	LS	$1,000,000	$1,000,000
Drain Piping	1	EA	$150,000	$150,000
Installation		%	40%	$1,040,000

Opinion of Probable Cost: Fourth Incinerator (Sheet 3/3)

ITEM	QUANTITY	UNIT	UNIT COST	TOTAL COST
Plumbing & HVAC				**$9,622,463**
Plumbing & HVAC	1	%	10.0%	$9,622,463
Electrical & Instrumentation & Controls				**$14,433,694**
MCCs / Wiring / Programming / SCADA	1	%	15.0%	$14,433,694
Subtotal				**$96,224,627**
Contingency				**$28,867,388**
Construction Contingency	1	%	15.0%	$14,433,694
General Contingency	1	%	15.0%	$14,433,694
Subtotal Construction Cost Estimate				**$125,092,015**
Design Engineering	1	%	10.0%	$12,509,201
Construction Engineering & Inspection	1	%	10.0%	$12,509,201
Total Project				**$150,110,418**

Opinion of Probable Cost: Renewal of Incinerators 1, 2 and 3 (Sheet 1/2)

ITEM	QUANTITY	UNIT	UNIT COST	TOTAL COST
Mobilization, Bonds, Insurance				**$1,545,366**
Mobilization and Bonds	1	%	8.0%	$1,545,366
Sludge Storage				**$230,000**
Replace two oldest SST progressing cavity pumps	2	EA	$55,000	$110,000
Replace 2 centrifugal transfer pumps	2	EA	$30,000	$60,000
Replace 2 piston transfer pumps	2	EA	$30,000	$60,000
Sludge Feed Equipment				**$2,400,000**
Replace cake bin extraction screws	8	EA	$75,000	$600,000
Retrofit cake pumps for larger capacity and replace level sensors	4	EA	$300,000	$1,200,000
Renew cake bins	4	EA	$150,000	$600,000
Incinerators				**$3,400,000**
Rehabilitate air distribution system	3	EA	$750,000	$2,250,000
Replace spray nozzles and cooling jacket	12	EA	$25,000	$300,000
Restore OFA	1	LS	$100,000	$100,000
Rehabilitate refractory lining and shell	3	EA	$250,000	$750,000
FABs, ID Fans and Ducts				**$610,000**
Replace FAB discharge check valves	3	EA	$20,000	$60,000
Hydraulic Improvements, e.g., baffles	1	LS	$250,000	$250,000
Replace expansion joints	1	LS	$300,000	$300,000
Primary Heat Exchangers				**$2,250,000**
Renew primary heat exchangers	3	EA	$750,000	$2,250,000
Waste Heat Boilers				**$1,500,000**
Replace worn tube segments and sections	3	EA	$500,000	$1,500,000
Baghouse				**$1,125,000**
Renew baghouse hoppers	3	EA	$300,000	$900,000
Replace baghouse inlet valves	9	EA	$25,000	$225,000
Wet Scrubber				**$300,000**
Replace mist eliminator with larger unit	3	EA	$100,000	$300,000
Wet ESP				**$450,000**
Miscellaneous electrical component upgrades	3	EA	$150,000	$450,000

Opinion of Probable Cost: Renewal of Incinerators 1, 2 and 3 (Sheet 2/2)

ITEM	QUANTITY	UNIT	UNIT COST	TOTAL COST
Turbine Generators and Auxiliary Boilers				**$3,575,000**
Steam Turbine	1	EA	$2,500,000	$2,500,000
Surface Condenser	1	EA	$500,000	$500,000
Condenser Cooling Water Pumps	2	EA	$75,000	$150,000
Condensate Recirculation Pumps	2	EA	$50,000	$100,000
Heat Exchangers - Plant Effluent	2	EA	$150,000	$300,000
Condensate Tank	1	EA	$25,000	$25,000
Electrical & I&C				**$1,931,707**
Wiring & MCCs / Programming / SCADA	1	%	10.0%	$1,931,707
Subtotal				**$19,317,073**
Subtotal				$19,317,073
Contingency				**$5,795,122**
Construction Contingency	1	%	15.0%	$2,897,561
General Contingency	1	%	15.0%	$2,897,561
Subtotal Construction Cost Estimate				**$25,112,195**
Design Engineering	1	%	10.0%	$2,511,220
Construction Engineering & Inspection	1	%	10.0%	$2,511,220
Total Project Cost Estimate				**$30,134,634**

Appendix K. Environmental Assessment Worksheet

July 2013 version

ENVIRONMENTAL ASSESSMENT WORKSHEET

This Environmental Assessment Worksheet (EAW) form and EAW Guidelines are available at the Environmental Quality Board's website at:
http://www.eqb.state.mn.us/EnvRevGuidanceDocuments.htm. The EAW form provides information about a project that may have the potential for significant environmental effects. The EAW Guidelines provide additional detail and resources for completing the EAW form.
Cumulative potential effects can either be addressed under each applicable EAW Item, or can be addresses collectively under EAW Item 19.
Note to reviewers: Comments must be submitted to the RGU during the 30-day comment period following notice of the EAW in the *EQB Monitor*. Comments should address the accuracy and completeness of information, potential impacts that warrant further investigation and the need for an EIS.

1. **Project title:** Fourth Fluidized Bed Incinerator at the Metro Wastewater Treatment Plant

2. **Proposer:**
Contact person: Rene Heflin
Title: Manager, Plant Engineering Technical Services
Address: 390 Robert St. North
City, State, ZIP: St. Paul, MN 55101
Phone: 651-602-1077
Fax:
Email: rene.heflin@metc.state.mn.us

3. **RGU:** MN Pollution Control Agency
Contact person: Nancy Drach
Title: Environmental Review
Address: 520 Lafayette Road
City, State, ZIP: St. Paul, MN 55155
Phone: 651-757-2317
Fax:
Email: Nancy.drach@state.mn.us

4. **Reason for EAW Preparation: (check one)**

Required:
☐ EIS Scoping
☐ Mandatory EAW

Discretionary:
☐ Citizen petition
☐ RGU discretion
☒ Proposer initiated

If EAW or EIS is mandatory give EQB rule category subpart number(s) and name(s):

5. **Project Location:**

County: Ramsey
City/Township: St. Paul/28 North
PLS Location (¼, ¼, Section, Township, Range): E ½ of the SW ¼-NW ¼ of Section 10, 28N, 22W
Watershed (81 major watershed scale):

Watershed	NHD Hydrologic Unit #	NHD Hydrologic Unit Name
HU_8 -	7010206	Twin Cities
HU_10 -	701020608	City of Saint Paul-Mississippi River
HU_12 -	70102060805	Harriet Island-Mississippi River

GPS Coordinates: Longitude = -93.0419, Latitude = 44.9287
Tax Parcel Number: 123-102822230001

At a minimum attach each of the following to the EAW:

- County map showing the general location of the project;
- U.S. Geological Survey 7.5 minute, 1:24,000 scale map indicating project boundaries (photocopy acceptable); and
- Site plans showing all significant project and natural features. Pre-construction site plan and post-construction site plan.

See Appendix A, Figures 1 through 3.

6. **Project Description:**

a. **Provide the brief project summary to be published in the *EQB Monitor*, (approximately 50 words).**

The proposed project is to provide additional solids processing capacity by adding an additional fluid bed incinerator train (FBI 4) to the existing FBI complex at the Metropolitan Wastewater Treatment Plant (Metro Plant). The Metro Plant, located in St. Paul on the Mississippi River, is owned and operated by the Metropolitan Council Environmental Services (MCES).

b. **Give a complete description of the proposed project and related new construction, including infrastructure needs. If the project is an expansion include a description of the existing facility. Emphasize: 1) construction, operation methods and features that will cause physical manipulation of the environment or will produce wastes, 2) modifications to existing equipment or industrial processes, 3) significant demolition, removal or remodeling of existing structures, and 4) timing and duration of construction activities.**

The proposed project will construct a fourth FBI train in parallel to three existing FBI trains in the Solids Management Building (SMB) located in the northeast portion of the Metro Plant. Each existing FBI train consists of an incinerator, heat recovery equipment (primary and secondary heat exchangers, waste heat boiler), flue gas treatment equipment (carbon injection, baghouse, scrubber, and electrostatic precipitator) and a flue gas stack. The proposed FBI train is similar, as shown on Figure 4, Appendix A, and will require a building expansion.

Other major process systems that will be modified and/or expanded to accommodate the new FBI train include dewatered cake conveyance to incineration, ash conveyance and loadout, and steam turbine power generation.

It is anticipated that alkaline stabilization, used as a backup solids stabilization process, will increase during construction due to down time required for tie-ins. Metro Plant currently landfills stabilized bisolids and ash.

Construction will occur within the existing Metro Plant levee and floodwall system. Building expansion will require excavation and dewatering (see 10.b and 11.b.iii for details); excavated materials will be used onsite. Options for recycling of construction demolition debris will be evaluated. Demolition will include 6300 square feet of asphalt. Asphalt removed in the demolition will be recycled.

Construction is scheduled to occur 2021 and 2024.

c. **Project magnitude:**

Total Project Acreage	0.5
Linear project length	N/A
Number and type of residential units	0
Commercial building area (in square feet)	0
Industrial building area (in square feet)	22,000
Institutional building area (in square feet)	0
Other uses – specify (in square feet)	0
Structure height(s)	70 ft
Stack height	150 ft

d. **Explain the project purpose; if the project will be carried out by a governmental unit, explain the need for the project and identify its beneficiaries.**

The project purpose is to increase available incineration capacity at the Metro Plant to more effectively support routine maintenance of solids processing equipment and to accommodate projected increases in solids processing requirements within a 30-year planning window.

The current dewatered cake production of 240 dtpd (2020) is projected to increase to 300 dtpd by 2050 due to population and economic growth in the Metro Plant service area.

e. **Are future stages of this development including development on any other property planned or likely to happen? ☐ Yes ☒ No**
If yes, briefly describe future stages, relationship to present project, timeline and plans for environmental review.

f. **Is this project a subsequent stage of an earlier project? ☒ Yes ☐ No**
If yes, briefly describe the past development, timeline and any past environmental review.

The existing three FBI trains at the Metro Plant were installed in 2004; startup was completed in 2005. An EAW was submitted by MCES at that time.

7. Cover types: Estimate the acreage of the site with each of the following cover types before and after development:

	Before	**After**		**Before**	**After**
Wetlands	-	-	Lawn/landscaping	0.1	0
Deep water/streams	-	-	Impervious surface	0.4	0.5
Wooded/forest	-	-	Stormwater Pond	-	-
Brush/Grassland	-	-	Other (describe)	-	-
Cropland	-	-			
			TOTAL	**0.5**	**0.5**

8. Permits and approvals required: List all known local, state and federal permits, approvals, certifications and financial assistance for the project. Include modifications of any existing permits, governmental review of plans and all direct and indirect forms of public financial assistance including bond guarantees, Tax Increment Financing and infrastructure. ***All of these final decisions are prohibited until all appropriate environmental review has been completed. See Minnesota Rules, Chapter 4410.3100.***

Unit of government	**Type of application**	**Status**
Federal Aviation Administration (FAA)	Notification of Proposed Construction or Alteration	To be applied for
National Park Service (NSP)	Plan review and coordination under Mississippi National River and Recreation Area (MNRRA)	
Minnesota Pollution Control Agency (MPCA)	Plan and Specification approval	To be submitted
MPCA	Facility Plan approval	To be submitted
Mn Public Facilities Authority	Minnesota State Loan Funding approval	To be submitted
MPCA	National Pollution Discharge Elimination System/State Disposal System (NPDES/SDS) Permit	To be applied for, if required
MPCA	Major amendment to Title V Permit	To be applied for
MPCA	Construction Stormwater Permit	To be applied for
MPCA	Stormwater Plan	To be amended, if required
MPCA	Toxic Pollution Prevention Plan	To be amended, if required

Unit of government	Type of application	Status
Minnesota Emergency Response Commission and Local Fire Department	SARA Title III Chemical Notification, Planning, and Reporting	To be amended, if required
DNR	Water Appropriation Permit may be required for dewatering if more than 10,000 gpd or one million gpd is proposed	To be applied for, if required
State Historic Preservation Officer (SHPO)	National Historic Preservation Act Section 106 and the Archaeological Resources Protection Act Review and Coordination. Office of the State Archaeologist (OSA) coordinates with the SHPO	
Ramsey County	Hazardous Waste Generator License	To be amended, if required
Ramsey County	Hazardous Waste Contingency Plan	To be amended, if required
Ramsey-Washington County Watershed District	Grading Permit	To be applied for
City of St. Paul	Plan review coordination regarding compliance with St. Paul Critical Area River Corridor Plan and Ordinance	To be submitted
City of St. Paul	Building Permit	To be applied for

Cumulative potential effects may be considered and addressed in response to individual EAW Item Nos. 9-18, or the RGU can address all cumulative potential effects in response to EAW Item No. 19. If addressing cumulative effect under individual items, make sure to include information requested in EAW Item No. 19

9. Land use:

a. Describe:

i. Existing land use of the site as well as areas adjacent to and near the site, including parks, trails, prime or unique farmlands.

See Appendix A, Figure 5, 6 and 7 and Table 1.

ii. Plans. Describe planned land use as identified in comprehensive plan (if available) and any other applicable plan for land use, water, or resources management by a local, regional, state, or federal agency.

See Appendix A, Figure 7.

iii. Zoning, including special districts or overlays such as shoreland, floodplain, wild and scenic rivers, critical area, agricultural preserves, etc.

The Metro Plant is located within the designated Critical Area for the Mississippi River and the Mississippi National River and Recreation Area (MNRRA) corridor.
The Metro Plant property falls within the 100-year floodplain. Figure 8 shows the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map. The base flood elevation is shown as 706 feet National Geodetic Vertical Datum (NGVD). This is the 100

year flood event. The Metro Plant's existing levee and floodwall are FEMA certified and designed to protect the facility from the 500-year flood.

The location of the Metro Plant within the Mississippi River floodplain and Critical Area requires compliance with the City of St. Paul River Corridor District Zoning Code. The Code utilizes hydrologic information provided by the Flood Insurance Study for St Paul, completed under the direction of FEMA. The project area is located within District RC-4-Urban Diversified District and is subject to applicable River Corridor ordinance provisions in Chapter 68. The project is a permitted use in the RC-4 District since it is a permitted use in the underlying I-2 District. Permitted uses are subject to the standards specified in Section 68.400 et. seq, including provisions for grading and filling, protection of wildlife and vegetation, and protection of water quality.

b. Discuss the project's compatibility with nearby land uses, zoning, and plans listed in Item 9a above, concentrating on implications for environmental effects.

This project will occur within the existing Metro Plant site, as expansion of the existing SMB, and will not substantially change the nature of the facility in terms of its effects on nearby adjacent lands.

c. Identify measures incorporated into the proposed project to mitigate any potential incompatibility as discussed in Item 9b above.

Not applicable.

10. Geology, soils and topography/land forms:

a. **Geology - Describe the geology underlying the project area and identify and map any susceptible geologic features such as sinkholes, shallow limestone formations, unconfined/shallow aquifers, or karst conditions. Discuss any limitations of these features for the project and any effects the project could have on these features. Identify any project designs or mitigation measures to address effects to geologic features.**

Most of the soils on the Metro Plant property consist of an old river basin filled with sand and muck. The Chaska Silt Loam and Kerston Muck cover a small portion of the plant property. Soils are generally fine-grained, including silty sand, silt, clay, and organic materials.

b. **Soils and topography - Describe the soils on the site, giving NRCS (SCS) classifications and descriptions, including limitations of soils. Describe topography, any special site conditions relating to erosion potential, soil stability or other soils limitations, such as steep slopes, highly permeable soils. Provide estimated volume and acreage of soil excavation and/or grading. Discuss impacts from project activities (distinguish between construction and operational activities) related to soils and topography. Identify measures during and after project construction to address soil limitations including stabilization, soil corrections or other measures. Erosion/sedimentation control related to stormwater runoff should be addressed in response to Item 11.b.ii.**

The soil survey of Washington and Ramsey Counties, Minnesota (Vinar 1980) shows most of the soils on the Metro Plant property to consist of Unorthadents-wet substratum and Urban Land. The Chaska Silt Loam and Kerston Muck cover a small portion of the plant property. Soils are generally fine-grained, including silty sand, silt, clay, and organic materials. It is assumed that the buildings would require pilings to an estimated depth of 50 feet.

Topography – There are no steep slopes or highly erodible soils associated with the project.

Soil Excavation and/or grading estimate – 9000 cubic yards of excavation and 0.15 acres of grading.

Temporary erosion controls will be implemented in an effort to curtail erosion and sediment transport and to maintain slope stability until permanent erosion controls have been adequately established. Erosion control will be maintained throughout the construction period by removing accumulated sediment, and by repairing or replacing damaged and deteriorated erosion control devices. Temporary erosion control devices typically include silt fence, straw bales, and storm sewer inlet protection.

Post construction erosion and sedimentation control is typically accomplished by establishing turf. Turf establishment will primarily consist of seeding and mulching. Sod may be placed to restore areas adjacent to maintained lawns, and in areas that may be determined to be particularly susceptible to erosion. Suitable temporary erosion control devices will be placed and maintained until permanent turf has been adequately established.

NOTE: For silica sand projects, the EAW must include a hydrogeological investigation assessing the potential groundwater and surface water effects and geologic conditions that could create an increased risk of potentially significant effects on groundwater and surface water. Descriptions of water resources and potential effects from the project in EAW Item 11 must be consistent with the geology, soils and topography/land forms and potential effects described in EAW Item 10.

11. **Water resources:**
   a. **Describe surface water and groundwater features on or near the site in a.i. and a.ii. below.**
      i. **Surface water - lakes, streams, wetlands, intermittent channels, and county/judicial ditches. Include any special designations such as public waters, trout stream/lake, wildlife lakes, migratory waterfowl feeding/resting lake, and outstanding resource value water. Include water quality impairments or special designations listed on the current MPCA 303d Impaired Waters List that are within 1 mile of the project. Include DNR Public Waters Inventory number(s), if any.**

         The Metro Plant is located within the designated Critical Area for the Mississippi River and the Mississippi National River and Recreation Area (MNRRA) corridor. Lands designated for Pigs Eye Park, around Pigs Eye Lake, are located to the south and southeast of the Metro Plant property. Farther to the southeast is the Pigs Eye Lake Scientific and Natural Area (SNA). The undeveloped character of much of the land near the Metro Plant, particularly to the south and east, provides a range of habitat, which includes wetlands, floodplain forest, and grasslands.

         All project activity will be within the existing levee and floodwall for the Metro Plant. Buildings, treatment tanks, roads, and storage areas occupy most of the area inside of the levee. With the exception of a stormwater treatment basin colonized by common wetland plants, plant communities inside of the levee and floodwall are limited to landscaped areas planted with grass. Neither project construction nor operation will affect nearby sensitive resources.

ii. **Groundwater – aquifers, springs, seeps. Include: 1) depth to groundwater; 2) if project is within a MDH wellhead protection area; 3) identification of any onsite and/or nearby wells, including unique numbers and well logs if available. If there are no wells known on site or nearby, explain the methodology used to determine this.**

1. Well 603089 is closest to the construction area and the well log shows the depth to groundwater as 21 feet from land surface, measured 10/25/2002.
2. Not applicable.
3. See Appendix A, Figure 9 plus well logs and Figure 10 plus boring logs.

b. Describe effects from project activities on water resources and measures to minimize or mitigate the effects in Item b.i. through Item b.iv. below.

i. **Wastewater - For each of the following, describe the sources, quantities and composition of all sanitary, municipal/domestic and industrial wastewater produced or treated at the site.**

1) If the wastewater discharge is to a publicly owned treatment facility, identify any pretreatment measures and the ability of the facility to handle the added water and waste loadings, including any effects on, or required expansion of, municipal wastewater infrastructure.

The proposed project adds solids processing capacity to an existing wastewater treatment plant, the Metropolitan Wastewater Treatment Plant (Metro Plant). The Metro Plant is an advanced secondary wastewater treatment plant providing removal of carbonaceous biochemical oxygen demand, 5-day ($CBOD_5$), total suspended solids (TSS), phosphorus (P), and ammonia (NH_4-N), as well as disinfection. The project is proposed to improve the Metro Plant and, directly or indirectly, the quality of effluent discharged from that facility to the Mississippi River in accordance with NPDES/SDS Permit Nos. MN 0029815 and MN 0070629.

The proposed project will have no anticipated adverse impacts on the plant's ability to continue to comply with permitted NPDES discharge limits.

2) If the wastewater discharge is to a subsurface sewage treatment systems (SSTS), describe the system used, the design flow, and suitability of site conditions for such a system.
Not applicable.

3) **If the wastewater discharge is to surface water, identify the wastewater treatment methods and identify discharge points and proposed effluent limitations to mitigate impacts. Discuss any effects to surface or groundwater from wastewater discharges**.
Not applicable.

ii. **Stormwater - Describe the quantity and quality of stormwater runoff at the site prior to and post construction. Include the routes and receiving water bodies for runoff from the site (major downstream water bodies as well as the immediate receiving waters).**

Discuss any environmental effects from stormwater discharges. Describe stormwater pollution prevention plans including temporary and permanent runoff controls and potential BMP site locations to manage or treat stormwater runoff. Identify specific erosion control, sedimentation control or stabilization measures to address soil limitations during and after project construction.

The project site is a wastewater treatment plant enclosed within a levee and floodwall. Site runoff is governed NPDES/SDS Permit Nos. MN 0029815 and the Stormwater Pollution Prevention Plan developed in accordance with the requirements of that permit. Stormwater from inside of the levee and floodwall discharges into the pump station to the chlorine contact channel and into the Mississippi River.

Because of the additional impervious surfaces created by new building, the quantity of stormwater runoff will increase. No change is anticipated in the quality of the stormwater runoff. Currently rooftop and impervious areas around the existing incineration building are routed to a stormwater retention pond which is pumped to the Mississippi river.

For post-construction stormwater collection, several options of green infrastructure (GI) designed to collect and treat the additional impervious area will be evaluated. Biofilters, bioswales, rain gardens, or infiltration systems would be ideal for this site.

Temporary erosion controls will be implemented in an effort to curtail erosion and sediment transport and to maintain slope stability until permanent erosion controls have been adequately established. Erosion control will be maintained throughout the construction period by removing accumulated sediment, and by repairing or replacing damaged and deteriorated erosion control devices. Temporary erosion control devices typically include silt fence, straw bales, and storm sewer inlet protection.

iii. **Water appropriation - Describe if the project proposes to appropriate surface or groundwater (including dewatering). Describe the source, quantity, duration, use and purpose of the water use and if a DNR water appropriation permit is required. Describe any well abandonment. If connecting to an existing municipal water supply, identify the wells to be used as a water source and any effects on, or required expansion of, municipal water infrastructure. Discuss environmental effects from water appropriation, including an assessment of the water resources available for appropriation. Identify any measures to avoid, minimize, or mitigate environmental effects from the water appropriation.**

It is anticipated that dewatering will be required during construction and that a DNR Water Appropriation Permit will be required. The design elevation of the basement floor for the Solids Management Building is approximately 684 feet, about 10 feet below ground surface. Allowing for a four-foot thick floor slab, supporting gravel and some extra allowance, site dewatering can be expected to approximate an elevation of 670 feet or about 30 feet below ground surface. The anticipated construction schedule will call for 6 to 12 months of dewatering.

iv. **Surface Waters**

a) **Wetlands - Describe any anticipated physical effects or alterations to wetland features such as draining, filling, permanent inundation, dredging and vegetative removal. Discuss direct and indirect environmental effects from physical modification of wetlands, including the anticipated effects that any proposed wetland alterations may have to the host watershed. Identify measures to avoid (e.g., available alternatives that were considered), minimize, or mitigate environmental effects to wetlands. Discuss whether any required compensatory wetland mitigation for unavoidable wetland impacts will occur in the same minor or major watershed, and identify those probable locations.**
Not applicable. The are no wetlands located inside the Metro Plant floodwall and berm area, where the proposed project will be constructed. Wetlands will not be impacted by the proposed project.

b) **Other surface waters- Describe any anticipated physical effects or alterations to surface water features (lakes, streams, ponds, intermittent channels, county/judicial ditches) such as draining, filling, permanent inundation, dredging, diking, stream diversion, impoundment, aquatic plant removal and riparian alteration. Discuss direct and indirect environmental effects from physical modification of water features. Identify measures to avoid, minimize, or mitigate environmental effects to surface water features, including in-water Best Management Practices that are proposed to avoid or minimize turbidity/sedimentation while physically altering the water features. Discuss how the project will change the number or type of watercraft on any water body, including current and projected watercraft usage.**
Not applicable.

12. Contamination/Hazardous Materials/Wastes:

a. **Pre-project site conditions - Describe existing contamination or potential environmental hazards on or in close proximity to the project site such as soil or ground water contamination, abandoned dumps, closed landfills, existing or abandoned storage tanks, and hazardous liquid or gas pipelines. Discuss any potential environmental effects from pre-project site conditions that would be caused or exacerbated by project construction and operation. Identify measures to avoid, minimize or mitigate adverse effects from existing contamination or potential environmental hazards. Include development of a Contingency Plan or Response Action Plan.**

The Metro WWTP is not under any remediation status with the MPCA and therefore does not have a Construction Contingency Plan or Response Action Plan. The Plant does have an active combined SPCC (Spill Prevention, Control and Countermeasure) and Minnesota Spill Bill Plan to address releases of stored petroleum products or stored wastewater treatment chemicals.

At the Metro Plant, petroleum-contaminated soils were investigated and subsequently treated following removal of underground storage tanks in 1990; the MPCA has closed the file on this incident (MPCA Site No. LEAK 00003096). The file for a separate release (MPCA Site No. LEAK 00004071) has also been closed. No further investigation has been required of diesel range organics detected when four USTs were upgraded in 1993 (MPCA Site No. LEAK 00007015). A small release of kerosene reported as MPCA Site No. LEAK 17085 in 2007 was determined to be insignificant, requiring no action. There are no other environmental hazards known to be associated with past activities at the proposed project location.

b. **Project related generation/storage of solid wastes - Describe solid wastes generated/stored during construction and/or operation of the project. Indicate method of disposal. Discuss potential environmental effects from solid waste handling, storage and disposal. Identify measures to avoid, minimize or mitigate adverse effects from the generation/storage of solid waste including source reduction and recycling.**

Dry ash from the FBIs and air pollution control equipment is hauled offsite for disposal in a MN landfill. In cases of high solids storage level and unavailable incineration capacity, raw wastewater sludge is limed prior to disposal in a MN landfill.

Demolition associated with expansion of existing solids management building will generate construction waste which will be properly disposed offsite.

c. **Project related use/storage of hazardous materials - Describe chemicals/hazardous materials used/stored during construction and/or operation of the project including method of storage. Indicate the number, location and size of any above or below ground tanks to store petroleum or other materials. Discuss potential environmental effects from accidental spill or release of hazardous materials. Identify measures to avoid, minimize or mitigate adverse effects from the use/storage of chemicals/hazardous materials including source reduction and recycling. Include development of a spill prevention plan.**

Sodium hydroxide, aluminum sulfate, sodium hypochlorite and sulfuric acid will be stored in storage tanks during operation of the project. Ammonium hydroxide may be needed (to be determined during design)

The contractor is required to follow MCES' spills reporting and mitigation procedure. MCES defines a spill as a release of wastewater, sludge, treated effluent, chemical, petroleum or other material outside of the contained, conduit or treatment unit in which it is stored, transferred or treated. The procedure requires: (1) Stop and contain the spill, ensuring access to waters and sewers is blocked, (2) Initiate spill response/recovery if it is safe to do so, (3) Notify site manager and CAR, and (4) Notify MCES' Regional Dispatch at (651) 602-4511. MCES Regional Dispatch will coordinate and facilitate appropriate spill responses and immediate corrective action, and complete all the necessary notifications and contacts with both internal and external parties. If the release is of a SARA Title III material or an Industrial Waste, the contractor is additionally required to contact the State Duty Officer at (651) 649-5451.

d. **Project related generation/storage of hazardous wastes - Describe hazardous wastes generated/stored during construction and/or operation of the project. Indicate method of disposal. Discuss potential environmental effects from hazardous waste handling, storage, and disposal. Identify measures to avoid, minimize or mitigate adverse effects from the generation/storage of hazardous waste including source reduction and recycling.**

A number of wastes generated as a result of Metro Plant operation and maintenance activities are classified as hazardous wastes by Minnesota Rules Chapter 7045. These include items such as paint thinner, corrosive laboratory chemicals, heavy metal lab wastes, nonchlorinated lab solvent, chlorinated solvent, degreasing solvent, paint sludges, COD ampoules and lab-packed hazardous waste. All of the plant's hazardous wastes are managed in compliance with these rules. Universal wastes include household batteries, light ballasts, small capacitors, florescent lamps, spent lead, acid batteries, mercury contaminated material and elemental mercury. Oily wastes include used oil, used oil filters and used oil absorbents.

13. Fish, wildlife, plant communities, and sensitive ecological resources (rare features):

a. Describe fish and wildlife resources as well as habitats and vegetation on or in near the site.

Figure 6 in Appendix A illustrates the ecologically significant areas around the Metro Plant.

The Mississippi River flows along the western edge of the Metro Plant. Lands designated for Pigs Eye Park, around Pigs Eye Lake, are located to the south and southeast of the Metro Plant property. Further to the southeast is the Pigs Eye Lake Scientific and Natural Area (SNA). The undeveloped character of much of the land near the Metro Plant, particularly to the south and east, provides a range of habitat, which includes wetlands, floodplain forest, and grasslands.

All project activity will be confined within the existing levee and floodwall for the Metro Plant. Buildings, treatment tanks, roads, and storage areas occupy most of the area inside of the levee. With the exception of a stormwater treatment basin colonized by common wetland plants, plant communities inside of the levee and floodwall are limited to landscaped areas planted with grass. Neither project construction nor operation will affect nearby sensitive resources.

b. Describe rare features such as state-listed (endangered, threatened or special concern) species, native plant communities, Minnesota County Biological Survey Sites of Biodiversity Significance, and other sensitive ecological resources on or within close proximity to the site. Provide the license agreement number (LA-____) and/or correspondence number (ERDB _____________) from which the data were obtained and attach the Natural Heritage letter from the figure. Indicate if any additional habitat or species survey work has been conducted within the site and describe the results.

No rare features were found. See attached letter ERDB 20150106 in Appendix B.

c. Discuss how the identified fish, wildlife, plant communities, rare features and ecosystems may be affected by the project. Include a discussion on introduction and spread of invasive species from the project construction and operation. Separately discuss effects to known threatened and endangered species.

Neither project construction nor operation will affect nearby sensitive resources.

d. Identify measures that will be taken to avoid, minimize, or mitigate adverse effects to fish, wildlife, plant communities, and sensitive ecological resources.

Under the Critical Area Program, Executive Order 79-19 establishes Standards and Guidelines for state and regional agencies with regard to permit regulation and in developing plans within their jurisdiction, and for the MCES regarding plan review, regulations, and development permit applications. In addition, regional and state agencies are directed to develop a capital improvement program or public facilities program, which specifies the sequence of actions consistent with the standards and guidelines. Standards and Guidelines that are particularly applicable to this project include the following:

- Minimize runoff and improve runoff quality.
- Minimize site alteration.
- Manage vegetation cutting.
- Address standards for site plans:
  - –Approval of site plans to determine that plans adequately assess and minimize adverse effects and maximize beneficial effects.
  - –Include measures that address adverse environmental effects.
  - –Include standards to ensure that structures, roads, screening, landscaping, construction placement, maintenance, and stormwater runoff are compatible with characteristics and use of corridor in that district.
  - –Provide opportunities for establishment of open space and public viewing where applicable, and specific conditions with regard to buffering, landscaping, and re-vegetation.
- Address standards for structure site and location to ensure riverbanks, bluffs and scenic overlooks remain in their natural state and minimize interference with views of and from the river, except for specific uses requiring river access.
- Include provisions to retain existing vegetation and landscaping.

FBI 4 will be next to the existing FBIs on land that is currently a parking lot. The new construction will be an expansion of the existing solids management building. No issues with sensitive resources around the construction site are anticipated.

14. Historic properties:
Describe any historic structures, archeological sites, and/or traditional cultural properties on or in close proximity to the site. Include: 1) historic designations, 2) known artifact areas, and 3) architectural features. Attach letter received from the State Historic Preservation Office (SHPO). Discuss any anticipated effects to historic properties during project construction and operation. Identify measures that will be taken to avoid, minimize, or mitigate adverse effects to historic properties.

See attached SHPO letter in Appendix B. The historic property database search was done for the following coordinates: SW NW S10 T28N R22W. No effects on historic properties are anticipated.

Construction will be on previously disturbed land within the existing floodwall and berm area of the plant.

15. Visual:
Describe any scenic views or vistas on or near the project site. Describe any project related visual effects such as vapor plumes or glare from intense lights. Discuss the potential visual effects from the project. Identify any measures to avoid, minimize, or mitigate visual effects.

The incinerator plume will be suppressed by high stack temperatures. Residual heat in the exhaust stream will be captured upstream of the wet scrubbers and added back into the air stream downstream of the wet scrubbers. This elevates the air stream by about 100º F. This addition of heat to the heat produced in the induced draft fan effectively increases exhaust stream temperature to 250º F as it enters the discharge stack.

16. Air:

1. **Stationary source emissions - Describe the type, sources, quantities and compositions of any emissions from stationary sources such as boilers or exhaust stacks. Include any hazardous air pollutants, criteria pollutants, and any greenhouse gases. Discuss effects to air quality including any sensitive receptors, human health or applicable regulatory criteria. Include a discussion of any methods used assess the project's effect on air quality and the results of that assessment. Identify pollution control equipment and other measures that will be taken to avoid, minimize, or mitigate adverse effects from stationary source emissions.**

16.1 EXISTING CONDITIONS

The existing Metro Plant facility provides treatment of wastewater and combusts wastewater solids. These processes result in air emissions from the facility. Current air emission sources at the facility include three fluidized bed incinerators (FBI), an alkaline stabilization system, liquids treatment processes, sludge tanks, boilers, ash handling and emergency generators. The facility off-permit, insignificant and exempt activities include: fuel tanks, maintenance activities with air emissions such as welding and degreasing, and handling and storage of sand, lime, and ash. The facility is regulated as a major Prevention of Significant Deterioration (PSD) facility, a major Title V facility, but a minor Hazardous Air Pollutant (HAP) facility. The facility is a major PSD facility for NOx.

The Metro Plant is located in the PM10 maintenance area along the Mississippi River in St. Paul. This maintenance area is the area that in the past had not met the PM10 National Ambient Air Quality Standard but now meets the standard. The Metro Plant and nearby facilities have on-going PM10 air permitting requirements for this maintenance area.

The existing facility operates under air permit 12300053-006. The permit expired on February 25, 2015. An air permit renewal application was submitted on August 26, 2014. Minnesota rules and Title V regulations allow operation of a facility on an expired permit if a renewal permit application was received 180 days prior to the expiration date. The MPCA indicated that the application was administratively complete.

The facility completes an air emission inventory each year, which is submitted to MPCA. The 2017 air emission inventory results for the facility's 2017 actual air emissions are shown below.

Table 1-1
Actual 2017 Metro Plant Air Emissions

Pollutant	Actual Emissions (ton/yr)
PM	1.2
PM_{10}	4.5
$PM_{2.5}$	3.8
SO_2	8.0
NO_x	34.8
VOC	1.6
CO	15.2
Lead	0.001
Mercury	0.0002

Acronyms:

PM	Particulate matter
PM_{10}	Particulate matter less than 10 microns in diameter
$PM_{2.5}$	Particulate matter less than 2.5 microns in diameter
SO_2	Sulfur dioxide
NO_x	Nitrogen dioxides, including primarily NO and NO_2
VOC	Volatile organic compound
CO	Carbon Monoxide

The Metro Plant facility has a nominal design capacity of 250 million gallons per day, and operated at an average of 179 million gallons per day during 2017. The existing FBI capacity is restricted to 315 dry ton/day by the air permit. The facility operated the FBIs at an average of 240 dry ton sludge/day total.

The existing FBIs will be regulated under 40 CFR 62 Subpart LLL, Federal Plan Requirements for Sewage Sludge Incinerator Units Constructed On or Before October 1, 2010. The facility demonstrated compliance with this standard by March 21, 2016.

Greenhouse gas emissions from anthropogenic (man-made) sources were also reported on the 2017 Air Emission Inventory Report. These emissions include only emissions from fossil fuel combustion at the facility and do not include greenhouse gases generated from treatment of wastewater. The emissions are shown below in Table 1-2.

Table 1-2
Actual 2017 Metro Plant Fossil Fuel Combustion Greenhouse Gas Emissions

Greenhouse Gas	Fossil Fuel Emissions (tons/yr)	Anthropogenic Emissions from Sludge*	Total Emissions (ton/yr)
Carbon Dioxide, CO2	8,326	Biogenic, non-reportable	8326
Methane, CH4	0.2	31.3	31.5
Nitrous Oxide, N2O	0.02	4.1	4.1
CO_2-e*	8,334	2,010	10,345

* Based on emission factors from 40 CFR 98, Subpart C. Biogen CO2 is non-reportable; anthropogenic N2O and

16.2 ENVIRONMENTAL CONSEQUENCES

MCES is proposing to expand the capacity of the existing Metro Plant sludge combustion system. This will require additional equipment, including a fourth FBI and associated air pollution control equipment. The project will require a major Minnesota air permit amendment to the facility's existing permit for new PM_{10}.

16.2.1 Proposed Equipment

MCES proposes to add a fourth fluidized bed reactor to the site. The proposed FBI 4 will be approximately the same capacity as the existing three existing incinerators (120-130 dry tons/day). The facility will include cake receiving to provide backup solids treatment for other MCES wastewater treatment facilities. Energy recovery and air pollution control equipment proposed for FBI 4, will be like the three existing incinerators. Further discussion on the air pollution control train at the facility is provided under Mitigation.

The project will convert a part of the dense phase (pressurized) ash transport system to vacuum transport which will add two additional dust collectors.

16.2.2 Regulatory Discussion

The proposed FBI 4 project will trigger a major Minnesota air permit amendment. The facility's existing permit notes that a major amendment is triggered for any new PM_{10} emission source since the site is located in a PM_{10} maintenance area. Air dispersion modeling for PM_{10} will also be completed and included with the facility's air permit amendment application, if needed.

Although Metro Plant is a major PSD source, the project is not expected to trigger PSD review requirements. An emission limit on $PM_{2.5}$, a subset of PM_{10}, will be proposed in the air permit amendment application. Establishing a site-specific limit also triggers a major air permit amendment.

FBI 4 will be subject to the New Source Performance Standard (NSPS) for Sewage Sludge Incinerators under 40 CFR 60 Subpart LLLL. This standard is a Clean Air Act Section 129 standard that addresses both criteria pollutants as well as hazardous air pollutants. FBI 4 and its control equipment train will be designed to meet the emission limits immediately upon startup.

There are additional federal and state limits that apply to sewage sludge incinerators, but emissions allowed under these standards are less stringent than the Subpart LLLL limits. These standards include EPA’s 40 CFR 503, self-implementing, requirements, and 40 CFR 60 Subpart O.

Minnesota Statute 116.85 requires installation of a continuous emission monitoring system (CEMS). The facility will operate CEMS for CO and oxygen (O_2), as well as a continuous opacity monitoring system.

16.2.3 Emissions Discussion

Criteria Pollutants

Criteria pollutant emissions are shown in Table 2-1 for the proposed FBI 4. The project is expected to qualify as a PSD synthetic minor modification. Potential emissions are calculated with the most stringent federal or state rule that applies for each pollutant. Stack testing for the existing FBIs is the basis of VOC emission estimates, and the particulate emission estimate assumes that a synthetic minor limit would be established. The condensable portion of particulates is not regulated under the applicable New Source Performance Standard.

Natural gas is used during startup to minimize emissions and ensure complete combustion. Natural gas emissions are not quantified due to the short time period. Sewage sludge is assumed to generate higher emissions than natural gas for all criteria pollutants; therefore, continuous sewage sludge combustion is assumed with no natural gas emissions as a worst case.

Table 2-1
FBI 4 Potential Criteria Pollutant Emissions (@ 130 dtpd)

Pollutant	Allowable Emissions (ton/yr)
PM, excluding condensable particulates	3.2
PM_{10}	3.8
$PM_{2.5}$	2.4
SO_2	4.7
NO_x	18.9
VOC	0.5
CO	10.4
Lead	2.1×10^{-4}

The project will increase allowable emissions of criteria pollutants at the facility, as the FBI 4 accommodates growth of the overall metropolitan area and would allow the facility to receive sludge from other MCES facilities. However, operation of FBI 4 would likely result in reduced operation of the three existing FBIs.

Greenhouse gases

The carbon dioxide emissions generated from sludge treatment are biogenic or naturally occurring, and would be expected to occur regardless of how the sludge is treated. Methane may also be generated from incomplete combustion. Nitrous oxide is emitted at combustion sources, and is temperature dependent. Nitrous oxide tends to decrease as NOx increases. The N_2O emissions are estimated from stack test results for the existing FBIs.

Table 2-2
FBI 4 Potential Greenhouse Gas Emissions

Greenhouse Gas	Potential Emissions (ton/yr)
CO_2	90,471
Methane	12
Nitrous Oxide	25
CO_2-e	98,285

HAPs

The hazardous air emissions from FBI 4 are expected to be metals, volatile organics, dioxin/furans compounds, and hydrochloric acid.

Allowable mercury emissions under the NSPS for FBI 4 are approximately 299 grams per year. This emission level is comparable to mercury emissions from accidentally breaking one compact fluorescent light bulb.

Table 2-3
FBI 4 Hazardous Air Pollutant Emissions

Hazardous Air Pollutant	Potential Emissions (ton/yr)
NSPS Regulated HAPs	
Lead	2.2×10^{-4}
Cadmium	3.65×10^{-4}
Mercury	3.32×10^{-4}
Hydrochloric acid	0.12
Total Dioxins/Furans, total mass basis	4.31×10^{-9}
All Other HAPs	
Maximum Individual HAP	0.005
Total HAPs	0.14

The technical support document for the facility's current permit indicates that total HAP emissions are 12.3 ton/year with the highest individual HAP at 3.7 ton/year. With FBI 4 emissions estimated at less than 1.0 ton/year, the facility will remain a minor HAP source after the project.

16.2.4 Air Quality

MCES will complete PM_{10} air dispersion modeling, if required, to support the air permit amendment application. The modeling is triggered by the PM_{10} maintenance area requirements. Air dispersion modeling was completed when the existing three FBIs were installed as well.

Ambient monitors are operated by MPCA for PM_{10} and $PM_{2.5}$ both upwind and downwind of the industrial area that includes the facility. The ambient monitoring in the area, in combination with the air dispersion modeling, ensures that particulate concentrations will remain below levels that would endanger public health.

EPA's 40 CFR 503 regulations require sewage sludge incinerators to identify a dispersion coefficient. MCES identified an annual average dispersion coefficient of 7.2 micrograms per cubic meter concentration, based on 1 gram per second emission rate for the existing facility equipment. FBI 4 will be co-located with the existing three FBI stacks at the same stack height and will have similar exhaust temperature and exit velocity. 40 CFR 503 will require the facility to identify a dispersion coefficient for FBI 4 as well.

FBI 4 is expected to meet all National Ambient Air Quality Standards. The National Ambient Air Quality Standards are intended to protect human health and the environment for criteria pollutants.

MCES will also complete an Air Emissions Risk Assessment (AERA) which evaluates air emissions for potential to impact human health. To quantitatively assess the potential for impacts, MCES will use MPCA's Risk Assessment Screening Spreadsheet (RASS) using the air dispersion modeling results and potential emissions for the changes to the facility. MCES will evaluate the increase in throughput for FBRs 1-3 and potential emissions of FBR 4. Estimates of acute hazard, chronic hazard, and chronic excess lifetime cancer risk will be compared to one-tenth of the Minnesota Department of Health (MDH) threshold levels. The AERA will also look at cumulative potential effects in the surrounding area of the facility. The FBRs are expected to pass the screening-level risk assessment and present no adverse impacts to human

16.3 MITIGATION

The proposed air pollution control train for FBI 4 will be, at minimum, the same as the existing scheme of carbon injection, baghouse, wet scrubber and wet electrostatic precipitator. MCES intends to examine alternatives and may propose an alternate scheme with equal or better control efficiency. The air pollution control train for FBI 4 may include ammonia injection for enhanced NOx control. Caustic addition to the scrubber will be included as with the existing FBIs.
All facility ash handling exhaust points are controlled with fabric filters. Fabric filters would continue to be used for any additional ash handling emissions.

16.4 ALTERNATIVES

The alternatives to incineration of sewage sludge involve stabilization and land disposal. Stabilization alternatives include alkaline treatment or anaerobic conversion to biosolids. Land disposal alternatives include tipping at a regulated landfill site or seasonal land application as soil amendment. Decomposition of the carbon in sludge to form CO_2 and other greenhouse gases would occur in any of these processes. Volatile organic emissions may be higher than from incineration since organics in the sludge are not combusted. Biosolids handling can generate particulate matter both at the conversion site and at the application site. Moving the biosolids will require additional energy resources and will generate tailpipe emissions through the use of heavy equipment and truck hauling. Odors are more common with landfilling sludge or biosolids conversion /land application. FBI 4 would have energy recovery and offset some energy use at the facility. Biosolids conversion and landfilling may not provide any energy recovery. However, biosolids would be expected to reduce energy use and emissions from the production of synthetic fertilizers.

2. **Vehicle emissions - Describe the effect of the project's traffic generation on air emissions. Discuss the project's vehicle-related emissions effect on air quality. Identify measures (e.g. traffic operational improvements, diesel idling minimization plan) that will be taken to minimize or mitigate vehicle-related emissions.**

   This minimal increase in truck traffic is not anticipated to significantly impact air quality, including CO levels.

3. **Dust and odors - Describe sources, characteristics, duration, quantities, and intensity of dust and odors generated during project construction and operation. (Fugitive dust may be discussed under item 16a). Discuss the effect of dust and odors in the vicinity of the project including nearby sensitive receptors and quality of life. Identify measures that will be taken to minimize or mitigate the effects of dust and odors.**

   The project will occur within the existing Metro Plant site in an area zoned for industrial use. The area in the vicinity of the Metro Plant is not expected to be adversely affected by noise, dust, or odors during construction or operation. Odor is expected to be reduced as a result of the operation of the facilities constructed under this project.

   Generation of dust can be anticipated during the limited amounts of demolition work that will occur. Nuisance levels of dust generated during demolition activities can be controlled though periodic wetting and/or other measures.

17. Noise

Describe sources, characteristics, duration, quantities, and intensity of noise generated during project construction and operation. Discuss the effect of noise in the vicinity of the project including 1) existing noise levels/sources in the area, 2) nearby sensitive receptors, 3) conformance to state noise standards, and 4) quality of life. Identify measures that will be taken to minimize or mitigate the effects of noise.

Varying degrees of noise can be expected during the construction period. Anticipated noise sources are primarily construction equipment and normal construction activities. Mitigative measures would include standard mufflers on engine driven equipment and possible ear protection as necessary for workers engaged in periodic demolition or other short term noise intensive activities.

18. Transportation

a. Describe traffic-related aspects of project construction and operation. Include: 1) existing and proposed additional parking spaces, 2) estimated total average daily traffic generated, 3) estimated maximum peak hour traffic generated and time of occurrence, 4) indicate source of trip generation rates used in the estimates, and 5) availability of transit and/or other alternative transportation modes.

1. Not applicable.
2. Temporary construction traffic will vary, depending upon construction stage, from an estimated 5 to 10 vehicles per day.
3. The average annual daily traffic volume (AADT) on Childs Road is 2850 vehicles per day (from the MN DOT 2013 Publication Traffic Volumes Metro Street Series). The minimal increase in traffic in this industrial area due to the Solids Project is not anticipated to significantly impact traffic flow or patterns or require any traffic improvements.
4. Trip generation rate estimates are based on experience in previous construction projects.
5. The train yard is within close proximity to the Metro Plant and may be available as an alternative transportation mode for shipping.

b. Discuss the effect on traffic congestion on affected roads and describe any traffic improvements necessary. The analysis must discuss the project's impact on the regional transportation system.
If the peak hour traffic generated exceeds 250 vehicles or the total daily trips exceeds 2,500, a traffic impact study must be prepared as part of the EAW. **Use the format and procedures described in the Minnesota Department of Transportation's Access Management Manual, Chapter 5** ***(available at: http://www.dot.state.mn.us/accessmanagement/resources.html)*** **or a similar local guidance.**

The minimal increase in traffic in this industrial area due to the project is not anticipated to significantly impact traffic flow or patterns or require any traffic improvements.

c. Identify measures that will be taken to minimize or mitigate project related transportation effects.

Not applicable.

19. Cumulative potential effects: (Preparers can leave this item blank if cumulative potential effects are addressed under the applicable EAW Items)

a. Describe the geographic scales and timeframes of the project related environmental effects that could combine with other environmental effects resulting in cumulative potential effects.

b. Describe any reasonably foreseeable future projects (for which a basis of expectation has been laid) that may interact with environmental effects of the proposed project within the geographic scales and timeframes identified above.

c. **Discuss the nature of the cumulative potential effects and summarize any other available information relevant to determining whether there is potential for significant environmental effects due to these cumulative effects.**

20. Other potential environmental effects: If the project may cause any additional environmental effects not addressed by items 1 to 19, describe the effects here, discuss the how the environment will be affected, and identify measures that will be taken to minimize and mitigate these effects.

No effects are anticipated except those addressed in this review. However, in response to growth, regulatory requirements, equipment replacement needs, or rehabilitation, modifications or expansion at the Metro Plant may be proposed in the future.

RGU CERTIFICATION. *(The Environmental Quality Board will only accept* ***SIGNED*** *Environmental Assessment Worksheets for public notice in the EQB Monitor.)*

I hereby certify that:

- The information contained in this document is accurate and complete to the best of my knowledge.
- The EAW describes the complete project; there are no other projects, stages or components other than those described in this document, which are related to the project as connected actions or phased actions, as defined at Minnesota Rules, parts 4410.0200, subparts 9c and 60, respectively.
- Copies of this EAW are being sent to the entire EQB distribution list.

Signature ________________________________ Date _______________________________

Title ________________________________

Appendix A

Figure 1. EAW - County Map and Location of Construction
Figure 2. EAW - USGS Map and Location of Construction Boundaries
Figure 3. EAW - Aerial View and Location of Construction
Figure 4. EAW - Metro WWTP Solids Management Building, Plan – 4^{th} Fluid Bed Incinerator
Figure 5. EAW - Parcels and Land Ownership Around Metro WWTP
Table 1.   Details of Parcel Information shown on Figure 5
Figure 6. EAW - Ecologically Significant Areas Around Metro WWTP
Figure 7. EAW - Land Use Around Metro WWTP (From MCES - Regional Planned Use Data Set, 2014)
Figure 8. EAW - Flood Insurance Rate Map
Figure 9. EAW – County Well Index, http://mdh-agua.health.state.mn.us/cwi/cwiViewer.htm
Well Log 506894
Well Log 506893
Well Log 501658
Well Log 501657
Well Log 603089
Well Log 226583
Well Log 200052
Well Log 226584
Well Log 151554
Well Log 501659
Figure 10. EAW – Metro Plant Water Table Contour Map, 1994
Boring Log B-201
Boring Log MW-211A

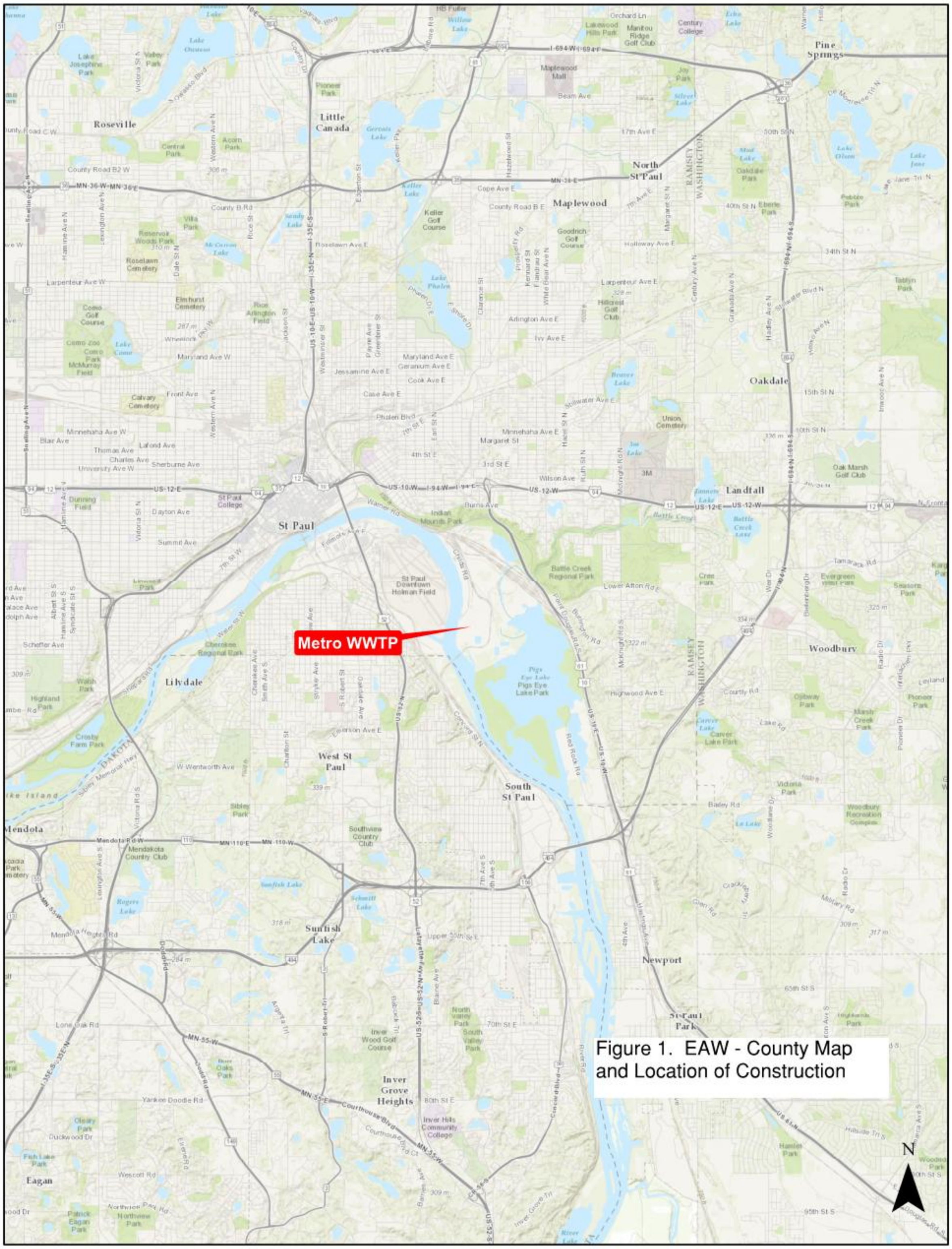


Figure 1. EAW - County Map and Location of Construction

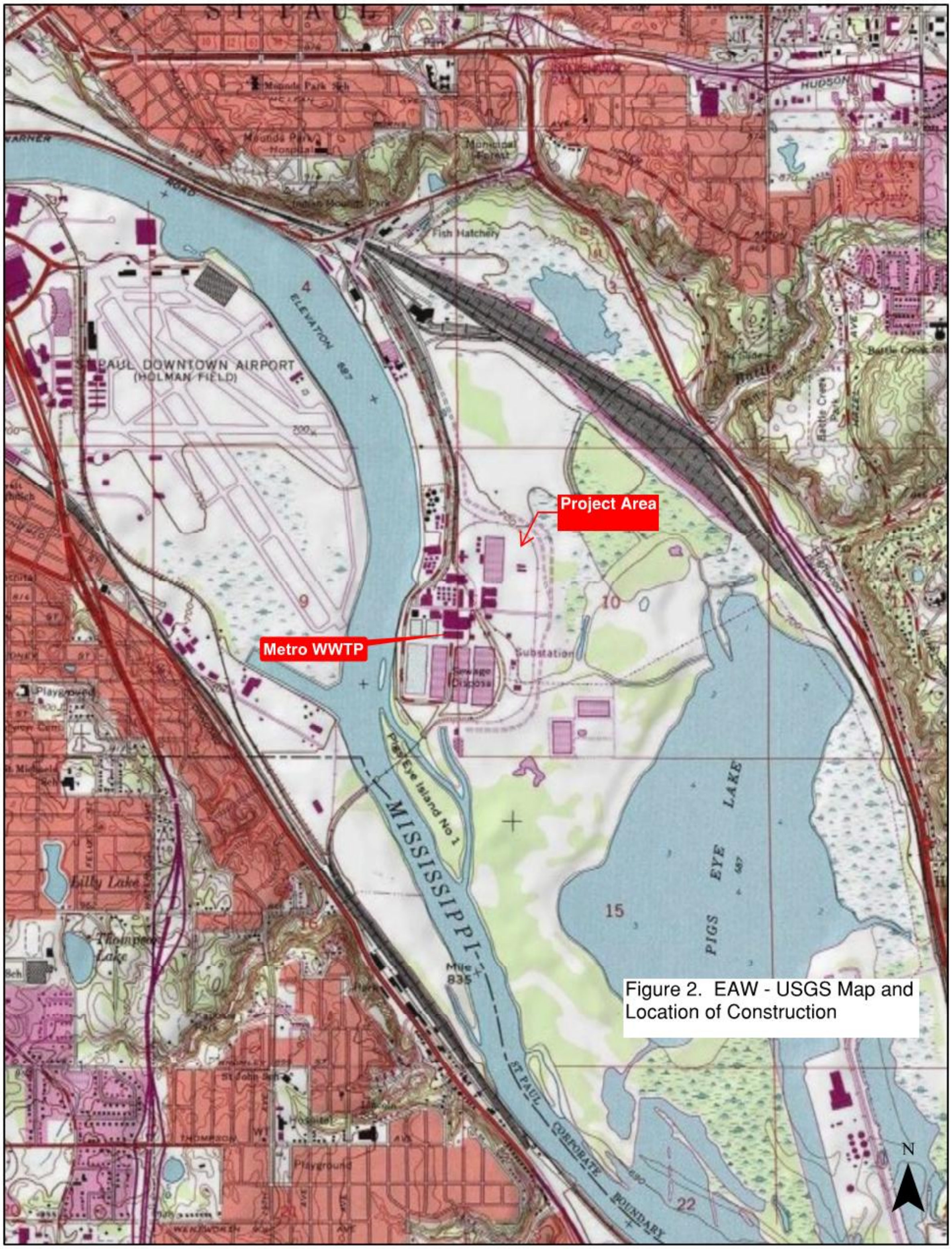


Figure 2. EAW - USGS Map and Location of Construction

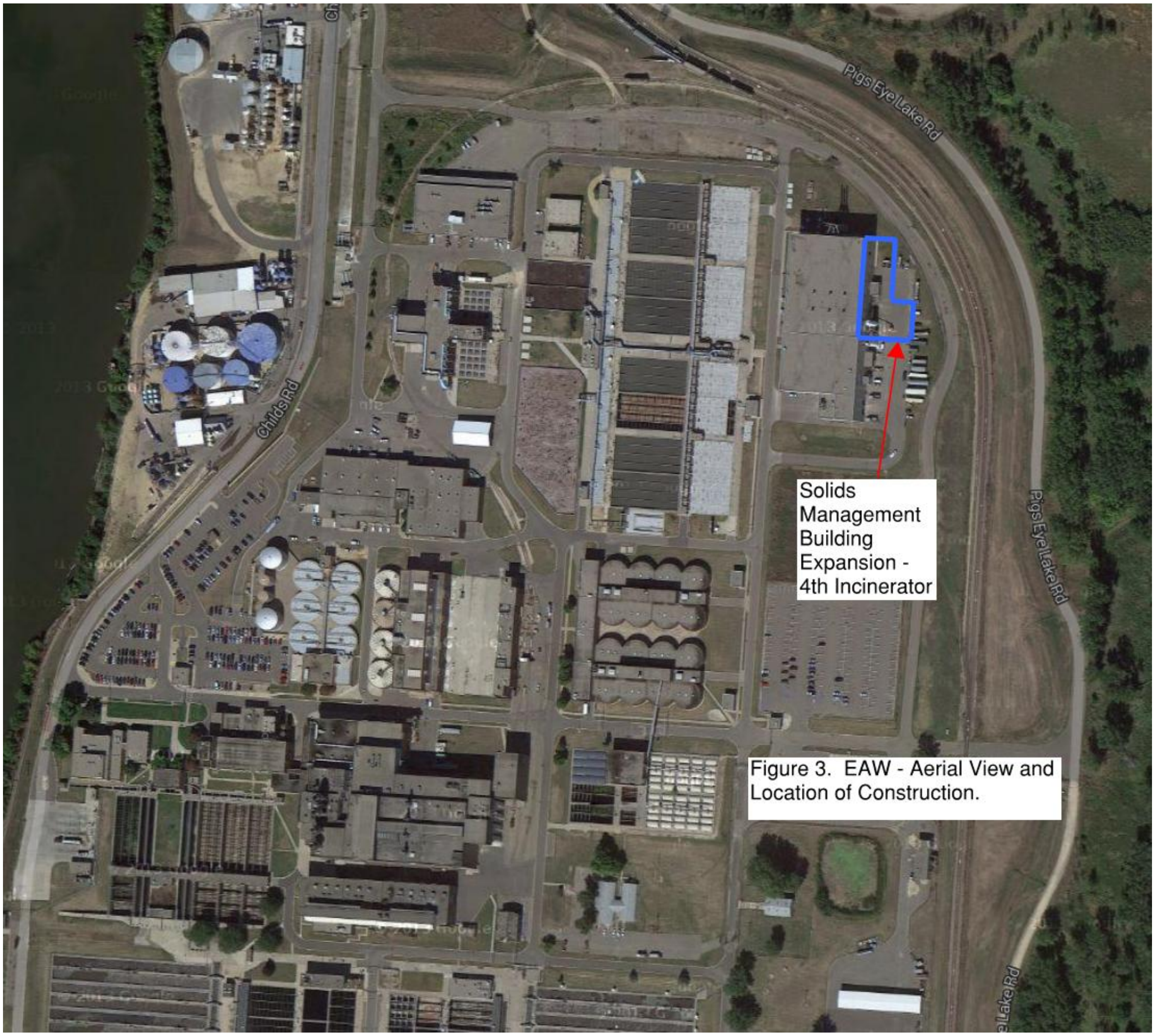


Figure 3. EAW - Aerial View and Location of Construction.

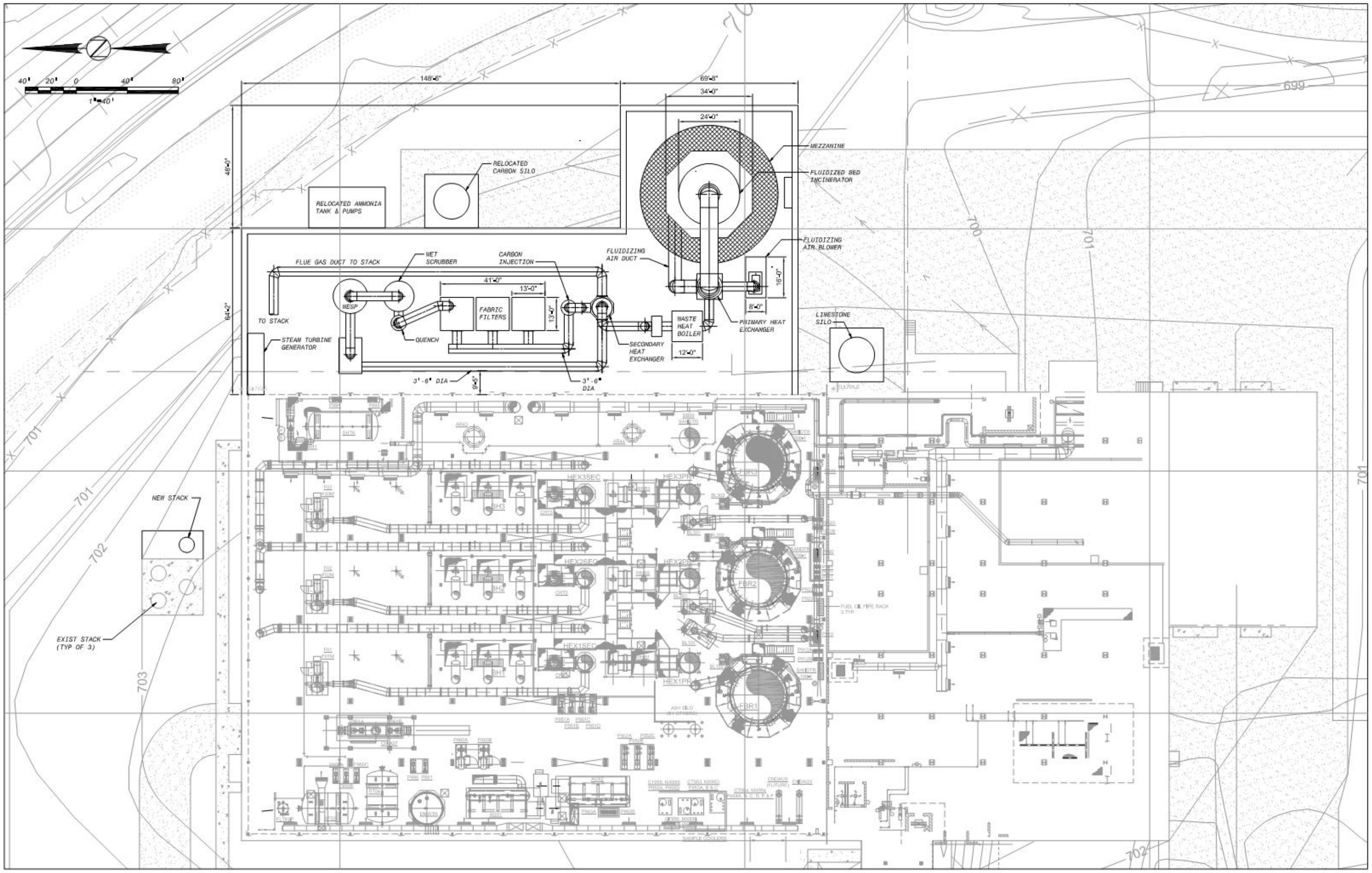


Figure 4.

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MINNEAPOLIS, MINNESOTA

MCES SOLIDS PROCESSING IMPROVEMENTS
METRO WWTP - SOLIDS MANAGEMENT BUILDING
PLAN - 4TH FLUID BED INCINERATOR

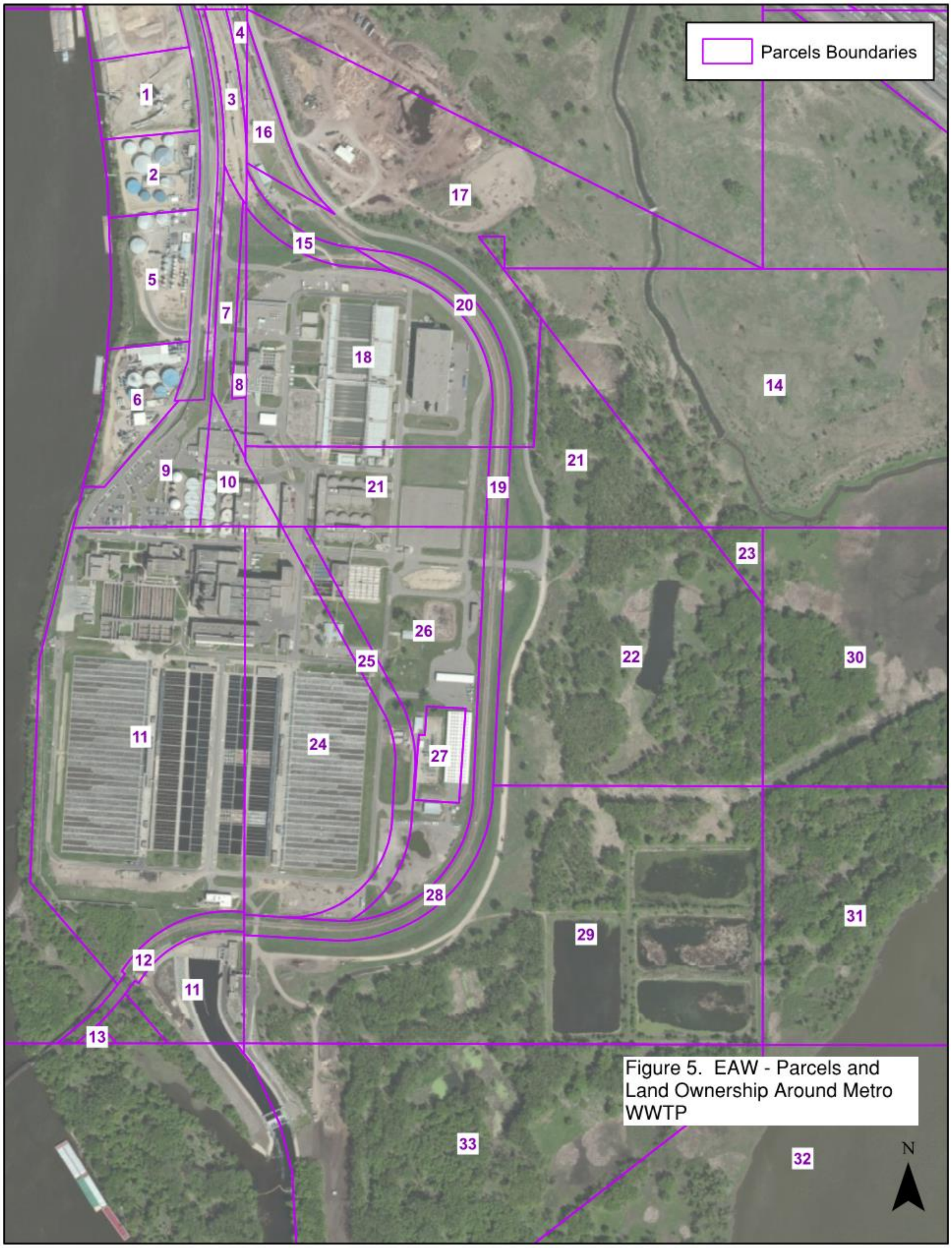

Figure 5. EAW - Parcels and Land Ownership Around Metro WWTP

Metro WWTP EAW Info

SW 1/4 of NW 1/4, Section 10, Township 28N, Range 22W

Longitude = -93.0419
Latitude = 44.9287
(East of Incinerator building)

Watershed	NHD Hydrologic Unit #	NHD Hydrologic Unit Name
HU_8 -	7010206	Twin Cities
HU_10 -	701020608	City of Saint Paul-Mississippi River
HU_12 -	70102060805	Harriet Island-Mississippi River

Parcel Info

Map Number	PIN (Tax #)	BLDG_NUM	STREETNAME	STREETTYPE	CITY	ZIP	OWNER_NAME	OWNER_MORE	OWN_ADD_L1	OWN_ADD_L2
1	123-092822110001	2145	CHILDS	RD	Saint Paul	55106	Port Authority Of St Paul	Port Authority Of St Paul	380 St Peter St Ste 850	Saint Paul MN 55102-1313
2	123-092822110002	2175	CHILDS	RD	Saint Paul	55106	Port Authority Of St Paul	Port Authority Of St Paul	380 St Peter St Ste 850	Saint Paul MN 55102-1313
3	123-092822110003	0	CHILDS	RD	Saint Paul	55119	Northwest Chemco Inc	Northwest Chemco Inc	1400 Douglas Stop 1640	Omaha NE 68179-0002
4	123-092822110004	0	CHILDS	RD	Saint Paul	55119	Chicago Nw Trans Co	Chicago Nw Trans Co	1400 Douglas Stop 1640	Omaha NE 68179-0002
5	123-092822140001	2209	CHILDS	RD	Saint Paul	55106	Port Authority Of St Paul	Port Authority Of St Paul	380 St Peter St Ste 850	Saint Paul MN 55102-1313
6	123-092822140002	2229	CHILDS	RD	Saint Paul	55106	Port Authority Of St Paul	Port Authority Of St Paul	380 St Peter St Ste 850	Saint Paul MN 55102-1313
7	123-092822140003	0	CHILDS	RD	Saint Paul	55119	Metro Waste Control Comm	Metro Waste Control Comm	390 Robert St N	Saint Paul MN 55101-1805
8	123-092822140004	0	CHILDS	RD	Saint Paul	55119	Metro Waste Control Comm	Metro Waste Control Comm	390 Robert St N	Saint Paul MN 55101-1805
9	123-092822140005	0	CHILDS	RD	Saint Paul	55119	Metro Sewer Serv Board Comm	Metro Sewer Serv Board Comm	390 Robert St N	Saint Paul MN 55101-1805
10	123-092822140007	0	UNASSIGNED		Saint Paul	55119	Nsp And Metro Waste Control	Nsp And Metro Waste Control	390 Robert St N	Saint Paul MN 55101-1805
11	123-092822410001	2400	CHILDS	RD	Saint Paul	55106	Metropolitan Waste Control	Metropolitan Waste Control	390 Robert St N	St Paul MN 55101-1805
12	123-092822440001	0	PIGSEYE LAKE	RD	Saint Paul	55119	Chicago Nwn Rr Co	Chicago Nwn Rr Co	1400 Douglas Stop 1640	Omaha NE 68179-0002
13	123-092822440002	0	PIGSEYE LAKE	RD	Saint Paul	55119	Great Northern Ry Co	Great Northern Ry Co	4105 Lexington Ave N Ste 20	Arden Hills MN 55126-6109
14	123-102822130006	0	PIGSEYE LAKE	RD	Saint Paul	55119	City Of St Paul	City Of St Paul	25 4th St W Rm 1000	St Paul MN 55102-1692
15	123-102822220007	0	UNASSIGNED		Saint Paul	55119	Metropolitan Council	Metropolitan Council	1400 Douglas Stop 1640	Omaha NE 68179-0002
16	123-102822220010	0	PIGS EYE LAKE	RD	Saint Paul	55119	City Of St Paul	City Of St Paul	25 4th St W Rm 1000	St Paul MN 55102-1692
17	123-102822220011	0	PIGSEYE LAKE	RD	Saint Paul	55119	City Of St Paul	City Of St Paul	25 4th St W Rm 1000	St Paul MN 55102-1692
18	123-102822230001	0	UNASSIGNED		Saint Paul	55119	Metro Waste Control Comm	Metro Waste Control Comm	390 Robert St N	Saint Paul MN 55101-1805
19	123-102822230002	0	PIGSEYE LAKE	RD	Saint Paul	55119	Northwest Chemco Inc	Northwest Chemco Inc	1400 Douglas Stop 1640	Omaha NE 68179-0002
20	123-102822230004	0	UNASSIGNED		Saint Paul	55119	Northwest Chemco Inc	Northwest Chemco Inc	1400 Douglas Stop 1640	Omaha NE 68179-0002
21	123-102822240006	0	PIGSEYE LAKE	RD	Saint Paul	55119	Metro Waste Control Comm	Metro Waste Control Comm	390 Robert St N	St Paul MN 55101-1805
22	123-102822310002	0	UNASSIGNED		Saint Paul	55119	Metropolitan Waste Control	Metropolitan Waste Control	390 Robert St N	St Paul MN 55101-1805
23	123-102822310003	0	UNASSIGNED		Saint Paul	55119	City Of St Paul Parks And Recreation	City Of St Paul Parks And Recreation	25 4th St W Suite 1000	St Paul MN 55102-1692
24	123-102822320001	0	UNASSIGNED		Saint Paul	55119	Metro Waste Control Comm	Metro Waste Control Comm	390 Robert St N	Saint Paul MN 55101-1805
25	123-102822320002	0	PIGSEYE LAKE	RD	Saint Paul	55119	Metro Waste Control Commissio	Metro Waste Control Commissio	390 Robert St N	St Paul MN 55101-1805
26	123-102822320003	0	PIGSEYE LAKE	RD	Saint Paul	55119	Metro Waste Control Commissio	Metro Waste Control Commissio	390 Robert St N	St Paul MN 55101-1805
27	123-102822320004	2898	CHILDS	RD	Saint Paul	55119	Northern States Power Co	Northern States Power Co	414 Nicollet Ave	Mpls MN 55401-1927
28	123-102822330001	0	UNASSIGNED		Saint Paul	55119	Chicago And Northwestern Ry	Chicago And Northwestern Ry	1400 Douglas Stop 1640	Omaha NE 68179-0002
29	123-102822340001	0	UNASSIGNED		Saint Paul	55119	Metropolitan Waste Control	Metropolitan Waste Control	390 Robert St N	St Paul MN 55101-1805
30	123-102822410001	0	PIGSEYE LAKE	RD	Saint Paul	55119	Ramsey County Parks And Rec	Ramsey County Parks And Rec	2015 Van Dyke St N	Maplewood MN 55109-3711
31	123-102822430002	0	PIGSEYE LAKE	RD	Saint Paul	55119	Ramsey County Parks And Rec	Ramsey County Parks And Rec	2015 Van Dyke St N	Maplewood MN 55109-3711
32	123-152822130001	0	UNASSIGNED		Saint Paul	55119	Ramsey County Parks And Rec	Ramsey County Parks And Rec	2015 Van Dyke St N	Maplewood MN 55109-3711
33	123-152822220003	0	UNASSIGNED		Saint Paul	55119	Metropolitan Waste Control	Metropolitan Waste Control	390 Robert St N	St Paul MN 55101-1805

Table 1. Details of Parcel Information shown on Figure 5.

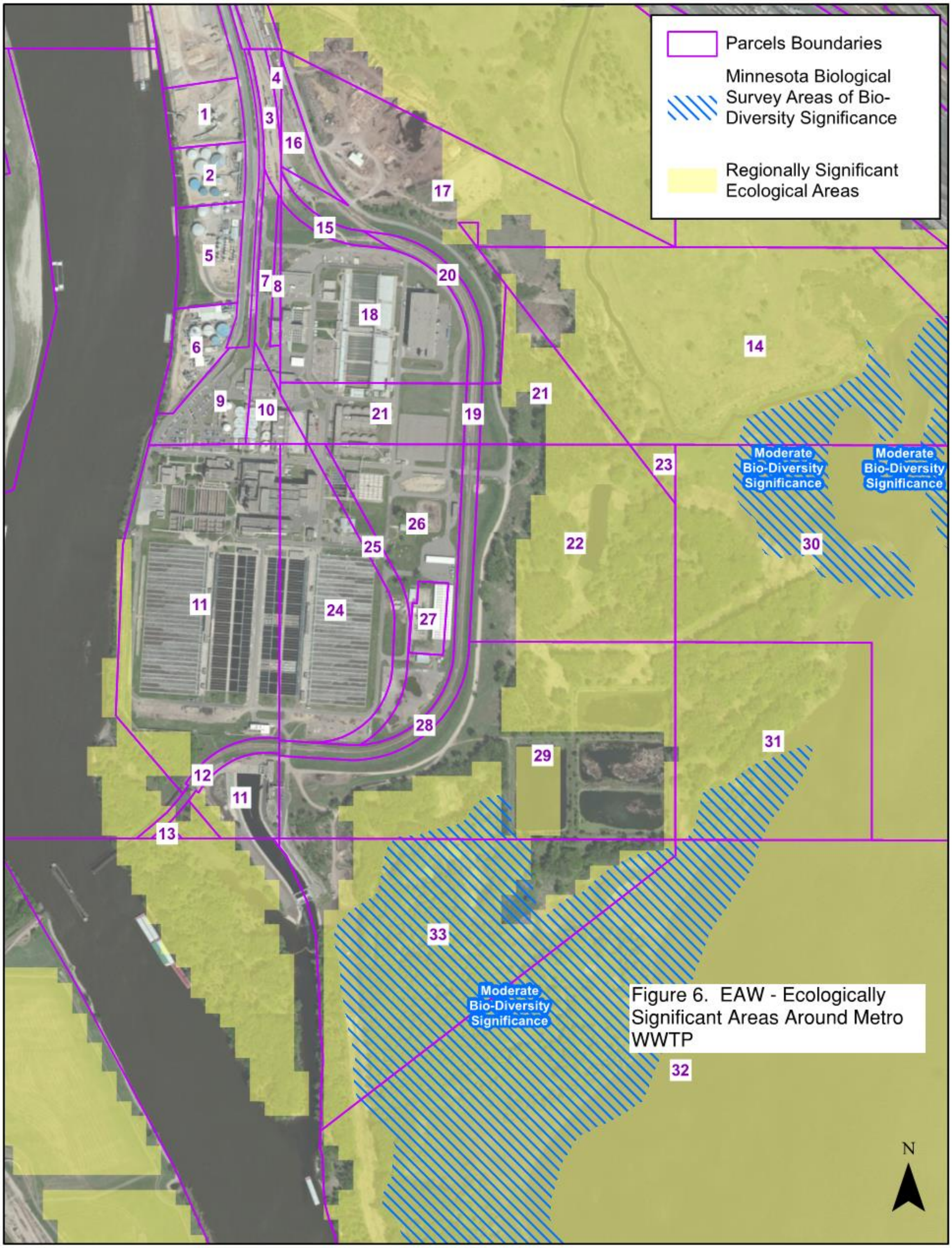

Figure 6. EAW - Ecologically Significant Areas Around Metro WWTP

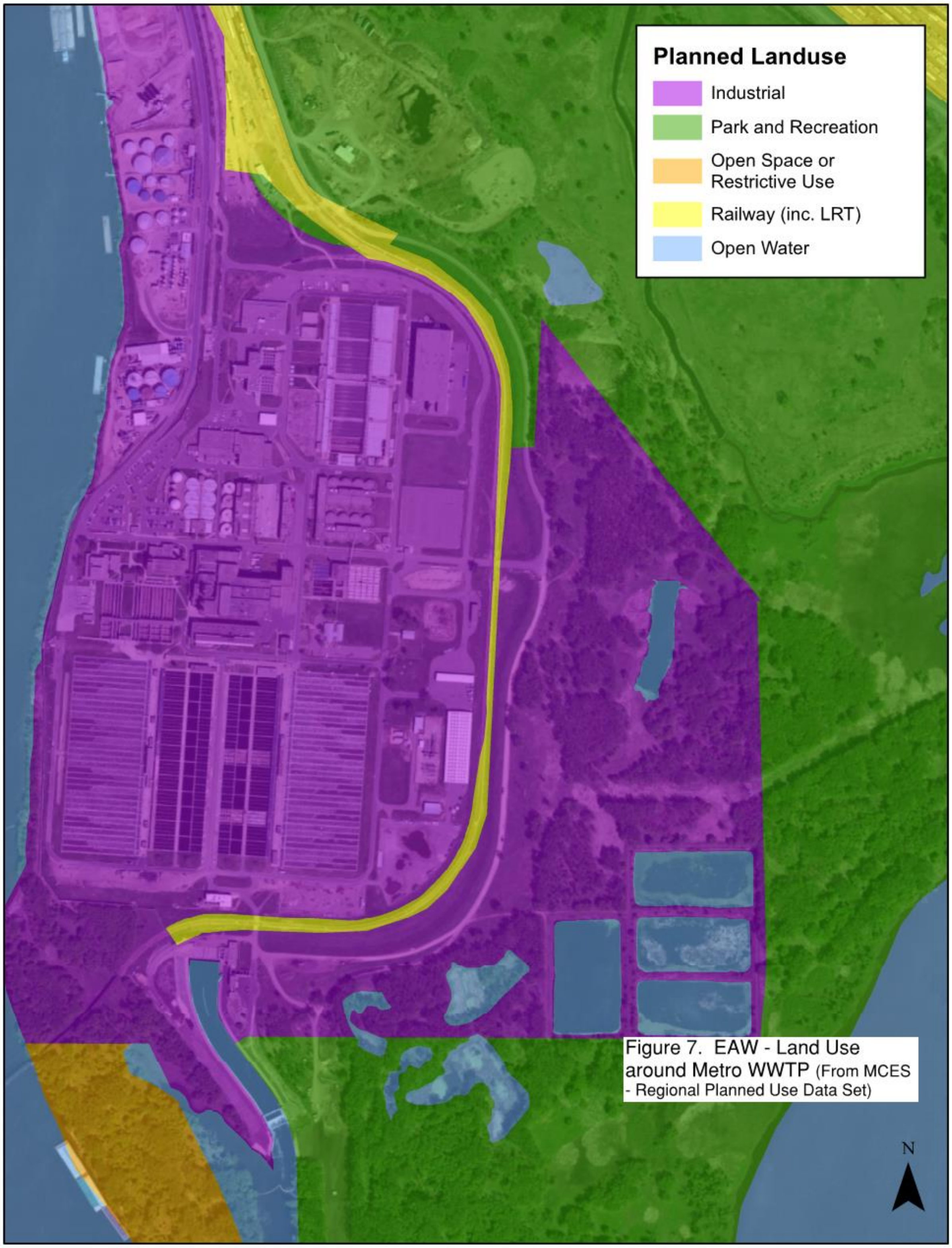

Figure 7. EAW - Land Use around Metro WWTP (From MCES - Regional Planned Use Data Set)

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) Report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS Report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures**. Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study Report for information on flood control structures for this jurisdiction.

Provisionally Accredited Levee Notes to Users: Check with your local community to obtain more information, such as the estimated level of protection provided (which may exceed the 1-percent-annual-chance level) and Emergency Action Plan, on the levee system(s) shown as providing protection for areas on this panel. To maintain accreditation, the levee owner or community is required to submit the data and documentation necessary to comply with Section 65.10 of the NFIP regulations by May 15, 2010. If the community or owner does not provide the necessary data and documentation or if the data and documentation provided indicate the levee system does not comply with Section 65.10 requirements, FEMA will revise the flood hazard information for this area to reflect de-accreditation of the levee system. To mitigate flood risk in residual risk areas, property owners and residents are encouraged to consider flood insurance and floodproofing or other protective measures. For more information on flood insurance, interested parties should visit the FEMA Website at http://www.fema.gov/business/nfip/index.shtm.

Coastal Base Flood Elevations shown on this map apply only landward of 0.0' North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study Report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study Report for this jurisdiction.

The **projection** used in the preparation of this map was Universal Transverse Mercator (UTM) zone 15. The **horizontal datum** was NAD 27, GRS 1980 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in mapfeatures across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum**. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-3242

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713- 3242**, or visit its website at http://www.ngs.noaa.gov.

Base Map information shown on this FIRM was provided for Ramsey County by Farm Services Administration, dated 2004 and captured at a resolution of one meter.

The **profile baselines** depicted on this map represent the hydraulic modeling baselines that match the flood profiles in the FIS report. As a result of improved topographic data, the **profile baseline**, in some cases, may deviate significantly from the channel centerline or appear outside the SFHA.

Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

Contact the **FEMA Map Service Center** at 1-800-358-9616 for information on available products associated with this FIRM. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. The FEMA Map Service Center may also be reached by Fax at 1-800-358-9620 and its website at http://msc.fema.gov.

If you have **questions about this map** or questions concerning the National Flood Insurance Program in general, please call **1- 877- FEMA MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov/business/nfip/.

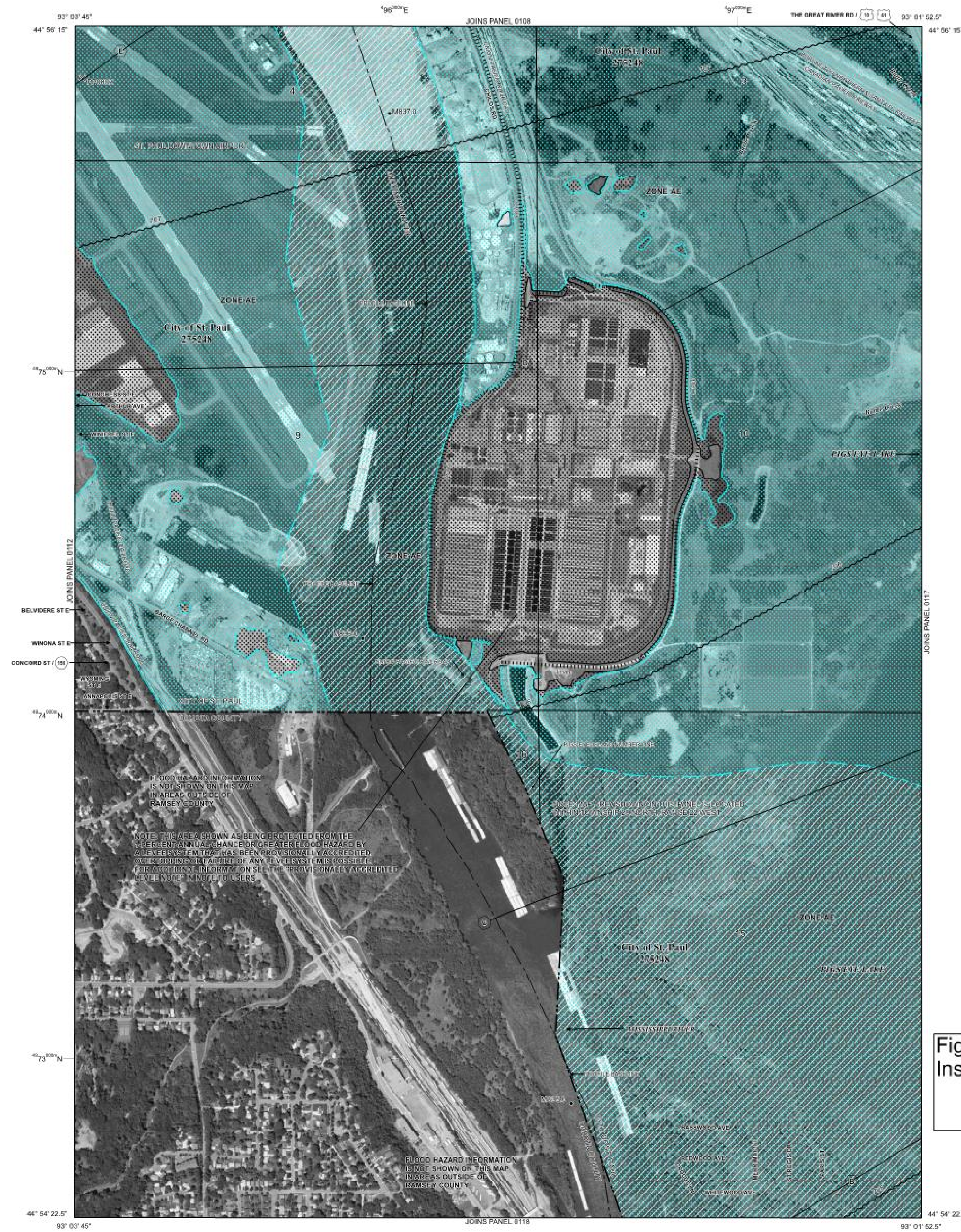

Figure 8. EAW - Flood Insurance Rate Map

LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Areas formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

1% Annual Chance Floodplain Boundary

0.2% Annual Chance Floodplain Boundary

Floodway boundary

Zone D boundary

CBRS and OPA boundary

Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.

513	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

*Referenced to the North American Vertical Datum of 1988

A —— A	Cross section line
23 - - - - - 23	Transect line
45° 02' 08", 93° 02' 12"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83) Western Hemisphere
4989000 N	1000-meter Universal Transverse Mercator grid values, zone 15N
DX5510 ×	Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5	River Mile

MAP REPOSITORIES
Refer to Map Repositories list on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
June 4, 2010

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 500'

250 0 500 1000 FEET
150 0 150 300 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0116G

FIRM
FLOOD INSURANCE RATE MAP

RAMSEY COUNTY, MINNESOTA
(ALL JURISDICTIONS)

PANEL 116 OF 140
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
ST. PAUL, CITY OF	275248	0116	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
27123C0116G

EFFECTIVE DATE
June 4, 2010

Federal Emergency Management Agency

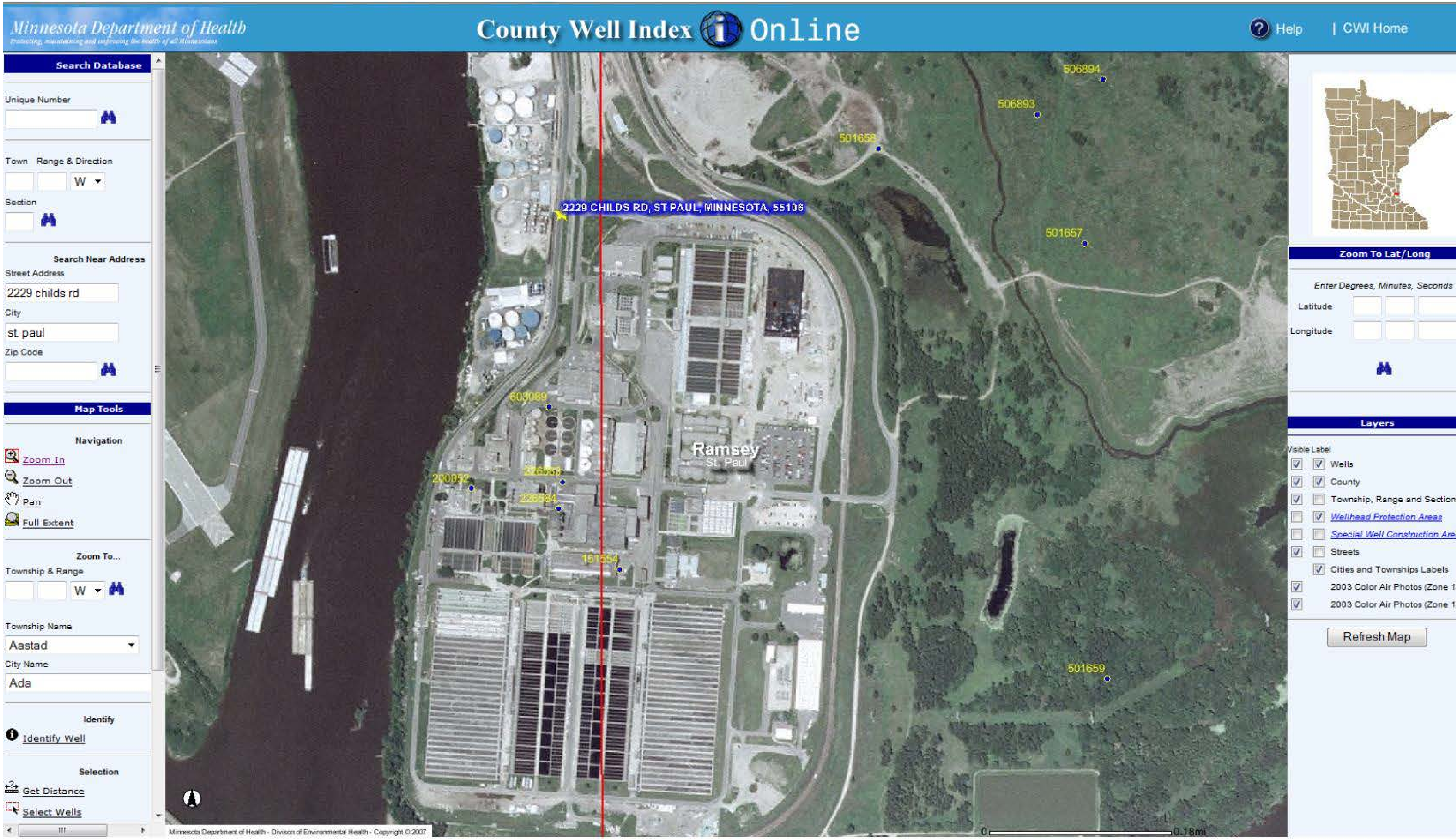

Figure 9. County Welll Index

Minnesota Unique Well No.

506894

County	Ramsey
Quad	St Paul East
Quad ID	103A

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 103I

Entry Date	05/20/1991
Update Date	02/14/2014
Received Date	

Well Name MWCC ASH PONDS MAD 6.

Township Range Dir Section Subsections Elevation 701 **ft.**

28 22 W 10 BAADDD **Elevation Method** 7.5 minute topographic map (+/- 5 feet)

Well Depth	Depth Completed	Date Well Completed
17 ft.	17 ft.	11/02/1989

Drilling Method Power Auger

Well Address

ST PAUL MN

Drilling Fluid --

Well Hydrofractured? Yes No From Ft. to Ft.

Use Abandoned **Status** Sealed

Geological Material	Color	Hardness	From	To
FILL SAND, CLAY, PLASTIC, TIRES			0	14
LEAN CLAY	DK. GRY	MEDIUM	14	17

Casing Type Plastic **Joint** No Information **Drive Shoe?** Yes ☑ No **Above/Below** 2.5 **ft.**

Casing Diameter	Weight	Hole Diameter
2 in. to 12 ft.	lbs./ft.	7 in. to 17 ft.

Open Hole from ft. to ft.

Screen YES **Make** TIMCO **Type** plastic

Diameter	Slot/Gauze	Length	Set Between
2	10	5	12 ft. and 17 ft.

Static Water Level
8 ft. from Land surface Date Measured 11/02/1989

PUMPING LEVEL (below land surface)
ft. after hrs. pumping g.p.m.

Well Head Completion
Pitless adapter manufacturer Model
☑ Casing Protection Y ☑ 12 in. above grade
☐ At-grade (Environmental Wells and Borings ONLY)

REMARKS
4220 89-2276. WELL MAD 6.
WELL SEALED 11-04-2004 BY 62012
ORIGINAL USE MW - MONITOR WELL

Grouting Information Well Grouted? ☑ Yes ☐ No ☐ Not Specified

Grout Material: Neat Cement from 0 to 9 ft. 0

Located by: Minnesota Geological Survey **Method:** Digitized - scale 1:24,000 or larger (Digitizing Table)

Unique Number Verification: Information from owner **Input Date:** 01/01/1990

System: *UTM - Nad83, Zone15, Meters* **X:** 497220 **Y:** 4975427

Nearest Known Source of Contamination
_feet _direction _type

Well disinfected upon completion? ☐ Yes ☐ No

Pump ☐ Not Installed Date Installed
Manufacturer's name Model number __ HP 0 Volts
Length of drop Pipe _ft. Capacity _g.p.m Type Material

Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☐ No

Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No

Well Contractor Certification

Gislason, John	M0070	SPERMBAUR, D.
License Business Name	Lic. Or Reg. No.	Name of Driller

First Bedrock **Aquifer** Quat. Water Table Aquifer

Last Strat clay-gray **Depth to Bedrock ft.**

County Well Index Online Report

506894

Printed 10/2/2014
HE-01205-07

Unique Well No.

393

County Ramsey
Quad St Paul East
Quad ID 103A

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 103I

Entry Date 05/20/1991
Update Date 02/14/2014
Received Date

C ASH PONDS MAD 7.

Range	Dir	Section	Subsections	Elevation	703 ft.
22	W	10	BADBAD	Elevation Method	7.5 minute topographic map (+/- 5 feet)

Well Depth	Depth Completed	Date Well Completed
15 ft.	15 ft.	11/02/1989

Drilling Method Power Auger

erial	Color	Hardness	From	To
ND, WOOD, TIRES			0	12
	DK. GRY	MEDIUM	12	15

Drilling Fluid
--

Well Hydrofractured? ☐ Yes ☐ No
From Ft. to Ft.

Use Monitor well

Casing Type Plastic Joint No Information Drive Shoe? ☐ Yes ☑ No Above/Below 2.5 ft.

Casing Diameter	Weight	Hole Diameter
2 in. to 10 ft.	lbs./ft.	7 in. to 15 ft.

Open Hole from ft. to ft.

Screen YES Make TIMCO Type plastic

Diameter	Slot/Gauze	Length	Set Between
2	10	5	10 ft. and 15 ft.

Static Water Level
11 ft. from Land surface Date Measured 11/02/1989

PUMPING LEVEL (below land surface)
ft. after hrs. pumping g.p.m.

Well Head Completion
Pitless adapter manufacturer Model
☑ Casing Protection Y ☑ 12 in. above grade
☐ At-grade (Environmental Wells and Borings ONLY)

0 6.

Grouting Information Well Grouted? ☑ Yes ☐ No ☐ Not Specified

Grout Material: Neat Cement from 0 to 7 ft. 0

esota Geological Survey
rification: Information from owner
d83, Zone15, Meters

Method: Digitized - scale 1:24,000 or larger (Digitizing Table)
Input Date: 01/01/1990
X: 497115 Y: 4975370

Nearest Known Source of Contamination
_feet _direction _type
Well disinfected upon completion? ☐ Yes ☐ No

Pump ☐ Not Installed Date Installed
Manufacturer's name Model number__ HP 0 Volts
Length of drop Pipe _ft. Capacity _g.p.m Type Material

Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☐ No

Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No

Well Contractor Certification

Gislason, John	M0070	SPERMBAUR, D.
License Business Name	Lic. Or Reg. No.	Name of Driller

ay

Aquifer Quat. Water Table Aquifer
Depth to Bedrock ft.

Well Index Online Report

506893

Printed 10/2/20
HE-01205-

Minnesota Unique Well No.

501658

County: Ramsey
Quad: St Paul East
Quad ID: 103A

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 103I

Entry Date: 05/20/1991
Update Date: 06/02/2014
Received Date:

Well Name PIGSEYE LANDFILL MW-2

Township	Range	Dir	Section	Subsections	Elevation	700 ft.
28	22	W	10	BACCBD	Elevation Method	7.5 minute topographic map (+/- 5 feet)

Well Depth	Depth Completed	Date Well Completed
23 ft.	23 ft.	12/19/1988

Drilling Method Power Auger

Well Address
WARNER/CHILDS RD
ST PAUL MN

Drilling Fluid
--

Well Hydrofractured? ☐ Yes ☐ No
From Ft. to Ft.

Use Abandoned **Status** Sealed

Casing Type Stainless Steel **Joint** No Information **Drive Shoe?** ☐ Yes ☑ No **Above/Below** 3.6 ft.

Geological Material	Color	Hardness	From	To
NOT SAMPLED			0	15
TRASH IN SANDY & CLAYEY MATRIX			15	19
SWAMP DEPOSITS OR FILL			19	23

Casing Diameter	Weight	Hole Diameter
2 in. to 17 ft.	lbs./ft.	7 in. to 23 ft.

Open Hole from ft. to ft.

Screen YES **Make** JOHNSON **Type** stainless steel

Diameter	Slot/Gauze	Length	Set Between
2	10	5	17 ft. and 22 ft.

Static Water Level
16 ft. from Land surface Date Measured 12/19/1989

PUMPING LEVEL (below land surface)
ft. after hrs. pumping g.p.m.

Well Head Completion
Pitless adapter manufacturer Model
☑ Casing Protection Y ☑ 12 in. above grade
☐ At-grade (Environmental Wells and Borings ONLY)

REMARKS
WELL SEALED 11-04-2004 BY 62012
ORIGINAL USE MW - MONITOR WELL

Grouting Information Well Grouted? ☑ Yes ☐ No ☐ Not Specified

Grout Material: Other	from 0 to 2 ft.	0
Grout Material: Neat Cement	from 2 to 15 ft.	0

Located by: Minnesota Geological Survey
Method: Digitized - scale 1:24,000 or larger (Digitizing Table)
Unique Number Verification: Other, note in remarks
Input Date: 01/01/1990
System: *UTM - Nad83, Zone15, Meters*
X: 496861 Y: 4975315

Nearest Known Source of Contamination
_feet _direction _type
Well disinfected upon completion? ☐ Yes ☐ No

Pump ☐ Not Installed Date Installed
Manufacturer's name Model number__ HP 0 Volts
Length of drop Pipe _ft Capacity _g.p.m Type Material

Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☐ No

Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No

First Bedrock
Aquifer Quat. Water Table Aquifer
Last Strat Recent deposit
Depth to Bedrock ft.

Well Contractor Certification

Braun Eng Testing	M0016	DOLAN, V.
License Business Name	Lic. Or Reg. No.	Name of Driller

County Well Index Online Report

501658

Printed 10/2/2014
HE-01205-07

Minnesota Unique Well No.

501657

County Ramsey
Quad St Paul East
Quad ID 103A

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 103I

Entry Date 05/20/1991
Update Date 02/14/2014
Received Date

Well Name PIGSEYE LANDFILL MW-1

Township Range Dir Section Subsections Elevation 695 ft.

28 22 W 10 BDAAAC **Elevation Method** 7.5 minute topographic map (+/- 5 feet)

Well Depth 30 ft. **Depth Completed** 22 ft. **Date Well Completed** 12/14/1988

Drilling Method Power Auger

Well Address

ST PAUL MN

Drilling Fluid --

Well Hydrofractured? Yes No From Ft. to Ft.

Use Abandoned **Status** Sealed

Geological Material	Color	Hardness	From	To
NOT SAMPLED			0	10
TRASH PAPER, WOOD, PLASTIC			10	20
FILL SILT			20	22
SWAMP DEPOSITS OR FILL	DK. BRN		22	30

Casing Type Stainless Steel **Joint** No Information **Drive Shoe?** Yes ☑ No **Above/Below** 3.8 ft.

Casing Diameter 2 in. to 17 ft. **Weight** lbs./ft. **Hole Diameter** 7 in. to 22 ft.

Open Hole from ft. to ft.

Screen YES **Make** JOHNSON **Type** stainless steel

Diameter	Slot/Gauze	Length	Set Between
2	10	5	17 ft. and 22 ft.

Static Water Level
14 ft. from Land surface Date Measured 12/14/1988

PUMPING LEVEL (below land surface)
ft. after hrs. pumping g.p.m.

Well Head Completion
Pitless adapter manufacturer Model
☑ Casing Protection Y ☑ 12 in. above grade
At-grade (Environmental Wells and Borings ONLY)

REMARKS
WELL SEALED 11-04-2004 BY 62012
ORIGINAL USE MW - MONITOR WELL

Grouting Information Well Grouted? ☑ Yes No Not Specified

Grout Material: Other from 0 to 2 ft. 0
Grout Material: Neat Cement from 2 to 15 ft. 0

Located by: Minnesota Geological Survey **Method:** Digitized - scale 1:24,000 or larger (Digitizing Table)

Unique Number Verification: Other, note in remarks **Input Date:** 01/01/1990

System: *UTM - Nad83, Zone15, Meters* **X:** 497191 **Y:** 4975162

Nearest Known Source of Contamination
_feet _direction _type

Well disinfected upon completion? Yes No

Pump Not Installed Date Installed
Manufacturer's name Model number __ HP 0 Volts
Length of drop Pipe _ft. Capacity _g.p.m Type Material

Abandoned Wells Does property have any not in use and not sealed well(s)? Yes No

Variance Was a variance granted from the MDH for this well? Yes No

Well Contractor Certification
Braun Eng Testing — License Business Name
M0016 — Lic. Or Reg. No.
DOLAN, V. — Name of Driller

First Bedrock **Aquifer** Quat. Water Table Aquifer
Last Strat Recent deposit-brown **Depth to Bedrock** ft.

County Well Index Online Report **501657** Printed 10/2/2014 HE-01205-07

Minnesota Unique Well No.

603089

County Ramsey
Quad St Paul East
Quad ID 103A

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 103I

Entry Date 11/22/2002
Update Date 03/10/2014
Received Date 10/11/2002

Well Name METROPOLITAN COUNCIL ENV

Township	Range	Dir	Section	Subsections	Elevation	708 ft.
28	22	W	9	DAA	Elevation Method	Calc from DEM (USGS 7.5 min or equiv.)

Well Address
2450 CHILDS RD
MN

Geological Material	Color	Hardness	From	To
TOP SOIL	BLACK	SOFT	0	3
SAND/GRAVEL	BROWN	SOFT	3	13
CLAY & SAND	GRAY	SOFT	13	35
ROCKS/GRAVEL	BROWN	SOFT	35	41
SANDSTONE	BROWN	MEDIUM	41	44
LIMESTONE	GRAY	HARD	44	110

Well Depth	Depth Completed	Date Well Completed
110 ft.	110 ft.	09/17/2002

Drilling Method Cable Tool

Drilling Fluid Water

Well Hydrofractured? ☐ Yes ☑ No
From Ft. to Ft.

Use Dewatering well

Casing Type Steel (black or low carbon) **Joint** Unknown **Drive Shoe?** ☑ Yes ☐ No **Above/Below** ft.

Casing Diameter	Weight	Hole Diameter
20 in. to 45 ft.	78.6 lbs./ft.	20 in. to 54 ft.
14 in. to 54 ft.	54.57 lbs./ft.	14 in. to 110 ft.

Open Hole from 54 ft. to 110 ft.

Screen NO **Make** **Type**

Diameter	Slot/Gauze	Length	Set Between

Static Water Level
21 ft. from Land surface Date Measured 10/25/2002

PUMPING LEVEL (below land surface)
51 ft. after 10 hrs. pumping 720 g.p.m.

Well Head Completion
Pitless adapter manufacturer Model PS14
☐ Casing Protection ☐ 12 in. above grade
☐ At-grade (Environmental Wells and Borings ONLY)

Grouting Information Well Grouted? ☑ Yes ☐ No ☐ Not Specified

Grout Material: Neat Cement from 0 to 54 ft. 52 bags

REMARKS
ARW-1

Located by: Minnesota Department of Health **Method:** GPS SA Off (averaged)
Unique Number Verification: Info/GPS from data source **Input Date:** 10/22/2001
System: *UTM - Nad83, Zone15, Meters* X: 496334 Y: 4974899

Nearest Known Source of Contamination
50 feet S direction Tanks type
Well disinfected upon completion? ☐ Yes ☐ No

Pump ☐ Not Installed Date Installed 09/19/2002
Manufacturer's name GOULD Model number 12 DHLC HP 75 Volts 460
Length of drop Pipe 70 ft. Capacity 1700 g.p.m Type Submersible Material

Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☑ No

Variance Was a variance granted from the MDH for this well? ☐ Yes ☑ No

Well Contractor Certification

Keys Well Co.	62012	GALVIN, M
License Business Name	Lic. Or Reg. No.	Name of Driller

First Bedrock **Aquifer**
Last Strat **Depth to Bedrock** ft.

County Well Index Online Report

603089

Printed 1/14/2015
HE-01205-07

Minnesota Unique Well No.

226583

County: Ramsey
Quad: St Paul East
Quad ID: 103A

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 103I

Entry Date: 08/14/1991
Update Date: 03/10/2014
Received Date:

Well Name MPLS.-ST. PAUL SANIT. 1

Township	Range	Dir	Section	Subsections	Elevation	703 ft.
28	22	W	9	DAAABD	Elevation Method	7.5 minute topographic map (+/- 5 feet)

Well Depth	Depth Completed	Date Well Completed
287 ft.	287 ft.	10/30/1965

Drilling Method Cable Tool

Well Address

ST PAUL MN

Geological Material	Color	Hardness	From	To
DRIFT			0	26
BROKEN LIMEROCK			26	34
LIMEROCK			34	192
JORDAN SANDROCK			192	284
GRAY SHALE			284	287

Drilling Fluid
--

Well Hydrofractured? ☐ Yes ☐ No
From Ft. to Ft.

Use Industrial

Casing Type Steel (black or low carbon) **Joint** No Information **Drive Shoe?** ☐ Yes ☐ No **Above/Below** 0 ft.

Casing Diameter	Weight	Hole Diameter
30 in. to 34 ft.	lbs./ft.	
24 in. to 87 ft.	lbs./ft.	

Open Hole from 87 ft. to 287 ft.

Screen NO **Make** **Type**

Diameter	Slot/Gauze	Length	Set Between

Static Water Level
19 ft. from Land surface Date Measured 10/30/1965

PUMPING LEVEL (below land surface)
49 ft. after hrs. pumping 2765 g.p.m.

Well Head Completion
Pitless adapter manufacturer Model
☐ Casing Protection ☐ 12 in. above grade
☐ At-grade (Environmental Wells and Borings ONLY)

NO REMARKS

Grouting Information Well Grouted? ☑ Yes ☐ No ☐ Not Specified

Located by: Minnesota Geological Survey
Unique Number Verification: Information from owner
System: *UTM - Nad83, Zone15, Meters*

Method: Digitized - scale 1:24,000 or larger (Digitizing Table)
Input Date: 01/01/1990
X: 496356 **Y:** 4974778

Nearest Known Source of Contamination
_feet _direction _type
Well disinfected upon completion? ☐ Yes ☐ No

Pump ☐ Not Installed Date Installed
Manufacturer's name Model number__ HP 0 Volts
Length of drop Pipe _ft Capacity _g.p.m Type Material

Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☐ No

Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No

Well Contractor Certification

Mueller Well Co.	96460	
License Business Name	Lic. Or Reg. No.	Name of Driller

First Bedrock Prairie Du Chien Group
Last Strat St.Lawrence Formation

Aquifer Multiple
Depth to Bedrock 26 ft.

County Well Index Online Report

226583

Printed 1/14/2015
HE-01205-07

Minnesota Unique Well No.

200052

County Ramsey
Quad St Paul East
Quad ID 103A

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 103I

Entry Date 08/14/1991
Update Date 04/09/2014
Received Date

Well Name ST. PAUL SANIT. ADMIN. B

Township	Range	Dir	Section	Subsections	Elevation	700 ft.
28	22	W	9	DABAAD	Elevation Method	7.5 minute topographic map (+/- 5 feet)

Well Depth	Depth Completed	Date Well Completed
91 ft.	91 ft.	06/06/1936

Drilling Method Cable Tool

Well Address
PIGSEYE ISLAND
ST PAUL MN

Geological Material	Color	Hardness	From	To
SILT			0	8
SAND AND GRAVEL			8	14
ST. PETER SANDROCK			14	28
SHAKOPEE			28	91

Drilling Fluid
--

Well Hydrofractured? ☐ Yes ☐ No
From Ft. to Ft.

Use Commercial

Casing Type Steel (black or low carbon) **Joint** No Information **Drive Shoe?** ☐ Yes ☐ No **Above/Below** 0 ft.

Casing Diameter	Weight	Hole Diameter
8 in. to 47 ft.	lbs./ft.	8 in. to 91 ft.

Open Hole from ft. to ft.

Screen **Make** **Type**

Diameter	Slot/Gauze	Length	Set Between

Static Water Level
20 ft. from Land surface Date Measured 11/27/1991

PUMPING LEVEL (below land surface)
3 ft. after hrs. pumping 200 g.p.m.

Well Head Completion
Pitless adapter manufacturer Model
☐ Casing Protection ☐ 12 in. above grade
☐ At-grade (Environmental Wells and Borings ONLY)

NO REMARKS

Grouting Information Well Grouted? ☐ Yes ☐ No ☐ Not Specified

Located by: Minnesota Geological Survey
Unique Number Verification: Information from owner
System: *UTM - Nad83, Zone15, Meters*

Method: Digitized - scale 1:24,000 or larger (Digitizing Table)
Input Date: 01/01/1990
X: 496210 Y: 4974768

Nearest Known Source of Contamination
_feet _direction _type
Well disinfected upon completion? ☐ Yes ☐ No

Pump ☐ Not Installed Date Installed
Manufacturer's name Model number __ HP 0 Volts
Length of drop Pipe _ft. Capacity _g.p.m Type Material

Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☐ No

Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No

First Bedrock St.Peter Sandstone
Last Strat Prairie Du Chien Group

Aquifer Prairie Du Chien Group
Depth to Bedrock 14 ft.

Well Contractor Certification

License Business Name	Lic. Or Reg. No.	Name of Driller
Keys Well Co.	62012	

County Well Index Online Report

200052

Printed 1/14/2015
HE-01205-07

Minnesota Unique Well No.

226584

County Ramsey
Quad St Paul East
Quad ID 103A

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 103I

Entry Date 08/14/1991
Update Date 03/10/2014
Received Date

Well Name MPLS.-ST.PAUL SANIT. 2

Township	Range	Dir	Section	Subsections	Elevation	703 ft.
28	22	W	9	DAAACA	Elevation Method	7.5 minute topographic map (+/- 5 feet)

Well Address

ST PAUL MN

Geological Material	Color	Hardness	From	To
DRIFT			0	26
SOFT SANDROCK & BROKEN LIMEROCK			26	41
HARD LIMEROCK			41	190
JORDAN SANDROCK			190	284

Well Depth	Depth Completed	Date Well Completed
284 ft.	284 ft.	10/30/1965

Drilling Method Cable Tool

Drilling Fluid
--

Well Hydrofractured? ☐ Yes ☐ No
From Ft. to Ft.

Use Industrial

Casing Type Steel (black or low carbon) **Joint** No Information **Drive Shoe?** ☐ Yes ☐ No **Above/Below** 0 ft.

Casing Diameter	Weight	Hole Diameter
30 in. to 41 ft.	lbs./ft.	
24 in. to 85 ft.	lbs./ft.	

Open Hole from 85 ft. to 284 ft.

Screen NO **Make** **Type**

Diameter	Slot/Gauze	Length	Set Between

Static Water Level
ft. from Date Measured

PUMPING LEVEL (below land surface)
ft. after hrs. pumping g.p.m.

Well Head Completion
Pitless adapter manufacturer Model
☐ Casing Protection ☐ 12 in. above grade
☐ At-grade (Environmental Wells and Borings ONLY)

Grouting Information Well Grouted? ☑ Yes ☐ No ☐ Not Specified

NO REMARKS

Located by: Minnesota Geological Survey
Unique Number Verification: Information from owner
System: *UTM - Nad83, Zone15, Meters*

Method: Digitized - scale 1:24,000 or larger (Digitizing Table)
Input Date: 01/01/1990
X: 496349 **Y:** 4974735

Nearest Known Source of Contamination
_feet _direction _type
Well disinfected upon completion? ☐ Yes ☐ No

Pump ☐ Not Installed Date Installed
Manufacturer's name Model number __ HP 0 Volts
Length of drop Pipe _ft. Capacity _g.p.m. Type Material

Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☐ No

Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No

Well Contractor Certification

Mueller Well Co.	96460	
License Business Name	Lic. Or Reg. No.	Name of Driller

First Bedrock St.Peter-Prairie Du Chien
Last Strat Jordan Sandstone

Aquifer Multiple
Depth to Bedrock 26 ft.

County Well Index Online Report

226584

Printed 1/14/2015
HE-01205-07

Minnesota Unique Well No.

151554

County Ramsey
Quad St Paul East
Quad ID 103A

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 103I

Entry Date 08/14/1991
Update Date 03/10/2014
Received Date

Well Name METRO WASTE CONTROL NO 3

Township Range Dir Section Subsections Elevation 703 ft.

28 22 W 10 CBBCCC **Elevation Method** 7.5 minute topographic map (+/- 5 feet)

Well Depth 268 ft. **Depth Completed** 268 ft. **Date Well Completed** 06/18/1980

Drilling Method Cable Tool

Well Address
2500 CHILDS RD
ST PAUL MN

Drilling Fluid --

Well Hydrofractured? Yes No From Ft. to Ft.

Use Industrial

Geological Material	Color	Hardness	From	To
SILT			0	27
ST. PETER		SOFT	27	37
SHAKOPEE			37	185
JORDAN			185	266
SHALE			266	268

Casing Type Steel (black or low carbon) **Joint** Welded **Drive Shoe?** Yes No **Above/Below** 4 ft.

Casing Diameter	Weight	Hole Diameter
30 in. to 46 ft.	lbs./ft.	29 in. to 268 ft.
24 in. to 102 ft.	lbs./ft.	

Open Hole from 102 ft. to 268 ft.

Screen NO **Make** **Type**

Diameter **Slot/Gauze** **Length** **Set Between**

Static Water Level
27 ft. from Land surface Date Measured 06/18/1980

PUMPING LEVEL (below land surface)
63 ft. after hrs. pumping 3072 g.p.m.

Well Head Completion
Pitless adapter manufacturer Model
☐ Casing Protection ☑ 12 in. above grade
☐ At-grade (Environmental Wells and Borings ONLY)

REMARKS
M.G.S. NO. 1588 GAMMA LOGGED 6/19/80. CASING IS 4 PT ABOVE GROUND

Grouting Information Well Grouted? ☑ Yes ☐ No ☐ Not Specified

Grout Material: Neat Cement from 0 to 102 ft. 12 yrds.

Located by: Minnesota Geological Survey
Method: Digitized - scale 1:24,000 or larger (Digitizing Table)

Unique Number Verification: Information from owner
Input Date: 01/01/1990

System: *UTM - Nad83, Zone15, Meters* **X:** 496447 **Y:** 4974637

Nearest Known Source of Contamination
100 feet S direction Septic tank/drain field type

Well disinfected upon completion? Yes No

Pump ☑ Not Installed Date Installed 09/29/1981
Manufacturer's name FAITBANKS MORSE Model number HP 200 Volts 460
Length of drop Pipe 85 ft. Capacity 2800 g.p.m
Type Turbine Material Stainless Steel

Abandoned Wells Does property have any not in use and not sealed well(s)? Yes No

Variance Was a variance granted from the MDH for this well? Yes No

Cuttings Yes **Borehole Geophysics** Yes

First Bedrock St.Peter Sandstone **Aquifer** Multiple

Last Strat St.Lawrence Formation **Depth to Bedrock** 27 **ft.**

Well Contractor Certification

Keys Well Co.	62012	O'BRIEN, J.
License Business Name	Lic. Or Reg. No.	Name of Driller

County Well Index Online Report **151554** Printed 10/2/2014 HE-01205-07

Minnesota Unique Well No.

501659

County Ramsey
Quad St Paul East
Quad ID 103A

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 103I

Entry Date 05/20/1991
Update Date 02/14/2014
Received Date

Well Name PIGSEYE LANDFILL MW-3

Township	Range	Dir	Section	Subsections	Elevation	690 ft.
28	22	W	10	DBCCCC	Elevation Method	7.5 minute topographic map (+/- 5 feet)

Well Depth	Depth Completed	Date Well Completed
12 ft.	12 ft.	12/19/1988

Drilling Method Power Auger

Well Address

ST PAUL MN

Geological Material	Color	Hardness	From	To
NOT SAMPLED			0	2
WEATHERED SOIL OR FILL	BROWN		2	8
FINE ALLUVIUM OR SWAMP DEPOSITS	GRAY		8	12

Drilling Fluid
–

Well Hydrofractured? ☐ Yes ☐ No
From Ft. to Ft.

Use Abandoned **Status** Sealed

Casing Type Stainless Steel **Joint** No Information **Drive Shoe?** ☐ Yes ☑ No **Above/Below** 3.6 ft.

Casing Diameter	Weight	Hole Diameter
2 in. to 7 ft.	lbs./ft.	7 in. to 12 ft.

Open Hole from ft. to ft.

Screen YES **Make** JOHNSON **Type** stainless steel

Diameter	Slot/Gauze	Length	Set Between
2	10	5	7 ft. and 12 ft.

Static Water Level
8 ft. from Land surface Date Measured 12/14/1989

PUMPING LEVEL (below land surface)
ft. after hrs. pumping g.p.m.

Well Head Completion
Pitless adapter manufacturer Model
☑ Casing Protection Y ☑ 12 in. above grade
☐ At-grade (Environmental Wells and Borings ONLY)

REMARKS
WELL SEALED 11-04-2004 BY 62012
ORIGINAL USE MW - MONITOR WELL

Located by: Minnesota Geological Survey
Unique Number Verification: Other, note in remarks
System: *UTM - Nad83, Zone15, Meters*

Method: Digitized - scale 1:24,000 or larger (Digitizing Table)
Input Date: 01/01/1990
X: 497227 **Y:** 4974461

Grouting Information Well Grouted? ☑ Yes ☐ No ☐ Not Specified

Grout Material: Other	from 0 to 2 ft.	0
Grout Material: Neat Cement	from 2 to 5 ft.	0

Nearest Known Source of Contamination
_feet _direction _type
Well disinfected upon completion? ☐ Yes ☐ No

Pump ☐ Not Installed Date Installed
Manufacturer's name Model number __ HP 0_ Volts
Length of drop Pipe _ ft. Capacity _g.p.m Type Material

Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☐ No

Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No

Well Contractor Certification

Braun Eng Testing	M0016	DOLAN, V.
License Business Name	Lic. Or Reg. No.	Name of Driller

First Bedrock
Last Strat Recent deposit-gray

Aquifer Quat. Water Table Aquifer
Depth to Bedrock ft.

County Well Index Online Report

501659

Printed 10/2/2014
HE-01205-07

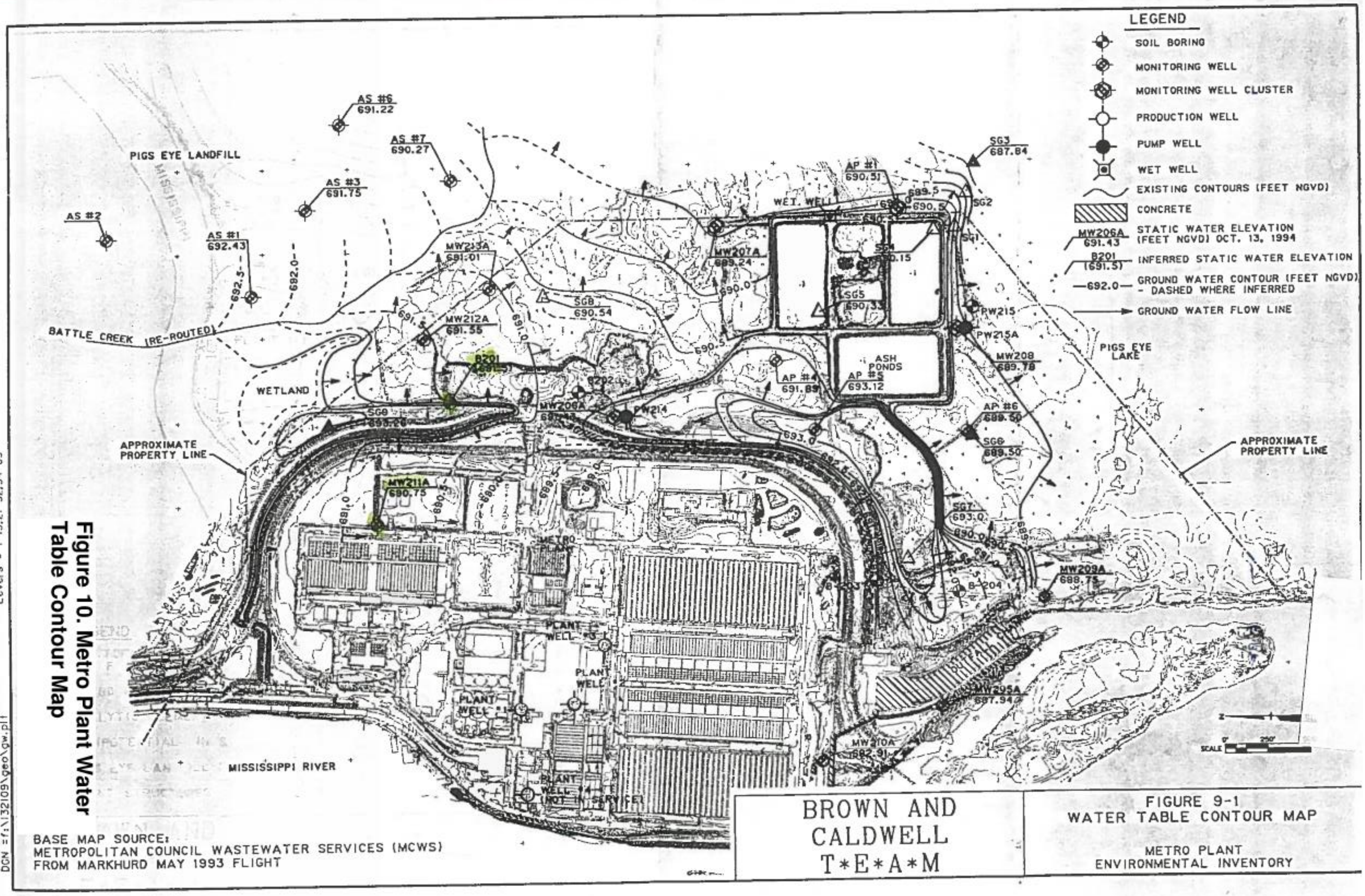

Figure 10. Metro Plant Water Table Contour Map

LOG OF BORING

PROJECT: BAAX-94-037 SOIL BORINGS & MONITORING WELLS MWCC Waste Water Treatment Plant Pigs Eye St. Paul, Minnesota	BORING: B-201 LOCATION: Refer to attached Ramsey County survey coordinates.

DRILLER: D. Lovaasen	METHOD: 3 1/4" HSA	DATE: 2/21/94	SCALE: 1" = 4'

Elev. 698.2	Depth 0.0	ASTM Symbol	Description of Materials (ASTM D2488)	BPF	WL	Tests or Notes
696.2	2.0	FILL	FILL: Silty Sand, fine- to medium-grained, with Gravel, brown, moist.			An open triangle in the water level (WL) column indicates the depth at which groundwater was observed while drilling. A solid triangle indicates the groundwater level in the boring on the date indicated. Groundwater levels fluctuate.
695.7	2.5	FILL	FILL: Sandy Lean Clay, brown, moist.			
692.7	5.5	FILL	FILL: Poorly Graded Sand, fine- to medium-grained, brown, moist.	5 14 16 7		
690.7	7.5	FILL	FILL: Clayey Sand, fine- to medium-grained, with Gravel, brown, wet.	13 19		
689.2	9.0	CL	LEAN CLAY, slightly organic with fibers, dark gray, wet. (Swamp Deposit)	2 3		
685.7	12.5	OL	ORGANIC CLAY, with seams of waterbearing Poorly Graded Silty Sand, brown, wet. (Swamp Deposit)	3 1 1 2		
678.7	19.5	SM	POORLY GRADED SILTY SAND, fine- to medium-grained, gray, waterbearing, very loose to loose. (Alluvium)	WH 1 1 1 2 2 3 4 4	▽	Jetting water used to wash sand out of the auger between the 16' and 17' depths.
677.2	21.0	OL	ORGANIC CLAY, with fibers, dark brown, wet. (Swamp Deposit)	1 1 1		

END OF BORING.

Water observed at 15' while drilling.

Bore hole grouted.

LOG OF BORING

PROJECT: BAAX-94-037 **SOIL BORINGS & MONITORING WELLS** MWCC Waste Water Treatment Plant Pigs Eye St. Paul, Minnesota		BORING: **MW-211A** LOCATION: Refer to attached Ramsey County survey coordinates.	
DRILLER: D. Lovaasen	METHOD: 3 1/4" HSA	DATE: 2/25/94	SCALE: 1" = 4'

Elev. 696.2	Depth 0.0	ASTM Symbol	Description of Materials (ASTM D2488)	BPF	WL	Tests or Notes
		FILL	FILL: Sandy Lean Clay, brown, frozen.			
694.7	1.5	FILL	FILL: Clayey Sand, fine- to medium-grained, with traces of wood, gray, moist.	5 7 8		
691.7	4.5	PT	PEAT, very dark grayish brown, moist. (Swamp Deposit)	4 2 2		
690.2	6.0	SM	SILTY SAND, fine- to medium-grained, with traces of wood, dark brown to dark gray, wet to waterbearing, very loose. (Alluvium)	1 1 1 1 1 1 1 1 1	∇	
681.7	14.5	SC	CLAYEY SAND, mostly fine-grained, gray, wet, very loose. (Alluvium)	1 1 1		
681.2	15.0	SM	SILTY SAND, fine- to medium-grained, dark gray, wet to waterbearing, very loose. (Alluvium)	1 1 1 1 1 2		
675.2	21.0					

END OF BORING.

Water observed at 8' while drilling.

Water down 14' with 19.5' of hollow-stem auger in the ground.

Water down 8' twenty hours after withdrawal of auger.

Bore hole overdrilled with 6 1/4" hollow-stem auger.

Monitoring well set to 14.5'.

Appendix B

Letter from MN DNR – Natural Heritage Review
Letter from the State Historic Preservation Office (SHPO)

Minnesota Department of Natural Resources
Division of Ecological and Water Resources, Box 25
500 Lafayette Road
St. Paul, Minnesota 55155-4025
Phone: (651) 259-5109 E-mail: lisa.joyal@state.mn.us

October 31, 2014 **Correspondence # ERDB 20150106**

Ms. Heidi McEllistrem
Brown and Caldwell
30 East 7th St., Suite 2500
St. Paul, MN 55101

RE: Natural Heritage Review of the proposed Metro WWTP Expansion;
T28N R22W Section 10; Ramsey County

Dear Ms. McEllistrem,

As requested, the above project has been reviewed for potential effects to known occurrences of rare features. A search of the Minnesota Natural Heritage Information System did identify rare features within an approximate one-mile radius of the proposed project, but these records did not include any federally listed species and were either historical or not of concern given the project details that were provided with the data request form. As such, I do not believe the proposed project will adversely affect any known occurrences of rare features.

The Natural Heritage Information System (NHIS), a collection of databases that contains information about Minnesota's rare natural features, is maintained by the Division of Ecological and Water Resources, Department of Natural Resources. The NHIS is continually updated as new information becomes available, and is the most complete source of data on Minnesota's rare or otherwise significant species, native plant communities, and other natural features. However, the NHIS is not an exhaustive inventory and thus does not represent all of the occurrences of rare features within the state. Therefore, ecologically significant features for which we have no records may exist within the project area.

For environmental review purposes, the results of this Natural Heritage Review are valid for one year; the results are only valid for the project location (noted above) and project description provided on the NHIS Data Request Form. Please contact me if project details change or if an updated review is needed.

Furthermore, the Natural Heritage Review does not constitute review or approval by the Department of Natural Resources as a whole. Instead, it identifies issues regarding known occurrences of rare features and potential effects to these rare features. Additional rare features for which we have no data may be present in the project area, or there may be other natural resource concerns associated with the proposed project. For these concerns, please contact your DNR Regional Environmental Assessment Ecologist (contact information available at http://www.dnr.state.mn.us/eco/ereview/erp_regioncontacts.html). Please be aware that additional site assessments or review may be required.

Thank you for consulting us on this matter, and for your interest in preserving Minnesota's rare natural resources. An invoice will be mailed to you under separate cover.

Sincerely,

Samantha Bump

Samantha Bump
Natural Heritage Review Specialist

Heflin, Katherine

Sent:
To:
Cc:
Subject: -
Attachments: -

Hi Rene – Here is your updated letter from the MN DNR. tg

From: Bump, Samantha (DNR) <samantha.bump@state.mn.us>
Sent: Thursday, July 26, 2018 5:33 PM
To: Gilchrist, Therese <Therese.Gilchrist@metc.state.mn.us>
Cc: Horton, Becky (DNR) <becky.horton@state.mn.us>; Parris, Leslie (DNR) <leslie.parris@state.mn.us>
Subject: RE: RE - Correspondence # ERDB 20150106

Therese,

I have reviewed the NHIS regarding the above project. There are no new state-listed species records in the vicinity of the project. However, the rusty patched bumble bee (*Bombus affinis*), a federally-listed endangered species, was documented recently in the vicinity of the proposed project. The rusty patched bumble bee typically occurs in grasslands and urban gardens with flowering plants from April through October. This species nests underground in abandoned rodent cavities or in clumps of grasses. Please reference the guidance at the USFWS rusty patched bumble bee website to determine if the project has the potential to impact this protected species.

The Natural Heritage letter dated October 31, 2014 with this email is valid until July 26, 2019. Thank you for consulting us on this matter. If you have any further questions, please feel free to contact me.

Have a great day,
Samantha Bump
NHIS Review Specialist | Ecological & Water Resources

Minnesota Department of Natural Resources
500 Lafayette Road
St. Paul, MN 55155
Phone: 651-259-5091
Email: samantha.bump@state.mn.us
mndnr.gov

DEPARTMENT OF
NATURAL RESOURCES

Links:

From: Gilchrist, Therese <Therese.Gilchrist@metc.state.mn.us>
Sent: Thursday, July 19, 2018 2:19 PM
To: Bump, Samantha (DNR) <samantha.bump@state.mn.us>
Subject: RE: RE - Correspondence # ERDB 20150106

Hi Samantha – we have changed some details but essentially it is the same, we are in the planning stages to add more solids handling capacity, all inside the already built area. Terry

---

From: Bump, Samantha (DNR) [mailto:samantha.bump@state.mn.us]
Sent: Thursday, July 19, 2018 2:16 PM
To: Gilchrist, Therese <Therese.Gilchrist@metc.state.mn.us>
Subject: RE: RE - Correspondence # ERDB 20150106
Hi Therese,

Thanks for getting in touch. Have there been any changes in the project since the previous review?

Thank you,

Samantha Bump
NHIS Review Specialist | Ecological & Water Resources

Minnesota Department of Natural Resources
500 Lafayette Road
St. Paul, MN 55155
Phone: 651-259-5091
Email: samantha.bump@state.mn.us
mndnr.gov

DEPARTMENT OF NATURAL RESOURCES

From: Gilchrist, Therese <Therese.Gilchrist@metc.state.mn.us>
Sent: Wednesday, July 18, 2018 1:16 PM
To: Bump, Samantha (DNR) <samantha.bump@state.mn.us>
Subject: RE - Correspondence # ERDB 20150106

Hi Samantha – You had helped us with a Natural Heritage Review in 2014. We are just getting ready to submit plans for this project. Since the Review was only valid for 1 year, could you let us know what it would take to update for 2017. Attached is a copy of the 1/31/2014 review letter.

Thank-you for your help.

METROPOLITAN COUNCIL

Therese A Gilchrist
Environmental Scientist | Environmental Services - EQA Department
therese.gilchrist@metc.state.mn.us
P. 651.602.1193
390 North Robert Street | St. Paul, MN | 55101 | metrocouncil.org

CONNECT WITH US

Rusty Patched Bumble Bee
Bombus affinis

Photo courtesy of Christy Stewart

The U.S. Fish and Wildlife Service listed the rusty patched bumble bee as endangered under the Endangered Species Act. Endangered species are animals and plants that are in danger of becoming extinct. Identifying, protecting and recovering endangered species is a primary objective of the U.S. Fish and Wildlife Service's endangered species program.

What is a rusty patched bumble bee?

Appearance: Rusty patched bumble bees live in colonies that include a single queen and female workers. The colony produces males and new queens in late summer. Queens are the largest bees in the colony, and workers are the smallest. All rusty patched bumble bees have entirely black heads, but only workers and males have a rusty reddish patch centrally located on the back.

Habitat: Rusty patched bumble bees once occupied grasslands and tallgrass prairies of the Upper Midwest and Northeast, but most grasslands and prairies have been lost, degraded, or fragmented by conversion to other uses. Bumble bees need areas that provide nectar and pollen from flowers, nesting sites (underground and abandoned rodent cavities or clumps of grasses), and overwintering sites for hibernating queens (undisturbed soil).

Illustrations of a rusty patched bumble bee queen (left), worker (center), and male (right) by Elaine Evans, The Xerces Society.

Reproduction: Rusty patched bumble bee colonies have an annual cycle. In spring, solitary queens emerge and find nest sites, collect nectar and pollen from flowers and begin laying eggs, which are fertilized by sperm stored since mating the previous fall. Workers hatch from these first eggs and colonies grow as workers collect food, defend the colony, and care for young. Queens remain within the nests and continue laying eggs. In late summer, new queens and males also hatch from eggs. Males disperse to mate with new queens from other colonies. In fall, founding queens, workers and males die. Only new queens go into diapause (a form of hibernation) over winter - and the cycle begins again in spring.

Feeding Habits: Bumble bees gather pollen and nectar from a variety of flowering plants. The rusty patched emerges early in spring and is one of the last species to go into hibernation.

Why conserve rusty patched bumble bees?

As pollinators, rusty patched bumble bees contribute to our food security and the healthy functioning of our ecosystems. Bumble bees are keystone species in most ecosystems, necessary not only for native wildflower reproduction, but also for creating seeds and fruits that feed wildlife as diverse as songbirds and grizzly bears.

Bumble bees are among the most important pollinators of crops such as blueberries, cranberries, and clover and almost the only insect pollinators of tomatoes. Bumble bees are more effective pollinators than honey bees for some crops because of their ability to "buzz pollinate." The economic value of pollination services provided by native insects (mostly bees) is estimated at $3 billion per year in the United States.

It needs a constant supply and diversity of flowers blooming throughout the colony's long life, April through September.

Range: Historically, the rusty patched bumble bee was broadly distributed across the eastern United States and Upper Midwest, from Maine in the U.S. and southern Quebec and Ontario in Canada, south to the northeast corner of Georgia, reaching west to the eastern edges of North and South Dakota. Its range included 28 states, the District of Columbia and 2 provinces in Canada. Since 2000, this bumble bee has been reported from only 13 states and 1 province: Illinois, Indiana, Iowa, Maine, Maryland, Massachusetts, Minnesota, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, Wisconsin – and Ontario, Canada.

Why is the rusty patched bumble bee declining?

Habitat loss and degradation: Most prairies and grasslands of the Upper Midwest and Northeast have been converted to monoculture farms or developed areas, such as cities and roads. Grasslands that remain tend to be small and isolated.

Intensive farming: Increases in farm size and technology advances improved the operating efficiency of farms but have led to practices that harm bumble bees: increased use of pesticides, loss of crop diversity resulting in flowering crops being available for only a short time, loss of hedgerows with flowering plants, and loss of legume pastures.

Disease: Pathogens and parasites may pose a threat, although their prevalence and effects in North American bumble bees are not well understood.

Pesticides: The rusty patched bumble bee may be vulnerable to pesticides. Pesticides are used widely on farms and in cities and have both lethal and sublethal toxic effects. Bumble bees can absorb toxins directly through their exoskeleton and through contaminated nectar and pollen. Rusty patched bumble bees nest in the ground and may be susceptible to pesticides that persist in agricultural soils, lawns and turf.

Global climate change: Climate changes that may harm bumble bees include increased temperature and precipitation extremes, increased drought, early snow melt and late frost events. These changes may lead to more exposure to or susceptibility to disease, fewer flowering plants, fewer places for queens to hibernate and nest, less time for foraging due to high temperatures, and asynchronous flowering plant and bumble bee spring emergence.

What is being done to conserve rusty patched bumble bees?

U.S. Fish and Wildlife Service: Several Service programs work to assess, protect, and restore pollinators and their habitats. Also, the Service works with partners to recover endangered and threatened pollinators and pollinator-dependent plants. Concern about pollinator declines prompted formation of the North American Pollinator Protection Campaign, a collaboration of people dedicated to pollinator conservation and education. The Service has a Memorandum of Understanding with the Pollinator Partnership to work together on those goals. The Service is a natural collaborator because our mission is to work with others to conserve, fish, wildlife, and plants and their habitats.

Other Efforts: Trusts, conservancies, restoration groups and partnerships are supporting pollinator initiatives and incorporating native plants that support bees and other pollinators into their current activities. For example, the USDA Natural Resource Conservation Service is working with landowners in Michigan, Minnesota, Montana, North Dakota, South Dakota, and Wisconsin to make bee-friendly conservation improvements to their land. Improvements include the practices of planting cover crops, wildflowers, or native grasses and improved management on grazing lands.

Research: Researchers are studying and monitoring the impacts of GMO crops and certain pesticides on pollinators. Efforts by citizen scientists and researchers to determine the status of declining bee species are underway throughout the United States.

What can I do to help conserve the rusty patched bumble bee?

Garden: Grow a garden or add a flowering tree or shrub to your yard. Even small areas or containers on patios can provide nectar and pollen for native bees.

Native plants: Use native plants in your yard such as lupines, asters, bee balm, native prairie plants and spring ephemerals. Don't forget spring blooming shrubs like ninebark and pussy willow! Avoid invasive non-native plants and remove them if they invade your yard. For more information on attracting native pollinators, visit www.fws.gov/pollinators/pdfs/PollinatorBookletFinalrevWeb.pdf.

Natural landscapes: Provide natural areas - many bumble bees build nests in undisturbed soil, abandoned rodent burrows or grasss clumps. Keep some unmowed, brushy areas and tolerate bumble bee nests if you find them. Reduce tilling soil and mowing where bumble bees might nest. Support natural areas in your community, county and state.

Minimize: Limit the use of pesticides and chemical fertilizer whenever possible or avoid them entirely. Pesticides cause lethal and sublethal effects to bees and other pollinators.

January 10, 2017