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A Sustainable Bio-Solids Management For The Grand Forks Wastewater Treatment Plant

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A SUSTAINABLE BIO-SOLIDS MANAGEMENT FOR THE GRAND FORKS WASTEWATER TREATMENT PLANT

By

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This thesis, submitted by Hasibul Hasan in partial fulfillment of the requirements for the degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory committee under whom the work has been done and is hereby approved.

Chairperson

This thesis meets the standards for appearance, conforms to the style and format requirements for the Graduate School of the University of North Dakota, and is hereby approved.

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LIST OF ACRONYMS

APLR: Annual Pollutant Loading Late

Ac: acre

BOD_5: 5-Day Biochemical Oxygen Demand

CFR: Code of Federal Regulations

CPLR: Cumulative Pollutant Loading Rate

DAF: Dissolved Air Floatation

EPA: Environmental Protection Agency

EQ: Exceptional Quality

g: Gram

GFWWTP: Grand Forks Waste Water Treatment Plant

ha: Hectare

Kg: Kilograms

l: Litre

lb: Pound

mg: Milligram

MGD: Millions Gallons per Day

NDSU: North Dakota State University

PC: Pollutant Concentration

PC2: Primary Cell 2

PFRP: Process to Further Reduce Pathogen

PSRP: Process to Significantly Reduce Pathogen

RAS: Return Activated Sludge

rpm: Rotations per Minute

SV: Sludge Volume

TSS: Total Suspended Solid

USEPA: United States Environmental Protection Agency

WAS: Waste Activated Sludge

wt.: Weight

yr.: Year

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ABSTRACT

A Sustainable Bio-solids Management for the Grand Forks Waste Water Treatment Plant

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The Grand Forks Waste Water Treatment Plant (GFWWTP) is currently sending its waste activated sludge (WAS) from the activated sludge treatment process to an existing on-site wastewater treatment lagoon which has been in operation since 2003. The plant produces approximately 65,000 gallons of WAS per day. Because of this high level of loading, the existing lagoon system is likely to get replaced by a more sustainable treatment option. Several methods were considered and studied thoroughly for this research, and – on site land application shows some potential. After surveying the Municipal Waste Water Treatment Facilities of the five neighboring states of North Dakota, no specific method was obviously "the strongest solution" for the biosolids' scenario of the GFWWTP. To investigate the feasibility of land application of sludge on agricultural field, several GIS maps using land survey data, water table data, and depth of the soil layer data were prepared. Use of sludge as fertilizers according to EPA regulations on different types of land was also studied. Demand of sludge as fertilizer to the local community was considered for this study. A study of the GFWWTP sludge characteristics shows lack of desired levels of nitrogen and phosphorus in it. So, composting seemed to be a less desirable option as it requires the presence of higher amount nitrogen and phosphorus. For composting, sludge quality may also need to be class A which adds more to the cost. Moreover, as the fertility of land around Grand Forks is high, composting did not seem to be promising. Incineration, which is a common management method for sludge in Minnesota, would not be preferred from the environmental perspective. Considering sludge quality, economical aspect, control, demand of sludge as fertilizer, land fertility, and EPA regulations, both land application and disposal in landfill site(s) seemed to be the most promising alternatives for sludge management.

Keywords: Biosolids, Marshall and Swift Equipment Cost Index (MSECI), Engineering News Record Construction Cost Index (ENRCCI), Total Dry Solids, Total Base Capital Cost, Annual Operation and Maintenance Cost, Head Loss, Head Difference.

1 INTRODUCTION

Wastewater treatment is the process of removing contaminants from wastewater. It includes different processes to remove physical, chemical and biological contaminants. Its objective is to produce an environmentally-safe fluid stream (or treated effluent) and a solid by-product (or treated sludge) suitable for disposal or reuse (usually as farm fertilizer). Using advanced technology, it is now possible to re-use sewage effluent for drinking water. Singapore uses this modern wastewater treatment technique for their drinking water source. (History of NEWater, 2011)

Solids collected from the wastewater treatment process, which have not undergone further treatment, are called sewage sludge. Sewage sludge can be treated further to significantly reduce disease causing pathogens and volatile organic matter, producing a stabilized product suitable for beneficial use, called biosolids. Biosolids normally contain between 3% and 90% solids (AWA, Australian & New Zeland Biosolids Partnership, 2009). Biosolids are carefully treated and monitored, and they must be used in accordance with regulatory requirements.

The United States Environmental Protection Agency (USEPA) has regulations regarding biosolids management, and these regulations are contained in USEPA 40 CFR Part 503.

As municipal budgets continue to constrict, cities across the United States are pursuing cost-effective ways to best manage their infrastructure and identify savings. Keeping this in mind, more municipalities are looking to expand from a traditional treatment and disposal approach to one that centers on resource recovery and finding value in waste. The city of Grand forks is currently developing a sustainable management plan for their biosolids.

A new sludge disposal method will probably require sludge dewatering followed by some type of land disposal or land application. Some research has already been done to facilitate a transition to an alternative biosolids disposal method. An aerobic digestion pilot study was completed by the UND Civil Engineering Department and the Grand Forks Waste Water Treatment Plant (GFWWTP). In addition, some research was done by the North Dakota State University Civil Engineering Department to study the use of mechanical dewatering systems at the GFWWTP. It is expected that when the sludge is dewatered, it can be permanently placed in the Grand Forks landfill. However if the sludge is to be disposed of by land application, it may have to be digested prior to dewatering in order to meet the Class B sludge disposal requirements (as stated in CFR Title 40, Part 503B). This research project evaluated alternative disposal methods for GFWWTP biosolids. The main disposal methods being evaluated are land application and land disposal (usually by mono fill disposal). All of these should be feasible disposal methods for the GFWWTP biosolids considering that the plant is located close to thousands of acres of farmland and other rural land, and a large municipal landfill.

This thesis concentrates on the selection of a biosolids disposal system for the GFWWTP for a land disposal purpose and cost analysis. The scope of this thesis includes two main tasks. The first task consisted of a regional survey on biosolids system management of five Midwestern states that have similar weather and similar biosolids handling capacity. This assessment was done to understand different disposal methods. It helped to create a shortlist of methodologies used for disposal. Considering factors such as the low demand of biosolids on local agricultural land, climate, and the high cost of hauling biosolids directed the selection of disposal method towards the direct disposal of biosolids on available land next to GFWWTP. The second task consisted of developing a detailed cost estimate for a direct land disposal process for the GFWWTP.

2 BACKGROUND

2.1 Grand Forks Wastewater Treatment Plant

The Grand Forks Waste Water Treatment Plant (GFWWTP) is the only wastewater treatment facility in the city of Grand Forks. It serves a population of nearly 55,000. It was first in operation in the year 2003. Since then, the GFWWTP has served the people of Grand Forks with wastewater treatment.

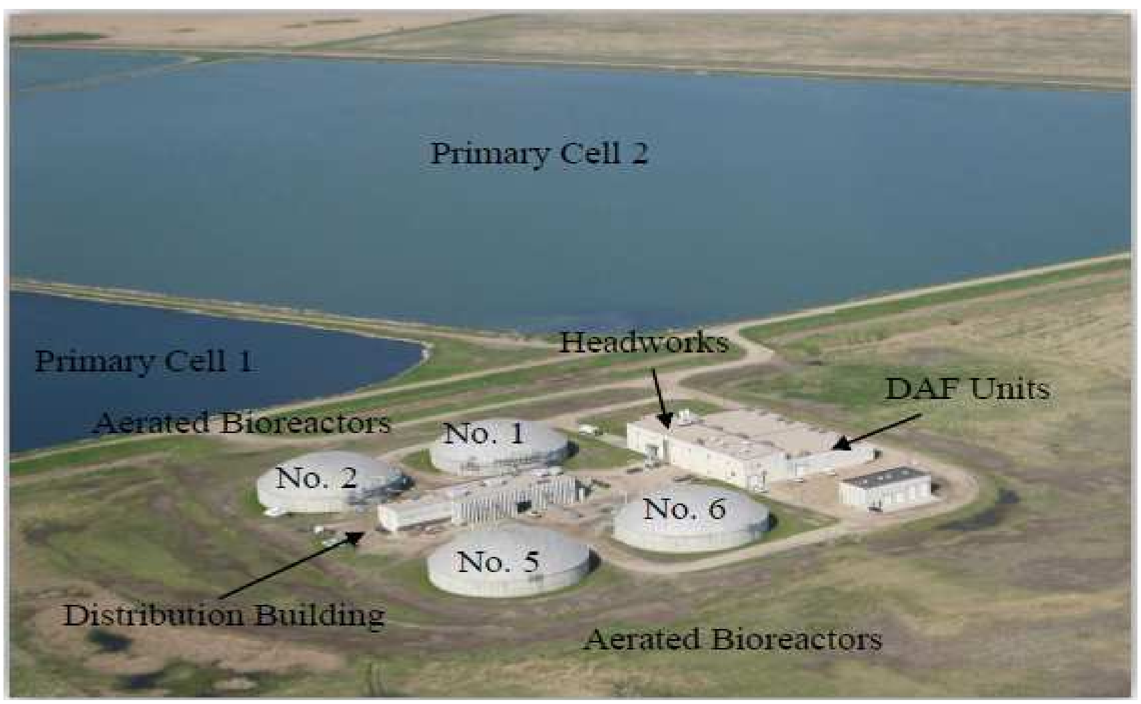


Figure 2-1: Aerial Photo of GFWWTP

(Source: Kistner, Brian T, 2011).

According to Mr. Donald Tucker, the GFWWTP superintendent, the plant is designed to handle a flow of 10MGD with a peaking factor of 3 and the plant is expandable to a capacity of 15 MGD with a 35 MGD peak flow. The design ratings for TSS and BOD concentrations are 1040 mg/l TSS and 480 mg/l BOD_5 respectively at the headworks. The current wastewater flow in the plant is around 5-8 MGD with 252 mg/l BOD_5 and 537 mg/l of TSS (Kistner, Brian T, 2011).

In the GFWWTP, the raw wastewater undergoes preliminary treatment through 10 mm rotary mechanical screens and vortex grit removal. After the wastewater goes through the grit chamber, 20% of this wastewater is bypassed to the lagoon and the rest moves through the remaining headwork processes by open concrete channels which are designed to have the water flow under the force of gravity. The wastewater drops down a forty-eight inch diameter steel pipe which transports the wastewater over to the distribution building. In the distribution building wastewater enters into a distribution channel. From the distribution channel, the water is transported by gravity to the biological reactors. In the reactor tanks, the wastewater gets mixed and treated by aerobic biological processes. There are different microorganisms in each tank which consume and digest various organic materials. The sludge that is produced is a combination of these microorganisms and other inert matter that is found in the wastewater.

The wastewater is sent to the flocculation basin and then to the post-aeration chambers in the distribution building after going through all in-service bioreactors. From the post-aeration chambers the wastewater then flows to the main treatment building and runs through six parallel dissolved air flotation (DAF) units. The solids are skimmed off the top of the DAF units at about 3-4 percent concentrations and collected in aerated sludge holding tanks located on the lower level of the main treatment building.

Around 85% of this sludge is pumped back to the biological processes as return activated sludge (RAS) and the rest of the sludge is pumped to the Primary Cell 2 (PC2) lagoon as waste activated sludge (WAS). The lagoon currently provides WAS volatile solids destruction through aerobic and anoxic biological processes simultaneously with treatment of the 20% raw wastewater, which is bypassed to the lagoon from the headworks processes.

The schematic diagram of the GFWWTP processes is shown in figure 2.2

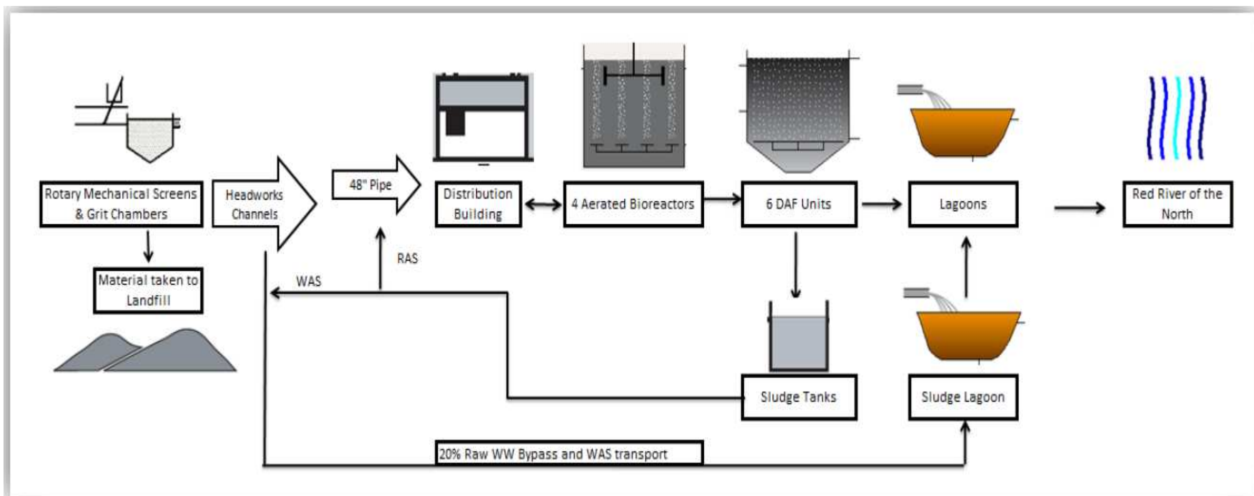


Figure 2-2 Current Schematic of GFWWTP Processes

The City of Grand Forks has been operating a wastewater stabilization lagoon system since the 1970s. Although they have started the GFWWTP in 2003, they are still using the lagoon system for treating the produced sludge and discharging the wastewater effluent. The capacity of the lagoons is approximately 1.3 billion gallons at 3.5 ft depth and 1.9 billion gallons at 5 ft depth. The approximate detention time for the water is about 0.9 to 1.1 years and then the water is released to the Red River of the North to return it to the hydrological cycle. The required detention time according to the Ten State Standards is 90 - 120 days (Recommended Standards for Wastewater Facilities, 2012) for a treatment pond. In winter time, the lagoon water cannot be discharged into the river below the ice. So, a particular time is chosen to discharge the wastewater when the water is not frozen. About 2-2.5 billion gallons from the lagoons are discharged between April and November (Kistner, Brian T, 2011). This time period was chosen to avoid a high ratio of treated wastewater to freshwater because the flow of the river is medium to high during that time of the year.

As the GFWWTP is pumping around 65,000 to 125,000 GPD of WAS into the lagoon system, it is classified as a high-level activated sludge plant. To comply with the regulations of Environmental Protection Agency (EPA), the city may decommission some or all the lagoon cells and find a sustainable disposal plan for these biosolids. After decommissioning the lagoon, the biosolids might need to be dewatered depending on the management plan.

3 LITERATURE REVIEW

3.1 Biosolids Management

Normally biosolids are a mix of water and organic materials which are obtained as a by-product of municipal wastewater treatment processes. Municipal wastewater comes from household kitchens, laundries and bathrooms. Biosolids may contain:

- Organic matter
- Macronutrients, such as nitrogen, phosphorus, potassium, sulphur and
- Micronutrients, such as copper, zinc, calcium, magnesium, iron, boron, molybdenum and manganese

Biosolids may also contain trace inorganic compounds, including arsenic, cadmium, chromium, lead, mercury, nickel and selenium. The USEPA has regulations to limit the extent of these nutrients and inorganics present in biosolids prior to use for various purposes.

Biosolids are produced by stabilizing sewage sludge. There are various ways to stabilize sewage sludge:

- Aerobic and anaerobic digestion
- Lime stabilization
- Composting

- Heat treatment

Not all biosolids can be used for all purposes. The use of biosolids depends on its nutrient level. Biosolids with a higher nutrient level are commonly used as fertilizers in the agricultural lands. Biosolids, enriched with nitrogen (N), phosphorus (P) and lime (after lime stabilization), are the best to be used as fertilizers. Biosolids also supply essential plant nutrients such as sulfur (S), manganese (Mn), Zinc (Zn), copper (Cu), iron (Fe), molybdenum (Mo) and boron (B). Biosolids lacking in these nutrients are often used for other purposes than fertilizing soil. These purposes include use of biosolids as road base, as daily cover in landfills, for landscaping and topsoil on dams, for incineration and mine reclamation. for example, the Fargo Wastewater Treatment Plant sends their biosolids to the Fargo landfill and these biosolids are used for producing methane which is used for commercial purpose. (History of Fargo Wastewater Treatment Plant, 2011).

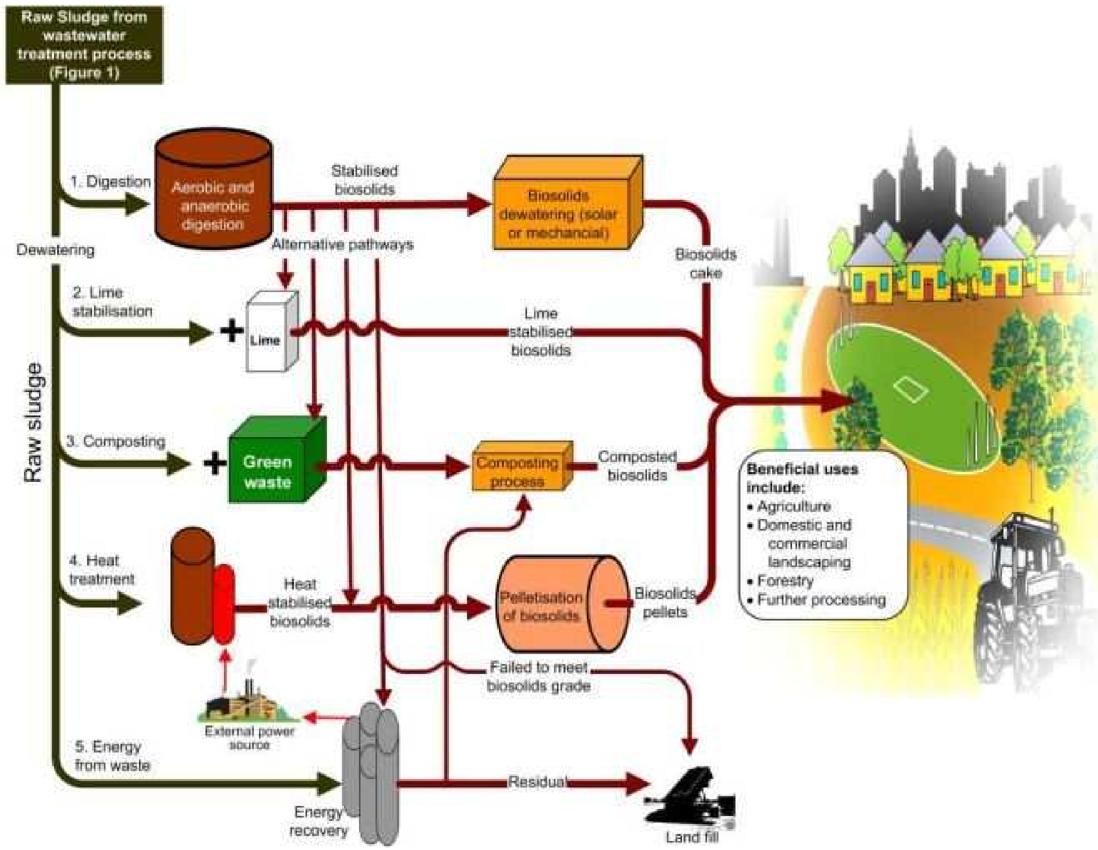


Figure 3-1: Typical Production Systems for Biosolids with Possible Alterative Production Pathways

The USEPA developed regulations to protect public health and environment from the adverse effects of specific pollutants that might be present in biosolids as a requirement of the Clean Water Act Amendments of 1987. They regulate the disposal or utilization methods under Title 40 of the Code of Federal Regulations (CFR) Part 503.

Title 40 CFR Part 503 defined the management practices and numerical criteria for the three major use and disposal options for biosolids – land application, incineration and surface disposal – that will protect public health and the environment. In addition to limiting where and when biosolids can be applied, the rule requires processes to kill pathogens and strictly limits amounts of metals that can be applied to any piece of land.

Federal, state and local governments play crucial roles in enforcing the Part 503 rule. Local government is also responsible for addressing related local concerns. North Dakota does not have any permitting laws regarding biosolids; therefore, the permit would come from the EPA. However, the North Dakota Department of Health receives a copy of the permit. Compliance with the permit would consist of monitoring and recording of sludge quantity, quality, distribution rates, and other information.

3.2 Land Application of Biosolids

Biosolids are typically applied on farm fields to supply nutrients and add organic matter to the soil. Application can be done to improve the soil and increase crop production or simply to reclaim poor soil for some other use. When biosolids are applied to farm fields, the application rate is usually limited by the amount of nitrogen in the biosolids and the amount of nitrogen that the field crop can take up from the soil.

When biosolids are applied to farm land, a number of factors will have to be evaluated. of primary importance is whether the biosolids meet the requirements set forth in the Code of Federal Regulations (Title 40; Part 503; Subpart B) for land application of sewage sludge. Since there are some very specific requirements stated in the regulations for land application, the sludge treatment processes used at the GFWWTP will have to be evaluated to determine what changes may be needed to meet the requirements. Sludge digestion, dewatering, and drying are three processes that can directly impact the feasibility of land application.

The Part 503 regulations also control to some extent how and to whom the biosolids can be distributed. If the intent is to apply the biosolids directly to farm fields or public land where the application rate and access to the land can be controlled, the biosolids typically have to meet Class B pathogen removal standards. If the intent is to distribute the biosolids to the public, use the biosolids for locations where access to the land cannot be controlled, or apply biosolids that will contact the edible part of the crop; the biosolids typically have to meet Class A pathogen removal standards.

Another important consideration is whether there will be enough local demand for treated biosolids to make land application feasible. The area closest to the GFWWTP includes many acres of land with saline soil that is marginally productive for crops, and the biosolids could possibly be used for some type of reclamation project for some of this land. Additionally, there are many thousands of acres of good quality farmland located 3 to 5 miles away from the GFWWTP, where the biosolids could possibly be used for conventional fertilizer.

3.2.1 Regulations for Land Application

When biosolids are applied to land for either conditioning the soil or fertilizing crops or other vegetation growth in the soil, the process is called land application. Normally two types of land are benefited by the application of biosolids- nonpublic contact sites (areas not frequently visited by people) and public contact sites (areas where people are likely to come into contact with biosolids applied to land).

Biosolids are applied to land using various techniques. They may be spread above the soil surface. They also may be incorporated into the soil after being spread on the surface or injected directly below the soil surface. Liquid biosolids can be applied using tractors, tank wagons or other special application vehicles. Dryer biosolids are applied using equipment similar to that used for applying limestone, animal manures or commercial fertilizers. (A Plain Guide to the EPA Part 503 Biosolids Rule, 2012)

Biosolids must meet the land application requirement before being land applied. These requirements are discussed below:

All biosolids applied to land must meet the ceiling concentrations for pollutants. These pollutant concentration limits are listed in Table 3.1.

- Land applied biosolids also need to meet either pollution concentration limits or cumulative pollutant loading rate limits or annual pollutant loading rate limits.
- Before land application of biosolids, one of either Class A and Class B requirements or site restrictions must be met. The two classes differ based on the level of pathogen reduction obtained after treatment.
- Vector attraction requirements must be met before land application of biosolids.

The EPA guide for Part 503 has four different options for meeting pollutant limits and pathogen and vector attraction requirements. These options are:

- The Exceptional Quality (EQ) option
- The Pollutant Concentration (PC) option
- The Cumulative Pollutant Loading Rate (CPLR) option
- The Annual Pollutant Loading Rate (APLR) option

Table 3.1: Pollutant Concentration Limits for Land Application of Biosolids

Pollutant Name	Ceiling Concentration Limits for All Biosolids Applied to Land (mg/kg)	Pollutant Concentration Limits for EQ and PC Biosolids (mg/kg)	Cumulative Pollutant Loading Rate Limits for CPLR Biosolids (kg/ha)	Annual Pollutant Loading Rate Limits for APLR Biosolids (kg/ha/yr)
Arsenic	75	41	41	2
Cadmium	85	39	39	1.9
Chromium	3,000	1,200	1,200	150
Copper	4,300	1,500	1,500	75
Lead	840	300	300	15
Mercury	57	17	17	0.85
Molybdenum	75	--	--	--
Nickel	420	420	420	21
Selenium	100	36	36	5
Zinc	7,500	2,800	2,800	140
Limits applies to	All land applied biosolids	Biosolids in bulk and bagged biosolids	Biosolids in Bulk	Bagged biosolids

(Source: A Plain Guide to the EPA Part 503 Biosolids Rule, 2012)

The EQ and APLR biosolids are Class A biosolids. Since Class A biosolids have no constraints for land application, these methods may be preferred over PC and CPLR for either class A or class B biosolids.

EPA categorizes biosolids in two different categories based on pathogenic organisms. These are:

- Class A
- Class B

EPA also states specific routes to decrease pathogens to these levels.

Class A Biosolids

Class A biosolids comprises of infinitesimal levels of pathogens. It can be land applied without any restriction as well as marketed to the public. There is specific guideline of the USEPA to accomplish Class A certification. Biosolids must be treated with following procedures for making it class A:

- Digestion
- Composting
- Heating
- Increased pH (lime addition)

Class B Biosolids

Class B requirements confirm that the pathogens in biosolids have been reduced to a level so that it could be used for agricultural production or disposal in a landfill where there is limited access to the public and grazing animals.

The common methods for Class B process are:

- Digestion

- Composting
- Heating
- Increased pH (lime addition)

Class B has both less standard requirements and less scope of applicability.

The requirements for Class A biosolids standards are shown in the following tables 3.2 and 3.3. If any one of the standards is met, then EPA considers them as Class A Biosolids.

Table 3.2: Summary of Class A Pathogen Reduction Requirements

Alternative 1: Thermally treated Biosolids
Biosolids must be subjected to one of four time-temperature regimes. These regimes are listed in Table 3.3.
Alternative 2: Biosolids treated in a high pH-High Temperature Process
Biosolids need to meet specific pH, temperature and air drying requirements.
Alternative 3: Biosolids treated in other processes
Demonstrate that the process can reduce enteric viruses and viable helminth ova. Maintain operating conditions used in the demonstration after the demonstration is completed.
Alternative 4: Biosolids Treated in Unknown Processes
Biosolids must be tested for *Salmonella* sp. or fecal coliform bacteria, enteric viruses, and viable helminth ova at the time the biosolids are used or disposed
Alternative 5: Biosolids Treated in PFRP
Biosolids must be treated in one of the Processes to Further Reduce Pathogens (Table 3.3)
Alternative 6: Biosolids Treated in a Process Equivalent to a PFRP
Biosolids must be treated in a process equivalent to one of the PFRPs as determined by the permitting authority.

Table 3.3: Time-Temperature Regimes for Meeting Class A Requirements

Regime	Applies to	Requirement	Time-Temperature Relationship
A	Biosolids with 7% solids or greater (Except those covered by Regime B	Temperature of Biosolids must be 50°C or higher for 20 minutes or longer	$D = \frac{131{,}700{,}000}{10^{0.14t}}$
B	Biosolids with 7% solids or greater in the form of small particles and heated by contact with either warmed gases or an immiscible liquid	Temperature of Biosolids must be 50°C or higher for 15 seconds or longer	$D = \frac{131{,}700{,}000}{10^{0.14t}}$
C	Biosolids with less than 7% solids	Heated for at least 15 seconds but less than 30 minutes	$D = \frac{131{,}700{,}000}{10^{0.14t}}$
D	Biosolids with less than 7% solids	Temperature of sludge is 50°C or higher with at least 30 minutes or longer contact time	$D = \frac{50{,}070{,}000}{10^{0.14t}}$

*D=time in days and t= temperature in degree Celsius

(Source: A Plain Guide to the EPA Part 503 Biosolids Rule, 2012)

Also, the pathogen requirements must be met for all the alternatives to be considered as Class A biosolids. As per the pathogen requirement, either the density of fecal coliform must be less than 1,000 most probable numbers (MPN) per gram total solids (dry-weight basis) (A Plain Guide to the EPA Part 503 Biosolids Rule, 2012) or the density of *Salmonella* sp. bacteria must be less than 3 MPN per 4 grams of total solids (dry-weight basis) (A Plain Guide to the EPA Part 503 Biosolids Rule, 2012)

for being considered as Class B, biosolids need to meet one of the three alternatives listed in Table 3.4.

Table 3.4: Summary of Class B Pathogen Reduction Requirements

Alternative 1: The monitoring of Indicator Organism
Test for fecal coliform density as an indicator for all pathogens. The geometric mean of seven samples shall be less than 2 million MPNs per gram of total solids or less than 2 million CFUs per gram of total solids at the time of use or disposal.
Alternative 2: Biosolids treated in a PSRP
Biosolids need to be treated in one of the Processes to Significantly Reduce pathogens (PSRP) Table: 3.5
Alternative 3: Biosolids treated in a Process Equivalent to PSRP
Biosolids must be treated in a process equivalent to one of the PSRPs, as determined by the permitting authority.

(Source: A Plain Guide to the EPA Part 503 Biosolids Rule, 2012)

Vector Attraction Reduction Requirements

When the pathogens in the biosolids come into contact with human or other susceptible hosts as plant or animal, they pose a significant amount of risk of spreading diseases. Pathogens can be transmitted to human and other sources by vectors such as birds, flies, mosquitoes, flea and rodents. So, chances for transmitting diseases from pathogens in biosolids decrease if vectors are less attracted to it.

40 CFR Part 503 contains 12 options for vector attraction reduction which are summarized in Table 3.5. These requirements are designed to either reduce the attractiveness of biosolids to vector contact with the biosolids.

Table 3.5: Summary of Options for Meeting Vector Attraction Reduction

Option No.	Description
1	Meet the 38% volatile solids content reduction
2	Demonstration of vector attraction reduction with additional anaerobic digestion in a bench scale unit
3	Demonstration of vector attraction reduction with additional aerobic digestion in a bench scale unit
4	Meet a specific oxygen uptake rate for aerobically digested biosolids
5	Use the anaerobic process at 40°C for 14 days or longer
6	Alkali addition under specified conditions
7	Dry biosolids with no unstabilized solids to at least 75% solids
8	Dry biosolids with unstabilized solids to at least 90% solids
9	Inject biosolids beneath the soil surface
10	Incorporate biosolids into the soil within 6 hours of application to or placement on a land
11	Cover biosolids placed on a surface disposal site with soil or other material by the end of each operating day
12	Alkaline treatment of domestic septage to pH 12 or above for 30 minutes without adding more alkaline material

(Source: A Plain Guide to the EPA Part 503 Biosolids Rule, 2012)

Among these options, No. 12 is only for domestic septage. for fulfilling the vector attraction reduction requirements, one of the first eleven options should be met.

3.3 Surface Disposal of Biosolids

Monofills are landfills where only biosolids are disposed. The mode of placement can be either trench or area fill. With area fill, excavation is not required and the biosolids can be placed on the ground surface in mounds, layers, or diked impoundments. Surface impoundments and lagoons are disposal sites where biosolids with higher water content are placed in an open area. (If lagoons are used for treatment, they are not considered surface disposal sites.) Waste piles are mounds of dewatered biosolids placed on the ground surface for final disposal. Dedicated disposal sites can receive repeated applications of biosolids for the sole purpose of disposal. (Handbook of Environmental Engineering).

There are some other requirements for surface disposal of biosolids. The part 503 standard for surface disposal of biosolids includes:

- General requirements
- Pollutant limits
- Management practices
- Operational standards for pathogen and vector attraction reduction
- Frequency of monitoring requirements
- Record keeping requirements and
- Reporting requirements.

3.4 Landfill Placement of Biosolids

For landfill disposal, a number of factors must be evaluated. One important consideration is how to best handle the dewatered sludge and place it in the landfill. Municipal solid waste currently placed in the Grand Forks Landfill is baled to minimize attraction of birds to the site. Thus it will most probably be necessary to bale or similarly package the biosolids. Another possible option is to use the sludge as daily cover for the landfill. This would be advantageous because it would minimize the amount of landfill space taken up by the sludge. However there may be problems with using the existing landfill equipment and placement methods to apply sludge as daily cover. If GFWWTP biosolids were to be used for daily cover, it would probably be necessary to blend in soil to improve the handling and compaction properties.

A further consideration with landfilling is whether sludge placement can enhance methane generation within the landfill. The Grand Forks Service Safety Committee has expressed interest in evaluating the potential for generating and collecting methane at the Grand Forks Landfill. Since the wastewater treatment sludge is mostly organic material, it will produce methane gas as it degrades. However a number of factors will affect methane generation. Extent of sludge digestion, temperature and moisture content in the landfill are important factors. The method used for placing the sludge in the landfill will also affect methane production. If the landfill is to be used for methane production, a gas collection system; a leachate recirculation system; and a perched water control system will have to be designed as well. A study was conducted by Black and Veatch Consultants to evaluate the feasibility of using the Grand Forks landfill for generating methane gas and the findings will be discussed in this report.

4 METHODOLOGY

This study was divided into two different tasks. The first task involved collecting general information about biosolids disposal methods in North Dakota regional area. The second task involved estimating the cost of the surface disposal method for GFWWTP. The following are the two tasks:

4.1 Task 1: Evaluation of the Wastewater Biosolids Reuse and Disposal Trends

The City of Grand Forks is situated in the Great Plains with extreme temperature conditions. The recorded lowest temperature of -43^{of} (January 30, 2004)[2] demands considering climate as an important factor this study on biosolids disposal for GFWWTP. In this first task, a telephone survey was conducted to study the current practices of biosolids disposal in the North Dakota region, following a literature study. The survey results are provided in Appendix II. The following steps are the detailed description:

1. A list of cities in the Midwest that had population similar to Grand Forks was populated in a table. (Table provided in Appendix-I)

2. A table of municipal waste water treatment plant contact personnel was also populated from EPA permits.
3. A phone survey questionnaire was drafted. (See Appendix II)
4. The list of contacts was revised for unavailable phone numbers.
5. The questionnaire was revised, along with literature review.
6. Literature was reviewed on the biosolids management processes.
7. Literature was reviewed on extreme weather condition disposal.
8. Literature was reviewed on 40 CFR 503 and the necessary practices to be introduced under the EPA regulations.
9. The Grand Forks landfill personnel and site operators were interviewed for their attitude towards sludge disposal.
10. The Grand Forks Waste Water Treatment Plant was surveyed.
11. Biosolids were sampled and tested for analysis and agronomic information.
12. A market study for composted and un-composted biosolids demands was conducted.
13. The landfill site methane reclamation alternative was reviewed.
14. Approximate annual dewatered biosolids volumes, estimated solids content and federal compliance information were collected. These data will be used to develop cost information for land application.
15. Land application costs for both vehicular transportation and pipeline transportation methods were estimated following cost calculation algorithms of USEPA handbook: Estimating sludge management costs. (1985) The cost algorithms are described in following section.

16. A final report on biosolids management was developed and submitted.

4.2 Task 2: Cost Estimation

The cost of surface disposal method was estimated with two different transportation systems for a comparative study. The method provided in EPA Handbook of cost estimation (1985) was followed. The base year for this cost estimation was considered 1984, the 1984 costs were inflated to current year (2013) using the Marshall and Swift Cost Index (MSECI) and the Engineering News Record Construction Cost Index (ENRCCI). All costs were calculated based on the USEPA- provided data with Handbook of Cost Estimation (1985). Since the current market price of the gas did not match the inflated diesel costs per gallon, the current market price was used. The detailed description of the methodology of cost estimation follows:

Steps:

1. Dry solids generation in dry-tons/year was calculated from solids concentration and flow data.
2. Biosolids application requisite area was calculated from the solids concentration data provided by GFWWTP.
3. Biosolids application rate was followed by vehicle application rate calculation. Vehicle capacity data were generated utilizing biosolids application rate.
4. Total land area requisite was estimated via vehicle biosolids application rate. Round cycle time taken from EPA Handbook of cost estimation (1985).
5. Land area requisite for lime addition follows the land area calculation.
6. Earthwork required and numbers of monitoring wells were calculated.

7. The number of labor operation hours per year and annual consumption of vehicle diesel fuel were estimated.
8. The cost of land per year was assumed to be insignificant, as it was assumed that biosolids will be disposed in a land reclamation site or city owned property.
9. The annual cost of lime addition to adjust pH of the soil, annual cost of grading earthwork, and annual cost of monitoring wells were also calculated.
10. The cost of onsite mobile biosolids application vehicles and annual cost of operation labor were estimated using the 1985 USEPA cost handbook. It was inflated to current year (2013) using the Marshall and Swift Equipment Cost Index (MSECI) and the Engineering News Record Construction Cost Index (ENRCCI).
11. Although the USEPA cost estimation hand book suggested following its values, but as diesel price has inflated more than the theoretical value, the diesel price was estimated to be the current state average diesel price, because the current price exceeded the theoretical inflation.
12. The annual costs of maintenance of the land reclamation site (other than vehicles) for monitoring, recordkeeping, etc. were also projected.
13. The total base capital cost was estimated along with annual operation, maintenance, land, and earthwork cost.

5 TASK 1: EVALUATION OF WASTEWATER SLUDGE REUSE AND DISPOSAL TRENDS

This section makes an effort to provide an overview of current methods being used at other municipal wastewater treatment plants to dispose of or beneficially reuse their biosolids. The discussion will be limited to waste activated sludge (WAS) because this is by far the largest sludge stream produced at the GFWWTP. The discussion will begin with a general description of national and regional trends in sludge management, and then continue on to sludge management practices at specific plants that may be directly applicable to the GFWWTP.

5.1 National Biosolids Management Trends

According to "A National Biosolids Regulation, Quality, End Use& Disposal Survey"[1], about 7,171,000 dry (U.S.) tons of biosolids were beneficially used or disposed of in the U.S. in 2004. The detailed descriptions of the survey are as following:

- About 49% (3,502,845 dry tons) were applied to soils for various beneficial purposes
- About 45% (3,247,666 dry tons) were disposed of in municipal solid waste landfills, other types of surface disposal units, and/or incinerators.

- The remaining 6% (420,712 dry tons) were managed by other methods such as long term storage, etc.
- About 759,347 dry tons of biosolids applied to soil met the EPA criteria for exceptional quality (EQ) biosolids. Since utilization of EQ biosolids requires minimal documentation, much of this material was publicly distributed for a variety of purposes including landscaping, horticulture, and agriculture.
- About 2,743,498 dry tons of biosolids not meeting the EQ criteria were applied to soil on farmlands for agricultural purposes. Small percentages of these biosolids were also used for land restoration and silviculture.
- for the 3,247,666 dry tons disposed of, about 2,023,508 dry tons were disposed of in municipal solid waste landfills, about 142,684 dry tons were placed in other surface disposal sites, and about 142,684 dry tons were sent to incinerators.

Figure 5.1 shows a breakdown of the dry (U.S.) tons of biosolids disposed of and recycled for various beneficial uses in the U.S. in 2004. Figure 5.2 shows a breakdown of how the fraction of biosolids being disposed of was handled.

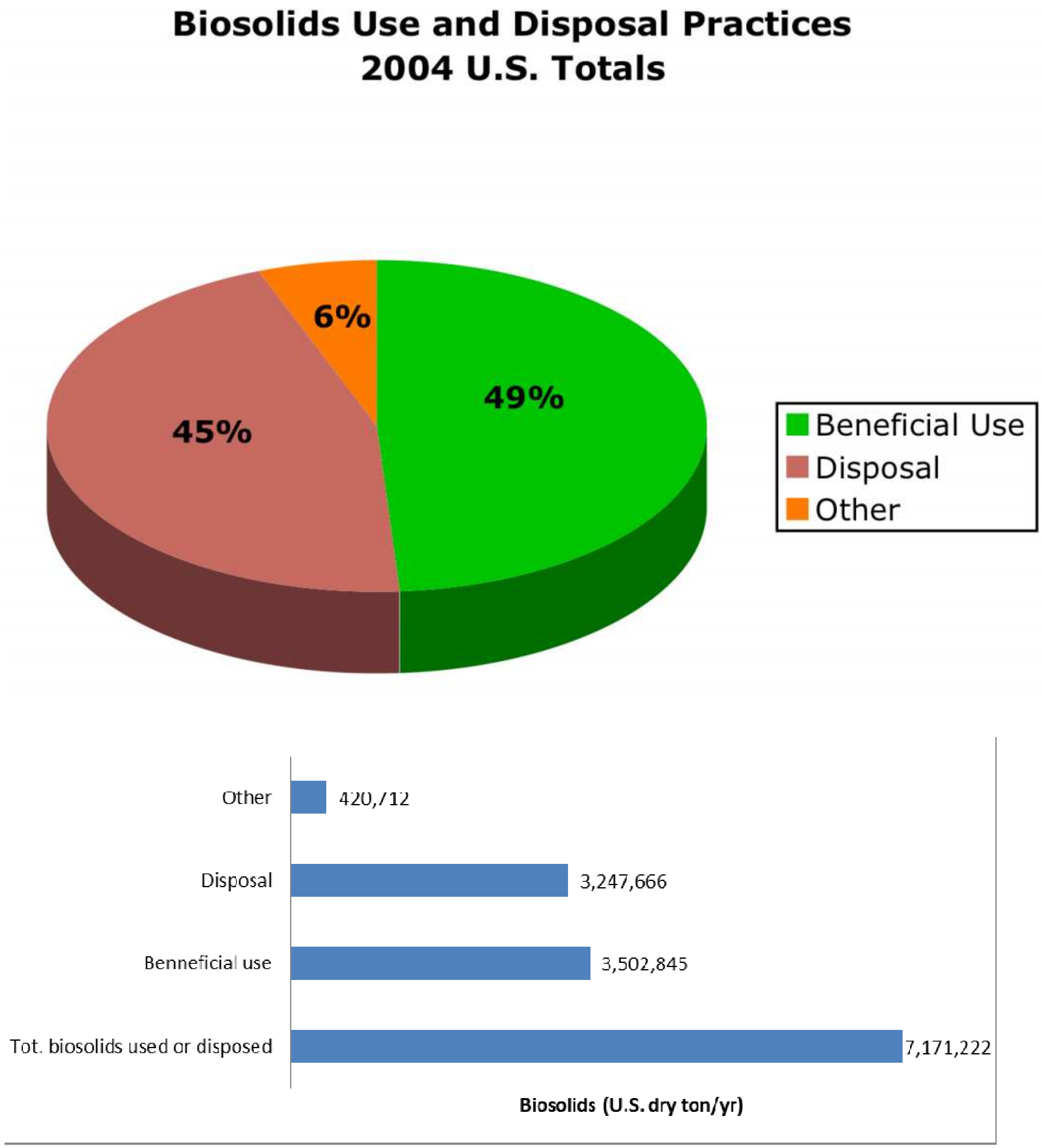


Figure 5-1: Total Biosolids Use and Disposal in U.S. (2004).

Source: "A National Biosolids Regulation, Quality, End Use& Disposal Survey" (2004) and "Wastewater Reuse and Disposal Trends" (2004) by Dr. Charles Moretti.

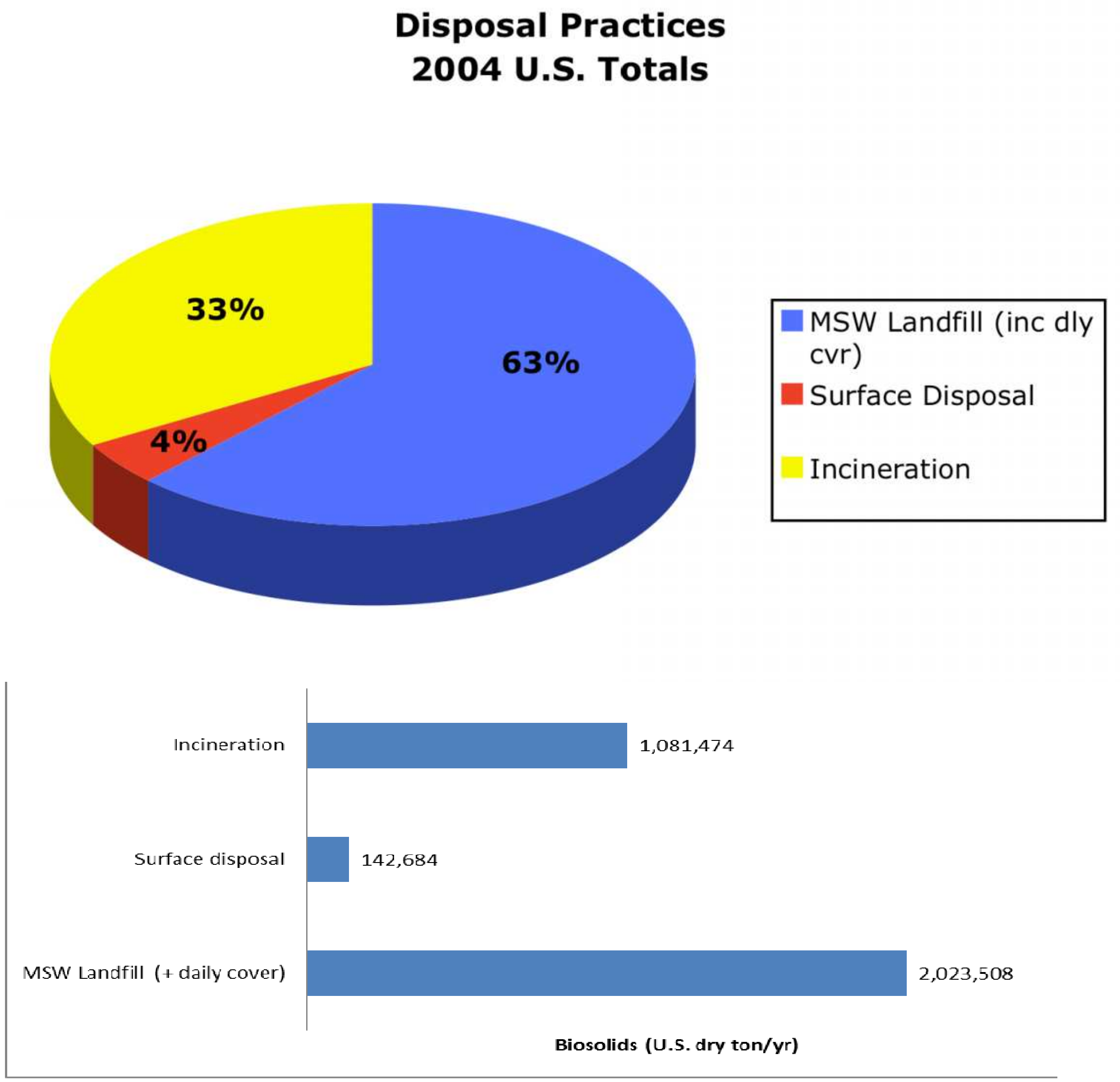


Figure 5-2: Disposal Methods for Biosolids in U.S.

Source: "A National Biosolids Regulation, Quality, End Use& Disposal Survey" (2004) and "Wastewater Reuse and Disposal Trends" (2004) by Dr. Charles Moretti.

When biosolids are being recycled for a beneficial use like land application, the material can be classified under the 40 CFR Part 503 regulations as meeting Class A or Class B standards for pathogen reduction. This classification is important for land application.. The following quality classification breakdown applies to the biosolids produced in the U.S. in 2004:

- About 1,651,400 dry tons met the Class A pathogen removal standard (almost all of these biosolids also met the EQ criteria)
- About 2,441,200 dry tons met the Class B pathogen removal standard
- for the remaining 3,087,400 dry tons, there was no data indicating whether the biosolids met either the Class A or the Class B standards

Figure 5.3 shows a breakdown of the amounts of different types of biosolids produced in the U.S. in 2004 and Figure 5.4 shows a breakdown of the amounts of biosolids used for various beneficial uses in the U.S. in 2004. From the figures, it appears that most of the Class B biosolids were used for agricultural purposes, but that only about half of the exceptional quality biosolids produced was distributed to the public.

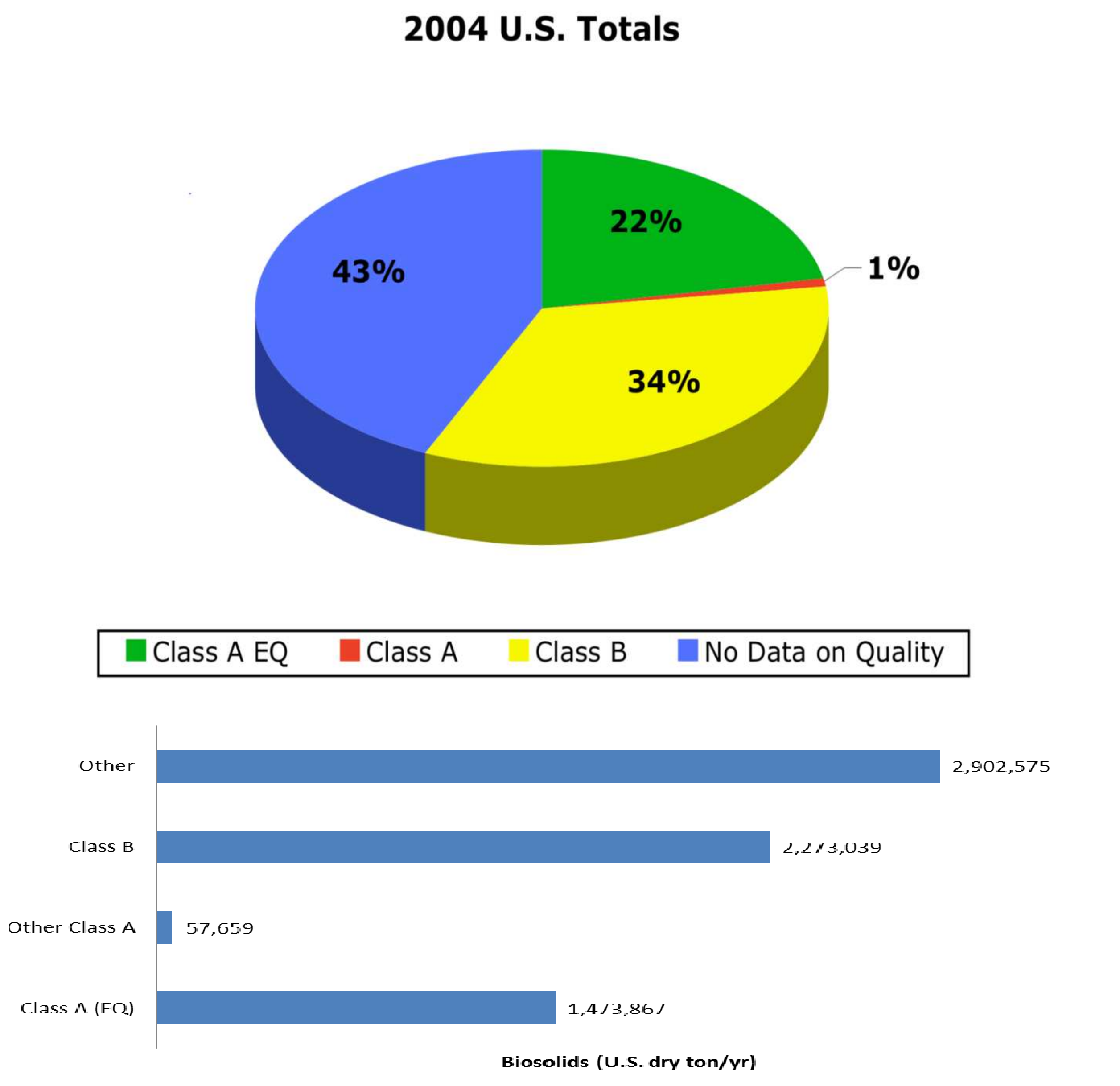
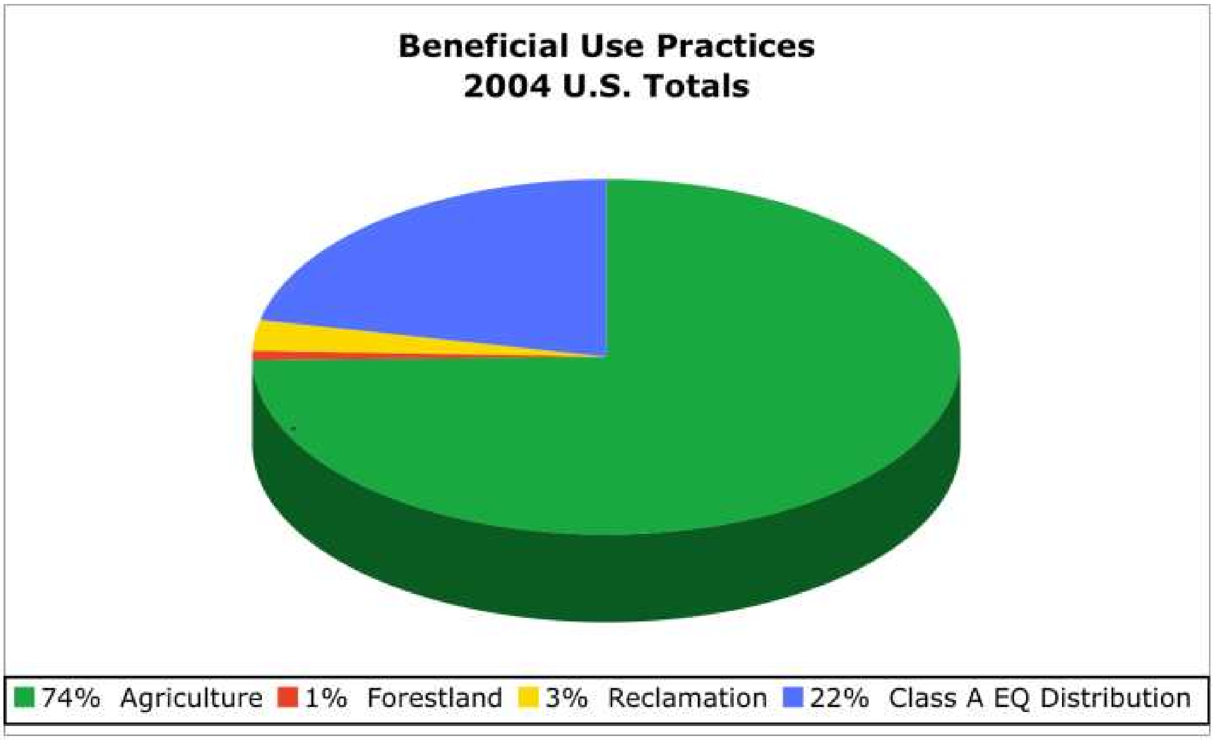


Figure 5-3: Biosolids Quality Classification in the U.S.

Source: “A National Biosolids Regulation, Quality, End Use& Disposal Survey” (2004) and “Wastewater Reuse and Disposal Trends” (2004) by Dr. Charles Moretti.



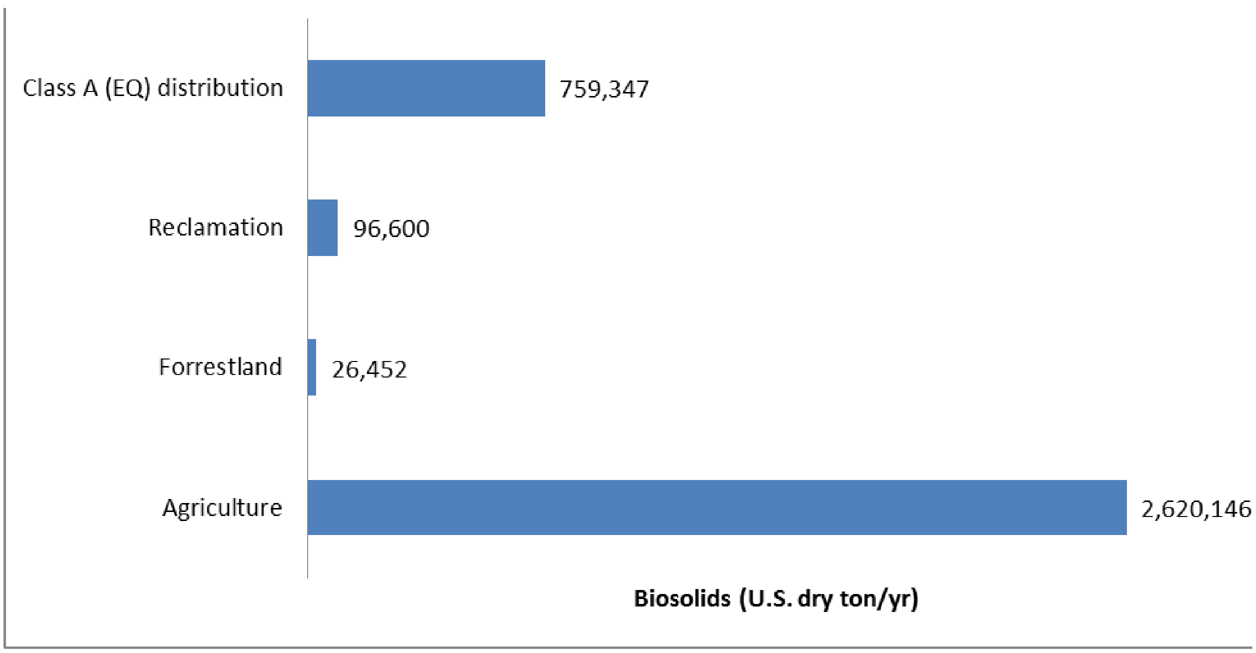


Figure 5-4: Beneficial Practices 2004 in U.S.

Source: "A National Biosolids Regulation, Quality, End Use& Disposal Survey" (2004) and "Wastewater Reuse and Disposal Trends" (2004) by Dr. Charles Moretti.

5.2 Biosolids Management Trends in the North Dakota Region

Additional research was done for information about biosolids management the State of North Dakota and the surrounding States of Iowa, Minnesota, Montana, South Dakota, and Wyoming.

5.2.1 Biosolids Management in Iowa

According to the National Biosolids Survey[1], about 66,660 U.S. dry tons of biosolids were produced in Iowa in 2004. Most of that was applied to agricultural land as Class B biosolids. A small percentage of the biosolids were distributed for public use as EQ material, and much of the remaining material was disposed of by incineration.

A breakdown of usage and disposal practices for Iowa is shown in Figure 5.5. Table 5.1 contains information about biosolids management in nine Iowa cities[1]. Information for Table 5.1 was obtained from the world-wide-web and from conversations with wastewater treatment plant personnel. Five of the nine cities listed in Table 5.1 stabilized their waste activated sludge with anaerobic digestion and three of the five used a belt filter press to dewater the stabilized sludge. Five of the nine cities used land application as the only use/disposal option and two cities used land application as an option along with disposal. One city used composting as the only usage option/disposal, one city used incineration as the sole disposal method, and one city indicated that incineration was a disposal option.

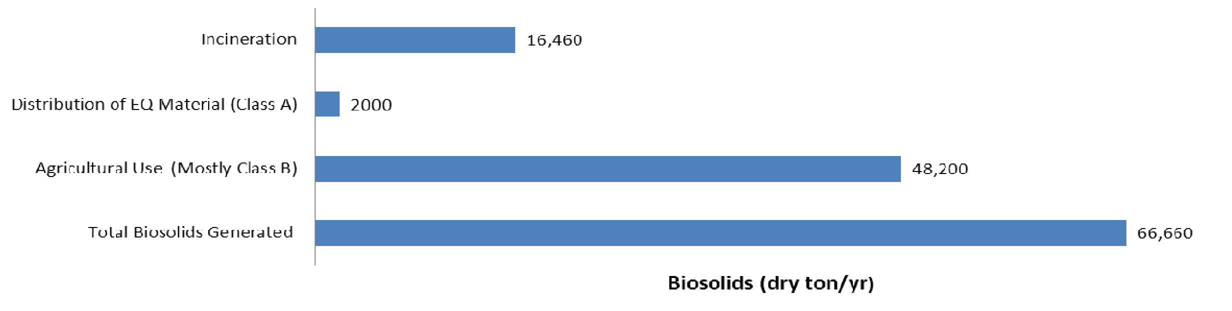


Figure 5-5: Biosolids Management and Practices

Source: " Wastewater Reuse and Disposal Trends" (2004) by Dr. Charles Moretti.

Table 5.1:Biosolids Management Practices in Nine Cities in Iowa

City	Population	Biosolids Management
Des Moines	203,433	Anaerobic digestion; Belt filter dewatering; Land application
Cedar Rapids	126,326	Centrifuge dewatering, Incineration or Land application or Landfill
Davenport	99,685	Anaerobic digestion; Belt filter dewatering; Composting
Sioux City	82,684	Filter press dewatering; Land application or landfill
Waterloo	68,406	Anaerobic digestion; Belt filter dewatering; Land application
Iowa City	76,862	Anaerobic digestion; Dewatering of some biosolids; Land application
Council Bluffs	62,230	Anaerobic digestion; Land application
Dubuque	57,637	Incineration
Muscatine	22,886	Land Application of waste activated sludge

5.2.2 Biosolids Management in Minnesota

The largest population center in the state of Minnesota is the Minneapolis/St. Paul metropolitan area. The Metropolitan Council Environmental Services operate six wastewater plants in this area that serve most of the communities in the region. See Figure 5.7 for the locations of the six "Metro" wastewater treatment plants. Biosolids from four of the Metro plants are incinerated. The other two plants process their biosolids for land application. The Blue lake plant dries biosolids to pellet form and distributes the material for fertilizer. The Empire Plant does land application of biosolids. The effect of the Metro plants can be seen in Figure 5.6, which shows that more than half of the biosolids produced in Minnesota are incinerated[1]. The larger cities outside of the Minneapolis/St. Paul area that have mechanical treatment plants do land application of their biosolids. In all, about 30% of the biosolids produced in Minnesota are land applied. Table 5.2 shows a breakdown of biosolids management practices in cities in Minnesota

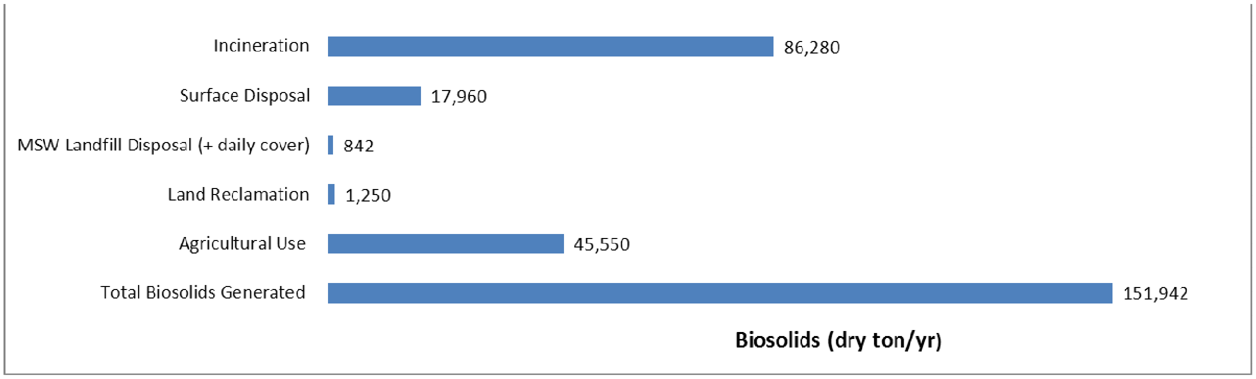


Figure 5-6: Biosolids Management Practices in Major Cities in Minnesota

Source: "A National Biosolids Regulation, Quality, End Use& Disposal Survey" (2004) and "Wastewater Reuse and Disposal Trends" (2004) by Dr. Charles Moretti.

Table 5.2. Biosolids Management Practices in Major Cities in Minnesota

City or WWTP	**Population or Number of Communities served**	**Wastewater Treatment/Biosolids Management**
Metro (MCES Plant)	65 Communities	Incineration
Seneca (MCES Plant)	8 Communities	Incineration
Eagles Point (MCES Plant)	2 Communities	Incineration
Hastings (MCES Plant)	1 Community	Incineration
Blue Lake (MCES Plant)	29 Communities	Biosolids dried and pelletized for fertilizer
Empire (MCES Plant)	5 Communities	Anaerobic digestion, land application
Rochester	100,413	Anaerobic digestion, land application

Duluth	84,284	Anaerobic digestion, dewatering, land application
St. Cloud	66,948	Anaerobic digestion, land application
Mankato	36,245	Anaerobic digestion, belt filtration, land application
Willmar	18,351	Anaerobic digestion, land application

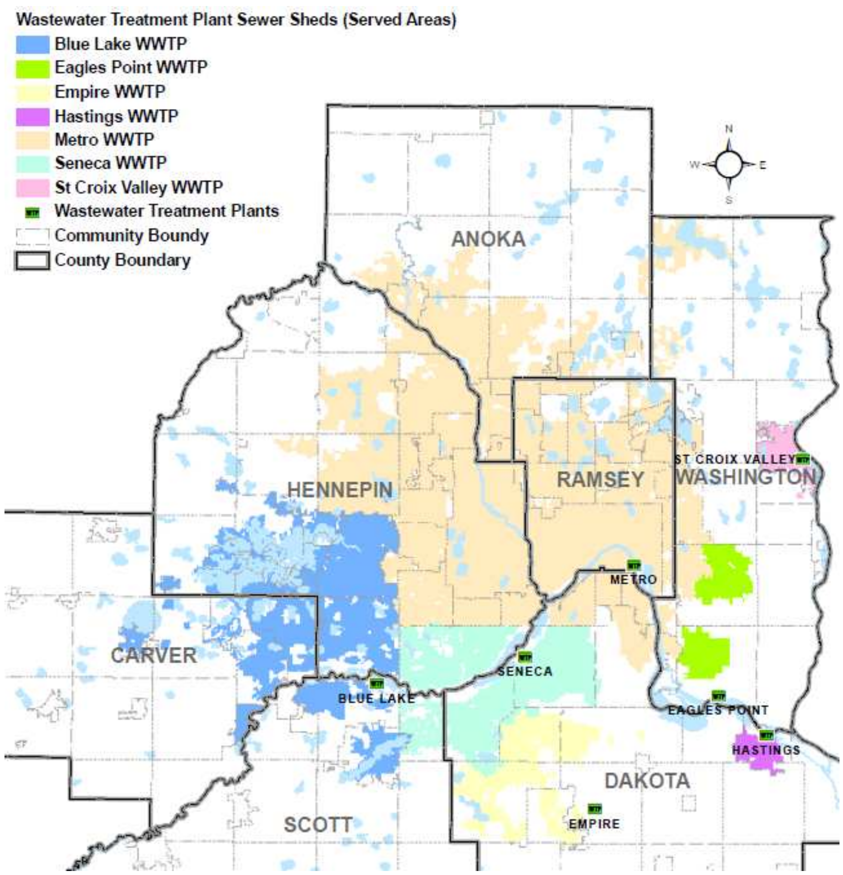


Figure 5-7: Location of Six Metro Wastewater Treatment Plant in Minneapolis Metropolis

5.2.3 Biosolids Management in Montana

About two thirds of the biosolids produced in Montana are used for some form of land application. About half of the land application biosolids is directly applied to farmland, one third is used for mine land reclamation, one sixth is processed for dry fertilizer, and a small fraction is applied to rangeland. It is interesting to note that the City of Missoula sends their biosolids to EKO Composting. EKO is a company that produces dried fertilizer from biosolids and then bags and sells the product. A breakdown of biosolids use and disposal in Montana is shown in Figure 5.8. Table 5.3 lists the biosolids management practices for some of the largest cities in Montana. This information was obtained from personal contacts and a search of the Web.

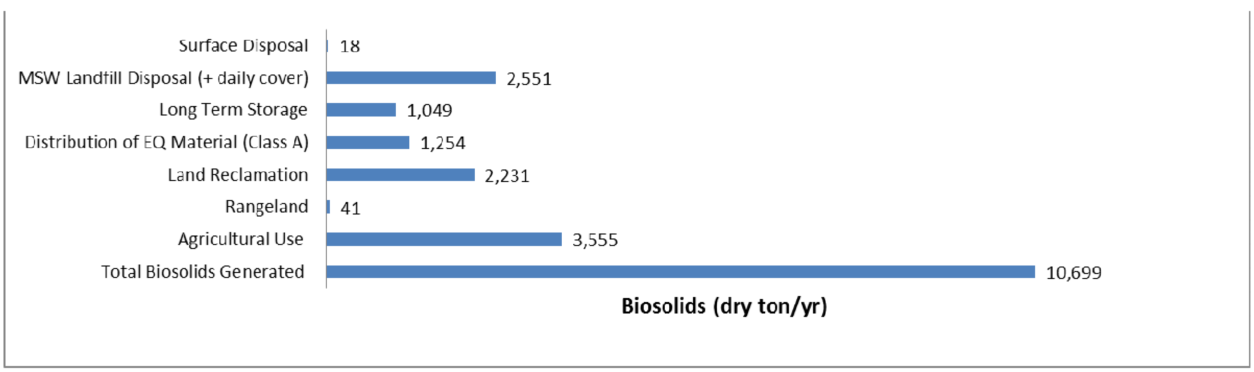


Figure 5-8 Montana Biosolids Beneficial Use (2004)

Source: “A National Biosolids Regulation, Quality, End Use& Disposal Survey” (2004) and “Wastewater Reuse and Disposal Trends” (2004) by Dr. Charles Moretti.

Table 5.3: Biosolids Management Practices in Major Cities in Montana

City	Population	Wastewater Treatment/Biosolids Management
Billings	103,994	Anaerobic digestion, centrifuge dewatering, landfill
Missoula	68,202	Digestion, belt press dewatering, biosolids sent to EKO Composting for processing
Great Falls	59,251	Digestion, centrifuge dewatering, landfill
Bozeman	39,442	Anaerobic digestion, land application (biosolids injection)
Butte-Silver Bow	32,119	No information available on biosolids
Helena	29,351	Composting

5.2.4 Biosolids Management in North Dakota

The City of Fargo is the largest producer of wastewater treatment biosolids in the State of North Dakota. The Fargo WWTP treats waste sludge with anaerobic stabilization, the digested sludge is dewatered either with a belt press or drying beds, and the dewatered biosolids are sent to the Fargo landfill. At the landfill, the biosolids are co-disposed with other solid waste. Fargo's biosolids make up about 82% of the total biosolids being either utilized or disposed of in North Dakota. The City of Bismarck is also a major producer of biosolids in the State. Bismarck treats waste sludge with anaerobic digestion and then applies the stabilized sludge directly to farmland. Bismarck accounts for the 1400 U.S. dry tons of biosolids used for agriculture shown in Figure 5.9. The other two large cities in North Dakota are Grand Forks and Minot. Both of these cities send their biosolids to lagoons for long term treatment. Table 5.4 lists the biosolids management practices for some of the largest cities in North Dakota. This information was obtained from personal contacts and a search of the Web.

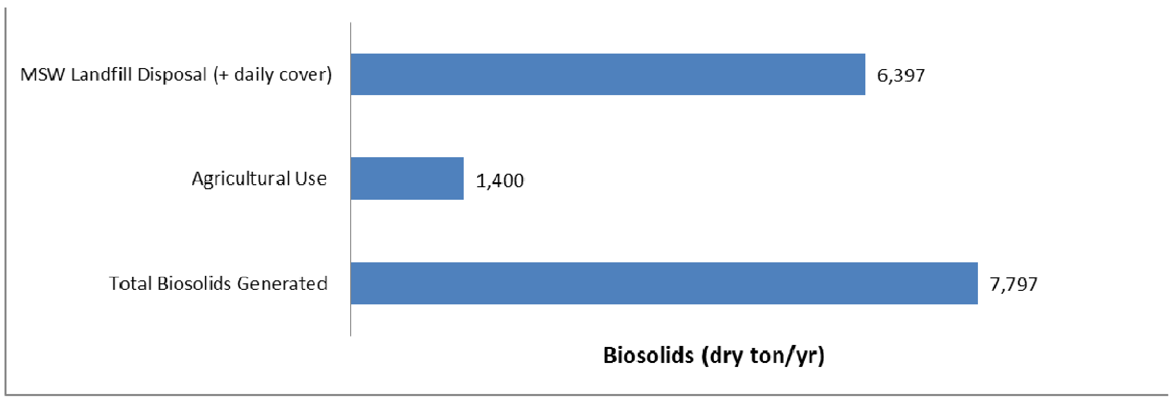


Figure 5-9: North Dakota Beneficial Use and Disposal

Source: "A National Biosolids Regulation, Quality, End Use& Disposal Survey" (2004) and "Wastewater Reuse and Disposal Trends" (2004) by Dr. Charles Moretti.

Table 5.4: Biosolids Management Practices in Major Cities in North Dakota

City	**Population**	**Wastewater Treatment/Biosolids Management**
Fargo	93,531	Anaerobic digestion, belt filtration , landfill
Bismarck	60,389	Anaerobic digestion, land application (biosolids injection)
Grand Forks	52,838	Long term treatment in lagoons
Minot	40,888	Long term treatment in lagoons

5.2.5 Biosolids Management in South Dakota

Wastewater treatment plants in South Dakota utilize about 62% of their biosolids for some form of land application. Most of the biosolids are used for application to cropland and a small fraction is used for land reclamation. About 5% of the biosolids are processed to produce EQ material that is distributed for public use. Figure 5.10 shows the breakdown of usage and disposal practices in South Dakota[1]. Table 5.5 is a list of the biosolids management practices for some of the largest cities in Montana. This information was obtained from personal contacts and a search of the Web.

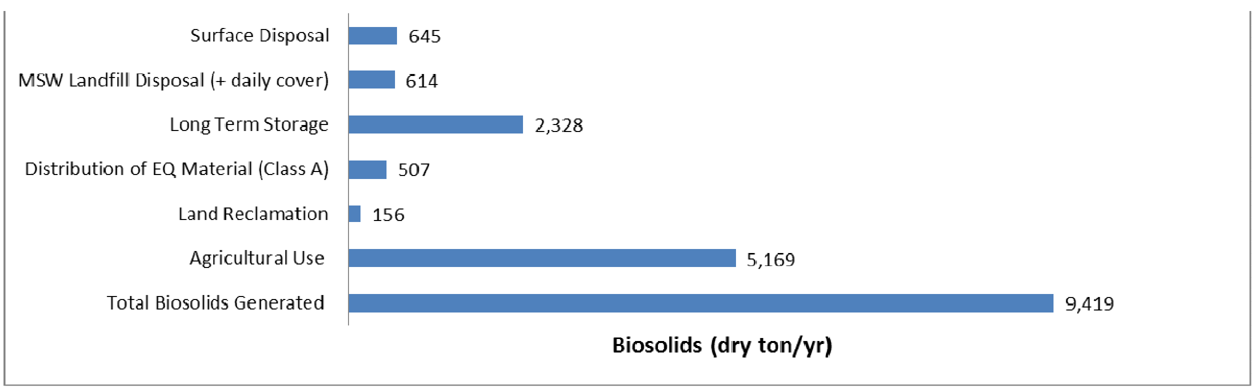


Figure 5-10: South Dakota Biosolids Beneficial Use and Disposal

Source: “A National Biosolids Regulation, Quality, End Use& Disposal Survey” (2004) and “Wastewater Reuse and Disposal Trends” (2004) by Dr. Charles Moretti.

Table 5.5: Biosolids Management in Major Cities in South Dakota

City	Population	Wastewater Treatment/Biosolids Management
Sioux Falls	154,997	Anaerobic digestion, land application
Rapid City	65,491	Biosolids composting, landfill
Aberdeen	24,460	Anaerobic digestion, land application
Watertown	20,488	Land application
Brookings	19,865	Land application, landfill
Pierre	13,899	Landfill
Yankton	13,798	Land Application
Huron	11,033	Land application
Vermillion	10,495	Anaerobic digestion, land application
Spearfish	10,010	Land application (daily cover)

5.2.6 Biosolids Management – Some Case Studies

Bismarck, North Dakota

The biosolids management program at the Bismarck Municipal Wastewater Treatment Plant (BWWTP) may also provide useful guidance for the GFWWTP. The BWWTP differs from the GFWWTP in that it does anaerobic digestion on primary sludge that contains trickling filter humus in addition to primary solids. However the Bismarck's management practices are worth reviewing because it is the only large municipal treatment plant in North Dakota that does land application of digested solids.

The BWWTP treats an average flow of about 6.5 MGD. The biosolids produced from the anaerobic digester are stored in three, 1.2 MG tanks and land applied to farmland in the spring, summer and fall. The 1400 dry tons/yr of biosolids are thickened from 2.5% solids to about 6% solids in the storage tanks. Biosolids are applied to about 3500 acres of farmland mostly in cornfield; however only about 700 acres is used for application in any one year. The biosolids are sprayed on the land by the BWWTP and then immediately disked into the ground. The biosolids are transported as much as 20 miles one way from the BWWTP for application. Though the authority was under the impression that that it was less expensive than other alternatives such as landfill disposal, authority was unable to provide any costs.

Sioux Falls, SD

The Wastewater Treatment Plant of Sioux Falls, SD (SFWWTP) was also investigated for this study. The Plant had design capacity of 21 MGD with 51,240 lbs/day BOD loading and 43,900 lbs/day TSS loading. It is currently running at two thirds of its capacity. The plant current flow is 14.47 MGD with a loading of 28,816 lbs/day BOD and 27,849 lbs/day TSS.

SFWWTP utilizes anaerobic digester to treat biosolids, which are sub-sequentially stabilized. The digestion process occurs in a sealed, heated reactor employing naturally ascending bacteria. Pathogen reduction and biosolids stabilization processes follow the digestion process to meet the standard of vector attraction.

Biological solids in the sludge are transformed to a gas. The gas is containing 60% methane & 40% carbon dioxide which is used to generate power. In 2009, 3,652,675 kilowatt hours of electricity were generated and most of it was utilized at the WWTP facility. Three hundred homes were getting electric service from the plant. Waste heat generated from the generators is also used to heat the digesters and supply some of the SFWWTP building heat.

Rapid City WWTP, SD

The Rapid City WWTP (RCWWTP) uses activated sludge systems to treat the waste water and anaerobic digester to digest the biosolids. The solids concentration of biosolids is 7%. Digestion process is followed by mixing, co-composting and landfill disposal. Drying beds are used as a part of a landfill disposal process options. The final solids content of the biosolids before landfill disposal is 28-29%. Since the landfill site had its own ground water monitoring system, the WWTP didn't require any new well installations.

Helena WWTP, MT

The WWTP of Helena uses a surface injection method for their biosolids disposal. During summer, the injection process is restricted to 100 to 140 days of application. The solids concentration of the biosolids is about 2%. The belt-press drying process is used during winter to reach a solids concentration up to 16~17%. The dried, anaerobically digested sludge is then hauled to a compost facility.

Edmond, Oklahoma

The wastewater treatment plant at Edmond, Oklahoma is similar to the GFWWTP in terms of its size and wastewater treatment scheme. The plant has three facultative lagoons for sludge storage. The role of each lagoon is rotated on an annual basis. At any time, one lagoon is receiving fresh biosolids from the plant, sludge feed to another lagoon is taken out of service and the accumulated biosolids are allowed to naturally degrade and stabilize, and the third lagoon is drained to remove the biosolids. Most of the time, the lagoons operate without any need for special attention. Occasionally mechanical aeration is used to control odors. When the biosolids are treated in the lagoons, there is a 75 to 85% reduction in volatile suspended solids. During treatment, there is almost complete die off of total coliform bacteria after six months. After treatment, the biosolids meet bacterial requirements for Class A biosolids, although they are not officially recognized as Class A material by the state regulatory group.

After the treatment phase, the free water is decanted from the lagoon. After decanting, the residual biosolids have a dry solids content of 4 to 4.5%. With this solids content, the biosolids are easily pumped from the lagoon into a tanker truck. The biosolids are transported to local farms and spread on the surface of grassland fields. Before the material is applied, the fields are prepared with a special roller with deep tynes that creates holes in the ground. The biosolids are applied as a liquid and fills the holes. Then a beater device with chains attached is used to work the surface and cover the holes.

The biosolids have to be worked into the ground within six hours after application. Field application is typically about 30,000 gal per acre per year and is limited by the nitrogen content of the sludge.

The wastewater treatment plant produces about 520 to 540 metric dry tons of sludge per year. It takes a few weeks to dredge and pump the biosolids out of the lagoon, which is done in late July/early August. In 2009, about 2.3 MG of sludge was transported from the plant to local fields in a 10 day period in July. The estimated cost of transporting and applying the biosolids is $225,000 to $325,000 per year. The land owners are not charged for the biosolids. The land application cost quoted by the superintendent of the Edmond, OK plant for their biosolids was $470 per dry ton. for comparison purposes, the EPA reports a cost range between $88 and $425 (adjusted for this report from 1996 to 2012 dollars) per dry ton for land application of biosolids. This range reflects a wide variety of land application methods and in some cases additional biosolids treatment steps such as dewatering.

6 TASK 2A: COST CALCULATIONS FOR VEHICULAR APPLICATION OF GFWWTP BIOSOLIDS TO A LAND DISPOSAL SITE

This chapter offers estimated costs for the biosolids land disposal systems. The disposal scenario study consisted of transporting the biosolids from the GFWWTP to the old Grand Forks Landfill for direct land application and ultimate disposal. The two biosolids transportation options considered and compared were:

- Truck Transportations
- Pipeline Transportations

Land disposal costs might be significantly reduced for the GFWWTP if the biosolids are applied to public land owned by the City of Grand Forks. The current landfill site is located within a few miles of the GFWWTP. The previous city municipal solid waste (MSW) landfill that was taken out of service a few years ago is situated south- southeast of the current GFWWTP and adjacent. Biosolids could be applied to the final cover to enrich the soil and promote a better stand of vegetation. The biosolids are transported (either by truck or pipeline) to the old Grand Forks landfill for application for either land reclamation or dedicated direct disposal. As there was no suggested procedure for estimating cost of ultimate land disposal; ultimate land disposal costs were calculated assuming the costs to be same as that of land reclamation.

According to the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995), the biosolids application rate for land reclamation may vary from 10 ton/acre to 100 tons/acre based on soil condition, and vegetation. The typical suggested value, 25 dry tons per acre per year; was used for the land area requirement calculation whereas the typical value for land application in farm land is 5 tons/acre/yr. When biosolids are used for reclamation, the application rate used can sometimes be higher than the agronomic rate. Any increase in the application rate would decrease the acreage needed for an application site. If biosolids are applied to public land located close to the GFWWTP, it might be possible to transport the biosolids from the plant with a pipeline and this could substantially reduce transportation costs as the calculations show in this and the following chapter.

The cost estimation process scope was limited to pipe line transportation and truck hauling cost along with maintenance and capital costs. Some of the biosolids management costs were not included in this chapter, such as sludge digestion treatment.

The cost estimation algorithms present a logical series of calculations using site-specific, process design, and cost data for deriving base capital and base annual operation and maintenance costs. All the design parameters presented as "typical values" were taken from the EPA'S Handbook (1985): Estimating Sludge Management Costs. The base year for these costs, however, was 1984; which was later inflated to 1994 by EPA’s manual: Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995), and then further adjusted to 2013 in this study’s calculation.

The cost estimation process follows the procedure of EPA'S Handbook: Estimating Sludge Management Costs (U.S. EPA, 1985) and EPA’s manual: Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). The costs given in this chapter was updated to current year by Marshall & Swift Equipment Cost Indices (MSECI) as well as Engineering News Record Construction Cost Indices (ENRCCI) inflated from 1994. This estimation contains capital costs and annual operating and maintenance (O&M) costs for land reclamation sites, as well as for transportation of biosolids.

6.1 Design Parameters and Economic Variables Assumption

Engineering News Record Construction Cost Index (ENRCCI) was used to inflate construction costs to the current year. for equipment purchase costs, the 1984 prices were inflated using the Marshall and Swift Equipment Cost Index (MSECI). The ratio of the 1994 to 1984 index number is used here to adjust construction related cost items (Base 1994 ENRCCI and MSECI index are 5,445.83 & 990.8). for example; the effective wage rate used in the calculations is $22.97 per hour. The $13.00 hourly wage rate was assumed in the 1985 EPA cost handbook, and was inflated to $22.97.

The following is the formula and example of using indexes:

formula:

(Present Index/ former index) x Known cost of the former year

Example:

The 1985 EPA cost handbook assumed an hourly wage of $13.00 for the operators of heavy equipment. This rate had been inflated to 1994 levels using the ENRCCI index, and adjusted using a factor of 1.3 to account for non-wage benefits paid by the employer. The effective wage rate for 1994, therefore, was $22.97 per hour. The Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995) handbook used this wage rate for further calculation. for the calculation of hourly wage, following equations and indices were used.

Cost of operational labor hourly wage for 2013= (Calculated Wage rate for 1994) x (ENRCCI for 2013/ENRCCI for 1994)= $22.97x (9453.02/5,445.83)

=22.97 x 1.735

=$39.85/hr;

Cost of operational labor hourly wage for 1994= (Assumed wage rate for 1884) x (ENRCCI for 1994/ENRCCI for 1884)= $13.00x (5,445.83/ 4189.1)

=13.00 x 1.3

=$22.97/hr;

ENRCCI for 2013 = 9453.02; ENRCCI for 1994 = 9453.02; ENRCCI for 1984= 4189.1; Effective Wage Rate for 1994 = $22.97; Assumed wage rate for 1985 = $13.00

Diesel fuel costs are assumed to average $4.00 per gallon, based on current (2013) costs as the inflated costs of diesel price differs from the current market price by a big margin.

The annual O&M costs for biosolids land application in this chapter do not consider costs for administration and laboratory sampling/analysis. Considering these additional costs, total annual O&M costs can be 30 percent higher than the costs derived from the algorithms in this chapter.

6.2 Dry Solids Generated

Total Dry Suspended Solids (TDSS) is a function of daily biosolids volume and the solids concentration. According Donald Trucker, the supervisor of the GFWWTP; the solids concentration of the GFWWTP varies from 2.5 % to 3.5%. Suspended Solids concentration (SS) was considered as 3.0% for the following calculations. According to the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995);

Total Dry Suspended Solids;

TDSS = [(SV)(8.34)(SS)(SSG)(365)]/(2,000)(100);

= [(65000)(8.34)(3)(1.01)(365)]/(2,000)(100)

=**2995≈3000 Tons/yr**

where:

TDSS= Total dry suspended solids, Tons/yr

SV= Wet biosolids volume, daily, gpd=65000

%SS= 3 =Biosolids suspended solids concentration, percent=3

SSG =1/[(100- SS)/100) + (SS)/(1.42)(100)]

=1/[(100- 3)/100) + (3)/(1.42)(100)]

=1.00895**≈1.01** (rounded)

where:

1.42= Biosolids solids specific gravity (Assumed the typical value), unit-less

8.34= Density of water, lb/gal

2,000= Conversion factor, lb/Ton

SSG= Sludge specific gravity (wet)

6.3 Biosolids Application Area

Biosolids application area is a function of Total Dry Suspended (TDSS) and Dry Solids Application Rate (DSAR). According to the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995);

Sludge- dry Application Area;

SDAR = (TDSS)/(DSAR) =(3000Tons/yr)/ (25 Tons/ac);

≈120 Acre/yr

where:

SDAR= Biosolids Disposal Application Area, ac/yr

TDSS=Total dry Suspended Solids applied to the land= 3000Tons/yr

DSAR= Dry Solids Application rate= 25 Tons/ac. (A Typical value for clay soil that is similar to soil of GFFWTP) =Average dry solids rate of application, Tons of dry solids/ac/yr. (10 ~ 100 for typical land reclamation sites)

The general approach for calculating sewage sludge application rates requires developing an accurate amass balance for N in the sewage sludge and soil-crop system as possible. This research used the "typical" and "suggested" values for all necessary parameters are provided in the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). The following table shows the fertilizer application recommendation for corn field in the Midwest.

Table 6.1: Representative Fertilizer Recommendation for Corn and Grain Sorghum in the Midwest

Yield (Metric tons/ha)	Nitrogen To Be Applied (kg/ha)	Fertilizer	Fertilizer P (P_2O_5) and K (K_2O) Recommended for Soil Fertility* †				
			Very Low	Low	Medium	High	Very High
			(kg/ha)				
6.7-7.4	134	P (P_2O_5):	49 (113)	35 (80)	25 (56)	15 (33)	0
		K (K_2O):	93 (112)	65 (78)	47 (57)	28 (34)	0
7.4-8.4	157	P (P_2O_5):	54 (123)	39 (90)	29 (67)	15 (33)	0
		K (K_2O):	112 (135)	84 (101)	56 (67)	28 (34)	0
8.4-10.1	190	P (P_2O_5):	59 (136)	45 (103)	29 (67)	20 (46)	4 (10)
		K (K_2O):	140 (169)	112 (135)	65 (78)	37 (45)	0
10.1-11.8	224	P (P_2O_5):	64 (146)	49 (113)	35 (80)	25 (56)	4 (10)
		K (K_2O):	167 (201)	130 (157)	84 (101)	56 (67)	0
11.8-13.4	258	P (P_2O_5):	74 (169)	59 (136)	39 (90)	25 (56)	4 (10)
		K (K_2O):	186 (224)	149 (179)	112 (135)	74 (89)	0

6.4 Hourly Biosolids Rate of Application

For the purpose of hourly biosolids application rate calculation, the following equation was adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Hourly Sludge Volume;

HSV= (SV)(365)/(DPY)(HPD)

=(65000 gpd)(365 days/yr)/(100 application days/yr)(8 hr/day)

=29656.25 gal/hr≈ **29700 gal/hr**

where:

HSV =Hourly biosolids rate of application, gal/hr

SV =Daily biosolids volume (wet), gpd=65000 gpd

DPY =Annual biosolids application period, days/yr. (100~180 days/yr for land reclamation sites) for Northern States DPY= 100 days/yr.

HPD =Daily biosolids application period, hr/day. Typical value = 8 hr/day.

6.5 Vehicles Capacity

For the purpose of calculating the number of vehicle required, following equation was adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). for HSV above 26,000 gal/hr, the number of 4,000-gal capacity vehicles is calculated by:

NOV = HSV/6,545 ;

where:

NOV = Number of onsite biosolids application vehicles

HSV= Hourly biosolids rate of application,

= 29656.25 Gal/hr

6,545 gal/ hr = Sludge application capacity of a 4,000 gal capacity vehicle assumed in the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995); (see Table 6.6)

NOV = HSV/6,545 = 29656.25 /6,545= 4.53**≈5**

Table 6.2: Capacity and Number of Onsite Biosolids Application Vehicle Required

Source: Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995)

Hourly Sludge Application rate	Vehicle Number of Each Capacity (NOV) Capacity (CAP) (GAL)			
HSV (Gal/hr)	1600	2200	3200	4000
0-3456	1			
3456-4243		1		
4243-5574			1	
5574-6545				1
6545-8500		2		
8500-11200			2	
11200-13100				2
13100-19600				3
19600-26000				4

6.6 Average Round Cycle Time

Following equation was adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995) for calculating Average Round Cycle Time.

Average cycle time for a 4000 gal vehicle;

CT = [(LT) + (ULT) + (TT)]/0.75= [(LT) + (ULT) + (TT)]/0.75;

= **33 min**

where:

CT= Average cycle time (round trip time onsite for biosolids application vehicle), min.

0.75= An efficiency factor

LT= Loading time, min,(varies with vehicle size) =9 min; (see Table 6.3)

ULT=Unloading time, min, (varies with vehicle size)= 11 min; (see Table 6.3)

TT= Travel time (Onsite time to and from biosolids loading facility to biosolids application area) = 5 min, (see Table 6.3)

Table 6.3 Vehicle Load, Unload and Onsite Travel Time

Source: Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995)

Vehicle Capacity	LT	ULT	TT	CT
1600	6	8	5	25
2,200	7	9	5	28
3,200	8	10	5	31
4,000	9	11	5	33

6.7 Total Land Area Needed Per Year

The space required for buffer zone, internal roads, storage etc. is usually calculated as a percent of total land requisite for land reclamation. Following equation was adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995) for calculating Total Land Area Needed per Year.

Total Land Area Needed per Year;

TLAR = (1 + FWWAB)(SDAR);

where:

TLAR= Total land area requisite for land reclamation sites, ac/yr

FWWAB= Fraction of land used in buffer zone, internal roads, biosolids storage, wasteland, etc. (Varies significantly depending on site-specific conditions.) Typical value = 0.3 for land reclamation sites.

SDAR =Site area required for biosolids application, ac/yr = 120 ac/yr

TLAR = (1 + FWWAB)(SDAR)

= (1 + 0.3)(120)

=120*1.3=**156 acres/ yr**

6.8 Land Area Requisite for Lime Addition

The space required for lime addition was calculated based on the following calculation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

TLAPH = (FRPH)(SDAR);

where:

TLAPH =Total land area requisite that must have lime applied for pH control, ac/yr.

FRPH=Fraction of land reclamation site area requiring addition of lime for adjustment of soil pH to a value of 6.5.

Typically, strip mining spoils have a low soil pH, and substantial lime addition may be required. Typical value =1.0 for land reclamation sites.

SDAR =Site Area Requisite for Biosolids Application, ac/yr

TLAPH = (FRPH)(SDAR)

=1*120

=**120 acre/yr**

6.9 Essential Earthwork

The total land requiring medium grading was calculated based on the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Total land area requiring medium grading;

TLARMG= (FRMG)(TLAR)

where:

TLARMG= Total land area requiring medium grading, ac/yr.

FRMG=Fraction of land area requiring medium grading.(Varies significantly depending on site-specific conditions) Typical value = 0.3

TLAR = Total land area required per year = 156 acre/yr

TLARMG = (FRMG)(TLAR)

=0.3*156=46.8~**47 acre/yr**

6.10 Number of Monitoring Wells

In this calculation, it is expected that even the smallest land reclamation site should have one down-gradient groundwater quality monitoring well, and one added monitoring well for each 200 ac/yr of total site area over 50 ac/yr. One up-gradient monitoring well also could be added for the existing ground water quality monitoring. The Number of Monitoring Wells was calculated based on the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Number of monitoring wells required;

NOMWR (down- grad) = 1 + [(TLAR) - 50]/200

where:

NOMWR = Number of monitoring wells required

TLAR = 156 ac/yr= Total land area required per year

NOMWR =1+ (156-50)/200= 1.53≈**2**

Number of monitoring wells required: up- gradient (NOMWR: up-grad) =1

Total NOMWR= NOMWR (down- grad)+ (NOMWR: up-grad)= 2+1= **3**

6.11 Number of Labor Operation Hours per Year

The Number of Labor Operation Hours per Year was calculated based on the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

The Number of Labor Operation Hours per Year;

L = 8 (NOV)(DPY)/0.7= 8 (5)(100)/0.7= **5715 hr/yr**

where:

L= Operation labor requirement, hr/yr.

8= Hr/day assumed, hr.

NOV= Number of onsite Biosolids application Vehicles= 5

DPY= Annual Biosolids application period=100 days/yr (varies from 100~140) for typical values.

Table 6.4: Typical number of Days of Sludge Application in Different zones of U.S.

Source: Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995)

Geographic Region	Typical Days/yr of Biosolids application
Northern US	100
Central US	120
Sunbelt States	140

0.7 = Efficiency factor.

6.12 Annual Consumption of Diesel Fuel for Vehicle

The diesel fuel usage was calculated based on the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Diesel fuel usage;

FU = (HSV)(HPD)(DPY)(DFRCAP)/(VHRCAP)

where:

FU= Diesel fuel usage, gal/yr.

HSV=Hourly Biosolids rate of application= 29656.25 gal/hr

HPD=Daily Biosolids application period= 8 hr/day

DPY=Annual Biosolids application period=100 days/yr

DFRCAP =Diesel fuel consumption rate for certain capacity vehicle = 6 gal/hr, (see the Table 6.5)

Table 6.5: Diesel Fuel Consumption Rate

Source: Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995)

Vehicle Capacity (CAP) (GAL)	DFRCAP
1,600	3.5
2,200	4
3,200	5
4,000	6

VHRCAP = Vehicle Biosolids handling rate = 6545 gal/hr, (see the Table 6.6)

Table 6.6: Vehicle Sludge Handling Capacity

Source: Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995)

Vehicle Capacity (CAP) (GAL)	VFRCAP(gal/hr)
1,600	3,456
2,200	4,243
3,200	5,574
4,000	6,545

FU = (HSV)(HPD)(DPY)(DFRCAP)/(VHRCAP)

= (29656)(8)(100)(6)/(6545)=**21750 gal/yr**

6.13 Cost of Land Per Year

The cost of land was assumed not using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Cost of Land; COSTLAND = (TLAR) (LAN DCST)=$**0**

where:

COSTLAND =Annual cost of land for land reclamation site,

TLAR =Total land area required for land reclamation sites= 156 ac/yr

LAN DCSAT=Cost of land, $/ac.

Typical value = 0 (Typically property owned by the municipality)

6.14 Annual Cost of Lime Addition to Adjust pH of The Soil

The cost of Lime addition was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Annual cost of lime addition for pH adjustment;

COSTPHT = (TLAPH)(PHCST)

where:

COSTPHT = Annual cost of lime addition for pH adjustment, $/yr.

TLAPH = Total land area which must have lime applied for pH control=120 ac/yr

PHCST = Cost of lime addition, $/ac.

Typical value = \$163/ac. x (ENRCCI/5,445.83) = \$163/ac. x (9453.02/5445.83)= 282.3≈**\$283** based on 4 Tons of lime/ac (in some cases up to 10 Tons/ac may be required for extreme pH conditions)

Engineering News Record Construction Cost Index (ENRCCI) for Feb, 2013= 9453.02

ENRCCI for 1994 =5445.83

COSTPHT = (TLAPH)(PHCST)= 120*283=**\$ 33960/yr**

6.15 Annual Cost of Grading Earthwork

The cost of Grading Earthwork was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Cost of earthwork grading;

COSTEW=(TLARLG)(LGEWCST)+(TLARMG)(MGEWCST)+(TLAREG)(EGEWCST)

=0+(TLARMG)(MGEWCST)+0

=47*4719= **\$221,793/yr**

where:

COSTEW= Cost of earthwork grading, \$/yr.

TLARMG = 47 acre/yr= Total land area requiring medium grading, ac/yr (see calculation Earthwork Required)

MGEWCST= Cost of medium grading earthwork, \$/ac. Typical value = \$2,719/ac. X (ENRCCI/5,445.83)= 2719 X (9453.02/5445.83)= \$4719 /ac

Engineering News Record Construction Cost Index (ENRCCI) for Feb, 2013= 9453.02

ENRCCI for 1994 =5445.83

6.16 Annual Cost of Monitoring Wells

The cost of monitoring was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Cost of monitoring wells;

COSTMW = (NOMWR)(MWCST)=3*11800=**$ 35400/yr**

where:

COSTMW =Cost of monitoring wells, $/yr.

NOMWR =Number of monitoring wells required/yr=3 (see Calculation Monitoring Wells Number).

MWCST =Cost of monitoring well, $/well.

Typical value = $6,797/well (ENRCCI/5,445.83)

=6797x 1.735=$**11800/well**

Engineering News Record Construction Cost Index (ENRCCI) for Feb, 2013= 9453.02

ENRCCI for 1994 =5445.83

6.17 Cost of Onsite Mobile Biosolids Application Vehicles

The cost of onsite mobile Biosolids application vehicles was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Cost of onsite mobile Biosolids application vehicles;

COSTMAV = [(NOV)(COSTPV)] MSECI/990.8

= [(5)(185,000)] X1545.9/990.8=**$1,443,000** (rounded)

where:

COSTMAV=Cost of onsite mobile Biosolids application vehicles, $.

NOV= 5=Number of onsite Biosolids application vehicles (see Calculation Biosolids Application Vehicles Capacity).

MSECI =Average Marshall and Swift Equipment Cost Index on 2012=1545.9.

990.8= Average Marshall and Swift Equipment Cost Index on 1994

COSTPV =$185,000= Cost/vehicle, $, obtained from bottom table.

Table 6.7: Cost of onsite mobile Biosolids application vehicle

Source: Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995)

Vehicle Capacity (CAP) (gal)	Cost Per Vehicle(COSTPV) (1994$)*
1600	112,000
2200	125,000
3200	158,000
4000	185,000

*Costs were taken from EPA's 1985 cost estimation handbook (US. EPA, 1985) and inflated to 1994 price level using MSECI

MSECI =Average Marshall and Swift Equipment Cost Index on 2012=1545.9.

6.18 Annual Cost of Operation Labor

The Operational cost of Labor was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Annual cost of operation labor;

COSTLB = (L)(COSTL)

= (5715)(39.85)

= $227,800/yr

where:

COSTLB=Annual cost of operation labor, $/yr

L=Annual operation labor required=5715 hr/yr

Cost of operational labor hourly wage for 2013= (Calculated Wage rate for 1994) x (ENRCCI for 2013/ENRCCI for 1994)= $22.97x (9453.02/5,445.83)

=22.97 x 1.735

=**$39.85/hr;**

Cost of operational labor hourly wage for 1994= (Assumed wage rate for 1884) x (ENRCCI for 1994/ENRCCI for 1884)= $13.00x (5,445.83/ 4189.1)

=13.00 x 1.3

=**$22.97/hr;**

ENRCCI for 2013 = 9453.02; ENRCCI for 1994 = 9453.02; ENRCCI for 1984= 4189.1; Effective Wage Rate for 1994 = $22.97; Assumed wage rate for 1985 = $13.00

6.19 Annual Cost of Diesel Fuel

The annual cost of fuel was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Annual cost of diesel fuel;

COSTDSL = (FU)(COSTDF)=(21750)(3.99)= **$86,800/yr**

where:

COSTDSL = Annual cost of diesel fuel, $/yr.

FU = Annual diesel fuel usage=21750 gal/yr

COSTDF = Cost of diesel fuel, $/gal.

=$ 3.99/gal. (Used current market values instead of the method)

MSECI =Average Marshall and Swift Equipment Cost Index on 2012=1545.9.

990.8= Average Marshall and Swift Equipment Cost Index on 1994

6.20 Annual Cost of Maintenance of Onsite Mobile Biosolids Application Vehicles

The annual cost of Maintenance of Onsite Mobile Biosolids Application Vehicles was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Annual cost of vehicle maintenance;

VMC = [(HSV)(HPD)(DPY)(MCSTCAP)/(VHRCAP)]* MSECI/990.8

= [(29700)(8)(100)(9.45)/(6545)(1545.9/990.8)

=$58,800/yr

where:

VMC = Annual cost of vehicle maintenance, $/yr.

HSV = 29700 gal/hr =Hourly Biosolids rate of application gal/hr (see Calculation Biosolids Application Vehicles Capacity).

HPD = 8 hr/day =Daily Biosolids application period, hr/day (see Calculation Biosolids Application Vehicles Capacity).

DPY = 100 days/yr = Annual Biosolids application period, days/yr (see Calculation Biosolids Application Vehicles Capacity).

MCSTCAP = $9.45/hr= Maintenance cost, $/hr of operation; for specific capacity of vehicle see following Table

VHRCAP = 6545 gal/hr = Vehicle Biosolids handling rate (see table Vehicle Biosolids Handling Capacity)

MSECI =Average Marshall and Swift Equipment Cost Index on 2012=1545.9.

990.8= Average Marshall and Swift Equipment Cost Index on 1994

Table 6.8: Hourly Maintenance Cost for Various Capacities of Biosolids Application Vehicles

Vehicle Capacity (CAP) (gal)	Maintenance Cost (1994,$/hr)*
1600	6.40
2200	7.01
3200	7.86
4000	9.45

*Costs were taken from EPA's Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

6.21 Annual Cost of Maintenance of Land Reclamation Site (Other Than Vehicles) for Monitoring, Recordkeeping, Etc.

The annual cost of Maintenance of Land Reclamation site was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

SMC = [(TLAR)(16)(ENRCCI/5,445.83]

=[156x16x1.735]=**$4330/yr**

where:

SMC= Annual cost of land reclamation site maintenance (other than vehicles), $/yr.

TLAR=156 acres/ yr = Total land area required, ac (see Calculation Total Land Area Required Per Year).

16 = Annual maintenance cost, $/ac. [Source: Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).]

ENRCCI= 9453.02 = Current Engineering News Record Construction Cost Index at time analysis is made (Feb, 2013)

6.22 Total Base Capital Cost

The total base capital cost was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Total base capital cost of land reclamation site using onsite mobile Biosolids application vehicles

TBCC = COSTMAV=**$1,443,000**

where:

TBCC = Total base capital cost of land reclamation site using onsite mobile Biosolids application vehicles, $.

COSTMAV =$1,443,000 = Cost of onsite mobile Biosolids application vehicles, $ (see Calculation in section 6.17)

6.23 Total Annual Operation, Maintenance, Land, and Earthwork Cost

The Total annual operation, maintenance using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Total annual operation, maintenance, land, and earthwork cost for land reclamation site using onsite mobile Biosolids application vehicles;

COSTOM = COSTLB + COSTDSL + VMC + SMC + COSTLAND + COSTPHT + COSTEW + COSTMW

=227,800+86,800+58,800+4330+0+33,960+221,793+35,400=$**670,000**

where:

COSTOM = Total annual operation, maintenance, land, and earthwork cost for land reclamation site using onsite mobile Biosolids application vehicles, $/yr.

COSTLB = $227,800/ yr = Annual cost of operation labor, $/yr

COSTDSL = $86,800/yr = Annual cost of diesel fuel, $/yr

VMC= 58,800= Annual cost of vehicle maintenance, $/yr

SMC=$4330/yr = Annual cost of site maintenance, $/yr

COSTLAND =0= Annual cost of land for reclamation site, $/yr

COSTPHT =$ 33960/yr = Annual cost of lime addition for pH adjustment,$/yr

COSTEW $221,793/yr= Annual cost of grading earthwork, $/yr

COSTMW = $ 35,400/yr = Annual cost of monitoring wells, $/yr

7 TASK 2B: COST ESTIMATION FOR PIPELINE TRANSPORT OF GFWWTP BIOSOLIDS TO LAND DISPOSAL SITE

7.1 Diameter of Pipeline

Pipe diameter is a function of Average Daily Biosolids volume and pumping hours. According to the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995);

Pipe diameter;

$PD = 12\ [SV(3)/(63{,}448)(HPD)]^{0.5}$

$=12\ [130000/(63448x\ 6)]^{0.5}$ **≈ 12 in**

where:

PD= Pipeline diameter, inches.

SV= 130,000 gpd = Maximum Daily Biosolids volume, gpd.

63,488= Conversion factor = (3.1416/4)[(3ft/sec)(7.48 gal/cu ft)(86,400sec/day)/(24 hr/day)]

HPD=6 hr/day =Hours per day of pumping, HPD, hr. (Assumed based on typical working hour) Note: Pipeline is assumed to be flowing full.

3= peaking factor

7.2 Head Loss Due to Pipeline Friction

The Head loss due to pipe friction was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Head loss due to pipe friction;

$PFL = K\,[(SV)/(HPD)(PD)^{2.63}(C)(16.892)]^{1.852}$

$=1.85[(65000)/(2)(12)^{2.63}(90)(16.892)]^{1.852}$ = **0.002 ft/ft**

where:

PFL= Head loss due to pipe friction, ft/ft. Is function of pipe diameter, velocity, and "C" value selected.

K= 1.85 (from chart below)= Coefficient to correct for increased head loss due to Biosolids solids content. K factors provided in the bottom Table are cut down and might give inaccurate results. An detailed method for design engineering calculations is provided in U.S. EPA, 1979.

2.63= Hazen-Williams constant.

C= Hazen-Williams friction coefficient. Typical value = 90

16.892= (646,000 gpd/cfs)/(24)(2.31)(12)

Table 7.1: Factors for Various Biosolids Concentrations and Two Types of Biosolids

Source: Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995)

Solids Concentration Percent by Weight	K Factor	
	Digested Biosolids	Untreated Primary Biosolids
1.0	1.05	1.20
2.0	1.10	1.60
3.0	1.25	2.10
4.0	1.45	2.70
5.0	1.65	3.40
6.0	1.85	4.30
7.0	2.10	5.70
8.0	2.60	7.20

7.3 Head Required Due to Elevation Difference

The Head required due to elevation difference was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Head required due to elevation difference;

HELEV = ELEVMX – PSELEV=871-842=**29 ft**

where:

HELEV = Head required due to elevation difference, ft.

ELEVMX = 871 ft=Maximum elevation in the pipeline, ft. (see Contour Map of GFWWTP in Appendix IV)

PSELEV = 842ft= Elevation at the start of the pipeline, ft. (see Contour Map of GFWWTP in Appendix IV)

7.4 Total Pumping Head Required.

The total pumping Head was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Total pumping head required;

H = [(PL)(PFL) + HELEV]

=[4000x0.002+29]= **37 ft**

where:

H= Total pumping head required, ft.

PL=6,000 ft = Pipeline length, ft.(Assuming it will be disposed to the abandoned land next to the plant. Length was measured via GIS)

PFL= 0.002 ft/ft =Head loss due to pipe friction, ft/ft (see Calculation 7.2).

HELEV= 29 ft= Head required due to elevation difference, ft (see Calculation 7.3).

7.5 Number of Pumping Stations

The total number of pumping station was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Number of pumping stations;

NOPS = H/HAVAIL=37/230≈**1**

where:

NOPS= Number of pumping stations.

H= Total pumping head required, ft.

H AVAIL=450ft= Head available from each pumping station, ft. This is a function of the type of pump, Biosolids flow rate, and whether or not pumps are placed in series. (see Table 7.2)

Table 7.2: Head Available from Each Pumping Station

Source: Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995)

Pipe Diameter (PD) (inches)	Head Available (HAVAIL) (ft)
4& 6	450
8	260
10& 12	230
14& 16	210
18&20	200

7.6 Energy Requirements for Pumps

The energy required was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Total pumping horsepower required;

HP = (H)(SV)(8.34)/(HPD)(60)(0.50)(33,000)

= (97)(65000)(8.34)/(8)(60)(0.50)(33,000)

= **20**

where:

HP = Total pumping horsepower required, hp.

SV = 130,000 gpd = Daily Biosolids volume, gpd

HPD = 2 hr = Hours per day of pumping, HPD, hr

33,000 = Conversion factor, hp to ft-lb/min.

60 = Conversion factor, min/hr.

0.50 = Assumed pump efficiency.

8.34 = Density of water, lb/gal.

7.7 Energy Requirement per Pump Station

The Horsepower required per pump station was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Horsepower required per pump station;

HPS = HP/NOPS= 20/1=**20 hp**

where:

HPS= Horsepower required per pump station, hp.

HP= 20= Total pumping horsepower required, hp

NOPS= Number of pumping stations =1

7.8 Electrical Energy Requirement

The electrical energy required was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Electrical energy required;

E = [(0.0003766)(1 .2)(H)/(0.5)(0.9)](SV) (365)(8.34)/1,000

=[(0.0003766)(1.2)(37)/(0.5)(0.9)](130,000) (365)(8.34)/1,000

= **14,705 kWhr/yr**

where:

E = Electrical energy, kWhr/yr.

0.0003766 = Conversion factor, kWhr/1,000 ft-lb.

H = 37 ft. = Total pumping head required, ft

SV= 130,000 gpd

8.34 = Density of water, lb/gal.

1.2 = Assumed specific gravity of Biosolids.

0.5 = Assumed pump efficiency.

0.9 = Assumed motor efficiency.

7.9 Operation and Maintenance Labor Requirement

The Annual operation and maintenance labor was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Annual operation and maintenance labor;

L = (NOPS)(LPS) + (PL)(0.02)= (1)(700) + (4000)(0.02)=**780 hr/yr**

where:

L = Annual operation and maintenance labor, hr/yr.

NOPS=1= Number of pumping stations

LPS=700=Annual labor per pump station, hr/yr. This is a function of pump station horsepower, HPS, as shown in Table Annual Labor Per Pump Station

PL= 4,000ft= Pipeline length, ft

0.02=Assumed maintenance hr/yr per ft of pipeline, hr/ft.

Table 7.3: Annual Labor per Pump Station

Source: Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995)

Pump Station	Annual O&M Labor
Horsepower (HPS)	(LPS) (hr)
25	700
50	720
75	780
100	820
150	840
200	870
250	910
300	940
350	980

7.10 Cost of Installed Pipeline

The cost of installed pipeline was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995).

Cost of installed pipeline;

COSTPL = (1 + 0.7 ROCK)(1 + 0.15 DEPTH)(PL)(COSTP)(ENRCCI)/5445.83

= (1 + 0.7 x0)(1 + 0.15x0)(4000)(41.33)(9453.02)/5445.83

=$ 287,000

where:

COSTPL = Cost of installed pipeline, $.

0.7 = Assumed fraction of pipeline length that requires rock excavation.

ROCK = 0 ft (Assumption) = Fraction of pipeline length that requires rock excavation.

0.15 = Assumed fraction of pipeline length that does not require rock excavation, but is greater than 6 ft deep

DEPTH = 0 =Fraction of pipeline length that does not involve rock excavation, but is greater than 6 ft deep

PL = 4,000ft= Pipeline length, ft

COSTP = 41.33/ft= Pipeline cost per unit length, $/ft. This cost is obtained from Table – Pipe Line Cost

ENRCCI =9453.02= Engineering News Record Construction Cost Index of Feb, 2013

Table 7.4: Pipeline Cost

Pipeline Diameter (PD)	Installed Cost (COSTP)
(inches)	($/ft, 1994 $)*
4	28.68
6	30.99
8	34.39
10	37.93
12	41.33
14	48.26
16	52.88
18	58.59
20	68.92

*Costs were taken from EPA's 1985 Cost Estimation Handbook (U.S. EPA, 1985) and inflated to 1994 price levels using the MSECI.

7.11 Cost of Pipeline Crossings

The Cost of pipe crossings was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Cost of pipe crossings;

COSTPC = [NOH($26,000) + NODH($52,000) +NRC($19,000) + NOSR($116,000) +NOLR($462,000)] xENRCCI/5445.83

=1x26000x9453.02/5445.83**=$45,110**

where:

COSTPC=Cost of pipe crossings, $.

NOH=Number of 2- or 4-lane highway crossings=1

NODH= 0 = Number of divided highway crossings, NODH. Typical value

NRC = Number of rail crossed.= 0

NOSR = Number of small rivers crossed. Typical value = 0.

NOLR = Number of large rivers crossed. Typical value = 0.

ENRCCI = 9453.02= Engineering News Record Construction Cost Index of Feb, 2013

7.12 Cost of Pump Stations

The construction cost of all pump stations was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Construction cost of all pump stations;

COSTPS = NOPS [$218,000 + $3,600 (HPS-25)] MSECI /990.8= 1 [$218,000 + $3,600 (25-25)] 1545.9/990.8

= $340,000

where:

COSTPS= Construction cost of all pump stations.

NOPS= 1=Number of pumping stations (see Calculation #5).

HPS=25(Minimum required for this calculation) = Horsepower required per pump station, hp (see Calculation #7).

MSECI= Avg Marshall and Swift Equip Cost Index of 2012

7.13 Annual Cost of Electrical Energy

The total annual cost of electricity was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Total annual cost of electricity;

COSTEL = (E)(COSTE)= 14,705 x0.08=$1,176≈**$1200**

where:

COSTEL = Total annual cost of electricity, $/yr.

E= 14,705 kWhr/yr = Electrical energy requirement, kWhr/yr (see Calculation #8)

COSTE= Unit cost of electricity, $/kWhr. Typical value = $0.121/kWhr (ENRCCI/5445.83)=

=0.121x9453.02/5445.83=0.21/kWhr

For GFWWTP COSTE considered = $0.08/ KWhr

7.14 Annual Cost of Operation and Maintenance Labor

The annual cost of operation and maintenance labor was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995 Annual cost of operation and maintenance labor;

COSTLB = (L)(COSTL)=780x39.85=**$31,000**

where:

COSTLB =Annual cost of operation and maintenance labor, $/yr.

L=780 hr/yr =Operation and maintenance labor requirement, hr/yr. (see Calculation #9)

COSTL =Unit cost of labor, $/hr. Typical value = $22.97/hr (9453.02/5445.83).=$39.85/hr

7.15 Cost of Pumping Station Replacement Parts and Materials

The Annual cost of pumping station replacement parts and materials was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Annual cost of pumping station replacement parts and materials;

COSTPM = NOPS (PS) (MSECI/990.8) =1x1420x (1545.9/990.8)=**$2200**

where:

COSTPM= Annual cost of pumping station replacement parts and materials, $/yr

NOPS=1= Number of Pump Station

PS= 1420$/yr=Annual cost of parts and supplies for a single pumping station, $/yr. This cost is a function of pumping station horse power as shown in Table

MSECI= 1545.9=Average Marshall and Swift Equipment Cost Index of 2012

Table 7.5: Annual Cost of Pumping Stations Parts and Supplies

Pump Station Horsepower (HPS)	Annual Parts and Supplies3 Cost (PS) ($/Yr, 1994 $)
25	1,420
50	1,490
75	1,680
100	1,820
150	1,980
200	2100
250	3750
300	3910
350	4100

*Costs were taken from EPA's 1985 Cost Estimation Handbook (U.S. EPA, 1985) and inflated to 1994 price levels using the MSECI.

7.16 Storage Tank Cost

Considering the storage tank is designed for five day storage, the volume of storage tank is; V= SV(5)(2)3=(130,000gal/day) (5)(2)

=1.3MG =0.1737 x10^6Cuft

where:

SV=130,000 gal/day= maximum flow, gal/day

5= no of day storage

2= Factor of safety

Table 7.6: Cost of Tank

Concrete volumes and costs:

general: volume = pi (R outer² - R inner²) * thickness

dimensions (ft)	_	_	ITEM:	Volume (ft^3)	volume (yd^3)	cost/ yard	cost		
R1	66.25		sidewall	8247	305.4	$600	$183,260		
R2	65.00		wall ftg	9935	368.0	$500	$183,987	If costs increase $50/yd	_
R3	68.25		slab	7144	264.6	$500	$132,291	total =	**$546,437**
R4	58.25		center pier	0	0.0	$500	$0		
R5	0.00		weir wall	0	0.0	$500	$0	If costs decrease $50/yd	_
R6	0		weir base	0	0.0	$400	$0	total =	**$452,638**
R7	0			**total**	**938.0**	**total**	**$499,538**		

Source: MFRA cost estimation

Cost of Tank Considered COSTANK = **$500,000**

7.17 Dredging Cost

The Mud Cat Series 370 "DRAGONT" dredge, named "CIECO's Pride", features 20 ft. digging depth capability, a 40 hp basket cutter with chisel teeth, 12 inch high density polyethylene discharge pipe rated SDR 17, and a spud operation with true free-fall.

Dredge Operation

A) Two-man crew plus supervisor

B) Three shifts per day, 5 days per week,3 months per year

C) Cubic yards of material pumped= (65000 gal/day)(365 day)(1.75)

= 41,518,750 gal (0.00495113169 Cubic yard/gal)=205,564 Cubic yard/yr

D) Unit dredging costs: $0.676 per cubic yard

E) Cost of dredging = ($0.676 per cubic yard)(205,564 Cubic yard/yr)

=$139,000/yr

F) Operating cost - (fuel, maintenance, labor, insurance, spare parts and pipeline depreciation) - $70,000

I) Average dredge production: 150 cubic yards per hour

J) Average cutting depth: 7-12 feet

Total Cost of dredging COSTD = $209,000

Pumping Distances

A) Average pipeline length is 3,000 feet at +40 feet elevation rise to the disposal area

7.18 Total Base Capital Cost

The total base capital cost was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Total base capital cost;

TBCC = COSTPL + COSTPC + COSTPS+ COSTANK

=$ 287,000+ $45,110+ $340,000+$500,000=**$832,000**

where:

TBCC= Total base capital cost, $

COSTPL= 287,000 =Cost of installed pipeline, $ (see Calculation 7.10)

COSTPC= $45,110=Cost of pipeline crossings, $ (see Calculation 7.11)

COSTPS= $340,000=Cost of pump stations, $ (see Calculation 7.12)

7.19 Total Annual Operation and Maintenance Cost

The total annual operation and maintenance cost was calculated using the following equation adopted from the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995). Total annual operation and maintenance cost;

COSTOM = COSTEL + COSTLB + COSTPM+COSTD

=$1,200+$31,000+$2200+$209,000

=$244,000/yr.

where:

COSTOM =Total annual operation and maintenance cost, \$/yr.

COSTEL = \$1200=Annual cost of electrical energy, \$/yr.

COSTLB = \$31,000=Annual cost of operation and maintenance labor, \$/yr.

COSTPM = \$2200=Cost of pumping station replacement parts and materials, \$/yr.

8 SUMMARY AND CONCLUSION

Land disposal costs might be significantly reduced for the GFWWTP if the biosolids are applied to public land owned by the City of Grand Forks. The current landfill site is located within a few miles of the GFWWTP. The previous city municipal solid waste (MSW) landfill that was taken out of service a few years ago is situated south- southeast of the current GFWWTP and adjacent. Biosolids could be applied to the final cover to enrich the soil and promote a better stand of vegetation. The current landfill designed life is 80 years. In the permitting report for the new landfill, it was stated that the site did not contain enough suitable soil for final cover and that some soil would have to be hauled to the site (Black and Veatch). Instead of hauling soil, it might be feasible to use biosolids to enrich the available soil so that it could be used for final cover. Another possible site for biosolids application is the ground currently occupied by the GFWWTP lagoons. Plans are being made to close some of the city's lagoons in the near future. During the closure and reclamation process, it should be possible to apply significant amounts of biosolids to rebuild the final topsoil cover at the site.

When biosolids are applied to public land, it may be possible to use higher nitrogen application rates than those used for conventional farm crops like corn or wheat. One way to increase the application rate would be to use a cover crop with a higher nitrogen uptake than conventional crops. Another way to increase the application rate is to use the biosolids for land reclamation. According to the Process Design Manual Land Application of Sewage Sludge and Domestic Septage (1995), the biosolids application rate for land reclamation may vary from 10 ton/acre to 100 tons/acre based on soil condition, and vegetation. The typical suggested value, 25 dry tons per acre per year; was used for the land area requirement calculation whereas the typical value for land application in farm land is 5 tons/acre/yr. When biosolids are used for reclamation, the application rate used can sometimes be higher than the agronomic rate. Any increase in the application rate would decrease the acreage needed for an application site. If biosolids are applied to public land located close to the GFWWTP, it might be possible to transport the biosolids from the plant with a pipeline and this could substantially reduce transportation costs as the calculations show.

Soil salinity and high groundwater would not necessarily pose a problem for land application if the biosolids were used for improving landfill cover because the groundwater level would be controlled at the landfill and the biosolids could actually help to reduce the salinity of the soil and promote vegetation.

When the existing lagoons are closed, biosolids could be used for reclaiming the land at the site. A strong case could be made that applying large amounts of biosolids might reduce soil salinity and promote vegetation. Biosolids are being used in Minnesota for mine land reclamation.

If public land (or private land) close to the GFWWTP is used for land application, some modifications may be needed to reduce the salinity of the soil. Modifications might include installing subsurface drains or using some type of irrigation system to apply the biosolids. These modifications would be an added expense to develop the site, but again a claim could be made that the land application is reclaiming a marginal soil.

Considering sludge quality, economic aspects, control, demand of sludge as fertilizer, land fertility, and EPA regulations, both land application and disposal in the landfill site seemed to be the promising alternatives for biosolids management.

Figure 8-1: Location of Two Grand Forks Landfills Relative to the GFWWTP

The cost estimation method used in this research could also be used for the land application process for disposal of biosolids on agricultural land. The total capital cost found by this study for pipe transportation of biosolids disposal was eight hundred and thirty two thousand USD ($832,00) while truck hauling of biosolids may take up to one million four hundred and forty thousand USD ($1,440,000). These costs were based on current rate of solids production. The annual operations costs for pipeline transportation and truck hauling process of biosolids disposal are respectively $244,000 and $658,000. It is a rational choice to pick pipeline transportation over vehicular transportation cost, though the capital cost of pipe transportation is much higher than that of vehicular transportation. But the successful operation depends on the engineering design. The main challenge would be to keep up with sedimentation. Sedimentation may cause dysfunctional operation or intermittent service. The method accounted for the pipeline was designed to be flowing full. These costs were estimated also considering that pumping was to land near GFWWTP. These costs may vary significantly for the application location. Since the pump was very close to land where it would applicable, the author didn't account for air release valve or any other structures required for long line pipe flow. The costs of land disposal were summarized in the following table:

Table 8.1: Costs Summary of Surface Disposal Method for GFWWTP

Costs Types	Vehicular Transportation	Pipeline Transportation
Total Base Capital Cost	$1,443,000	$832,000
Total Annual Operations and Maintenance Cost	$658,000	$244,000
Total Cost after 20 years	$14,603,000	$5,712,000

Another important aspect of this surface disposal to the land next to GFWWTP is that it reduces the dependency of the GFWWTP for its biosolids disposal. The agricultural land application depends on the demand of farmers. Landfill site disposal requires coordinating different authority. This surface disposal method gives GFWWTP more control over this process. A possible disadvantage of surface disposal is that more site preparation and monitoring would probably be needed compared to land application and the site will eventually have to be closed. With surface disposal, a greater fraction of the development cost may be for site preparation, monitoring, and closure compared to land application. Alternatively with land application, much of the cost may be operating cost for transporting and applying the biosolids.

Another important reason for selecting surface disposal method over the land application is its capacity to handle higher loading. Much higher biosolids application rates could be used for surface disposal than for most types of land application and higher application rates would reduce the amount of land needed for the disposal site. There appears to be a large amount of land close to the GFWWTP that would be suitable for land disposal which is an extra advantage for prolonged surface disposal.

APPENDICES

APPENDIX I

Table 0.1: List of Selected cities with population from 2010 census

State	Cities	Population	State	City	Population
ND	Fargo	105,549	MN	Maplewood	38,018
	Bismarck	61,272		Shakopee	37,076
	Grand Forks	52,838		Richfield	35,228
	Minot	40,888		Cottage Grove	34,589
Mn	Minneapolis	382,578		Inver Grove Heights	33,880
	Saint Paul	285,068		Roseville	33,660
	Rochester	106,769		Andover	30,598
	Duluth	86,265		Brooklyn Center	30,104
	Bloomington	82,893	Mo	Billings	104,170
	Brooklyn Park	75,781		Missoula	66,788
	Plymouth	70,576		Great Falls	58,505
	St. Cloud	65,842		Bozeman	37,280
	Eagan	64,206		Butte	34,200
	Woodbury	61,961		Helena	28,180
	Maple Grove	61,567	SD	Sioux Falls	153,888
	Coon Rapids	61,476		Rapid City	67,956
	Eden Prairie	60,797		Aberdeen	26,091
	Burnsville	60,306	IA	Des Moines	203,433
	Blaine	57,186		Cedar Rapids	126,326
	Lakeville	55,954		Davenport	99,685
	Minnetonka	49,734		Sioux City	82,684
	Apple Valley	49,084		Waterloo	68,406
	Edina	47,941		Iowa City	67,862
	St. Louis Park	45,250		Council Bluffs	62,230
	Mankato	39,309		Ames	58,965

APPENDIX II

Table 0.2: LIST of WASTE WATER TREATMENT FACILITIES WITH CONTACTS FOR PHONE SURVEYING:

Facility Address	City	State	ZIP	Program ID#	COGNIZANT OFFICIAL	COGNIZANT OFFICIAL TEL.
123 S. LINCOLN ST.	ABERDEEN	SD	57401	SD0020702	PETER HESLA, WW SUPT.	605-626-7099
38520 130TH ST	ABERDEEN	SD	57401	SDG826999	DEBORAH J BREITAG, MANAGER	605-229-4343
3 MI S of PACTOLA R NE 1/4 of	RAPID CITY	SD	57702	SDG827952	BUTCH SCHOELLERMAN, MANAGER	605-574-2293
1-3/4MI.S.OFINTER.of HWY12 &US	ABERDEEN	SD	57401	SD0025976	TOBY ROLFE, MANAGER	605-229-4248
PO BOX 1086	ABERDEEN	SD	57401	SD0026425	BRUCE MITCHELL, CHAIRMAN	605-226-0900
7903 SOUTHSIDE DRIVE	RAPID CITY	SD	57703	SD0023574	DAVID VAN CLEAVE, WW SUPT.	6053944174
224 W 9TH	SIOUX FALLS	SD	57104	SDS000001		
4500 N SYCAMORE AVE	SIOUX FALLS	SD	57104	SD0022128	LYLE D. JOHNSON, PUB WRKS DIR	605-336-7088
6514 JENNIFER ST.	RAPID CITY	SD	57701	SD0028142	BOB REYNOLDS	605-342-9470
2700 N 4TH ST	SIOUX FALLS	SD	57104	SD0028363		

Facility Name	Facility Street	Facility City	Facility State	Facility Zip Code	Program ID#	Cognizant Official	Cognizant Official Tel
City of Billings WWTP	725 Hwy 87 E	Billings	MT	59101	Mtr000459	Jesse Melvin, Plant Supervisor	
City of Billings WWTP	725 Hwy 87 E	Billings	MT	59101	Mt0022586	Carl Christensen	4066578307
City of Bozeman WWTP	255 Moss Bridge Road	Bozeman	MT	59718	Mt0022608	WWTP Superintendent	406-582-3200
City of Great Falls WWTP	1600 6th Street NE	Great Falls	MT	59404	Mt0021920	Jim Rearden, Dir. Pub. Works	406-727-1325
City of Missoula WWTP	1100 Clark Fork Lane	Missoula	MT	59802	Mt0022594	Wastewater Div. Superintendent	406-552-6600
Great Falls WWTP	1600 6th St Ne	Great Falls	MT	59404	Mtr000452	John Lawton	406-761-7004
Knife River Billings - Private Contract 622 Granite Peaks Su	54th St W and Grand Ave	Billings	MT	59108	Mtr104052	N/A	
Smeg & T Co-Op Inc - Highwood Generating Station	Generating Station Site	Great Falls	MT	59405	Mtr103153	N/A	
Sun Prairie Village WWTP	1047 Grant Drive	Great Falls	MT	59404	Mt0028665	Bobby Broadway, Gen. Manager	406-965-3944
Applegate Meadows	Lincoln Rd W	Helena	MT	59602	Mtx000176	N/A	

Facility Name	Facility Street	Facility City	Facility State	Facility Zip Code	Program ID#	Cognizant Official	Cogniza Tel
Butte Silver Bow Tifid Waste Water Conveyance System	N Browns Gulch Rd & Grizzly Trail	Butte	MT	59701	Mtr103742	N/A	
Butte Silver Bow WWTP and Sod Farm	800 Centennial Avenue	Butte	MT	59701	Mtr000488	N/A	
Butte-Silver Bow WWTP	SW Of Intersection of Centennial & Santa Claus Rd	Butte	MT	59701	Mt0022012	William R. Daly	406-723-8262
City of Helena WWTP	1708 Custer Avenue East	Helena	MT	59602	Mt0022641	Wastewater Superintendent	406-457-8558
Glacier Point Subdivision	W of I-15 Near Valley Speedway Rd	Helena	MT	59601	Mtx000178	N/A	
Ueland Land Development - Homestake Meadows Phase II	Blacktail Canyon Rd & Trail Creek Rd	Butte	MT	59701	Mtr103503	Ron Ueland	4067824670

Facility Street	Facility City	Facility State	Facility Zip Code	Program Id#	Cognizant Official	Cognizant Official Tel
7525 Bertram Road SE	Cedar Rapids	IA	52401	Ia0042641	George Milligan, WPC Director	319-398-5260
2606 S. Concord Street	Davenport	IA	52808	Ia0043052	James Resnick, Dir Mun WWTP	319-326-7962
2400 West Lake Boulevard P.O.Box 3606	Davenport	IA		Ia0076261	James Resnick, Dir Mun WWTP	319-326-7962
3000 Vandalia Road	Des Moines	IA	50317	Ia0044130	Director of Public Works	515-283-4276
3100 South Lewis Blvd, Rr 6	Sioux City	IA	51106	Ia0043095	Richard Wilford, Director	712-277-2121
405 6th St P.O. Box 447	Sioux City	IA	51102	Ia0078662	N/A	
76797 280th Street	Ames	IA	50010	Ia0035955	John W. Ringlestein	515-232-6210
209 Pearl St	Council Bluffs	IA	51503	Ia0078271	N/A	
18542 Applewood Road	Council Bluffs	IA	51503	Ia0036641	William Thomas, Plant Supt	712-366-9236
5092 American Legion Rd	Iowa City	IA	52240	Ia0074985	Hillary Maurer	319-358-2542
1000 S. Clinton Street	Iowa City	IA	52240	Ia0042617	Harry Boren - Supt	319-354-1800
4366 Napoleon St. SE	Iowa City	IA	52240	Ia0070866	Dave Elias	319-356-5170
C/O Robert H. Wolf, President C/O Robert H. Wolf President,	Iowa City	IA	52240	Ia0074284	N/A	
1000ft East of Sycamore Rd	Iowa City	IA	52240	Ia0073733	N/A	
4009 Mathews Road	Ames	IA	50014	Ia0068276	N/A	
3505 Easton Avenue city Hall	Waterloo	IA	50705	Ia0042650	M.L. Wickersheim, Superintendent	319-291-4553
1102 SE Creekview Drive	Ankeny	IA	50021	Ia0038628	James Mckenna, Superintendent	515-964-5500
410 W. First St.	Ankeny	IA	50023	Ia0078611	N/A	
795 Julien Dubuque Drive	Dubuque	IA	52003	Ia0044458	Michael A Koch, City Engineer	319-583-6441
50 W 13th St	Dubuque	IA	52001	Ia0078671	N/A	

Facility Street	Facility City	Facility State	Facility Zip Code	Program Id#	Cognizant Official	Cognizant Official Tel
11941 Rt 52 N18709 Eichman Rd	Dubuque	IA	52002	Ia0063240	N/A	
8854 Pheasant Ln8854 Pheasant Lane.	Dubuque	IA	52003	Ia0063991	N/A	
10420 Key West Drive10420 Key West Drive	Dubuque	IA		Ia0061298	N/A	
10685 Jet Center Drive	Dubuque	IA	52003	Ia0064751	William Titterington	
3600 86th St	Urbandale	IA	50322	Ia0078620	David J. Mckay	Idnr_Efd
4403 Devils Glen Road	Bettendorf	IA	52722	Ia0078191	N/A	
501 East 4th Street City Hall	Cedar Falls	IA	50613	Ia0036633	James R Glover, Dir Public Wrk	319-268-0141
1225 6th Ave.	Marion	IA	52302	Ia0078689	John Bender	Idnr_Efd

Facility Name	Facility Street	Facility City	Facility State	Facility Zip Code	Program Id#	Population	Cognizant Official	Cognizant Official Tel
Bismarck City WWTP	601 London Ave	Bismarck	ND	58502	Nd0023434	61,272	Lab Manager, Industrial Pre-Treatment Coordinator	701-222-6471 701-355-1700
Fargo City WWTP	200 3rd St N	Fargo	ND	58102	Nd0022870	105,549	Steve Sprague	7012411454
Grand Forks WWTP	3251 N 69th St	Grand Forks	ND	58206	Nd0022888	52,838	Melanie Parvey	701-738-8781
Minot City WWTP	515 2nd Ave SW	Minot	ND	58701	Nd0022896	40,888	Dave Burckhard, Water/Sewer Maintenance Superintendent	701-857-4150

APPENDIX III

Table 0.3: Average recorded Temperature of Grand Forks, ND

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °F (°C)	52 (11)	67 (19)	83 (28)	100 (38)	105 (41)	105 (41)	109 (43)	104 (40)	103 (39)	95 (35)	75 (24)	58 (14)	109 (43)
Average high °F (°C)	16.5 (−8.6)	21.9 (−5.6)	34.2 (1.2)	53.9 (12.2)	68.0 (20)	76.1 (24.5)	81.0 (27.2)	80.2 (26.8)	69.6 (20.9)	54.3 (12.4)	35.1 (1.7)	20.3 (−6.5)	50.9 (10.5)
Average low °F (°C)	−3.1 (−19.5)	2.1 (−16.6)	16.1 (−8.8)	30.0 (−1.1)	41.5 (5.3)	52.0 (11.1)	56.3 (13.5)	54.0 (12.2)	44.2 (6.8)	31.9 (−0.1)	17.0 (−8.3)	2.6 (−16.3)	28.7 (−1.8)
Record low °F (°C)	−43 (−42)	−42 (−41)	−36 (−38)	−9 (−23)	5 (−15)	28 (−2)	30 (−1)	30 (−1)	11 (−12)	−9 (−23)	−35 (−37)	−37 (−38)	−43 (−42)

Source: "NOWData - NOAA Online Weather Data". National

APPENDIX IV

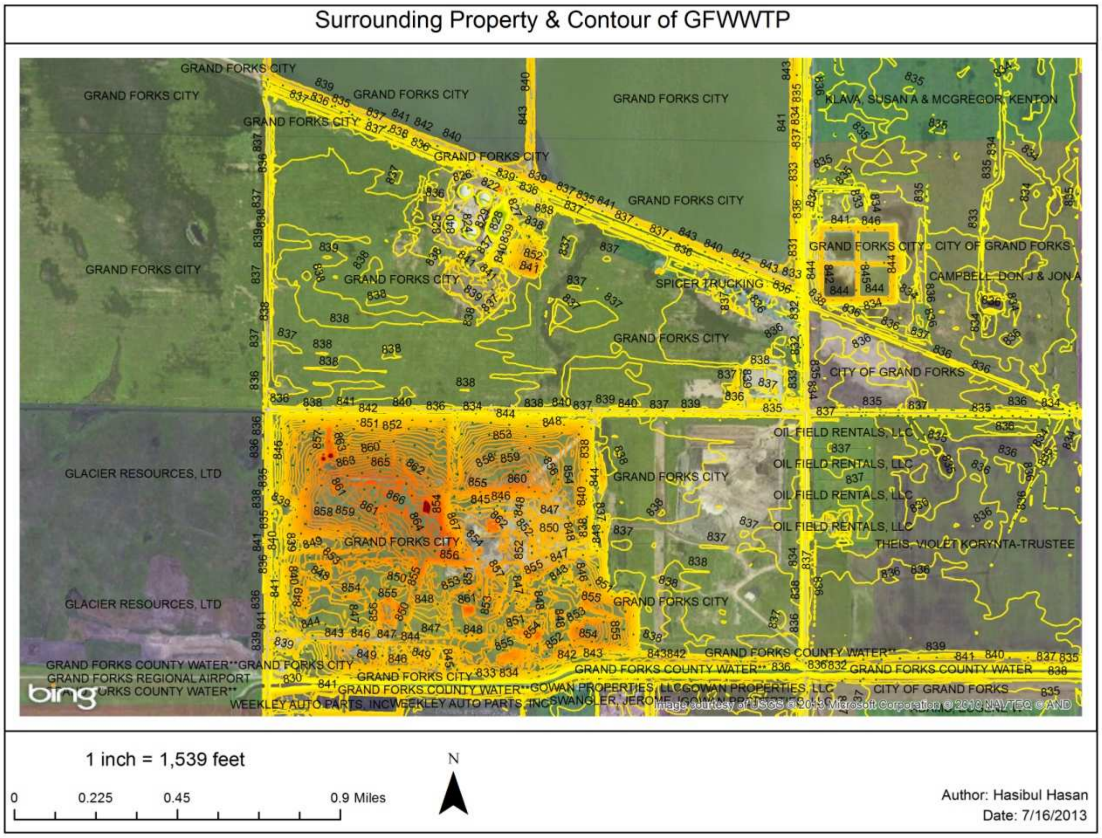
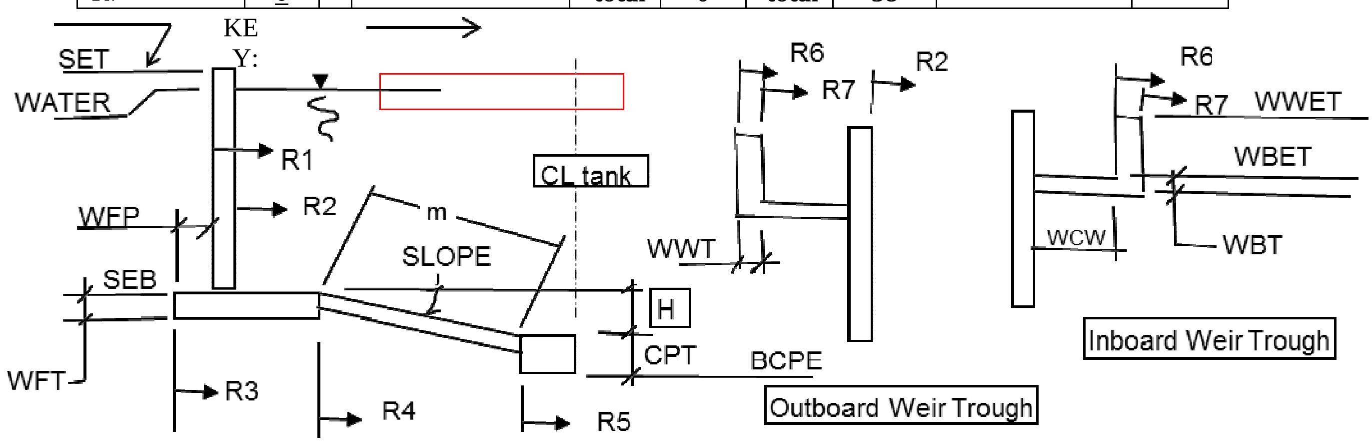


Figure 0-1: Contour Map of GFWWTP

APPENDIX V

Concrete volumes and costs:
general: volume = pi (R outer² - R inner²) * thickness

dimensions (ft)	_	_	ITEM:	volume (ft^3)	volume (yd^3)	cost/ yard	cost		
R1	66.25		sidewall	8247	305.4	$600	$183,260		
R2	65.00		wall ftg	9935	368.0	$500	$183,987	If costs increase $50/yd	_
R3	68.25		slab	7144	264.6	$500	$132,291	total =	**$546,437**
R4	58.25		center pier	0	0.0	$500	$0		
R5	0.00		weir wall	0	0.0	$500	$0	If costs decrease $50/yd	_
R6	0		weir base	0	0.0	$400	$0	total =	**$452,638**
R7	0			**total**	**938.0**	**total**	**$499,538**		



APPENDIX VI

Table 0.1: Marshall & Swift Equipment Cost Index

MARSHALL & SWIFT
THE BUILDING COST PEOPLE

Timeframe: Q22013
Base 1926: = 100

	4/2013	1/2013	10/2012	7/2012	4/2012
Average of all M & S Equipment Indexes	1552.8	1556.6	1552.8	1551.6	1553.4
Process Industries Average	1610.4	1610.6	1610.4	1611.8	1612.4
Cement Manufacturing	1627.5	1620.5	1622.3	1620.7	1610.3
Chemical	1572.8	1574.2	1576.8	1578.4	1569.8
Clay Products	1615.2	1608.5	1607.8	1606.9	1595.9
Glass Manufacturing	1511.2	1508.9	1508.9	1510.5	1500.2
Paint Manufacturing	1628.3	1626.3	1627.4	1629.2	1619.5
Paper Manufacturing	1527.5	1524.7	1524.0	1522.4	1513.2
Petroleum Industry	1724.8	1722.2	1722.0	1721.1	1710.3
Rubber	1648.6	1653.1	1655.9	1657.1	1652.7
Related Industries:					
Electrical Power Equipment	1496.9	1496.7	1499.2	1519.0	1507.7
Mining & Milling	1715.5	1697.7	1700.1	1693.9	1682.0
Refrigeration	1908.5	1906.3	1906.5	1908.9	1896.1
Steam Power	1579.4	1579.1	1581.9	1587.8	1578.5

Annual Index of all M & S Equipment Indexes:

2004	1157.3	2009	1468.6
2005	1245.0	2010	1457.4
2006	1302.3	2011	1503.2
2007	1373.3	2012	1545.9
2008	1427.3		

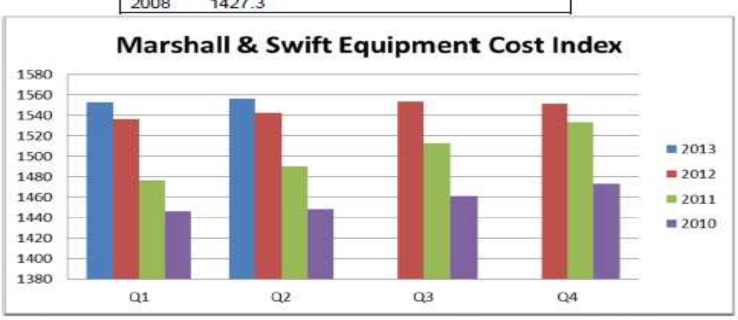


Table 0.2: Engineering News Record Construction Cost Index

Cost Indexes

Construction Cost Index

The CCI increased 0.2% this month, pushing up the annual escalation rate for the index to 2.6% from 2.5%.

20-CITY: 1913=100	DEC. 2012 INDEX VALUE	% CHG. MONTH	% CHG. YEAR
CONSTRUCTION COST	9412.25	+0.2	+2.6
COMMON LABOR	20056.05	+0.3	+3.0
WAGE $/HR.	38.11	+0.3	+3.0

Building Cost Index

The BCI declined 0.1% this month, cutting its annual inflation rate to 1.9% from 2.0% last month.

20-CITY: 1913=100	DEC. 2012 INDEX VALUE	% CHG. MONTH	% CHG. YEAR
BUILDING COST	5210.20	−0.1	+1.9
SKILLED LABOR	9009.67	+0.1	+2.4
WAGE $/HR.	50.00	+0.1	+2.4

Materials Cost Index

A 0.9% decline in steel prices over-powered price increases for cement and lumber, pulling the MCI down.

20-CITY: 1913=100	DEC. 2012 INDEX VALUE	% CHG. MONTH	% CHG. YEAR
MATERIALS	2888.62	−0.4	+0.9
CEMENT $/TON	109.26	+0.4	+3.8
STEEL $/CWT	48.63	−0.9	−0.8
LUMBER $/MBF	410.80	+0.7	+5.1

St. Louis Inflation Below National Average

Construction costs in St. Louis closed the year with a 2.4% annual increase, according to ENR's construction cost index for the city. This uptick was a nudge below the 2.6% annual increase measured by ENR's 20-city average CCI. The St. Louis index received a boost from material prices, which were up 2.1% for the year, compared to a 0.9% increase nationwide. Lumber prices in the St. Louis index were up 12.1% for the year, compared to a 5.1% increase for the national index. The city's cement price was up 1.5% from a year ago.

Cost Indexes by City

1913=100	CONSTRUCTION COST		BUILDING COST		COMMON LABOR		SKILLED LABOR		MATERIALS	
CITY	DEC. '12 INDEX	% CHG. YEAR	DEC. '12 INDEX	% CHG. YEAR	DEC. '12 INDEX	% CHG. YEAR	DEC. '12 INDEX	% CHG. YEAR	DEC. '12 INDEX	% CHG. YEAR
ATLANTA	5892.99	+0.4	3971.29	+0.5	10852.63	0.0	5803.00	0.0	2863.22	+1.2
BALTIMORE	6820.38	+4.5	4658.60	+3.9	12947.37	+4.6	7267.87	+3.7	3065.13	+4.2
BIRMINGHAM	6648.38	+4.3	3994.20	+2.5	12928.95	+4.7	5951.95	+2.1	2799.00	+3.0
BOSTON	12019.38	+0.1	6447.90	+2.4	26934.21	0.0	12268.29	+3.0	2878.04	+0.8
CHICAGO	13547.07	+2.8	6488.49	+0.7	30931.58	+3.3	12372.37	+1.0	2892.04	−0.1
CINCINNATI	8502.19	+1.4	4499.13	+0.5	17821.05	+1.7	7296.10	+0.8	2790.63	−0.1
CLEVELAND	10725.28	+5.6	5012.70	+2.5	23665.79	+6.3	8643.84	+2.8	2794.00	+2.0
DALLAS	5392.16	−0.6	4006.54	+2.8	9521.05	0.0	5882.28	+6.8	2861.55	−1.9
DENVER	6979.25	+1.4	4310.75	+3.3	13868.42	+2.0	6654.65	+6.1	2879.44	−0.5
DETROIT	10242.89	+3.0	5419.40	+2.4	22336.84	+3.0	9656.45	+2.2	2830.14	+2.9
KANSAS CITY	10656.62	+1.5	5573.62	+1.1	23121.05	+2.0	9757.36	+2.0	3017.13	−0.5
LOS ANGELES	10270.93	+1.8	5522.98	+2.1	22278.95	+2.2	9797.00	+3.1	2911.18	0.0
MINNEAPOLIS	10796.60	+5.1	5301.79	+0.9	23757.89	+5.6	9309.91	0.0	2852.57	+2.6
NEW ORLEANS	5739.18	+0.2	3708.44	+0.2	10494.74	0.0	5157.36	0.0	2824.48	+0.5
NEW YORK CITY	14495.14	+5.0	7532.75	+4.0	33078.95	+5.9	14775.98	+5.8	3105.06	−0.8
PHILADELPHIA	11586.66	+2.0	6251.30	+1.1	25684.21	+2.3	11658.66	+1.3	2946.22	+0.4
PITTSBURGH	8308.93	+3.5	5114.52	+4.2	17231.58	+3.3	8836.64	+4.3	2840.22	+4.1
ST. LOUIS	9853.49	+2.4	5058.26	+1.2	21323.68	+2.5	8715.92	+0.7	2823.37	+2.1
SAN FRANCISCO	10355.09	+1.5	6012.77	+1.1	22478.95	+1.8	11066.07	+1.6	2924.35	−0.1
SEATTLE	9412.52	+3.9	5318.52	0.0	20063.16	+5.0	9301.50	+0.3	2884.70	−0.6
MONTREAL	9726.81	+0.1	5412.76	+0.1	20263.16	0.0	8921.92	0.0	3289.05	+0.2
TORONTO	9956.30	+0.1	5242.66	+0.1	20400.00	0.0	8006.01	0.0	3555.33	+0.2

Sewer, Water and Drain Pipe

ITEM	UNIT	ATLANTA	BALTIMORE	BIRMINGHAM	BOSTON	CHICAGO	CINCINNATI	CLEVELAND	DALLAS	DENVER	DETROIT	KANSAS CITY
REINFORCED-CONCRETE PIPE (RCP):												
12"	ft	15.25	24.09	12.00	15.49	16.05	14.10	−18.65	15.62	15.66	17.75	14.20
24"	ft	34.89	47.96	24.00	31.70	31.85	26.76	−28.15	33.20	27.93	30.88	29.45
36"	ft	60.20	90.15	40.00	63.00	59.32	59.25	−58.40	63.85	59.15	63.88	58.60
48"	ft	94.62	151.95	62.00	96.25	95.00	120.40	96.00	96.77	89.25	118.00	94.91
CORRUGATED-STEEL PIPE:												
12"	ft	9.52	11.71	8.06	9.22	10.15	10.90	10.77	10.16	9.35	8.35	9.67
36"	ft	31.25	33.88	27.95	31.00	22.60	29.85	31.35	28.39	30.62	27.48	28.69
60"	ft	71.55	70.13	55.59	69.19	81.30	56.12	70.55	75.98	73.19	87.55	71.06
VITRIFIED-CLAY PIPE (VCP): PREMIUM JOINT												
12"	ft	15.00	19.38	13.70	15.76	15.80	9.95	13.70	—	—	14.95	13.00
24"	ft	64.00	71.77	68.20	67.50	67.38	54.95	71.15	—	—	76.20	50.00
POLYETHYLENE PIPE (PE): UNDERDRAIN												
4"	ft	1.30	—	0.35	1.23	1.42	1.23	0.88	1.40	1.18	0.82	—
POLYVINYL-CHLORIDE PIPE (PVC): SEWER												
4"	ft	2.32	3.10	2.05	1.85	2.18	−1.19	1.15	2.35	1.79	1.72	1.11
8"	ft	6.50	—	7.64	5.42	5.98	−4.15	2.95	6.49	6.25	4.48	5.64
Water 6"	ft	7.15	1.63	5.75	6.19	7.26	−5.75	3.98	6.95	6.20	6.15	2.53
8"	ft	10.08	2.91	8.88	10.27	9.20	−12.95	6.00	9.95	9.10	11.70	4.55
12"	ft	19.10	10.96	19.18	20.89	17.71	−18.31	9.15	16.98	17.40	23.35	11.10
DUCTILE-IRON PIPE (DIP):												
6"	ft	18.19	27.21	15.00	+18.44	18.55	24.88	15.25	18.62	+18.70	15.90	11.80
8"	ft	24.95	36.95	20.00	+27.65	31.98	+48.64	22.50	23.97	+24.95	21.65	16.20
12"	ft	37.83	50.11	33.00	+39.75	37.98	64.42	35.25	37.88	+36.97	34.90	27.30
COPPER WATER TUBING: TYPE L												
1/2"	ft	2.77	−1.22	2.29	2.39	2.69	−1.22	2.10	2.79	2.82	2.48	2.10
1 1/2"	ft	5.62	−5.50	4.85	5.75	5.10	−5.50	−5.42	−5.05	5.08	7.50	4.56

+ or − denotes price has risen or fallen since previous report; a=meters, includes federal tax; b=meters, excludes tax; c=1.5 meters. Monthly market quotations by ENR field reporters as of Nov. 30, 2012. All prices are spot prices quoted from a single source. Quotes are delivered prices unless noted. Some prices may include taxes or discounts for prompt payment, etc. Product specification may vary, depending on what is most commonly used or most accessible in a city. All quantities are truckloads unless noted. Quotes for Montreal and Toronto are in Canadian dollars and a mix of metric and American units. RCP pipe is ASTM C76; 12 in. and 24 in. are rubber-gasket jointed, while others are non-corrugated. Corrugated steel pipe is plain galvanized; 12 in. is

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REFERENCES

Apedaile, E. (2001). A perspective on biosolids management. *The Canadian Journal of Infectious Diseases, 12*(4), 202.

Das, D. (2013). *Determination of optimum polymer dose for grand Forks waste water treatment plant lagoon sludge dewatering.* (Unpublished Master of Science).

Engineering News Record. (2012, Engineering news record construction cost index.

Epstein, E. (2003). *Land application of sewage sludge and biosolids*. Hoboken: CRC Press.

Evanylo, G. K., & Virginia Cooperative Extension. (1999). *Agricultural land application of biosolids in virginia : Production and characteristics of biosolids*. Blacksburg, Va.: Virginia Polytechnic Institute and State University.

Fytili, D. (2008). Utilization of sewage sludge in EU application of old and new methods--A review. *Renewable Sustainable Energy Reviews, 12*(1), 116. doi:10.1016/j.rser.2006.05.014

Kistner, B. (2011). *Sludge diegtion and management at grand Forks wasrewater treatment plant.* (Unpublished Master of Science). University of North Dakota, Marshall& Swift. (2013), Marshall& swift equipment cost index.

Moretti, D. C. (2013). *Wastewater reuse and dispoal tends.* Unpublished manuscript.

U.S. EPA, Office of Research and Development. (1985). *Handbook: Estimating sludge managment costs* U.S. EPA, Office of Research and Development.

U.S. EPA, Office of Research and Development. (2004). *A national biosolids regualtion, quality, end use & disposal survey.* ().

United States. Environmental Protection Agency. Office of Research and Development. (1995). *Process design manual land application of sewage sludge and domestic septage* U.S. EPA, Office of Research and Development.

40 CFR part 503 requirements & biosolids inspection, (2006).