# LIFE-CYCLE ENERGY AND EMISSIONS FOR MUNICIPAL WATER AND WASTEWATER SERVICES: CASE-STUDIES OF TREATMENT PLANTS IN US

By:

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## Abstract

This study documents the energy intensity and environmental impacts from operation of water and wastewater treatment systems through case-studies in US. Life-cycle energy and impact assessments were conducted for the Ann Arbor Water Treatment Plant (WTP) and Ann Arbor Wastewater Treatment Plant (WWTP) in Michigan. The framework for assessment was modified to assess the environmental burdens from Laguna WWTP in California and Ypsilanti Community Utility Authority (YCUA) WWTP in Michigan.

From the comparative assessment of the three WWTPs, it is found that the life-cycle energy for the YCUA WWTP is the highest- 21 GJ/MG; out of which, 46% is from electricity used for operation, 44% from natural gas used for the sludge incinerator and 10% from production of chemicals used for treatment. For Ann Arbor WWTP, electricity utilized accounts for 50%, natural gas use for 25%, sludge-hauling for 16% and chemicals used for 9% of the total life-cycle energy of 16 GJ/MG. The life-cycle energy for the Laguna WWTP is the lowest - 11 GJ/MG, as it meets the total requirement for natural gas and 40% of the electricity required from methane produced upon anaerobic sludge digestion. Hence, 91% of the life-cycle energy for Laguna WWTP is from electricity, 8% from chemicals and a mere 1% from sludge-disposal.

From the assessment of the Ann Arbor 'water and wastewater' system, it is found that the Ann Arbor 'water and wastewater' treatment system accounts for 54% of the total electricity required by the Ann Arbor municipal government sector. Further, the life-cycle energy required for the system is 40 GJ/MG of clean water, out of which 60% is from the operation of the Ann Arbor WTP. The system also generates 5,230 kg $CO_2$ eq. /MG clean water or 3.57 million kgs $CO_2$ eq. per year. Electricity required for operation of the Ann Arbor WTP and WWTP contributes significantly to the total life-cycle energy and emissions. Thus, energy conservation at the plants, adoption of renewable energy and an anaerobic sludge digestion system coupled with co-generation unit would prove to be useful for reducing the total life-cycle energy and environmental burdens from the system.

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## Summary

Water utilities and wastewater facilities require significant amounts of energy to collect, treat and deliver clean water as well as collect, treat and discharge treated wastewater. Consequently, these systems are pivotal for any municipality in terms of direct costs and indirect costs such as environmental impacts associated with high energy consumption. Hence, in-depth research analyzing energy consumption at all stages in water and wastewater systems is vital for identifying and mitigating inefficiencies in the system consequently reducing energy consumption. This study carries forth the initiative taken by the Center for Sustainable Systems, at the University of Michigan, through - 'Preliminary Application of Life-cycle Assessment to U.S. Water and Wastewater Treatment Facilities', developing an initial framework to evaluate life-cycle environmental performance of water and wastewater treatment plants in US.

This study employs life-cycle assessments for analyzing the sustainability of four case-studies in the US using total life-cycle energy and impacts as indicators. The treatment plants analyzed as part of this research are- Ann Arbor Water Treatment Plant (WTP), Ann Arbor Wastewater Treatment Plant (WWTP), Laguna WWTP and Ypsilanti Community Utility Authority WWTP. The analysis is based on data collected from each plant for six years from 2000 to 2005. The total life-cycle energy, in Giga Joules per million gallons (GJ/MG) required for operation of each plant, is calculated based on the utilization of electricity, natural gas, chemicals and diesel fuel. Further, emissions generated due to the operation of these plants have been categorized into global warming potential (kg CO2 eq. /MG), eutrophication potential (g N eq. /MG) and acidification potential (kmoles of H+ eq. /MG).

The life-cycle energy for operation of the Ann Arbor WTP is 25 GJ/MG of clean water delivered to the customers in Ann Arbor. Electricity required for operation accounts for 36%, energy required for production of chemicals accounts for 35% and natural gas used for heating contributes 28% of the total life-cycle energy for the plant. Further, the global warming potential from operation of the Ann Arbor WTP is 3,300 kg

$CO_2$ eq. /MG, out of which emissions from electricity contribute 56% and emissions from production of chemicals used for treatment, contribute 34%.

Presently, the operation of Ann Arbor Wastewater Treatment Plant (WWTP) requires life-cycle energy of 16 GJ/MG wastewater treated at the plant. Electricity utilization accounts for 50%, natural gas use for 26%, diesel fuel used for sludge hauling for 16% and energy consumed for production of chemicals for 9% of the total life-cycle energy for the plant. The total global warming potential from operation of the plant is 1,984 kg $CO_2$ eq. /MG, out of which emissions from electricity contribute 87%, emissions from sludge-hauling contribute 9% and emissions from production of chemicals required for treatment contribute 5%.

The results obtained from the assessment of Ann Arbor WWTP were compared with the assessments of Laguna WWTP and YCUA WWTP. A summary of the results is provided below-

| Wastewater Treatment Plant | Life-cycle Energy | Global Warming Potential | Atmospheric Eutrophication Potential | Aquatic Eutrophication Potential | Acidification Potential |
|---|---|---|---|---|---|
| | GJ/MG | kg $CO_2$ eq./MG | g N eq./MG | g N eq./MG | kmoles $H^+$ eq./MG |
| **Ann Arbor WWTP** | 16 | 1,984 | 291 | 3 | 673 |
| **Laguna WWTP** | 11 | 2,192 | 204 | 4 | 629 |
| **YCUA WWTP** | 21 | 2,747 | 222 | 4 | 1094 |

The total life cycle energy for the Laguna WWTP is the lowest of the three WWTPs despite the fact that its electricity utilization is higher than that of the Ann Arbor WWTP and the YCUA WWTP. This is due to the adoption of an anaerobic digestion system coupled with a co-generation facility at the plant. The methane emissions from sludge treatment are utilized for meeting the total natural gas requirement for the plant and 40% of the electricity requirement for operation. As a result, the life-cycle energy and emissions from the plant are reduced. Electricity imported from the grid accounts for 91%, production of chemicals used for treatment for 8% and sludge disposal accounts for 1% of the total life-cycle energy for the plant. Further, emissions from electricity imported from the grid are responsible for 99% of the total global warming potential from the plant.

On the other hand, the life-cycle energy for YCUA WWTP is the highest of the three WWTPs analyzed. YCUA WWTP employs a sludge incineration unit for management of sludge produced upon treatment, due to which the natural gas consumption is four times higher than the Ann Arbor WWTP. Further, the energy for production of chemicals used at the plant is also higher than that of the chemicals used at the Ann Arbor and Laguna WWTPs. Electricity utilization and natural gas use dominate the total life-cycle energy for operation of the plant contributing 46% and 44% respectively. Greenhouse gas emissions from electricity used contribute 79% and emissions from natural gas use contribute 20% of the total life cycle global warming potential.

The main factor distinguishing YCUA WWTP from the other two facilities is the adoption of incineration for sludge disposal which increases the natural gas use at the plant significantly leading to high life-cycle energy and emissions from operation of the plant. Similarly, a major drawback of the method of sludge disposal for Ann Arbor WWTP was a long one-way distance to the landfill, which increases the diesel fuel consumption and consequently the total life-cycle energy and emissions from operation of the plant. The life-cycle energy for both Ann Arbor and YCUA WWTPs could be reduced by adoption of a closed anaerobic sludge treatment system. A comparison of the methane produced from such a system and natural gas requirement for both facilities is shown below-

| Wastewater Treatment Plant | Natural Gas Requirement per month (Average) | Methane Production from Sludge Treatment per month (Average) |
|---|---|---|
| | CCF | CCF |
| **Ann Arbor WWTP** | 17,706 | 24,439,602 |
| **YCUA WWTP** | 58,438 | 23,298,000 |

Hence, the methane produced at YCUA and Ann Arbor WWTP can be utilized for meeting the respective natural gas requirements at the plant completely and generating part of the electricity required for operation.

Reduction of energy consumption through such changes in the process or technology would eventually reduce the environmental burdens for the city or town governments responsible for operation of these plants. For instance, the Ann Arbor WTP and Ann

Arbor WWTP together utilize 54% of the total direct electrical energy requirement of the Ann Arbor municipal government sector.

| Year | Ann Arbor WTP | | Ann Arbor WWTP | | Ann Arbor WTP and WWTP | | Ann Arbor Municipal Govt. Sector |
|---|---|---|---|---|---|---|---|
| 2000 | kWh | % of Total | kWh | % of Total | kWh | % of Total | kWh |
| | 11,631,010 | 25 | 13,726,765 | 29 | 25,357,775 | 54 | 46,681,772 |

Electricity for operation, natural gas for heating and chemicals required for treatment comprise of a large percentage of the total life-cycle energy of 216,000 GJ/year for the system. This energy is equivalent to the life-cycle energy for 2160 passenger cars and 685 residential homes. Further, the emissions from the operation of the WTP and the WWTP lead to a global warming potential of 5,230 kg $CO_2$ eq. /MG clean water or 3.57 million kgs $CO_2$ eq. /year. The key findings for the Ann Arbor 'water and wastewater' treatment system based on an analysis of 1 million gallons of clean water are compiled below-

| Year | Life-cycle Energy for Operation | Total Global Warming Potential | Atmospheric Eutrophication Potential | Aquatic Eutrophication Potential | Acidification Potential |
|---|---|---|---|---|---|
| | GJ/MG | kg $CO_2$ eq./MG | g N eq./ MG | G N eq./ MG | kmoles H+ eq./MG |
| 2003 | 40 | 5213 | 534 | 14 | 1240 |
| 2004 | 40 | 5250 | 505 | 13 | 1174 |

While the operation of water and wastewater treatment plants is essential for public health and environmental management, in light of the increasing global demands for energy, it is imperative to reduce the energy used at these facilities. In general, adoption of renewable energy for meeting part of the energy requirement would reduce the burdens from these facilities greatly. Also, case-specific and innovative solutions may be required for different treatment plants. For example, although sludge disposal at landfill and land-application sites for the Ann Arbor WWTP is less energy expensive than the energy required for sludge incineration at the YCUA, further improvement would lead to reduced energy consumption for the Ann Arbor WWTP if nearer disposal sites are used.

While this study has prepared a detailed framework for life-cycle energy and impacts assessment for water and wastewater treatment plants, further research is needed in this field. For example, it would be very useful if further studies employ separate meters for gauging the energy consumption at each stage of treatment. Also, incorporation of the initial construction and decommissioning of these plants would provide a more comprehensive assessment for water and wastewater treatment plants. Further, economic modeling coupled with life-cycle energy assessment would provide clearer picture of the feasibility of the opportunities identified for improvement. The basic framework developed for this study can be utilized for treatment plants similar to the ones studied for this research or after case-specific modifications for other facilities. Finally, the findings of this study are useful for life-cycle energy studies requiring the primary energy for clean water or service provided in terms of wastewater treated.

# Chapter 1

# Introduction

## 1.1 Background

Water is indispensable for human health and well being, and crucial for Sustainable Development. Hence, water and wastewater infrastructure is fundamental for protecting the human population and environment. During the 20th century global water use increased six-fold, more than twice the rate of population growth.[1] Further, it has been predicted that the growth in world requirements for development of additional water supplies will range from 25% to 57% by the year 2025[2]. Thus, the rapid rate of increase in population creates challenges in terms of constant technological improvement and higher efficiencies through innovation in treatment processes for water and wastewater as well as supply of drinking water. Such innovations require significant developments in research in the field of water and wastewater treatment.

It is well known fact that only 2.5% of the Earth's total water resources comprise of freshwater, out of which only 0.5% is directly usable[3]. Thus, efficient use of water and reduction of losses are vital for water supply systems. Furthermore, the wastewater discharged, if untreated or treated below standards, invariably deteriorates the environment it is discharged in. This creates the need for efficient treatment of wastewater before it is discharged. As a result, since the 1700s when the first water filters for domestic water treatment were applied[4], significant efforts have been made towards advancements achieving higher quality of drinking water and lower level of pollutants in the wastewater discharged to the environment. However, the sustainability of water and wastewater systems is not limited to the quality of service provided. A sustainability assessment should also incorporate resource and energy consumption and the positive and negative environmental impacts on the environment from these systems.

In light of a growing awareness towards depletion of sources of energy and adverse impacts of fossil fuels on the environment, there is a much stronger need for energy efficiency in all sectors. Operation of water and wastewater treatment facilities consumes a large part of the total electricity required at the city/town government level. Reduced electricity consumption at these facilities would mean lower costs for municipalities or agencies responsible for their operation. At the same time the ecological footprint[†] associated with the per capita energy consumption would be reduced. However, energy efficiency at water and wastewater treatment facilities is difficult to achieve unless the current patterns of energy consumption are assessed and sources of loss or inefficiency are identified in the system.

## 1.2 Rationale

Globally, commercial energy consumed for delivering water is more than 26 Quads which accounts for 7% of the total world consumption.[5] Since this figure does not include the energy consumed for treatment of wastewater, the energy consumed by water and wastewater systems together would account for a larger percentage. Water and wastewater treatment plants require considerably large amounts of energy to acquire, treat, deliver clean water as well as collect, treat and discharge treated effluent. Energy is required to lift water from depths in aquifers, pump water through canals and pipes, control water flow, collect and treat waste water, and desalinate brackish water or sea water.

In US, 4% of the nation’s annual electricity is utilized for the treatment of water and wastewater, including the electricity required for acquiring water and discharging wastewater.[6] Unit electricity consumption for ‘surface water supply’ and ‘groundwater supply’ systems in the US is estimated to be 1,400 kWh/MG and 1,800 kWh/MG respectively.[7] Further, Publicly Operated Treatment Works (POTW) for wastewater treatment alone accounted for 21 million MWh of electricity in the year 2000[8], out of a total U.S. electricity consumption of approximately 3.8 billion MWh[9]. Since privately operated wastewater treatment facilities are estimated to consume more energy[‡] than the

[†] "Ecological Footprint" is a term used to depict the amount of land and water area a human population would hypothetically need to provide the resources required to support it and to absorb its wastes, given prevailing technology. The term was first coined in 1992 by Canadian ecologist and professor at the University of British Columbia, William Rees.
[‡] Because of their smaller size and potentially higher loading when compared with POTWs since these facilities are generally industrial or commercial

energy required for POTWs [8], the overall electrical consumption for treatment facilities in the U.S. is even higher. With these significant amounts of electrical energy consumption figures for water treatment plants, it is not surprising that approximately 80% of municipal water processing and distribution costs are for electricity.[9]

The water and wastewater systems are also central for any municipality in terms of environmental impacts owing to the different processes involved. While there are obvious benefits from water and wastewater treatment plants, there are negative environmental impacts in the form of greenhouse gas emissions. For example, in the year 2004, emissions resulting from domestic wastewater treatment resulted into an estimated 20 million metric tons $CO_2$ equivalence global warming potential, and emissions from industrial wastewater treatment resulted into 17 million metric tons of $CO_2$ equivalence global warming potential.[10] The environmental emissions from water treatment plants further increase the global warming potential from water and wastewater treatment systems.

One of the most serious forms of environmental pollution threatening both human health and sustainable development can be a result of uncontrolled municipal sewage discharge. Further inefficiencies at various stages in water and wastewater sector can contribute significantly towards high energy consumption due to energy losses and consequently increased greenhouse gas emissions resulting from energy generation. Thus, energy savings are crucial to both water and wastewater sectors to meet national and international targets for reducing greenhouse gas emissions (GHG) and to decrease dependence on imported energy sources. In order to meet the growing water and energy demands, priority should be given to wise and efficient use of existing water and energy supplies. Transformation is needed at all levels- from the national policy level to innovations and efficient practices at very small scales such as the city level.

### 1.3 Thesis Statement

This study contributes to sustainable water and waste water treatment systems for cities in the US through an in-depth energy and emissions analysis using life-cycle assessment methods for four different case-studies. These analyses will quantify burdens and highlight the opportunities for improvement. Reporting energy consumption patterns for water and wastewater systems enable energy efficient technological advancements and reduction of losses in the system. While the framework for assessment is based on data from specific facilities for this study, it can be replicated for similar facilities and modified for dissimilar facilities within the US as well as internationally.

## 1.4 Scope of Study

This research is restricted to an assessment of water and wastewater treatment facilities in the US in terms of total energy consumed at the various stages of operation and emissions from these stages. Four case-studies, three wastewater treatment plants (WWTPs) and one water treatment plant (WTP), have been used for characterizing the amounts of energy and emissions from such facilities. The data obtained from the Ann Arbor Water Treatment Plant and the Ann Arbor Wastewater Treatment Plant have been analyzed for energy consumption and emissions from different treatment stages with an aim to ascertain the total energy consumed by the 'water and wastewater' system.

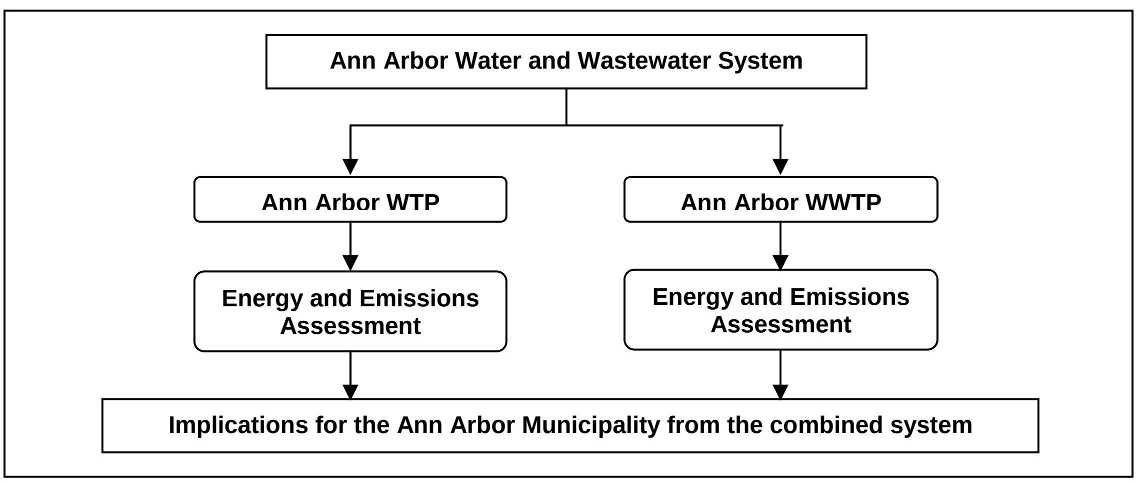


Figure 1-1. Scope of Study for Ann Arbor 'Water and Wastewater' System

This study does not discuss the energy consumed and emissions from the initial construction of these facilities. The scope is restricted to operation of the treatment plant and pumping stations, production of chemicals required for treatment, fuels used at the plants, and fuels used for disposal of sludge from each facility. For example, the electricity consumed for operating the Ann Arbor WTP and the pumping stations has been included for the assessment along with the total natural gas consumption at the plant and the energy required for producing the chemicals used for water treatment.

Further, this research analyzes two additional wastewater treatment plants in US. The Ypsilanti Community Utility Authority (YCUA) in Southeast Michigan and Laguna Treatment Plant in Santa Rosa, California were included in this research. The assessment for the wastewater treatment plants includes electricity required for operation of the plant and pumping stations, energy required for production of chemicals utilized for treatment, energy in the form of natural gas used at each plant and energy for sludge disposal at landfills or land-application sites.

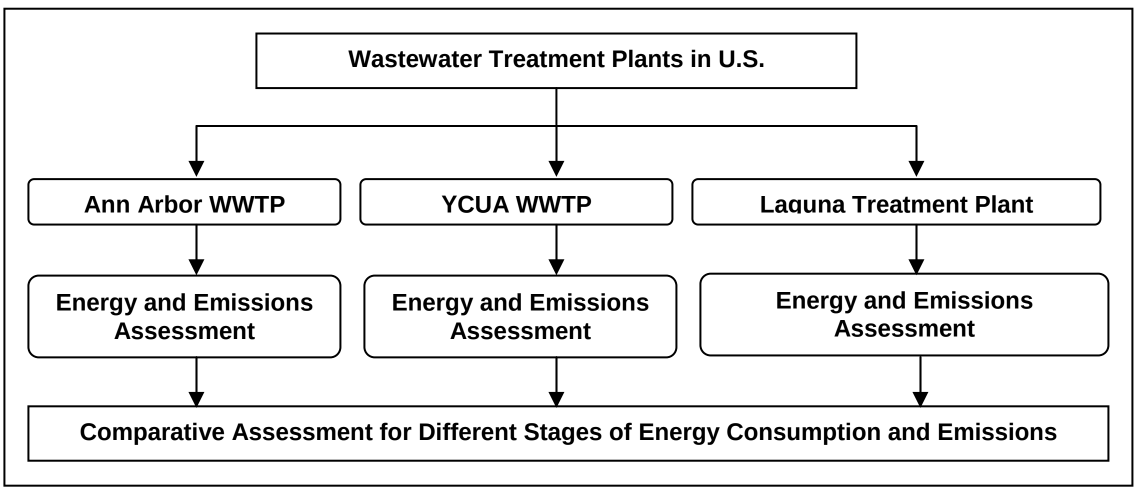


Figure 1-2. Scope of Study for Wastewater Treatment Plants

All three wastewater treatment plants under consideration are tertiary treatment facilities, with approximately equal treatment capacities, however, the variation in operation processes used at these systems make them unique. Lastly, although different methodologies can be adopted for energy assessment for water and wastewater systems, this study relies on life-cycle energy and emissions assessment.

## 1.5 Methodology

This study follows a life-cycle approach for assessment of energy consumption and environmental impacts related with operation of water and wastewater treatment plants.

Although the energy and impact assessment has been presented separately for each facility, together it has been referred to as ‘Life-cycle Energy and Impact Assessment’ or LCEIA in this report.

### 1.5.1 Life-cycle Energy and Impact Assessment

Life-cycle Energy Analysis (LCEA) is an approach in which all energy inputs to a product are accounted for, not only the direct energy inputs during production or manufacturing, but also all energy inputs needed to produce components, materials and services needed for the product or process. The procedures of life-cycle analysis are a part of ISO 14000. The ISO 14040- “Environmental Management- Life-cycle Assessment – Principles and Framework” - defines[11] Life-cycle Assessment (LCA) as a technique for assessing the environmental aspects and potential impacts associated with a product, by-

- Compiling an inventory of relevant inputs and outputs of a product system ;
- Evaluating potential environmental impacts associated with the inputs and outputs
- Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

Following the principles above, this study identifies the key stages of energy consumption for operating water and wastewater treatment plants.

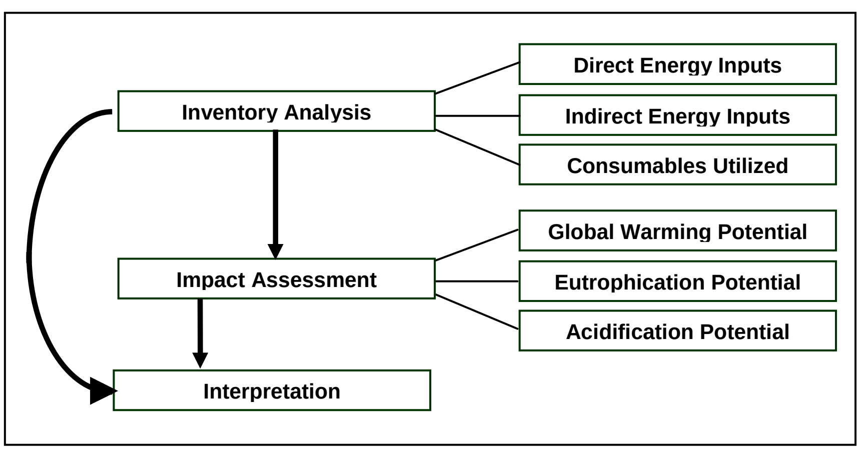


Figure 1-3. Life-cycle Energy and Impacts Assessment Methodology

Impact assessment in LCA is a technical, quantitative, and qualitative process for characterizing and assessing the effects of environmental burdens identified in the inventory component. The impact assessment consists of three components[12] – classification, characterization and valuation-

- Classification, where the data from the inventory is grouped into a number of impact categories.
- Characterization, in which impacts are analyzed/quantified and aggregated within identified impact categories.
- Valuation, in which the contributions from the different specific impact categories are weighted so that they can be compared among themselves.

### 1.5.2 LCEIA Modeling and Key Parameters for Assessment

The model for LCEIA was created in Microsoft Excel and modified for individual case-studies. The framework for analyzing energy consumption and environmental impacts is explicated in this section.

***Total Life-Cycle Energy***

The life-cycle energy for operation of each of the treatment facilities includes energy consumption in the form of energy sources such as electricity, natural gas and diesel fuel, as well as energy in form of chemicals consumed for treatment.

*i. Electricity consumption*

The electricity consumption for each case-study is reported in terms of kWh per month as the total electrical consumption for plant operations including the electricity consumed at administrative buildings, pumping stations, UV disinfection and ozonation.

*ii. Natural Gas consumption*

The natural gas consumption for heating in buildings, or plant operations such as sludge incineration at YCUA WWTP are reported in terms of cubic feet (cuft) or hundred cubic feet (CCF) per month for plant operations as well as heating in buildings. The calculation for conversion from CCF of natural gas to Giga Joules included pre-combustion and combustion energy for natural gas which is equal to 1.16 million BTU† per 1000 cuft of natural gas.[13]

*iii. Energy consumed in the form of chemicals utilized for treatment at the plant*

The chemicals consumed for treatment at each facility are reported in terms of metric tons per month. The material production energy for chemicals used for water and wastewater treatment is calculated based on figures from Table 1-1. Some of the energy consumption figures adopted from Owen (1982) were updated to include the primary energy consumed. The material production energy for the rest of the chemicals has been adopted from APME database on life-cycle energy for production of chemicals and SimaPro 6.0 life-cycle assessment database.

Table 1-1 Material Production Energy for Chemicals Utilized

| Material Production Energy for Chemicals | | |
|---|---|---|
| **Chemical** | **MJ/metric ton** | **Source** |
| Aluminum Sulfate (Alum) | 6290 | (a) |
| Ferric Chloride | 1200 | (b) |
| Ferrous Chloride | 1200 | (b) |
| Chlorine | 20130 | (c) |
| Sodium Hypochlorite | 59525 | (b) |
| Lime | 6500 | (a) |
| Polymers | 44682 | (b) |
| Carbon Dioxide | 12900 | (a) |
| Oxygen | 5590 | (a) |
| Sodium Hydroxide | 22040 | (c) |
| Sodium Hexametaphosphate | 12800 | (d) |
| Ammonia | 35760 | (c) |
| Sodium Silico Fluoride | 12800 | (d) |

Sources: (a) Semipro 6.0 - BUWAL250, Eco-indicator 95
(b) Owen William F. 'Energy in Wastewater Treatment'. 1982 (upgraded)
(c) APME, Ecoprofiles of the European Plastic Industry
(d) NREL, 'Life-cycle Inventory of Biodiesel fuel and Petroleum Diesel fuel'. 1998

The energy for production of chemicals used presented in Table 1-1 above has been calculated based on secondary information and processes involved in production for the

† 1 BTU = 3412 kWh = 3.412 * 3.6 GJ

specific chemicals. The detailed calculations and sources of secondary data on energy consumed in production of these chemicals are included in Appendix F-I.

*iv. Energy consumed for disposal of sludge after treatment*

The energy consumed for disposal of sludge produced at wastewater treatment plants is calculated based on the specific method of disposal used at the plant. The energy is calculated based on the quantity of diesel fuel consumed for transporting the sludge to landfill or land application sites and natural gas consumed for incineration. The inherent energy of diesel fuel includes the pre-combustion and combustion energy, which is equal to 158 million BTU per 1000 gallons of diesel fuel consumed.[14]

***Total Life-Cycle Emissions***

The life-cycle impact assessment included atmospheric and aquatic emissions from consumption of electricity, natural gas and diesel fuel at each facility. The sources for each and details are presented in this section.

*i. Emissions from Electricity*

This study utilizes the information provided in a recent study by Kim and Dale - 'Life-cycle Inventory Information of the United States Electricity System'[14]- which compiles the emissions from one Mega Joule of electricity based on the average US grid. Thus, the calculation of emissions from electricity consumption for each case-study is based on the emissions factors provided by Kim and Dale (Appendix F-II-a).

*ii. Emissions from Natural Gas*

The total pre-combustion and combustion emissions from natural gas consumption per 1000 cuft of natural gas have been adopted from information compiled in Franklin's Appendix A, Table A-20[15] (Appendix F-II-b).

*iii. Emissions from Chemicals Utilized*

The impact assessment includes emissions from production of chemicals utilized for treatment at each treatment facility. The emission factors used have been summarized in Table 1-2.

Table 1-2 Environmental Impacts from Production of Chemicals Used for Treatment

| **Environmental Impacts from Production of Chemicals Utilized for Treatment** | | | | |
|---|---|---|---|---|
| | Global Warming | Atmospheric Eutrophication | Aquatic Eutrophication | Acidification Potential |
| **Chemical** | **kg CO2 eq./MT** | **g N eq./MT** | **g N eq./MT** | **kmoles H+ eq./MT** |
| Aluminum Sulfate (a) | 276 | 0.04 | 0.02 | 753 |
| Ferric Chloride (b) | 77 | 8 | 0 | 24 |
| Ferrous Chloride(b) | 77 | 8 | 0.09 | 24 |
| Chlorine (f) | 780 | 0.06 | 0.01 | 121 |
| Sodium Hypochlorite(b) | 1065 | 105 | 1.31 | 333 |
| Lime (a) | 1264 | 0.03 | 0.003 | 47 |
| Polymers (b) | 2082 | 0.0004 | 0.01 | 191 |
| Carbon Dioxide (a) | 346 | 0.01 | 0 | 0.3 |
| Oxygen (a) | 226 | 0.02 | 0.02 | 79 |
| Sodium Hydroxide (c) | 1376 | 0.12 | 0.000002 | 369 |
| Ammonia (c) | 2400 | 90 | 34 | 182 |

Sources: (a) SimaPro 6.0 - BUWAL250, Eco-indicator 95
(b) Owen William F. 'Energy in Wastewater Treatment'. 1982 (upgraded)
(c) APME, Ecoprofiles of the European Plastic Industry

*iv. Emissions from Diesel fuel*

The total pre-combustion and combustion emissions from diesel fuel consumption per 1000 gallons of diesel fuel have been adopted from information compiled in Franklin's Appendix A, Table A-20[16] (Appendix F-II-c).

The emissions from each of the source above have been aggregated within three different impact categories- global warming potential, eutrophication potential and acidification potential. The environmental impact factors used are presented in Table 1-2.

Table 1-2 Environmental Impact Factors based on a 100-year Time Horizon

| Environmental Impact Factors Over a 100-year horizon | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Global Warming Potential** | | **Eutrophication -** (kg N equivalent/kg) | | | | **Acidification** | |
| ($CO_2$ equivalence/kg) | | Atmospheric | | Aquatic | | (kmoles of $H^+$ equivalent/kg) | |
| $CO_2$ | 1.00 | NOx | 0.04 | N | 1.00 | $SO_2$ | 50.79 |
| $CH_4$ | 23.00 | $NH_3$ | 0.12 | $NH_4$+ | 0.78 | HCl | 81.26 |
| $N_2O$ | 300.00 | $NO_3^-$ | 0.24 | COD[†] | 0.05 | NOx | 40.04 |
| | | P | 1.12 | $NO_3^-$ | 0.10 | $NH_3$ | 95.49 |
| | | | | $PO_4^{3-}$ | 2.38 | | |
| | | | | P | 7.29 | | |

Source: US EPA. TRACI Characterization Factors. US Average 2006.

Further, methane emissions from the anaerobic sludge treatment[‡] process were computed. The emission factor adopted from 'IPCC Good Practice Guidance' study for calculating $CH_4$ emissions from a closed anaerobic sludge treatment process is as below-

0.6 grams $CH_4$ per gram BOD[17]

Since the energy consumption figures as well as the emissions were derived in different units a common functional unit for the total life-cycle energy and life-cycle impact from operation of each treatment plant is necessary for ease in making comparisons.

### 1.5.3 Functional Unit

The life-cycle energy consumption for operation of water treatment plant and wastewater treatment plants has been reported in terms of Giga Joules[Ψ] per million gallons of water delivered or wastewater treated respectively. Since emissions have been categorized in terms of total global warming, eutrophication and acidification potential, the units for each is in terms of kilograms of carbon dioxide equivalent per million gallons, grams of nitrogen equivalent per million gallons and kilogram moles (kmoles) of hydrogen ion equivalent per million gallons respectively. It is to be noted that all results presented in

[†] Organic Carbon shown in terms of COD (Chemical Oxygen Demand)

[‡] Although both Ann Arbor WWTP and YCUA WWTP employ activated sludge treatment (aerobic), this calculation was required a proposed closed anaerobic treatment method for utilizing the sludge for production of energy at the plant

[Ψ] One GJ is equal to 3600 kWh

terms of per million gallons are on the basis of million gallons of clean water delivered in case of the water treatment plant and million gallons of wastewater treated in case of the wastewater treatment plant.

### 1.5.4 Data Quality and Key Assumptions

Most of the information on the four case studies presented in this report is primary information collected from the treatment facilities in a standard format. The consumption of electricity is either calculated from monthly electric bills or monthly reports. Consumption of natural gas and chemicals is also recorded on a monthly basis for each plant except for the Ann Arbor water treatment plant. The diesel fuel consumption is calculated based on the total quantity of sludge produced per month and the distance to the landfills or land application sites. Although the data is collected on a monthly basis for a period of six years from the year 2000 to 2005 some of the information is unavailable or incomplete. Hence, the results presented in this study are only for the years for which the information is complete for each category and month. Also, certain assumptions are made for computations where exact information is unavailable. The key factors adopted and assumptions made for the purpose of homogeneity in calculations for this study are listed below.

- The average tare weight[†] of the truck used for sludge disposal to landfill and land application sites was reported to be approximately 16 metric tons[‡] for the Ann Arbor Wastewater Treatment Plant. It was assumed that the trucks used for sludge disposal at other facilities weighed the same for the purpose of consistency.
- Although the electric grid for the state of California is different from that of Michigan, the emissions from electricity were calculated based the composition of the average US grid for both states. A more accurate method would be to compute calculations based on the individual grids, however, this would have been a lengthy procedure and the difference in emissions are not considered to be significant in the context of this research effort.

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[†] Tare weight is the weight of a vehicles when it is empty
[‡] Source: phone conversation with Don Popma, Director of Operations, Synagro Tech Inc., responsible for sludge disposal for the Ann Arbor Wastewater Treatment Plant

## 1.6 Literature Overview and Previous Studies

The necessity of safe and reliable water treatment systems was recognized in US during late 19th century to early 20th century[18]. Methods such as sedimentation, filtration and disinfection processes were combined to provide these systems before the water was sent to storage and distribution. The plant locations for these early systems were chosen so that water flowed by gravity. Simpler methods and location of these early systems required less energy. Compared to those simpler methods the existing treatment plants employing modern technologies such microfiltration, ultrafiltration, ozone disinfection and ultraviolet disinfection require more energy. Also, meeting present water standards requires usage of more chemicals for treatment. Hence, water treatment plants currently in operation in the US require greater amount of energy to operate.

Wastewater treatment systems in the US also date from the late 19th century when septic systems were developed and became popular in rural and urban settings. The federal funding for construction of municipal wastewater treatment plants by the US government began in the year 1948 and State Revolving Funds (SRF)[†] were introduced in the 1987 amendments to the Clean Water Act[‡]. To meet the more stringent discharge limits as per the Clean Water Act of 1977 more sophisticated and advanced treatment technologies such as biological nutrient removal and ultraviolet disinfection were adopted. Water and wastewater treatment plants require significant energy for operation. The provision of clean water and collection and treatment of wastewater contribute considerably to the energy requirement for municipal governments. Research and development contributing to energy conservation in the water and wastewater treatment sector is needed.

A pioneer study contributing to energy accounting in the field of wastewater treatment is "Energy in Wastewater Treatment"[19] by William F. Owen, published in 1982. The study is significant not only in terms of an effort for accounting electricity consumption at various stages in the treatment process at wastewater treatment plants but also a detailed description of energy consumption for production of chemicals consumed for treatment. Most studies

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[†] Loans to local governments for specific water-pollution-control purposes

[‡] Growing public awareness and concern for controlling water pollution led to enactment of the Federal Water Pollution Control Act Amendments of 1972. As amended in 1977, this law became commonly known as the Clean Water Act.

focusing on energy consumption for operation of water and wastewater treatment facilities ignore the consumption of energy in the form of chemicals utilized for treatment. Owen in his book provides detailed information on energy consumed for production of consumables or chemicals, based on secondary information and primary data from the industries manufacturing these chemicals. Hence, even though this study does not assess wastewater treatment systems using LCEA as method of assessment, it proves to be very useful for studies assessing energy consumption at wastewater treatment plants.

More recently, there have been additional studies analyzing the energy consumption patterns, comparing alternative treatment processes in terms of energy consumption or discussing the different stages of energy consumption at water and wastewater treatment plants. A study conducted in 2002- “Energy Efficient Technologies for the Fortuna Wastewater Treatment Facility”[20]- by Jennifer Fuller for ‘The Community Clean Water Institute Fortuna water Quality Institute’ studied energy consumption patterns at Fortuna Wastewater Treatment Facility in California. Since the study focused on electrical consumption at the plant, the method of assessment was not LCEA. However, there is a good discussion on the prospects for alternative energy-efficient options for operation and management of the Fortuna wastewater treatment plant. Such alternatives can be employed at other facilities in the US for achieving energy efficiency in operation of wastewater treatment plants.

Life-cycle energy is increasingly becoming a popular indicator of overall sustainability for water and wastewater treatment systems. For example, “Life-cycle Assessment of Water Production Technologies”[21] by Raluy et al assesses life-cycle energy for three different desalination technologies currently used on a commercial scale for producing clean water. Based on modeling and analysis using LCA software SimaPro 5.0 the study concluded that Reverse Osmosis was environmentally more sustainable than the other two technologies in question- Multi Effect Desalination and Multi Stage Flash.

Another such study- “Life-cycle Energy Assessment of Alternative Water Supply Systems”[22] by Stokes et al., assessed three water supply alternatives (Importing, recycling and desalination) for the state of California. Interestingly, the study employed a hybrid LCA approach, combining elements of economic input-output method with process-based LCA. The authors created a Microsoft Excel based model, named Water-Energy Sustainability Tool

(WEST), which quantifies material and energy inputs into water systems as well as environmental outputs.

A similar approach has been used for "Preliminary Application of Life-cycle Assessment to US Water and Wastewater Treatment Facilities" a working paper for the Center for Sustainable Systems at the University of Michigan, Ann Arbor. Although similar in regard that MS Excel based models have been developed for assessing water and wastewater treatment plants for typical treatment processes and plant capacities, the CSS study does not incorporate economic modeling. The generic models have been modified for assessing individual case studies in the state of New York and Southeast Michigan.

This study analyzes individual case-studies on the City of Ann Arbor's Water Treatment Plant, City of Ann Arbor's Wastewater Treatment Plant, Ypsilanti Community Utility Authority Wastewater Treatment Plant and City of Santa Rosa's Laguna Wastewater Treatment Plant.

# Chapter 2

## Ann Arbor Water Treatment Plant

### 2.1 Background

The City of Ann Arbor Water Treatment Plant (WTP) supplies water to 120,000 customers in the City of Ann Arbor. It has a total capacity of 50 million gallons per day (MGD). The treatment system consists of two separate water treatment plants. The older plant constructed in 1938 and upgraded in 1949 has a capacity of 22 MGD. The newer plant constructed in 1966 and upgraded in 1975 has a capacity of 28 MGD. Most of the water supplied to the city comes from the Huron River.

The water treatment plant operates and maintains four dams located on the Huron River- Barton, Argo, Geddes, and Superior. Each of the four dams is operated with an automatic controller designed to maintain the pond level within a 31 mm range. The Barton and Superior dams also generate hydroelectric power.[23] The WTP also manages the City's water distribution system comprising of five pressure districts within the city. The main reservoir, three outlying reservoirs, four remote pumping stations and two elevated tanks supply these districts. The distribution system also consists of 439 miles of water mains, 3646 fire hydrants, and 5635 water main valves.[20]

### 2.2 Water Treatment

Each plant at the Ann Arbor WTP has two stages of treatment- primary treatment and secondary treatment. The water is softened in the primary stage and recarbonated in the secondary stage. Each stage has three steps explained below-

- Rapid Mixing for quick dispersion of the chemicals being added
- Flocculation or slow mixing, for providing the chemical reaction time
- Settling for removal of solids from the water by gravity.

After the settling stages the water is sent to the primary disinfection stage. Finally, the water is filtered and disinfected once again.

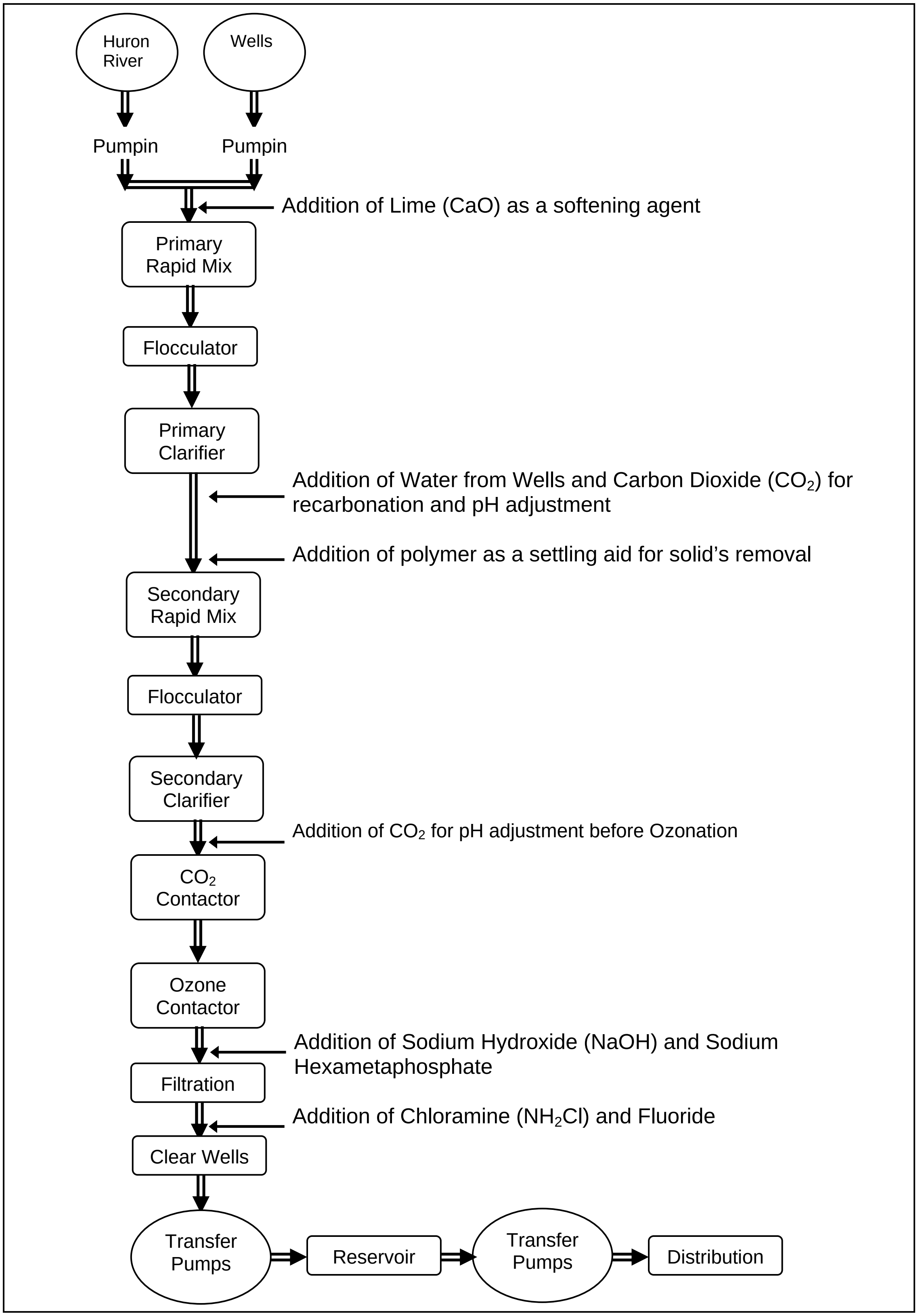


Figure 2-1. Process Flow Chart for Ann Arbor Water Treatment Plant (Source: Information provided by the Ann Arbor WTP)

Figure 2-1 provides an overview of treatment process at the Ann arbor WTP along with each treatment stage and the key chemical inputs. The Barton pumping station located on the Huron River has a capacity of 40 MGD; the wells can provide upto 10 MGD. The water from the wells is used in the primary rapid mix or diverted to the primary clarifier effluent for pH adjustment. Further details on the total flow at the Ann Arbor Water Treatment Plant are presented in the following section.

## 2.3 Total Flow

The Ann Arbor WTP withdraws approximately 13 MGD from the Huron River and around 3 MGD from the wells. The maximum quantity of water withdrawn during the period of six years being studied was 23 MGD from the river in July 2002 and approximately 5 MGD from the wells in February 2004. The lowest during the same period was found to be 9 MGD from the river in March 2005 and 2 MGD from wells in May 2005. Figure 2-2 illustrates the pattern of water acquisition at the Ann Arbor WTP in terms of MGD.

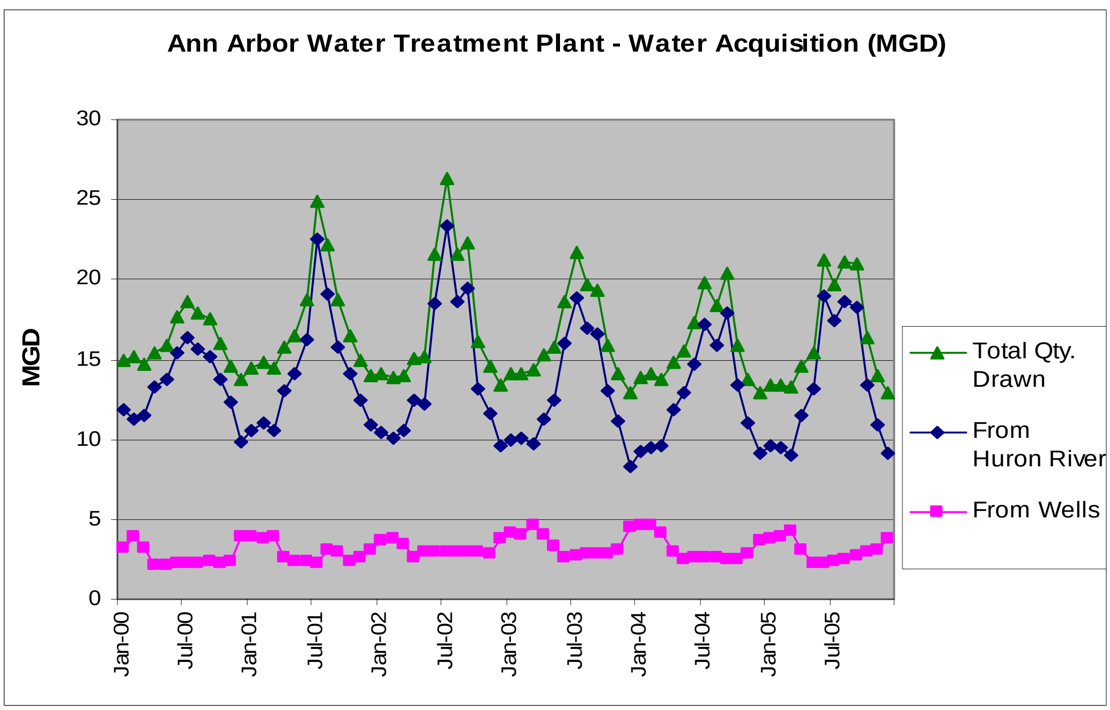


Figure 2-2. Water Acquisition for Ann Arbor WTP from Huron River and Wells (MGD)

The average withdrawal of water for the six year period from 2000 to 2005 is 14 MGD from the Huron River and 3 MGD from wells.

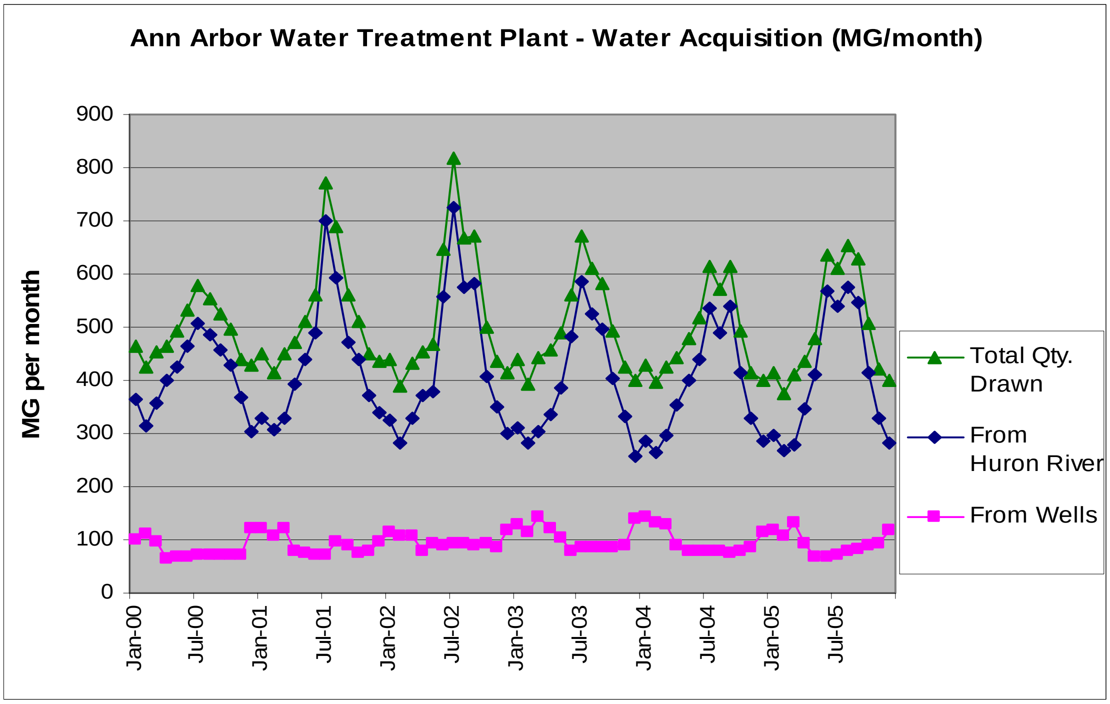


Figure 2-3. Water Acquisition from Huron River and Wells for Ann Arbor WTP (MG/month)

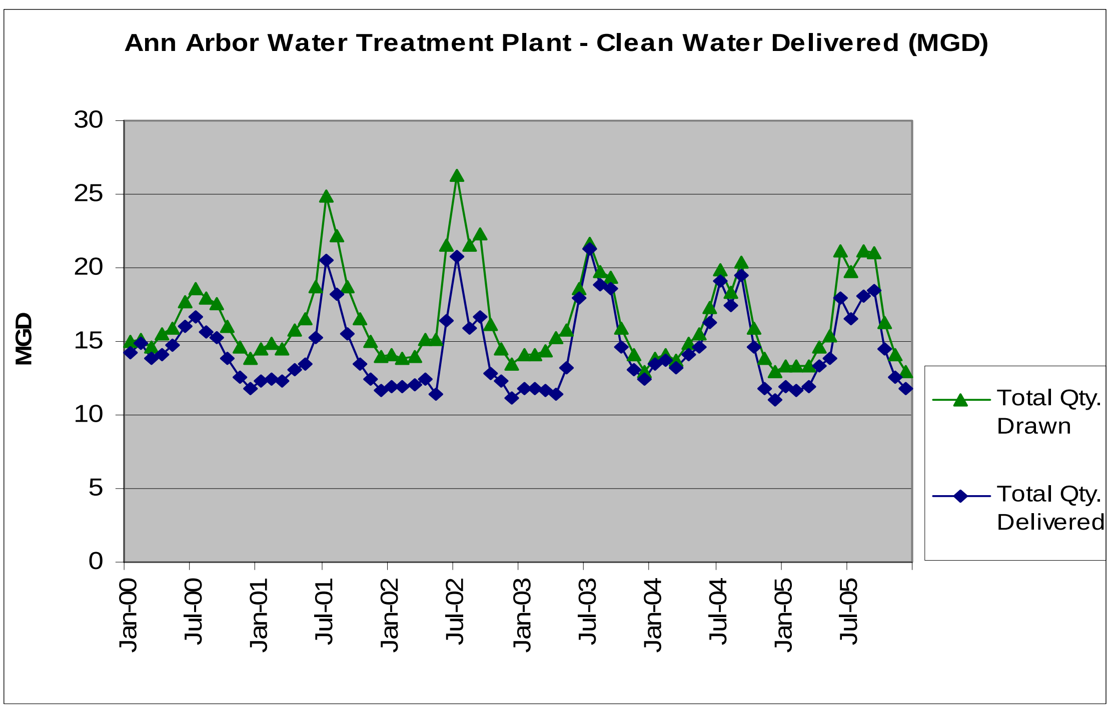


Figure 2-4. Quantity of Water Delivered from the Ann Arbor WTP to the City (MGD)

The water intake is generally high during the period of April to October with the highest consumption being generally in the month of July due to a higher demand of water for gardening and irrigation during spring and summer months. The water intake from the wells is generally high during the winter months when the low temperature water from the Huron needs to be moderated with the groundwater (Figure 2-3). Figure 2-4 illustrates the quantity of water delivered to the City of Ann Arbor by the Ann Arbor WTP in MGD. The average quantity of water delivered by the Ann Arbor WTP was found to be 14 MGD (Figure 2-4).

Figure 2-5 illustrates the relationship of the volume of water withdrawn from the Huron River and groundwater wells with the total volume of water delivered on a monthly basis. The average volume of water delivered to the customers from the Ann Arbor WTP is 440 MG per month (Figure 2-5).

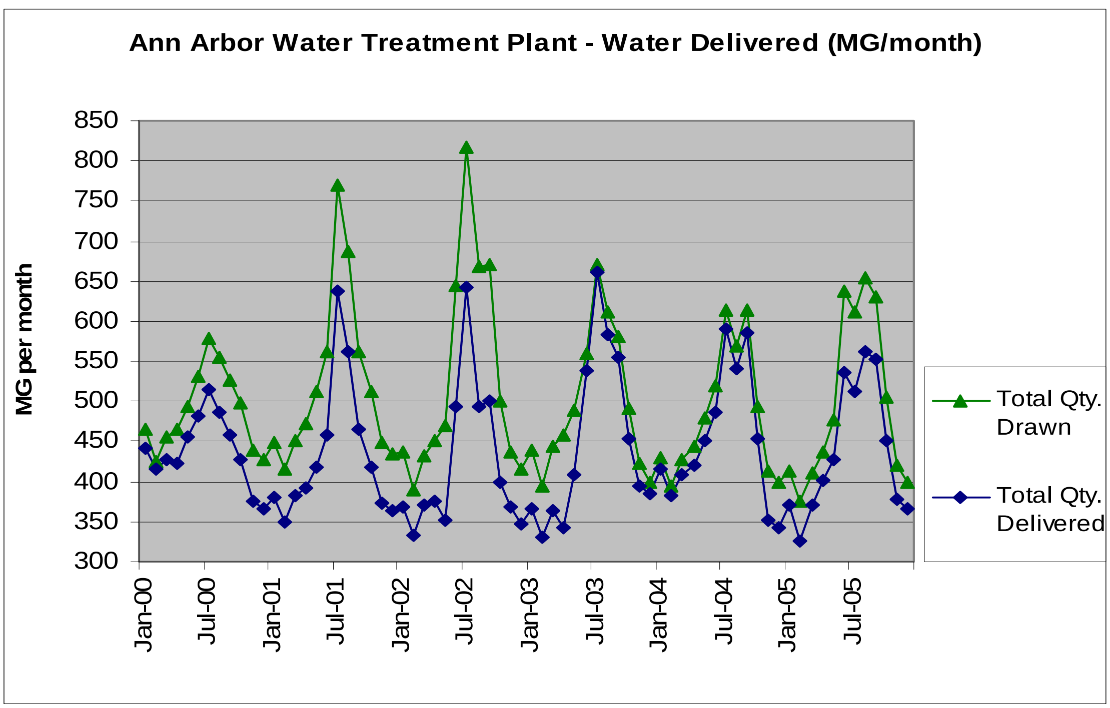


Figure 2-5. Quantity of Water Delivered from the Ann Arbor WTP to the City (MG/month)

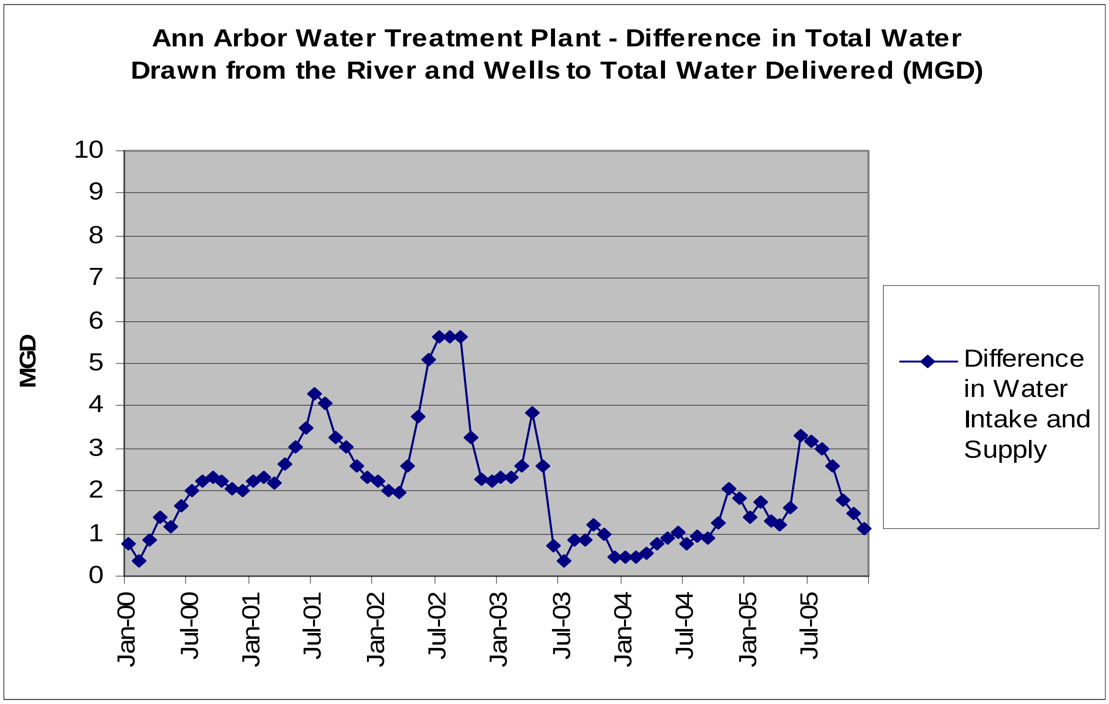


Figure 2-6. Difference in Total Quantity Withdrawn and Delivered at Ann Arbor WTP (MGD)

The difference in total quantity of water withdrawn from the Huron River and groundwater wells to the quantity of water delivered to the city of Ann Arbor ranges from less than 1 MGD to 6 MGD (Figure 2-6). The difference is generally higher during spring and summer months and less in winter months since the total quantity of water consumed is higher in summer months. Further details on the information on plant influent and flow for the Ann Arbor Water Treatment Plant have been attached in Appendix A-I-a.

## 2.4 Electricity Consumption

The electricity utilization for the Ann Arbor water treatment plant includes electricity consumed for pumping water from the Barton ponds and the groundwater wells, operation of the treatment plant, administrative buildings and the distribution pumping stations. The electricity utilization for the Ann Arbor WTP for the period of six years from 2000 to 2005 averaged 1,039,895 kWh per month. Operation of the water treatment plant alone consumes more than 60% of the total electrical consumption for the water treatment and supply system (Figure 2-7).

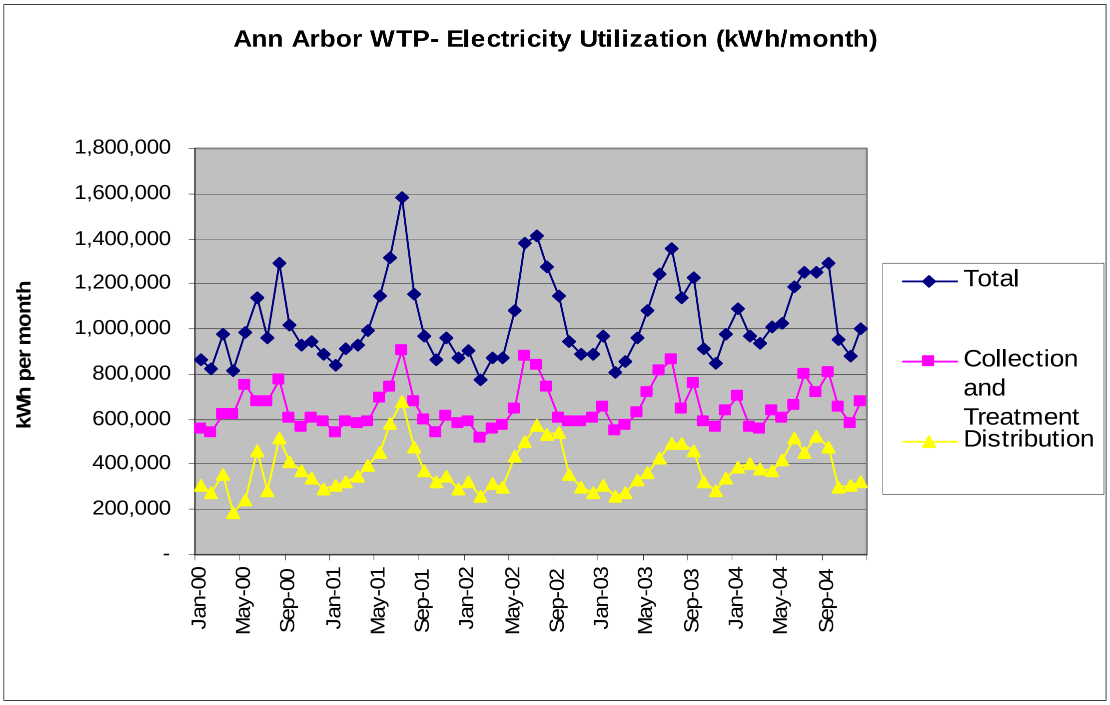


Figure 2-7. Electricity Utilization for Ann Arbor Water Treatment and Distribution System (kWh/month)

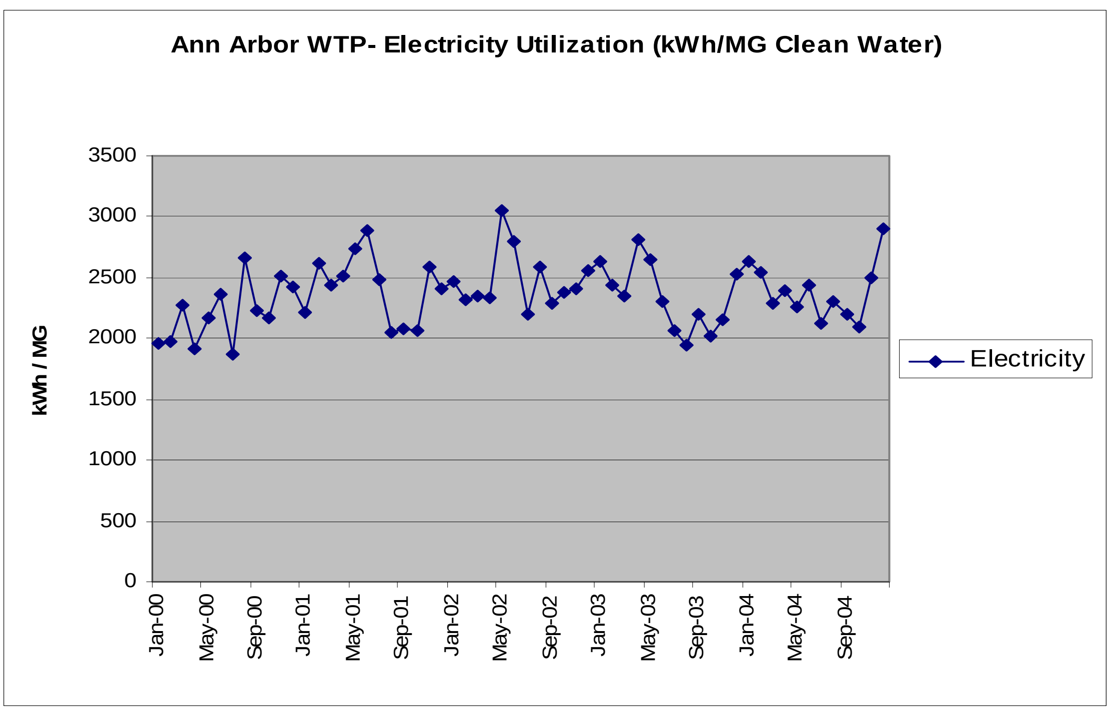


Figure 2-8. Electricity Utilization for Ann Arbor Water Treatment and Distribution System (kWh/MG)

The electricity utilized for treating and supplying 1 million gallons of clean water to the customers in the City of Ann Arbor ranges from 1,960 kWh/MG to 2,900 kWh/MG (Figure 2-8). The average consumption for the six year period is 2,390 kWh/MG. Further details of electricity consumption for Ann Arbor WTP are attached in Appendix A-I-b.

## 2.5 Natural Gas Utilization

The natural gas utilization for Ann Arbor Water Treatment Plant includes the quantity required for heating at the treatment plant, Barton pumping station, and Steere Farm wells pumping station. It is reported in terms of the annual consumption for five years from 2001 to 2005. The average consumption for the five year period is found to be 29,685 CCF per year. Figure 2-9 illustrates the total natural gas consumption at the Ann Arbor WTP in CCF per year.

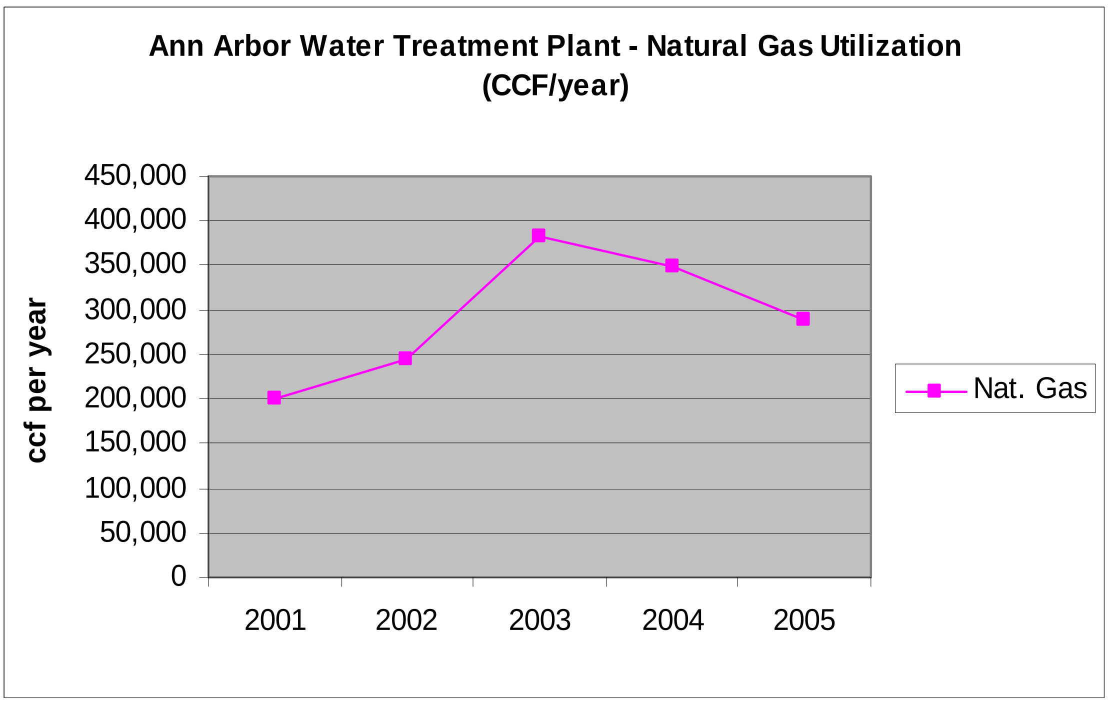


Figure 2-9. Natural Gas Utilization for the Ann Arbor Water Treatment and Distribution System (CCF/year)

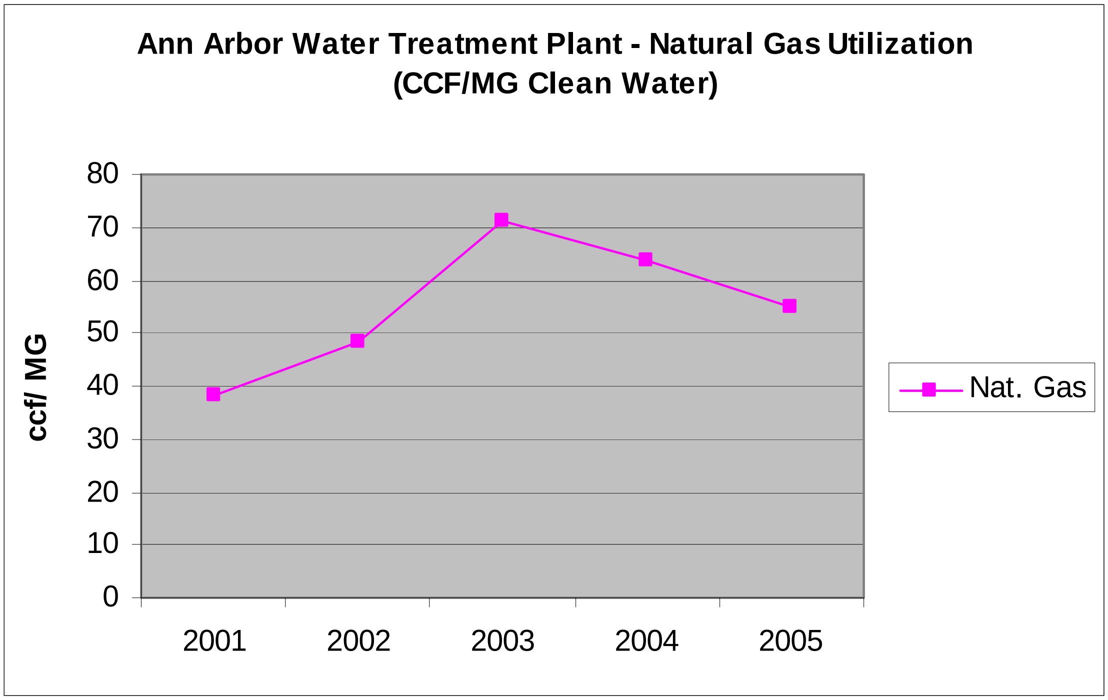


Figure 2-10. Natural Gas Utilization for the Ann Arbor Water Treatment and Distribution System (CCF/MG)

Based on the total quantity of water delivered to the City of Ann Arbor for the years from 2000 to 2005, natural gas consumption per million gallons of clean water delivered is calculated (Figure 2-10).

## 2.6 Chemicals Utilized for Treatment

The Ann Arbor Water treatment Plant uses lime, phosphate, sodium silico fluoride, carbon dioxide, liquid oxygen, sodium hypochlorite, chloramine, polymers, ammonia, and sodium hydroxide for the treatment process for water withdrawn from the river and the wells before supplying water to the city.

### *i. Lime*

Lime is added to the water withdrawn from the Huron River and the wells in the primary rapid mix. Lime softens hard water by removing calcium and magnesium. The quantity of lime consumed ranges from 219 metric tons per month to 544 metric tons per month.

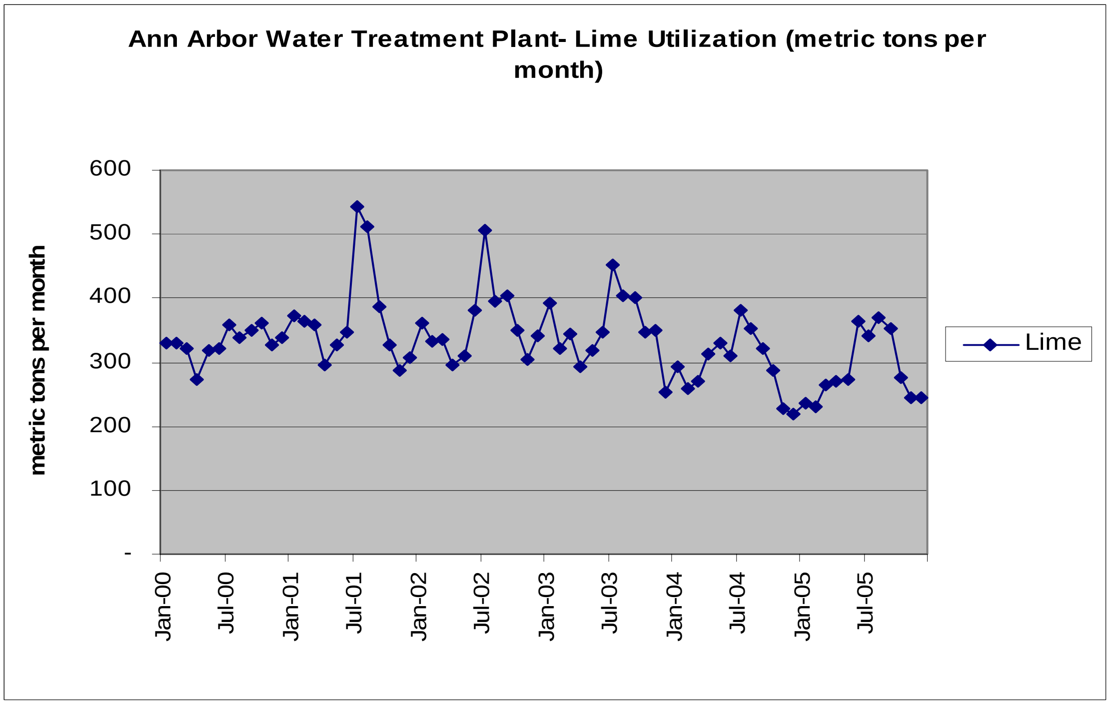


Figure 2-11. Lime Utilized for Treatment at Ann Arbor WTP (metric tons/month)

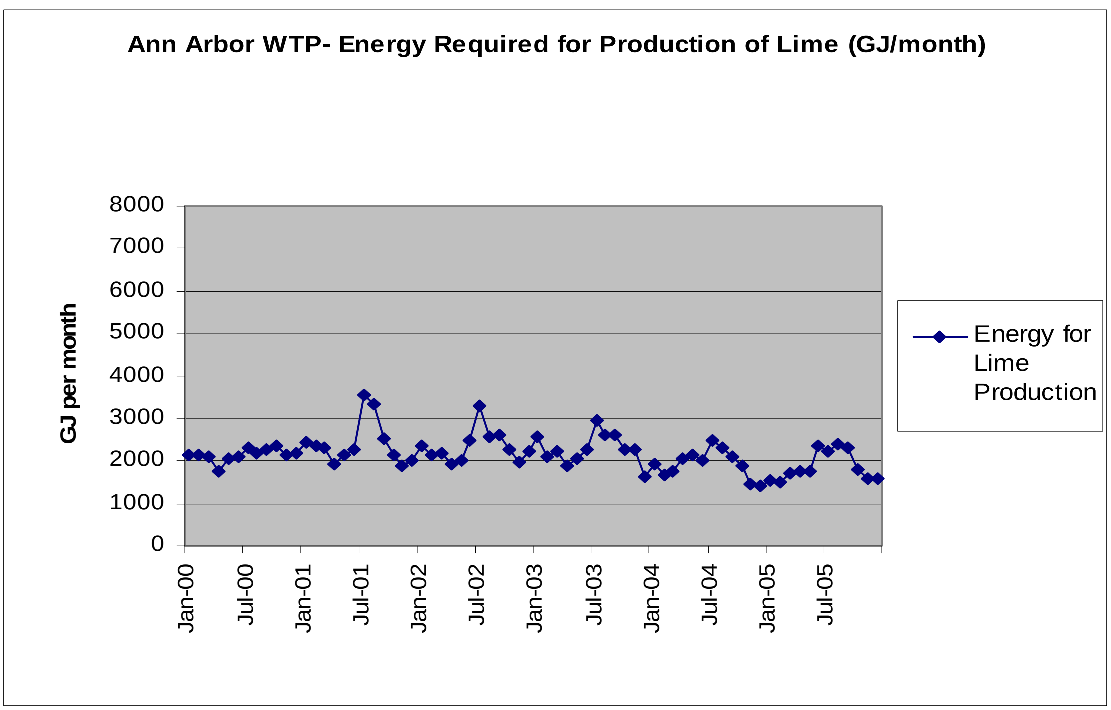


Figure 2-12. Energy Consumed for Production of Lime Utilized at Ann Arbor WTP (GJ/month)

Lime consumption is the highest in the month of July corresponding to the high quantity of water delivered in this month each year. The energy required for production of lime has been calculated using the energy factors in Section 1.5.2- ***iii.*** Although production process for Lime is not very energy intensive the energy related to lime use at the Ann Arbor WTP is quite high since the amount of lime consumed per month is significantly high. The average monthly energy consumption related with lime utilized for treatment at the Ann Arbor WTP is 2,163 GJ per month.

### *ii. Carbon Dioxide*

Carbon Dioxide ($CO_2$) is added to the water after it has passed through the primary clarifiers for the purpose of recarbonation and pH adjustment. Carbon dioxide is also added in the $CO_2$ contactor after the water has passed through the secondary clarifiers for lowering and adjusting the pH in order to enable effective and efficient ozonation to occur. The quantities of $CO_2$ reported in Figure 2-13 includes the quantity consumed at both the stages discussed above.

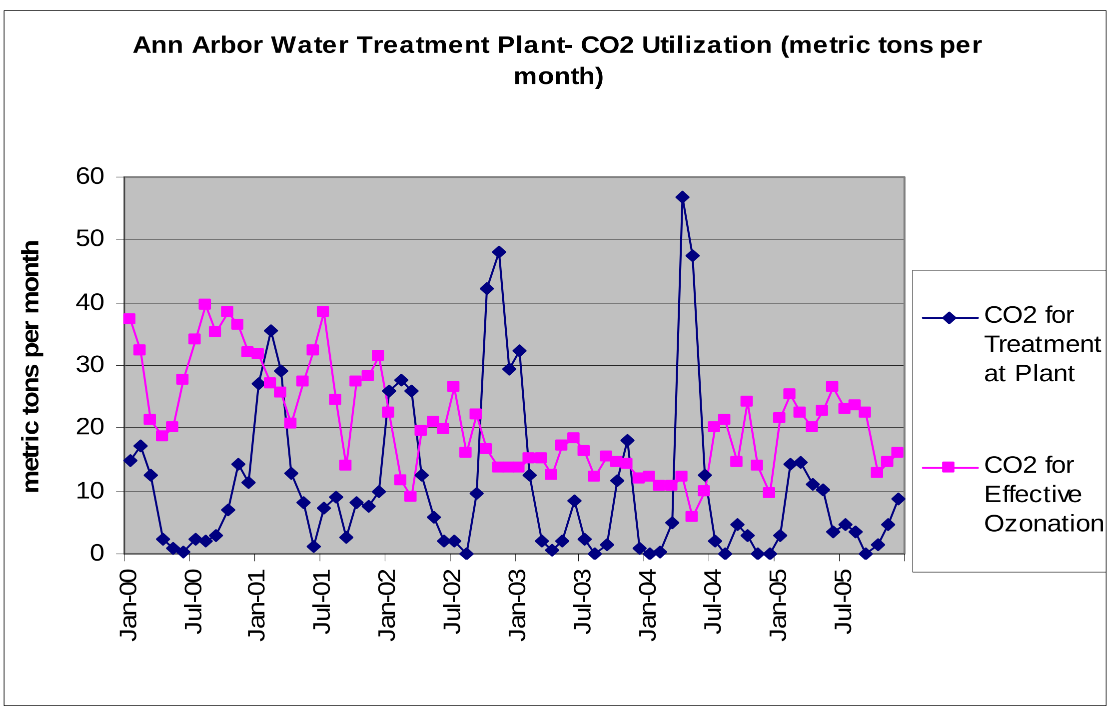


Figure 2-13. $CO_2$ Utilized for Treatment at Ann Arbor WTP (metric tons/month)

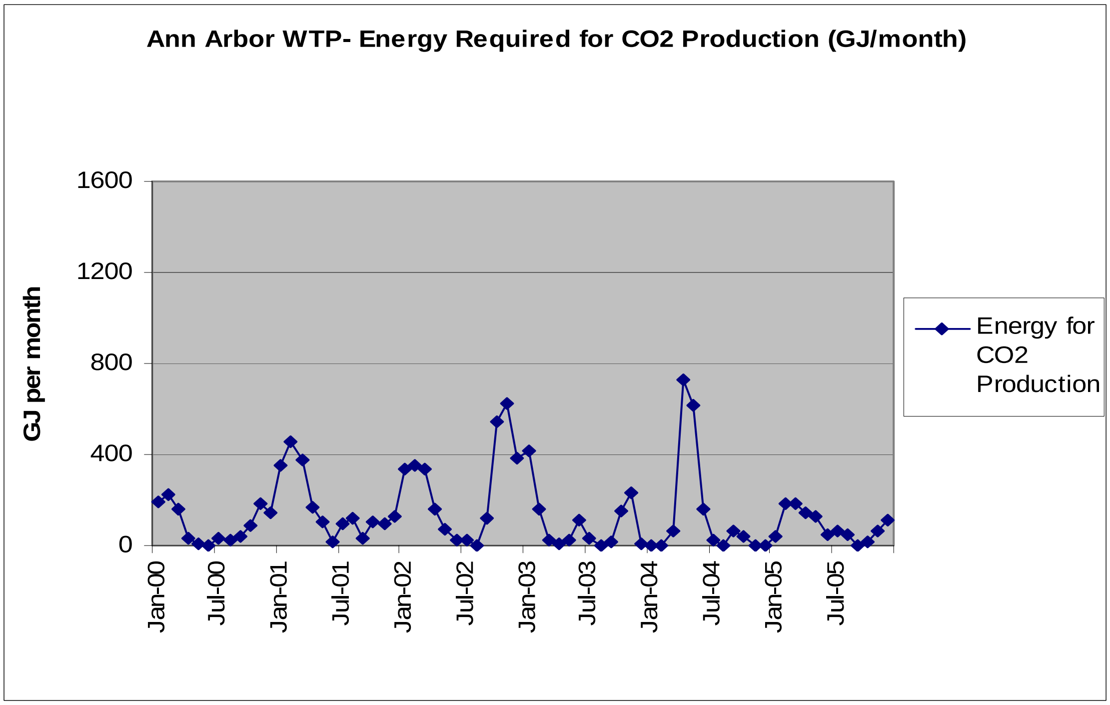


Figure 2-14. Total Energy Consumed for Production of $CO_2$ Utilized at Ann Arbor WTP (GJ per month)

Compared to lime production, $CO_2$ production is more energy intensive- 12,900 MJ/metric ton as opposed to 6500 MJ/metric ton (Table 1.1); however, since the quantity of $CO_2$ utilized per month is ten times less than the quantity of lime utilized at the plant per month, the energy related to $CO_2$ is lower at an average of 140 GJ per month.

### *iii. Polymers*

Cationic polymer NALCO's CatFloc TL is added during the treatment process to enhance coagulation in the secondary rapid mix for removal of solids in the secondary clarifier. The quantity of this polymer used ranges from 0.88 metric tons per month to 1.70 metric tons per month. However, during the months of high consumption of water in Ann Arbor (between May to October), another polymer called Barton polymer is also added at this stage to further facilitate coagulation. Figure 2-15 illustrates the use of polymers for coagulation at the Ann Arbor WTP. The energy required to produce both of the polymers has been combined and the result is presented in Figure 2-16.

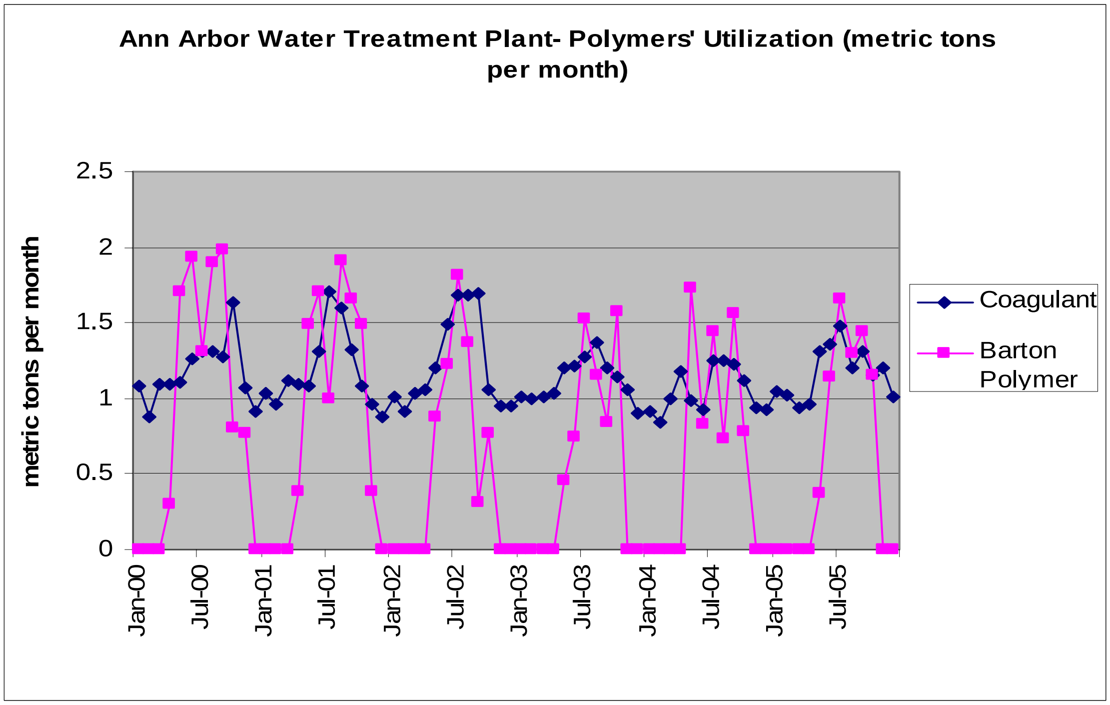


Figure 2-15. Polymers Utilized as Coagulants for Treatment at the Ann Arbor WTP (metric tons/month)

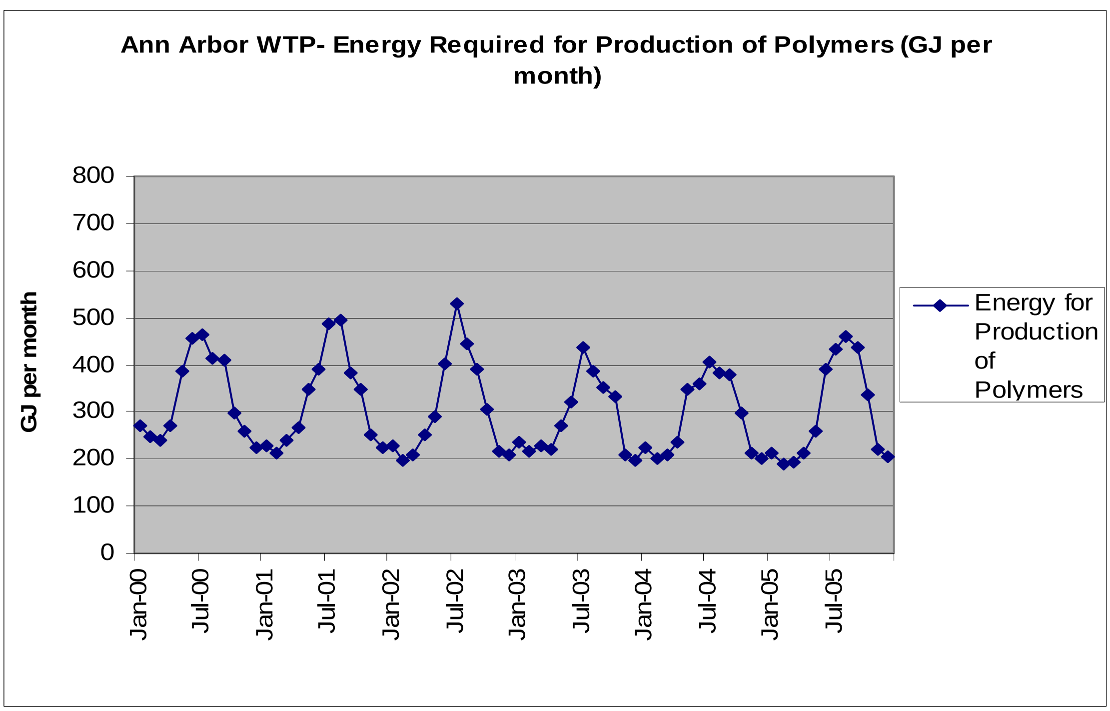


Figure 2-16. Energy Used for Production of Polymers Utilized at Ann Arbor WTP (GJ/month)

The unit production of polymers is an energy intensive process- 44,682 MJ/metric ton (Table 1-1), however, since the amounts of these polymers consumed is not as high as some of the other chemicals used at the plant, the energy required for producing polymers utilized at the WTP averages 304 GJ/month.

### *iv. Liquid Oxygen*

Liquid oxygen is required for the production of ozone in the ozone contactor. Ozone is applied to the water for disinfection since it kills harmful microorganisms such as bacteria viruses and protozoa. Additionally it also reduces taste, odor and potentially harmful chlorinated byproducts. The quantity of liquid oxygen consumed at the plant from the year 2000 to 2005 ranges from 1 metric ton per month to 11 metric tons per month (Figure 2-17).

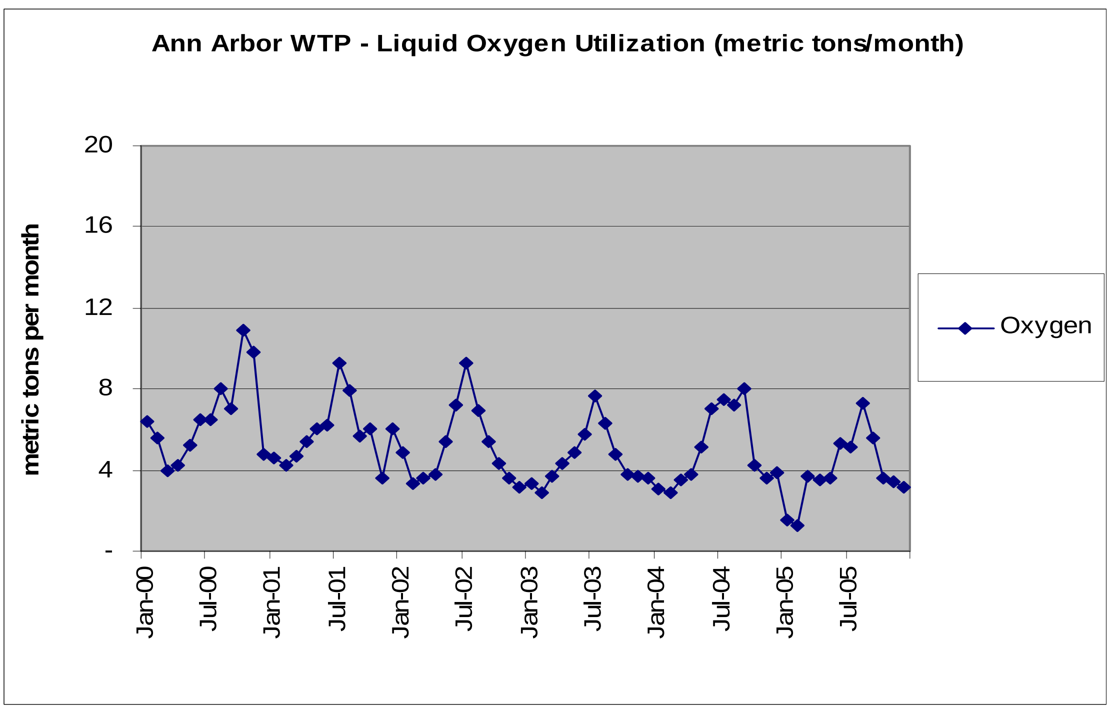


Figure 2-17. Oxygen Utilized for Ozone Production at Ann Arbor WTP (metric tons/month)

The use of liquid oxygen is high during summer months and low during winter months since the demand for water is higher during the summer months. Also, fecal coliform count is higher in the water being treated during the summer months; hence more liquid oxygen is required for production of ozone for disinfection. The energy required to produce liquid oxygen ranges from 7 GJ/month to 61 GJ/month. The average energy consumption for production of oxygen required for ozone production in the ozone contactor is 29 GJ/month (Figure 2-18).

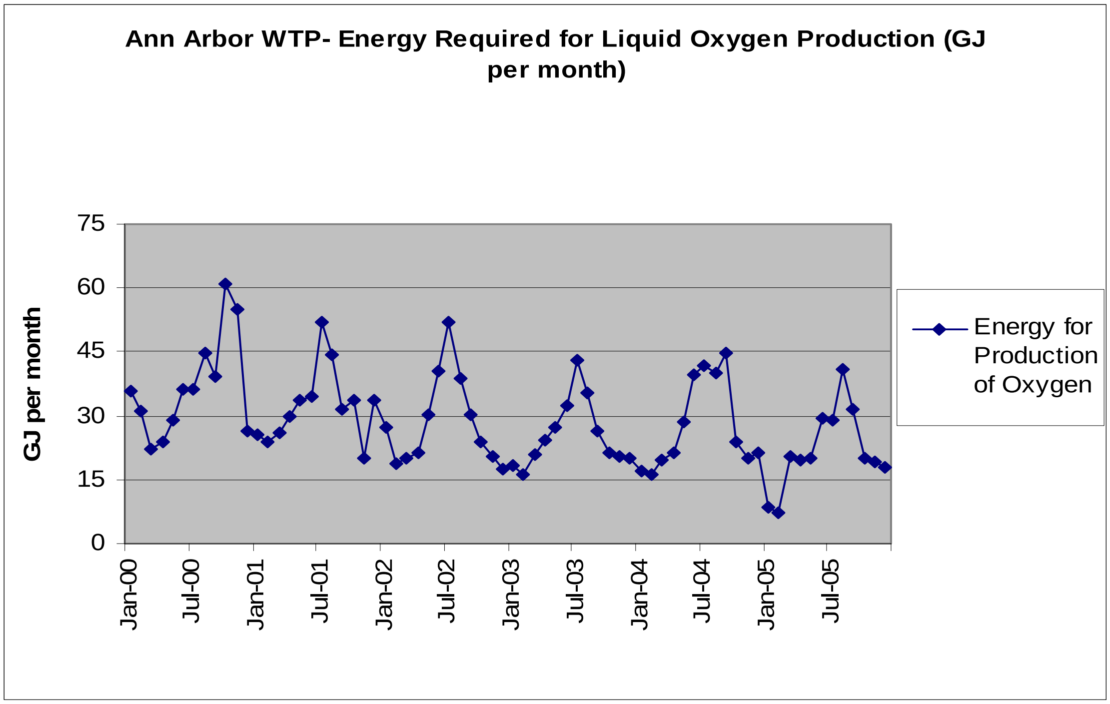


Figure 2-18. Energy Required for Production of Oxygen Utilized at Ann Arbor WTP (GJ/month)

### *v. Sodium Hydroxide*

Sodium Hydroxide (NaOH) is added to raise the pH of water after it has undergone ozonation in the ozone contactor at the plant. The quantity of NaOH added ranges from 1 metric ton/month to 54 metric tons/month. The energy required for unit production of NaOH is 22,040 MJ/metric ton (Table 1-1). Correspondingly, the energy required to produce NaOH ranges from 24 GJ per month to 1,190 GJ per month. Based on the information available, the average energy required to produce NaOH utilized at the plant is 600 GJ/month. Figure 2-19 presents the monthly use of NaOH and Figure 2-20 presents the calculated energy required to produce the NaOH utilized at the Ann Arbor Water Treatment Plant in GJ per month.

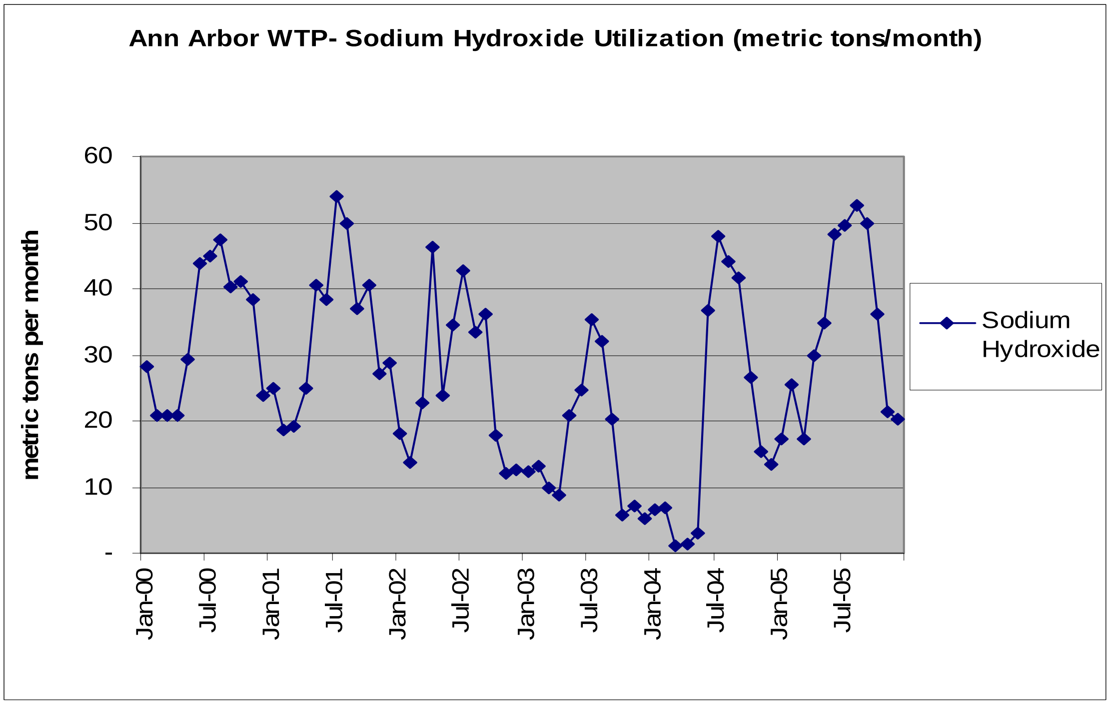


Figure 2-19. Sodium Hydroxide Utilized for Treatment at Ann Arbor WTP (metric tons/month)

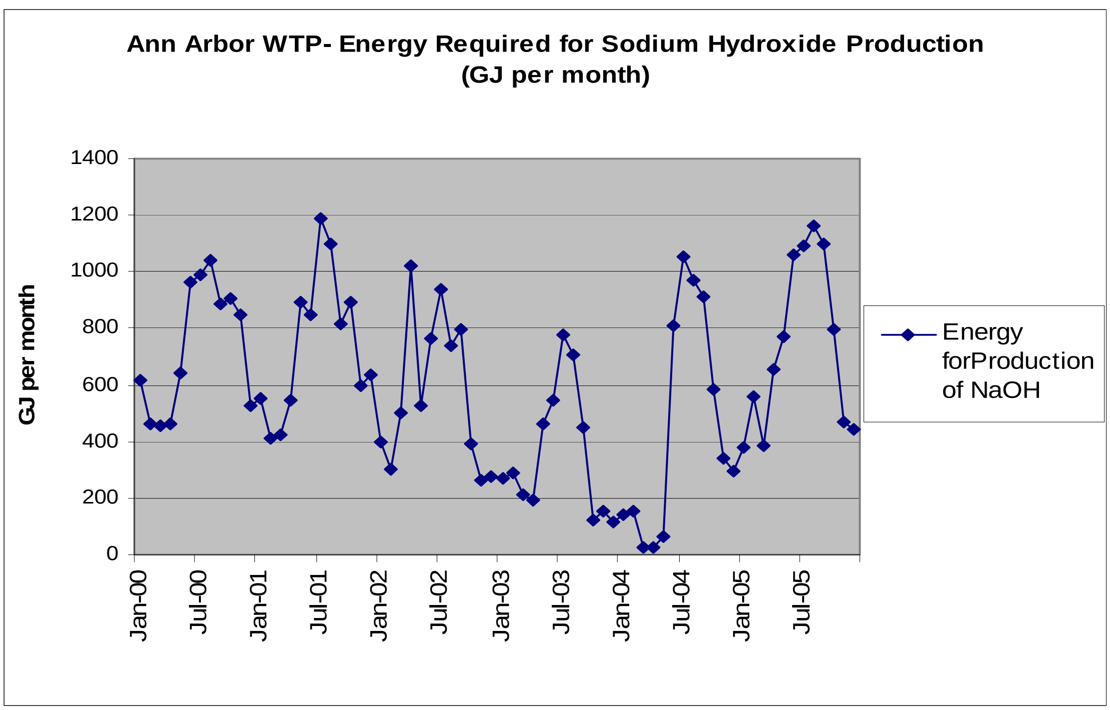


Figure 2-20. Energy Required for Sodium Hydroxide Utilized at Ann Arbor WTP (GJ/month)

### *vi. Sodium Hexametaphosphate*

Sodium hexametaphosphate is added after ozonation to stop the softening reaction and prevent precipitation of calcium on the filter media. The quantity of the phosphate used per month for treatment ranges from 1 metric ton to 3 metric tons.

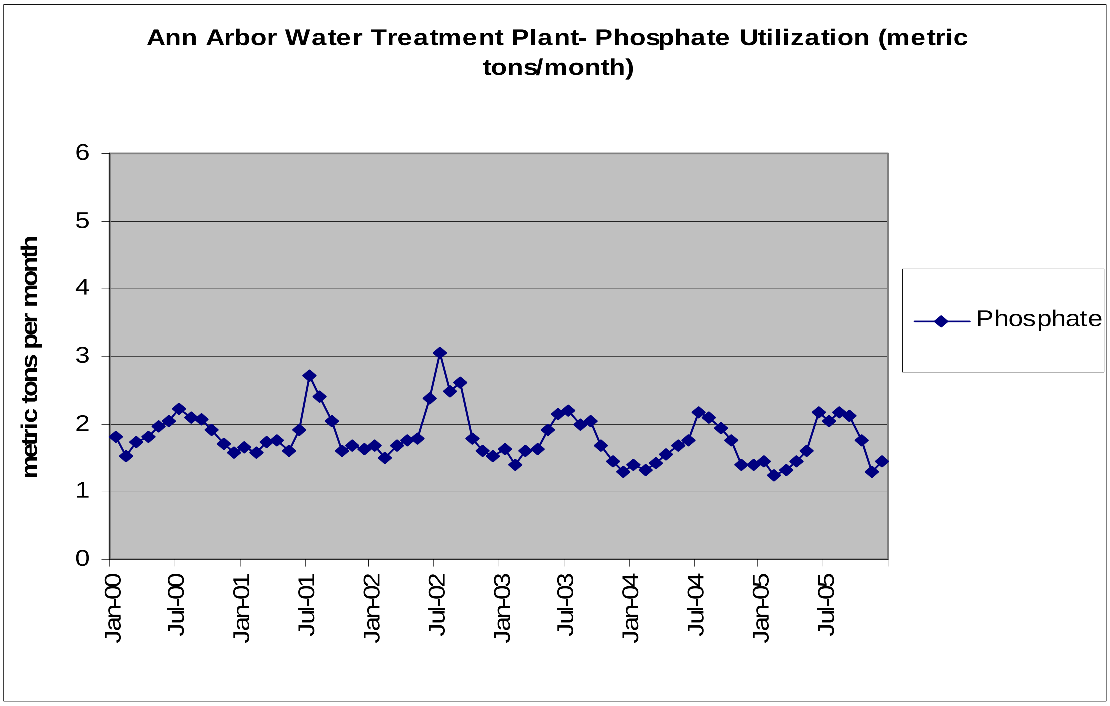


Figure 2-21. Sodium Hexametaphosphate Utilized for Treatment at Ann Arbor WTP (metric tons/month)

The corresponding energy required to produce sodium hexametaphosphate ranges from 16 GJ/month to 39 GJ/ month (energy required for unit production of sodium hexametaphosphate is 12,800 MJ/metric[24] – Table 1.1). The average energy utilization related with sodium hexametaphosphate consumption at the plant is 23 GJ/month. Figure 2-22 presents the energy required for production of the sodium hexametaphosphate required for treatment at the Ann Arbor WTP calculated on a monthly basis.

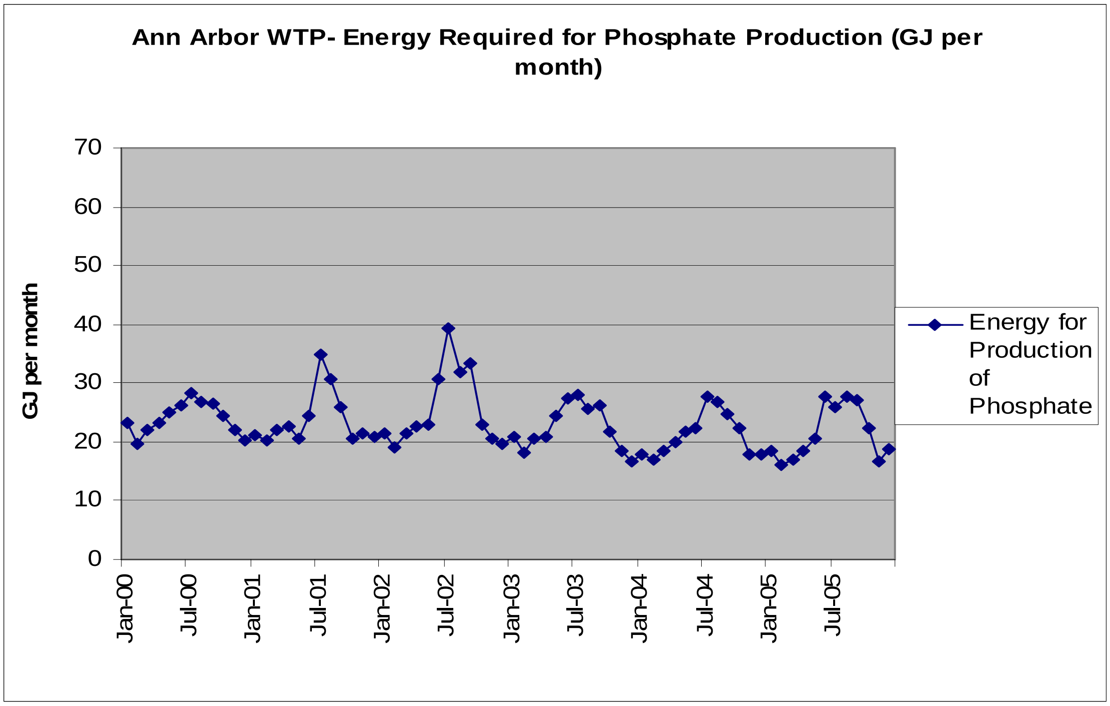


Figure 2-22. Energy Required for Producing Sodium Hexametaphosphate Utilized at Ann Arbor WTP (GJ/month)

### *vii. Mono Chloramine*

After filtration, ammonia ($NH_3$) and sodium hypochlorite are added together to form mono-chloramine ($NH_2Cl$) to provide disinfection for water in the city's distribution system. Since the quantities of these two components consumed per month were available from the monthly operation reports (MORs) at the Ann Arbor WTP, the quantities of ammonia and sodium hypochlorite are plotted separately (Figure 2-23).

The quantity of ammonia utilized ranges from 1 metric ton to 3 metric tons per month and hypochlorite from 4 metric tons/month to 10 metric tons/month. The quantities utilized reflect the quantity of influent treated at the plant; hence a greater amount of both chemicals is required during spring and summer months when the demand for water is higher.

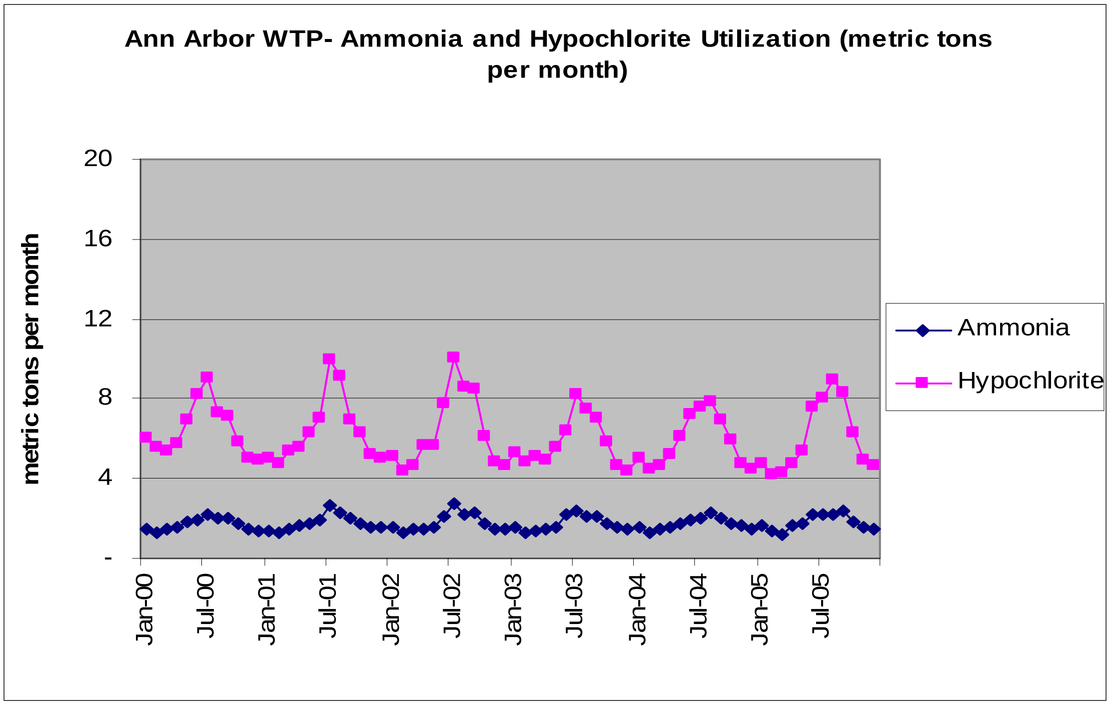


Figure 2-23. Ammonia and Hypochlorite Used at Ann Arbor WTP (metric tons/month)

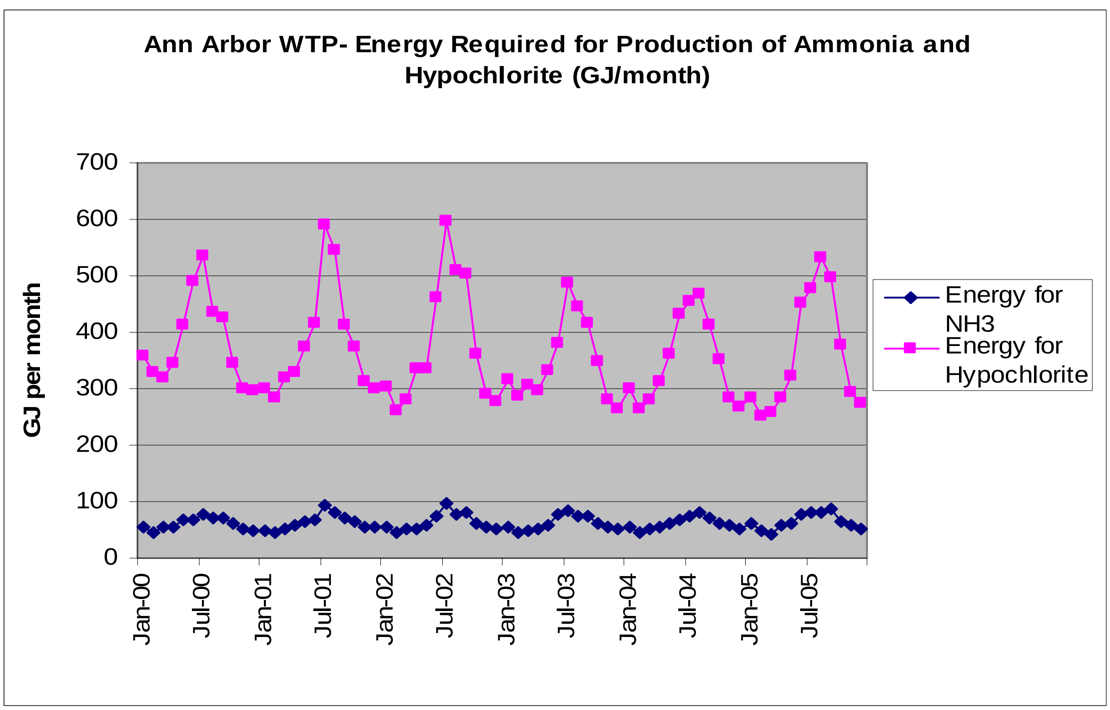


Figure 2-24. Energy Required for Producing Ammonia and Hypochlorite Utilized at Ann Arbor WTP (GJ/month)

The production process for hypochlorite is more energy intensive than ammonia – 60 GJ per month as opposed to 36 GJ per month (refer Section 1.5.2- ***iii***). Further, the quantity of hypochlorite consumed per month is also higher than that of Ammonia. Consequently energy associated with production of hypochlorite consumed at the plant is magnitudes higher than the energy associated with ammonia. The average energy consumption related to utilization of ammonia is 97 GJ per month and related to the utilization of hypochlorite is 595 GJ per month.

### *viii. Fluoride*

Sodium silico fluoride is added to the water after treatment in the clearwells for dental protection. The quantity of fluoride added reflects the volume of water treated per month, ranging from 1 metric ton per month to 3 metric tons per month during the six year period. The material production energy for fluoride calculated based on the process used for its production is 12,800 MJ/metric (Table 1.1).

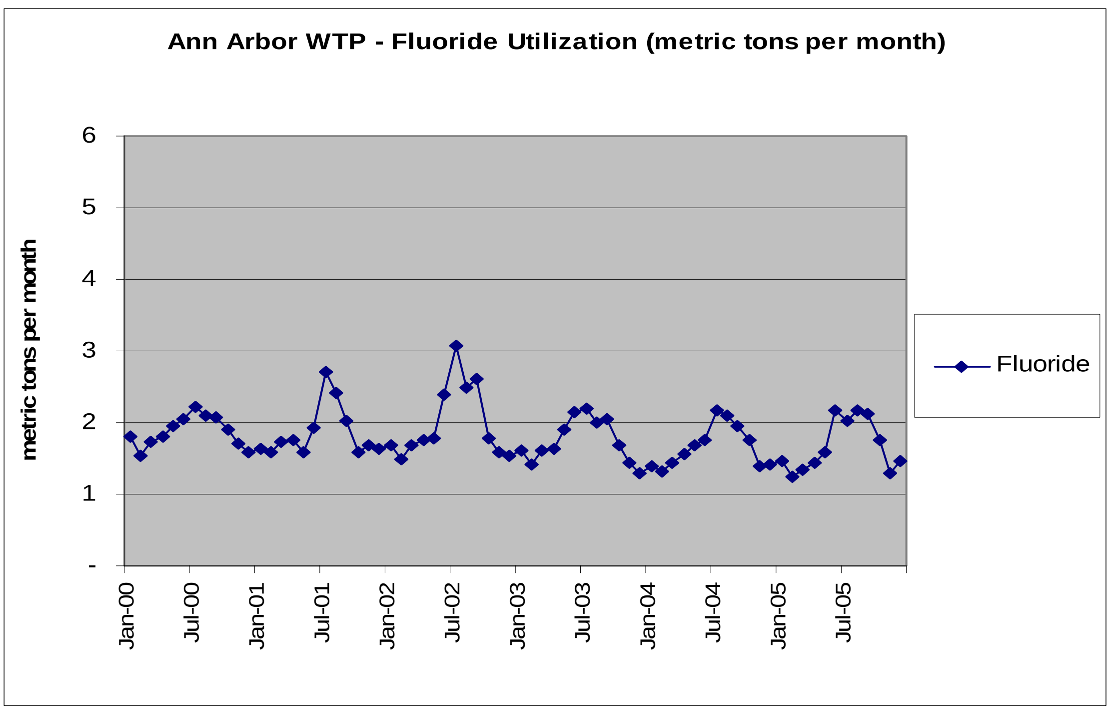


Figure 2-25. Fluoride Utilized for Treatment at Ann Arbor WTP (metric tons/month)

Figure 2-25 presents the total quantity of fluoride utilized per month at the Ann Arbor WTP and Figure 2-26 presents the total energy required for producing the fluoride utilized at the plant in GJ per month.

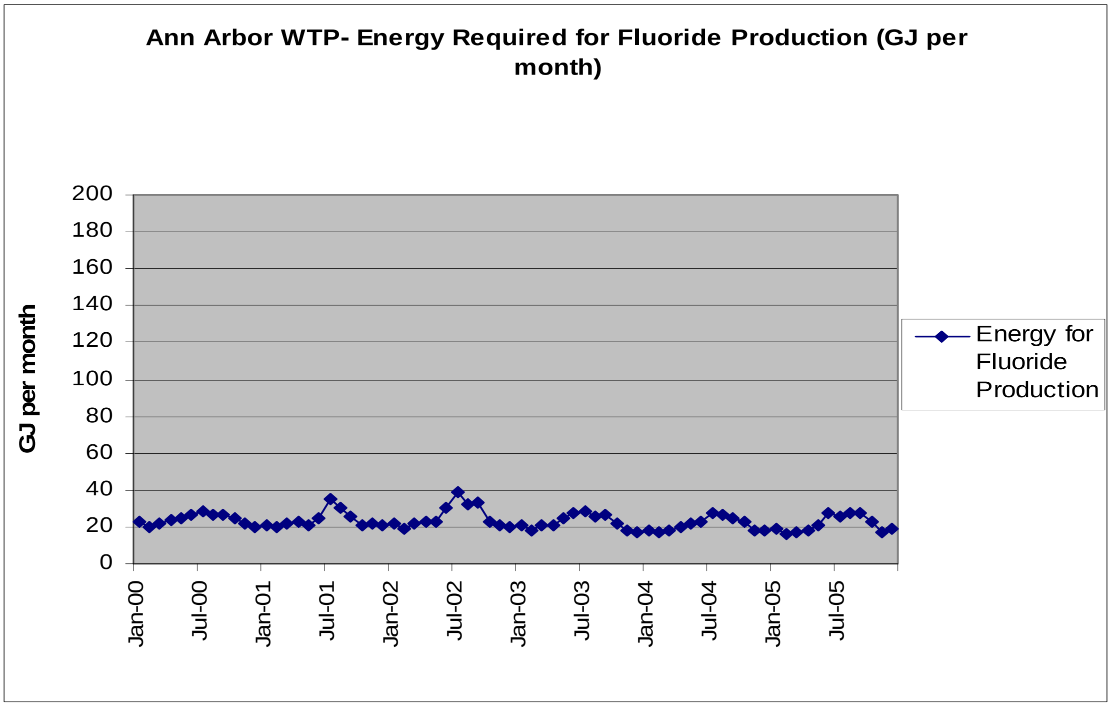


Figure 2-26. Energy Consumed for Producing Fluoride Utilized at Ann Arbor WTP (GJ/month)

## 2.7 Life-Cycle Energy Consumption for Operation of Ann Arbor WTP

The total energy consumed per month for operating the plant includes energy utilized for generating electricity for operating the plant and pumping stations; generating natural gas for heating purposes at the plant and pumping stations; and, producing the chemicals required for treatment of water at the plant. This section presents the contribution of each of these energy consuming activities to the total life-cycle energy for operating the Ann Arbor WTP. Table 2-1 below summarizes the findings on a yearly basis for five years from 2001 to 2005.

Table 2-1 Life-cycle Energy for Operation of Ann Arbor Water Treatment Plant

| Year | Electricity | | | Natural Gas | | | Chemicals | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | GJ | GJ/MG | % | GJ | GJ/MG | % | GJ | GJ/MG | % | GJ | GJ/MG |
| 2001 | 45129 | 9 | 38 | 24462 | 5 | 20 | 49867 | 10 | 42 | 119459 | 23 |
| 2002 | 44778 | 9 | 37 | 24462 | 6 | 24 | 47891 | 9 | 39 | 117131 | 24 |
| 2003 | 44500 | 8 | 33 | 24462 | 9 | 35 | 42120 | 8 | 32 | 111083 | 25 |
| 2004 | 46224 | 9 | 36 | 24462 | 8 | 33 | 39451 | 7 | 31 | 110138 | 24 |
| 2005 | 47038 | 9 | 38 | 24462 | 7 | 28 | 41820 | 8 | 34 | 113320 | 24 |

The total life-cycle energy consumed per year for operation of Ann Arbor WTP ranges from 110,138 GJ per year to 119,459 GJ per year. Based on this yearly consumption, the life-cycle energy per million gallons of clean water delivered to the city of Ann Arbor is calculated. The life-cycle energy for operation of the plant per million gallons clean water delivered to the city is 24 GJ/MG.

Figure 2-27 below, illustrates the contribution of electricity, natural gas and chemicals to the total life-cycle energy consumption for operation of the Ann Arbor WTP and Figure 2-28 illustrates the contribution per million gallons of clean water delivered to the city.

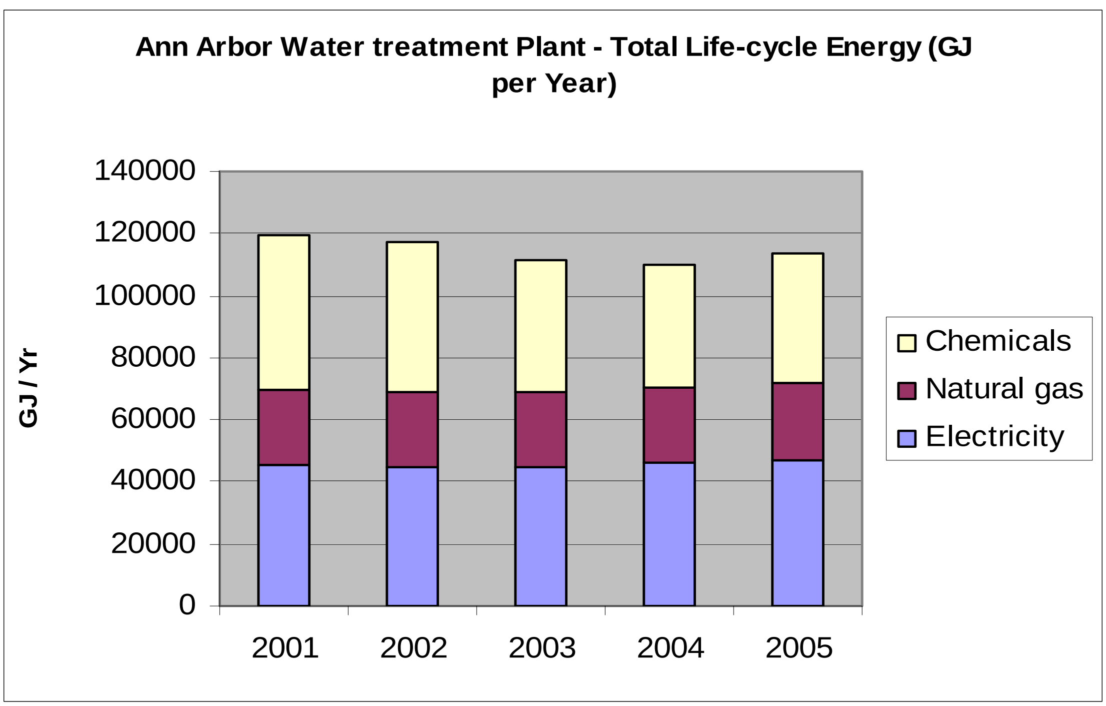


Figure 2-27. Total Life-cycle Energy for Operation of Ann Arbor WTP (GJ/Year)

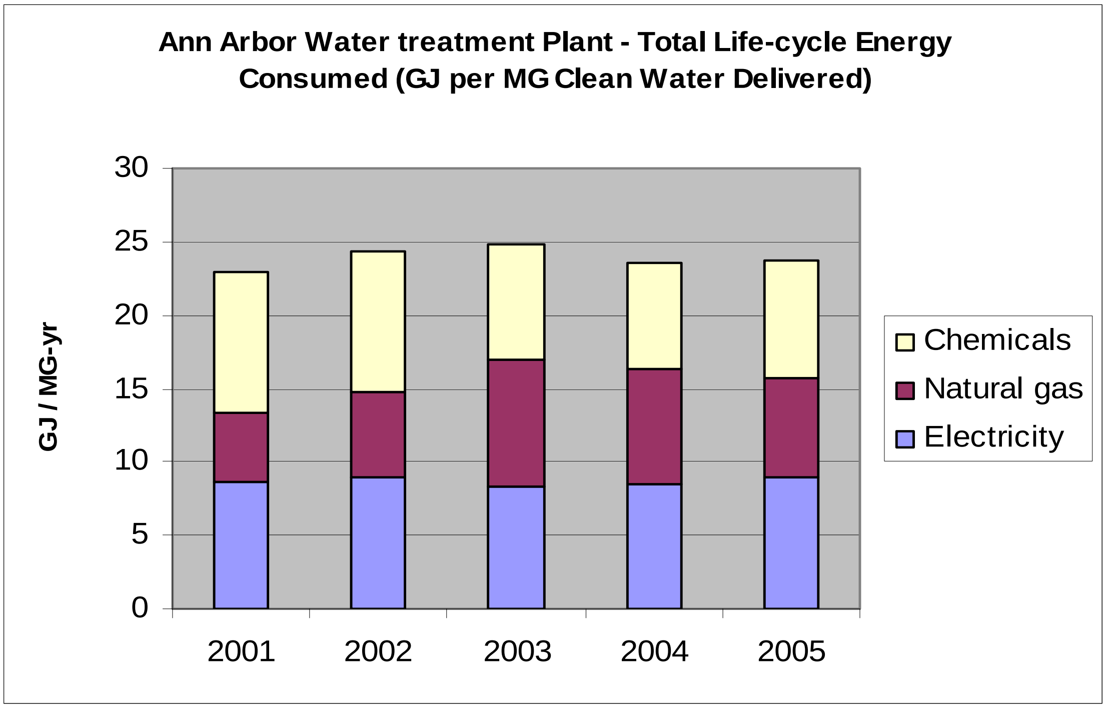


Figure 2-28. Total Life-cycle Energy for Operation of Ann Arbor WTP (GJ/MG)

The energy for production of chemicals utilized at the plant contributes 35% of the total life-cycle energy for operation. Electricity required for operating the treatment plant and pumping stations contributes 36% and natural gas consumption accounts for 28% of the total life-cycle energy consumed for operation of the Ann Arbor WTP. Based on the total energy consumed for operating the plant the life-cycle emissions per year for operating the Ann Arbor WTP were calculated.

## 2.8 Life-Cycle Impacts from Operation of Ann Arbor WTP

The life-cycle emissions from production of unit electricity and natural gas were used to calculate the total life-cycle emissions for operating the Ann Arbor Water Treatment Plant. These emissions were then characterized into predefined categories of global warming potential, eutrophication potential and acidification potential. The emissions analysis is conducted for five years from 2001 to 2005 on a yearly basis as opposed to monthly emissions since the reported natural gas use is on an annual basis.

### *i. Global Warming Potential*

The total GWP for the plant ranges from 3,206 kg $CO_2$ equivalent to 3,362 kg $CO_2$ equivalent per MG of clean water delivered. Table 2-2 summarizes the results obtained for the total global warming potential for the plant.

Table 2-2 Global Warming Potential for the Ann Arbor WTP (kg $CO_2$ eq. /MG)

| Global Warming Potential for Ann Arbor WTP in terms of kilograms of CO2 equiv./MG | | | | |
|---|---|---|---|---|
| **2001** | | | | |
| | ***Electricity*** | ***Nat. Gas*** | **Chemicals** | ***Total*** |
| Carbon Dioxide | 1732 | 239 | 1076 | 3047 |
| Methane CH4 | 68 | 15 | 42 | 126 |
| Nitrogen Oxide | 29 | 0 | 5 | 34 |
| **Total GWP/MG** | 1829 | 254 | 1123 | 3206 |
| % of total | 57 | 8 | 35 | |
| **2002** | | | | |
| | ***Electricity*** | ***Nat. Gas*** | **Chemicals** | ***Total*** |
| Carbon Dioxide | 1771 | 301 | 1109 | 3181 |
| Methane CH4 | 70 | 19 | 43 | 132 |
| Nitrous Oxide | 30 | 0 | 5 | 34 |
| **Total GWP/MG** | 1870 | 320 | 1158 | 3348 |
| % of total | 56 | 10 | 35 | |
| **2003** | | | | |
| | ***Electricity*** | ***Nat. Gas*** | **Chemicals** | ***Total*** |
| Carbon Dioxide | 1649 | 442 | 1040 | 3131 |
| Methane CH4 | 65 | 28 | 41 | 134 |
| Nitrous Oxide | 28 | 0 | 4 | 32 |
| **Total GWP/MG** | 1742 | 470 | 1085 | 3297 |
| % of total | 53 | 14 | 33 | |
| **2004** | | | | |
| | ***Electricity*** | ***Nat. Gas*** | **Chemicals** | ***Total*** |
| Carbon Dioxide | 1696 | 397 | 1029 | 3123 |
| Methane CH4 | 67 | 25 | 40 | 132 |
| Nitrous Oxide | 28 | 0 | 4 | 33 |
| **Total GWP/MG** | 1791 | 423 | 1074 | 3288 |
| % of total | 54 | 13 | 33 | |
| **2005** | | | | |
| | ***Electricity*** | ***Nat. Gas*** | **Chemicals** | ***Total*** |
| Carbon Dioxide | 1786 | 342 | 1065 | 3194 |
| Methane CH4 | 70 | 22 | 42 | 134 |
| Nitrous Oxide | 30 | 0 | 5 | 34 |
| **Total GWP/MG** | 1886 | 364 | 1112 | 3362 |
| % of total | 56 | 11 | 33 | |

It is evident from the figures presented in Table 2-2 above that electricity utilization accounts for 55%, chemicals for 34%, and natural gas utilization for 11% of the total global warming potential for the plant. Figure 2-29 presents the total global warming potential from the use of electricity, natural gas and chemicals at the Ann Arbor WTP. Emissions from use of electricity account for 1,824 kg $CO_2$ eq. / MG, emissions from production of chemicals emit 1,110 kg $CO_2$ eq. / MG and emissions from Natural Gas account for 366 kg $CO_2$ equivalent per MG of the clean water delivered for the five years under consideration.

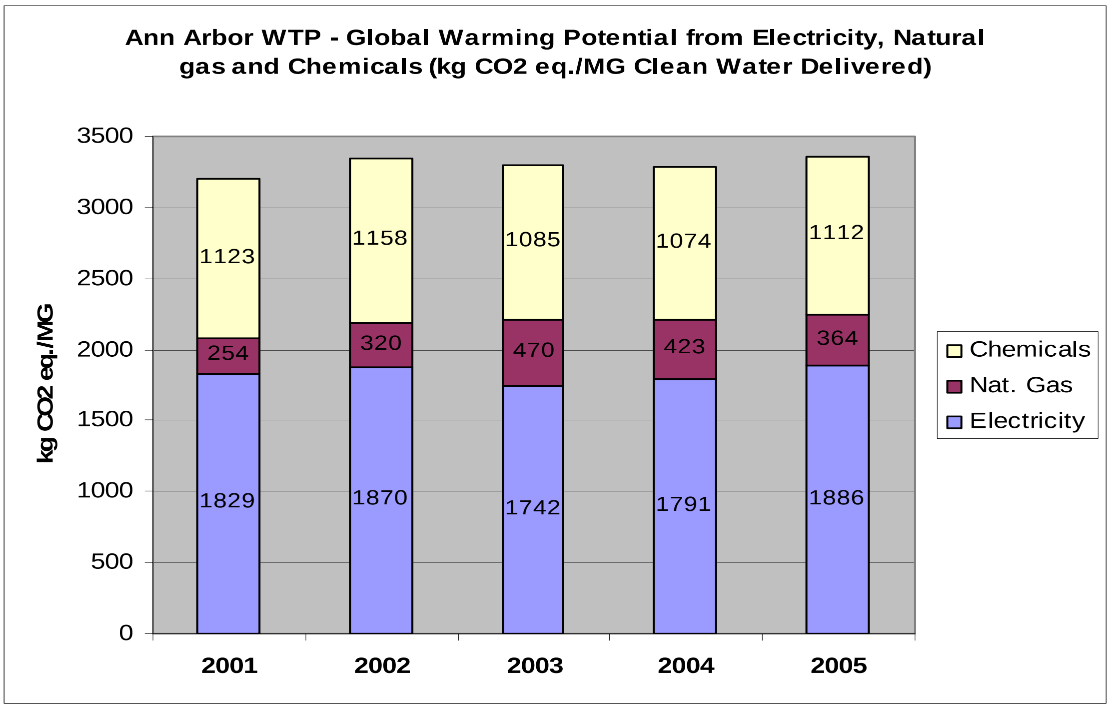


Figure 2-29. Life-Cycle Global Warming Potential from the Electricity, Natural Gas and Chemicals Utilized at the Ann Arbor WTP (kg $CO_2$ eq. /MG)

Carbon dioxide emissions from electricity, production of chemicals and natural gas are the single largest contributing factor to the total global warming potential for the Ann Arbor WTP (Figure 2-30).

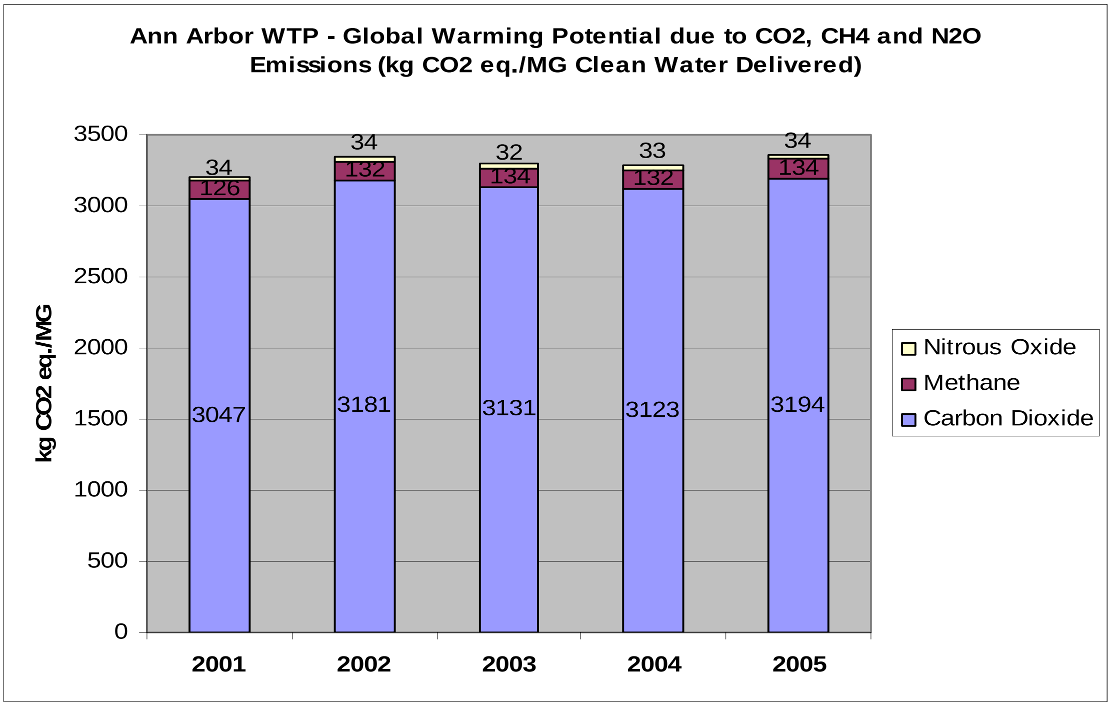


Figure 2-30. Life-Cycle Global Warming Potential due to Carbon Dioxide, Methane and Nitrous Oxide Emissions (kg $CO_2$ eq. /MG)

Further details of calculations and results on the analysis for global warming potential for Ann Arbor WTP can be found in Appendix A-II-a.

### *ii. Eutrophication Potential*

Eutrophication potential in terms of grams of Nitrogen (N) equivalence is calculated separately for atmospheric and aquatic emissions for the five year period. The total atmospheric eutrophication potential for the five year period ranges from 221 g N equivalent to 243 g N equivalent per MG of clean water delivered to the city. The total aquatic eutrophication was much less since aquatic emissions are significantly lower than the atmospheric emissions.

It is found that the single largest sources of atmospheric eutrophication potential for the plant are NOx emissions from electricity utilization. Also, the major sources of aquatic eutrophication Potential are $NH_3$ and organic emissions in terms COD from electricity consumption.

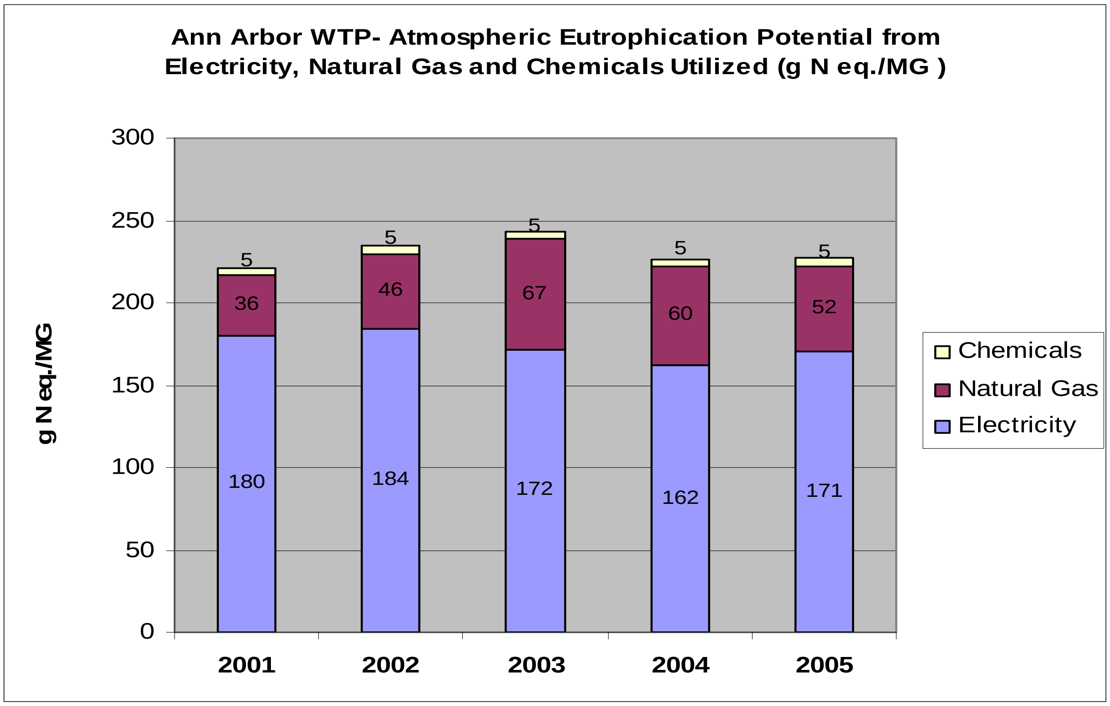


Figure 2-31. Atmospheric Eutrophication Potential from Electricity, Chemicals and Natural gas Utilization (g N eq. /MG)

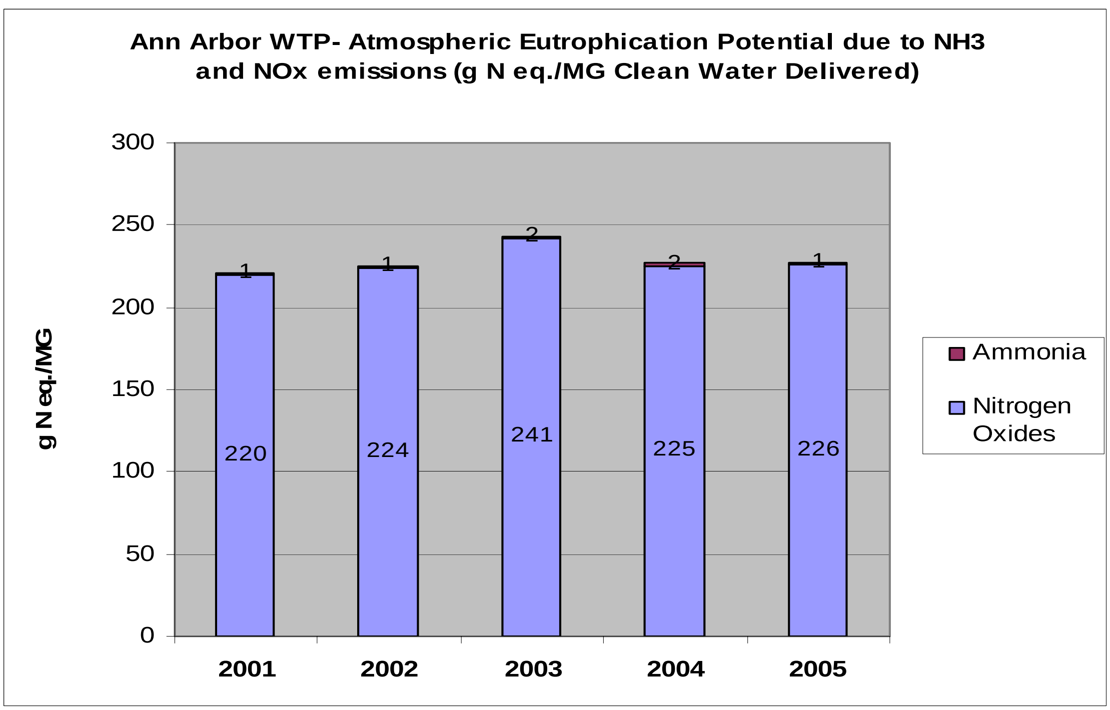


Figure 2-32. Atmospheric Eutrophication Potential Owing to Ammonia and NOx emissions from Operation of Ann Arbor Water Treatment Plant (g N eq. /MG)

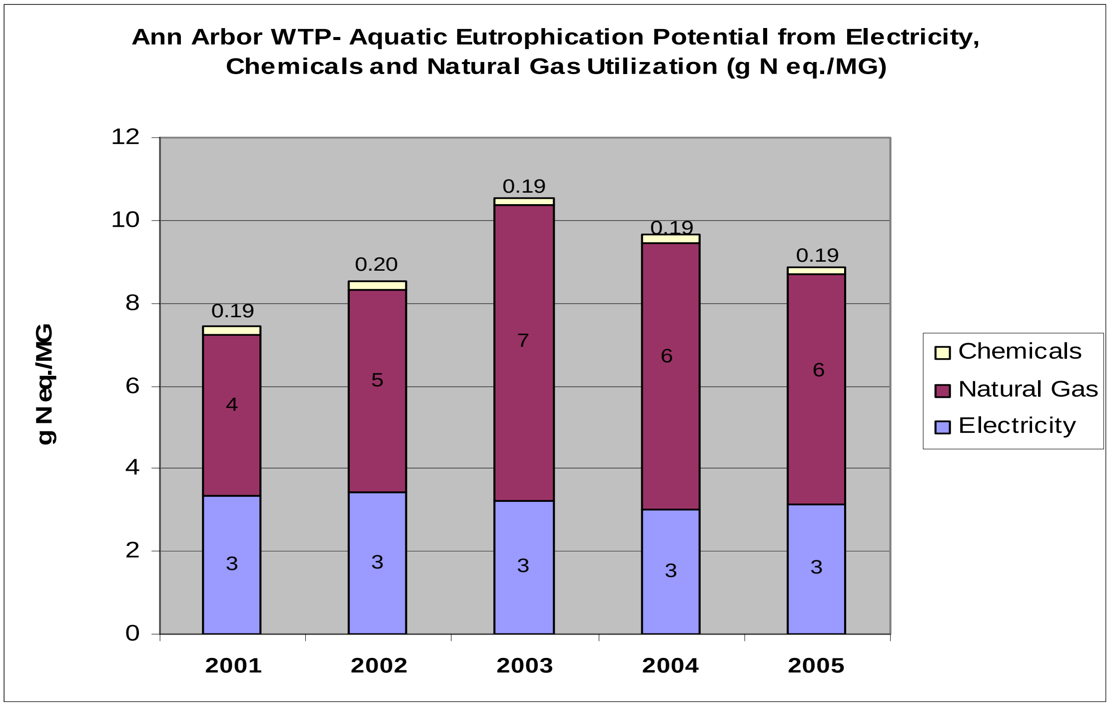


Figure 2-33. Aquatic Eutrophication Potential from Electricity, Chemicals and Natural Gas Utilization at the Ann Arbor WTP (g N eq. /MG)

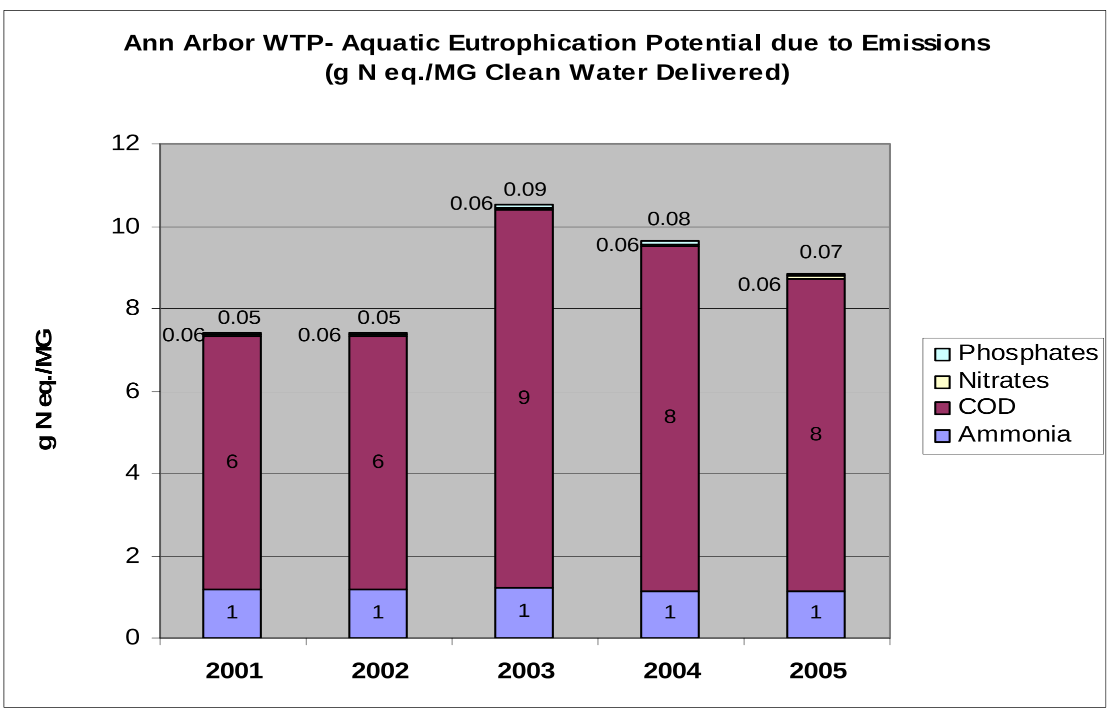


Figure 2-34. Aquatic Eutrophication Potential from Emissions (g N eq. /MG)

Table 2-3 summarizes these results categorized into total atmospheric eutrophication potential and aquatic eutrophication potential per year.

Table 2-3 Eutrophication Potential for Ann Arbor WTP

| **Eutrophication Potential for Ann Arbor WTP** *(grams of Nitrogen eq./MG)* | | |
|---|---|---|
| **Year** | **Atmospheric** | **Aquatic** |
| 2001 | 221 | 7 |
| 2002 | 225 | 7 |
| 2003 | 243 | 11 |
| 2004 | 227 | 10 |
| 2005 | 227 | 9 |

Further results can be found in Appendix A-II-b, which illustrate the key findings presented in Table 2-3 and Table 2-4 in a more detailed form.

### *iii. Acidification Potential*

The acidification potential is calculated in terms of kmoles of $H^+$ equivalence per million gallons of clean water delivered. The Acidification Potential for the Ann Arbor WTP ranges from 517 kmoles of $H^+$ eq. / MG to 666 kmoles of $H^+$ eq. / MG of clean water delivered for the period of 2001 to 2005.

Table 2-5 Acidification Potential for Ann Arbor WTP

| **Acidification Potential for Ann Arbor WTP (kmoles of $H^+$ eq./MG)** | | | | | |
|---|---|---|---|---|---|
| | $SO_2$ | HCl | NOx | $NH_3$ | **Total/MG** |
| **2001** | 410 | 39 | 218 | 0.3 | 666 |
| **2002** | 420 | 40 | 223 | 0.3 | 588 |
| **2003** | 393 | 37 | 208 | 0.3 | 549 |
| **2004** | 373 | 35 | 198 | 0.3 | 517 |
| **2005** | 391 | 37 | 208 | 0.3 | 544 |

Table 2-5 summarizes the emissions accounting for the total acidification potential for the Ann Arbor Water WTP. Figure 2-29 illustrates the contribution of electricity, chemicals and natural gas consumption towards the total acidification potential.

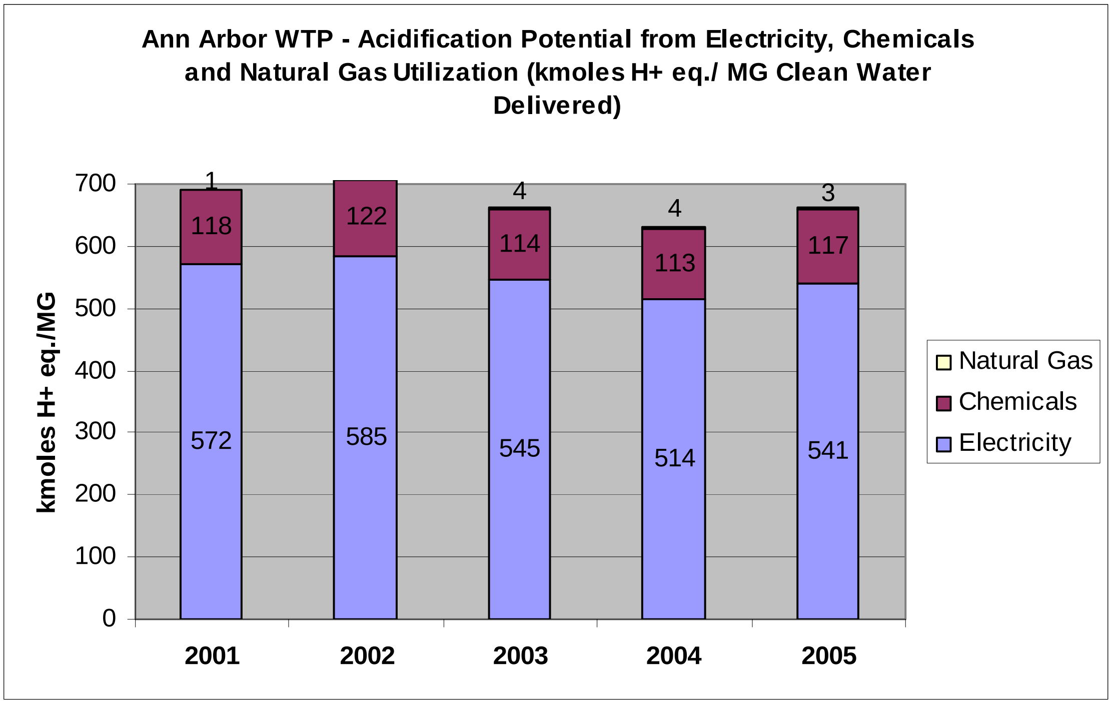


Figure 2-35. Acidification Potential for Ann Arbor WTP from Electricity, Chemicals and Natural Gas Utilization (kmoles of $H^+$ eq. /MG)

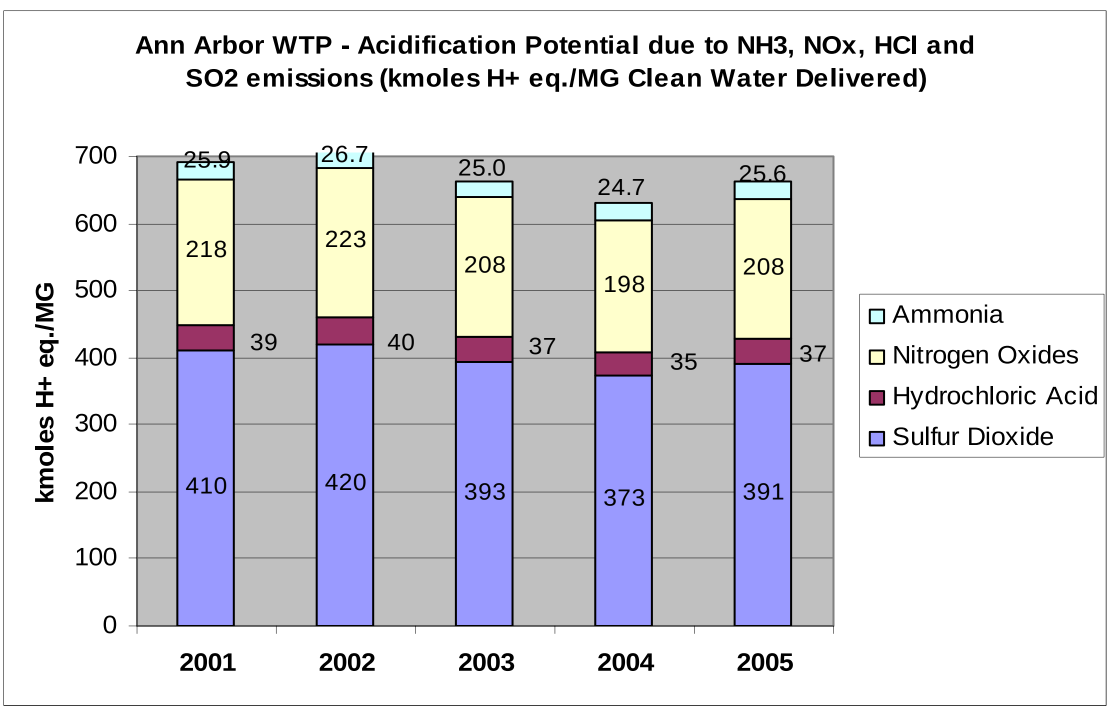


Figure 2-36. Acidification Potential due to $NH_3$, NOx, HCl and $SO_2$ Emissions from Operation of Ann Arbor WTP (kmoles of $H^+$ eq. /MG)

Electricity utilization accounts for 85% of the total acidification potential for the Ann Arbor WTP for the five year period. Production processes of the chemicals utilized for treatment account for 14% of the total acidification potential. The $SO_2$ and NOx emissions from electricity were major contributors to the total Acidification potential for the plant (Appendix A-II-c).

This chapter has presented the total life-cycle environmental impacts from operation of the Ann Arbor Water Treatment Plant. The findings discussed in this chapter and the findings from the analysis of the Ann Arbor WWTP will be discussed together in chapter 6 for a combined assessment of the Ann Arbor 'water and wastewater' treatment system. The next chapter presents an assessment of the total life-cycle environmental impacts resulting from operation of the Ann Arbor Wastewater Treatment Plant.

# Chapter 3

## Ann Arbor Wastewater Treatment Plant

### 3.1 Background

The Ann Arbor Wastewater Treatment Plant is responsible for the collection, tertiary treatment and discharge of wastewater in accordance with the NPDES† permits issued under the provision of CWA‡. The service area includes the City of Ann Arbor and parts of Pittsfield, and Scio townships. The plant constructed in 1937 and upgraded in 1977 comprises of two independent and similar plants - 'East Plant' and 'West Plant'- together designed to treat an average of 29.5 MGD and up to 48 MGD. Eight sewage lift stations located around the city are operated and maintained for effective collection of wastewater. The Ann Arbor Wastewater Treatment Plant (WWTP) provides Primary, Secondary and Tertiary treatment to the influent.

### 3.2 Wastewater Treatment

Preliminary treatment is provided to the influent by catenary bar screens, a climbing rake bar screen and grit chambers before the flow is diverted to the East or West plants.

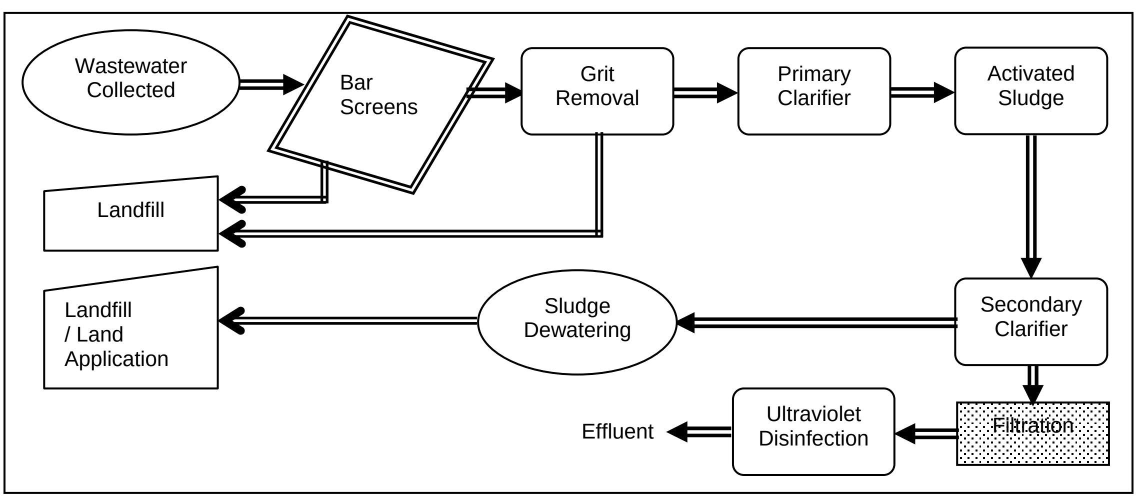


Figure 3-1. Treatment Process Flow for Ann Arbor WWTP

† National Pollutant Discharge Elimination System
‡ Clean Water Act

Common facilities are utilized for preliminary treatment, retention and equalization, solids handling and tertiary treatment. Primary treatment consists of the settling of biosolids by gravity using ten rectangular tanks (clarifiers) in the West plant and four circular clarifiers in the East plant. Secondary treatment consists of activated sludge process for biological removal of dissolved solids†. For secondary treatment, two aeration tanks and five circular clarifiers are used in the West plant and four aeration tanks and four circular clarifiers are used in the East plant. Tertiary treatment is provided by twelve mixed media filters. Disinfection is achieved through ultraviolet (UV) disinfection, before the treated water is returned to the Huron River. A flow retention and equalization facility with a total capacity of approximately seventeen million gallons enables the plant to process a steady flow of wastewater.

## 3.3 Total Flow

The average quantity of influent received by the Ann Arbor WWTP for the six years under consideration from 2000 to 2005 was 19 million gallons per day (MGD).

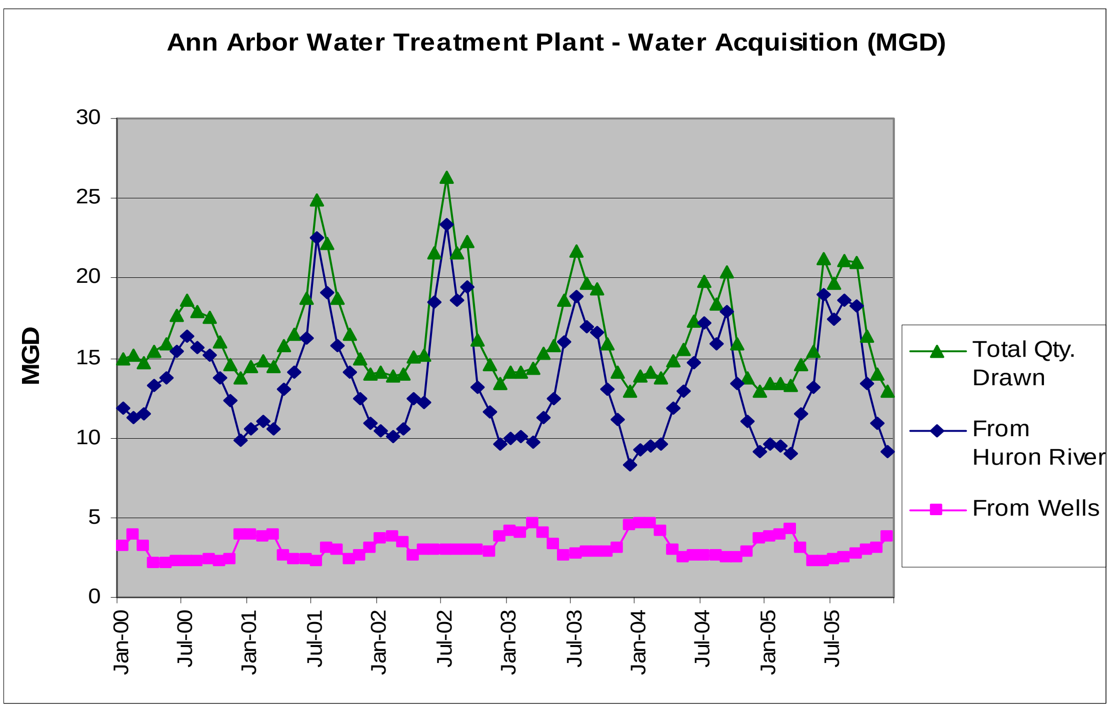


Figure 3-2. Total Influent at the Ann Arbor Wastewater Treatment Plant (MGD)

† The activated sludge process incorporates the anoxic/oxic (A/O) system to increase phosphorous removal, and fine bubble diffusion to enhance the transfer of oxygen needed for secondary treatment.

The maximum quantity treated during this period is 23 MGD in the month of February in 2001. The lowest influent flow recorded during the same period is 17 MGD in January 2000. Figure 3-2 illustrates the quantity of wastewater treated at the plant in terms of million gallons per day (MGD) based on the monthly data obtained from the plant. The influent quantity was generally low during winter months and high during summer months ranging from 450 MG per month to 675 MG per month. The average quantity of influent treated at the plant was 568 MG per month for the duration of six years. Figure 3-3 presents the quantity of influent received and treated at the plant in MG/month.

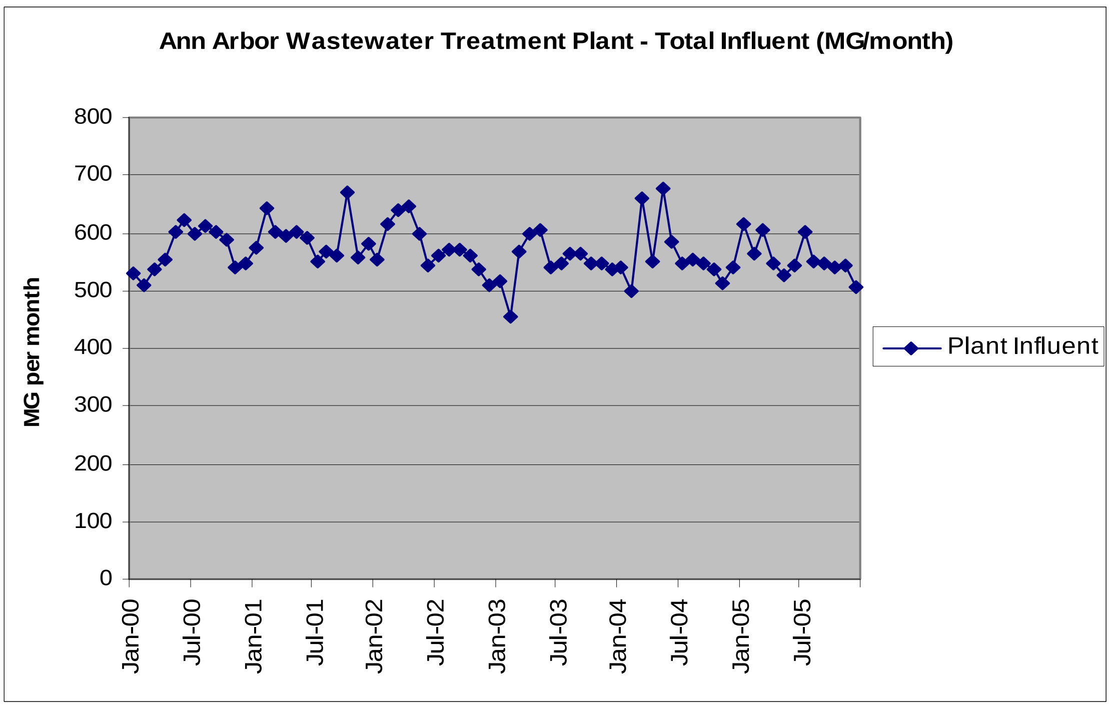


Figure 3-3. Total Flow at the Ann Arbor Wastewater Treatment Plant (MG/month)

Further details of the plant influent received by the Ann Arbor WWTP are located in Appendix B-I-a.

### 3.3 Electricity Utilization

The electricity utilized by the Ann Arbor Wastewater treatment plant includes the electricity consumed for operation of both treatment plants and administrative buildings. The average electricity utilized by the Ann Arbor WWTP for the period of six years is

1,103,685 kWh per month. The maximum monthly electricity utilization during the six year period from 2000 to 2005 is 1,354,608 kWh in March 2003.

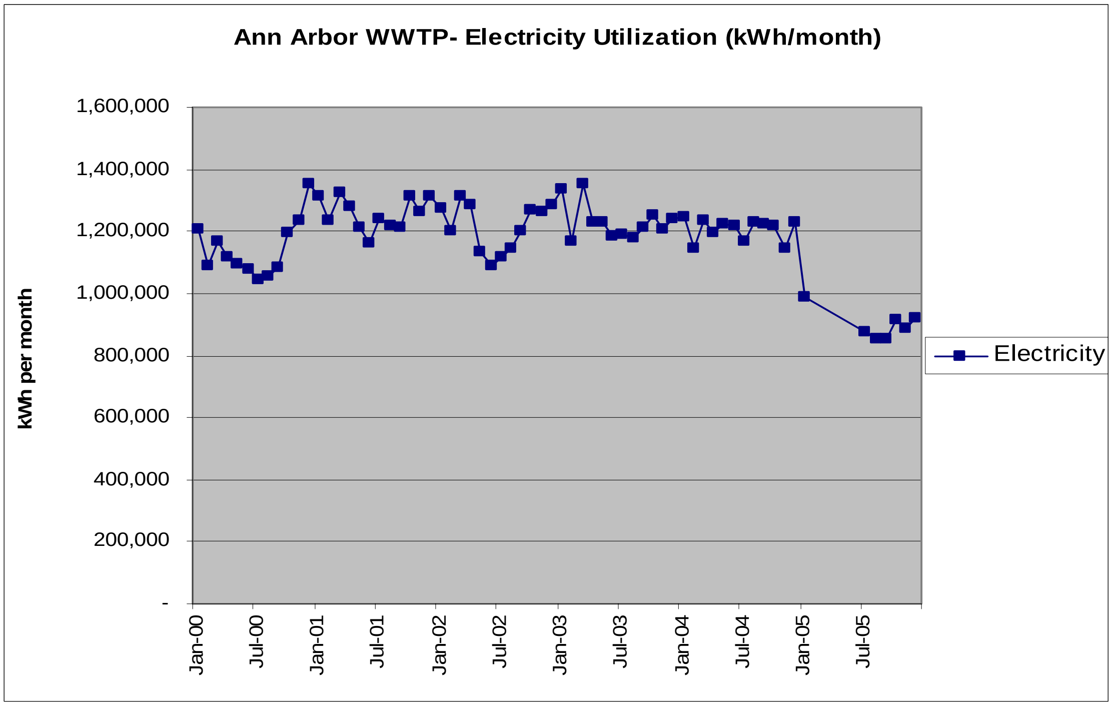


Figure 3-4. Total Electricity Utilization for Ann Arbor WWTP (kWh/month)

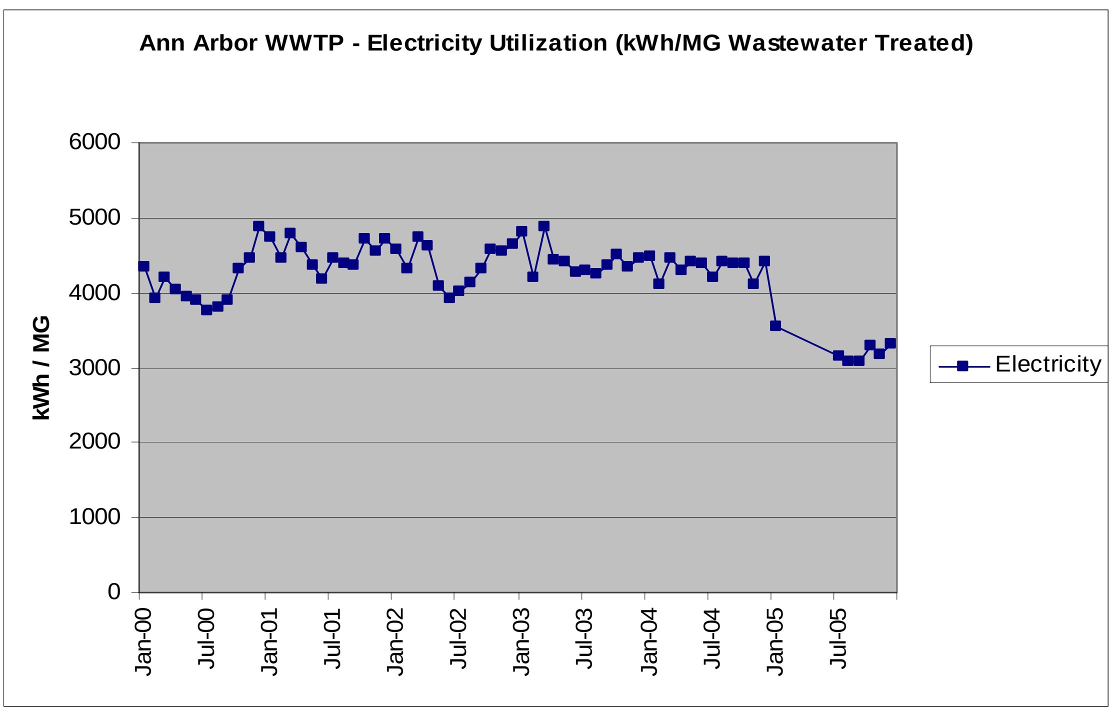


Figure 3-5. Total Electricity Utilization (kWh/MG)

The electricity utilization gets reduced in 2005 (Figure 3-4 and Figure 3-5) when compared with the recorded consumption in previous years. The details of the electricity utilization per month at the East Plant and the West Plant have been included in Appendix B-I-b.

### 3.4 Natural Gas Utilization

The natural gas utilization at the Ann Arbor Wastewater Treatment Plant is reported as CCF per month. The consumption figures were available from July 2002 to December 2005; hence, the analysis is based on only data available for this period. Average consumption for the six year period is 17,706 CCF per month. This figure includes the consumption in the boilers, retention building and administrative building. Figure 3-6 illustrates the total natural gas consumption at the Ann Arbor WWTP per month in terms of CCF/month.

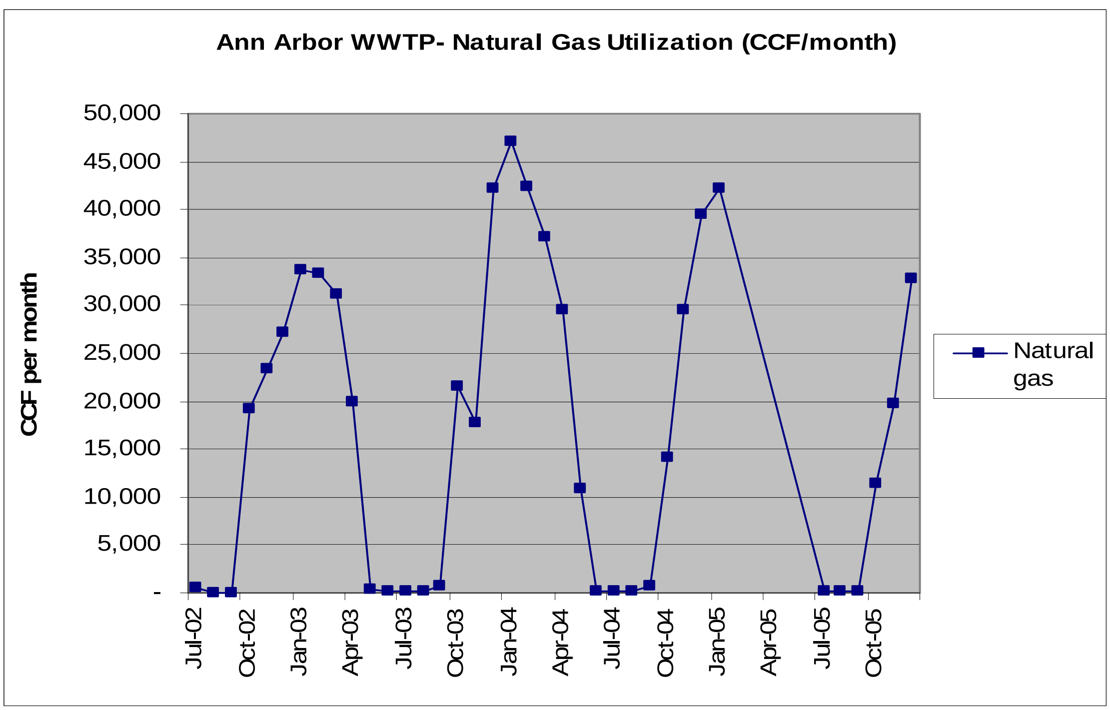


Figure 3-6. Natural Gas Consumption for Ann Arbor WWTP (CCF/month)

The consumption of natural gas is high during the winter months for heating. The quantity of natural gas consumed per million gallons of wastewater treated at the Ann Arbor WWTP is also high during the winter months. Figure 3-7, presents the natural gas consumption for treating one million gallons of wastewater at the plant during the winter months over the entire year.

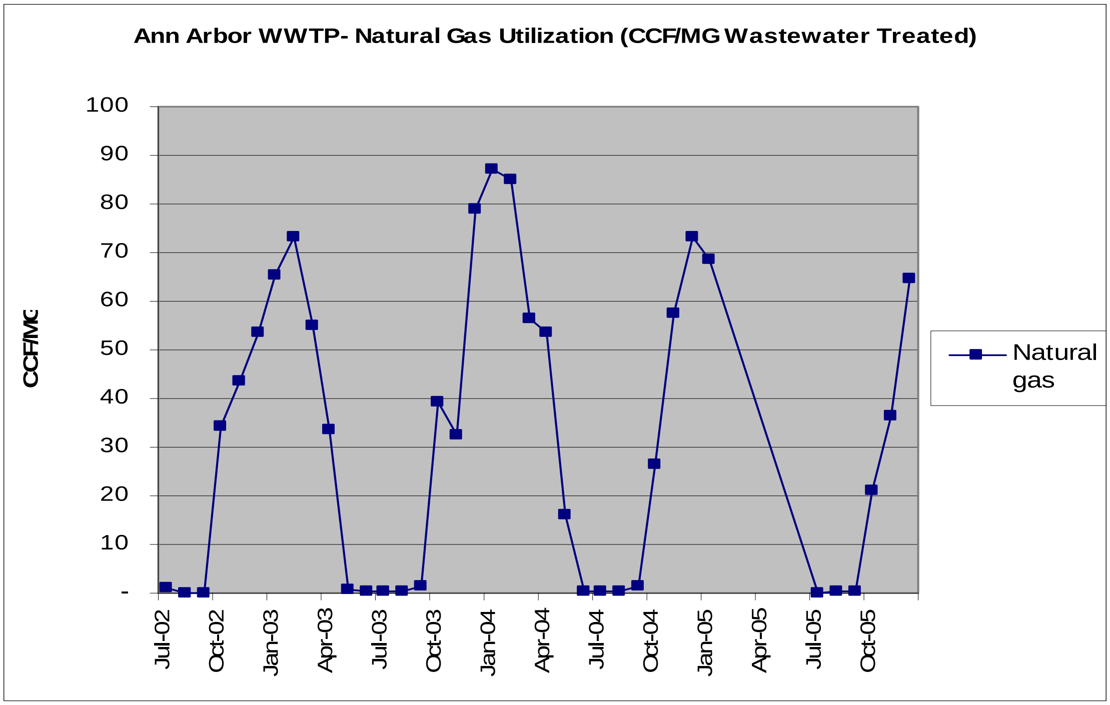


Figure 3-7. Natural Gas Utilization at the Ann Arbor WWTP (CCF/MG)

The natural gas utilization per million gallons of wastewater treated at the plant ranges from less than 1 CCF/MG to 74 CCF/MG. The average consumption from July 2002 to December 2005 is 32 CCF/MG wastewater treated at the plant.

### 3.4 Chemicals Utilized for Treatment

The Ann Arbor WWTP uses only two chemicals for treatment of wastewater - ferric chloride and lime. The quantity of ferric chloride utilized per month from January 2000 to December 2005 ranges from 3 metric tons in June 2001 to 120 metric tons in December 2000. The average utilization of ferric chloride for the six year period is 31 metric tons per month. Lime utilization for the same period ranges from 55 metric tons in November 2004 to 336 metric tons in November 2000. The average utilization of lime during this period is 120 metric tons per month. The quantity of lime utilized is exceptionally high for November 2000 and October 2005 (Figure 3-8).

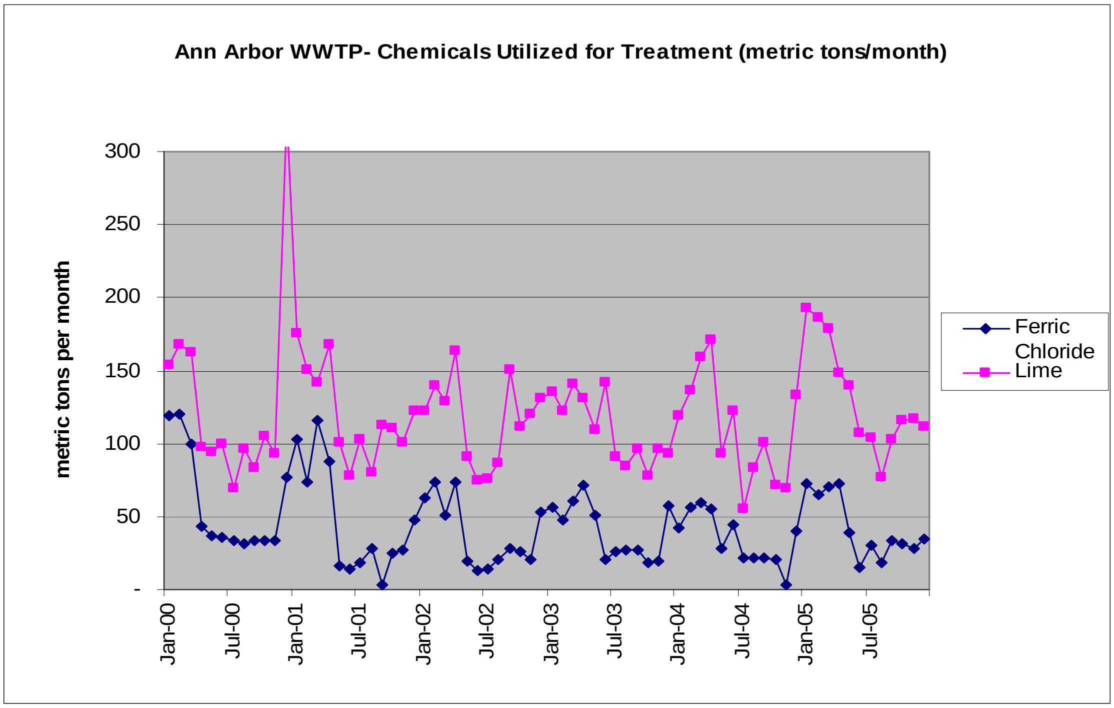


Figure 3-8. Chemicals Utilized at the Ann Arbor WWTP (metric tons/month)

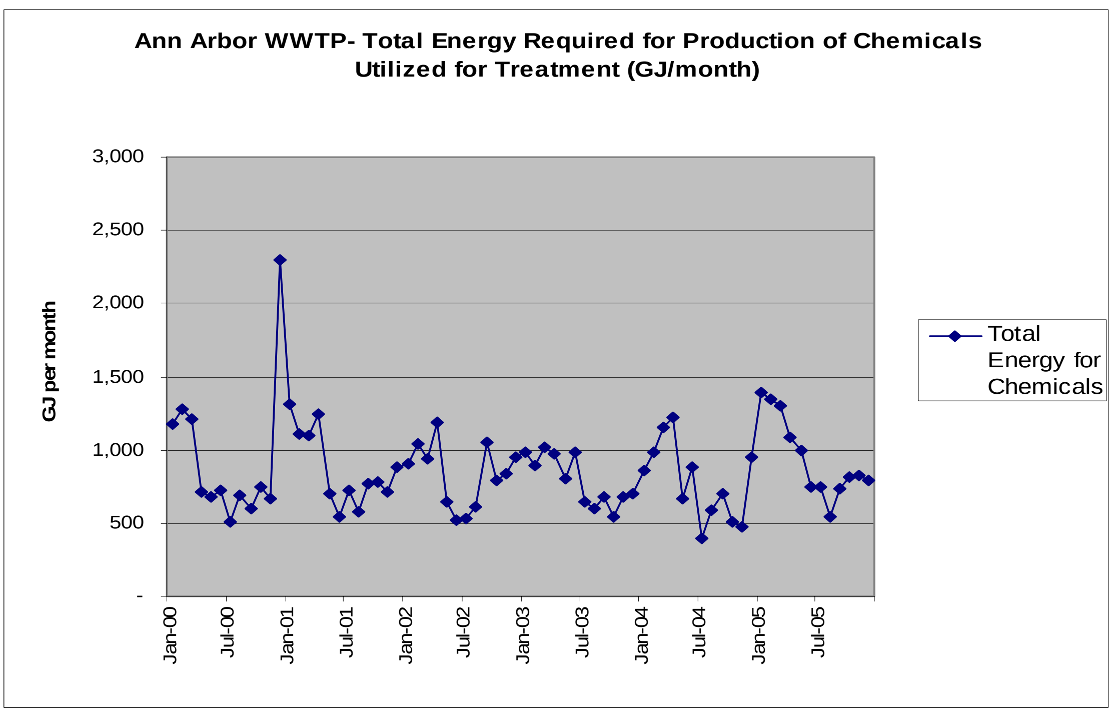


Figure 3-9. Energy required for Production of Chemicals Utilized for Treatment at the Ann Arbor WWTP (GJ/month)

Energy required for producing Ferric Chloride and Lime each was computed based on the assumptions and figures in section 1.5.2. The average energy consumption for production of chemicals used at the plant during 2000 to 2005 is 829 GJ per month. Details of the data used for these calculations are included in Appendix B-I-d.

### 3.5 Sludge Disposal

The Ann Arbor WWTP uses landfill and land-application sites for disposal of sludge produced upon treatment of wastewater at the plant. The total volume of sludge produced prior to dewatering for the six-year period ranges from 2,121 kGal per month to 4,250 kGal per month (Figure 3-10).

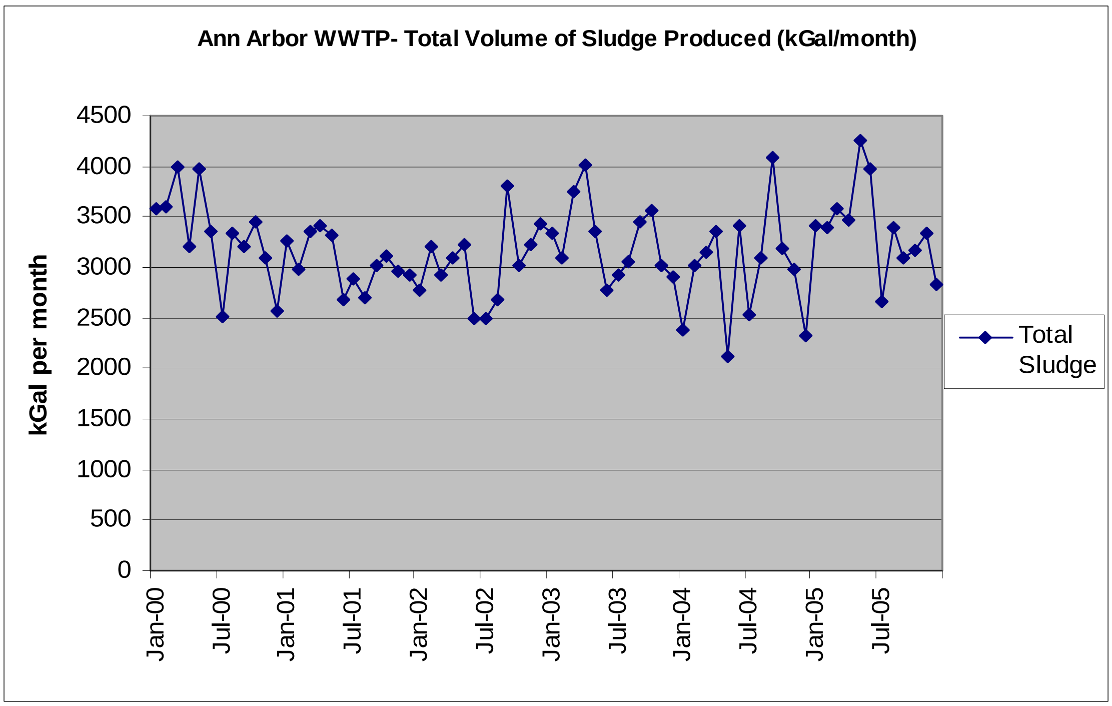


Figure 3-10. Total Volume of Sludge Produced at the Ann Arbor WWTP (kGal/month)

More than 50% of the total sludge is sent to land-application sites every year. Land-application does not usually take place from January to March and is usually low in November, December and April. Figure 3-11, shows the quantities of sludge transported to landfill and land-application sites.

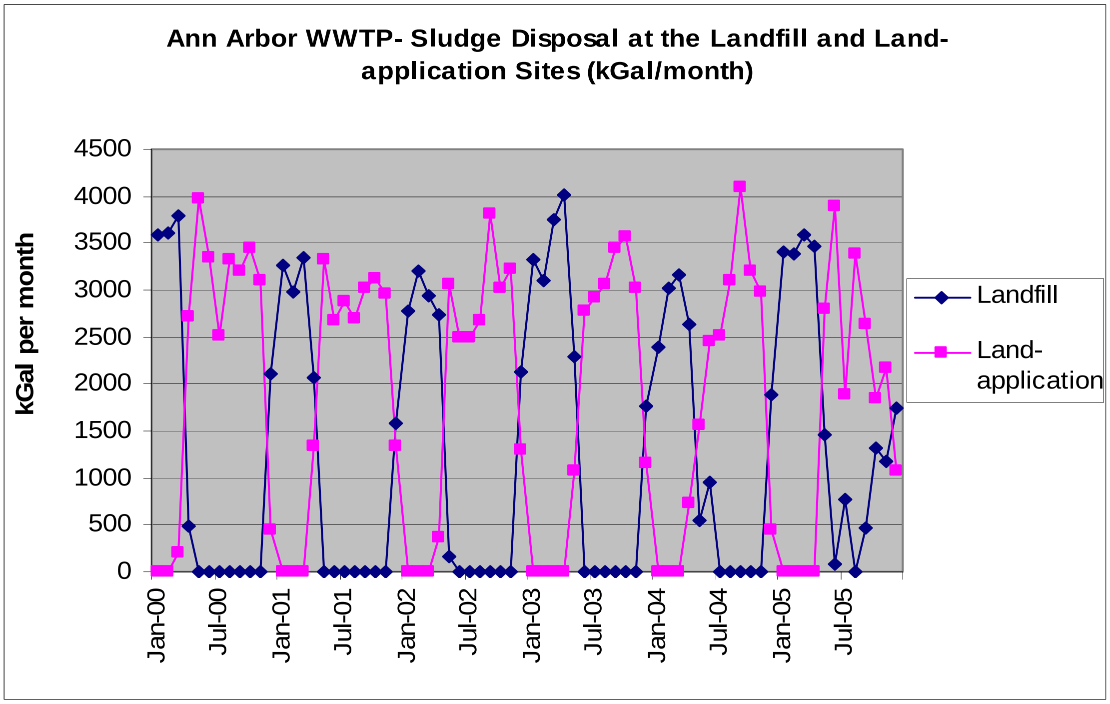


Figure 3-11. Sludge Disposal at Landfill and Land-application Sites for Ann Arbor WWTP (kGal/month)

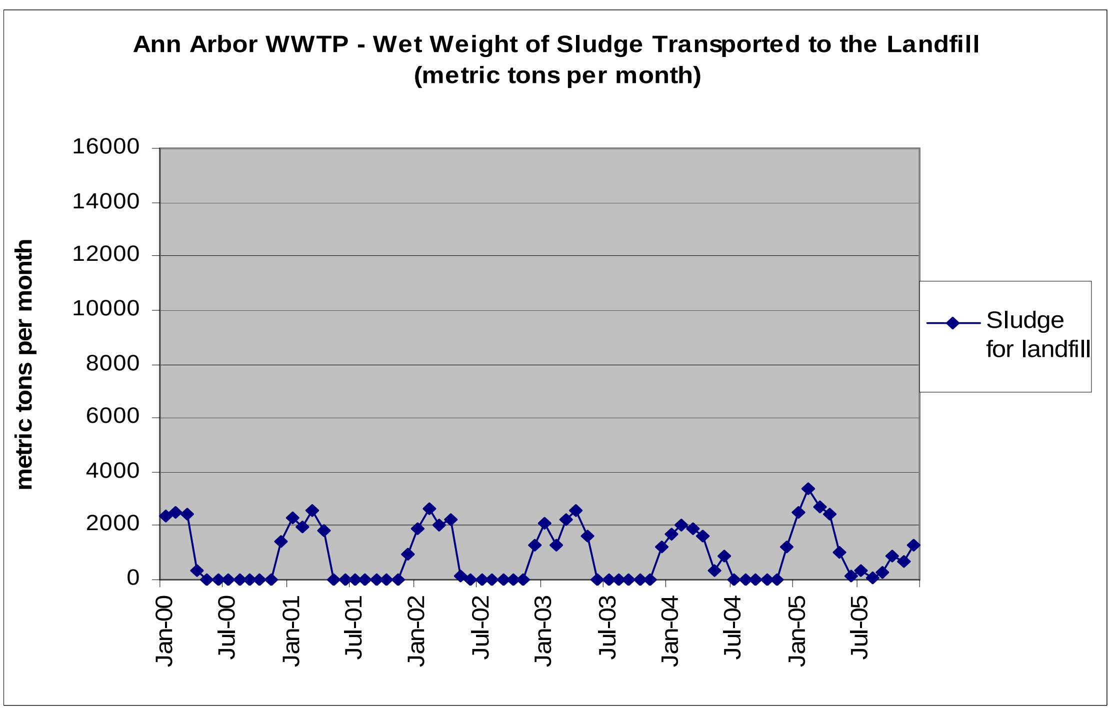


Figure 3-12. Wet Weight of Sludge Transported from Ann Arbor WWTP to the Landfill (metric tons/month)

The average quantity of sludge transported to the landfill is 902 metric tons per month based on information available for 2000 to 2005 (Figure 3-12). Further, the quantity of dry solids transported to the landfill has been plotted in Figure 3-13. The average quantity of dry solids disposed at the landfill is 222 metric tons per month.

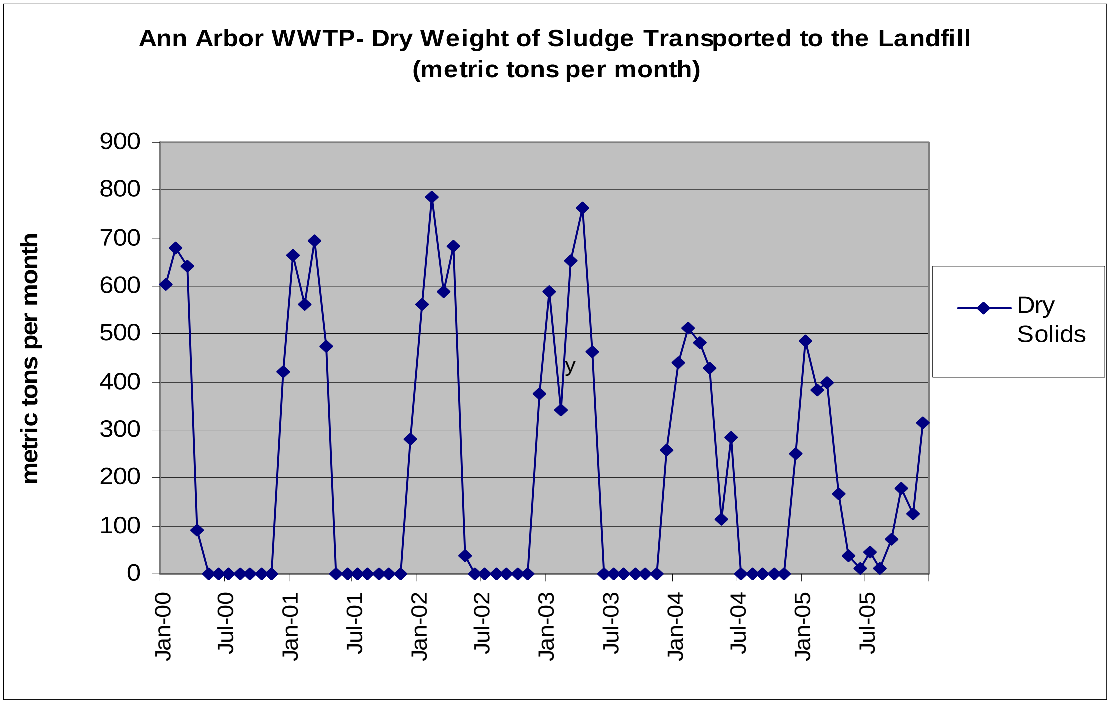


Figure 3-13. Dry Weight of Sludge Transported from Ann Arbor WWTP to the Landfill (metric tons/month)

Since the sludge transported to landfill is dewatered and compressed into wet-cakes with 25% solids, the average weight of the sludge transported to the land-fill is less than the weight of liquid transported for land-application (Figure 3-13).

Figure 3-14 illustrates the wet weight of the sludge transported to the land-application sites. The average quantity of sludge transported to the land-application sites during January 2000 to December 2005 is 6,764 metric tons per month. The percentage of solids in the liquid used for land-application is less than 5%. Figure 3-15 presents the dry weight of sludge transported for land-application. The dry weight is nearly the same as the dry weight of sludge transported to landfill, however, the wet weight is significantly higher because of the water being transported with the sludge.

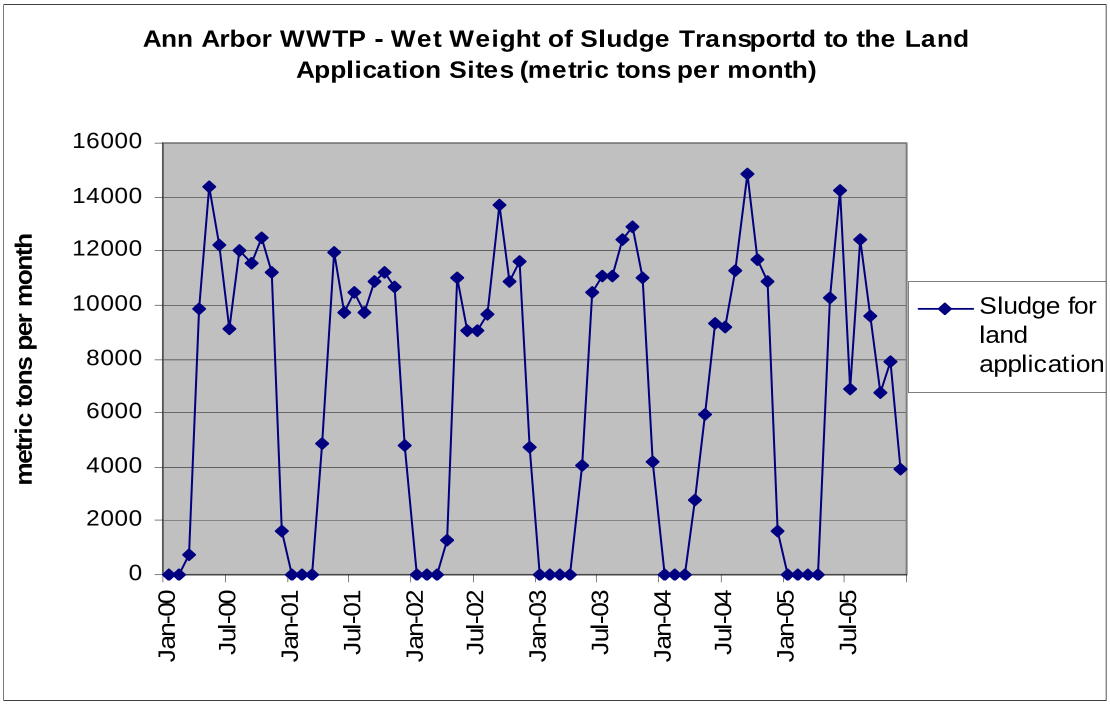


Figure 3-14. Wet Weight of Water and Sludge Transported for Land-application from Ann Arbor WWTP (metric tons/month)

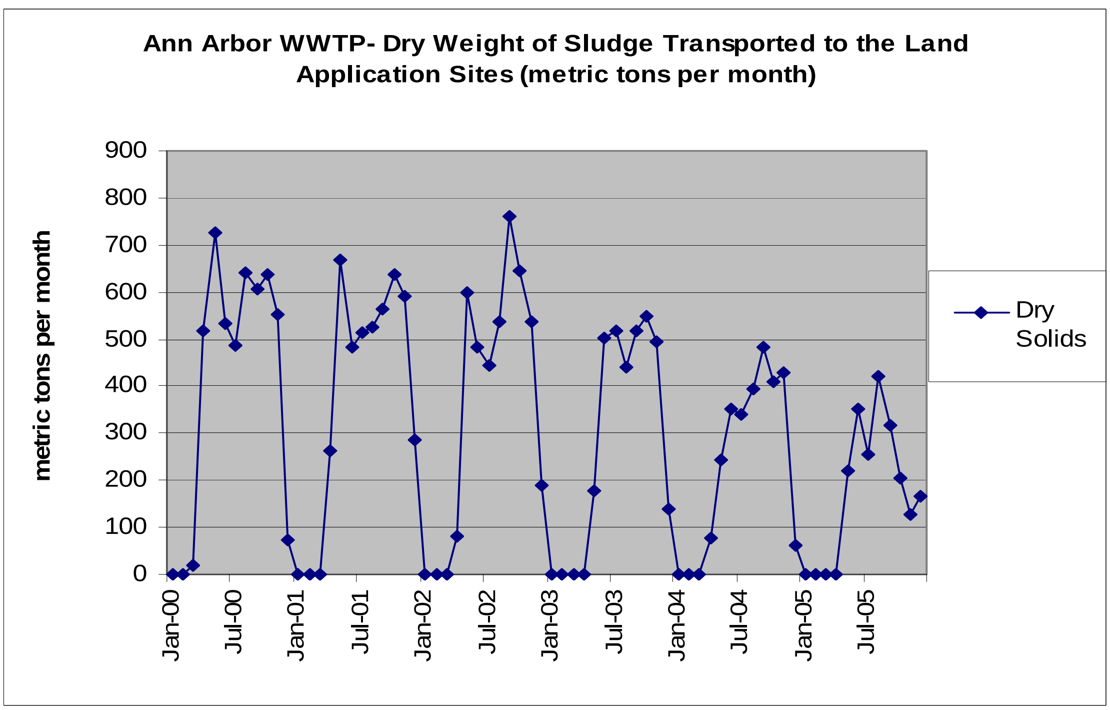


Figure 3-15. Dry Weight of Sludge Transported from Ann Arbor WWTP to the Land-application Sites (metric tons/month)

The quantity of diesel fuel required for transporting sludge to land-application sites and to the landfill is calculated on a monthly basis (Section 1.5.4). The average one-way distance to the land-application sites was 32 miles and the average one-way distance to the landfill was 80 miles. Figure 3-16 presents a comparison of the total wet weight of the sludge transported for landfill and land-application per month. It is clear in this figure that the weight of the sludge transported for land-application is much higher than that for landfill.

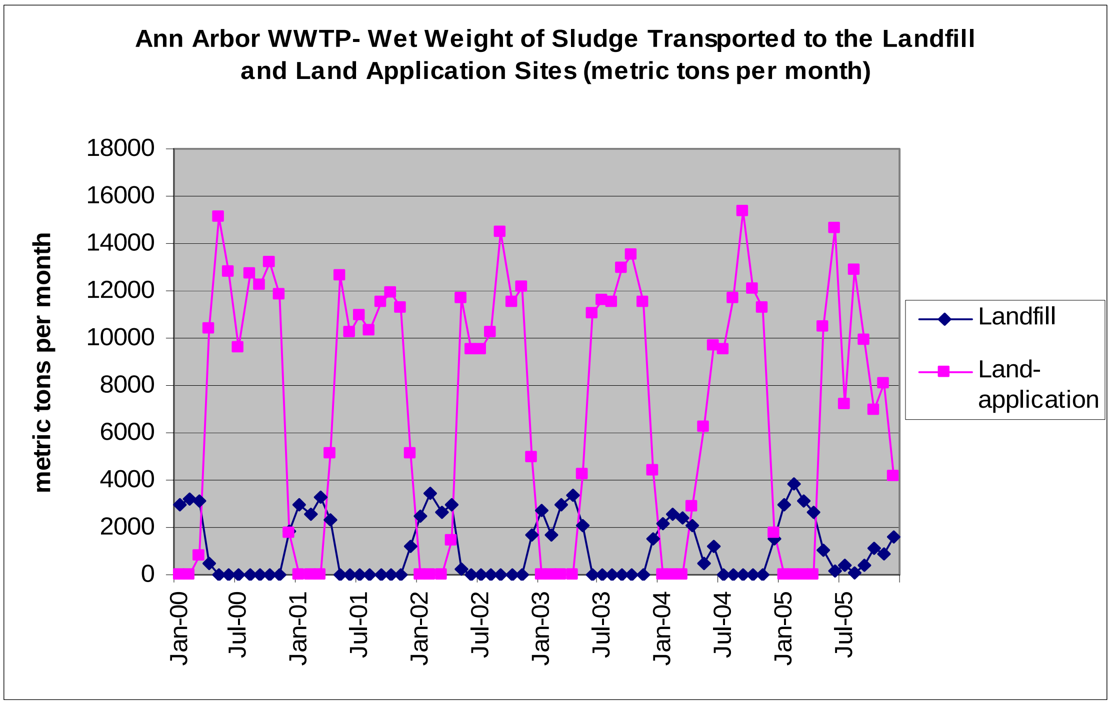


Figure 3-16. Wet Weight of Sludge Transported from Ann Arbor WWTP to the Landfill and Land Application Sites (metric tons/month)

However, even though a large difference is observed in the wet weights for landfill and land-application the quantity of diesel fuel consumed per month for transporting sludge to landfill and land-application does not differ in the same proportion as the wet weight. This is because the distance to the landfill is much more than the distance to the land-application sites. Figure 3-17 illustrates the amount of diesel fuel consumed for transporting sludge.

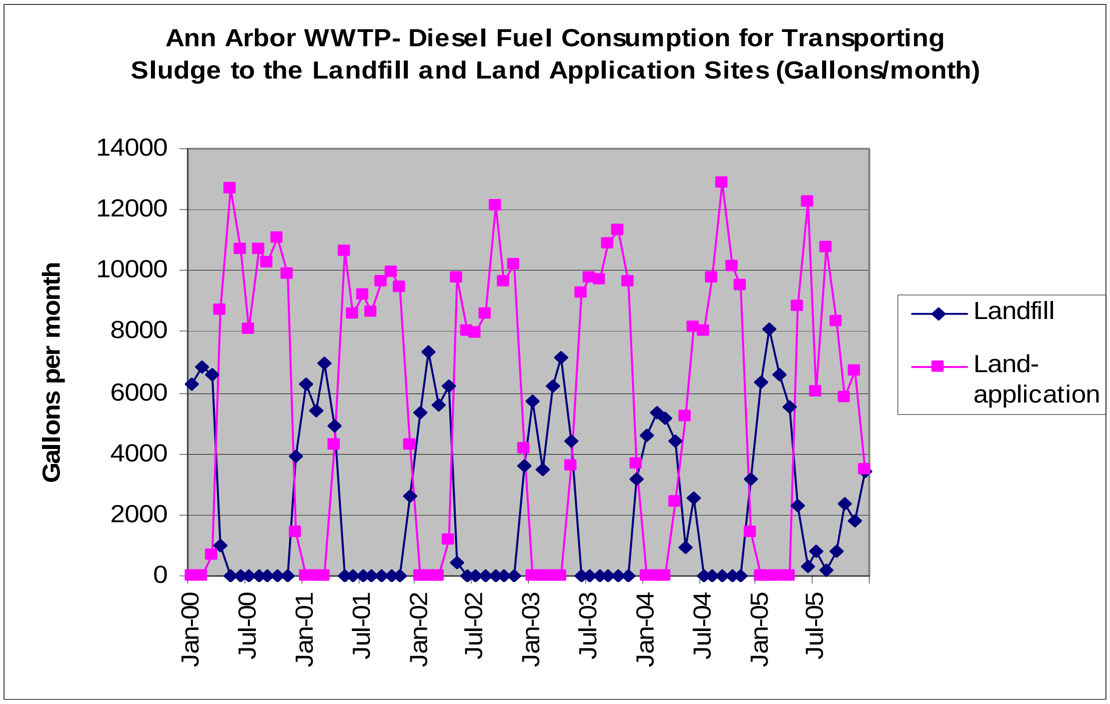


Figure 3-17. Diesel fuel Consumption for Sludge Hauling (gallons/month)

The data presented in Table 3-1 summarizes the annual consumption of diesel fuel for sludge hauling based on the total weight of sludge transported to land-fill and land-application sites.

Table 3-1 Sludge Disposal at Landfill and Land-application sites for Ann Arbor WWTP

| Year | Total Sludge | Sludge for Land filling | | Sludge for Land application | | Diesel fuel Consumed for Sludge Hauling | |
|---|---|---|---|---|---|---|---|
| | Landfill and land-appli. | (wet cake and dry solids) | | (sludge and water) | | Landfill | Land-applicati-on |
| | metric tons | metric tons | metric ton-miles | metric tons | metric ton-miles | Gallons | Gallons |
| **2000** | 111,534 | 11,636 | 930,841 | 100,059 | 3,178,654 | 24,667 | 84,234 |
| **2001** | 100,943 | 12,332 | 986,596 | 88,770 | 2,820,184 | 26,145 | 74,735 |
| **2002** | 98,489 | 13,499 | 1,079,919 | 85,182 | 2,706,546 | 30,164 | 71,723 |
| **2003** | 94,632 | 14,228 | 1,138,246 | 80,596 | 2,560,321 | 30,164 | 67,849 |
| **2004** | 92,353 | 12,386 | 990,903 | 80,190 | 2,548,480 | 26,259 | 67,535 |
| **2005** | 91,779 | 18,183 | 1,454,677 | 73,980 | 2,350,807 | 38,549 | 62,296 |

Since the one-way distance to the landfill is 80miles which is much more than the average distance to the land-application sites, the diesel fuel consumed per metric-ton of sludge disposed at the landfill is certainly higher (2.12 gallons/metric ton as opposed to 0.84 gallons/metric ton for land-application). However, the weight of the sludge transported in liquid form† for land-application is much more than the weight of the sludge transported in the form of wet cakes‡. Hence, disposal at landfill could be more energy efficient in terms of sludge disposal if the distance to the landfill is reduced.

Further, since the sludge disposal at land-application site replaces the fertilizer at these sites, the primary energy for fertilizers is saved. Although the system boundary for this study does not include an analysis on the energy saved due to replacement of fertilizers, an analysis can be conducted to determine the more energy-efficient option between land-fill and land-application. However, land-application sites cannot be used for sludge-disposal during the winter months, thus both options are required for sludge disposal over a year. Further details of data and calculations are included in Appendix B-I (e).

## 3.6 Life-cycle Energy Consumption for Operation of Ann Arbor WWTP

The total life-cycle energy consumed per month for operating the Ann Arbor WWTP includes energy consumed for generating electricity for operating the plant; using natural gas for heating purposes; producing the chemicals required for treatment at the plant; and, transporting the sludge produced to the disposal sites. The total life –cycle energy is not computed for all the six years since some of the data on electricity consumption is missing for the year 2005. Also, the natural gas consumption figures are unavailable or partially available from 2000 to 2002. As a result, Table 3-2 presents the findings of the life-cycle analysis for two years- 2003 and 2004.

Table 3-2 Life-cycle Energy Consumed for Operation of Ann Arbor WWTP

| Year | Electricity | | | Natural Gas | | | Chemicals | | | Disposal | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GJ | GJ/MG | % | GJ | GJ/MG | % | GJ | GJ/MG | % | GJ | GJ/MG | % | GJ | GJ/MG |
| 2003 | 53229 | 8 | 51 | 24660 | 4 | 24 | 9167 | 1 | 9 | 16339 | 2 | 16 | 103,396 | 16 |
| 2004 | 52096 | 8 | 48 | 30803 | 5 | 29 | 9037 | 1 | 8 | 15636 | 2 | 15 | 107,571 | 16 |

† with less than 5% solids
‡ with approximately 25% solids

The total life-cycle energy for operation of Ann Arbor WWTP is 103,396 GJ for 2003 and 107,571 GJ for the year 2004. Based on this total life-cycle energy per year, the life-cycle energy per million gallons of wastewater treated at the plant is calculated. The life-cycle energy for operation of the plant per million gallons wastewater treated is 16 GJ/MG. Figure 3-18 shows the contribution of electricity, natural gas, chemicals and diesel fuel consumption to the total life-cycle energy for operation of the Ann Arbor WWTP in 2003 and 2004.

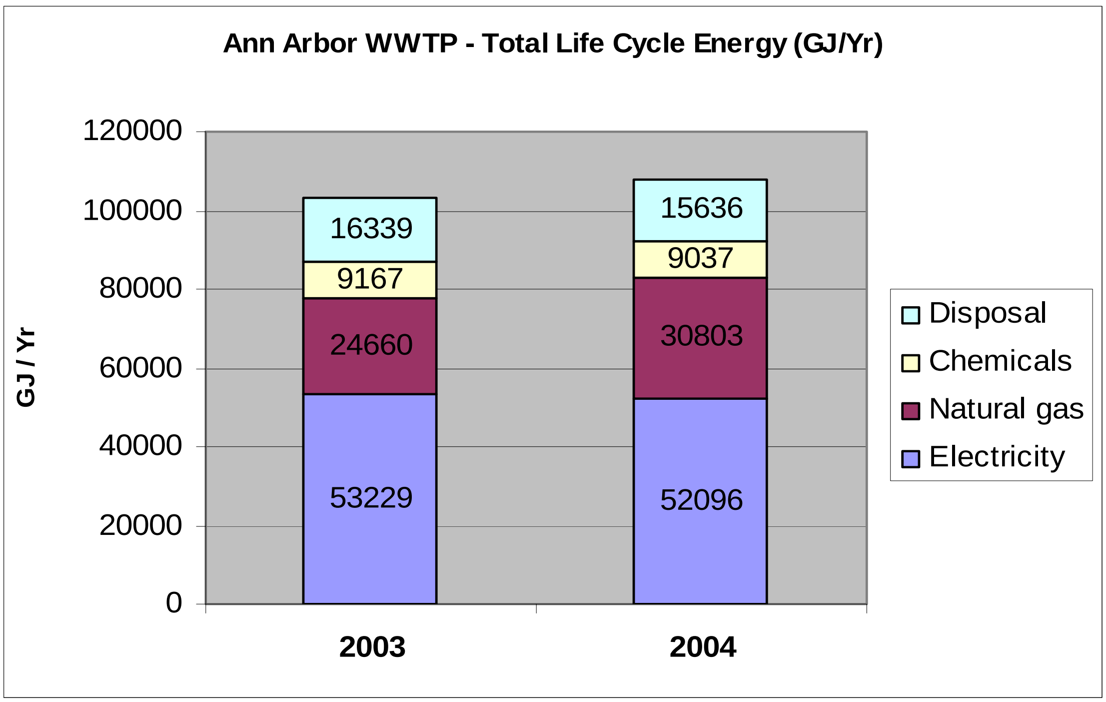


Figure 3-18. Total Life-cycle Energy for Operation of Ann Arbor Wastewater Treatment Plant (GJ/Year)

Direct electricity utilization for plant operation is 50% of the total life-cycle energy for the plant. Natural gas consumption represents 26% of the total life-cycle energy. The production of chemicals utilized for treatment constitutes 9% of the total life-cycle energy for operation of the plant. Surprisingly, Sludge Disposal phase was quite energy expensive, accounting for 16% of the total life-cycle energy calculated for this study. While energy can be conserved in each of the categories, sludge disposal is one phase in which energy consumption can be reduced by getting access to closer sites for sludge disposal. The total life-cycle energy figures are normalized to report the total life-cycle energy per million gallons of the wastewater treated. These results are presented in Figure 3-19.

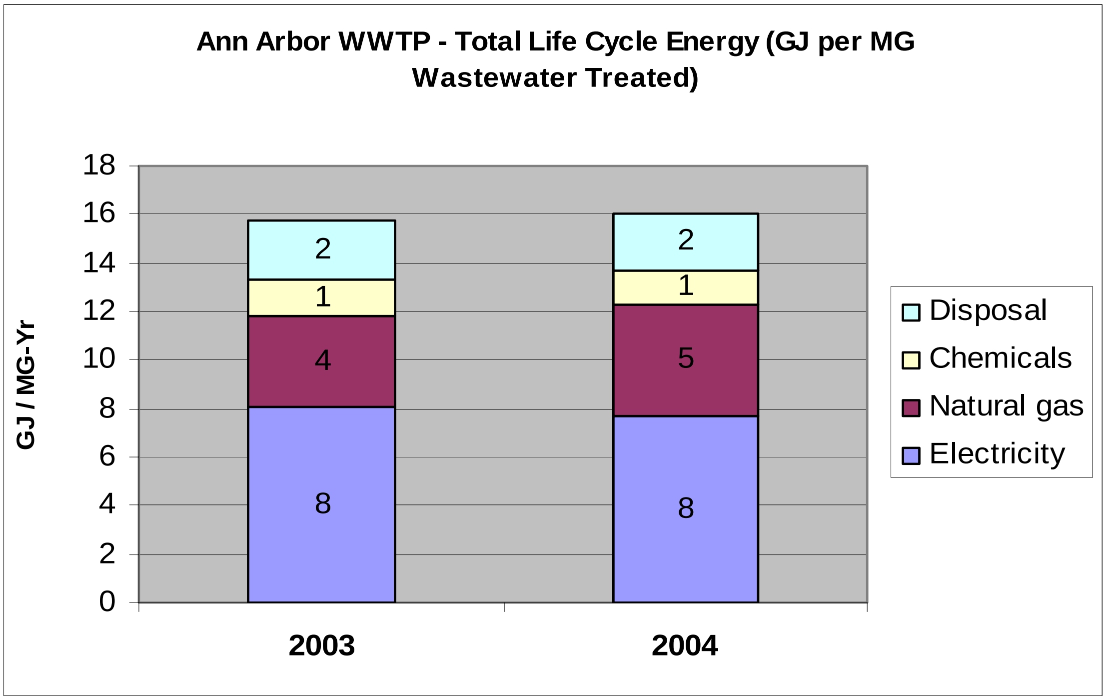


Figure 3-17. Total Life-cycle Energy for Operation of Ann Arbor WWTP (GJ/MG)

The life-cycle energy consumed for treating one million gallons of wastewater at the Ann Arbor WWTP is 16 GJ. The energy associated with direct electricity for plant operation is 8 GJ/MG and the energy for natural gas required at the plant is 5 GJ/MG. Production of chemicals utilized for treatment at the plant and sludge disposal accounted for approximately 1 GJ/MG and 2 GJ/MG respectively.

### 3.7 Life-cycle Emissions from Operation of Ann Arbor WWTP

The total life-cycle emissions for the Ann Arbor WWTP are computed for 2003 and 2004 based on the energy consumed for each year. The detailed calculations for this section are located in Appendix B-II. The results obtained from the annual figures have been categorized into Global Warming Potential, Eutrophication Potential and Acidification Potential in this section.

### *i. Global Warming Potential*

The contribution of electricity utilization, natural gas utilization, diesel fuel consumption and sludge hauling towards the total global warming potential from operation of the Ann Arbor WWTP is shown in Figure 3-20.

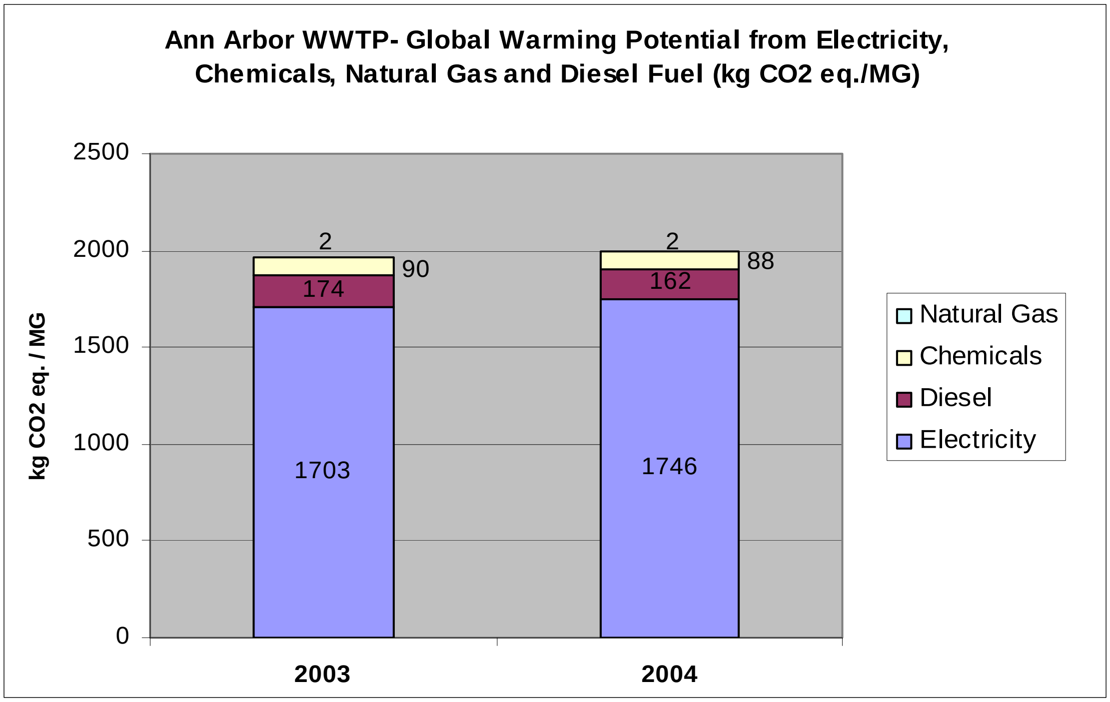


Figure 3-20. Life-Cycle Global Warming Potential from Electricity, Chemicals, Natural Gas and Diesel fuel Utilized at Ann Arbor WWTP (kg $CO_2$ eq. /MG)

The total global warming potential from operation of the plant is 1,980 kg $CO_2$ equivalent per MG. Emissions from electricity account for 1,725 kg $CO_2$ equivalent per MG for each year, emissions from diesel fuel consumption account for 166 kg $CO_2$ equivalent per MG and 89 kg $CO_2$ equivalent per MG from chemicals per year for 2003 and 2004. Thus, electricity utilized accounts for 87% of the total GWP, diesel fuel used for sludge hauling for 9% and production of chemicals used for treatment results into 5% of the total GWP. Figure 3-21 illustrates the results upon emissions analysis categorized into key greenhouse gases- carbon dioxide, methane and nitrous oxide.

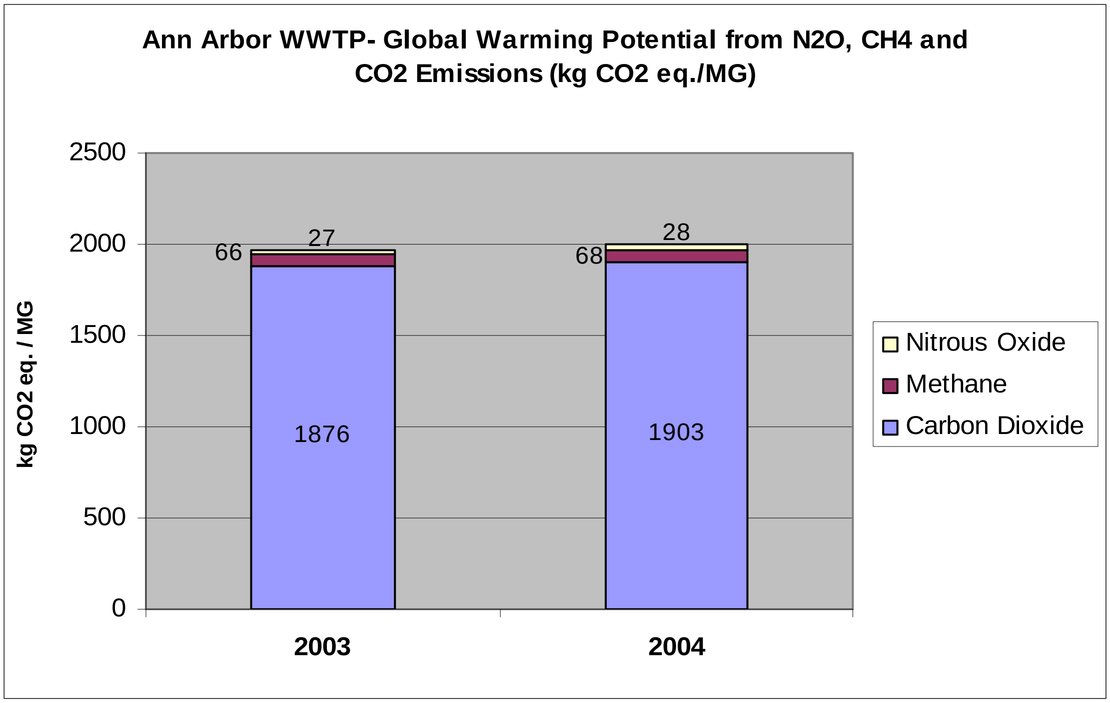


Figure 3-21. Life-Cycle Global Warming Potential from Carbon Dioxide, Nitrous Oxide and Methane emissions at the Ann Arbor WWTP (kg $CO_2$ eq./MG)

Table 3-3 Global Warming Potential from the Ann Arbor WWTP (kg $CO_2$ eq. /MG)

| Global Warming Potential for Ann Arbor WWTP (kgs of CO2 eq./MG) | | | | | |
|---|---|---|---|---|---|
| 2003 | | | | | |
| | ***Electricity*** | ***Nat. Gas*** | ***Diesel fuel*** | ***Chemicals*** | ***Total/MG*** |
| Carbon Dioxide | 1613 | 2 | 173 | 88 | 1876 |
| Methane CH4 | 63 | 0 | 1 | 2 | 66 |
| Nitrous Oxide | 27 | 0 | 0 | 0 | 27 |
| **Total GWP/MG** | 1703 | 2 | 174 | 90 | 1970 |
| % of Total GWP/MG | 86 | 0.1 | 9 | 5 | |
| 2004 | | | | | |
| | ***Electricity*** | ***Nat. Gas*** | ***Diesel fuel*** | ***Chemicals*** | ***Total/MG*** |
| Carbon Dioxide | 1653 | 2 | 162 | 86 | 1903 |
| Methane CH4 | 65 | 0 | 1 | 2 | 68 |
| Nitrous Oxide | 28 | 0 | 0 | 0 | 28 |
| **Total GWP/MG** | 1746 | 2 | 162 | 88 | 1999 |
| % of Total GWP/MG | 87 | 0.1 | 8 | 4 | |

A summary of the results obtained upon emissions analysis for determining the total global warming potential from operating the Ann Arbor WWTP is compiled in Table 3-3 above. It is evident from the figures presented in Table 3-3 that $CO_2$ emissions from electricity utilization represent a significantly high percentage of the total global warming potential for the plant. Further details can be found in Appendix B-II-a.

### *ii. Eutrophication Potential*

Eutrophication potential in terms of grams of Nitrogen (N) equivalence is computed separately for atmospheric and aquatic emissions for the two year period. The total atmospheric eutrophication potential for 2003 and 2004 is 650 g N equivalent per MG of treated wastewater. Figure 3-22, shows the atmospheric emissions in terms of eutrophication potential from electricity, natural gas and diesel fuel consumption.

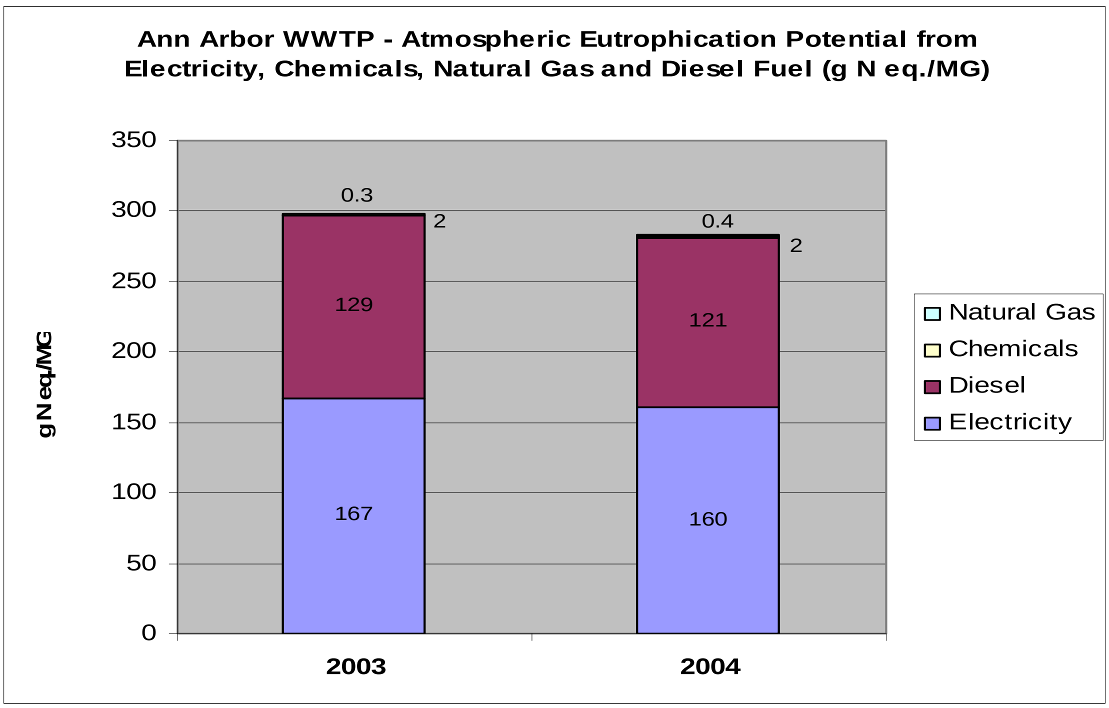


Figure 3-22. Atmospheric Eutrophication Potential from Electricity, Chemicals, Natural Gas and Diesel fuel Used at Ann Arbor WWTP (g N eq. /MG)

Electricity utilization accounts for 56% of the total atmospheric eutrophication potential. Further, diesel fuel consumption contributes 43% the total atmospheric eutrophication potential. High NOx emissions from electricity and diesel fuel are greatly responsible for the total atmospheric eutrophication potential. Figure 3-23, presents the atmospheric eutrophication potential resulting from nitrogen oxides and ammonia emissions due to electricity, natural gas and diesel fuel utilization.

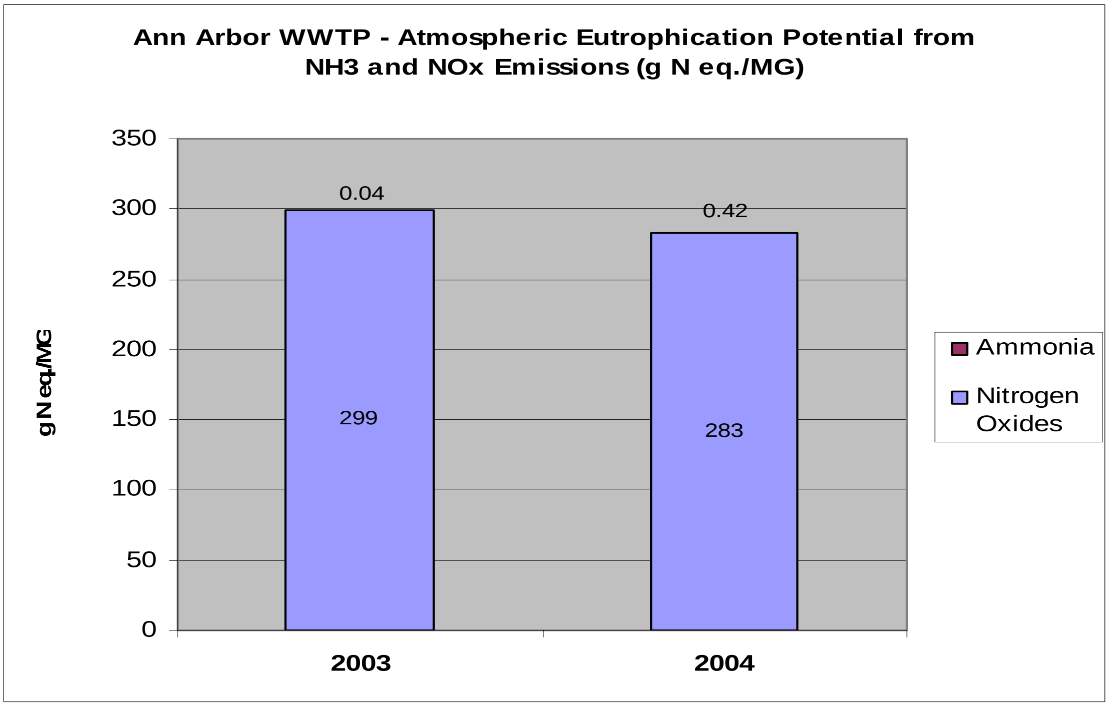


Figure 3-23. Atmospheric Eutrophication Potential from Ammonia and Nitrogen Oxide Emissions at Ann Arbor WWTP (g N eq. /MG)

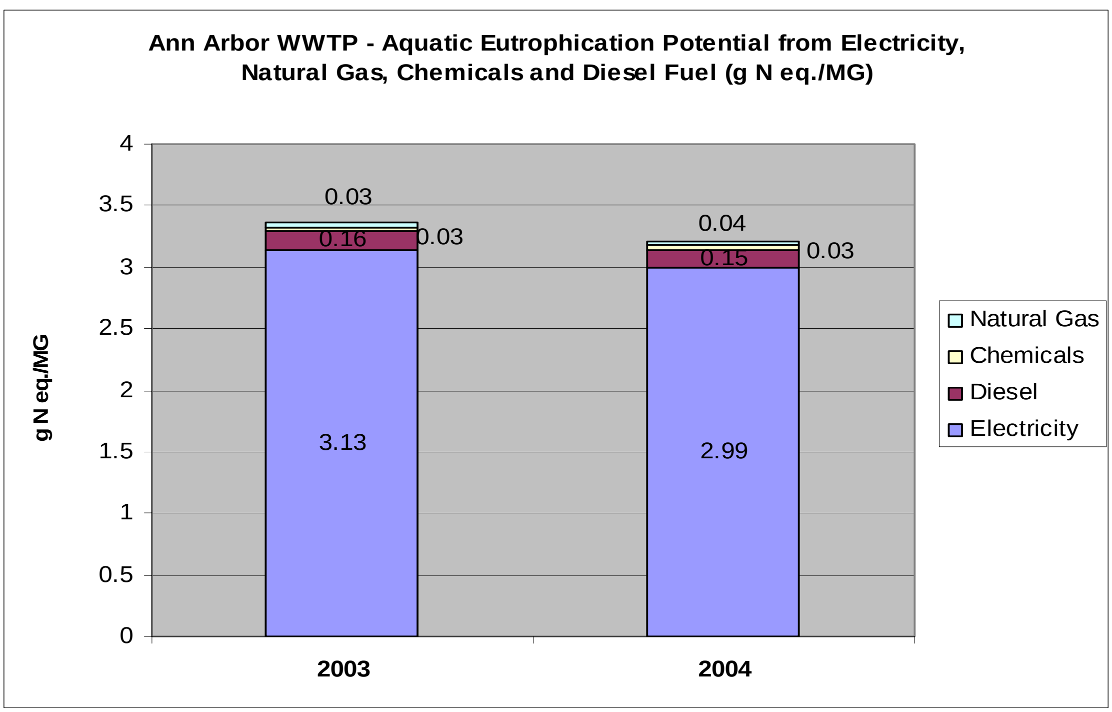


Figure 3-24. Aquatic Eutrophication Potential from Electricity, Natural Gas and Diesel fuel Utilized at Ann Arbor WWTP (g N eq. /MG)

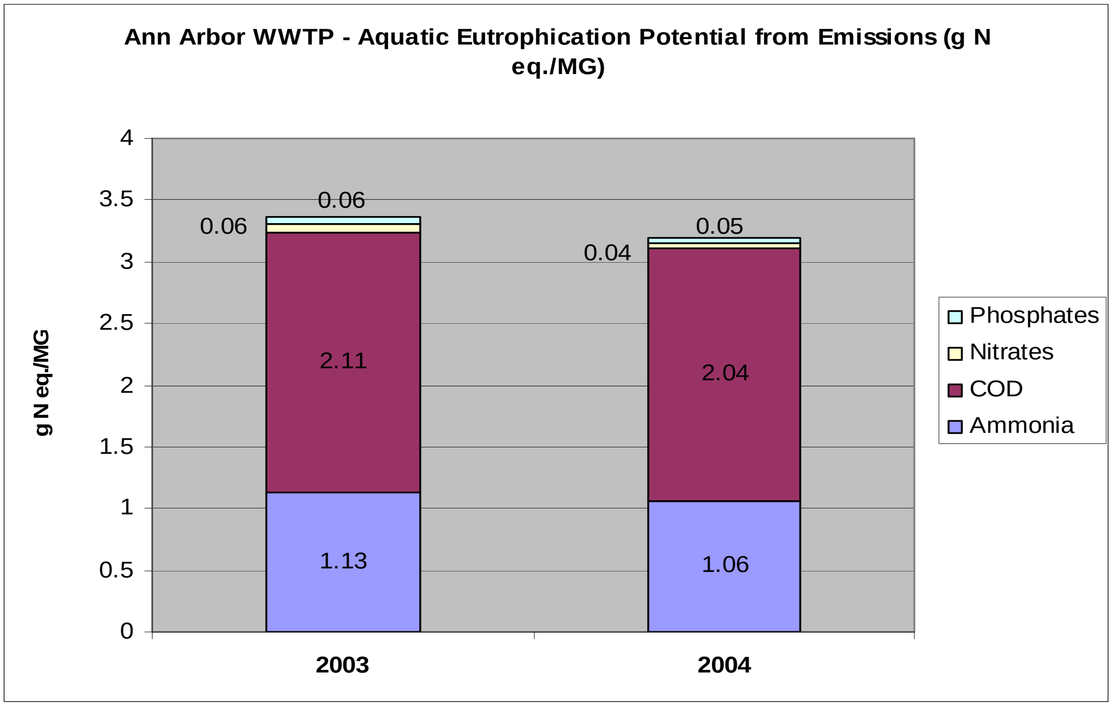


Figure 3-25. Aquatic Eutrophication Potential from Electricity, Natural Gas and Diesel fuel Consumption for Ann Arbor WWTP (g N eq. /MG)

The total aquatic eutrophication is much less since aquatic emissions are significantly lower than the atmospheric emissions. The total aquatic eutrophication potential for the Ann Arbor WWTP for 2003 and 2004 is 3 g N equivalent per MG of wastewater treated at the plant. Electricity and natural gas consumption contribute significantly to this the total aquatic eutrophication potential. Figure 3-24, presents the contribution of electricity, natural gas and diesel fuel towards the total aquatic eutrophication potential for operation of Ann Arbor WWTP.

The organic emissions expressed as COD from electricity and natural gas are the main component of the total aquatic eutrophication potential accounting for more than 60% of the total figure. Further, ammonia emissions from electricity consumption are also high. Figure 3-25, shows the contribution of emissions from energy consumption at the plant towards the total aquatic eutrophication potential. Table 3-4 summarizes the key findings on eutrophication potential from emissions resulting from operation of Ann Arbor WWTP.

Table 3-4 Eutrophication Potential for of Ann Arbor WWTP (g N eq. /MG)

| Eutrophication Potential for Ann Arbor WWTP | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2003 | | | | 2004 | | | |
| ***Atmospheric*** | | ***Aquatic*** | | ***Atmospheric*** | | ***Aquatic*** | |
| ***g Nitrogen eq. /MG*** | | ***g Nitrogen eq. /MG*** | | ***g Nitrogen eq. /MG*** | | ***g Nitrogen eq. /MG*** | |
| NOx | 299 | N | | NOx | 283 | N | |
| $NH_3$ | 0.04 | $NH_3$ | 1 | $NH_3$ | 0.4 | $NH_3$ | 1 |
| $NH_4$+ | | COD | 2 | $NH_4$+ | | COD | 2 |
| $NO_3^-$ | | $NO_3^-$ | 0.06 | $NO_3^-$ | | $NO_3^-$ | 0.04 |
| $PO_4^{3-}$ | | $PO_4^{3-}$ | 0.06 | $PO_4^{3-}$ | | $PO_4^{3-}$ | 0.05 |
| P | | P | | P | | P | |
| **Total** | 299 | | 3 | **Total** | 283 | | 3 |

Further details on calculations and results are included in Appendix B-II-b.

### *iii. Acidification Potential*

The total acidification potential in terms of kmoles of $H^+$ equivalent per million gallons of wastewater treated at the Ann Arbor WWTP is 667 kmoles of $H^+$ equivalent/MG.

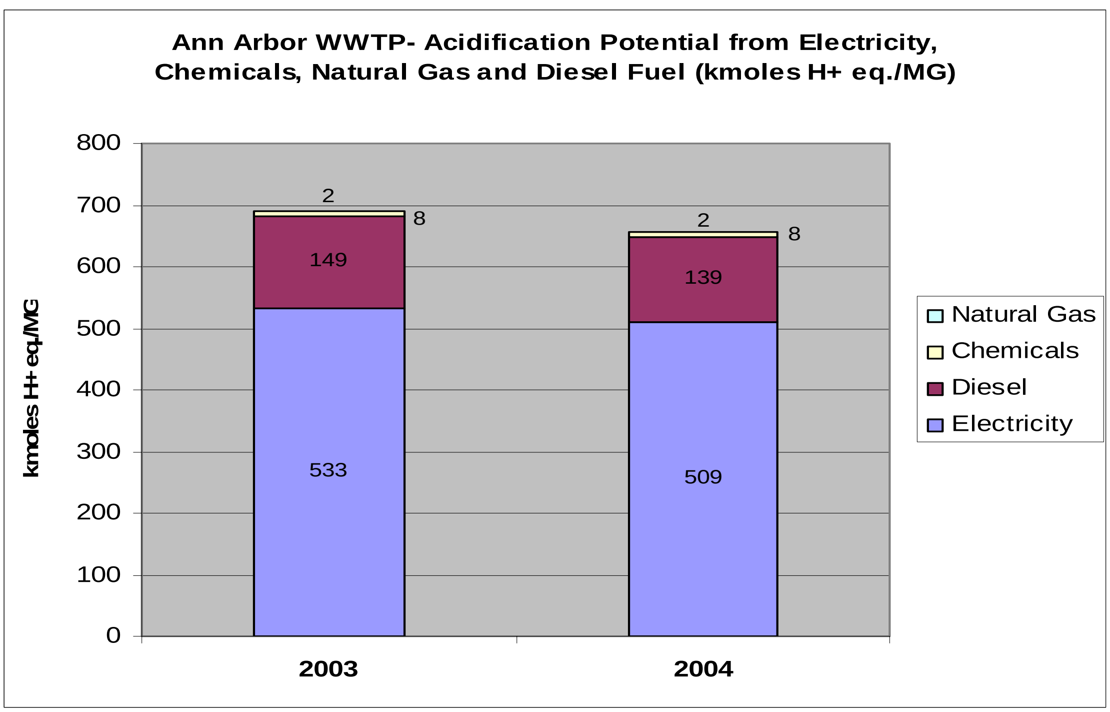


Figure 3-24. Acidification Potential from Electricity, Chemicals, Natural Gas and Diesel Fuel Used at Ann Arbor WWTP (kmoles $H^+$ eq. /MG)

More than 78% of the total acidification potential is a result of emissions from electricity utilization.

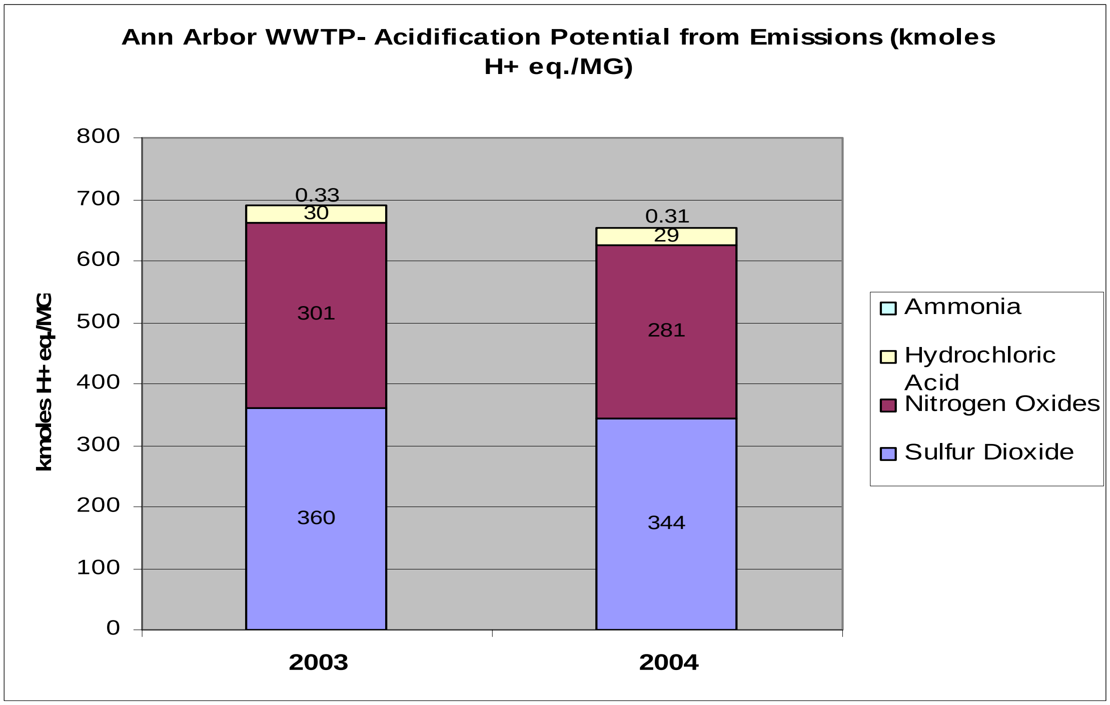


Figure 3-25. Acidification Potential for Ann Arbor WWTP (kmoles $H^+$ eq. /MG Treated)

Figure 3-24 shows the acidification potential from electricity, chemicals, natural gas and diesel fuel used at the plant. High sulfur dioxide emissions and nitrogen oxide emissions from electricity utilized for operation of the Ann Arbor WWTP contribute significantly to the total acidification potential.

Further, high nitrogen oxide emissions from diesel fuel used to transport sludge to disposal sites also account towards the total acidification potential. Figure 3-25 presents the contribution of ammonia, nitrogen oxides, hydrochloric acid and sulfur dioxide towards the total acidification potential from operation of the plant. These results are summarized in Table 3-5.

Table 3-5 Acidification Potential for Ann Arbor WWTP (kmoles of $H^+$ eq. /MG)

| Acidification Potential for Ann Arbor WWTP | | |
|---|---|---|
| | **2003** | **2004** |
| | Kmoles of $H^+$ eq./MG | Kmoles of $H^+$ eq./MG |
| $SO_2$ | 360 | 344 |
| HCl | 30 | 29 |
| NOx | 301 | 281 |
| $NH_3$ | 0.3 | 0.3 |
| Total | 691 | 654 |

The total life-cycle energy and emissions from operation of the Ann Arbor WWTP are further discussed for a comparative assessment with other wastewater treatment plants studied as part of this research effort in Chapter 5. Further the results obtained from the analyses of the Ann Arbor WWTP are combined for an assessment of the Ann Arbor 'water and wastewater' treatment system in Chapter 6.

# Chapter 4

## Laguna Wastewater Treatment Plant

### 4.1 Background

The Laguna Wastewater Treatment Plant is a tertiary-level treatment facility that has an average daily dry weather flow of 17.5 million gallons per day (MGD). Constructed in 1968 it serves the Cities of Santa Rosa, Rohnert Park, Sebastopol and Cotati. The plant has many unique environmentally beneficial characteristics. Firstly, it is a part of the Subregional System in California, which is one of the largest recyclers in the world. The system irrigates around 6,400 acres of farmlands, vineyards and public and private landscaping. [25] More detailed information has been provided in Appendix C-I-a.

Secondly, the plant is connected to the Geysers Recharge system, a geothermal operation which generates around 85 megawatts per day using the treated water from the Laguna Treatment Plant. The geysers steam fields are a rare geothermal occurrence in which natural steam is produced when underground water comes into contact with the rocks that have been heated by underlying magma[†]. The steam thus generated, escapes from the ground in the form of hot springs or fumaroles because the magma in the geysers area is relatively close to the Earth's surface. When the steam reaches the surface in production wells that have been drilled by energy companies, it travels through insulated pipelines to a generator unit where it spins turbines to create electricity. Further details of the geysers recharge system are included in Appendix C-I-b. Further, the plant utilizes co-generators with three 900 KW Waukesha lean-burn engines reducing the burden of electricity imported from the grid.

### 4.2 Wastewater Treatment

Large bar screens remove wood, paper, and plastics from the sewage collected from homes, businesses, and industries before the wastewater reaches the treatment plant. Sand and gravel then settle out in the grit tank and are removed. After this preliminary

[†] Magma is molten rock

treatment the sewage undergoes primary treatment. Figure 4-1, shows the treatment process at the Plant.

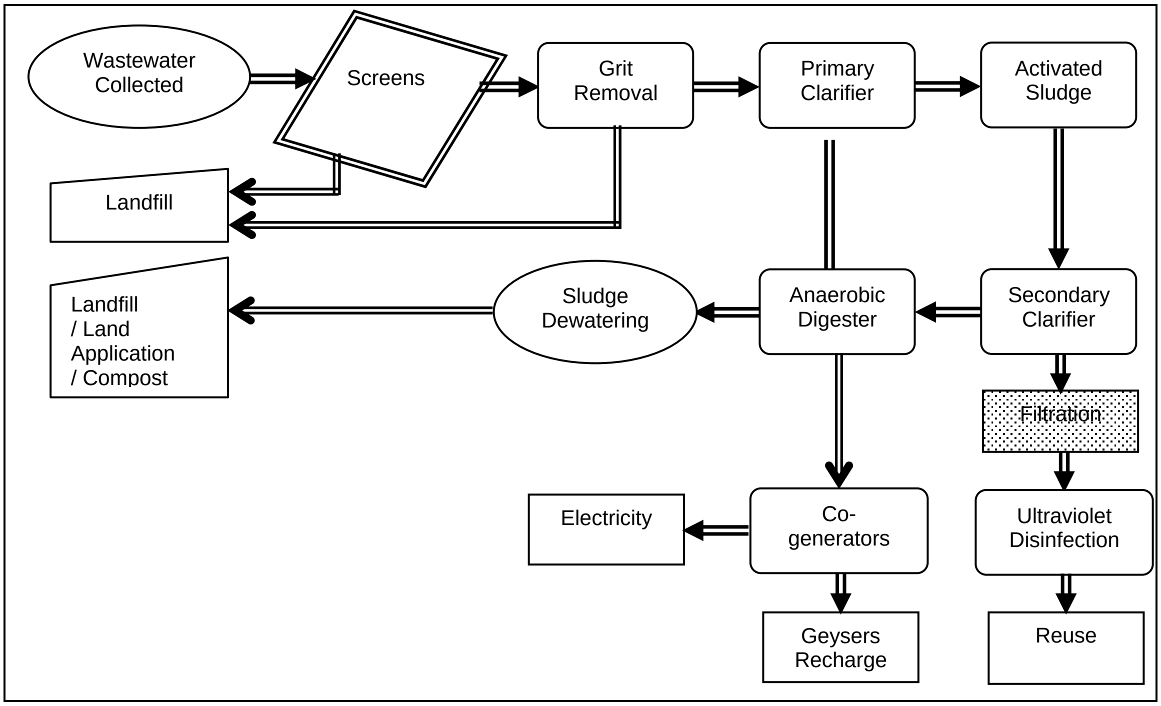


Figure 4-1. Flow Diagram of the Treatment Process at the Laguna WWTP

Primary clarification tanks allow lighter materials to float to the surface, which is then skimmed off. Biosolids, which are heavier, fall to the bottom and get pumped to anaerobic digesters. Bacteria in the digesters break solids down, creating methane gas. Methane powered generators serve as the source of energy for one-sixth of the treatment process. Solids are digested for up to thirty days, reducing their volume by 50%. Biosolids are blended with green waste material to create compost after dewatering, or they are applied directly to agricultural fields as fertilizer. A very small quantity of the sludge is sent to the landfill.

Secondary treatment at the plant utilizes aeration basins[†], where microorganisms modify pollutants to reduce their impact on the environment. The microorganisms get removed in clarification tanks before the next treatment phase. As they settle to the bottom of the

[†] The aeration basins are tanks injected with oxygen to stimulate the growth of microorganisms and their consumption of dissolved wastes.

clarifiers, they are returned to the aeration basins to re-supply the self-sustaining population of microorganisms. For tertiary treatment, water flows through a four-foot bed of coal. This small, black, granular coal acts as a filter to trap fine suspended solids and some potential pathogens, or disease causing organisms. Finally, ultraviolet light (UV) removes bacteria and viruses by destroying their DNA, the genetic material needed to reproduce. The reclaimed water then leaves the plant, and is utilized for many reuse purposes.

### 4.3 Total Flow

The average quantity of plant influent received by the Laguna WWTP for the six year period from 2000 to 2005 is 21 MGD. The influent quantity is significantly high during the winter months due to infiltration of water from winter storms (Figure 4-2).

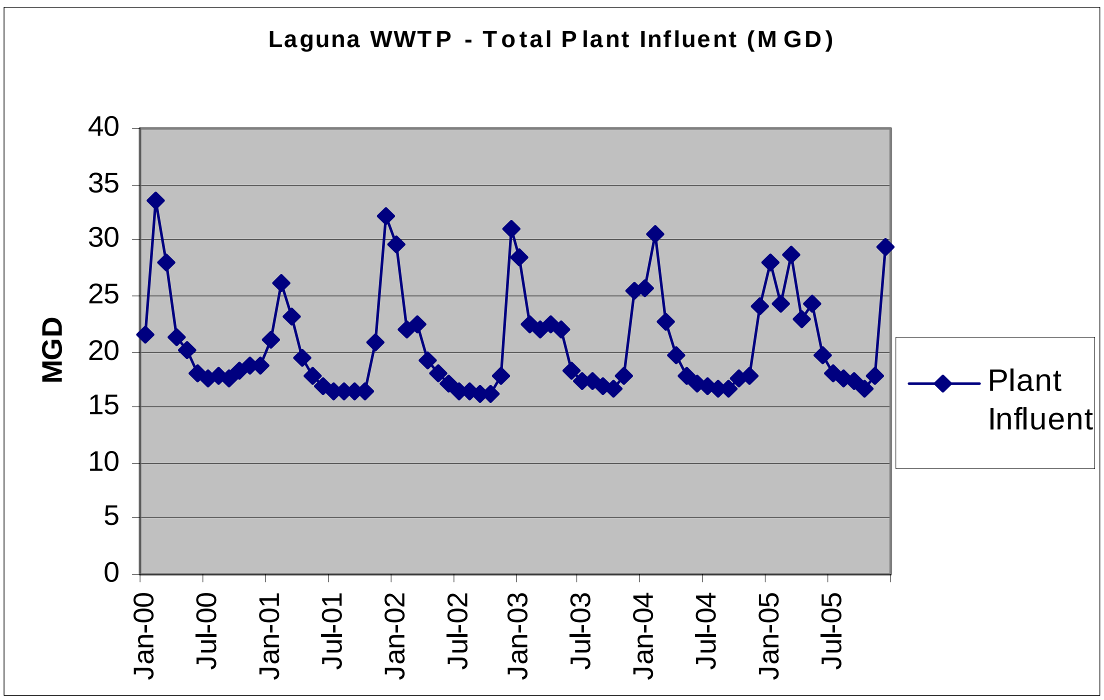


Figure 4-2. Total Plant Influent Received at Laguna WWTP (MGD)

Figure 4-3, illustrates the monthly flow at the plant in terms of millions of gallons per month. The total quantity of influent treated per month ranged from 494 MG in September 2001 to 997 MG in December 2001. The average volume of the influent received during this period is 629 MG per month. Further details can be found in Appendix C-I-c.

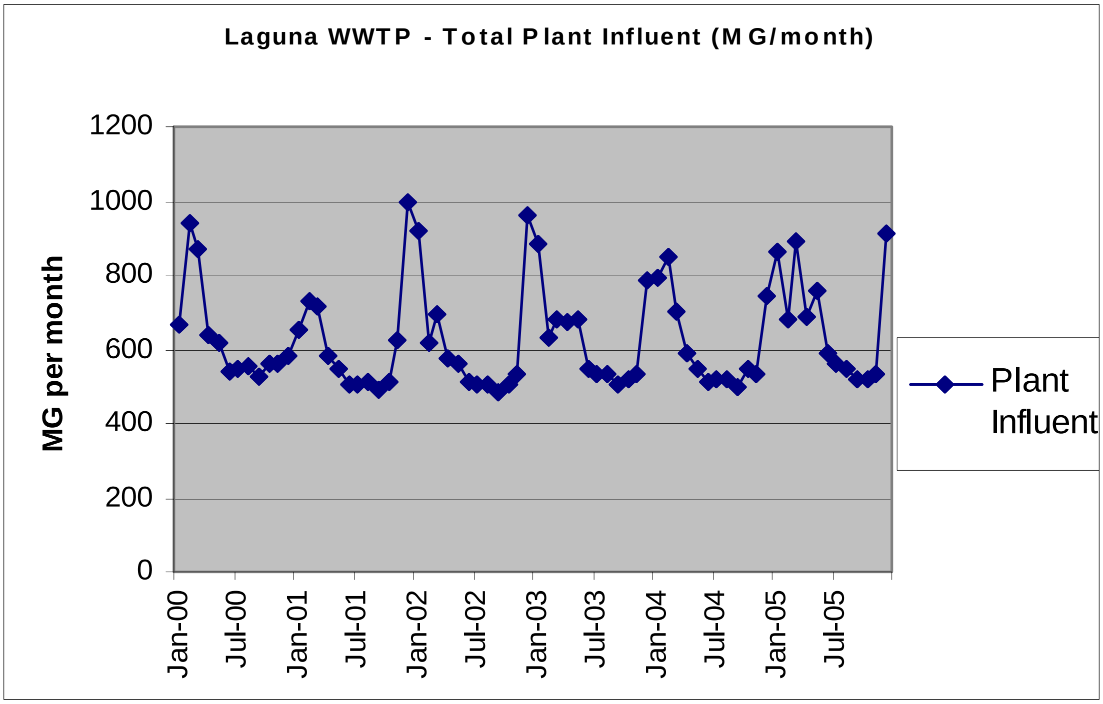


Figure 4-3. Total Plant Influent Received at Laguna WWTP (MG/month)

## 4.4 Electricity Utilization

The electricity utilization for the Laguna Wastewater treatment plant includes the electricity used for operation of treatment plant and administrative buildings. Additionally it also includes part of the electricity consumed for pumping stations used for recycling and geysers recharge systems. The average electricity consumption for the Laguna WWTP for the period of six years is 2,848,891 kWh per month. Electricity imported from the grid contributes around 60% of the total electricity consumption. The remaining 40% is generated at the co-generation facility at the plant which uses methane gas produced from anaerobic digestion at the plant for generating electricity. This reduces the burden of electricity from the grid significantly. Figure 4-4, presents the total electricity consumption and Figure 4-5 shows the electricity segregated into electricity from the grid and electricity from the co-generators.

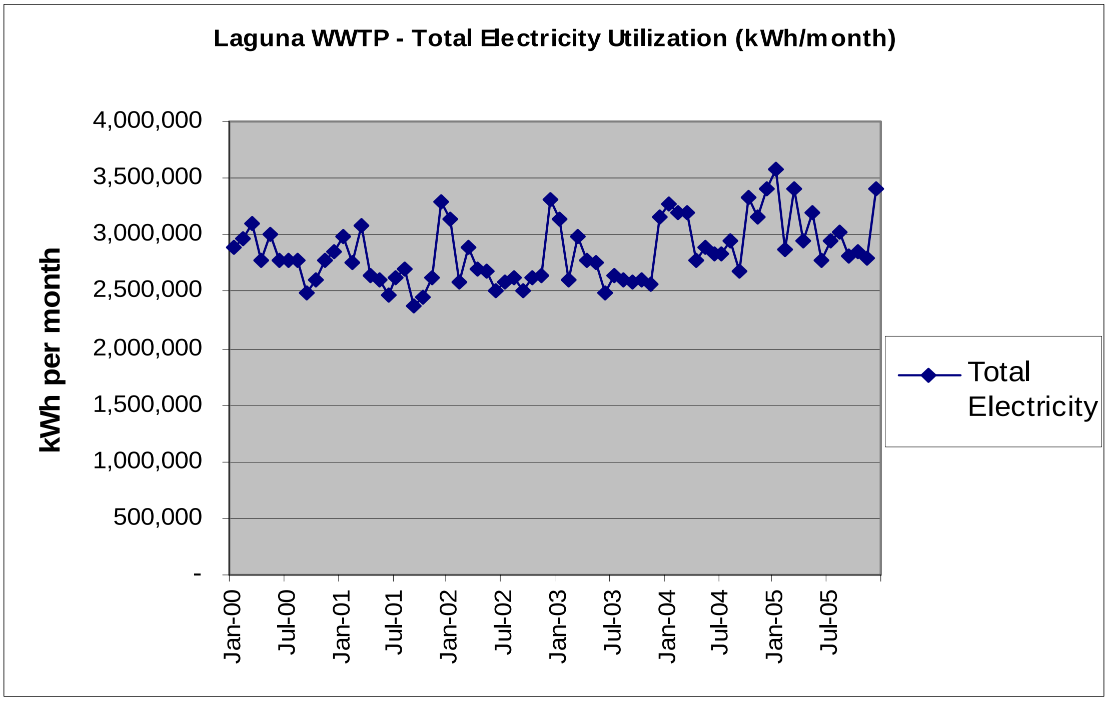


Figure 4-4. Electricity Utilization for Operation of Laguna WWTP (kWh/month)

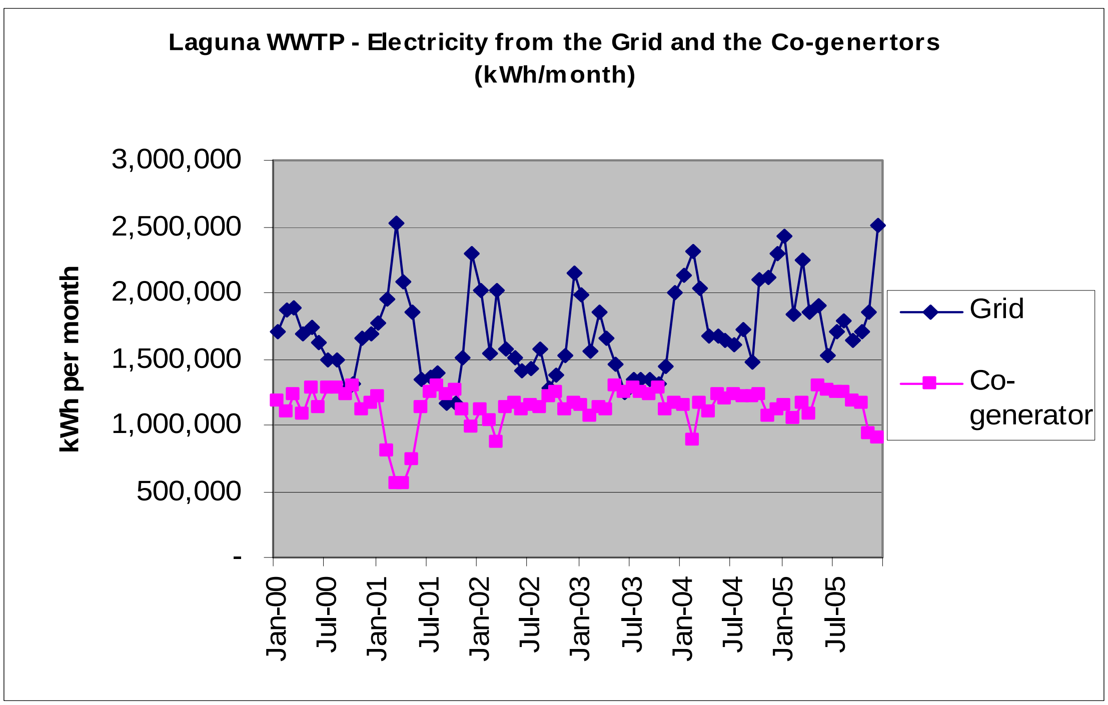


Figure 4-5. Electricity Supplied from the Grid and Co-generators at the Plant for Operation of Laguna WWTP (kWh/month)

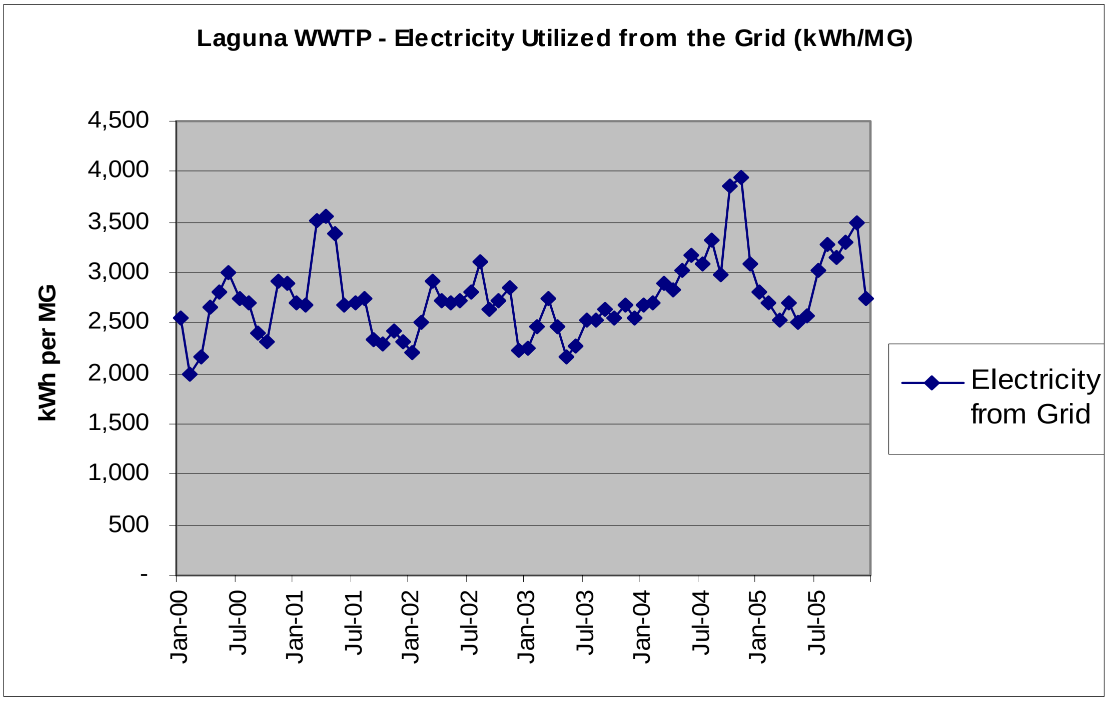


Figure 4-6. Electricity Utilized from the Grid for Operation of Laguna WWTP (kWh/MG)

The calculations for total life-cycle energy and impacts were based on the actual electricity consumption from the grid as opposed to the total requirement for operating the plant. The average consumption of electricity from the grid for the six year period is 1,724,506 kWh per month. The average electricity obtained from the grid for operation of the Laguna WWTP is 2773 kWh/MG wastewater treated at the plant. Further data, calculations and results relevant to electricity consumption at the plant are located in Appendix C-II-a.

## 4.4 Natural Gas Utilization

The natural gas utilized for the purpose of heating at the plant is produced at the plant's cogeneration facility using the gas discharged upon anaerobic digestion of the sludge. The natural gas use at the Laguna WWTP ranges from 45 CCF/month to 2,890 CCF/month. The average consumption for the six year period is 2,170 CCF/month. Figure 4-7 shows the consumption of natural gas in terms of CCF/month. The average consumption of natural gas per million gallons of wastewater treated at the plant is 4

CCF/MG. Figure 4-8 presents the consumption of natural gas per million gallons of wastewater treated. Further details are included in Appendix C-I (e).

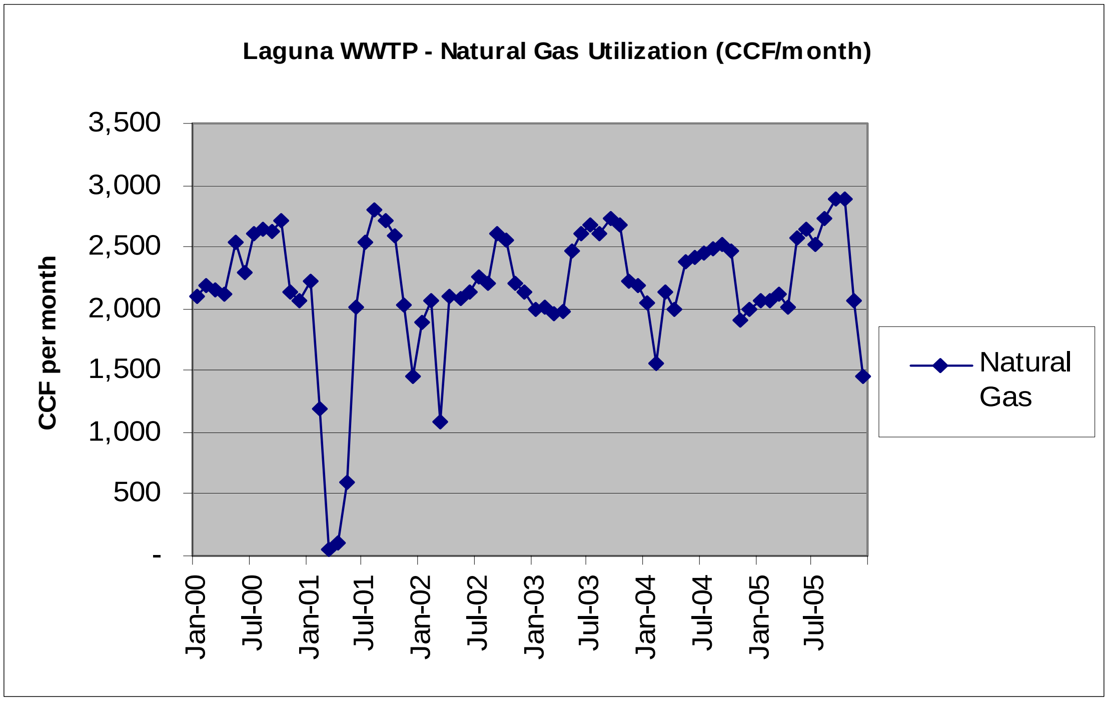


Figure 4-7. Natural Gas Utilization at the Laguna WWTP (CCF/month)

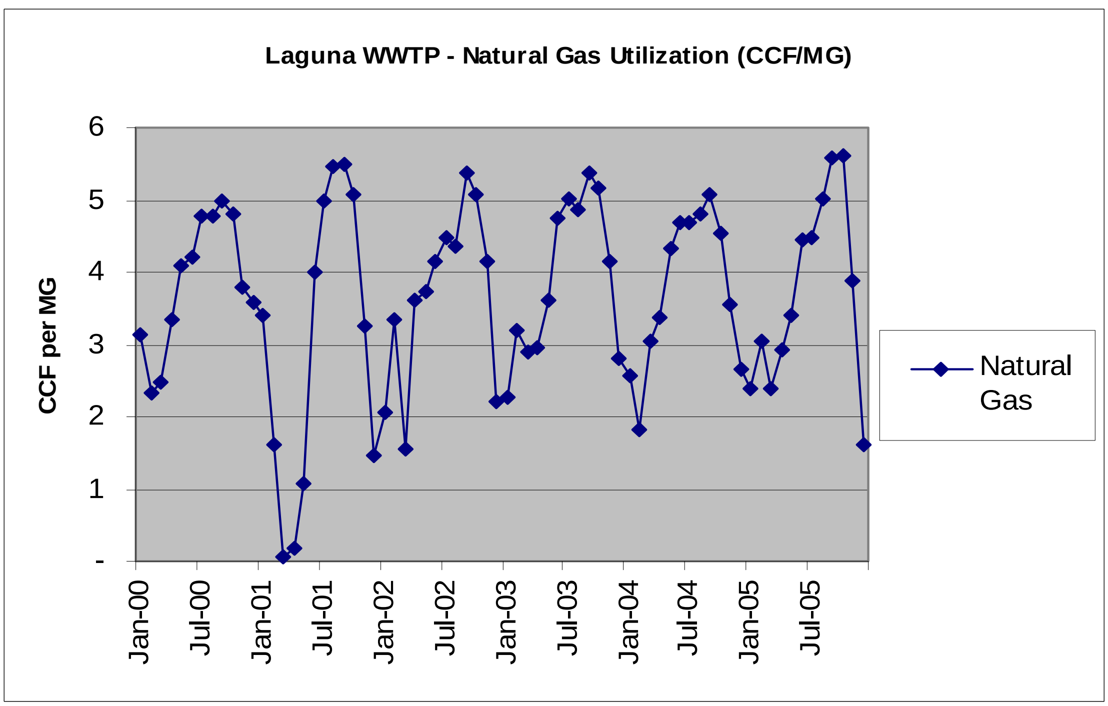


Figure 4-8. Natural Gas Utilization at the Laguna WWTP (CCF/MG)

## 4.5 Chemicals Utilized for Treatment

The Laguna WWTP utilizes ferric chloride, aluminum sulfate (alum) and sodium hypochlorite for treatment. The quantities of ferric chloride and alum were reported in metric tons per month, whereas the quantity of the hypochlorite used was reported as the total volume in gallons per year. Hence, Figure 4-9 that shows the consumption of chemicals per month, comprises of only ferric chloride and alum.

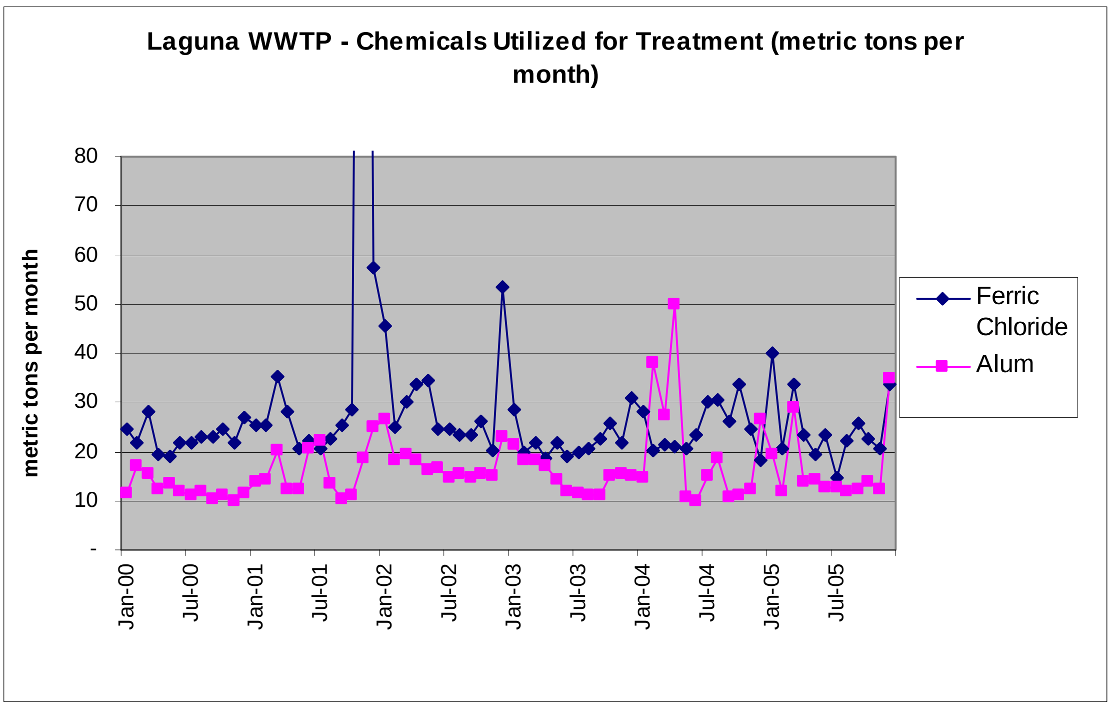


Figure 4-9. Chemicals Utilized for Treatment at the Laguna WWTP (metric tons/month)

The average consumption of ferric chloride for the six year period is 30 metric tons per month. Consumption of ferric chloride for the plant ranges from 15 metric tons/month to 352 metric tons/month. The consumption in November 2001 was exceptionally high. The consumption of alum on the other hand was significantly high in April 2004. The average consumption of alum for the six-year period is 16 metric tons/month, ranging from 10 metric tons/month to 50 metric tons/month.

The energy calculation for production of chemicals includes the average monthly consumption calculated from the annual consumption figures of hypochlorite in addition to the monthly consumption of ferric chloride and alum. Figure 4-10, shows the total energy required for production these chemicals per month.

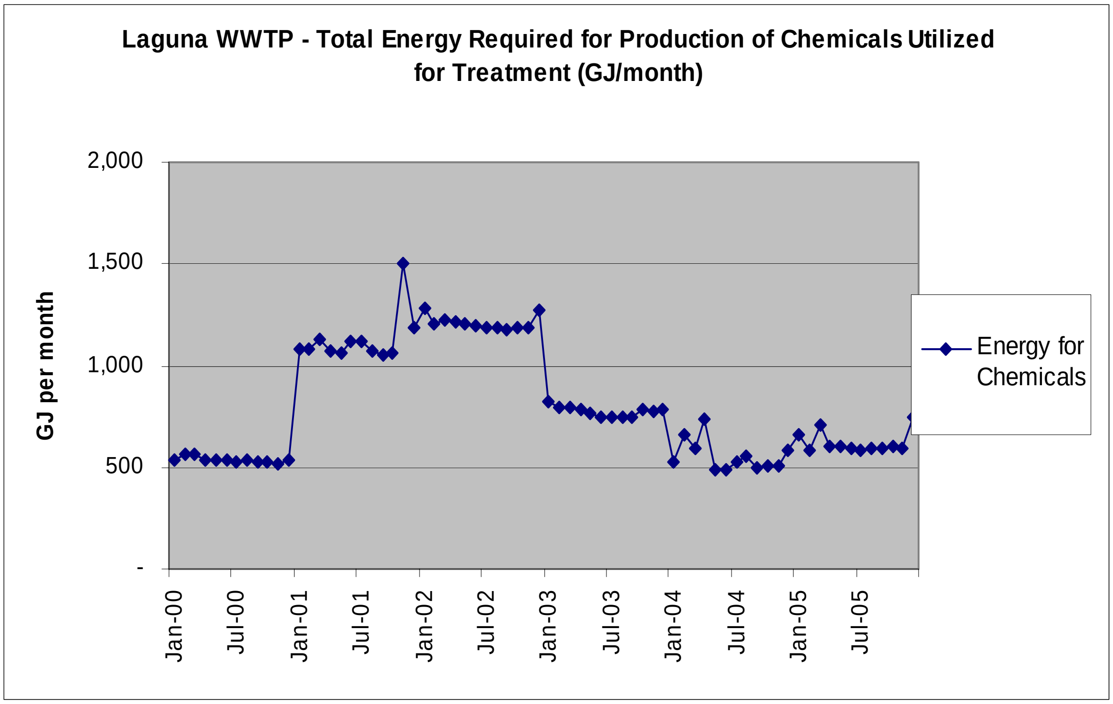


Figure 4-10. Total Energy Required for Production of Chemicals Utilized for Treatment at the Laguna WWTP (GJ/month)

The average energy required for production of all the three chemicals utilized for treatment at the plant is 805 GJ per month. Further details of the calculations involved are attached in Appendix C-I-f.

## 4.6 Sludge Disposal

The sludge generated at the Laguna WWTP is either disposed at the landfill or land application sites or it is composted very near to the plant. The energy required for sludge hauling was therefore calculated based on the total quantity of sludge transported to the landfill or the land application sites. Further, the energy consumption was calculated only for the year 2005 since the required information was unavailable for all previous years.

Table 4-1 Energy Consumption for Sludge Hauling from Laguna WWTP

| Date | Total Sludge | Land application I | | Land application II | | Landfill | | Total Hauled | Diesel Fuel Consumed | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Wt. | Dist. | Wt. | Dist. | Wt. | Dist. | | | | |
| Month/ Year | metric tons | metric tons | Miles | metric tons | Miles | Metric tons | Miles | metric ton-miles | Gallons | GJ | GJ/ MG |
| Year 2005 | 25,398 | 6898 | 18 | 5693 | 5 | 6300 | 7 | 196,729 | 5213 | 869 | 0.11 |

Table 4-1, summarizes the energy consumption for sludge hauling at the Laguna WWTP. Around 25% of the sludge produced upon treatment is composted; the energy estimate for composting is not included in this analysis. The diesel fuel consumption was calculated based on the total distance to the disposal sites and the total wet weight of the sludge transported for disposal (Section 1.5.4). The energy calculated in terms of gallons of diesel fuel is converted to GJ for calculation of the total life-cycle energy.

### 4.7 Life-cycle Energy for Operation of the Laguna WWTP

The life-cycle energy required for operation of the Laguna WWTP is computed for a single year due to lack of data on sludge hauling for rest of the years. The total life-cycle energy for operation of the plant for the year 2005 is 91,068 GJ.

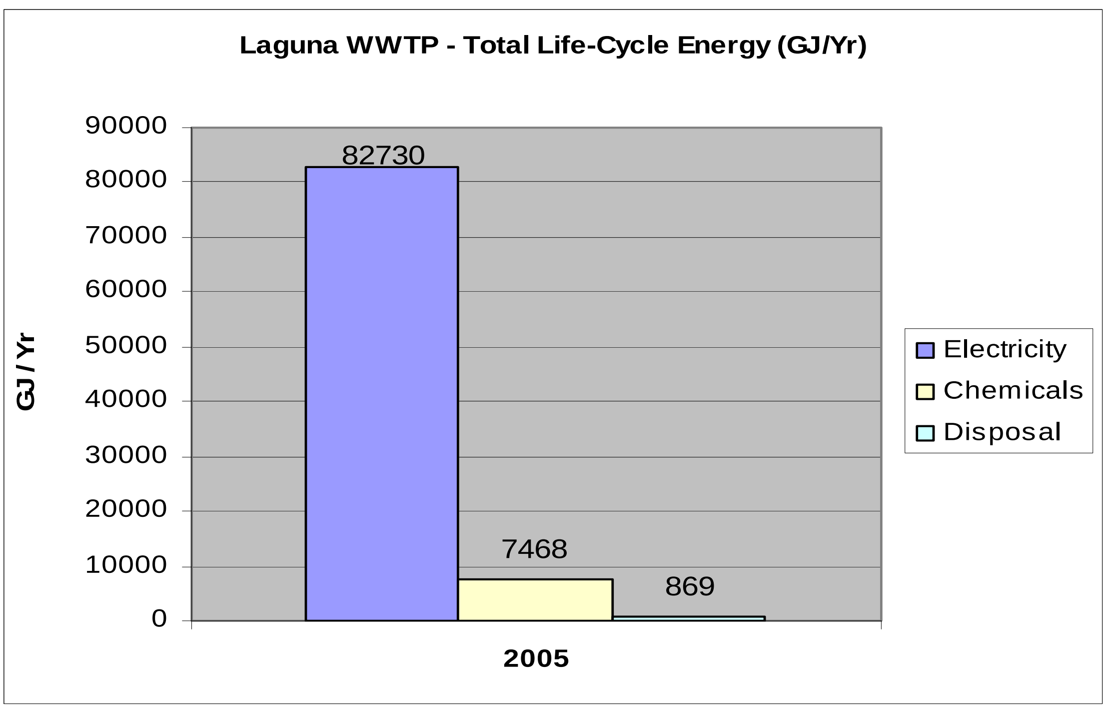


Figure 4-11. Total Life-cycle Energy for operation of Laguna WWTP (GJ/Yr)

The total energy consumed does not include natural gas utilization at the plant, since it is produced through co-generation. Electricity imported from the grid accounts for 91% of the total life-cycle energy for operating the Laguna WWTP for the year 2005. Energy required for producing chemicals utilized for treatment and sludge hauling accounts for mere 8% and 1% of the total Life-cycle energy respectively.

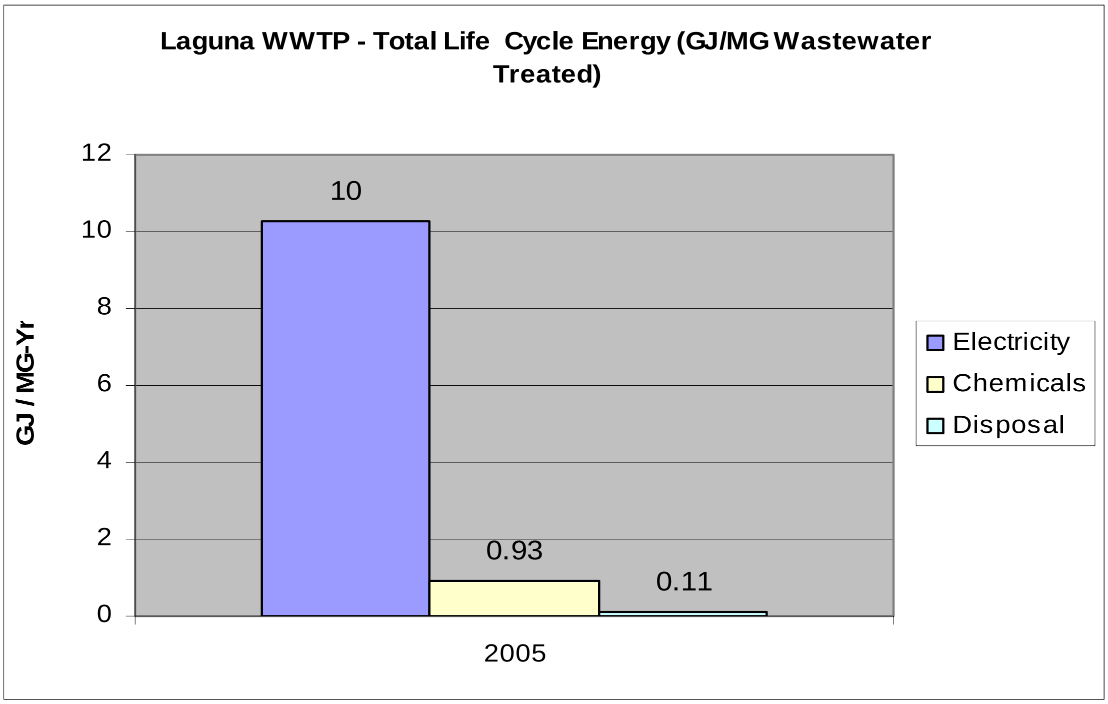


Figure 4-12. Total Life-cycle Energy for Operation of the Laguna WWTP (GJ/MG)

The life-cycle energy for operation of the plant for 2005 is 11 GJ per million gallons wastewater treated, out of which, electricity required for operation accounts for 10 GJ/MG. Based on the total life-cycle energy figures, the total life-cycle-emissions from operation of the plant were calculated.

## 4.8 Life-Cycle Emissions from Operation of Laguna WWTP

Since the energy consumption figures were complete for only 2005, the emissions analysis was also conducted on the data from 2005. Emissions from electricity generation and sludge hauling for operation of the Laguna WWTP were categorized into Global Warming Potential, Eutrophication Potential and Acidification Potential.

### *i. Global Warming Potential*

The total global warming potential for the plant is 2,171 kg $CO_2$ equivalent per million gallons of wastewater treated over a hundred year time horizon.

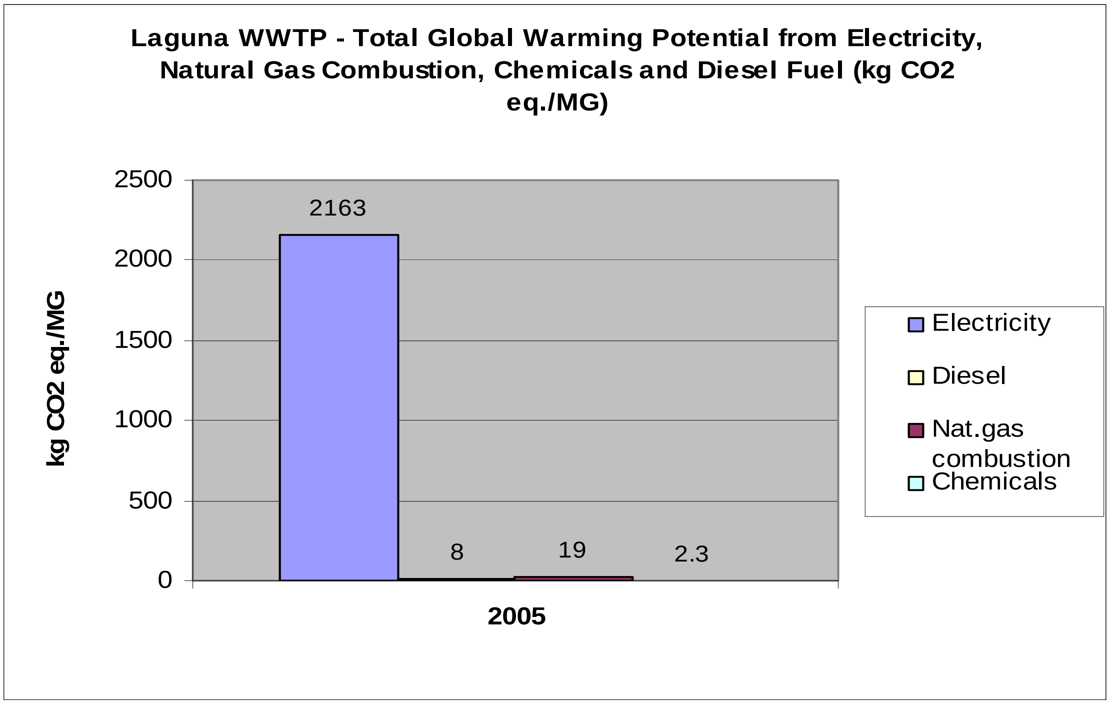


Figure 4-13. Global Warming Potential for Laguna WWTP (kg $CO_2$ eq. /MG)

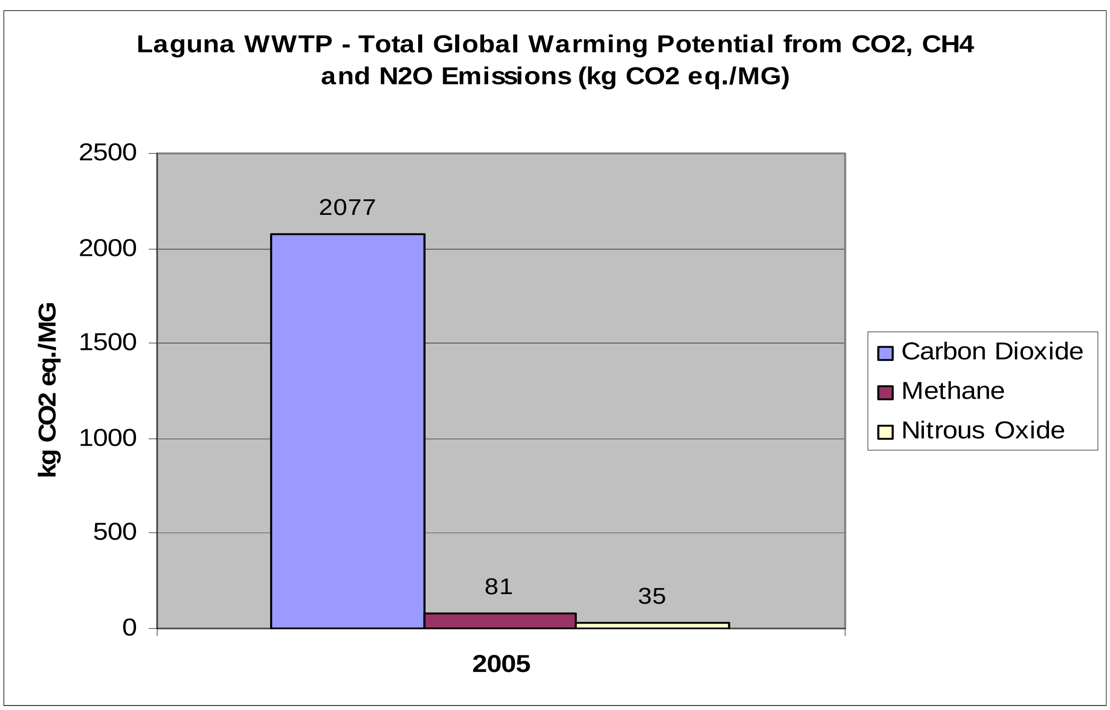


Figure 4-13. Global Warming Potential for Laguna WWTP (kg $CO_2$ eq. /MG)

Emissions from electricity imported from the grid account for 99% of the total global warming potential. Since methane produced upon sludge treatment is utilized for heating as well as electricity generation at the plant, the plant saves on emissions from production of natural gas and 40% of the total electricity required for operation.

### *ii. Eutrophication Potential*

The total atmospheric eutrophication potential for the plant is 204 g N equivalent per million gallons of wastewater treated over a hundred year time horizon. Emissions from electricity imported from the grid account for more than 96% of the total atmospheric eutrophication potential. Diesel fuel consumed for sludge hauling to the disposal sites accounts for 3% and very small quantities of emissions from natural gas combustion and production of chemicals constitute the rest of the atmospheric eutrophication potential. Figure 4-14 shows the g N eq. /MG atmospheric eutrophication potential from electricity, chemicals, natural gas and diesel fuel consumption at the Laguna WWTP.

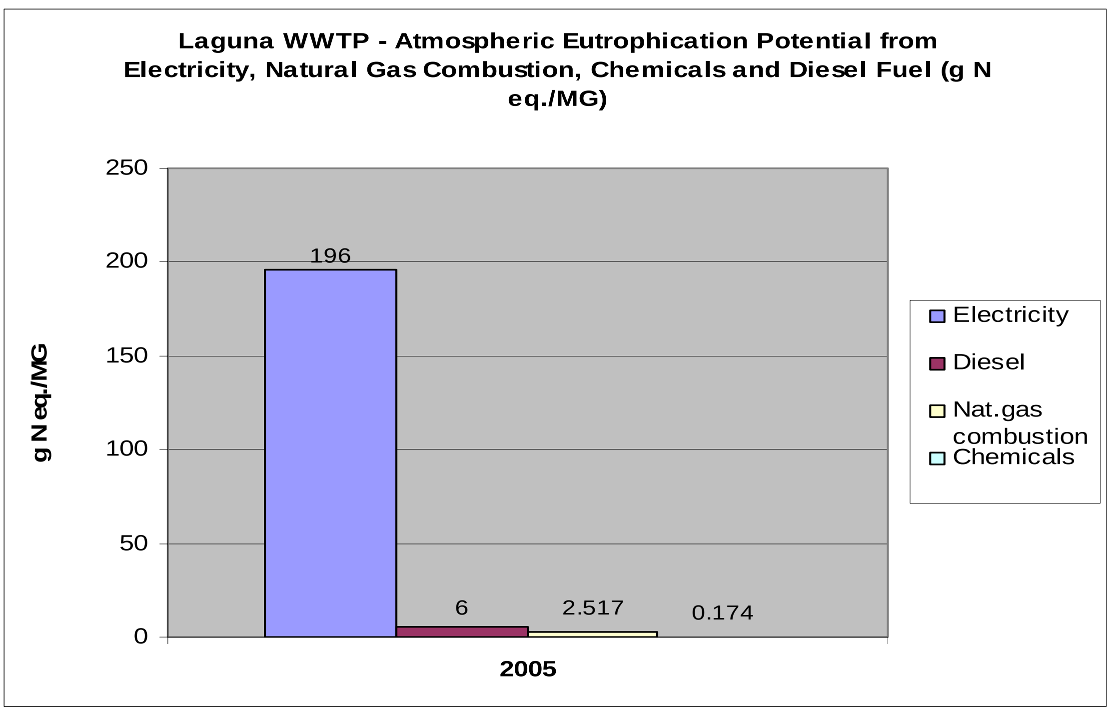


Figure 4-14. Atmospheric Eutrophication Potential from Electricity, Natural Gas Combustion, Chemicals and Diesel fuel Use at the Laguna WWTP (g N eq. /MG)

The details of the calculations made and results obtained upon eutrophication assessment emissions are attached in Appendix C-II-b. Further, Figure 4-15 presents the contribution of emissions in the form of nitrogen oxides and ammonia mainly from electricity consumption at the plant and small amounts from diesel fuel consumption.

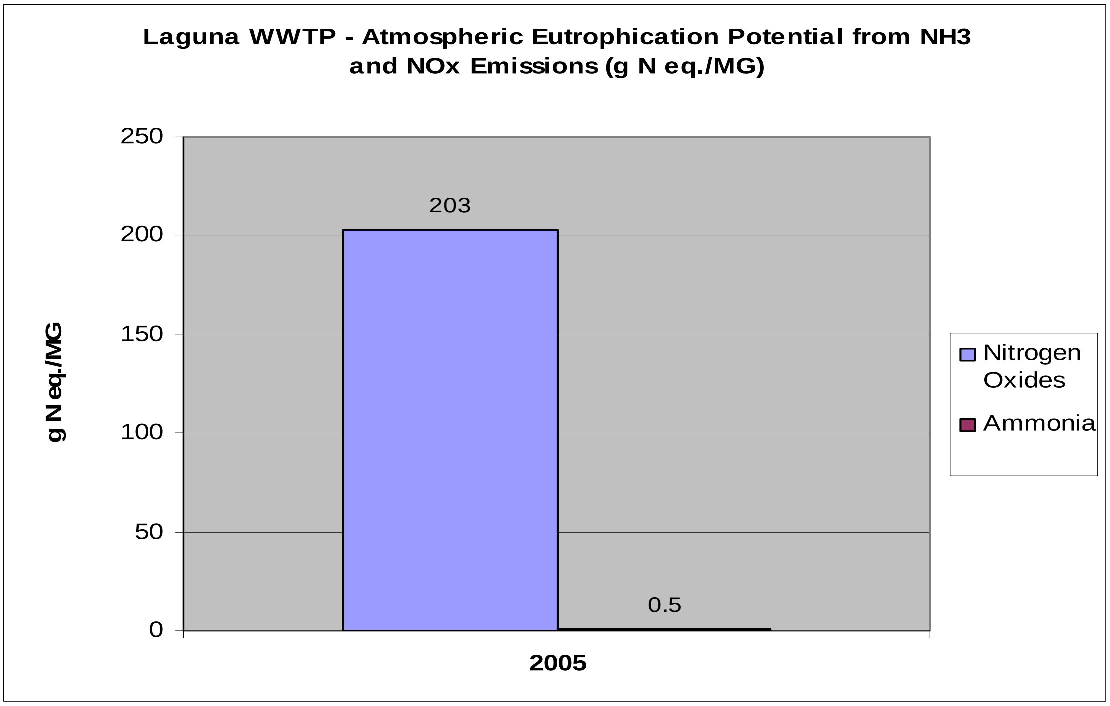


Figure 4-15. Atmospheric Eutrophication Potential from Ammonia and Nitrogen Oxide Emissions at the Laguna WWTP (g N eq. /MG)

The total aquatic eutrophication Potential from the emissions from electricity, natural gas combustion, chemicals and diesel fuel consumption for the year 2005 is far less than the atmospheric eutrophication potential. The aquatic eutrophication calculated based on a 100 year time horizon is 4 g N equivalent per million gallons of treated wastewater at the Laguna WWTP. COD and Ammonia emissions from electricity imported from the grid contribute significantly to the total aquatic eutrophication potential. While, Figure 4-16 presents the total eutrophication potential for 2005 for the plant, the emissions in the form of ammonia, COD, nitrate and phosphates have been shown in Figure 4-17, in terms of total g N equivalent per million gallons of treated wastewater at the Laguna WWTP. Additional information regarding calculations of atmospheric and aquatic eutrophication potentials for operation of the Laguna WWTP is included in Appendix C-II-b.

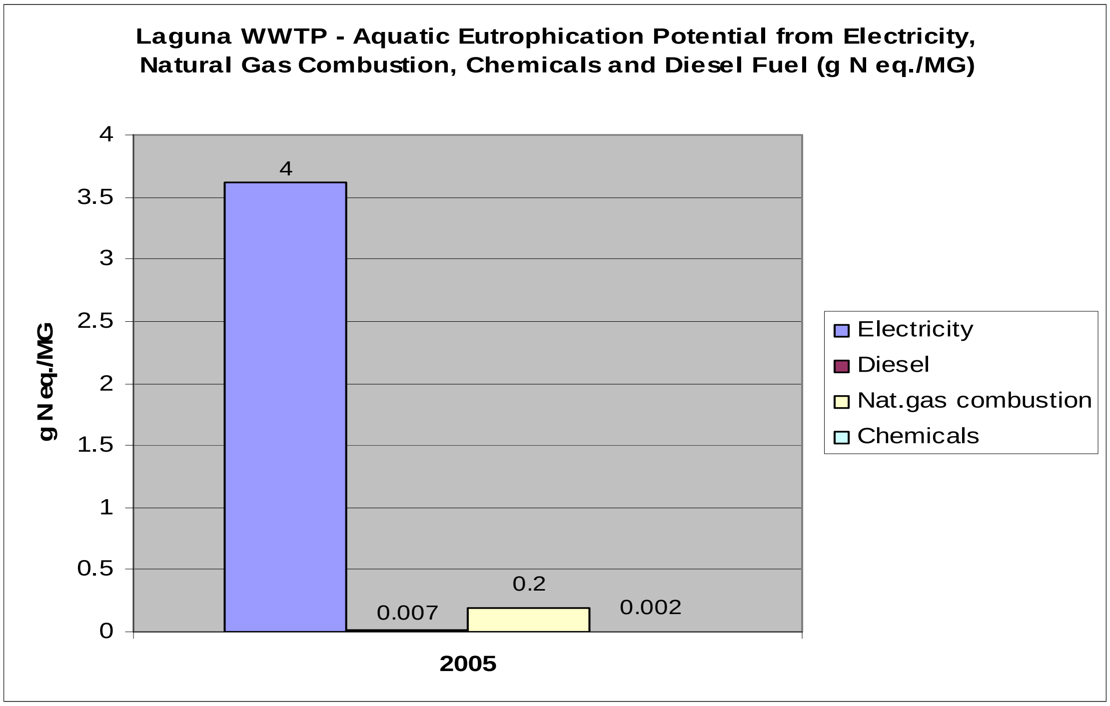


Figure 4-16. Aquatic Eutrophication Potential for Laguna WWTP (g N eq. /MG)

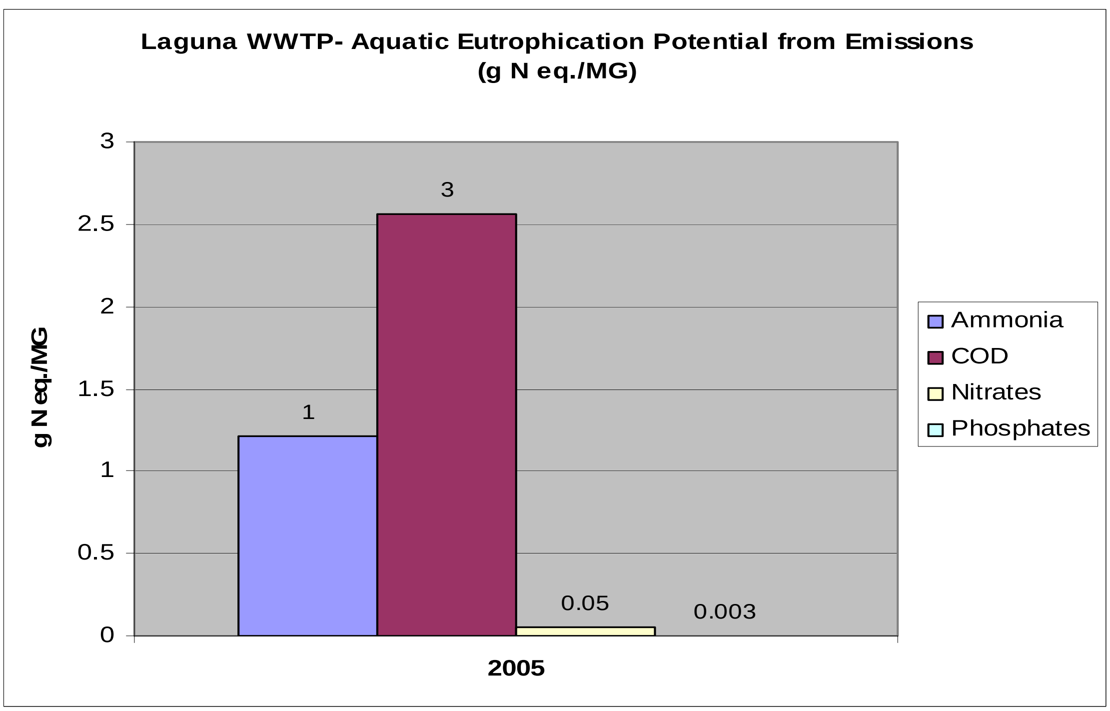


Figure 4-17. Aquatic Eutrophication Potential from Emissions at the Laguna WWTP (g N eq. /MG)

### *iii. Acidification Potential*

The total acidification potential for operating the Laguna WWTP in the year 2005 is 646 kmoles of $H^+$ equivalent per MG of wastewater treated at the plant. Emissions from electricity contribute nearly 99% of the total acidification potential for a 100 year time horizon. Figure 4-18 presents the Acidification Potential results obtained upon analysis of emissions from electricity and diesel fuel in kmoles of $H^+$ equivalent per MG.

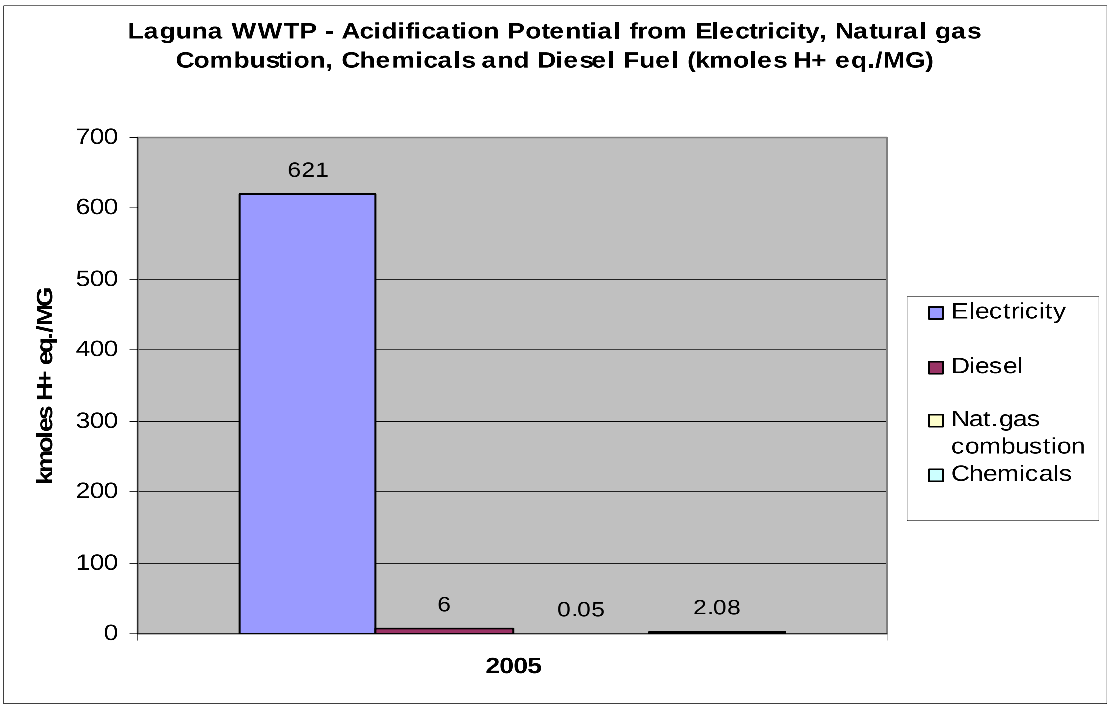


Figure 4-18. Acidification Potential from Electricity, Natural Gas, Chemicals and Diesel Fuel for Laguna WWTP (kmoles of $H^+$ eq. / MG)

The results are also presented in the form of sulfur dioxide, hydrochloric acid, nitrogen oxides and ammonia emissions mainly from electricity consumption but there are very small quantities from diesel fuel consumption as well. Figure 4-19 presents these results in the form of kmoles of $H^+$ equivalent per MG acidification potential from the operation of the Laguna WWTP in the year 2005. High sulfur dioxide emissions due to consumption of electricity from the grid are a major contributing factor to the total acidification potential.

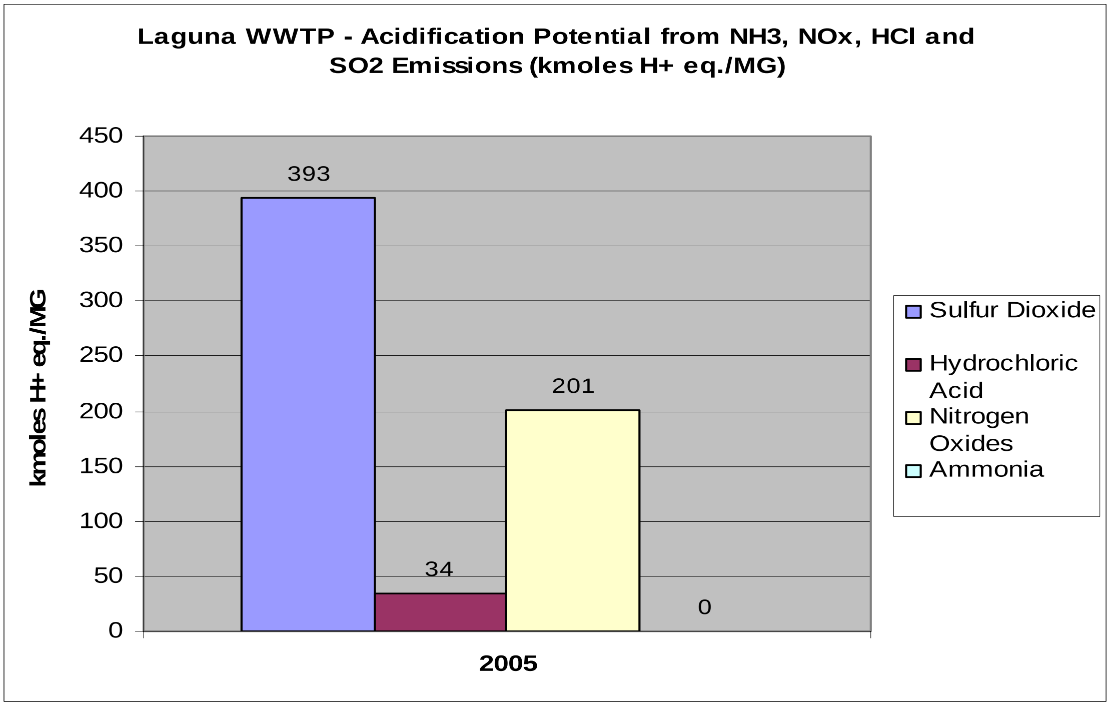


Figure 4-19. Acidification Potential from NH3, NOx, HCl and $SO_2$ Emissions at Laguna WWTP (kmoles of $H^+$ eq. / MG)

Further details of the data, calculations and results pertinent to the total acidification potential from the plant can be found in Appendix C-II-c of this report. Although the total life-cycle energy and emissions for Laguna WWTP are calculated based on data from a single year, the results obtained are fairy indicative of the contribution of various energy sources used for operating the plant to the total environmental burden from the plant. The results from this chapter will be discussed further in Chapter 5 which compares the performance and environmental burdens from three wastewater treatment plants in the US.

# Chapter 5

## Comparative Assessment for Ann Arbor, YCUA and Laguna Wastewater Treatment Plants

### 5.1 Background

The detailed background information and analyses for Ann Arbor Wastewater Treatment Plant and Laguna Wastewater Treatment Plant have already been explained in this report (Chapter 3 and Chapter 4). Another important case-study in Michigan conducted by the Center for Sustainable Systems for the study 'Preliminary Application of Life-cycle Assessment to US Water and Wastewater Treatment Facilities' (Deslauriers et al)[26] is the Ypsilanti Community Utilities Authority (YCUA) WWTP. Although the information about this plant is included in the report by Deslauriers et al, the data was updated and new results were generated to enable a comparison with the Ann Arbor and Laguna WWTPs. The background information for this plant is attached in Appendix D-I. The reason for including this case-study in this research is that YCUA WWTP is also a tertiary treatment plant with a plant capacity similar to the other two case-studies discussed in this report. Since there are certain dissimilarities in operation of each of these plants, it is interesting to discuss how these dissimilarities impact the total energy and environmental performance of a plant compared to the other two.

### 5.2 Total Flow

The average total flow recorded for the four year period from 2001 to 2004 at the Ann Arbor WWTP is 569 MG per month. During the same period Laguna WWTP received 618 MG per month on an average. The plant influent received at YCUA WWTP is the highest- 666 MG per month. Total influent for Ann Arbor and YCUA is generally low for the winter months and fluctuates a little during the year, but the difference in the influent treated during summer months and winter months is not exceptionally high. On the other hand, for Laguna WWTP the total influent is significantly high every year from December to March, i.e., the winter months. The increase in plant flow during the winter months reflects winter storms, which cause the groundwater to rise, which then makes its way into the sewer system through cracks.

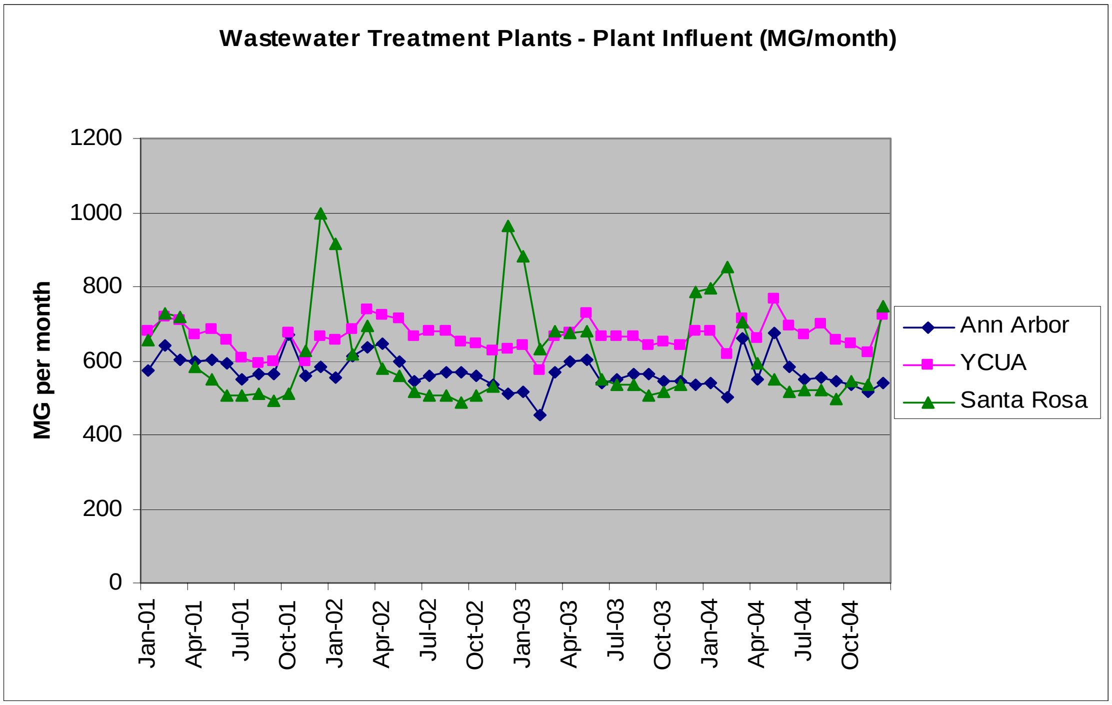


Figure 5-1. Total Plant Influent for Ann Arbor, Laguna and YCUA Wastewater Treatment Plants (MG/month)

The total plant influent treated at the plant is crucial for all further comparisons made in this report for energy consumption and emissions, since the functional unit for comparison is 'per million gallons wastewater treated'.

## 5.2 Electricity Utilization

The electricity consumption for YCUA WWTP is the highest of the three plants studied. The average electricity consumption per month is for YCUA for four years from 2001 to 2004 was 1,974,250 kWh per month. The average electricity consumption for the Laguna WWTP, only slightly less for the same period, equaled 1,691,044 kWh per month. It is to be noted that the actual electricity requirement for Laguna WWTP is much more, since nearly 40% of the electricity required for its operation comes from co-generators working on methane generated upon treatment of sewage at the plant.  The Ann Arbor WWTP utilizes much less electrical energy; the average electricity consumption for the plant is only 1,227,556 kWh per month.

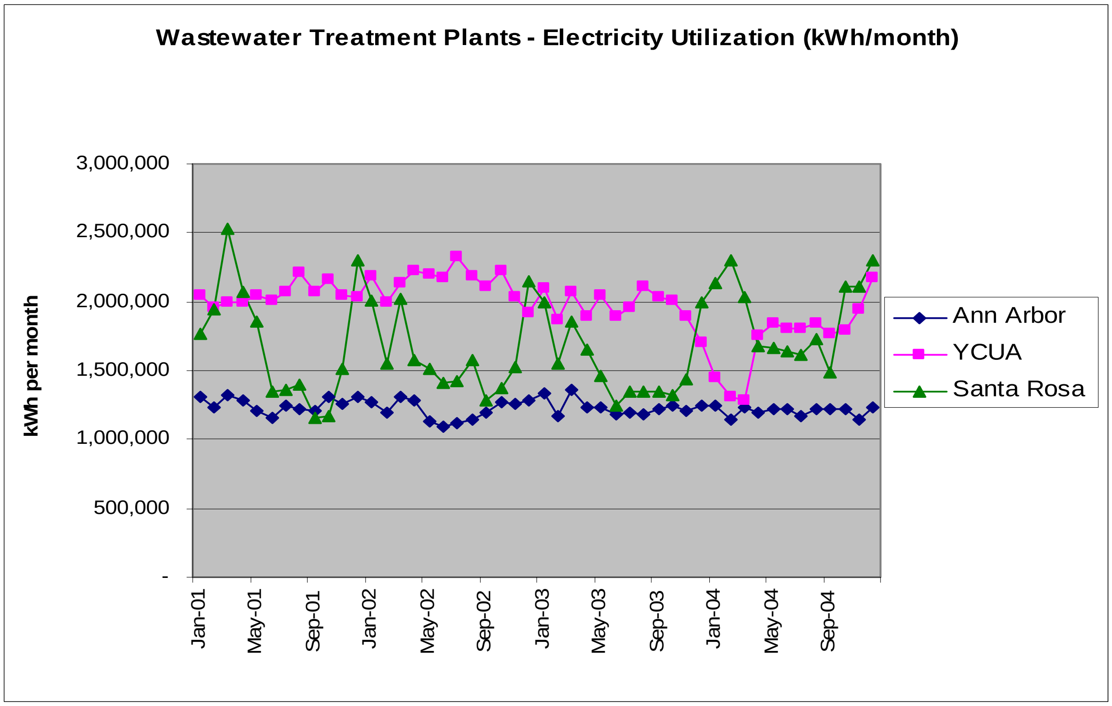


Figure 5-2. Electricity Utilization for Operation of Ann Arbor, YCUA and Laguna WWTP (kWh/month)

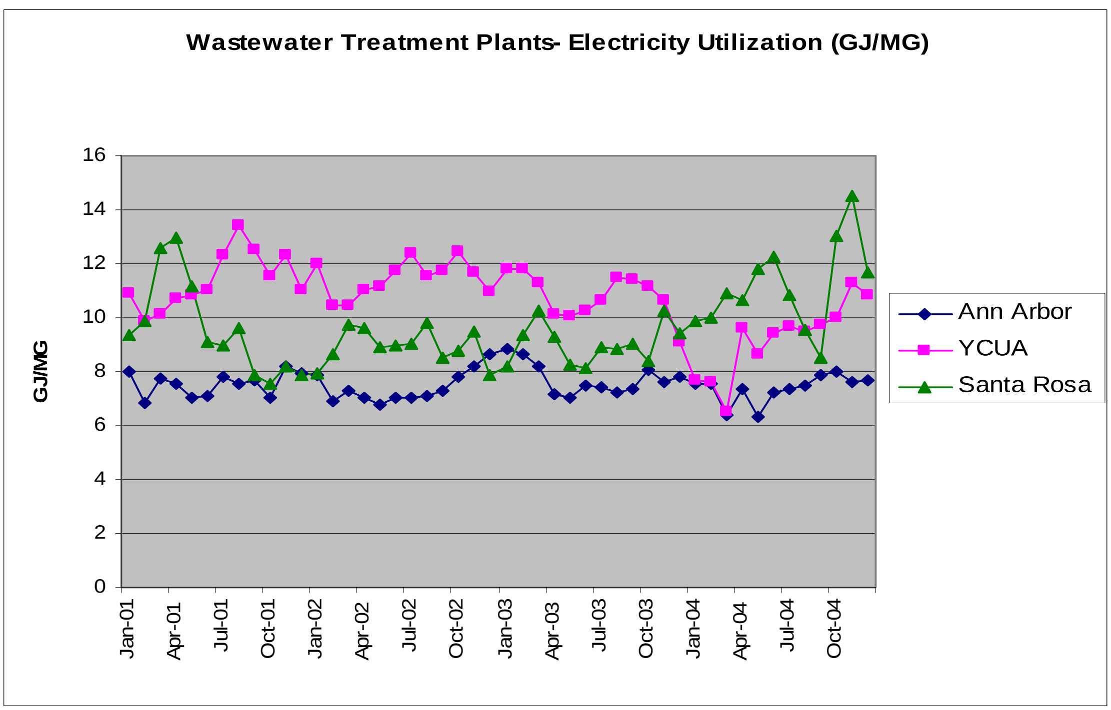


Figure 5-3. Electricity Utilization for Operation of Ann Arbor, YCUA and Laguna WWTP (GJ/MG)

Figure 5-2, shows the electricity consumption for each plant in terms of kWh utilized per month for four years. Since the life-cycle energy consumption is expressed in terms of Giga Joules per month in this report and the functional unit is per million gallons of wastewater treated at the plant, the electricity consumption for each facility is converted to GJ/MG. These results are presented in Figure 5-3 above. Although the total monthly electricity consumption is higher for YCUA WWTP when compared with the Ann Arbor WWTP, YCUA WWTP is actually more efficient in terms of electricity consumption since the total quantity of influent treated at the plant is more than that at the Ann Arbor WWTP. At Laguna WWTP, the total electricity imported from the grid also supports pumping stations for recycling and geysers recharge systems, hence the electricity utilized at the plant is highest of the three WWTPs. However, Laguna WWTP utilizes methane produced at the plant for generating 40% of the electricity required for plant operation, reducing the burden from the grid considerably.

### 5.3 Natural Gas Utilization

Natural gas use is also the highest for YCUA WWTP since the plant uses incinerator for sludge disposal which requires much more natural gas than the amount required for heating at Ann Arbor WWTP and Laguna WWTP. The average monthly consumption of natural gas for YCUA WWTP for 2001 to 2004 is 56,087 CCF per month. On an average Ann Arbor WWTP consumes 17,451 CCF per month and the average consumption for Laguna is 2,086 CCF per month for the same period. Since the natural gas consumption reported in this section is solely for the purpose of heating for Ann Arbor and Laguna WWTPs as opposed to natural gas consumption for incineration at YCUA, there is an obvious difference between the quantities consumed. Further, the quantity required for heating at Laguna WWTP is much less than that required at Ann Arbor WWTP due to a significant difference in the weather in Ann Arbor, Michigan and Santa Rosa California.

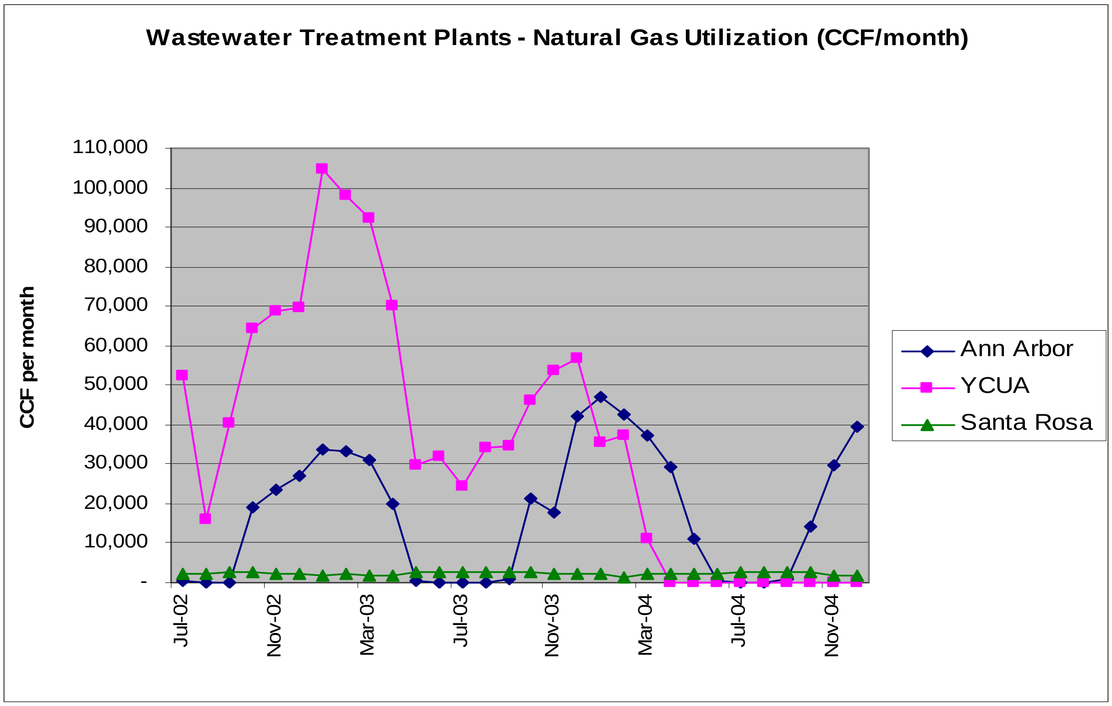


Figure 5-4. Natural Gas Utilization at Ann Arbor, YCUA and Laguna WWTP (CCF/month)

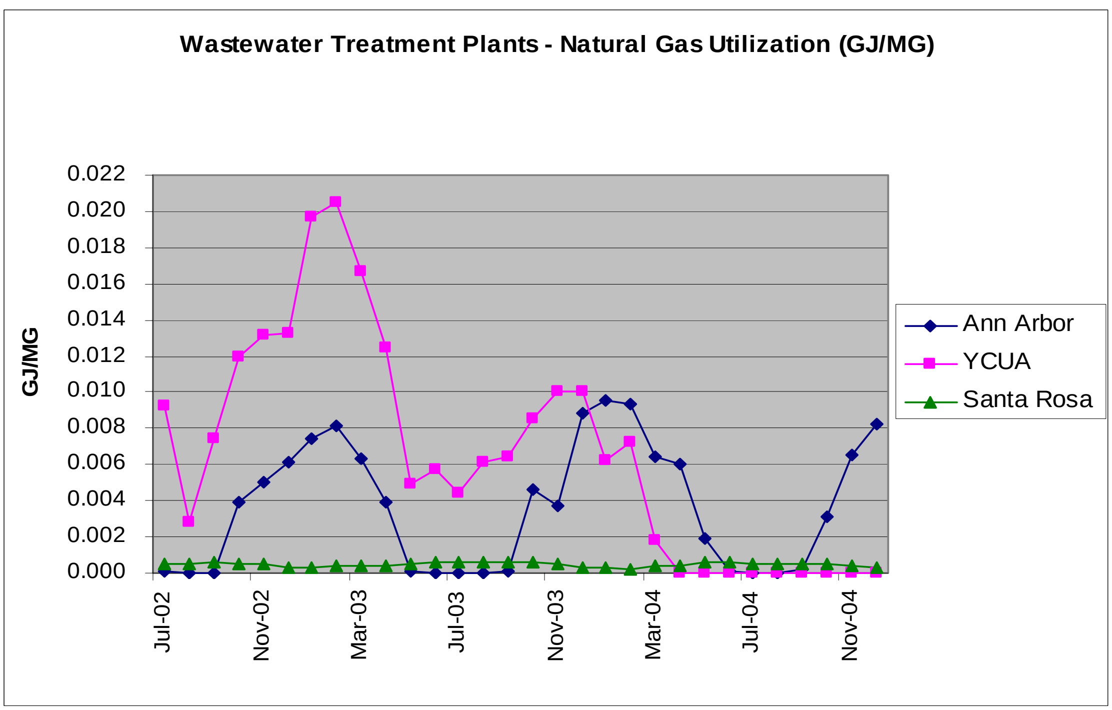


Figure 5-5. Natural Gas Utilization at Ann Arbor, YCUA and Laguna WWTP (GJ/MG)

Interestingly, even though the natural gas requirement for heating at the plant is low for Laguna WWTP, the required quantity is produced at its co-generation facility using the gas produced after activated sludge treatment. This becomes a major factor responsible for lower environmental emissions from operation of the Laguna WWTP, discussed later in this chapter. Figure 5-4 shows the consumption of natural gas at the three WWTPs from July 2002 to December 2004.

The old incinerator at the YCUA WWTP was replaced in 2004; as a result, the sludge had to be disposed completely at the landfill. This reduces the natural gas consumption for the remaining part of the year drastically. Since the details of the presently used incinerator are not included in this report, it cannot be stated whether the natural gas and electricity requirement of the plant is reduced since then. The natural gas use for each plant was converted to GJ per million gallons wastewater (Figure 5-5) treated at the plant to contribute to total life-cycle energy consumption for operating each facility, discussed later in this chapter.

## 5.4 Energy Required for Production of Chemicals Utilized

Different chemicals are utilized at the Ann Arbor, YCUA and Laguna WWTPs for treatment of wastewater at different stages. The Ann Arbor WWTP uses only ferric chloride and lime for treatment. YCUA WWTP utilized chlorine, ferric chloride, ferrous chloride, lime, and a polymer for treatment during 2001 to 2004. The Laguna WWTP uses only ferric chloride, alum and hypochlorite.

Since the number of chemicals used and respective quantities are high for YCUA WWTP (Appendix D), the energy associated with production of chemicals utilized per month for treatment is also the highest for YCUA WWTP. The average energy consumption associated with chemicals utilized at YCUA WWTP is 1,236 GJ per month; 790 GJ per month for Ann Arbor WWTP; and 917 GJ per month for Laguna WWTP

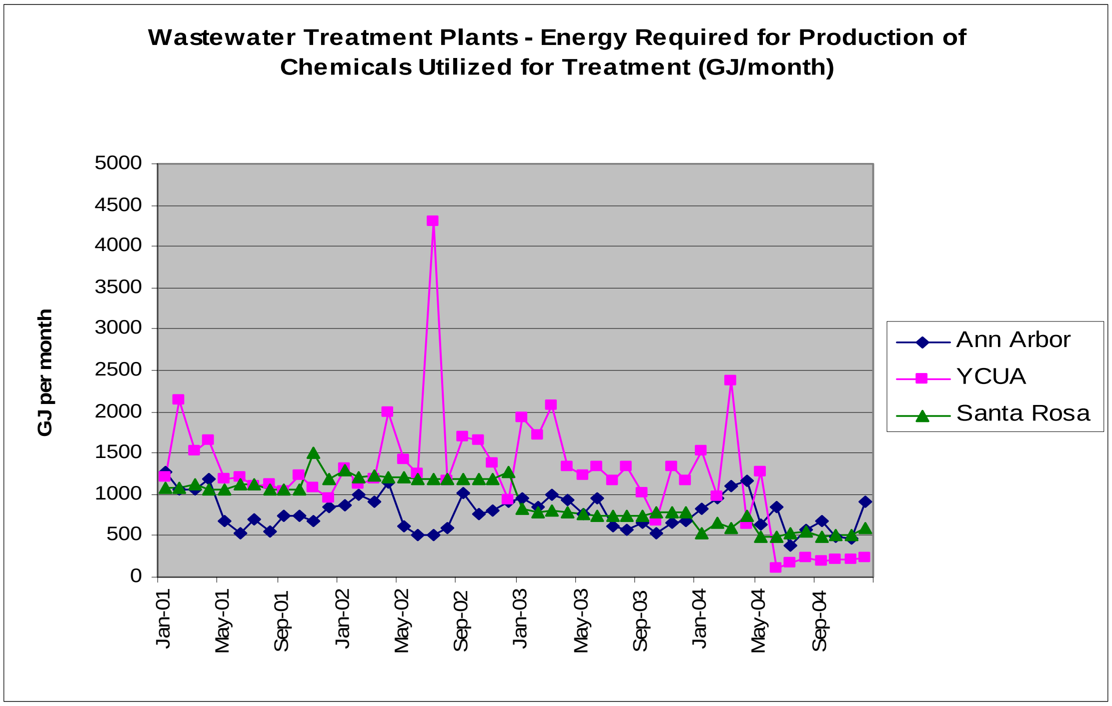


Figure 5-6. Energy Required for Production of Chemicals Utilized at Ann Arbor, YCUA and Laguna WWTPs (GJ/month)

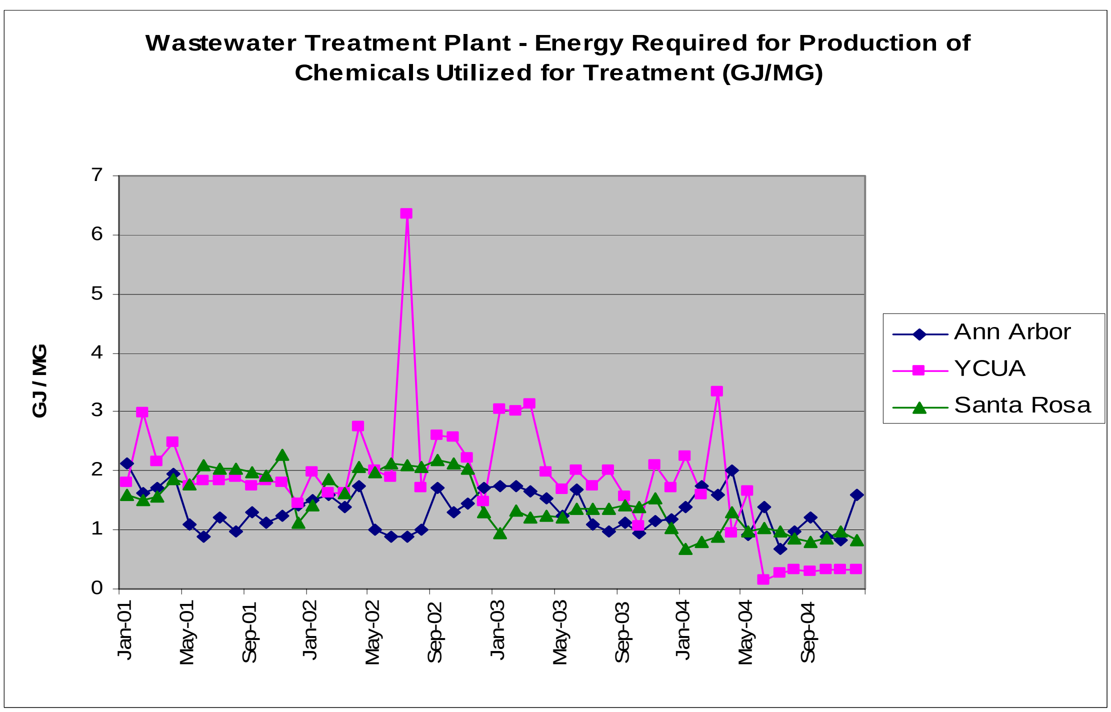


Figure 5-7. Energy Required for Production of Chemicals Utilized at Ann Arbor, YCUA and Laguna WWTPs (GJ/MG)

The average energy required for production of chemicals utilized for treatment at YCUA WWTP is over 2 GJ/MG. The energy consumption for production of chemicals used for treatment at the Ann Arbor WWTP and Laguna WWTP is a little over 1 GJ/MG. These figures are incorporated in the calculations for total life-cycle energy for operation of the three treatment plants.

### 5.4 Energy Required for Sludge Disposal

The YCUA WWTP employed incineration and landfill for disposing sludge produced after treatment. The Ann Arbor WWTP does not use incinerator and disposes all the sludge at land-application sites or landfills. The Laguna WWTP on the other hand employs composting in addition to disposal at landfill and land-application sites. However, the quantity of sludge produced and the method of disposal for Laguna WWTP was unavailable for 2001 to 2004, hence this section compares the pros and cons of the methods of disposal adopted at Ann Arbor and YCUA WWTPs for the years 2001 to 2004 and there a discussion on the energy consumption for sludge disposal at Laguna WWTP and Ann Arbor WWTP during the year 2005.

Table 5-1 Sludge Disposal for YCUA WWTP for 2001 to 2004

| Year | Total Sludge | Incineration | | | Landfill | | | | Total Energy |
|---|---|---|---|---|---|---|---|---|---|
| | Wet | Sludge | Ash | Natural Gas | Sludge | Sludge and Ash | | Diesel fuel | Natural gas, Diesel fuel |
| | Metric tons | Metric tons | Metric tons | GJ | Metric tons | Metric tons | metric ton-miles | GJ | GJ |
| 2001 | 30,377 | 25,036 | 5,829 | 84,779 | 5,341 | 11,169 | 207,957 | 919 | 85,698 |
| 2002 | 27,459 | 20,081 | 8,037 | 89,982 | 6,840 | 14,876 | 284,363 | 1,256 | 91,238 |
| 2003 | 33,063 | 24,684 | 6,020 | 82,723 | 8,380 | 14,399 | 374,451 | 1,685 | 84,409 |
| 2004 | 31,555 | 6,559 | 3,616 | 10,232 | 24,996 | 28,612 | 575,323 | 2,542 | 12,774 |

For YCUA WWTP, more than 75% of the average total sludge was incinerated at the plant from January 2001 to March 2004. Incineration was stopped in April 2004 and all the sludge produced was disposed at the landfill during April 2004 to December 2004. The landfill used for disposal is located at a one-way distance of 18 miles from the plant. A summary of the findings on sludge disposal at YCUA is presented in Table 5-1.

As shown above the natural gas consumption from 2001 to 2003 was very high since most of the sludge was incinerated. When the quantity of sludge disposed at the landfill and the quantity of sludge incinerated are reversed in 2004, the total energy consumed in terms of GJ reduces significantly (almost 85% reduction from an average of 84,409 GJ in 2003 to 12,774 GJ in 2004). Since the energy content of natural gas is significantly high, the use of natural gas for incineration is more energy expensive than sludge disposal at the landfill for YCUA. A detailed comparison of the energy consumption for sludge disposal at the landfill vs. incineration is located in (Appendix D-I).

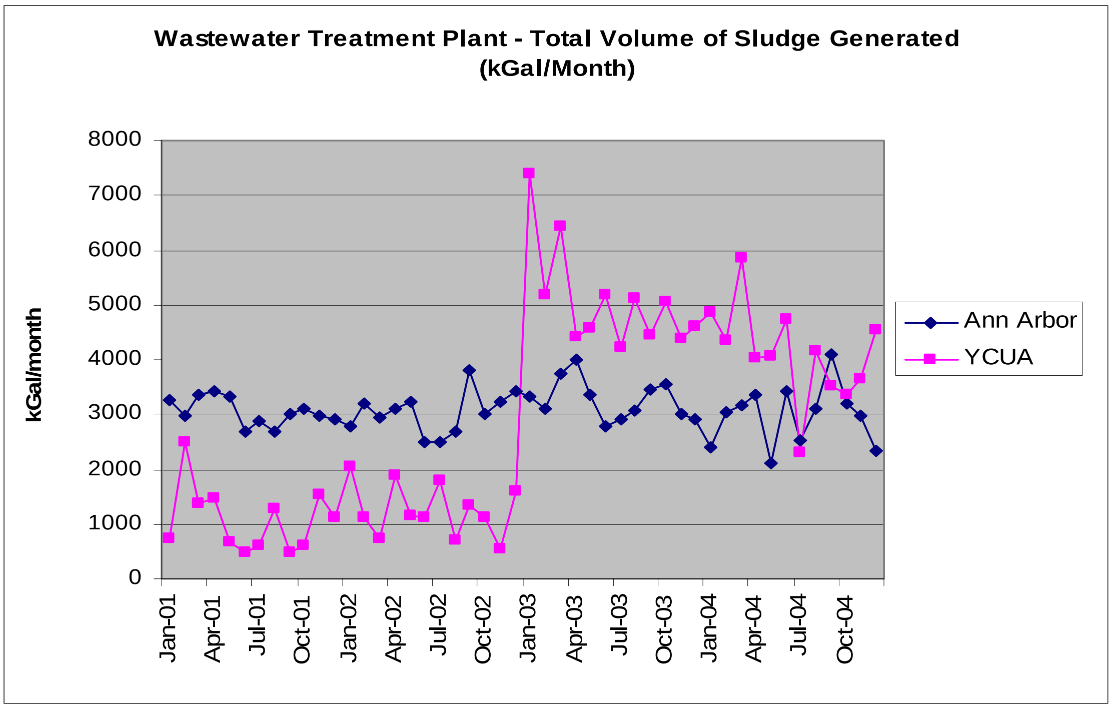


Figure 5-8. Total Volume of Sludge Generated in at the Ann Arbor and YCUA WWTPs (kGal/month)

Compared to the Ann Arbor WWTP, the quantity of sludge produced per month at the YCUA WWTP shows a sudden increase in January 2003. The quantity of sludge produced at the YCUA WWTP is an average of 1,166 kilo gallons (kGal) per month from January 2001 to December 2002. However from January 2003 to December 2004 the quantity of sludge is four times higher- an average of 4,603 kilo gal (Figure 5-8). Since the quantity of influent received during this period does not show an increase, the reason for this sudden increase sludge production is not known.

Consequently, the energy consumed for sludge disposal for the YCUA WWTP is significantly higher for January 2003. Surprisingly, the natural gas consumption does not remain as high after January 2003 (Figure 5-9). However, the energy consumption for disposal of sludge is significantly higher till March 2004 and becomes lower than the energy consumption for disposal at the Ann Arbor WWTP from April 2004 onwards. The reason for this reduction is the reduction in natural gas consumption after April 2004 due to stoppage of incineration until December 2004.

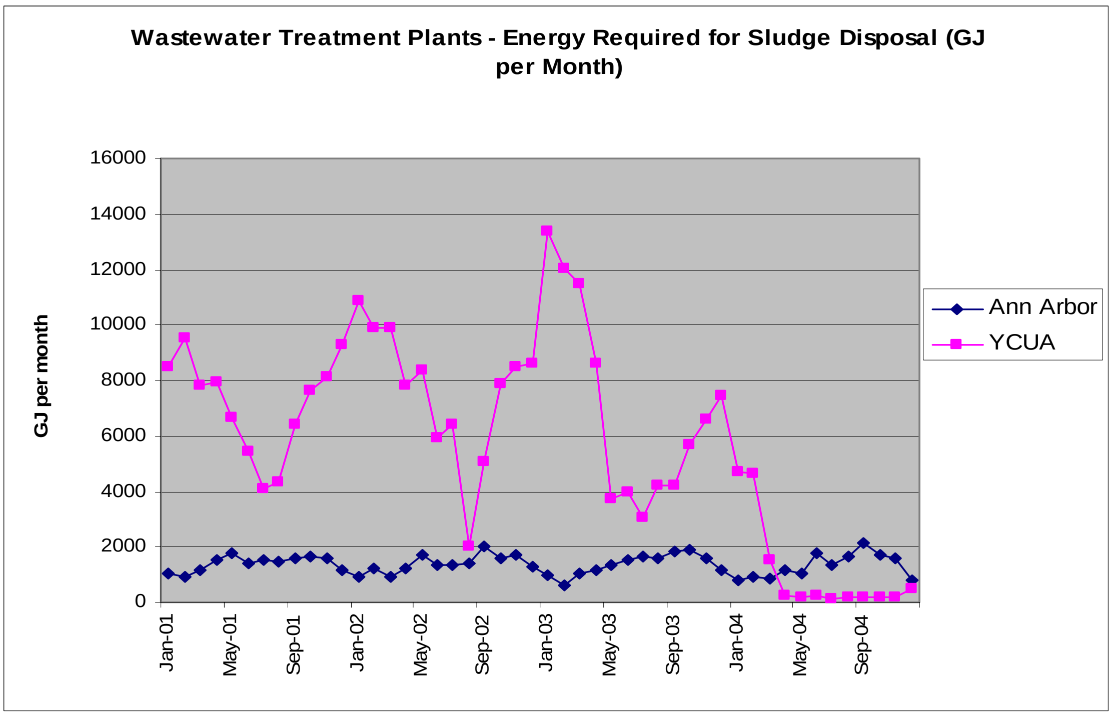


Figure 5-9. Energy Required for Sludge Disposal for Ann Arbor and YCUA WWTP (GJ/month)

The adoption of incineration for sludge disposal is certainly more energy expensive than opting for disposal at landfills or land-application sites. Even when the one-way distance to the landfill used by the Ann Arbor WWTP for disposal of the sludge produced from it is 80 miles, the energy consumption is not anywhere near to the energy consumed in the form of natural gas for incineration at the YCUA WWTP. Hence, the total life-cycle energy for YCUA WWTP is impacted significantly due to the use of the sludge incinerator.

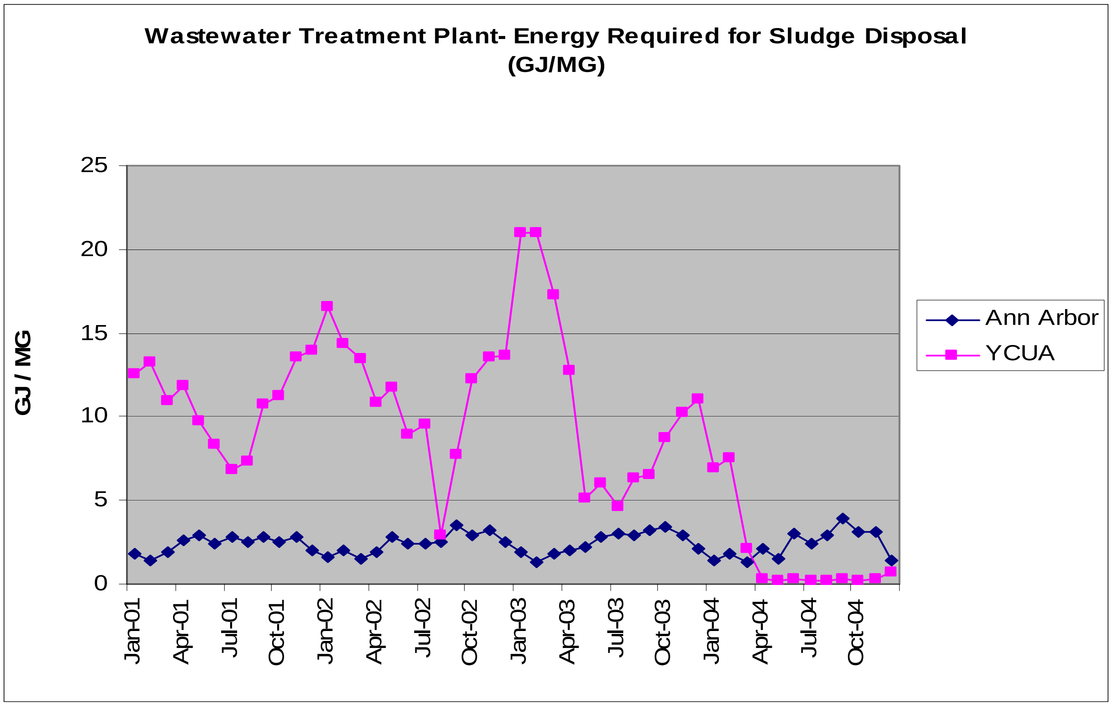


Figure 5-10. Energy Required for Sludge Disposal for Ann Arbor and YCUA WWTP (GJ/MG)

Like Ann Arbor WWTP, the Laguna WWTP does not use incineration for sludge disposal. The total energy consumed for disposal of sludge from Laguna WWTP in the year 2005 is 869 GJ per month, or 1 GJ per MG wastewater treated at the plant. The reason for this low energy consumption for disposal is the fact that nearly 25% of the total sludge from Laguna WWTP was composted very near to the plant.

Further, the distance from the Laguna WWTP to the landfill and land-application sites is much less when compared with the distance of Ann Arbor WWTP from its sludge disposal sites. On the other hand the energy consumed for sludge disposal from Ann Arbor WWTP is 3 GJ per MG wastewater treated at the plant. Evidently the low energy consumption for disposal for Laguna WWTP impacts the total life-cycle energy consumed for operation of the plant.

## 5.5 Total Life-cycle Energy for Operation of the WWTPs

The total life-cycle energy is calculated by inventorying electricity consumption, natural gas consumption, chemicals utilized and diesel fuel consumption at each wastewater treatment plant. The detailed discussion on the total life-cycle energy for operation of Ann Arbor and Laguna WWTP are presented in Chapters 3 & 4 and complete results for YCUA WWTP are included in Appendix D. The total life-cycle energy for operation of YCUA WWTP is 21 GJ/MG for the year 2003 compared to the total life-cycle energy of 16 GJ/MG for operation of Ann Arbor WWTP.

However in the year 2004, the total life-cycle energy for operation of Ann Arbor WWTP is higher than that of YCUA WWTP because of a significant decrease in the consumption of natural gas at the YCUA WWTP in that year. Figure 5-11 and 5-12 present the total life-cycle energy consumption for Ann Arbor and YCUA WWTP for the years 2003 and 2004 respectively.

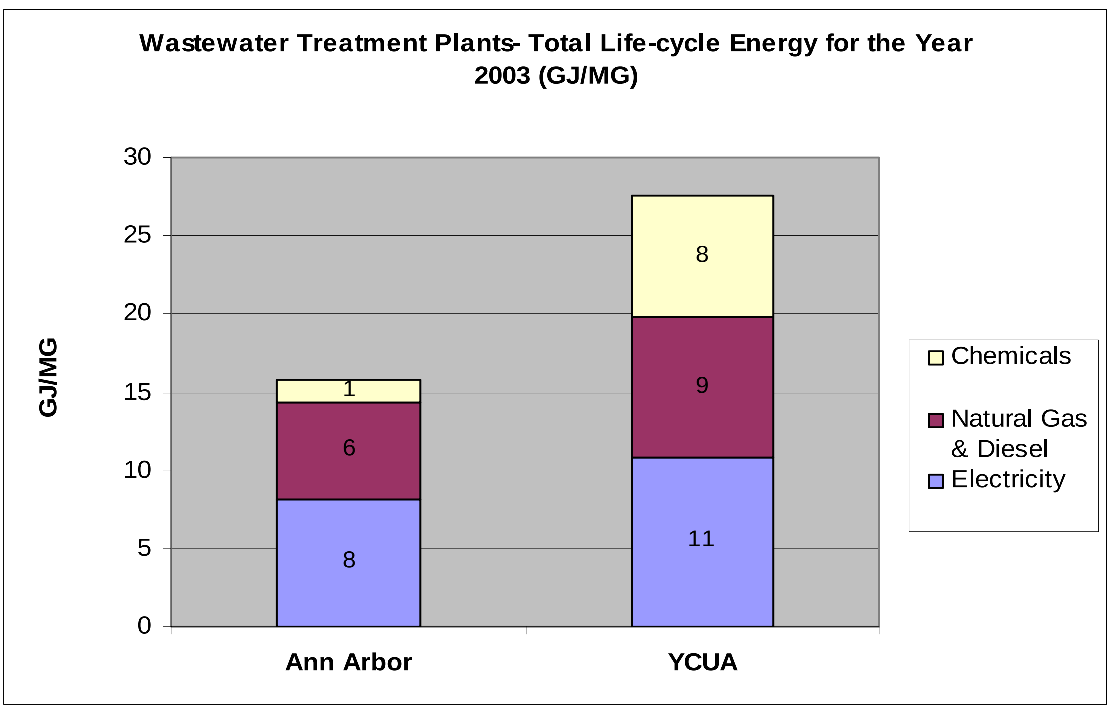


Figure 5-11. Life-cycle Energy for Ann Arbor and YCUA WWTPs in 2003 (GJ/MG)

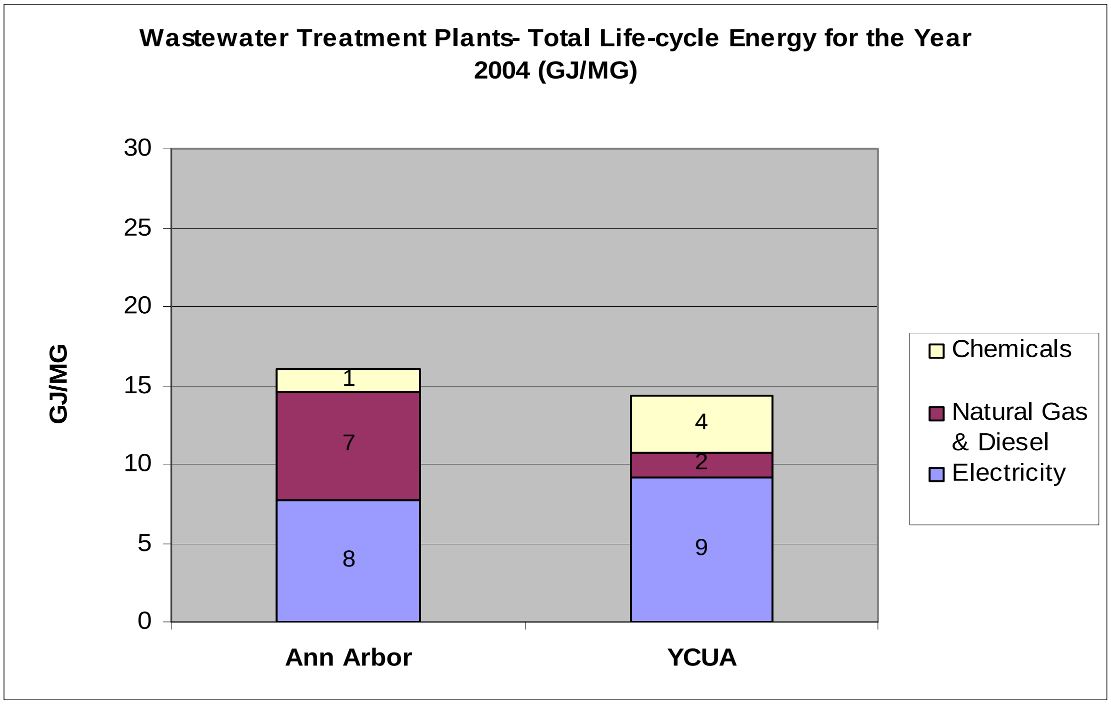


Figure 5-11. Life-cycle Energy for Ann Arbor and YCUA WWTPs in 2004 (GJ/MG)

The reduction in consumption of natural gas in the year 2004 leads to a drastic reduction in the total life-cycle energy for operation of YCUA WWTP, since natural gas and diesel fuel consumption together constitute a large percentage of the total-life-cycle energy for the plant in 2003. The same is applicable to Ann Arbor WWTP, but the natural gas consumed for heating purposes at the plant and the pumping stations is not very high; instead diesel fuel consumption for sludge disposal contributes more to the life-cycle energy for Ann Arbor WWTP. As a result YCUA WWTP appears to be more energy efficient in 2004. However, since a new incinerator came in use in 2005 at YCUA WWTP it cannot be stated if the plant consumes more energy or less than the Ann Arbor WWTP presently.

Further, a comparison on life-cycle energy for operation of the Laguna WWTP and the Ann Arbor WWTP could not be made since the complete information was not available for the Laguna WWTP except for the year 2005. However, in the year 2005 the total energy consumption for the Laguna WWTP was 11 GJ/MG which is less than the life-cycle energy required for operation of Ann Arbor WWTP in the year 2004. Since there has not been a drastic change in the monthly consumption of electricity, natural gas, chemicals usage or diesel fuel consumption for disposal for the Ann Arbor WWTP it would be fair to state that based on the available information for the year 2005 for both plants Laguna WWTP appears to be more energy efficient than the Ann Arbor WWTP.

### 5.6 Conclusions and Recommendations

The comparative assessment of the Ann Arbor, YCUA and Laguna WWTPs provides an understanding that the difference in methods adopted during each stage of plant operation variegates the total-life-cycle energy and emissions of similar treatment plants. For instance, natural gas consumption for incineration at the YCUA WWTP increases the total energy burden on the plant significantly. Similarly, the use of a landfill at a farther distance for sludge disposal for the Ann Arbor WWTP increases the total life-cycle energy for the plant. Based on the life-cycle energy and emissions assessment conducted for each case-study, the average life-cycle energy and environmental impacts from each facility was obtained. A summary of the life-cycle energy consumption at the Ann Arbor, YCUA and Laguna WWTPs and the environmental impacts from operation of these plants is presented in Table 5-2.

Table 5-2 Life-cycle Energy and Impacts from Operation of Ann Arbor, YCUA and Laguna WWTPs

| Wastewater Treatment Plant | Total Life-cycle Energy | Global Warming Potential | Atmospheric Eutrophication Potential | Aquatic Eutrophication Potential | Acidification Potential |
|---|---|---|---|---|---|
| | GJ/MG | kg $CO_2$ eq./MG | g N eq./MG | g N eq./MG | kmoles $H^+$ eq./MG |
| Ann Arbor WWTP | 16 | 1,984 | 291 | 3 | 673 |
| Laguna WWTP | 11 | 2,192 | 204 | 4 | 629 |
| YCUA WWTP | 21 | 2,747 | 222 | 4 | 1094 |

Note: These are average values obtained from analysis of each case-study

The highest life-cycle energy of the three case-studies is for YCUA WWTP. Incineration of sludge at YCUA WWTP requires considerably large amount of natural gas per month, as a result life-cycle energy for operation of the plant is significantly higher than the other plants. Although the old incinerator at YCUA WWTP was replaced in 2005, the detailed information on energy consumption and emissions from the new incinerator is not included in this research study. On an average 120,000 kgs of methane gas emissions or

23,298,000[†] CCF per month of methane is produced from sludge treatment at the plant. Interestingly, the natural gas requirement at the plant with the old incinerator was much smaller- 56,086 CCF per month. Similarly, the natural gas requirement for the Ann Arbor WWTP is much lower than the quantity of methane generated as a result of sludge treatment at the plant (Table 5-3).

Table 5-3 Methane Emissions from Sludge Treatment Compared to Monthly Natural Gas Requirement for operation of the WWTPs

| Wastewater Treatment Plant | Natural Gas Requirement per month (Average) | Methane Production from Sludge Treatment per month (Average) |
|---|---|---|
| | CCF | CCF |
| **Ann Arbor WWTP** | 17,706 | 24,439,602 |
| **YCUA WWTP** | 58,438 | 23,298,000 |

Hence, the methane produced at YCUA and Ann Arbor WWTP can be utilized for meeting the respective natural gas requirements at the plant completely. Further, like Laguna WWTP, the excess methane can be utilized to produce electricity by adopting a co-generation system at YCUA and Ann Arbor WWTPs. Additionally, the life-cycle energy can be reduced further by energy conservation during sludge hauling. As mentioned earlier, the diesel fuel consumption for sludge hauling accounts for 13% of the total life-cycle energy for operation of the plant. The diesel fuel consumption can be reduced by opting for a landfill located nearer to the plant for disposal of sludge.

This study has provided the basic framework for a life-cycle energy and impact assessment for wastewater treatment plants. Detailed analysis using meters for gauging the electricity consumption at each stage of the treatment process at the wastewater treatment plants would prove to be extremely beneficial for. Also, studies analyzing the energy consumption from construction and maintenance of the physical structure of these plants would provide accurate information on the total life-cycle energy of these plants. Further, incorporation of economic modeling for each facility would provide insightful information for adoption of strategies that are environmentally sustainable as well as economical.

[†] Density of gaseous methane is 1.819 g/m3 thus 1kg of methane is equal to 19,415 CCF

Lastly, life-cycle assessments can be carried forth for the municipal water treatment and supply systems complimenting each case-study, providing the total environmental impact of ‘water and wastewater treatment’ system. A similar effort has been made in the next chapter of this report presenting the energy analysis and impacts for the Ann Arbor ‘water and wastewater treatment’ system with an aim to facilitate further studies and development of sustainable energy practices at these plants based on the findings in this study.

# Chapter 6

# Ann Arbor Water and Wastewater System

## 6.1 Background

The detailed background information and analyses for Ann Arbor Water Treatment Plant and Ann Arbor Wastewater Treatment Plant are provided in Chapter 2 and Chapter 3 of this report respectively. Since the water and wastewater system for any city is crucial in terms of the environmental benefits[†] and burdens[‡] associated with the operation of treatment plants this chapter discusses the performance of the water treatment plant and the wastewater treatment plant combined as one system.

## 6.2 Total Flow

The quantity of the influent received at the Ann Arbor WWTP per month is generally higher than the total quantity of water delivered to the customers by the Ann Arbor WTP for all six years under consideration from 2000 to 2005. An exception to this monthly flow is when the quantity of water delivered is very high i.e., during the summer months every year. The average quantity of water supplied from the Ann Arbor WTP for the six year period is 439 MG per month and the average quantity of influent received at the Ann Arbor WWTP is 582 MG per month. Thus, more than 140 MG of the total influent is a result of infiltration and inflow of storm water into the system.

Figure 6-1 shows the monthly flow for the Ann Arbor water and wastewater system in MG per month. The difference in quantity of influent received at the Ann Arbor WWTP and the quantity delivered from the Ann Arbor WTP is illustrated in Figure 6-2.

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[†] Public health benefits due to treatment of water supplied to the city and environmental benefits in the form of pollution mitigation of surface water sources due to treatment of wastewater before discharging
[‡] Environmental burdens due to consumption of natural resources for operation of these plants and emissions from various stages of operation

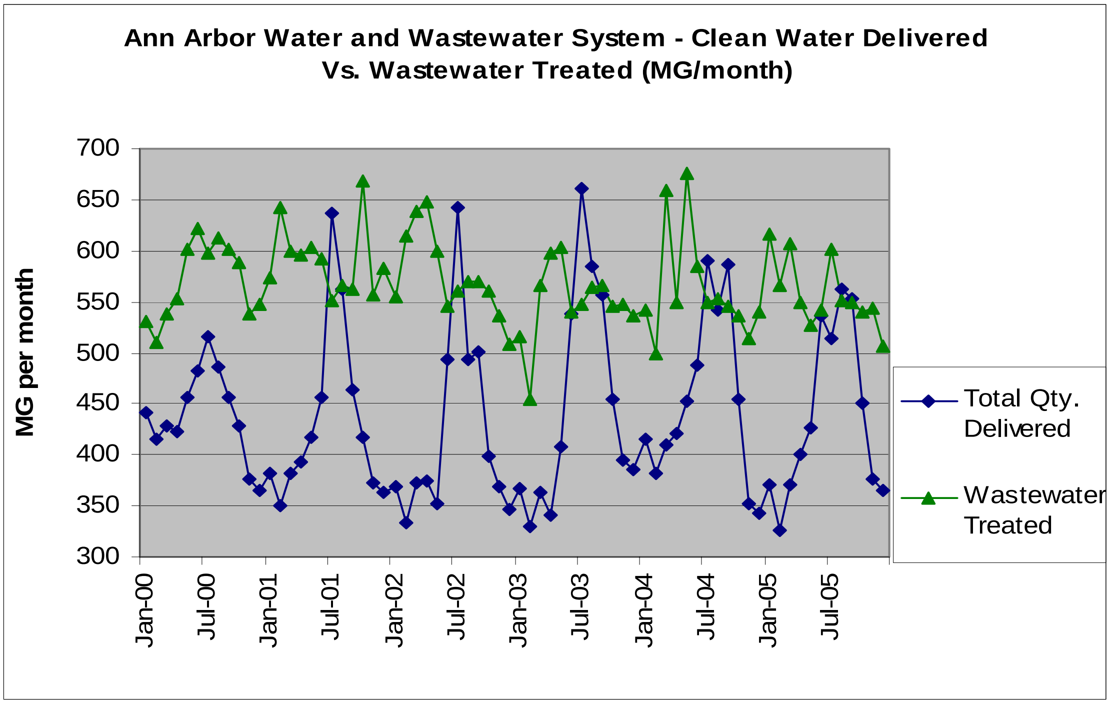


Figure 6-1. Ann Arbor Water and Wastewater System – Clean Water Delivered from the Ann Arbor WTP vs. Wastewater Treated at the Ann Arbor WWTP (MG/month)

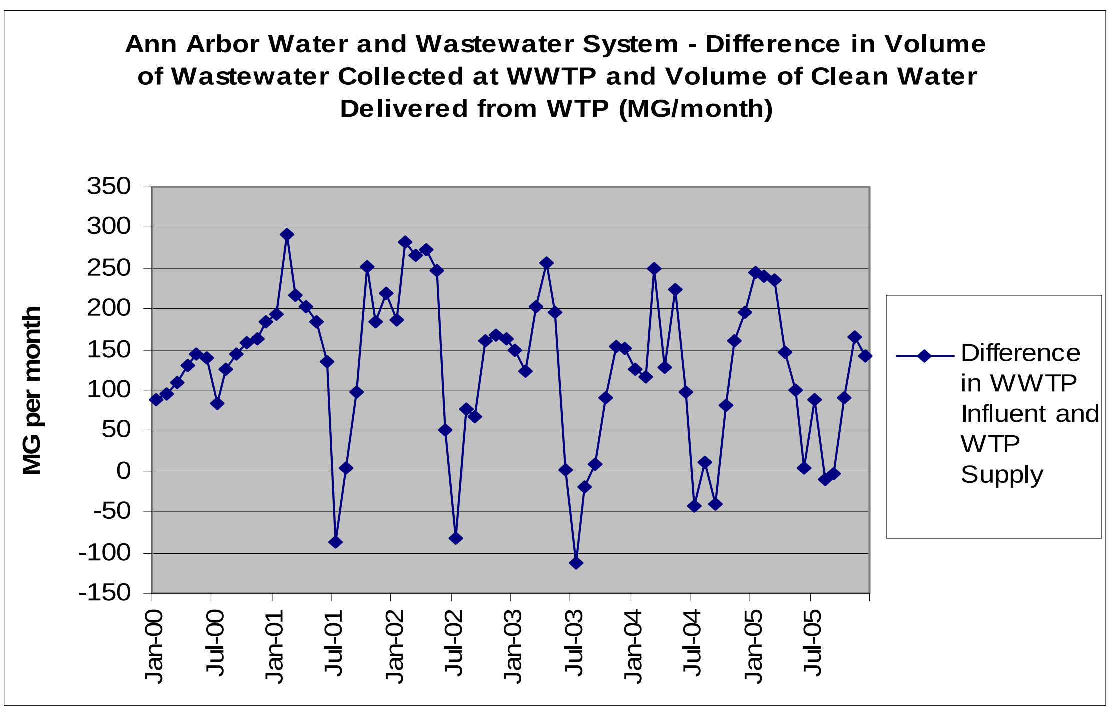


Figure 6-2. Ann Arbor Water and Wastewater System – Difference in Wastewater Collected at the WWTP and Clean Water Delivered from the WTP (MG/month)

Another interesting aspect of the Ann Arbor Water and Wastewater system is its impact on the Huron River. The Ann Arbor WTP collects 80% of the raw water required for meeting the demand from the Huron River and the Ann Arbor WWTP discharges the treated effluent into Huron River.

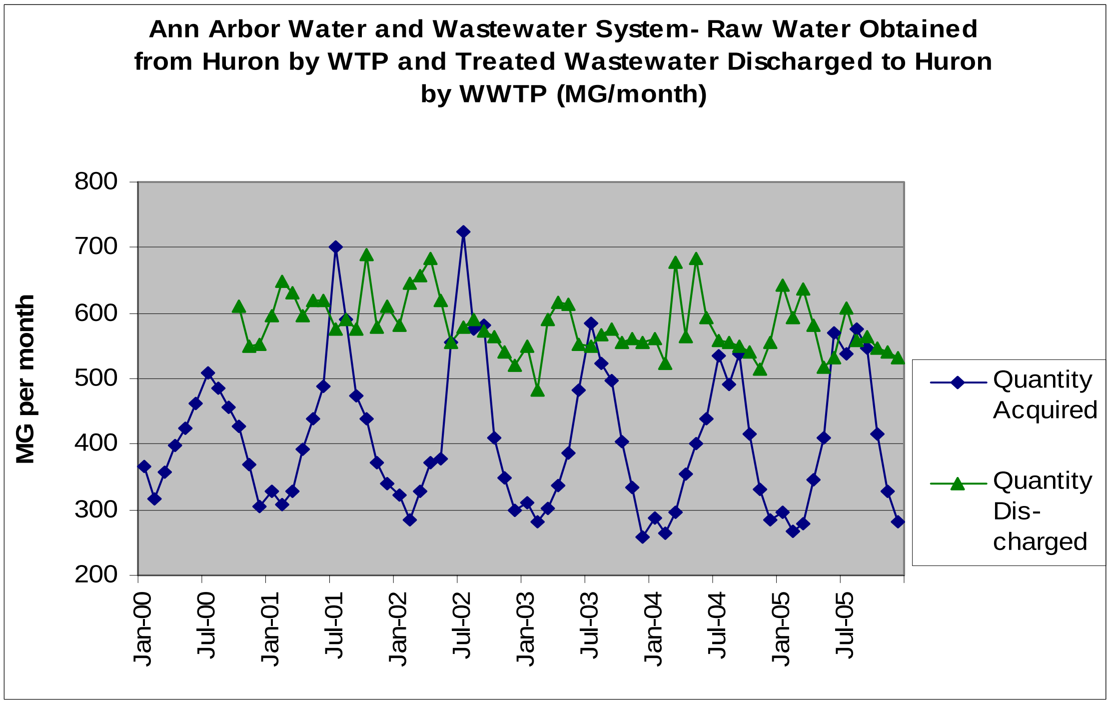


Figure 6-3. Ann Arbor Water and Wastewater System – Raw Water Obtained from Huron by the WTP Vs. Treated Wastewater Discharged from the WWTP (MG/month)

The monthly quantity of treated effluent discharged to the Huron River is generally higher than the quantity of water withdrawn from the river. One reason for this difference is that the Ann Arbor WTP adds around 20% groundwater from the wells to the river water before treatment and supply to the city. The second reason is the infiltration of storm water in the system and consequently a larger quantity of influent received at the WWTP for treatment. Since the quantity of water delivered to the customers in the city of Ann Arbor is high during the summer months and a significant part of this supply is consumed for irrigation and gardening in the summer months, the effluent discharged from the Ann Arbor WWTP is lower the quantity of water withdrawn from the river in the summer months (generally in the month of July). The difference in the quantity of water acquired from the Huron and the quantity of treated effluent discharged in Huron from the WWTP is shown in Figure 6-4.

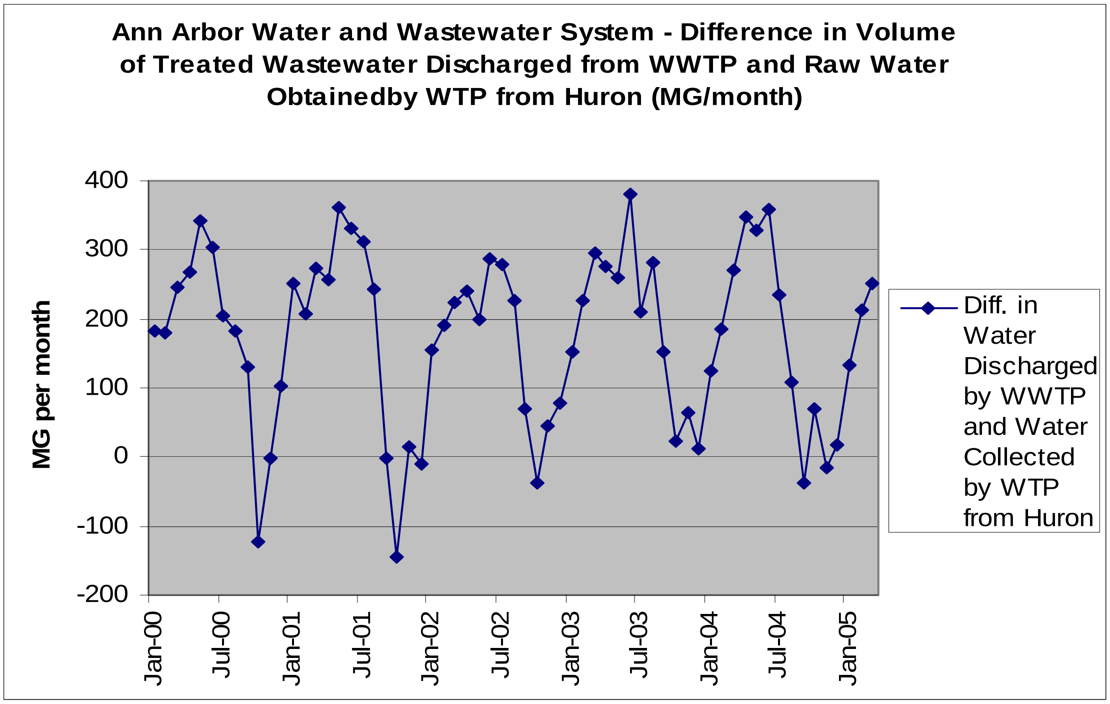


Figure 6-4. Ann Arbor Water and Wastewater System – Difference in Treated Effluent Discharged from WWTP and Raw Water Obtained at WTP from Huron (MG/month)

Although the quantity of treated effluent discharged to the river is lower in summer months, the total quantity of water discharged in Huron per year is always higher than the total quantity of water withdrawn from the river. Table 6-1, shows the quantity of water withdrawn from Huron and the quantity discharged to Huron per year

Table 6-1 Ann Arbor Water and Wastewater System – Quantity of Water Collected from Huron at WTP and Quantity of Water Discharged to Huron from WWTP

| Year | Water Withdrawn at WTP | | Total Effluent Discharged |
|---|---|---|---|
| | Total | From Huron | from WWTP to Huron |
| | MG/Yr | MG/Yr | MG/Yr |
| 2001 | 6277 | 5195 | 7334 |
| 2002 | 6334 | 5180 | 7114 |
| 2003 | 5958 | 4701 | 6767 |
| 2004 | 5800 | 4636 | 6873 |
| 2005 | 5975 | 4851 | 6857 |

Interestingly, the quantity of treated wastewater discharged from the Ann Arbor WWTP to the Huron River is also higher than the total quantity of water collected at the Ann Arbor WTP from the wells and the river combined. Thus, a significant amount of storm water gets collected and treated at the wastewater treatment plant and consequently discharged to the river in addition to the groundwater and surface water supplied to the city. Further, the quality of treated effluent discharged to the river meets the wastewater effluent standards and discharge permits.

## 6.3 Water Quality

The treated effluent discharged from the Ann Arbor WWTP meets Michigan Water Quality Standards (MWQS) as well as the National Pollutant Discharge Elimination System (NPDES). The water quality parameters reported in the monthly reports obtained from the Ann Arbor WWTP included- biological oxygen demand ($BOD_5$), carbonaceous biological oxygen demand ($CBOD_5$), total suspended solids (TSS), total phosphorus, ammonia nitrate ($NH_3$-N), nitrate nitrogen ($NO_3$-N), nitrite nitrogen ($NO_2$-N), alkalinity, fecal coliform and dissolved oxygen (DO). The water quality information is attached in Appendix E. The final effluent discharged to the Huron is well under the water quality limits specified in the NPDES permits[†]. The quality of effluent discharged to the river is further compared with the quality of water withdrawn from the Huron River by the Ann Arbor WTP.

Table 6-2 shows the quality of water collected at the Ann Arbor WTP from Huron and the quality of water discharged from the Ann Arbor WWTP to the Huron River. Since $BOD_5$[‡] is not tested for the water withdrawn from Huron at the Ann Arbor WTP, instead the total organic carbon (TOC)[Ψ] is tested; it is not possible to compare this key water quality parameter. However, the monthly reports from the Ann Arbor WWTP show a more than 99% $BOD_5$ removal upon treatment.

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[†] Tallied with Permit Number MIG570000

[‡] Biochemical Oxygen Demand is supposed to measure the amount of food (or organic carbons) that bacteria can oxidize.

[Ψ] The Total Organic Carbon test measures all organic carbon as CO2

Table 6-2 Quality of Water Withdrawn from Huron at WTP and Water Discharged to Huron from WWTP

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH (SU) | WTP | 8.20 | 8.10 | 8.20 | 8.20 | 8.10 | 8.00 | 8.00 | 8.00 | 8.00 | 8.20 | 8.30 | 8.20 |
| | WWTP | 6.83 | 6.83 | 6.80 | 6.79 | 6.93 | 6.93 | 6.82 | 6.75 | 6.72 | 6.87 | 6.90 | 6.92 |
| TOC (mg/l) | WTP | 3.30 | 4.00 | 5.00 | 5.70 | 6.80 | 7.40 | 7.50 | 7.50 | 6.60 | 6.50 | 6.10 | 5.80 |
| $BOD_5$ (mg/l) | WWTP | 2.27 | 1.79 | 1.84 | 1.32 | 1.26 | 2.07 | 1.72 | 1.24 | 1.33 | 2.35 | 2.00 | 1.60 |
| SS (mg/l) | WTP | 478 | 456 | 484 | 434 | 475 | 349 | 470 | 405 | 397 | 410 | 454 | 443 |
| | WWTP | 1.76 | 1.96 | 2.31 | 1.92 | 2.00 | 1.74 | 1.87 | 1.80 | 2.15 | 1.95 | 1.70 | 1.82 |
| P (mg/l) | WTP | 0.02 | 0.03 | 0.02 | 0.02 | 0.21 | 0.02 | 0.03 | 0.03 | 0.03 | 0.02 | 0.01 | 0.02 |
| | WWTP | 0.13 | 0.11 | 0.13 | 0.11 | 0.24 | 0.28 | 0.39 | 0.30 | 0.31 | 0.32 | 0.30 | 0.24 |
| $NH_3$-N (mg/l) | WTP | 0.02 | 0.32 | 0.05 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.08 |
| | WWTP | 0.08 | 0.06 | 0.08 | 0.06 | 0.05 | 0.09 | 0.07 | 0.14 | 0.13 | 0.11 | 0.00 | 0.22 |
| $NO_3$-N (mg/l) | WTP | 0.54 | 0.51 | 0.68 | 0.41 | 0.87 | 0.79 | 0.28 | 0.34 | 0.34 | 0.24 | 0.29 | 0.38 |
| | WWTP | 14 | 11 | 14 | 14 | 12 | 12 | 13 | 13 | 16 | 14 | 15 | 13 |
| Alkalinity (mg/l) | WTP | 220 | 225 | 214 | 207 | 203 | 200 | 199 | 203 | 212 | 216 | 220 | 231 |
| | WWTP | 105 | 148 | 119 | 147 | 135 | 123 | 105 | 83 | 85 | 136 | 121 | 135 |
| Fecal Coliform (/100ml) | WTP | 785 | 615 | 40 | 108 | 484 | 638 | 1058 | 1479 | 1023 | 319 | 228 | 1044 |
| | WWTP | 20 | 15 | 32 | 17 | 27 | 63 | 51 | 30 | 32 | 32 | 5 | 33 |

Out of all other parameters shown in the Table above, Suspended Solids, Alkalinity and Fecal Coliform for the final effluent discharged from the WWTP are lower than the water collected at the WTP. Also, even though the quantities of total phosphorus, Ammonia-nitrogen and nitrate nitrogen is higher in the effluent discharged, they meets the NPDES permit limits and there is a 99% removal of all the three pollutants upon treatment of wastewater at the Ann Arbor WWTP. Thus, the treatment of wastewater prevents pollution in the Huron significantly.

## 6.4 Electricity Utilization

The average electricity consumption for the Ann Arbor WTP for the period of six years from 2000 to 2005 was found to be close to 1,039,895 kWh per month. The average electricity consumption for the Ann Arbor WWTP was higher for the same period and found to be 1,103,685 kWh per month. Figure 6-5, shows the electricity consumption for the Ann Arbor WTP and WWTP in terms of kWh per month. Figure 6-6, presents the electricity consumption for the Ann Arbor WTP per MG of clean water delivered and electricity consumption for Ann Arbor WWTP per MG wastewater treated.

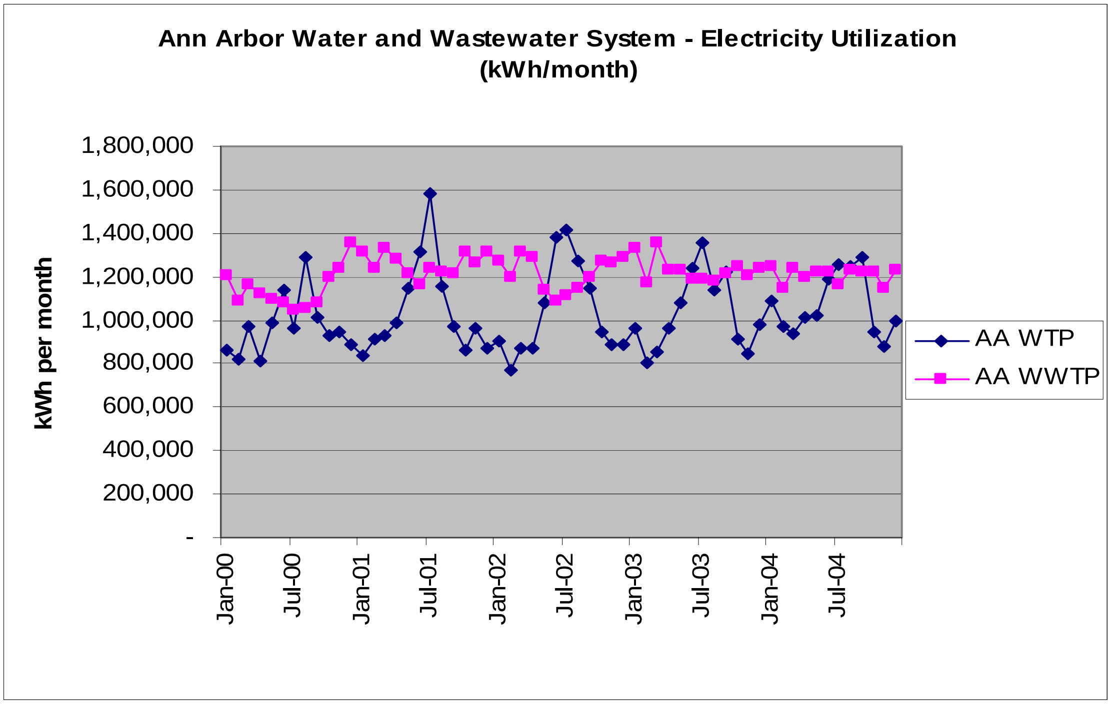


Figure 6-5. Ann Arbor Water and Wastewater System – Electricity Utilization (kWh/month)

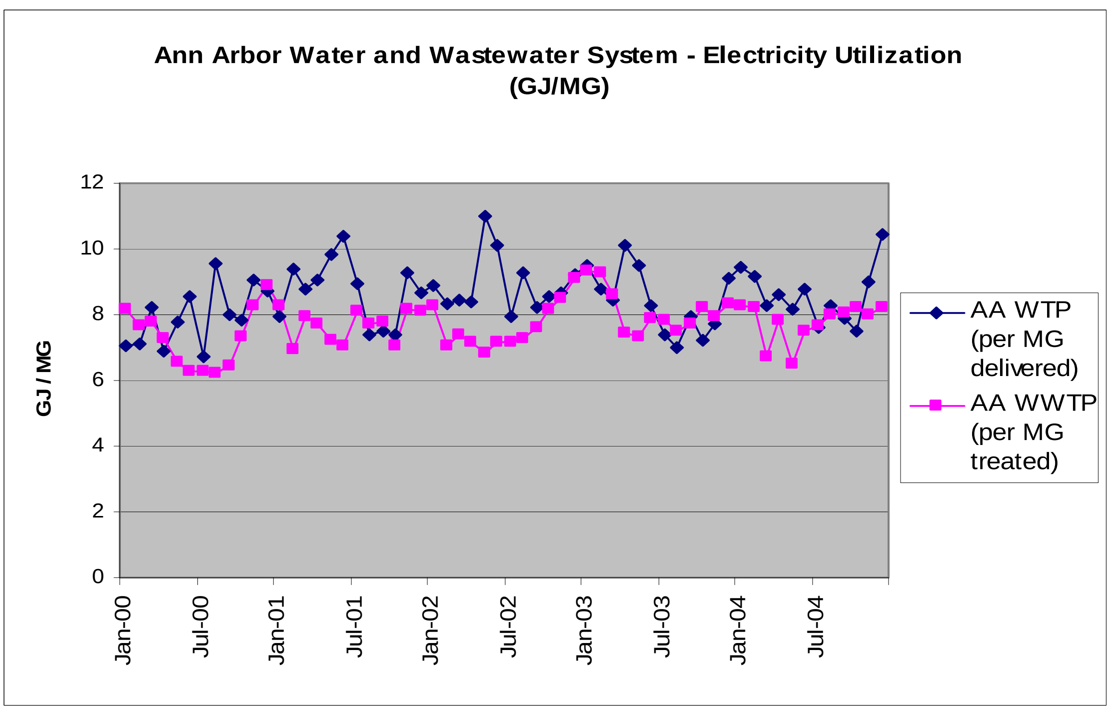


Figure 6-6. Ann Arbor Water and Wastewater System – Electricity Utilization (GJ/MG)

For the year 2000 the total electricity consumption calculated from primary data available from the plants for the Ann Arbor 'water and wastewater' system is 25,357,775 kWh. In a study conducted by Epstein et.al[27] on GHG emissions reduction strategy for the City of Ann Arbor the total electricity consumption for the Municipal Government Sector for the same year was reported to be 46,681,772 kWh.

Table 6-3 Electricity Consumption for the Ann Arbor Municipal Government Sector

| Year | **Ann Arbor WTP** | | **Ann Arbor WWTP** | | **Ann Arbor WTP and WWTP** | | **Ann Arbor Municipal Govt. Sector** |
|---|---|---|---|---|---|---|---|
| 2000 | kWh | % of Total | kWh | % of Total | kWh | % of Total | kWh |
| | 11,631,010 | 25 | 13,726,765 | 29 | 25,357,775 | 54 | 46,681,772 |

Based on the figures above the Ann Arbor WTP consumes 25% of the total electricity consumption of the municipal government sector in Ann Arbor and Ann Arbor WWTP accounts to 29%. Thus, the 'water and wastewater' system accounts for 54% of the total electricity consumed for the services[†] provided by the Ann Arbor City Government. Energy savings practices for reduction of electricity consumption at the water and wastewater treatment plants for Ann Arbor could reduce the total burden of electricity consumption from the grid significantly. However, the total life-cycle energy for operation of the water and wastewater system in the city comprises of other sources as well.

## 6.4 Total Life-cycle Energy for the Ann Arbor Water and Wastewater System

The life-cycle energy consumed per month for operating the Ann Arbor WTP and Ann Arbor WWTP is presented in Chapter 2 and Chapter 3 respectively. This section discusses the life-cycle energy for the water and wastewater system as a whole. The life-cycle energy for operating the Ann Arbor WTP was 111,083 GJ for the year 2003 and 110,138 GJ for the year 2004. The Ann Arbor WWTP consumed 103,396 GJ and 107,571 GJ for 2003 and 2004 respectively. Table 6-4 shows the contribution of Ann

[†] Including Water treatment (incl. lift pumps), Wastewater treatment (incl. lift pumps), Office space (incl. City Hall), Maintenance garages, Park shelters and canoe liveries, Community centers, Fire stations, Pools and ice rinks, parking lots and structures, Leslie Science Center, golf courses, and miscellaneous.

Arbor WTP and WWTP to the total life-cycle energy for operation of the water and wastewater treatment system as a whole.

Table 6-4 Life-cycle Energy Consumed for Operation of Ann Arbor Water and Wastewater System

| Year | Ann Arbor WTP | Ann Arbor WWTP | Life-cycle energy for the Water and Wastewater System |
|---|---|---|---|
| | GJ/Yr | GJ/Yr | GJ/Yr |
| 2003 | 111,083 | 103,396 | 214,479 |
| 2004 | 110,138 | 107,751 | 217,889 |

The production of chemicals utilized at the Ann Arbor WTP plant is responsible for 37% and electricity consumption for operation of the plant and pumping stations accounts for 35% of the total life-cycle energy for operation of the plant. On the other hand, 50% of the life-cycle energy for operation of the Ann Arbor WWTP is from electricity consumption for at the plant and 26% from consumption of natural gas for heating.

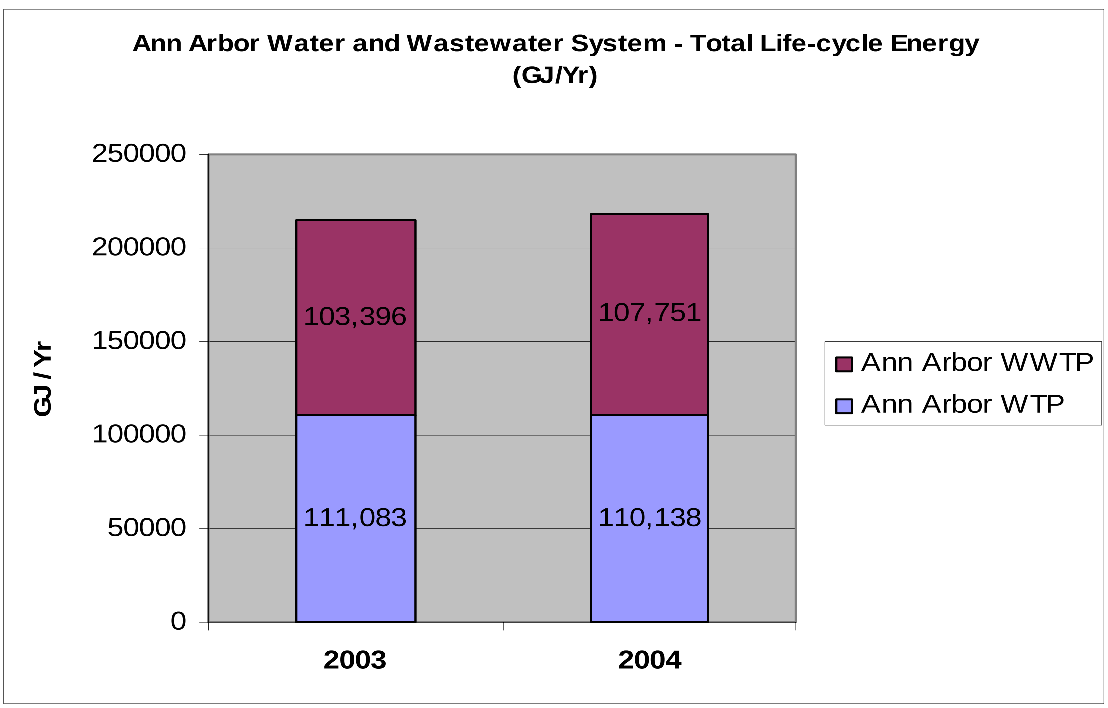


Figure 6-6. Total Life-cycle Energy for the Ann Arbor Water and Wastewater System (GJ/Yr)

The Ann Arbor WTP accounts for 52% of the total life-cycle energy for the water and wastewater system for 2003 and 51% for 2004. Although the quantity of chemicals consumed for treatment at the WTP or the WWTP cannot be reduced for reducing the total-cycle energy for the system, the consumption of electricity and natural gas can be reduced by employing energy-saving equipments and utilizing co-generation‡ at the wastewater treatment plant for reducing the burdens of electricity and natural gas consumption thereby reducing the life-cycle emissions for the system.

### 6.5 Life-cycle Emissions from Ann Arbor Water and Wastewater System

The natural gas consumption for heating purposes at the Ann Arbor WTP, Barton and Steere Farm Pumping stations and distribution pumping stations together account for a large part of the total greenhouse gas emissions from operation of the plant. Also, the production processes of chemicals required for treatment at the WTP result into emission of greenhouse gases. As a result, the total life-cycle global warming potential from emissions is much higher for the WTP when compared with the Ann Arbor WWTP.

Table 6-5 Global Warming Potential for Ann Arbor Water and Wastewater System (kg $CO_2$ equivalent per year)

| Year | Ann Arbor WTP | Ann Arbor WWTP | Life-cycle GWP from Ann Arbor Water and Wastewater System |
|---|---|---|---|
| | kg $CO_2$ eq./Yr | kg $CO_2$ eq./Yr | kg $CO_2$ eq./Yr |
| 2003 | 22,308,448 | 12,965,912 | 35,274,360 |
| 2004 | 22,598,446 | 13,484,100 | 36,082,546 |

The electricity consumption for operation of the Ann Arbor WTP and WWTP are major sources of greenhouse gas emissions for the Ann Arbor WWTP.

Further, a major part of the total atmospheric eutrophication potential for the system over a hundred year time horizon is a result of NOx emissions from electricity consumption at the WTP and WWTP. The total atmospheric eutrophication potential for the system is 542 g N eq. for 2003 and 510 kg N eq. for 2004. Table 6-6 shows the contribution of the

‡ The co-generation system for the Laguna WWTP has been discussed in Chapter 5

WTP and WWTP each to the total atmospheric eutrophication potential from the Ann Arbor water and wastewater system as a whole.

Table 6-6 Eutrophication Potential from the Ann Arbor Water and Wastewater System (g N eq. /MG)

| Year | Atmospheric Eutrophication Potential kg Nitrogen eq./Yr | | | Aquatic Eutrophication Potential g Nitrogen eq./Yr | | |
|---|---|---|---|---|---|---|
| | Ann Arbor WTP | Ann Arbor WWTP | Water and Wastewater System | Ann Arbor WTP | Ann Arbor WWTP | Water and Wastewater System |
| 2003 | 243 | 299 | 542 | 11 | 3 | 14 |
| 2004 | 227 | 283 | 510 | 10 | 3 | 13 |

The aquatic eutrophication potential is higher from the Ann Arbor WTP since the natural gas consumption is higher for the WTP when compared with the WWTP and the COD and Ammonia emissions from natural gas consumption are major factors responsible for the total aquatic eutrophication potential for the system. The total aquatic eutrophication potential for the Ann Arbor water and wastewater system is 14 g N eq. for 2003 and 13 g N eq. for the year 2004.

The total acidification potential from operation of the Ann Arbor water and wastewater system is 1,300 kmoles of $H^+$ eq. per year for the two year period from 2003 to 2004. Table 6-7 presents the total life-cycle acidification potential per year from the Ann Arbor water and wastewater system comprising of the Ann Arbor WTP and Ann Arbor WWTP.

Table 6-7 Acidification Potential from the Ann Arbor Water and Wastewater System (kmoles of $H^+$ eq. per year)

| Year | Acidification Potential in terms of kmoles of $H^+$ eq. per year | | |
|---|---|---|---|
| | Ann Arbor WTP | Ann Arbor WWTP | Ann Arbor Water and Wastewater System |
| 2003 | 663 | 691 | 1,354 |
| 2004 | 631 | 657 | 1,288 |

The major contributors to the total acidification potential from the system are sulfur dioxide emissions from electricity used at both treatment plants. Since the electricity utilization is higher for Ann Arbor WWTP the total impact in terms of acidification potential over a hundred year time horizon is also higher for the Ann Arbor WWTP when compared with the Ann Arbor WTP.

## 6.6 Conclusions

Water and wastewater treatment plants are essential for modern society in terms of the service provided towards the people and the environment of a city. This research effort does not focus on the benefits in terms of public health and reduction of environmental pollution. The main focus of this study is to document the energy intensity and environmental impacts from operation of Ann Arbor Water and Wastewater Treatment System. Table 6-8 presents the total life-cycle energy and environmental impacts from operation of Ann Arbor 'water and wastewater treatment system per million gallons clean water[†].

Table 6-8 Energy and Environmental Impacts from Ann Arbor Water and Wastewater System

| Year | Life-cycle Energy for Operation | Total Global Warming Potential | Atmospheric Eutrophication Potential | Aquatic Eutrophication Potential | Acidification Potential |
|---|---|---|---|---|---|
| | GJ/MG | kg $CO_2$ eq./MG | g N eq./ MG | g N eq./ MG | kmoles H+ eq./MG |
| 2003 | 40 | 5213 | 534 | 14 | 1240 |
| 2004 | 40 | 5250 | 505 | 13 | 1174 |

The total life-cycle energy for operation of Ann Arbor 'water and wastewater treatment' system is 40 GJ per million gallons clean water or 216,000 GJ per year (Table 6-4). The life-cycle energy of the Ann Arbor 'water and wastewater' system per year is equivalent to that of 2160[‡] passenger cars or 685[Ψ] residential homes[28].

Although the annual electricity consumption at the WTP is lower than that of the WWTP, high energy consumption in the form of chemicals and natural gas contributes significantly to the total life-cycle energy for the Ann Arbor WTP. As result, the Ann Arbor WTP contributes 60% of the total life-cycle energy for operation of the Ann Arbor 'water and wastewater treatment system'.

[†] Although this study uses million gallons of wastewater treated as a functional unit for all results presented in previous chapters the results in Table 6-8 are based on per million gallons of clean water or effluent discharged from the Ann Arbor WWTP.
[‡] Life-cycle energy of a passenger car (120,000 miles and 10 years) is 100 GJ/Yr
[Ψ] Life-cycle energy of a residential home (228m$^2$, 50 years) is 320 GJ/Yr

The total global warming potential from operation of the Ann Arbor ‘water and wastewater treatment’ system is 5,232 kg $CO_2$ eq. /MG. As with the total life-cycle energy, the contribution of the Ann Arbor WTP to this environmental impact is much higher than that of the Ann Arbor WWTP. However, the atmospheric eutrophication potential from the Ann Arbor WWTP is significantly higher than the Ann Arbor WTP contributing over 55% of the total atmospheric eutrophication potential of 526 g N eq. /MG.

The aquatic eutrophication potential from the Ann Arbor WTP is higher than that of the Ann Arbor WWTP contributing 77% of the total aquatic eutrophication potential due to high COD emissions from natural gas consumption. The total life-cycle aquatic eutrophication potential from operation of the Ann Arbor ‘water and wastewater treatment’ system is 13 g N eq. per million gallons clean water. Lastly, the life-cycle acidification potential from the system is 1,321 kmoles of $H^+$ eq. per million gallons of clean water, out of which 50% is contributed from operation of WTP and WWTP each.

## 6.7 Recommendations and Future Directions

Sustainability analyses using life-cycle assessments for water and wastewater system as a whole are uncommon. The presently available literature and research focus on water treatment plants and wastewater treatment plants as individual systems. However, the interdependence of these systems and their significance in a city make studies focusing on the ‘water and wastewater treatment’ system crucial for development of sustainable strategies. The framework for life-cycle energy and emissions analyses for the ‘Ann Arbor Water and Wastewater’ system and the findings compiled in this study can be utilized for comparative assessments with similar facilities in future.

The life-cycle energy for the Ann Arbor ‘water and wastewater treatment’ would reduce significantly by reducing the electricity consumption for operation of the plants and natural gas consumption for heating. The adoption of anaerobic sludge treatment process at the Ann Arbor WWTP could produce approximately 125,880 kg of methane per month which is equal to 24,439,602 CCF[†]. The average monthly requirement of natural gas for heating at the Ann Arbor WWTP plant is 17,706 CCF and the average monthly requirement for the WTP 24,390 CCF. The methane gas produced from the proposed system at the Ann Arbor WWTP is sufficient for meeting the total natural gas requirements for heating at the Ann Arbor water and wastewater treatment plants. Further, the excess methane can be used for production of electricity at the plant using a co-generation system. This would also reduce the total global warming potential from the 'water and wastewater treatment' system.

Life-cycle energy and emissions assessments would be much more beneficial if the contribution of each treatment stage towards the total life-cycle energy and impacts can be ascertained. Since, it is difficult to track the energy consumption at each stage without separate metering systems for each treatment stage; it was difficult to pin-point particular stages of high electricity consumption for the Ann Arbor 'water and wastewater' system. Future studies employing meters at the different stages of treatment at the plants combined with the findings of this study should prove to be beneficial for development of strategies for reducing the total energy consumption and consequent emissions from operation of water and wastewater treatment plants.

Further, incorporation of the construction and maintenance of the physical structure of water and wastewater treatment systems in the life-cycle energy and emissions assessments would provide a more comprehensive analysis. Lastly, a life-cycle cost analysis for the water and wastewater treatment plants complimenting the findings of this study would certainly be more beneficial for understanding the economic aspect of these plants. Such studies, together with the findings presented in this study would aid decision-making for sustainable management of water and wastewater treatment systems.

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[†] Density of gaseous methane is 1.819 kg/m3, thus 1 kg is equal to 19.415 CCF of the gas.

# Appendix A-I

## Ann Arbor Water Treatment Plant Energy Consumption

### a. Ann Arbor Water Treatment Plant - Total Flow

| Date | From | | | From | | Total | | | Filtered | | Delivered | | | Difference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | River | | | Well | | Influent | | | | | | | | Acqd-Delivd |
| Month/Yr | MGD | MG | MG/Yr | MGD | MG | MGD | MG | MG/Yr | MGD | MG | MGD | MG | MG/yr | MG |
| Jan-00 | 11.81 | 366.00 | 4874.17 | 3.18 | 98.65 | 14.99 | 464.65 | 5855.49 | 15.35 | 475.84 | 14.22 | 440.94 | 5274.29 | 23.72 |
| Feb-00 | 11.27 | 315.48 | | 3.92 | 109.89 | 15.19 | 425.37 | | 15.64 | 437.91 | 14.84 | 415.63 | | 9.73 |
| Mar-00 | 11.52 | 357.09 | | 3.15 | 97.67 | 14.67 | 454.77 | | 15.00 | 464.89 | 13.82 | 428.27 | | 26.49 |
| Apr-00 | 13.30 | 399.14 | | 2.17 | 64.97 | 15.47 | 464.11 | | 15.77 | 473.16 | 14.10 | 422.86 | | 41.25 |
| May-00 | 13.70 | 424.80 | | 2.18 | 67.65 | 15.89 | 492.45 | | 16.21 | 502.46 | 14.72 | 456.35 | | 36.10 |
| Jun-00 | 15.44 | 463.29 | | 2.26 | 67.90 | 17.71 | 531.20 | | 18.05 | 541.59 | 16.06 | 481.77 | | 49.42 |
| Jul-00 | 16.37 | 507.57 | | 2.26 | 70.02 | 18.63 | 577.58 | | 19.19 | 594.96 | 16.61 | 514.89 | | 62.69 |
| Aug-00 | 15.64 | 484.89 | | 2.27 | 70.37 | 17.91 | 555.26 | | 18.43 | 571.32 | 15.68 | 486.13 | | 69.13 |
| Sep-00 | 15.20 | 455.91 | | 2.35 | 70.56 | 17.55 | 526.47 | | 18.09 | 542.75 | 15.24 | 457.21 | | 69.26 |
| Oct-00 | 13.77 | 426.93 | | 2.28 | 70.75 | 16.05 | 497.68 | | 16.59 | 514.18 | 13.82 | 428.28 | | 69.39 |
| Nov-00 | 12.29 | 368.80 | | 2.33 | 69.81 | 14.62 | 438.61 | | 14.94 | 448.07 | 12.55 | 376.59 | | 62.02 |
| Dec-00 | 9.82 | 304.28 | | 3.97 | 123.08 | 13.79 | 427.36 | | 14.12 | 437.73 | 11.79 | 365.35 | | 62.01 |
| Jan-01 | 10.56 | 327.31 | 5194.95 | 3.95 | 122.48 | 14.51 | 449.79 | 6277.06 | 14.79 | 458.46 | 12.29 | 381.10 | 5198.00 | 68.69 |
| Feb-01 | 11.01 | 308.26 | | 3.81 | 106.61 | 14.82 | 414.87 | | 15.19 | 425.21 | 12.48 | 349.49 | | 65.38 |
| Mar-01 | 10.59 | 328.32 | | 3.93 | 121.81 | 14.52 | 450.13 | | 14.90 | 461.87 | 12.34 | 382.60 | | 67.53 |
| Apr-01 | 13.08 | 392.49 | | 2.66 | 79.67 | 15.74 | 472.16 | | 16.16 | 484.93 | 13.10 | 393.03 | | 79.13 |
| May-01 | 14.12 | 437.57 | | 2.41 | 74.57 | 16.52 | 512.14 | | 16.93 | 524.78 | 13.47 | 417.58 | | 94.56 |
| Jun-01 | 16.30 | 489.08 | | 2.40 | 71.94 | 18.70 | 561.01 | | 19.13 | 574.01 | 15.24 | 457.09 | | 103.93 |
| Jul-01 | 22.57 | 699.70 | | 2.28 | 70.70 | 24.85 | 770.40 | | 25.48 | 790.03 | 20.57 | 637.53 | | 132.87 |
| Aug-01 | 19.08 | 591.41 | | 3.12 | 96.68 | 22.20 | 688.08 | | 22.68 | 703.12 | 18.14 | 562.37 | | 125.71 |
| Sep-01 | 15.76 | 472.71 | | 2.99 | 89.72 | 18.75 | 562.43 | | 19.09 | 572.60 | 15.48 | 464.45 | | 97.98 |
| Oct-01 | 14.12 | 437.57 | | 2.41 | 74.57 | 16.52 | 512.14 | | 16.93 | 524.78 | 13.47 | 417.58 | | 94.56 |
| Nov-01 | 12.40 | 372.05 | | 2.59 | 77.79 | 14.99 | 449.84 | | 15.18 | 455.47 | 12.42 | 372.63 | | 77.21 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec-01 | 10.92 | 338.50 | | 3.08 | 95.59 | 14.00 | 434.09 | | 14.26 | 441.96 | 11.70 | 362.57 | | 71.52 |
| Jan-02 | 10.43 | 323.30 | 5179.78 | 3.70 | 114.71 | 14.13 | 438.01 | 6334.02 | 14.40 | 446.34 | 11.88 | 368.24 | 5044.03 | 69.77 |
| Feb-02 | 10.13 | 283.68 | | 3.77 | 105.53 | 13.90 | 389.20 | | 14.21 | 397.76 | 11.90 | 333.06 | | 56.14 |
| Mar-02 | 10.55 | 327.09 | | 3.42 | 106.12 | 13.97 | 433.21 | | 14.31 | 443.56 | 12.00 | 371.93 | | 61.28 |
| Apr-02 | 12.43 | 372.88 | | 2.64 | 79.15 | 15.07 | 452.03 | | 15.42 | 462.62 | 12.49 | 374.56 | | 77.46 |
| May-02 | 12.16 | 376.88 | | 2.99 | 92.63 | 15.15 | 469.50 | | 15.47 | 479.58 | 11.39 | 352.94 | | 116.57 |
| Jun-02 | 18.55 | 556.60 | | 2.97 | 89.21 | 21.53 | 645.81 | | 21.81 | 654.25 | 16.45 | 493.45 | | 152.36 |
| Jul-02 | 23.39 | 725.23 | | 2.95 | 91.38 | 26.34 | 816.61 | | 26.69 | 827.53 | 20.71 | 641.97 | | 174.64 |
| Aug-02 | 18.58 | 576.04 | | 2.94 | 91.17 | 21.52 | 667.21 | | 21.89 | 678.52 | 15.91 | 493.21 | | 173.99 |
| Sep-02 | 19.40 | 582.10 | | 2.94 | 88.12 | 22.34 | 670.22 | | 22.96 | 688.82 | 16.71 | 501.35 | | 168.87 |
| Oct-02 | 13.19 | 408.74 | | 2.96 | 91.75 | 16.14 | 500.49 | | 16.60 | 514.50 | 12.87 | 398.82 | | 101.67 |
| Nov-02 | 11.64 | 349.05 | | 2.90 | 87.01 | 14.54 | 436.06 | | 15.03 | 450.88 | 12.27 | 367.99 | | 68.06 |
| Dec-02 | 9.62 | 298.22 | | 3.79 | 117.47 | 13.41 | 415.68 | | 13.46 | 417.15 | 11.18 | 346.50 | | 69.18 |
| Jan-03 | 10.01 | 310.29 | 4701.02 | 4.12 | 127.83 | 14.13 | 438.11 | 5958.48 | 14.68 | 455.07 | 11.83 | 366.60 | 5381.46 | 71.51 |
| Feb-03 | 10.07 | 281.97 | | 4.02 | 112.65 | 14.09 | 394.63 | | 14.47 | 405.13 | 11.78 | 329.85 | | 64.77 |
| Mar-03 | 9.74 | 301.97 | | 4.58 | 141.91 | 14.32 | 443.88 | | 14.63 | 453.41 | 11.71 | 363.12 | | 80.76 |
| Apr-03 | 11.21 | 336.26 | | 4.03 | 120.93 | 15.24 | 457.19 | | 15.63 | 468.81 | 11.38 | 341.39 | | 115.80 |
| May-03 | 12.45 | 386.02 | | 3.29 | 102.03 | 15.74 | 488.05 | | 16.11 | 499.38 | 13.15 | 407.74 | | 80.32 |
| Jun-03 | 16.06 | 481.90 | | 2.57 | 77.18 | 18.64 | 559.09 | | 18.97 | 569.00 | 17.93 | 538.01 | | 21.08 |
| Jul-03 | 18.89 | 585.71 | | 2.76 | 85.45 | 21.65 | 671.17 | | 22.01 | 682.31 | 21.31 | 660.74 | | 10.43 |
| Aug-03 | 16.92 | 524.40 | | 2.79 | 86.40 | 19.70 | 610.81 | | 20.11 | 623.46 | 18.84 | 583.93 | | 26.88 |
| Sep-03 | 16.57 | 497.23 | | 2.81 | 84.36 | 19.39 | 581.59 | | 19.78 | 593.29 | 18.54 | 556.11 | | 25.48 |
| Oct-03 | 13.03 | 403.91 | | 2.81 | 87.19 | 15.84 | 491.10 | | 16.16 | 500.81 | 14.65 | 454.15 | | 36.95 |
| Nov-03 | 11.09 | 332.65 | | 3.02 | 90.72 | 14.11 | 423.36 | | 14.42 | 432.49 | 13.13 | 394.00 | | 29.36 |
| Dec-03 | 8.35 | 258.71 | | 4.54 | 140.81 | 12.89 | 399.52 | | 13.13 | 407.16 | 12.45 | 385.83 | | 13.69 |
| Jan-04 | 9.23 | 286.10 | 4636.13 | 4.63 | 143.41 | 13.86 | 429.51 | 5799.87 | 14.39 | 445.97 | 13.40 | 415.48 | 5436.70 | 14.03 |
| Feb-04 | 9.44 | 264.44 | | 4.68 | 131.05 | 14.12 | 395.49 | | 14.42 | 403.62 | 13.66 | 382.39 | | 13.10 |
| Mar-04 | 9.58 | 296.84 | | 4.18 | 129.56 | 13.75 | 426.40 | | 14.04 | 435.34 | 13.21 | 409.59 | | 16.81 |
| Apr-04 | 11.82 | 354.53 | | 2.99 | 89.82 | 14.81 | 444.35 | | 15.23 | 456.87 | 14.04 | 421.24 | | 23.11 |
| May-04 | 12.94 | 401.14 | | 2.55 | 78.98 | 15.49 | 480.13 | | 15.95 | 494.50 | 14.58 | 451.85 | | 28.28 |
| Jun-04 | 14.66 | 439.72 | | 2.63 | 78.78 | 17.28 | 518.50 | | 17.79 | 533.56 | 16.24 | 487.17 | | 31.33 |
| Jul-04 | 17.25 | 534.65 | | 2.57 | 79.77 | 19.82 | 614.42 | | 20.34 | 630.47 | 19.05 | 590.46 | | 23.95 |
| Aug-04 | 15.84 | 490.93 | | 2.55 | 79.07 | 18.39 | 570.00 | | 18.86 | 584.67 | 17.47 | 541.51 | | 28.49 |
| Sep-04 | 17.92 | 537.72 | | 2.52 | 75.60 | 20.44 | 613.32 | | 21.00 | 629.91 | 19.54 | 586.29 | | 27.03 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct-04 | 13.41 | 415.65 | | 2.52 | 78.27 | 15.93 | 493.92 | | 16.46 | 510.21 | 14.66 | 454.56 | | 39.36 |
| Nov-04 | 11.00 | 330.05 | | 2.81 | 84.34 | 13.81 | 414.40 | | 14.22 | 426.71 | 11.76 | 352.92 | | 61.47 |
| Dec-04 | 9.17 | 284.36 | | 3.71 | 115.09 | 12.89 | 399.45 | | 13.28 | 411.75 | 11.07 | 343.25 | | 56.21 |
| Jan-05 | 9.58 | 296.89 | 4851.24 | 3.77 | 116.81 | 13.35 | 413.70 | 5975.31 | 13.70 | 424.85 | 11.96 | 370.67 | 5252.57 | 43.03 |
| Feb-05 | 9.51 | 266.14 | | 3.88 | 108.64 | 13.39 | 374.78 | | 13.74 | 384.81 | 11.63 | 325.56 | | 49.22 |
| Mar-05 | 9.00 | 278.87 | | 4.28 | 132.53 | 13.27 | 411.40 | | 13.61 | 421.79 | 11.98 | 371.26 | | 40.14 |
| Apr-05 | 11.52 | 345.66 | | 3.06 | 91.78 | 14.58 | 437.44 | | 14.95 | 448.63 | 13.36 | 400.77 | | 36.67 |
| May-05 | 13.20 | 409.34 | | 2.21 | 68.52 | 15.41 | 477.86 | | 15.81 | 490.11 | 13.79 | 427.36 | | 50.50 |
| Jun-05 | 18.96 | 568.66 | | 2.26 | 67.85 | 21.22 | 636.50 | | 21.72 | 651.57 | 17.90 | 536.89 | | 99.62 |
| Jul-05 | 17.37 | 538.59 | | 2.36 | 73.02 | 19.73 | 611.60 | | 20.32 | 629.79 | 16.56 | 513.41 | | 98.19 |
| Aug-05 | 18.59 | 576.16 | | 2.54 | 78.82 | 21.13 | 654.98 | | 21.79 | 675.34 | 18.12 | 561.61 | | 93.37 |
| Sep-05 | 18.23 | 546.96 | | 2.77 | 82.98 | 21.00 | 629.94 | | 21.57 | 647.13 | 18.42 | 552.47 | | 77.47 |
| Oct-05 | 13.38 | 414.63 | | 2.94 | 91.02 | 16.31 | 505.64 | | 16.81 | 521.18 | 14.52 | 450.16 | | 55.49 |
| Nov-05 | 10.92 | 327.56 | | 3.13 | 93.97 | 14.05 | 421.52 | | 14.41 | 432.39 | 12.57 | 377.21 | | 44.31 |
| Dec-05 | 9.09 | 281.79 | | 3.81 | 118.15 | 12.90 | 399.94 | | 13.25 | 410.70 | 11.78 | 365.21 | | 34.74 |

## b. Ann Arbor Water Treatment Plant – Electrical Consumption

| Date | Total | Total | Treatment | Distribution | Total Electrical | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow | Delivered | Plant | Pumping Sta. | Energy Supplied | | | | | | |
| Month/Yr | MG | MG | kWh | kWh | kWh | kWh/MG | kWh/Yr | GJ | GJ/Yr | GJ/MG-Yr | GJ/MG |
| Jan-00 | 464.65 | 440.94 | 558400.00 | 305280.00 | 863680.00 | 1958.74 | 11631010.00 | 3109.25 | 41871.64 | 8.30 | 7.05 |
| Feb-00 | 425.37 | 415.63 | 543040.00 | 277500.00 | 820540.00 | 1974.19 | | 2953.94 | | | 7.11 |
| Mar-00 | 454.77 | 428.27 | 620800.00 | 354380.00 | 975180.00 | 2277.01 | | 3510.65 | | | 8.20 |
| Apr-00 | 464.11 | 422.86 | 623360.00 | 188920.00 | 812280.00 | 1920.92 | | 2924.21 | | | 6.92 |
| May-00 | 492.45 | 456.35 | 749440.00 | 238560.00 | 988000.00 | 2165.01 | | 3556.80 | | | 7.79 |
| Jun-00 | 531.20 | 481.77 | 679360.00 | 462180.00 | 1141540.00 | 2369.45 | | 4109.54 | | | 8.53 |
| Jul-00 | 577.58 | 514.89 | 678720.00 | 281280.00 | 960000.00 | 1864.47 | | 3456.00 | | | 6.71 |
| Aug-00 | 555.26 | 486.13 | 774080.00 | 519070.00 | 1293150.00 | 2660.08 | | 4655.34 | | | 9.58 |
| Sep-00 | 526.47 | 457.21 | 606720.00 | 409280.00 | 1016000.00 | 2222.20 | | 3657.60 | | | 8.00 |
| Oct-00 | 497.68 | 428.28 | 561920.00 | 368430.00 | 930350.00 | 2172.27 | | 3349.26 | | | 7.82 |
| Nov-00 | 438.61 | 376.59 | 605120.00 | 341190.00 | 946310.00 | 2512.81 | | 3406.72 | | | 9.05 |
| Dec-00 | 427.36 | 365.35 | 589440.00 | 294540.00 | 883980.00 | 2419.54 | | 3182.33 | | | 8.71 |
| Jan-01 | 449.79 | 381.10 | 536960.00 | 304330.00 | 841290.00 | 2207.55 | 29057.98 | 3028.64 | 45129.38 | 8.68 | 7.95 |
| Feb-01 | 414.87 | 349.49 | 590400.00 | 322360.00 | 912760.00 | 2611.72 | | 3285.94 | | | 9.40 |
| Mar-01 | 450.13 | 382.60 | 579520.00 | 350770.00 | 930290.00 | 2431.51 | | 3349.04 | | | 8.75 |
| Apr-01 | 472.16 | 393.03 | 591680.00 | 397720.00 | 989400.00 | 2517.36 | | 3561.84 | | | 9.06 |
| May-01 | 512.14 | 417.58 | 690880.00 | 452060.00 | 1142940.00 | 2737.07 | | 4114.58 | | | 9.85 |
| Jun-01 | 561.01 | 457.09 | 739840.00 | 578150.00 | 1317990.00 | 2883.46 | | 4744.76 | | | 10.38 |
| Jul-01 | 770.40 | 637.53 | 904640.00 | 681090.00 | 1585730.00 | 2487.29 | | 5708.63 | | | 8.95 |
| Aug-01 | 688.08 | 562.37 | 674240.00 | 479150.00 | 1153390.00 | 2050.94 | | 4152.20 | | | 7.38 |
| Sep-01 | 562.43 | 464.45 | 596800.00 | 370860.00 | 967660.00 | 2083.47 | | 3483.58 | | | 7.50 |
| Oct-01 | 512.14 | 417.58 | 537600.00 | 322270.00 | 859870.00 | 2059.18 | | 3095.53 | | | 7.41 |
| Nov-01 | 449.84 | 372.63 | 612480.00 | 349670.00 | 962150.00 | 2582.08 | | 3463.74 | | | 9.30 |
| Dec-01 | 434.09 | 362.57 | 579520.00 | 292950.00 | 872470.00 | 2406.34 | | 3140.89 | | | 8.66 |
| Jan-02 | 438.01 | 368.24 | 586240.00 | 320230.00 | 906470.00 | 2461.63 | 29727.40 | 3263.29 | 44777.74 | 8.88 | 8.86 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb-02 | 389.20 | 333.06 | 513280.00 | 259570.00 | 772850.00 | 2320.45 | | 2782.26 | | | 8.35 |
| Mar-02 | 433.21 | 371.93 | 556800.00 | 316420.00 | 873220.00 | 2347.83 | | 3143.59 | | | 8.45 |
| Apr-02 | 452.03 | 374.56 | 576000.00 | 298230.00 | 874230.00 | 2333.99 | | 3147.23 | | | 8.40 |
| May-02 | 469.50 | 352.94 | 642880.00 | 436630.00 | 1079510.00 | 3058.65 | | 3886.24 | | | 11.01 |
| Jun-02 | 645.81 | 493.45 | 880960.00 | 502760.00 | 1383720.00 | 2804.17 | | 4981.39 | | | 10.10 |
| Jul-02 | 816.61 | 641.97 | 840320.00 | 571780.00 | 1412100.00 | 2199.65 | | 5083.56 | | | 7.92 |
| Aug-02 | 667.21 | 493.21 | 744640.00 | 529380.00 | 1274020.00 | 2583.11 | | 4586.47 | | | 9.30 |
| Sep-02 | 670.22 | 501.35 | 605120.00 | 539340.00 | 1144460.00 | 2282.74 | | 4120.06 | | | 8.22 |
| Oct-02 | 500.49 | 398.82 | 592640.00 | 355570.00 | 948210.00 | 2377.52 | | 3413.56 | | | 8.56 |
| Nov-02 | 436.06 | 367.99 | 586880.00 | 297090.00 | 883970.00 | 2402.14 | | 3182.29 | | | 8.65 |
| Dec-02 | 415.68 | 346.50 | 608640.00 | 276860.00 | 885500.00 | 2555.53 | | 3187.80 | | | 9.20 |
| Jan-03 | 438.11 | 366.60 | 656640.00 | 309950.00 | 966590.00 | 2636.63 | 28085.36 | 3479.72 | 44499.96 | 8.27 | 9.49 |
| Feb-03 | 394.63 | 329.85 | 549120.00 | 255300.00 | 804420.00 | 2438.74 | | 2895.91 | | | 8.78 |
| Mar-03 | 443.88 | 363.12 | 575040.00 | 276940.00 | 851980.00 | 2346.30 | | 3067.13 | | | 8.45 |
| Apr-03 | 457.19 | 341.39 | 629120.00 | 330490.00 | 959610.00 | 2810.87 | | 3454.60 | | | 10.12 |
| May-03 | 488.05 | 407.74 | 716160.00 | 362900.00 | 1079060.00 | 2646.46 | | 3884.62 | | | 9.53 |
| Jun-03 | 559.09 | 538.01 | 813120.00 | 426920.00 | 1240040.00 | 2304.86 | | 4464.14 | | | 8.30 |
| Jul-03 | 671.17 | 660.74 | 863360.00 | 495870.00 | 1359230.00 | 2057.14 | | 4893.23 | | | 7.41 |
| Aug-03 | 610.81 | 583.93 | 647040.00 | 489760.00 | 1136800.00 | 1946.81 | | 4092.48 | | | 7.01 |
| Sep-03 | 581.59 | 556.11 | 762560.00 | 463490.00 | 1226050.00 | 2204.70 | | 4413.78 | | | 7.94 |
| Oct-03 | 491.10 | 454.15 | 591680.00 | 322000.00 | 913680.00 | 2011.83 | | 3289.25 | | | 7.24 |
| Nov-03 | 423.36 | 394.00 | 568000.00 | 279300.00 | 847300.00 | 2150.50 | | 3050.28 | | | 7.74 |
| Dec-03 | 399.52 | 385.83 | 634560.00 | 341780.00 | 976340.00 | 2530.52 | | 3514.82 | | | 9.11 |
| Jan-04 | 429.51 | 415.48 | 701120.00 | 390060.00 | 1091180.00 | 2626.34 | 28677.80 | 3928.25 | 46224.32 | 8.50 | 9.45 |
| Feb-04 | 395.49 | 382.39 | 567360.00 | 404920.00 | 972280.00 | 2542.67 | | 3500.21 | | | 9.15 |
| Mar-04 | 426.40 | 409.59 | 559040.00 | 380010.00 | 939050.00 | 2292.66 | | 3380.58 | | | 8.25 |
| Apr-04 | 444.35 | 421.24 | 636480.00 | 374080.00 | 1010560.00 | 2399.01 | | 3638.02 | | | 8.64 |
| May-04 | 480.13 | 451.85 | 605440.00 | 417330.00 | 1022770.00 | 2263.51 | | 3681.97 | | | 8.15 |
| Jun-04 | 518.50 | 487.17 | 664960.00 | 520410.00 | 1185370.00 | 2433.16 | | 4267.33 | | | 8.76 |
| Jul-04 | 614.42 | 590.46 | 797440.00 | 455280.00 | 1252720.00 | 2121.60 | | 4509.79 | | | 7.64 |
| Aug-04 | 570.00 | 541.51 | 721280.00 | 527400.00 | 1248680.00 | 2305.93 | | 4495.25 | | | 8.30 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| Sep-04 | 613.32 | 586.29 | 811200.00 | 476420.00 | 1287620.00 | 2196.22 | | 4635.43 | | | 7.91 |
| Oct-04 | 493.92 | 454.56 | 649920.00 | 299280.00 | 949200.00 | 2088.19 | | 3417.12 | | | 7.52 |
| Nov-04 | 414.40 | 352.92 | 577920.00 | 304890.00 | 882810.00 | 2501.42 | | 3178.12 | | | 9.01 |
| Dec-04 | 399.45 | 343.25 | 675520.00 | 322330.00 | 997850.00 | 2907.10 | | 3592.26 | | | 10.47 |
| Jan-05 | 413.70 | 370.67 | 570240.00 | 292980.00 | 863220.00 | 2328.84 | 29969.15 | 3107.59 | 47037.82 | 8.96 | 8.38 |
| Feb-05 | 374.78 | 325.56 | 602080.00 | 292230.00 | 894310.00 | 2746.96 | | 3219.52 | | | 9.89 |
| Mar-05 | 411.40 | 371.26 | 633920.00 | 343770.00 | 977690.00 | 2633.45 | | 3519.68 | | | 9.48 |
| Apr-05 | 437.44 | 400.77 | 568000.00 | 351960.00 | 919960.00 | 2295.47 | | 3311.86 | | | 8.26 |
| May-05 | 477.86 | 427.36 | 752000.00 | 499650.00 | 1251650.00 | 2928.77 | | 4505.94 | | | 10.54 |
| Jun-05 | 636.50 | 536.89 | 844800.00 | 548060.00 | 1392860.00 | 2594.33 | | 5014.30 | | | 9.34 |
| Jul-05 | 611.60 | 513.41 | 856320.00 | 518900.00 | 1375220.00 | 2678.58 | | 4950.79 | | | 9.64 |
| Aug-05 | 654.98 | 561.61 | 884160.00 | 593320.00 | 1477480.00 | 2630.81 | | 5318.93 | | | 9.47 |
| Sep-05 | 629.94 | 552.47 | 678720.00 | 441940.00 | 1120660.00 | 2028.47 | | 4034.38 | | | 7.30 |
| Oct-05 | 505.64 | 450.16 | 592320.00 | 310440.00 | 902760.00 | 2005.42 | | 3249.94 | | | 7.22 |
| Nov-05 | 421.52 | 377.21 | 610560.00 | 282490.00 | 893050.00 | 2367.52 | | 3214.98 | | | 8.52 |
| Dec-05 | 399.94 | 365.21 | 699520.00 | 297680.00 | 997200.00 | 2730.52 | | 3589.92 | | | 9.83 |

## c. Ann Arbor Water Treatment Plant – Chemicals Utilized for Treatment

| Date | Water | Chemicals Feed | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Delivered | CaO | Phosphate | Fluoride | CO2 Plant | CO2 Ozone | Coagulant | Cl2:NH3-Y | Polymer | NaOCl | NH3 | O2 | NaOH |
| - | MG | Lbs | Lbs | Lbs | Lbs | Lbs | Lbs | Lbs | Lbs | Lbs | Lbs | Lbs | Lbs |
| Jan-00 | 440.94 | 729590.00 | 3978.00 | 13634.00 | 32680.00 | 82053.00 | 2374.00 | 181.77 | 0.00 | 13254.00 | 3303.00 | 14103.00 | 61912.00 |
| Feb-00 | 415.63 | 728220.00 | 3367.00 | 12595.00 | 37663.00 | 71080.00 | 1937.00 | 183.98 | 0.00 | 12214.00 | 2867.00 | 12346.00 | 45948.00 |
| Mar-00 | 428.27 | 706080.00 | 3807.00 | 14046.00 | 27470.00 | 46719.00 | 2399.00 | 158.29 | 0.00 | 11812.00 | 3304.00 | 8816.00 | 45859.00 |
| Apr-00 | 422.86 | 600070.00 | 4001.00 | 14715.00 | 5433.00 | 41276.00 | 2408.00 | 149.74 | 652.00 | 12726.00 | 3480.00 | 9351.00 | 46166.00 |
| May-00 | 456.35 | 701650.00 | 4316.00 | 17791.00 | 1911.00 | 44137.00 | 2446.00 | 154.87 | 3756.00 | 15329.00 | 4113.00 | 11449.00 | 64527.00 |
| Jun-00 | 481.77 | 707838.00 | 4531.00 | 19520.00 | 425.00 | 61050.00 | 2787.00 | 183.50 | 4256.00 | 18196.00 | 4133.00 | 14206.00 | 96453.00 |
| Jul-00 | 514.89 | 787650.00 | 4884.00 | 20343.00 | 5319.00 | 75100.00 | 2900.00 | 170.47 | 2896.00 | 19892.00 | 4786.00 | 14263.00 | 99056.00 |
| Aug-00 | 486.13 | 743980.00 | 4627.00 | 21187.00 | 4637.00 | 87160.00 | 2894.00 | 165.17 | 4177.00 | 16167.00 | 4355.00 | 17717.00 | 104326.00 |
| Sep-00 | 457.21 | 769110.00 | 4583.00 | 19026.00 | 6598.00 | 77480.00 | 2796.00 | 153.20 | 4385.00 | 15759.00 | 4405.00 | 15541.30 | 88618.00 |
| Oct-00 | 428.28 | 793430.00 | 4202.00 | 18018.00 | 15449.00 | 84880.00 | 3604.00 | 155.79 | 1779.00 | 12836.00 | 3745.00 | 23967.00 | 90405.00 |
| Nov-00 | 376.59 | 719020.00 | 3775.00 | 15414.00 | 31757.00 | 80051.00 | 2363.00 | 153.43 | 1707.00 | 11087.00 | 3275.00 | 21712.00 | 84765.00 |
| Dec-00 | 365.35 | 744940.00 | 3486.00 | 15435.00 | 25161.00 | 70825.00 | 2001.00 | 171.35 | 0.00 | 10966.00 | 2962.00 | 10475.00 | 52444.00 |
| Jan-01 | 381.10 | 820580.00 | 3622.00 | 16433.00 | 59649.00 | 70013.00 | 2287.00 | 173.22 | 0.00 | 11165.00 | 2922.00 | 10086.00 | 54932.00 |
| Feb-01 | 349.49 | 801569.00 | 3469.00 | 14488.00 | 78528.00 | 59847.00 | 2108.00 | 154.79 | 0.00 | 10523.00 | 2792.00 | 9418.81 | 41202.00 |
| Mar-01 | 382.60 | 789750.00 | 3798.00 | 16258.00 | 64052.00 | 56668.00 | 2460.00 | 163.74 | 0.00 | 11792.00 | 3249.00 | 10320.00 | 42427.00 |
| Apr-01 | 393.03 | 650350.00 | 3889.00 | 13521.00 | 28313.00 | 45697.00 | 2401.00 | 153.65 | 835.00 | 12234.00 | 3532.00 | 11828.00 | 54689.00 |
| May-01 | 417.58 | 719560.00 | 3520.00 | 16557.00 | 18198.00 | 60642.00 | 2376.00 | 160.85 | 3291.00 | 13829.00 | 3883.00 | 13293.00 | 89282.00 |
| Jun-01 | 457.09 | 766550.00 | 4230.00 | 17586.00 | 2751.00 | 71317.00 | 2901.00 | 148.20 | 3769.00 | 15463.00 | 4216.00 | 13681.00 | 84586.00 |
| Jul-01 | 637.53 | 1198260.00 | 5979.00 | 27546.00 | 16201.00 | 84906.00 | 3750.00 | 149.44 | 2209.00 | 21859.00 | 5859.00 | 20509.00 | 119051.00 |
| Aug-01 | 562.37 | 1130160.00 | 5298.00 | 25910.00 | 19955.00 | 53999.00 | 3513.00 | 151.44 | 4215.00 | 20234.00 | 5040.00 | 17410.00 | 109736.00 |
| Sep-01 | 464.45 | 855520.00 | 4484.00 | 21126.00 | 5690.00 | 30504.00 | 2907.00 | 131.07 | 3645.00 | 15303.00 | 4432.00 | 12432.00 | 81511.00 |
| Oct-01 | 417.58 | 719560.00 | 3520.00 | 16557.00 | 18198.00 | 60642.00 | 2376.00 | 160.85 | 3291.00 | 13829.00 | 3883.00 | 13293.00 | 89282.00 |
| Nov-01 | 372.63 | 633070.00 | 3692.00 | 14848.00 | 16475.00 | 62530.00 | 2113.00 | 134.14 | 861.00 | 11570.00 | 3416.00 | 7913.00 | 59564.00 |
| Dec-01 | 362.57 | 676880.00 | 3598.00 | 15404.00 | 21546.00 | 69420.00 | 1938.00 | 146.33 | 0.00 | 11060.00 | 3392.00 | 13263.00 | 63481.00 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan-02 | 368.24 | 799160.00 | 3689.00 | 15651.00 | 57217.00 | 49230.00 | 2225.00 | 156.08 | 0.00 | 11288.00 | 3411.00 | 10753.00 | 40015.00 |
| Feb-02 | 333.06 | 730530.00 | 3296.00 | 13058.00 | 60743.00 | 25820.00 | 2024.00 | 145.04 | 0.00 | 9693.00 | 2773.00 | 7383.00 | 30254.00 |
| Mar-02 | 371.93 | 737270.00 | 3713.00 | 14344.00 | 57134.00 | 19890.00 | 2279.00 | 156.37 | 0.00 | 10347.00 | 3158.00 | 7950.00 | 50338.00 |
| Apr-02 | 374.56 | 654690.00 | 3884.00 | 15816.00 | 27902.00 | 43213.00 | 2325.00 | 159.87 | 0.00 | 12465.00 | 3279.00 | 8430.00 | 102335.00 |
| May-02 | 352.94 | 684938.00 | 3927.00 | 16855.00 | 12692.00 | 46441.00 | 2651.00 | 155.21 | 1939.00 | 12410.00 | 3500.00 | 11910.00 | 52788.00 |
| Jun-02 | 493.45 | 840533.00 | 5271.00 | 21470.00 | 4362.00 | 43506.00 | 3283.00 | 148.56 | 2711.00 | 17070.00 | 4659.00 | 15900.00 | 76379.00 |
| Jul-02 | 641.97 | 1114402.00 | 6749.00 | 25088.00 | 4285.00 | 58128.00 | 3715.00 | 150.74 | 3998.00 | 22047.00 | 5994.00 | 20457.00 | 94077.00 |
| Aug-02 | 493.21 | 873084.00 | 5486.00 | 18333.00 | 143.00 | 35252.00 | 3707.00 | 154.65 | 3021.00 | 18877.00 | 4870.00 | 15334.00 | 73816.00 |
| Sep-02 | 501.35 | 887714.00 | 5756.00 | 23214.00 | 21142.00 | 48691.00 | 3728.00 | 142.81 | 677.00 | 18666.00 | 4956.00 | 11921.00 | 79808.00 |
| Oct-02 | 398.82 | 774073.00 | 3937.00 | 17491.00 | 92898.00 | 36406.00 | 2326.00 | 146.83 | 1693.00 | 13412.00 | 3827.00 | 9446.00 | 39444.00 |
| Nov-02 | 367.99 | 670879.00 | 3522.00 | 14701.00 | 106246.00 | 30293.00 | 2090.00 | 142.44 | 0.00 | 10694.00 | 3286.00 | 8036.69 | 26500.00 |
| Dec-02 | 346.50 | 755056.00 | 3377.00 | 12885.00 | 65072.00 | 30259.00 | 2096.00 | 149.09 | 0.00 | 10274.00 | 3135.00 | 6944.00 | 27530.00 |
| Jan-03 | 366.60 | 868149.00 | 3570.00 | 14316.00 | 71123.00 | 30148.00 | 2238.00 | 147.66 | 0.00 | 11671.00 | 3451.00 | 7297.00 | 27141.00 |
| Feb-03 | 329.85 | 708376.00 | 3105.00 | 12706.00 | 27598.00 | 33590.00 | 2211.00 | 145.10 | 0.00 | 10667.00 | 2806.00 | 6394.00 | 28752.00 |
| Mar-03 | 363.12 | 757385.00 | 3559.00 | 15703.00 | 4449.00 | 33473.00 | 2239.00 | 170.39 | 0.00 | 11344.00 | 2961.00 | 8159.00 | 21450.00 |
| Apr-03 | 341.39 | 645223.00 | 3606.00 | 15702.00 | 1560.00 | 27693.00 | 2274.00 | 151.35 | 0.00 | 10953.00 | 3163.00 | 9594.00 | 19357.00 |
| May-03 | 407.74 | 702591.00 | 4191.00 | 17631.00 | 4425.00 | 37606.00 | 2649.00 | 145.39 | 1002.00 | 12298.00 | 3498.00 | 10806.00 | 46109.00 |
| Jun-03 | 538.01 | 767900.00 | 4722.00 | 19228.00 | 18726.00 | 40228.00 | 2675.00 | 130.87 | 1649.00 | 14120.00 | 4775.00 | 12728.00 | 54446.00 |
| Jul-03 | 660.74 | 994543.00 | 4836.00 | 25609.00 | 5255.00 | 36044.00 | 2805.00 | 147.19 | 3378.00 | 18100.00 | 5192.00 | 16944.00 | 77721.00 |
| Aug-03 | 583.93 | 890425.00 | 4388.00 | 21087.00 | 36.00 | 27164.00 | 3011.00 | 149.79 | 2539.00 | 16522.00 | 4618.00 | 13953.00 | 70696.00 |
| Sep-03 | 556.11 | 885857.00 | 4501.00 | 21963.00 | 3282.00 | 34064.00 | 2639.00 | 137.62 | 1844.00 | 15415.00 | 4617.00 | 10457.00 | 44992.00 |
| Oct-03 | 454.15 | 767306.00 | 3725.00 | 15444.00 | 25820.00 | 31820.00 | 2530.00 | 140.79 | 3475.00 | 12933.00 | 3869.00 | 8384.00 | 12460.00 |
| Nov-03 | 394.00 | 772813.00 | 3173.00 | 13437.00 | 40100.00 | 31287.00 | 2323.00 | 131.72 | 0.00 | 10353.00 | 3369.00 | 8102.00 | 15635.00 |
| Dec-03 | 385.83 | 558031.00 | 2867.00 | 11698.00 | 2048.00 | 26130.00 | 1976.00 | 139.48 | 0.00 | 9763.00 | 3159.00 | 7888.00 | 11554.00 |
| Jan-04 | 415.48 | 646678.00 | 3070.00 | 11767.00 | 0.00 | 27073.00 | 2026.00 | 148.61 | 0.00 | 11062.00 | 3326.00 | 6721.15 | 14214.00 |
| Feb-04 | 382.39 | 572135.00 | 2907.00 | 10909.00 | 383.00 | 23503.00 | 1864.00 | 143.10 | 0.00 | 9821.00 | 2832.00 | 6423.00 | 15371.00 |
| Mar-04 | 409.59 | 594458.00 | 3163.00 | 11763.00 | 10630.00 | 23665.00 | 2212.00 | 148.41 | 0.00 | 10338.00 | 3152.00 | 7737.00 | 2426.00 |
| Apr-04 | 421.24 | 690892.00 | 3449.00 | 12600.00 | 124967.00 | 26889.00 | 2603.00 | 148.28 | 0.00 | 11540.00 | 3330.00 | 8417.00 | 2806.00 |
| May-04 | 451.85 | 725016.00 | 3722.00 | 16918.00 | 104866.00 | 12538.00 | 2181.00 | 147.12 | 3804.00 | 13422.00 | 3776.00 | 11291.00 | 6361.00 |
| Jun-04 | 487.17 | 684432.00 | 3861.00 | 18515.00 | 27859.00 | 21851.00 | 2037.00 | 155.10 | 1830.00 | 15960.00 | 4223.00 | 15586.00 | 80871.00 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-04 | 590.46 | 837791.00 | 4761.00 | 21782.00 | 4324.00 | 44052.00 | 2766.00 | 136.88 | 3174.00 | 16792.00 | 4502.00 | 16502.00 | 105437.00 |
| Aug-04 | 541.51 | 779435.00 | 4640.00 | 18874.00 | 0.00 | 47001.00 | 2767.00 | 149.72 | 1622.00 | 17280.00 | 5003.00 | 15861.00 | 97208.00 |
| Sep-04 | 586.29 | 706102.00 | 4280.00 | 19582.00 | 10439.00 | 31819.00 | 2698.00 | 144.73 | 3436.00 | 15325.00 | 4431.00 | 17698.00 | 91514.00 |
| Oct-04 | 454.56 | 634848.00 | 3873.00 | 15009.00 | 6362.00 | 53075.00 | 2472.00 | 135.89 | 1717.00 | 13022.00 | 3849.00 | 9428.00 | 58752.00 |
| Nov-04 | 352.92 | 500045.00 | 3085.00 | 12315.00 | 0.00 | 30724.00 | 2059.00 | 134.50 | 0.00 | 10511.00 | 3548.00 | 7945.00 | 33782.00 |
| Dec-04 | 343.25 | 481017.00 | 3103.00 | 11322.00 | 0.00 | 21122.00 | 2032.00 | 146.58 | 0.00 | 9939.00 | 3265.00 | 8474.00 | 29473.00 |
| Jan-05 | 370.67 | 518985.00 | 3206.00 | 11474.00 | 6493.00 | 47310.00 | 2313.00 | 149.70 | 0.00 | 10469.00 | 3698.00 | 3393.00 | 38184.00 |
| Feb-05 | 325.56 | 506620.00 | 2759.00 | 10834.00 | 31325.00 | 55753.00 | 2245.00 | 149.69 | 0.00 | 9266.00 | 3025.00 | 2849.00 | 55882.00 |
| Mar-05 | 371.26 | 585866.00 | 2935.00 | 13188.00 | 31813.00 | 49231.00 | 2065.00 | 112.70 | 0.00 | 9527.00 | 2523.00 | 8104.00 | 38352.00 |
| Apr-05 | 400.77 | 597553.00 | 3180.00 | 14346.00 | 24314.00 | 44193.00 | 2121.00 | 142.24 | 0.00 | 10557.00 | 3528.00 | 7667.00 | 65699.00 |
| May-05 | 427.36 | 601925.00 | 3515.00 | 16553.00 | 22434.00 | 49986.00 | 2881.00 | 150.02 | 809.00 | 11906.00 | 3783.00 | 7952.00 | 76769.00 |
| Jun-05 | 536.89 | 799809.00 | 4780.00 | 19528.00 | 7529.00 | 58746.00 | 3007.00 | 150.04 | 2518.00 | 16669.00 | 4861.00 | 11627.00 | 106216.00 |
| Jul-05 | 513.41 | 751933.00 | 4476.00 | 19765.00 | 10286.00 | 50583.00 | 3253.00 | 153.83 | 3648.00 | 17629.00 | 4877.00 | 11382.00 | 109228.00 |
| Aug-05 | 561.61 | 812403.00 | 4775.00 | 21157.00 | 7867.00 | 51894.00 | 2645.00 | 144.67 | 2873.00 | 19729.00 | 4899.00 | 16136.00 | 116087.00 |
| Sep-05 | 552.47 | 776669.00 | 4688.00 | 19504.00 | 0.00 | 49229.00 | 2897.00 | 134.07 | 3173.00 | 18370.00 | 5283.00 | 12399.00 | 110113.00 |
| Oct-05 | 450.16 | 609150.00 | 3850.00 | 14774.00 | 3287.00 | 27963.00 | 2531.00 | 139.87 | 2547.00 | 13972.00 | 4069.00 | 7867.00 | 79581.00 |
| Nov-05 | 377.21 | 542122.00 | 2861.00 | 12346.00 | 10290.00 | 31904.00 | 2647.00 | 133.62 | 0.00 | 10931.00 | 3509.00 | 7516.00 | 47039.00 |
| Dec-05 | 365.21 | 541034.00 | 3212.00 | 9058.00 | 19275.00 | 35626.00 | 2223.00 | 144.24 | 0.00 | 10176.00 | 3182.00 | 6985.00 | 44619.00 |

# Appendix A-II

## Ann Arbor Water Treatment Plant Emissions

### a. Global Warming Potential

| Global Warming Potential for 2001 - Electricity | | | | |
|---|---|---|---|---|
| | *g/MJe* | Total for 2001 | *g $CO_2$ eq.//MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 183 | 9001958226.480 | 1731811.228 | 1731.811 |
| Non-fossil Carbon Dioxide | 0.000297 | 14609.735 | 2.811 | 0.003 |
| Methane CH4 | 0.313 | 15396791.939 | 68127.372 | 68.127 |
| Nitrous Oxide | 0.0102 | 501748.491 | 28958.155 | 28.958 |
| **Total GWP** | | | 1828899.565 | 1828.900 |

| Global Warming Potential for 2002 - Electricity | | | | |
|---|---|---|---|---|
| | *g/MJe* | Total for 2002 | *g $CO_2$ eq.//MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 183 | 8931814999.920 | 1770769.603 | 1770.770 |
| Non-fossil Carbon Dioxide | 0.000297 | 14495.896 | 2.874 | 0.003 |
| Methane CH4 | 0.313 | 15276820.191 | 69659.947 | 69.660 |
| Nitrous Oxide | 0.0102 | 497838.869 | 29609.590 | 29.610 |
| **Total GWP** | | | 1870042.014 | 1870.042 |

| Global Warming Potential for 2003 - Electricity | | | | |
|---|---|---|---|---|
| | *g/MJe* | Total for 2003 | *g $CO_2$ eq.//MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 183 | 8876407021.200 | 1649440.937 | 1649.441 |
| Non-fossil Carbon Dioxide | 0.000297 | 14405.972 | 2.677 | 0.003 |
| Methane CH4 | 0.313 | 15182051.353 | 64887.024 | 64.887 |
| Nitrous Oxide | 0.0102 | 494750.555 | 27580.816 | 27.581 |
| **Total GWP** | | | 1741911.453 | 1741.911 |

| Global Warming Potential for 2004 - Electricity | | | | |
|---|---|---|---|---|
| | *g/MJe* | Total for 2004 | *g $CO_2$ eq.//MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 183 | 9220365908.280 | 1695948.372 | 1695.948 |
| Non-fossil Carbon Dioxide | 0.000297 | 14964.200 | 2.752 | 0.003 |
| Methane CH4 | 0.313 | 15770352.619 | 66716.570 | 66.717 |
| Nitrous Oxide | 0.0102 | 513922.034 | 28358.481 | 28.358 |
| **Total GWP** | | | 1791026.176 | 1791.026 |

| Global Warming Potential for 2005 - Electricity | | | | |
|---|---|---|---|---|
| | *g/MJe* | Total for 2004 | *g $CO_2$ eq.//MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 183 | 9382633157.520 | 1786294.467 | 1786.294 |
| Non-fossil Carbon Dioxide | 0.000297 | 15227.552 | 2.899 | 0.003 |
| Methane CH4 | 0.313 | 16047891.685 | 70270.677 | 70.271 |
| Nitrous Oxide | 0.0102 | 522966.438 | 29869.186 | 29.869 |
| **Total GWP** | | | 1886437.229 | 1886.437 |

| Global Warming Potential for 2001- Natural Gas | | | | |
|---|---|---|---|---|
| | *g/1000cuft* | *Total in 2001* | *g $CO_2$ eq.//MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 62142.150 | 1242035152.050 | 238944.724 | 238.945 |
| Non-fossil Carbon Dioxide | 12.701 | 253854.887 | 48.837 | 0.049 |
| Methane CH4 | 172.365 | 3445059.255 | 15243.619 | 15.244 |
| Nitrous Oxide | 0.005 | 99.935 | 5.768 | 0.006 |
| **Total GWP** | | | 254242.948 | 254.243 |

| Global Warming Potential for 2002- Natural Gas | | | | |
|---|---|---|---|---|
| | *g/1000cuft* | *Total in 2002* | *g $CO_2$ eq.//MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 62142.150 | 1517977369.125 | 300945.349 | 300.945 |
| Non-fossil Carbon Dioxide | 12.701 | 310253.678 | 61.509 | 0.062 |
| Methane CH4 | 172.365 | 4210446.038 | 19198.986 | 19.199 |
| Nitrous Oxide | 0.005 | 122.138 | 7.167 | 0.007 |
| **Total GWP** | | | 320213.011 | 320.213 |

| Global Warming Potential for 2003- Natural Gas | | | | |
|---|---|---|---|---|
| | *g/1000cuft* | *Total in 2003* | *g $CO_2$ eq.//MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 62142.150 | 2376446314.515 | 441598.479 | 441.598 |
| Non-fossil Carbon Dioxide | 12.701 | 485712.912 | 90.257 | 0.090 |
| Methane CH4 | 172.365 | 6591599.567 | 28172.035 | 28.172 |
| Nitrous Oxide | 0.005 | 191.211 | 10.517 | 0.0105 |
| **Total GWP** | | | 469871.287 | 469.871 |

| Global Warming Potential for 2004- Natural Gas | | | | |
|---|---|---|---|---|
| | *g/1000cuft* | *Total in 2004* | *g $CO_2$ eq.//MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 62142.150 | 2160539629 | 397398.943 | 397.399 |
| Non-fossil Carbon Dioxide | 12.701 | 441584.5577 | 81.223 | 0.081 |
| Methane CH4 | 172.365 | 5992734.611 | 25352.299 | 25.352 |
| Nitrous Oxide | 0.005 | 173.8385 | 9.465 | 0.00946 |
| **Total GWP** | | | 422841.930 | 422.842 |

| Global Warming Potential for 2005- Natural Gas | | | | |
|---|---|---|---|---|
| | *g/1000cuft* | *Total in 2005* | *g $CO_2$ eq.//MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 62142.150 | 1797039122 | 342125.818 | 342.126 |
| Non-fossil Carbon Dioxide | 12.701 | 0.063505 | 0.00001 | 0.00000001 |
| Methane CH4 | 172.365 | 4984485.543 | 21826.118 | 21.826 |
| Nitrous Oxide | 0.005 | 144.591 | 8.148 | 0.00815 |
| **Total GWP** | | | 363960.084 | 363.960 |

| Global Warming Potential for 2001 - Chemicals | | |
|---|---|---|
| | ***kg $CO_2$ eq./Yr*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 5595299.99 | 1076.433 |
| Methane CH4 | 219404.88 | 42.209 |
| Nitrous Oxide | 24006.80 | 4.618 |
| **Total GWP** | | 1123.261 |

| Global Warming Potential for 2002 - Chemicals | | |
|---|---|---|
| | ***kg $CO_2$ eq./Yr*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 5595299.99 | 1109.292 |
| Methane CH4 | 219404.88 | 43.498 |
| Nitrous Oxide | 24006.80 | 4.759 |
| **Total GWP** | | 1157.549 |

| Global Warming Potential for 2003 - Chemicals | | |
|---|---|---|
| | ***kg $CO_2$ eq./Yr*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 5595299.99 | 1039.736 |
| Methane CH4 | 219404.88 | 40.770 |
| Nitrous Oxide | 24006.80 | 4.461 |
| **Total GWP** | | 1084.967 |

| Global Warming Potential for 2004 - Chemicals | | |
|---|---|---|
| | ***kg $CO_2$ eq./Yr*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 5595299.99 | 1029.172 |
| Methane CH4 | 219404.88 | 40.356 |
| Nitrous Oxide | 24006.80 | 4.416 |
| **Total GWP** | | 1073.944 |

| Global Warming Potential for 2005 - Chemicals | | |
|---|---|---|
| | ***kg $CO_2$ eq./Yr*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 5595299.99 | 1065.250 |
| Methane CH4 | 219404.88 | 41.771 |
| Nitrous Oxide | 24006.80 | 4.570 |
| **Total GWP** | | 1111.592 |

## b. Eutrophication Potential

| Eutrophication Potential for 2001- Electricity | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/MJe* | *Total in 2001* | kg phosphate eq./MG | | *g/MJe* | *Total in 2001* | kg phosphate eq./MG |
| NOx | 0.475 | 23365738.566 | 0.180 | N | | | |
| $NH_3$ | 0.00035 | 17216.860 | 0.000 | $NH_3$ | 0.000151 | 7427.845 | 0.00111 |
| $NH_4$+ | | | | COD | 0.004660 | 229230.193 | 0.002 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.000047 | 2326.736 | 0.00004 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.000000002 | 0.091 | 0.00000004 |
| P | | | | P | | | |
| Total | | | 0.180 | | | | 0.00336 |
| Eutrophication Potential for 2002- Electricity | | | | | | | |
| Atmospheric | | | | Aquatic | | | |
| | *g/MJe* | *Total in 2002* | kg phosphate eq./MG | | *g/MJe* | *Total in 2002* | kg phosphate eq./MG |
| NOx | 0.475 | 23183672.814 | 0.184 | N | | | |
| $NH_3$ | 0.00035 | 17082.706 | 0.000 | $NH_3$ | 0.000151 | 7369.968 | 0.00114 |
| $NH_4$+ | | | | COD | 0.004660 | 227444.032 | 0.00225 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.0000473 | 2308.606 | 0.00005 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.000000002 | 0.090 | 0.00000004 |
| P | | | | P | | | |
| Total | | | 0.184 | | | | 0.00344 |
| Eutrophication Potential for 2003- Electricity | | | | | | | |
| Atmospheric | | | | Aquatic | | | |
| | *g/MJe* | *Total in 2003* | kg phosphate eq./MG | | *g/MJe* | *Total in 2003* | kg phosphate eq./MG |
| NOx | 0.475 | 23039854.290 | 0.171 | N | | | |
| $NH_3$ | 0.00035 | 16976.735 | 0.000 | $NH_3$ | 0.000151 | 7324.248 | 0.00106 |
| $NH_4$+ | | | | COD | 0.00466 | 226033.097 | 0.00210 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.0000473 | 2294.284 | 0.00004 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.000000002 | 0.090 | 0.00000 |
| P | | | | P | | | |
| Total | | | 0.172 | | | | 0.00320 |
| Eutrophication Potential for 2004- Electricity | | | | | | | |
| Atmospheric | | | | Aquatic | | | |
| | *g/MJe* | *Total in 2004* | kg phosphate eq./MG | | *g/MJe* | *Total in 2004* | kg phosphate eq./MG |
| NOx | 0.475 | 21956553.900 | 0.162 | N | | | |
| $NH_3$ | 0.00035 | 16178.513 | 0.000 | $NH_3$ | 0.000151 | 6979.873 | 0.0010 |
| $NH_4$+ | | | | COD | 0.00466 | 215405.350 | 0.0020 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.0000473 | 2186.411 | 0.00004 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.000000002 | 0.086 | 0.00000004 |
| P | | | | P | | | |
| Total | | | 0.162 | | | | 0.00302 |

| Eutrophication Potential for 2005- Electricity | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/MJe* | *Total in 2005* | kg phosphate eq./MG | | *g/MJe* | *Total in 2005* | kg phosphate eq./MG |
| NOx | 0.475 | 22342962.600 | 0.170 | N | | | |
| $NH_3$ | 0.00035 | 16463.236 | 0.000 | $NH_3$ | 0.000151 | 6979.873 | 0.0010 |
| $NH_4$+ | | | | COD | 0.00466 | 215405.350 | 0.0021 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.0000473 | 2186.411 | 0.00004 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.000000002 | 0.086 | 0.00000004 |
| P | | | | P | | | |
| Total | | | 0.171 | | | | 0.00313 |

| Eutrophication Potential for 2001- Natural Gas | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/1000 cuft.* | *Total in 2001* | kg phosphate eq./MG | | *g/1000 cuft.* | *Total in 2001* | kg phosphate eq./MG |
| NOx | 231.332 | 4623632.684 | 0.036 | N | | | |
| $NH_3$ | 1.361 | 27202.307 | 0.00063 | $NH_3$ | 0.027 | 539.649 | 0.0000810 |
| $NH_4$+ | | | | COD | 19.504 | 389826.448 | 0.003750 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.000082 | 1.639 | 0.0000000315 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.005 | 99.935 | 0.0000458 |
| P | | | | P | | | |
| Total | | | 0.036 | | | | 0.00388 |
| Eutrophication Potential for 2002- Natural Gas | | | | | | | |
| Atmospheric | | | | Aquatic | | | |
| | *g/1000 cuft.* | *Total in 2002* | kg phosphate eq./MG | | *g/1000 cuft.* | *Total in 2002* | kg phosphate eq./MG |
| NOx | 231.332 | 5650862.430 | 0.146 | N | | | |
| $NH_3$ | 1.361 | 33245.828 | 0.00231 | $NH_3$ | 0.027 | 659.543 | 0.0000431 |
| $NH_4$+ | | | | COD | 19.504 | 476433.960 | 0.002078 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.000082 | 2.003 | 0.0000000397 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.005 | 122.138 | 0.0000242 |
| P | | | | P | | | |
| Total | | | 0.148 | | | | 0.00215 |
| Eutrophication Potential for 2003- Natural Gas | | | | | | | |
| Atmospheric | | | | Aquatic | | | |
| | *g/1000 cuft.* | *Total in 2003* | kg phosphate eq./MG | | *g/1000 cuft.* | *Total in 2003* | kg phosphate eq./MG |
| NOx | 231.332 | 8846621.477 | 0.214 | N | | | |
| $NH_3$ | 1.361 | 52047.498 | 0.00339 | $NH_3$ | 0.027 | 1032.537 | 0.000063 |
| $NH_4$+ | | | | COD | 19.504 | 745873.918 | 0.00305 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.000082 | 3.136 | 0.000000058 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.005 | 191.211 | 0.0000355 |
| P | | | | P | | | |
| Total | | | 0.217 | | | | 0.00315 |

| Eutrophication Potential for 2004- Natural Gas | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/1000 cuft.* | *Total in 2004* | kg phosphate eq./MG | | *g/1000 cuft.* | *Total in 2004* | kg phosphate eq./MG |
| NOx | 231.332 | 8042881.576 | 0.192 | N | | | |
| $NH_3$ | 1.361 | 47318.840 | 0.00305 | $NH_3$ | 0.027 | 938.728 | 0.000057 |
| $NH_4$+ | | | | COD | 19.504 | 678109.221 | 0.002744 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.000082 | 2.851 | 0.000000052 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.005 | 173.839 | 0.0000320 |
| P | | | | P | | | |
| Total | | | 0.195 | | | | 0.00283 |

| Eutrophication Potential for 2005- Natural Gas | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/1000 cuft.* | *Total in 2005* | kg phosphate eq./MG | | *g/1000 cuft.* | *Total in 2005* | kg phosphate eq./MG |
| NOx | 231.332 | 6689705.042 | 0.166 | N | | | |
| $NH_3$ | 1.361 | 39357.670 | 0.00262 | $NH_3$ | 0.027 | 780.791 | 0.0000491 |
| $NH_4$+ | | | | COD | 19.504 | 564020.573 | 0.002362 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.000082 | 2.371 | 0.0000000451 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.005 | 144.591 | 0.0000275 |
| P | | | | P | | | |
| Total | | | 0.168 | | | | 0.00244 |

| **Eutrophication Potential for 2001- Chemicals** | | | | | |
|---|---|---|---|---|---|
| **Atmospheric** | | | **Aquatic** | | |
| | ***g N/Yr*** | ***g N/MG*** | | ***g N/Yr*** | ***g N/MG*** |
| NOx | 23916 | 4.60 | N | 75 | 0.0144 |
| $NH_3$ | 761 | 0.15 | $NH_3$ | 3.26 | 0.0006 |
| $NH_4$+ | | | COD | 840 | 0.1616 |
| $NO_3^-$ | | | $NO_3^-$ | 89 | 0.0171 |
| $PO_4^{3-}$ | | | $PO_4^{3-}$ | 8 | 0.0015 |
| P | | | P | | |
| **Total** | | 4.75 | | | 0.20 |

| **Eutrophication Potential for 2002- Chemicals** | | | | | |
|---|---|---|---|---|---|
| **Atmospheric** | | | **Aquatic** | | |
| | ***g N/Yr*** | ***g N/MG*** | | ***g N/Yr*** | ***g N/MG*** |
| NOx | 23916 | 4.74 | N | 75 | 0.0148 |
| $NH_3$ | 761 | 0.15 | $NH_3$ | 3.26 | 0.0006 |
| $NH_4$+ | | | COD | 840 | 0.1666 |
| $NO_3^-$ | | | $NO_3^-$ | 89 | 0.0176 |
| $PO_4^{3-}$ | | | $PO_4^{3-}$ | 8 | 0.0015 |
| P | | | P | | |
| **Total** | | 4.89 | | | 0.20 |

| Eutrophication Potential for 2003- Chemicals | | | | | |
|---|---|---|---|---|---|
| Atmospheric | | | Aquatic | | |
| | ***g N/Yr*** | ***g N/MG*** | | ***g N/Yr*** | ***g N/MG*** |
| NOx | 23916 | 4.44 | N | 75 | 0.0139 |
| $NH_3$ | 761 | 0.14 | $NH_3$ | 3 | 0.0006 |
| $NH_4$+ | | | COD | 840 | 0.1561 |
| $NO_3^-$ | | | $NO_3^-$ | 89 | 0.0165 |
| $PO_4^{3-}$ | | | $PO_4^{3-}$ | 8 | 0.0014 |
| P | | | P | | |
| **Total** | | 4.59 | | | 0.19 |

| Eutrophication Potential for 2004- Chemicals | | | | | |
|---|---|---|---|---|---|
| Atmospheric | | | Aquatic | | |
| | ***g N/Yr*** | ***g N/MG*** | | ***g N/Yr*** | ***g N/MG*** |
| NOx | 23916 | 4.40 | N | 75 | 0.0137 |
| $NH_3$ | 761 | 0.14 | $NH_3$ | 3 | 0.0006 |
| $NH_4$+ | | | COD | 840 | 0.1545 |
| $NO_3^-$ | | | $NO_3^-$ | 89 | 0.0163 |
| $PO_4^{3-}$ | | | $PO_4^{3-}$ | 8 | 0.0014 |
| P | | | P | | |
| **Total** | | 4.54 | | | 0.19 |

| Eutrophication Potential for 2005- Chemicals | | | | | |
|---|---|---|---|---|---|
| Atmospheric | | | Aquatic | | |
| | ***g N/Yr*** | ***g N/MG*** | | ***g N/Yr*** | ***g N/MG*** |
| NOx | 23916 | 4.55 | N | 75 | 0.0142 |
| $NH_3$ | 761 | 0.14 | $NH_3$ | 3 | 0.0006 |
| $NH_4$+ | | | COD | 840 | 0.1599 |
| $NO_3^-$ | | | $NO_3^-$ | 89 | 0.0169 |
| $PO_4^{3-}$ | | | $PO_4^{3-}$ | 8 | 0.0014 |
| P | | | P | | |
| **Total** | | 4.70 | | | 0.19 |

## c. Acidification Potential

| Acidification Potential for 2001- Electricity | | | |
|---|---|---|---|
| | ***g/MJe*** | ***Total in 2001*** | ***moles of H+ eq./MG*** |
| $SO_2$ | 38.042 | 1871310843.081 | 360.006 |
| HCl | 3.356 | 165086961.106 | 31.760 |
| NOx | 19.019 | 935564172.183 | 179.985 |
| $NH_3$ | 0.033 | 1644037.961 | 0.316 |
| Total | | | 572.067 |

| Acidification Potential for 2002- Electricity | | | |
|---|---|---|---|
| | ***g/MJe*** | ***Total in 2002*** | ***moles of H+ eq./MG*** |
| $SO_2$ | 38.042 | 1856729595.632 | 368.104 |
| HCl | 3.3560 | 163800604.091 | 32.474 |
| NOx | 19.019 | 928274259.473 | 184.034 |
| $NH_3$ | 0.033 | 1631227.623 | 0.323 |
| Total | | | 584.936 |

| Acidification Potential for 2003- Electricity | | | |
|---|---|---|---|
| | ***g/MJe*** | ***Total in 2003*** | ***moles of H+ eq./MG*** |
| $SO_2$ | 38.042 | 1845211485 | 342.883 |
| HCl | 3.356 | 162784476.9 | 30.249 |
| NOx | 19.019 | 922515765.8 | 171.425 |
| $NH_3$ | 0.033 | 1621108.4 | 0.301 |
| Total | | | 544.858 |

| Acidification Potential for 2004- Electricity | | | |
|---|---|---|---|
| | ***g/MJe*** | ***Total in 2004*** | ***moles of H+ eq./MG*** |
| $SO_2$ | 38.042 | 1758452328.554 | 323.441 |
| HCl | 3.356 | 155130587.868 | 28.534 |
| NOx | 19.019 | 879140418.156 | 161.705 |
| $NH_3$ | 0.033 | 1544886.245 | 0.284 |
| Total | | | 513.964 |

| Acidification Potential for 2005- Electricity | | | |
|---|---|---|---|
| | ***g/MJe*** | ***Total in 2005*** | ***moles of H+ eq./MG*** |
| $SO_2$ | 38.042 | 1789398955.305 | 340.671 |
| HCl | 3.356 | 157860697.933 | 30.054 |
| NOx | 19.019 | 894612222.504 | 170.319 |
| $NH_3$ | 0.033 | 1572074.367 | 0.299 |
| Total | | | 541.344 |

| Acidification Potential for 2001- Natural Gas | | | |
|---|---|---|---|
| | ***g/MJe*** | ***Total in 2001*** | ***moles of H+ eq./MG*** |
| $SO_2$ | 893.577 | 178599.235 | 1.229 |
| HCl | 0.044 | 8.79428 | 0.000097 |
| NOx | 231.332 | 46236.32684 | 0.251 |
| $NH_3$ | 1.361 | 272.02307 | 0.00352 |
| Total | | | 1.483 |

| Acidification Potential for 2002- Natural Gas | | | |
|---|---|---|---|
| | ***g/1000 cuft*** | ***Total in 2002*** | ***moles of H+ eq./MG*** |
| $SO_2$ | 893.577 | 218278.5217 | 2.198 |
| HCl | 0.044 | 10.7481 | 0.000173 |
| NOx | 231.332 | 56508.6243 | 0.449 |
| $NH_3$ | 1.361 | 332.458275 | 0.0063 |
| Total | | | 2.653 |

| Acidification Potential for 2003- Natural Gas | | | |
|---|---|---|---|
| | ***g/1000 cuft*** | ***Total in 2003*** | ***moles of H+ eq./MG*** |
| $SO_2$ | 893.577 | 341722.6099 | 3.225 |
| HCl | 0.044 | 16.826524 | 0.000254 |
| NOx | 231.332 | 88466.21477 | 0.658 |
| $NH_3$ | 1.361 | 520.474981 | 0.0092 |
| Total | | | 3.893 |

| Acidification Potential for 2004- Natural Gas | | | |
|---|---|---|---|
| | ***g/1000 cuft*** | ***Total in 2004*** | ***moles of H+ eq./MG*** |
| $SO_2$ | 893.577 | 310676.1706 | 2.902 |
| HCl | 0.044 | 15.297788 | 0.000229 |
| NOx | 231.332 | 80428.81576 | 0.592 |
| $NH_3$ | 1.361 | 473.188397 | 0.0083 |
| Total | | | 3.503 |

| Acidification Potential for 2005- Natural Gas | | | |
|---|---|---|---|
| | ***g/1000 cuft*** | ***Total in 2005*** | ***moles of H+ eq./MG*** |
| $SO_2$ | 893.577 | 258406.384 | 2.499 |
| HCl | 0.044 | 12.724008 | 0.000197 |
| NOx | 231.332 | 66897.05042 | 0.510 |
| $NH_3$ | 1.361 | 393.576702 | 0.0072 |
| Total | | | 3.016 |

| Acidification Potential for 2001-Chemicals | | |
|---|---|---|
| | ***moles H+ eq./Yr*** | ***moles H+ eq./MG*** |
| $SO_2$ | 250959 | 48 |
| HCl | 36391 | 7.00 |
| NOx | 195174 | 38 |
| $NH_3$ | 132834 | 25.55 |
| Total | | 118 |

| Acidification Potential for 2002-Chemicals | | |
|---|---|---|
| | ***moles H+ eq./Yr*** | ***moles H+ eq./MG*** |
| $SO_2$ | 250959 | 50 |
| HCl | 36391 | 7.21 |
| NOx | 195174 | 39 |
| $NH_3$ | 132834 | 26.33 |
| Total | | 122 |

| Acidification Potential for 2003-Chemicals | | |
|---|---|---|
| | ***moles H+ eq./Yr*** | ***moles H+ eq./MG*** |
| $SO_2$ | 250959 | 47 |
| HCl | 36391 | 6.76 |
| NOx | 195174 | 36 |
| $NH_3$ | 132834 | 24.68 |
| Total | | 114 |

| Acidification Potential for 2004-Chemicals | | |
|---|---|---|
| | ***moles H+ eq./Yr*** | ***moles H+ eq./MG*** |
| $SO_2$ | 250959 | 46 |
| HCl | 36391 | 6.69 |
| NOx | 195174 | 36 |
| $NH_3$ | 132834 | 24.43 |
| Total | | 113 |

| Acidification Potential for 2005-Chemicals | | |
|---|---|---|
| | ***moles H+ eq./Yr*** | ***moles H+ eq./MG*** |
| $SO_2$ | 250959 | 48 |
| HCl | 36391 | 6.93 |
| NOx | 195174 | 37 |
| $NH_3$ | 132834 | 25.29 |
| Total | | 117 |

# Appendix B-I

## Ann Arbor Wastewater Treatment Plant Energy Consumption

### a. Ann Arbor Wastewater Treatment Plant - Total Flow

| Date | Total Flow | | |
|---|---|---|---|
| | | | |
| Month/Year | MGD | MG | MG/Yr |
| Jan-00 | 17.10 | 530.20 | 6841.90 |
| Feb-00 | 18.21 | 509.90 | |
| Mar-00 | 17.36 | 538.30 | |
| Apr-00 | 18.44 | 553.10 | |
| May-00 | 19.41 | 601.60 | |
| Jun-00 | 20.73 | 622.00 | |
| Jul-00 | 19.27 | 597.40 | |
| Aug-00 | 19.77 | 612.80 | |
| Sep-00 | 20.07 | 602.00 | |
| Oct-00 | 18.95 | 587.50 | |
| Nov-00 | 17.96 | 538.80 | |
| Dec-00 | 17.69 | 548.30 | |
| Jan-01 | 18.50 | 573.40 | 7093.30 |
| Feb-01 | 22.91 | 641.50 | |
| Mar-01 | 19.36 | 600.30 | |
| Apr-01 | 19.84 | 595.20 | |
| May-01 | 19.44 | 602.70 | |
| Jun-01 | 19.75 | 592.50 | |
| Jul-01 | 17.75 | 550.40 | |
| Aug-01 | 18.26 | 566.20 | |
| Sep-01 | 18.74 | 562.20 | |
| Oct-01 | 21.58 | 668.90 | |
| Nov-01 | 18.59 | 557.60 | |
| Dec-01 | 18.79 | 582.40 | |
| Jan-02 | 17.89 | 554.50 | 6903.40 |
| Feb-02 | 21.94 | 614.40 | |
| Mar-02 | 20.59 | 638.30 | |
| Apr-02 | 21.59 | 647.70 | |
| May-02 | 19.32 | 599.00 | |
| Jun-02 | 18.16 | 544.80 | |
| Jul-02 | 18.07 | 560.20 | |
| Aug-02 | 18.37 | 569.50 | |
| Sep-02 | 18.98 | 569.40 | |
| Oct-02 | 18.08 | 560.40 | |
| Nov-02 | 17.87 | 536.20 | |
| Dec-02 | 16.42 | 509.00 | |
| Jan-03 | 16.64 | 515.70 | 6582.60 |
| Feb-03 | 16.22 | 454.10 | |
| Mar-03 | 18.27 | 566.30 | |
| Apr-03 | 19.89 | 596.80 | |

| | | | |
|---|---|---|---|
| May-03 | 19.47 | 603.60 | |
| Jun-03 | 18.00 | 539.90 | |
| Jul-03 | 17.66 | 547.50 | |
| Aug-03 | 18.20 | 564.10 | |
| Sep-03 | 18.85 | 565.40 | |
| Oct-03 | 17.61 | 545.80 | |
| Nov-03 | 18.22 | 546.70 | |
| Dec-03 | 17.31 | 536.70 | |
| Jan-04 | 17.46 | 541.20 | 6746.80 |
| Feb-04 | 17.82 | 499.00 | |
| Mar-04 | 21.28 | 659.80 | |
| Apr-04 | 18.31 | 549.30 | |
| May-04 | 21.80 | 675.80 | |
| Jun-04 | 19.48 | 584.40 | |
| Jul-04 | 17.70 | 548.70 | |
| Aug-04 | 17.85 | 553.50 | |
| Sep-04 | 18.19 | 545.80 | |
| Oct-04 | 17.27 | 535.50 | |
| Nov-04 | 17.13 | 514.00 | |
| Dec-04 | 17.41 | 539.80 | |
| Jan-05 | 19.88 | 616.30 | 6696.80 |
| Feb-05 | 20.20 | 565.50 | |
| Mar-05 | 19.57 | 606.60 | |
| Apr-05 | 18.28 | 548.40 | |
| May-05 | 16.97 | 526.20 | |
| Jun-05 | 18.07 | 542.00 | |
| Jul-05 | 19.38 | 600.80 | |
| Aug-05 | 17.80 | 551.90 | |
| Sep-05 | 18.29 | 548.70 | |
| Oct-05 | 17.43 | 540.30 | |
| Nov-05 | 18.10 | 543.10 | |
| Dec-05 | 16.35 | 507.00 | |

## b. Ann Arbor Wastewater Treatment Plant – Electricity Consumption

| Date | Total Flow | Electricity Supplied to the Plant | | | Generator | | Electrical Energy | | Electrical Energy | | Electricity used per | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | North Feed | South Feed | Total | | Fuel | for WWTP Operation | | for WWTP Operation | | MG WW Treated | |
| Month/Yr | MG | kWh | kWh | kWh | kWh | gallons | kWh | kWh/MG | GJ | GJ/Yr | GJ/MG | GJ/MG-Yr |
| Jan-00 | 530.20 | 851575.20 | 352896.20 | 1204471.40 | 1868.60 | 218.84 | 1206340.00 | 2275.25 | 4342.82 | 49416.35 | 8.19 | 7.22 |
| Feb-00 | 509.90 | 897338.00 | 190336.90 | 1087674.90 | 0.00 | 0.00 | 1087674.90 | 2133.11 | 3915.63 | | 7.68 | |
| Mar-00 | 538.30 | 770771.20 | 394930.90 | 1165702.10 | 0.00 | 0.00 | 1165702.10 | 2165.52 | 4196.53 | | 7.80 | |
| Apr-00 | 553.10 | 367093.40 | 751948.10 | 1119041.50 | 0.00 | 0.00 | 1119041.50 | 2023.22 | 4028.55 | | 7.28 | |
| May-00 | 601.60 | 366910.70 | 722520.90 | 1089431.60 | 7929.80 | 4.20 | 1097361.40 | 1824.07 | 3950.50 | | 6.57 | |
| Jun-00 | 622.00 | 413479.40 | 667020.90 | 1080500.30 | 0.00 | 0.00 | 1080500.30 | 1737.14 | 3889.80 | | 6.25 | |
| Jul-00 | 597.40 | 367896.80 | 677903.70 | 1045800.50 | 0.00 | 0.00 | 1045800.50 | 1750.59 | 3764.88 | | 6.30 | |
| Aug-00 | 612.80 | 395631.80 | 658836.00 | 1054467.80 | 0.00 | 0.00 | 1054467.80 | 1720.74 | 3796.08 | | 6.19 | |
| Sep-00 | 602.00 | 354374.20 | 726643.20 | 1081017.40 | 0.00 | 0.00 | 1081017.40 | 1795.71 | 3891.66 | | 6.46 | |
| Oct-00 | 587.50 | 413235.40 | 784282.10 | 1197517.50 | 0.00 | 0.00 | 1197517.50 | 2038.33 | 4311.06 | | 7.34 | |
| Nov-00 | 538.80 | 413030.40 | 824194.00 | 1237224.40 | 0.00 | 0.00 | 1237224.40 | 2296.26 | 4454.01 | | 8.27 | |
| Dec-00 | 548.30 | 474250.50 | 879866.40 | 1354116.90 | 0.00 | 0.00 | 1354116.90 | 2469.66 | 4874.82 | | 8.89 | |
| Jan-01 | 573.40 | 825544.40 | 488499.30 | 1314043.70 | 0.00 | 0.00 | 1314043.70 | 2291.67 | 4730.56 | 54298.94 | 8.25 | 7.65 |
| Feb-01 | 641.50 | 928460.70 | 307567.70 | 1236028.40 | 0.00 | 0.00 | 1236028.40 | 1926.78 | 4449.70 | | 6.94 | |
| Mar-01 | 600.30 | 531627.70 | 795832.60 | 1327460.30 | 0.00 | 0.00 | 1327460.30 | 2211.33 | 4778.86 | | 7.96 | |
| Apr-01 | 595.20 | 437623.30 | 840822.80 | 1278446.10 | 0.00 | 0.00 | 1278446.10 | 2147.93 | 4602.41 | | 7.73 | |
| May-01 | 602.70 | 425808.00 | 783940.10 | 1209748.10 | 93.50 | 0.00 | 1209841.60 | 2007.37 | 4355.43 | | 7.23 | |
| Jun-01 | 592.50 | 520619.20 | 638605.60 | 1159224.80 | 1157.90 | 0.00 | 1160382.70 | 1958.45 | 4177.38 | | 7.05 | |
| Jul-01 | 550.40 | 471705.90 | 767905.70 | 1239611.60 | 0.00 | 0.00 | 1239611.60 | 2252.20 | 4462.60 | | 8.11 | |
| Aug-01 | 566.20 | 913089.70 | 305137.40 | 1218227.10 | 0.00 | 0.00 | 1218227.10 | 2151.58 | 4385.62 | | 7.75 | |
| Sep-01 | 562.20 | 563819.30 | 647346.20 | 1211165.50 | 0.00 | 0.00 | 1211165.50 | 2154.33 | 4360.20 | | 7.76 | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct-01 | 668.90 | 453685.90 | 858569.70 | 1312255.60 | 0.00 | 0.00 | 1312255.60 | 1961.81 | 4724.12 | | 7.06 | |
| Nov-01 | 557.60 | 399129.40 | 865054.10 | 1264183.50 | 0.00 | 0.00 | 1264183.50 | 2267.19 | 4551.06 | | 8.16 | |
| Dec-01 | 582.40 | 624784.60 | 686608.00 | 1311392.60 | 0.00 | 0.00 | 1311392.60 | 2251.70 | 4721.01 | | 8.11 | |
| Jan-02 | 554.50 | 896333.00 | 377002.30 | 1273335.30 | 0.00 | 0.00 | 1273335.30 | 2296.37 | 4584.01 | 52497.91 | 8.27 | 7.60 |
| Feb-02 | 614.40 | 871113.80 | 328336.50 | 1199450.30 | 0.00 | 0.00 | 1199450.30 | 1952.23 | 4318.02 | | 7.03 | |
| Mar-02 | 638.30 | 728696.60 | 584737.10 | 1313433.70 | 0.00 | 0.00 | 1313433.70 | 2057.71 | 4728.36 | | 7.41 | |
| Apr-02 | 647.70 | 549736.50 | 736013.70 | 1285750.20 | 0.00 | 0.00 | 1285750.20 | 1985.10 | 4628.70 | | 7.15 | |
| May-02 | 599.00 | 393921.80 | 742045.70 | 1135967.50 | 0.00 | 0.00 | 1135967.50 | 1896.44 | 4089.48 | | 6.83 | |
| Jun-02 | 544.80 | 497282.80 | 591140.00 | 1088422.80 | 0.00 | 0.00 | 1088422.80 | 1997.84 | 3918.32 | | 7.19 | |
| Jul-02 | 560.20 | 507489.20 | 609668.50 | 1117157.70 | 0.00 | 0.00 | 1117157.70 | 1994.21 | 4021.77 | | 7.18 | |
| Aug-02 | 569.50 | 838739.80 | 308559.60 | 1147299.40 | 0.00 | 0.00 | 1147299.40 | 2014.57 | 4130.28 | | 7.25 | |
| Sep-02 | 569.40 | 951660.70 | 248845.70 | 1200506.40 | 0.00 | 0.00 | 1200506.40 | 2108.37 | 4321.82 | | 7.59 | |
| Oct-02 | 560.40 | 944484.80 | 324424.60 | 1268909.40 | 0.00 | 0.00 | 1268909.40 | 2264.29 | 4568.07 | | 8.15 | |
| Nov-02 | 536.20 | 930297.10 | 334490.60 | 1264787.70 | 0.00 | 0.00 | 1264787.70 | 2358.80 | 4553.24 | | 8.49 | |
| Dec-02 | 509.00 | 509738.50 | 777993.60 | 1287732.10 | 0.00 | 0.00 | 1287732.10 | 2529.93 | 4635.84 | | 9.11 | |
| Jan-03 | 515.70 | 429921.30 | 903949.20 | 1333870.50 | 0.00 | 0.00 | 1333870.50 | 2586.52 | 4801.93 | 53229.44 | 9.31 | 8.09 |
| Feb-03 | 454.10 | 787367.90 | 382775.30 | 1170143.20 | 0.00 | 0.00 | 1170143.20 | 2576.84 | 4212.52 | | 9.28 | |
| Mar-03 | 566.30 | 501816.90 | 852791.00 | 1354607.90 | 0.00 | 0.00 | 1354607.90 | 2392.03 | 4876.59 | | 8.61 | |
| Apr-03 | 596.80 | 832947.80 | 397420.70 | 1230368.50 | 0.00 | 0.00 | 1230368.50 | 2061.61 | 4429.33 | | 7.42 | |
| May-03 | 603.60 | 916891.50 | 308130.00 | 1225021.50 | 3330.00 | 2.00 | 1228351.50 | 2035.04 | 4422.07 | | 7.33 | |
| Jun-03 | 539.90 | 406072.80 | 779570.20 | 1185643.00 | 0.00 | 0.00 | 1185643.00 | 2196.04 | 4268.31 | | 7.91 | |
| Jul-03 | 547.50 | 807215.10 | 382867.70 | 1190082.80 | 0.00 | 0.00 | 1190082.80 | 2173.67 | 4284.30 | | 7.83 | |
| Aug-03 | 564.10 | 589241.60 | 575177.80 | 1164419.40 | 13935.00 | 484.80 | 1178354.40 | 2088.91 | 4242.08 | | 7.52 | |
| Sep-03 | 565.40 | 514463.00 | 700234.40 | 1214697.40 | 0.00 | 0.00 | 1214697.40 | 2148.39 | 4372.91 | | 7.73 | |
| Oct-03 | 545.80 | 475784.10 | 774807.60 | 1250591.70 | 0.00 | 0.00 | 1250591.70 | 2291.30 | 4502.13 | | 8.25 | |
| Nov-03 | 546.70 | 390824.20 | 817718.90 | 1208543.10 | 0.00 | 0.00 | 1208543.10 | 2210.61 | 4350.76 | | 7.96 | |
| Dec-03 | 536.70 | 412269.00 | 828433.30 | 1240702.30 | 0.00 | 0.00 | 1240702.30 | 2311.72 | 4466.53 | | 8.32 | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan-04 | 541.20 | 478306.70 | 768741.90 | 1247048.60 | 379.00 | 0.00 | 1247427.60 | 2304.93 | 4490.74 | 52095.54 | 8.30 | 7.72 |
| Feb-04 | 499.00 | 773573.60 | 369940.00 | 1143513.60 | 0.00 | 0.00 | 1143513.60 | 2291.61 | 4116.65 | | 8.25 | |
| Mar-04 | 659.80 | 874384.60 | 361036.30 | 1235420.90 | 0.00 | 0.00 | 1235420.90 | 1872.42 | 4447.52 | | 6.74 | |
| Apr-04 | 549.30 | 750259.30 | 442218.20 | 1192477.50 | 650.00 | 5.00 | 1193127.50 | 2172.09 | 4295.26 | | 7.82 | |
| May-04 | 675.80 | 553375.10 | 671067.90 | 1224443.00 | 0.00 | 0.00 | 1224443.00 | 1811.84 | 4407.99 | | 6.52 | |
| Jun-04 | 584.40 | 357031.50 | 822705.80 | 1179737.30 | 39124.00 | 0.00 | 1218861.30 | 2085.66 | 4387.90 | | 7.51 | |
| Jul-04 | 548.70 | 414128.70 | 752823.20 | 1166951.90 | 49.70 | 117.23 | 1167001.60 | 2126.85 | 4201.21 | | 7.66 | |
| Aug-04 | 553.50 | 408497.80 | 817818.80 | 1226316.60 | 377.00 | 0.00 | 1226693.60 | 2216.25 | 4416.10 | | 7.98 | |
| Sep-04 | 545.80 | 464986.10 | 757133.10 | 1222119.20 | 0.00 | 0.00 | 1222119.20 | 2239.13 | 4399.63 | | 8.06 | |
| Oct-04 | 535.50 | 879138.60 | 341550.70 | 1220689.30 | 0.00 | 0.00 | 1220689.30 | 2279.53 | 4394.48 | | 8.21 | |
| Nov-04 | 514.00 | 863229.10 | 279737.40 | 1142966.50 | 0.00 | 0.00 | 1142966.50 | 2223.67 | 4114.68 | | 8.01 | |
| Dec-04 | 539.80 | 729420.50 | 499299.70 | 1228720.20 | 0.00 | 0.00 | 1228720.20 | 2276.25 | 4423.39 | | 8.19 | |
| Jan-05 | 616.30 | 705500.80 | 283324.10 | 988824.90 | 0.00 | 0.00 | 988824.90 | 1604.45 | 3559.77 | | 5.78 | |
| Jul-05 | 600.80 | 665157.70 | 210262.80 | 875420.50 | 0.00 | 0.00 | 875420.50 | 1457.09 | 3151.51 | | 5.25 | |
| Aug-05 | 551.90 | 591410.40 | 263935.70 | 855346.10 | 0.00 | 0.00 | 855346.10 | 1549.82 | 3079.25 | | 5.58 | |
| Sep-05 | 548.70 | 282014.40 | 572570.00 | 854584.40 | 0.00 | 0.00 | 854584.40 | 1557.47 | 3076.50 | | 5.61 | |
| Oct-05 | 540.30 | 331913.00 | 580927.60 | 912840.60 | 0.00 | 0.00 | 912840.60 | 1689.51 | 3286.23 | | 6.08 | |
| Nov-05 | 543.10 | 667434.50 | 217532.20 | 884966.70 | 0.00 | 0.00 | 884966.70 | 1629.47 | 3185.88 | | 5.87 | |
| Dec-05 | 507.00 | 733134.90 | 190362.40 | 923497.30 | 0.00 | 0.00 | 923497.30 | 1821.49 | 3324.59 | | 6.56 | |

## c. Ann Arbor Wastewater Treatment Plant – Natural Gas Consumption

| Date | Natural Gas Consumption | | | | | | |
|---|---|---|---|---|---|---|---|
| | Boilers | Retention Bldg | Admin Bldg | Total | | | |
| Month/Year | CCF | CCF | CCF | Cuft | Cuft/MG | GJ | GJ/Yr |
| Jul-02 | 570.00 | | | 57000.00 | 101.75 | 69.76 | |
| Aug-02 | 12.00 | | | 1200.00 | 2.11 | 1.47 | |
| Sep-02 | 2.00 | | | 200.00 | 0.35 | 0.24 | |
| Oct-02 | 19165.00 | | | 1916500.00 | 3419.88 | 2345.63 | |
| Nov-02 | 23372.00 | | | 2337200.00 | 4358.82 | 2860.54 | |
| Dec-02 | 27246.60 | | | 2724660.00 | 5352.97 | 3334.75 | |
| Jan-03 | 33772.00 | | | 3377200.00 | 6548.77 | 4133.41 | 24660.43 |
| Feb-03 | 28407.00 | 2358.00 | 2498.00 | 3326300.00 | 7325.04 | 4071.11 | |
| Mar-03 | 27075.00 | 2047.00 | 2122.00 | 3124400.00 | 5517.22 | 3824.00 | |
| Apr-03 | 18814.00 | 0.00 | 1201.00 | 2001500.00 | 3353.72 | 2449.67 | |
| May-03 | 125.00 | 0.00 | 207.00 | 33200.00 | 55.00 | 40.63 | |
| Jun-03 | 68.00 | 0.00 | 106.00 | 17400.00 | 32.23 | 21.30 | |
| Jul-03 | 57.00 | 0.00 | 103.00 | 16000.00 | 29.22 | 19.58 | |
| Aug-03 | 87.00 | 0.00 | 103.00 | 19000.00 | 33.68 | 23.25 | |
| Sep-03 | 449.00 | 0.00 | 288.00 | 73700.00 | 130.35 | 90.20 | |
| Oct-03 | 19752.00 | 0.00 | 1733.00 | 2148500.00 | 3936.42 | 2629.58 | |
| Nov-03 | 13766.00 | 0.00 | 4067.00 | 1783300.00 | 3261.94 | 2182.61 | |
| Dec-03 | 36908.00 | 0.00 | 5375.00 | 4228300.00 | 7878.33 | 5175.08 | |
| Jan-04 | 39988.00 | 2149.90 | 5011.00 | 4714890.00 | 8711.92 | 5770.63 | 30802.53 |
| Feb-04 | 36077.00 | 2565.00 | 3804.00 | 4244600.00 | 8506.21 | 5195.03 | |
| Mar-04 | 33125.00 | 0.00 | 4091.00 | 3721600.00 | 5640.50 | 4554.92 | |
| Apr-04 | 26860.00 | 0.00 | 2592.00 | 2945200.00 | 5361.73 | 3604.68 | |
| May-04 | 10038.00 | 0.00 | 895.00 | 1093300.00 | 1617.79 | 1338.11 | |
| Jun-04 | 164.00 | 0.00 | 95.00 | 25900.00 | 44.32 | 31.70 | |
| Jul-04 | 85.00 | 0.00 | 86.00 | 17100.00 | 31.16 | 20.93 | |
| Aug-04 | 108.00 | 0.00 | 85.00 | 19300.00 | 34.87 | 23.62 | |
| Sep-04 | 340.10 | 0.00 | 368.00 | 70810.00 | 129.74 | 86.67 | |

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|---|---|---|---|---|---|---|---|
| Oct-04 | 11723.00 | 0.00 | 2357.00 | 1408000.00 | 2629.32 | 1723.27 | |
| Nov-04 | 25620.00 | 0.00 | 3954.00 | 2957400.00 | 5753.70 | 3619.61 | |
| Dec-04 | 33772.00 | 0.00 | 5719.00 | 3949100.00 | 7315.86 | 4833.37 | |
| Jan-05 | 36163.00 | 0.00 | 6055.50 | 4221850.00 | 6850.32 | 5167.19 | |
| Jul-05 | 29.00 | 0.00 | 72.00 | 10100.00 | 16.81 | 12.36 | |
| Aug-05 | 31.00 | 0.00 | 69.00 | 10000.00 | 18.12 | 12.24 | |
| Sep-05 | 30.00 | 0.00 | 134.50 | 16450.00 | 29.98 | 20.13 | |
| Oct-05 | 9504.00 | 0.00 | 1962.60 | 1146660.00 | 2122.27 | 1403.42 | |
| Nov-05 | 17527.00 | 0.00 | 2180.00 | 1970700.00 | 3628.61 | 2411.97 | |
| Dec-05 | 29262.00 | 0.00 | 3517.00 | 3277900.00 | 6465.29 | 4011.87 | |

## d. Ann Arbor Wastewater Treatment Plant – Chemicals Utilized for Treatment

| Date | Ferric Chloride ($FeCl3-$) | | Energy for producing | Lime (CaO) | |
|---|---|---|---|---|---|
| | Total | $FeCl^{3-}$ | $FeCl^{3-}$ | Total | |
| | Lbs | Lbs/MG | kWh | Lbs | Lbs/MG |
| Jan-00 | 261616.04 | 493.43 | 13080.80 | 338868.66 | 639.13 |
| Feb-00 | 265274.82 | 520.25 | 13263.74 | 369506.47 | 724.66 |
| Mar-00 | 219331.94 | 407.45 | 10966.60 | 357256.89 | 663.68 |
| Apr-00 | 95684.52 | 173.00 | 4784.23 | 215043.38 | 388.80 |
| May-00 | 80720.96 | 134.18 | 4036.05 | 208175.23 | 346.04 |
| Jun-00 | 79087.83 | 127.15 | 3954.39 | 220786.18 | 354.96 |
| Jul-00 | 74510.64 | 124.72 | 3725.53 | 153599.76 | 257.11 |
| Aug-00 | 69681.63 | 113.71 | 3484.08 | 213390.19 | 348.22 |
| Sep-00 | 73221.90 | 121.63 | 3661.10 | 183236.76 | 304.38 |
| Oct-00 | 73165.71 | 124.54 | 3658.29 | 230478.51 | 392.30 |
| Nov-00 | 74514.38 | 138.30 | 3725.72 | 204200.91 | 378.99 |
| Dec-00 | 170069.88 | 310.18 | 8503.49 | 718453.01 | 1310.33 |
| Jan-01 | 227295.84 | 396.40 | 11364.79 | 386363.73 | 673.81 |
| Feb-01 | 162933.29 | 253.99 | 8146.66 | 332030.94 | 517.59 |
| Mar-01 | 255883.35 | 426.26 | 12794.17 | 311642.84 | 519.15 |
| Apr-01 | 192964.05 | 324.20 | 9648.20 | 369897.54 | 621.47 |
| May-01 | 35911.71 | 59.58 | 1795.59 | 222411.46 | 369.03 |
| Jun-01 | 32004.36 | 54.02 | 1600.22 | 172947.23 | 291.89 |
| Jul-01 | 40081.29 | 72.82 | 2004.06 | 227603.76 | 413.52 |
| Aug-01 | 62700.46 | 110.74 | 3135.02 | 177862.15 | 314.13 |
| Sep-01 | 6364.07 | 11.32 | 318.20 | 247964.09 | 441.06 |
| Oct-01 | 53779.47 | 80.40 | 2688.97 | 243917.57 | 364.65 |
| Nov-01 | 59320.85 | 106.39 | 2966.04 | 222290.70 | 398.66 |
| Dec-01 | 105616.76 | 181.35 | 5280.84 | 269070.89 | 462.00 |
| Jan-02 | 138653.34 | 250.05 | 6932.67 | 269457.98 | 485.95 |

| | | | | | |
|---|---|---|---|---|---|
| Feb-02 | 162934.23 | 265.19 | 8146.71 | 308489.31 | 502.10 |
| Mar-02 | 112296.15 | 175.93 | 5614.81 | 284818.13 | 446.21 |
| Apr-02 | 161464.31 | 249.29 | 8073.22 | 360116.38 | 555.99 |
| May-02 | 42958.30 | 71.72 | 2147.92 | 201146.00 | 335.80 |
| Jun-02 | 29525.86 | 54.20 | 1476.29 | 163866.26 | 300.78 |
| Jul-02 | 31989.39 | 57.10 | 1599.47 | 167300.52 | 298.64 |
| Aug-02 | 45784.11 | 80.39 | 2289.21 | 191918.41 | 336.99 |
| Sep-02 | 62604.92 | 109.95 | 3130.25 | 332704.98 | 584.31 |
| Oct-02 | 57273.85 | 102.20 | 2863.69 | 246310.80 | 439.53 |
| Nov-02 | 45824.18 | 85.46 | 2291.21 | 265027.67 | 494.27 |
| Dec-02 | 116378.53 | 228.64 | 5818.93 | 289708.05 | 569.17 |
| Jan-03 | 124325.17 | 241.08 | 6216.26 | 298025.26 | 577.90 |
| Feb-03 | 105556.72 | 232.45 | 5277.84 | 270968.00 | 596.71 |
| Mar-03 | 134122.42 | 236.84 | 6706.12 | 309842.96 | 547.14 |
| Apr-03 | 158333.25 | 265.30 | 7916.66 | 289947.38 | 485.84 |
| May-03 | 113166.29 | 187.49 | 5658.31 | 240224.93 | 397.99 |
| Jun-03 | 45750.65 | 84.74 | 2287.53 | 313665.56 | 580.97 |
| Jul-03 | 57705.00 | 105.40 | 2885.25 | 201206.48 | 367.50 |
| Aug-03 | 59562.12 | 105.59 | 2978.11 | 185329.40 | 328.54 |
| Sep-03 | 60819.86 | 107.57 | 3040.99 | 211500.85 | 374.07 |
| Oct-03 | 41640.43 | 76.29 | 2082.02 | 170943.24 | 313.20 |
| Nov-03 | 43134.64 | 78.90 | 2156.73 | 213686.54 | 390.87 |
| Dec-03 | 125837.63 | 234.47 | 6291.88 | 206236.21 | 384.27 |
| Jan-04 | 92163.75 | 170.30 | 4608.19 | 262106.41 | 484.31 |
| Feb-04 | 123451.84 | 247.40 | 6172.59 | 300064.40 | 601.33 |
| Mar-04 | 130390.64 | 197.62 | 6519.53 | 351255.11 | 532.37 |
| Apr-04 | 122436.94 | 222.90 | 6121.85 | 376131.63 | 684.75 |
| May-04 | 62878.08 | 93.04 | 3143.90 | 205233.78 | 303.69 |
| Jun-04 | 97291.23 | 166.48 | 4864.56 | 269613.05 | 461.35 |
| Jul-04 | 48464.25 | 88.33 | 2423.21 | 120883.00 | 220.31 |
| Aug-04 | 47554.47 | 85.92 | 2377.72 | 184805.80 | 333.89 |
| Sep-04 | 46957.75 | 86.03 | 2347.89 | 220984.98 | 404.88 |

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|---|---|---|---|---|---|
| Oct-04 | 45255.31 | 84.51 | 2262.77 | 157890.18 | 294.85 |
| Nov-04 | 7627.56 | 14.84 | 381.38 | 153432.17 | 298.51 |
| Dec-04 | 88105.35 | 163.22 | 4405.27 | 294286.98 | 545.18 |
| Jan-05 | 159446.40 | 258.72 | 7972.32 | 424594.58 | 688.94 |
| Feb-05 | 144420.45 | 255.39 | 7221.02 | 411546.07 | 727.76 |
| Mar-05 | 156337.48 | 257.73 | 7816.87 | 394850.44 | 650.92 |
| Apr-05 | 159172.01 | 290.25 | 7958.60 | 326994.40 | 596.27 |
| May-05 | 84929.40 | 161.40 | 4246.47 | 308673.78 | 586.61 |
| Jun-05 | 34026.60 | 62.78 | 1701.33 | 235648.55 | 434.78 |
| Jul-05 | 66539.87 | 110.75 | 3326.99 | 230048.53 | 382.90 |
| Aug-05 | 40833.90 | 73.99 | 2041.69 | 169123.14 | 306.44 |
| Sep-05 | 73731.34 | 134.37 | 3686.57 | 227882.10 | 415.31 |
| Oct-05 | | 0.00 | 0.00 | 254992.46 | 471.95 |
| Nov-05 | 63177.46 | 474.66 | 3158.87 | 256810.87 | 1929.46 |
| Dec-05 | 75576.38 | 149.07 | 3778.82 | 245698.19 | 484.61 |

## e. Ann Arbor Wastewater Treatment Plant – Sludge Disposal

For January 2000, the volume of sludge for landfill before compression was 3581.49 kGal and the weight of the wet cake (2338.61 metric tons) and dry solids (603.60 metric tons) together after compression turned out to be 2942.21 metric tons, thus the ratio of weight transported per kGal of sludge = **0.82 metric tons/kGal.** Compared to this the volume of sludge for land-application in March 2000 was 206.00 kGal and the corresponding weight to be transported was 782.24 metric tons (including sludge, water, solids), thus the ratio of weight transported per kGal of sludge = **3.79 metric tons/kGal**. The same pattern can be observed for other months as well.

| Date | Total Sludge Produced | | | Total Hauled to and from Landfill | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Volume | Weight | | To | From | Total | | | | Diesel | |
| Month/Yr | kGal | metric tons | metric tons/yr | metric tons | metric tons | metric tons | metric tons/yr | metric ton-miles | metric ton-miles/yr | Gallons | Gallons/yr |
| Jan-00 | 3581.49 | 2942.21 | 111534.07 | 2958.21 | 16.00 | 2974.21 | 11635.52 | 237936.60 | 930841.48 | 6305.32 | 24667.30 |
| Feb-00 | 3602.20 | 3186.68 | | 3202.68 | 16.00 | 3218.68 | | 257494.39 | | 6823.60 | |
| Mar-00 | 3997.80 | 3862.19 | | 3095.95 | 16.00 | 3111.95 | | 248956.18 | | 6597.34 | |
| Apr-00 | 3200.30 | 10803.95 | | 451.91 | 16.00 | 467.91 | | 37432.67 | | 991.97 | |
| May-00 | 3974.10 | 15118.88 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Jun-00 | 3352.30 | 12737.14 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Jul-00 | 2517.00 | 9577.04 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Aug-00 | 3333.40 | 12689.21 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Sep-00 | 3199.40 | 12179.44 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Oct-00 | 3450.20 | 13131.84 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Nov-00 | 3095.10 | 11774.29 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Dec-00 | 2560.90 | 3531.20 | | 1846.77 | 16.00 | 1862.77 | | 149021.63 | | 3949.07 | |
| Jan-01 | 3261.90 | 2934.34 | 100942.90 | 2950.34 | 16.00 | 2966.34 | 12332.45 | 237307.30 | 986595.82 | 6288.64 | 26144.79 |
| Feb-01 | 2978.49 | 2521.62 | | 2537.62 | 16.00 | 2553.62 | | 204289.27 | | 5413.67 | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar-01 | 3350.80 | 3241.52 | | 3257.52 | 16.00 | 3273.52 | | 261881.27 | | 6939.85 | |
| Apr-01 | 3410.10 | 7367.59 | | 2288.11 | 16.00 | 2304.11 | | 184328.64 | | 4884.71 | |
| May-01 | 3318.60 | 12626.14 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Jun-01 | 2682.20 | 10198.14 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Jul-01 | 2881.00 | 10956.91 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Aug-01 | 2694.00 | 10253.17 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Sep-01 | 3014.10 | 11454.29 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Oct-01 | 3117.40 | 11860.24 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Nov-01 | 2965.10 | 11253.62 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Dec-01 | 2915.70 | 6275.32 | | 1218.87 | 16.00 | 1234.87 | | 98789.34 | | 2617.92 | |
| Jan-02 | 2773.00 | 2482.31 | 98488.85 | 2498.31 | 16.00 | 2514.31 | 13498.99 | 201145.00 | 1079919.00 | 5330.34 | 28617.85 |
| Feb-02 | 3212.70 | 3443.77 | | 3459.77 | 16.00 | 3475.77 | | 278061.55 | | 7368.63 | |
| Mar-02 | 2929.60 | 2619.87 | | 2635.87 | 16.00 | 2651.87 | | 212149.24 | | 5621.95 | |
| Apr-02 | 3102.25 | 4286.17 | | 2930.84 | 16.00 | 2946.84 | | 235747.08 | | 6247.30 | |
| May-02 | 3222.11 | 11811.48 | | 192.54 | 16.00 | 208.54 | | 16683.48 | | 442.11 | |
| Jun-02 | 2498.91 | 9506.36 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Jul-02 | 2496.69 | 9473.30 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Aug-02 | 2684.20 | 10209.28 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Sep-02 | 3802.30 | 14453.79 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Oct-02 | 3016.90 | 11487.26 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Nov-02 | 3224.75 | 12133.26 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Dec-02 | 3423.10 | 6582.01 | | 1685.66 | 16.00 | 1701.66 | | 136132.66 | | 3607.52 | |
| Jan-03 | 3329.60 | 2680.52 | 94632.33 | 2696.52 | 16.00 | 2712.52 | 14228.08 | 217001.79 | 1138246.06 | 5750.55 | 30163.52 |
| Feb-03 | 3101.60 | 1622.77 | | 1638.77 | 16.00 | 1654.77 | | 132381.72 | | 3508.12 | |
| Mar-03 | 3756.00 | 2896.11 | | 2912.11 | 16.00 | 2928.11 | | 234248.54 | | 6207.59 | |
| Apr-03 | 4011.20 | 3332.29 | | 3348.29 | 16.00 | 3364.29 | | 269142.99 | | 7132.29 | |
| May-03 | 3355.91 | 6296.28 | | 2065.98 | 16.00 | 2081.98 | | 166558.66 | | 4413.80 | |
| Jun-03 | 2770.01 | 10995.75 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Jul-03 | 2925.88 | 11601.28 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Aug-03 | 3062.51 | 11518.36 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Sep-03 | 3443.74 | 12950.42 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Oct-03 | 3564.05 | 13467.24 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nov-03 | 3015.38 | 11483.02 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Dec-03 | 2915.42 | 5788.29 | | 1470.40 | 16.00 | 1486.40 | | 118912.36 | | 3151.18 | |
| Jan-04 | 2387.24 | 2143.58 | 92352.60 | 2159.58 | 16.00 | 2175.58 | 12386.28 | 174046.12 | 990902.55 | 4612.22 | 26258.92 |
| Feb-04 | 3026.50 | 2505.56 | | 2521.56 | 16.00 | 2537.56 | | 203005.06 | | 5379.63 | |
| Mar-04 | 3154.76 | 2392.50 | | 2408.50 | 16.00 | 2424.50 | | 193960.27 | | 5139.95 | |
| Apr-04 | 3360.83 | 4891.29 | | 2081.34 | 16.00 | 2097.34 | | 167787.07 | | 4446.36 | |
| May-04 | 2120.58 | 6615.29 | | 435.40 | 16.00 | 451.40 | | 36112.31 | | 956.98 | |
| Jun-04 | 3411.88 | 10834.88 | | 1189.19 | 16.00 | 1205.19 | | 96415.22 | | 2555.00 | |
| Jul-04 | 2522.98 | 9498.85 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Aug-04 | 3103.08 | 11641.00 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Sep-04 | 4094.92 | 15333.15 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Oct-04 | 3195.22 | 12054.49 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Nov-04 | 2972.60 | 11279.96 | | 0.00 | 0.00 | 0.00 | | 0.00 | | 0.00 | |
| Dec-04 | 2322.97 | 3162.06 | | 1478.71 | 16.00 | 1494.71 | | 119576.50 | | 3168.78 | |
| Jan-05 | 3412.20 | 2966.45 | 91779.46 | 2982.45 | 16.00 | 2998.45 | 18183.46 | 239876.39 | 1454677.10 | 6356.72 | 38548.94 |
| Feb-05 | 3392.00 | 3776.40 | | 3792.40 | 16.00 | 3808.40 | | 304672.00 | | 8073.81 | |
| Mar-05 | 3579.32 | 3072.77 | | 3088.77 | 16.00 | 3104.77 | | 248381.53 | | 6582.11 | |
| Apr-05 | 3463.47 | 2580.73 | | 2596.73 | 16.00 | 2612.73 | | 209018.22 | | 5538.98 | |
| May-05 | 4249.80 | 11534.12 | | 1062.14 | 16.00 | 1078.14 | | 86251.27 | | 2285.66 | |
| Jun-05 | 3966.88 | 14732.58 | | 140.74 | 16.00 | 156.74 | | 12538.88 | | 332.28 | |
| Jul-05 | 2658.37 | 7503.47 | | 378.68 | 16.00 | 394.68 | | 31574.05 | | 836.71 | |
| Aug-05 | 3386.90 | 12856.55 | | 62.37 | 16.00 | 78.37 | | 6269.42 | | 166.14 | |
| Sep-05 | 3092.62 | 10236.12 | | 360.36 | 16.00 | 376.36 | | 30108.60 | | 797.88 | |
| Oct-05 | 3162.06 | 8014.69 | | 1093.31 | 16.00 | 1109.31 | | 88744.52 | | 2351.73 | |
| Nov-05 | 3333.37 | 8828.46 | | 835.91 | 16.00 | 851.91 | | 68152.68 | | 1806.05 | |
| Dec-05 | 2827.55 | 5677.14 | | 1597.62 | 16.00 | 1613.62 | | 129089.55 | | 3420.87 | |

| Date | Total Hauled to and from Land application | | | | | | | | Total Diesel Consumption | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | To | From | Total | Dist* | | | Diesel | | | | | | |
| Month /Yr | metric tons | metric tons | metric tons | Miles | metric ton-miles | metric ton-miles/yr | Gallons | Gallons /year | Gallons | GJ/ month | GJ/ MG | GJ/yr | GJ/ MG-Yr |
| Jan-00 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | 3178654.06 | 0.00 | 84234.33 | 6305.32 | 1051.13 | 1.98 | 18154.53 | 2.65 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb-00 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | | 0.00 | | 6823.60 | 1137.53 | 2.23 | | |
| Mar-00 | 798.24 | 16.00 | 814.24 | 31.67 | 25784.27 | | 683.28 | | 7280.62 | 1213.72 | 2.25 | | |
| Apr-00 | 10384.04 | 16.00 | 10400.04 | 31.67 | 329334.68 | | 8727.37 | | 9719.33 | 1620.27 | 2.93 | | |
| May-00 | 15134.88 | 16.00 | 15150.88 | 31.67 | 479777.80 | | 12714.11 | | 12714.11 | 2119.52 | 3.52 | | |
| Jun-00 | 12753.14 | 16.00 | 12769.14 | 31.67 | 404356.12 | | 10715.44 | | 10715.44 | 1786.32 | 2.87 | | |
| Jul-00 | 9593.04 | 16.00 | 9609.04 | 31.67 | 304286.25 | | 8063.59 | | 8063.59 | 1344.25 | 2.25 | | |
| Aug-00 | 12705.21 | 16.00 | 12721.21 | 31.67 | 402838.38 | | 10675.22 | | 10675.22 | 1779.62 | 2.90 | | |
| Sep-00 | 12195.44 | 16.00 | 12211.44 | 31.67 | 386695.47 | | 10247.43 | | 10247.43 | 1708.31 | 2.84 | | |
| Oct-00 | 13147.84 | 16.00 | 13163.84 | 31.67 | 416854.89 | | 11046.65 | | 11046.65 | 1841.54 | 3.13 | | |
| Nov-00 | 11790.29 | 16.00 | 11806.29 | 31.67 | 373865.89 | | 9907.45 | | 9907.45 | 1651.63 | 3.07 | | |
| Dec-00 | 1716.43 | 16.00 | 1732.43 | 31.67 | 54860.31 | | 1453.80 | | 5402.87 | 900.69 | 1.64 | | |
| Jan-01 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | 2820184.17 | 0.00 | 74734.88 | 6288.64 | 1048.35 | 1.83 | 16817.22 | 2.6 |
| Feb-01 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | | 0.00 | | 5413.67 | 902.49 | 1.41 | | |
| Mar-01 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | | 0.00 | | 6939.85 | 1156.91 | 1.93 | | |
| Apr-01 | 5111.49 | 16.00 | 5127.49 | 31.67 | 162370.37 | | 4302.81 | | 9187.52 | 1531.61 | 2.57 | | |
| May-01 | 12642.14 | 16.00 | 12658.14 | 31.67 | 400840.95 | | 10622.29 | | 10622.29 | 1770.80 | 2.94 | | |
| Jun-01 | 10214.14 | 16.00 | 10230.14 | 31.67 | 323954.38 | | 8584.79 | | 8584.79 | 1431.13 | 2.42 | | |
| Jul-01 | 10972.91 | 16.00 | 10988.91 | 31.67 | 347982.18 | | 9221.53 | | 9221.53 | 1537.28 | 2.79 | | |
| Aug-01 | 10269.17 | 16.00 | 10285.17 | 31.67 | 325697.10 | | 8630.97 | | 8630.97 | 1438.83 | 2.54 | | |
| Sep-01 | 11470.29 | 16.00 | 11486.29 | 31.67 | 363732.42 | | 9638.91 | | 9638.91 | 1606.86 | 2.86 | | |
| Oct-01 | 11876.24 | 16.00 | 11892.24 | 31.67 | 376587.73 | | 9979.57 | | 9979.57 | 1663.65 | 2.49 | | |
| Nov-01 | 11269.62 | 16.00 | 11285.62 | 31.67 | 357378.07 | | 9470.52 | | 9470.52 | 1578.79 | 2.83 | | |
| Dec-01 | 5088.45 | 16.00 | 5104.45 | 31.67 | 161640.96 | | 4283.49 | | 6901.40 | 1150.50 | 1.98 | | |
| Jan-02 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | 2706545.62 | 0.00 | 71723.46 | 5330.34 | 888.60 | 1.60 | 16727.47 | 2.4 |
| Feb-02 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | | 0.00 | | 7368.63 | 1228.39 | 2.00 | | |
| Mar-02 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | | 0.00 | | 5621.95 | 937.21 | 1.47 | | |
| Apr-02 | 1387.33 | 16.00 | 1403.33 | 31.67 | 44438.70 | | 1177.63 | | 7424.92 | 1237.78 | 1.91 | | |
| May-02 | 11650.94 | 16.00 | 11666.94 | 31.67 | 369453.04 | | 9790.51 | | 10232.62 | 1705.84 | 2.85 | | |
| Jun-02 | 9522.36 | 16.00 | 9538.36 | 31.67 | 302048.06 | | 8004.27 | | 8004.27 | 1334.36 | 2.45 | | |
| Jul-02 | 9489.30 | 16.00 | 9505.30 | 31.67 | 301001.14 | | 7976.53 | | 7976.53 | 1329.73 | 2.37 | | |
| Aug-02 | 10225.28 | 16.00 | 10241.28 | 31.67 | 324307.21 | | 8594.14 | | 8594.14 | 1432.69 | 2.52 | | |
| Sep-02 | 14469.79 | 16.00 | 14485.79 | 31.67 | 458716.54 | | 12155.99 | | 12155.99 | 2026.47 | 3.56 | | |
| Oct-02 | 11503.26 | 16.00 | 11519.26 | 31.67 | 364776.72 | | 9666.58 | | 9666.58 | 1611.47 | 2.88 | | |
| Nov-02 | 12149.26 | 16.00 | 12165.26 | 31.67 | 385233.22 | | 10208.68 | | 10208.68 | 1701.85 | 3.17 | | |
| Dec-02 | 4928.35 | 16.00 | 4944.35 | 31.67 | 156570.99 | | 4149.13 | | 7756.65 | 1293.08 | 2.54 | | |
| Jan-03 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | 2560321.26 | 0.00 | 67848.51 | 5750.55 | 958.65 | 1.86 | 16339.17 | 2.5 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb-03 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | | 0.00 | | 3508.12 | 584.82 | 1.29 | | |
| Mar-03 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | | 0.00 | | 6207.59 | 1034.84 | 1.83 | | |
| Apr-03 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | | 0.00 | | 7132.29 | 1188.99 | 1.99 | | |
| May-03 | 4262.29 | 16.00 | 4278.29 | 31.67 | 135479.25 | | 3590.20 | | 8004.00 | 1334.31 | 2.21 | | |
| Jun-03 | 11011.75 | 16.00 | 11027.75 | 31.67 | 349212.13 | | 9254.12 | | 9254.12 | 1542.72 | 2.86 | | |
| Jul-03 | 11617.28 | 16.00 | 11633.28 | 31.67 | 368387.05 | | 9762.26 | | 9762.26 | 1627.42 | 2.97 | | |
| Aug-03 | 11534.36 | 16.00 | 11550.36 | 31.67 | 365761.52 | | 9692.68 | | 9692.68 | 1615.83 | 2.86 | | |
| Sep-03 | 12966.42 | 16.00 | 12982.42 | 31.67 | 411110.07 | | 10894.42 | | 10894.42 | 1816.16 | 3.21 | | |
| Oct-03 | 13483.24 | 16.00 | 13499.24 | 31.67 | 427475.82 | | 11328.11 | | 11328.11 | 1888.46 | 3.46 | | |
| Nov-03 | 11499.02 | 16.00 | 11515.02 | 31.67 | 364642.27 | | 9663.02 | | 9663.02 | 1610.88 | 2.95 | | |
| Dec-03 | 4349.89 | 16.00 | 4365.89 | 31.67 | 138253.14 | | 3663.71 | | 6814.89 | 1136.08 | 2.12 | | |
| Jan-04 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | 2548480.00 | 0.00 | 67534.72 | 4612.22 | 768.88 | 1.42 | 15635.94 | 2.32 |
| Feb-04 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | | 0.00 | | 5379.63 | 896.82 | 1.80 | | |
| Mar-04 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | | 0.00 | | 5139.95 | 856.86 | 1.30 | | |
| Apr-04 | 2841.95 | 16.00 | 2857.95 | 31.67 | 90501.81 | | 2398.30 | | 6844.66 | 1141.04 | 2.08 | | |
| May-04 | 6211.89 | 16.00 | 6227.89 | 31.67 | 197216.55 | | 5226.24 | | 6183.21 | 1030.78 | 1.53 | | |
| Jun-04 | 9677.68 | 16.00 | 9693.68 | 31.67 | 306966.69 | | 8134.62 | | 10689.62 | 1782.02 | 3.05 | | |
| Jul-04 | 9514.85 | 16.00 | 9530.85 | 31.67 | 301810.14 | | 7997.97 | | 7997.97 | 1333.31 | 2.43 | | |
| Aug-04 | 11657.00 | 16.00 | 11673.00 | 31.67 | 369645.00 | | 9795.59 | | 9795.59 | 1632.98 | 2.95 | | |
| Sep-04 | 15349.15 | 16.00 | 15365.15 | 31.67 | 486562.95 | | 12893.92 | | 12893.92 | 2149.49 | 3.94 | | |
| Oct-04 | 12070.49 | 16.00 | 12086.49 | 31.67 | 382738.83 | | 10142.58 | | 10142.58 | 1690.83 | 3.16 | | |
| Nov-04 | 11295.96 | 16.00 | 11311.96 | 31.67 | 358211.93 | | 9492.62 | | 9492.62 | 1582.47 | 3.08 | | |
| Dec-04 | 1715.35 | 16.00 | 1731.35 | 31.67 | 54826.10 | | 1452.89 | | 4621.67 | 770.46 | 1.43 | | |
| Jan-05 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | 2350806.66 | 0.00 | 62296.38 | 6356.72 | 1059.70 | 1.72 | 16811.49 | 2.51 |
| Feb-05 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | | 0.00 | | 8073.81 | 1345.95 | 2.38 | | |
| Mar-05 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | | 0.00 | | 6582.11 | 1097.28 | 1.81 | | |
| Apr-05 | 0.00 | 0.00 | 0.00 | 31.67 | 0.00 | | 0.00 | | 5538.98 | 923.38 | 1.68 | | |
| May-05 | 10503.98 | 16.00 | 10519.98 | 31.67 | 333132.71 | | 8828.02 | | 11113.68 | 1852.71 | 3.52 | | |
| Jun-05 | 14623.84 | 16.00 | 14639.84 | 31.67 | 463594.93 | | 12285.27 | | 12617.55 | 2103.42 | 3.88 | | |
| Jul-05 | 7156.79 | 16.00 | 7172.79 | 31.67 | 227138.48 | | 6019.17 | | 6855.88 | 1142.91 | 1.90 | | |
| Aug-05 | 12826.18 | 16.00 | 12842.18 | 31.67 | 406668.97 | | 10776.73 | | 10942.87 | 1824.24 | 3.31 | | |
| Sep-05 | 9907.76 | 16.00 | 9923.76 | 31.67 | 314252.33 | | 8327.69 | | 9125.56 | 1521.28 | 2.77 | | |
| Oct-05 | 6953.38 | 16.00 | 6969.38 | 31.67 | 220697.09 | | 5848.47 | | 8200.20 | 1367.02 | 2.53 | | |
| Nov-05 | 8024.55 | 16.00 | 8040.55 | 31.67 | 254617.32 | | 6747.36 | | 8553.41 | 1425.90 | 2.63 | | |
| Dec-05 | 4111.52 | 16.00 | 4127.52 | 31.67 | 130704.82 | | 3463.68 | | 6884.55 | 1147.69 | 2.26 | | |

# Appendix B-II

## Ann Arbor Wastewater Treatment Plant Emissions Analysis

### a. Ann Arbor Wastewater Treatment Plant – Global Warming Potential

| Global Warming Potential for 2003 - Electricity | | | | |
|---|---|---|---|---|
| | *g/MJe* | Total for 2003 | *g $CO_2$ eq./MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 183 | 10617676931 | 1612991 | 1613 |
| Non-fossil Carbon Dioxide | 0.000297 | 17232 | 3 | 0 |
| Methane CH4 | 0.313 | 18160289 | 63453 | 63 |
| Nitrous Oxide | 0.0102 | 591805 | 26971 | 27 |
| **Total GWP** | | | 1703418 | 1703 |

| Global Warming Potential for 2004 - Electricity | | | | |
|---|---|---|---|---|
| | *g/MJe* | Total for 2004 | *g $CO_2$ eq./MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 183 | 10391498058 | 1652907 | 1653 |
| Non-fossil Carbon Dioxide | 0.000297 | 16865 | 3 | 0 |
| Methane CH4 | 0.313 | 17773437 | 65023 | 65 |
| Nitrous Oxide | 0.0102 | 579198 | 27639 | 28 |
| **Total GWP** | | | 1745572 | 1746 |

| Global Warming Potential for 2003- Natural Gas | | | | |
|---|---|---|---|---|
| | *g/1000cuft* | *Total in 2003* | *g $CO_2$ eq./MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 62142.150 | 12520897.519 | 1902.120 | 1.902 |
| Non-fossil Carbon Dioxide | 12.701 | 2559.099 | 0.389 | 0.000 |
| Methane CH4 | 172.365 | 34729.479 | 121.347 | 0.121 |
| Nitrous Oxide | 0.005 | 1.007 | 0.046 | 0.000 |
| **Total GWP** | | | 2023.902 | 2.024 |

| Global Warming Potential for 2004- Natural Gas | | | | |
|---|---|---|---|---|
| | *g/1000cuft* | *Total in 2004* | *g $CO_2$ eq./MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 62142.150 | 15639439.17 | 2318.053 | 2.318 |
| Non-fossil Carbon Dioxide | 12.701 | 3196.486 | 0.474 | 0.000 |
| Methane CH4 | 172.365 | 43379.444 | 147.882 | 0.148 |
| Nitrous Oxide | 0.005 | 1.258 | 0.056 | 0.000 |
| **Total GWP** | | | 2466.464 | 2.466 |

| Global Warming Potential for 2003- Diesel | | | | |
|---|---|---|---|---|
| | *g/1000cuft* | *Total in 2003* | *g $CO_2$ eq./MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 11626480.00 | 1139534950.59 | 173113.20 | 173.113 |
| Non-fossil Carbon Dioxide | 2766.913 | 271190.770 | 41.20 | 0.041 |
| Methane CH4 | 1837.049 | 180052.909 | 629.12 | 0.629 |
| Nitrous Oxide | 0.007 | 0.686 | 0.03 | 0.000 |
| **Total GWP** | | | 173783.55 | 173.784 |

| Global Warming Potential for 2004- Diesel | | | | |
|---|---|---|---|---|
| | *g/1000cuft* | *Total in 2004* | *g $CO_2$ eq./MG* | *kg $CO_2$ eq./MG* |
| Fossil Carbon Dioxide | 11626480.00 | 1090489851.76 | 161630.68 | 161.631 |
| Non-fossil Carbon Dioxide | 2766.913 | 259518.835 | 38.47 | 0.038 |
| Methane CH4 | 1837.049 | 172303.508 | 587.39 | 0.587 |
| Nitrous Oxide | 0.007 | 0.657 | 0.03 | 0.000 |
| **Total GWP** | | | 162256.56 | 162.257 |

| Global Warming Potential for 2003- Chemicals | | |
|---|---|---|
| | *kg CO2eq./Yr* | *kg CO2eq./MG* |
| Carbon Dioxide | 580778 | 88 |
| Methane CH4 | 12709 | 2 |
| Nitrous Oxide | 2233 | 0 |
| **Total GWP** | 595720 | 90 |

| Global Warming Potential for 2003- Chemicals | | |
|---|---|---|
| | *kg CO2eq./Yr* | *kg CO2eq./MG* |
| Carbon Dioxide | 580778 | 86 |
| Methane CH4 | 12709 | 2 |
| Nitrous Oxide | 2233 | 0 |
| **Total GWP** | 595720 | 88 |

## b. Ann Arbor Wastewater Treatment Plant – Eutrophication Potential

| Eutrophication Potential for 2003- Electricity | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/MJe* | *Total in 2003* | *kg N eq./MG* | | *g/MJe* | *Total in 2003* | *kg N eq./MG* |
| NOx | 0.475 | 27559543.948 | 0.167 | N | | | |
| $NH_3$ | 0.00035 | 20307.032 | 0.000000 | $NH_3$ | 0.000151 | 8761.034 | 0.0010 |
| $NH_4$+ | | | | COD | 0.00466 | 270373.631 | 0.002 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.0000473 | 2744.350 | 0.00004 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.000000002 | 0.107 | 0.00000012 |
| P | | | | P | | | |
| Total | | | 0.167 | | | | 0.003 |

| Eutrophication Potential for 2004- Electricity | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/MJe* | *Total in 2004* | *kg N eq./MG* | | *g/MJe* | *Total in 2004* | *kg N eq./MG* |
| NOx | 0.475 | 26972467.637 | 0.160 | N | | | |
| $NH_3$ | 0.00035 | 19874.450 | 0.000 | $NH_3$ | 0.000151 | 8574.406 | 0.0010 |
| $NH_4$+ | | | | COD | 0.00466 | 264614.104 | 0.002 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.0000473 | 2685.890 | 0.00004 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.000000002 | 0.105 | 0.00000011 |
| P | | | | P | | | |
| Total | | | 0.160 | | | | 0.003 |

| Eutrophication Potential for 2003- Natural Gas | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/1000 cuft.* | *Total in 2003* | *kg N eq./MG* | | *g/1000 cuft.* | *Total in 2003* | *kg N eq./MG* |
| NOx | 231.332 | 46610.622 | 0.0003 | N | | | |
| $NH_3$ | 1.361 | 274.225 | 0.000005 | $NH_3$ | 0.027 | 5.440 | 0.0000006 |
| $NH_4$+ | | | | COD | 19.504 | 3929.822 | 0.000030 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.000082 | 0.017 | 0.0000000003 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.005 | 1.007 | 0.0000004 |
| P | | | | P | | | |
| Total | | | 0.000 | | | | 0.000031 |

| Eutrophication Potential for 2004- Natural Gas | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/1000 cuft.* | *Total in 2004* | *kg N eq./MG* | | *g/1000 cuft.* | *Total in 2004* | *kg N eq./MG* |
| NOx | 231.332 | 58219.787 | 0.0003 | N | | | |
| $NH_3$ | 1.361 | 342.526 | 0.000006 | $NH_3$ | 0.027 | 6.795 | 0.0000008 |
| $NH_4$+ | | | | COD | 19.504 | 4908.611 | 0.000036 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.000082 | 0.021 | 0.0000000003 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.005 | 1.258 | 0.00000 |
| P | | | | P | | | |
| Total | | | 0.000 | | | | 0.000038 |

| Eutrophication Potential for 2003- Diesel | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/1000 cuft.* | *Total in 2003* | *kg N eq./MG* | | *g/1000 cuft.* | *Total in 2003* | *kg N eq./MG* |
| NOx | 216950.400 | 21263749.94 | 0.129 | N | | | |
| $NH_3$ | 18.144 | 1778.330 | 0.00003 | $NH_3$ | 6.35 | 622.376 | 0.00007 |
| $NH_4$+ | | | | COD | 39.463 | 3867.849 | 0.000029 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.018 | 1.764 | 0.00000003 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 1.588 | 155.643 | 0.000056 |
| P | | | | P | | | |
| Total | | | 0.129 | | | | 0.000159 |

| Eutrophication Potential for 2004- Diesel | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/1000 cuft.* | *Total in 2004* | *kg N eq./MG* | | *g/1000 cuft.* | *Total in 2004* | *kg N eq./MG* |
| NOx | 216950.400 | 20348567.20 | 0.121 | N | | | |
| $NH_3$ | 18.144 | 1701.792 | 0.000030 | $NH_3$ | 6.35 | 595.590 | 0.000069 |
| $NH_4$+ | | | | COD | 39.463 | 3701.378 | 0.000027 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.018 | 1.688 | 0.00000003 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 1.588 | 148.944 | 0.000053 |
| P | | | | P | | | |
| Total | | | 0.121 | | | | 0.000149 |

| **Eutrophication Potential for 2003- Chemicals** | | | | | |
|---|---|---|---|---|---|
| **Atmospheric** | | | **Aquatic** | | |
| | ***g N eq./Yr*** | ***g N eq./MG*** | | ***g N eq./Yr*** | ***g N eq./MG*** |
| NOx | 10874 | 2 | N | 86.67 | 0.01 |
| $NH_3$ | 24 | 0.004 | $NH_3$ | 0.31 | 0.000047 |
| $NH_4$+ | | | COD | 133.23 | 0.02 |
| $NO_3^-$ | | | $NO_3^-$ | 2.73 | 0.0004 |
| $PO_4^{3-}$ | | | $PO_4^{3-}$ | 0.62 | 0.0001 |
| P | | | P | | |
| **Total** | | 2 | | | 0.03 |

| **Eutrophication Potential for 2004- Chemicals** | | | | | |
|---|---|---|---|---|---|
| **Atmospheric** | | | **Aquatic** | | |
| | ***g N eq./Yr*** | ***g N eq./MG*** | | ***g N eq./Yr*** | ***g N eq./MG*** |
| NOx | 10874 | 2 | N | 86.67 | 0.01 |
| $NH_3$ | 24 | 0.004 | $NH_3$ | 0.31 | 0.000046 |
| $NH_4$+ | | | COD | 133.23 | 0.02 |
| $NO_3^-$ | | | $NO_3^-$ | 2.73 | 0.0004 |
| $PO_4^{3-}$ | | | $PO_4^{3-}$ | 0.62 | 0.0001 |
| P | | | P | 0.00 | |
| **Total** | | 2 | | | 0.03 |

## c. Ann Arbor Wastewater Treatment Plant –Acidification Potential

| Acidification Potential for 2003- Electricity | | | |
|---|---|---|---|
| | ***g/MJe*** | ***Total in 2003*** | ***moles H+ eq./MG*** |
| $SO_2$ | 38.042 | 2207183534 | 335.31 |
| HCl | 3.3560380 | 194717635.3 | 29.581 |
| NOx | 19.0190 | 1103484140 | 167.637 |
| $NH_3$ | 0.033422 | 1939118.522 | 0.295 |
| Total | | | 532.817 |

| Acidification Potential for 2004- Electricity | | | |
|---|---|---|---|
| | ***g/MJe*** | ***Total in 2004*** | ***moles H+ eq./MG*** |
| $SO_2$ | 38.042 | 2160165878 | 320.176 |
| HCl | 3.356 | 190569739.7 | 28.246 |
| NOx | 19.019 | 1079977604 | 160.073 |
| $NH_3$ | 0.033 | 1897811.215 | 0.281 |
| Total | | | 508.776 |

| Acidification Potential for 2003- Natural Gas | | | |
|---|---|---|---|
| | ***g/1000 cuft*** | ***Total in 2003*** | ***moles H+ eq./MG*** |
| $SO_2$ | 893.577 | 180045.0426 | 1.389 |
| HCl | 0.044 | 8.865472 | 0.000109 |
| NOx | 231.332 | 46610.62202 | 0.284 |
| $NH_3$ | 1.361 | 274.225168 | 0.0040 |
| Total | | | 1.677 |

| Acidification Potential for 2004- Natural Gas | | | |
|---|---|---|---|
| | ***g/1000 cuft*** | ***Total in 2004*** | ***moles H+ eq./MG*** |
| $SO_2$ | 893.577 | 224888.3107 | 1.693 |
| HCl | 0.044 | 11.073568 | 0.000133 |
| NOx | 231.332 | 58219.7871 | 0.346 |
| $NH_3$ | 1.361 | 342.525592 | 0.0048 |
| Total | | | 2.043 |

| Acidification Potential for 2003- Diesel | | | |
|---|---|---|---|
| | ***g/1000 gallons*** | ***Total in 2003*** | ***kg $SO_2$ equiv./MG*** |
| $SO_2$ | 25854.77 | 2534078.591 | 19.552 |
| HCl | 11.34 | 1111.456463 | 0.0137 |
| NOx | 216590.4 | 21228465.6 | 129.126 |
| $NH_3$ | 18.144 | 1778.330341 | 0.0258 |
| Total | | | 148.718 |

| Acidification Potential for 2004- Diesel | | | |
|---|---|---|---|
| | ***g/1000 gallons*** | ***Total in 2004*** | ***moles H+ eq./MG*** |
| $SO_2$ | 25854.77 | 2425012.928 | 18.256 |
| HCl | 11.34 | 1063.61985 | 0.0128 |
| NOx | 216590.4 | 20314801.49 | 120.562 |
| $NH_3$ | 18.144 | 1701.791761 | 0.0241 |
| Total | | | 138.854 |

| Acidification Potential for 2003- Chemicals | | |
|---|---|---|
| | ***moles H+ eq./Yr*** | ***moles H+ eq./MG*** |
| $SO_2$ | 27560 | 4 |
| HCl | 2061 | 0.3 |
| NOx | 23050 | 4 |
| $NH_3$ | 22 | 0.003 |
| Total | | 8 |

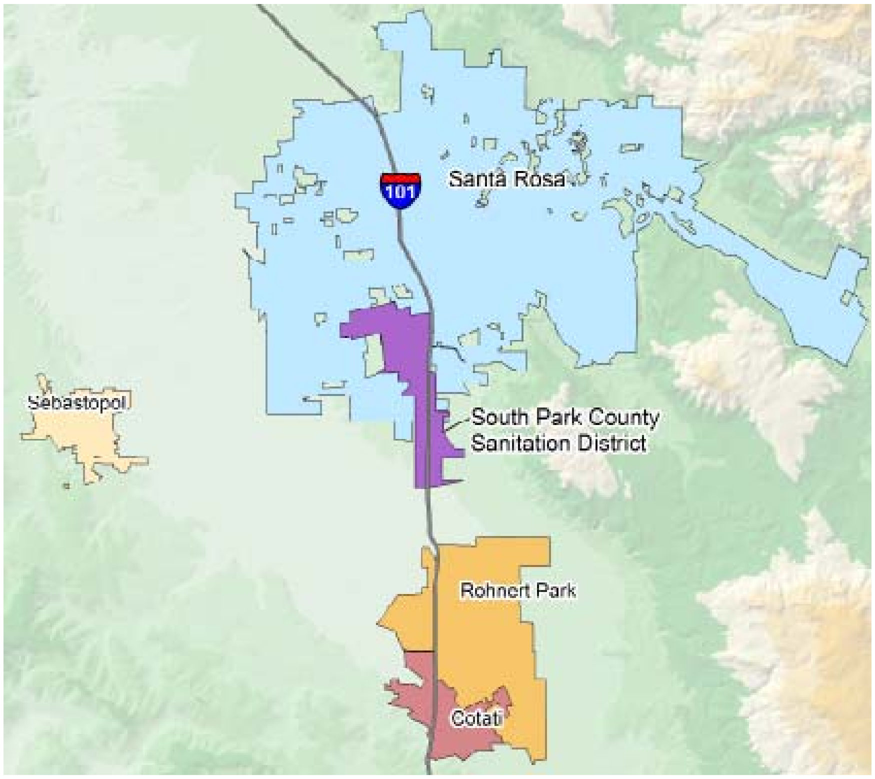
| Acidification Potential for 2004- Chemicals | | |
|---|---|---|
| | ***moles H+ eq./Yr*** | ***moles H+ eq./MG*** |
| $SO_2$ | 27560 | 4 |
| HCl | 2061 | 0.3 |
| NOx | 23050 | 3 |
| $NH_3$ | 22 | 0.003 |
| Total | | 8 |

# Appendix C-I

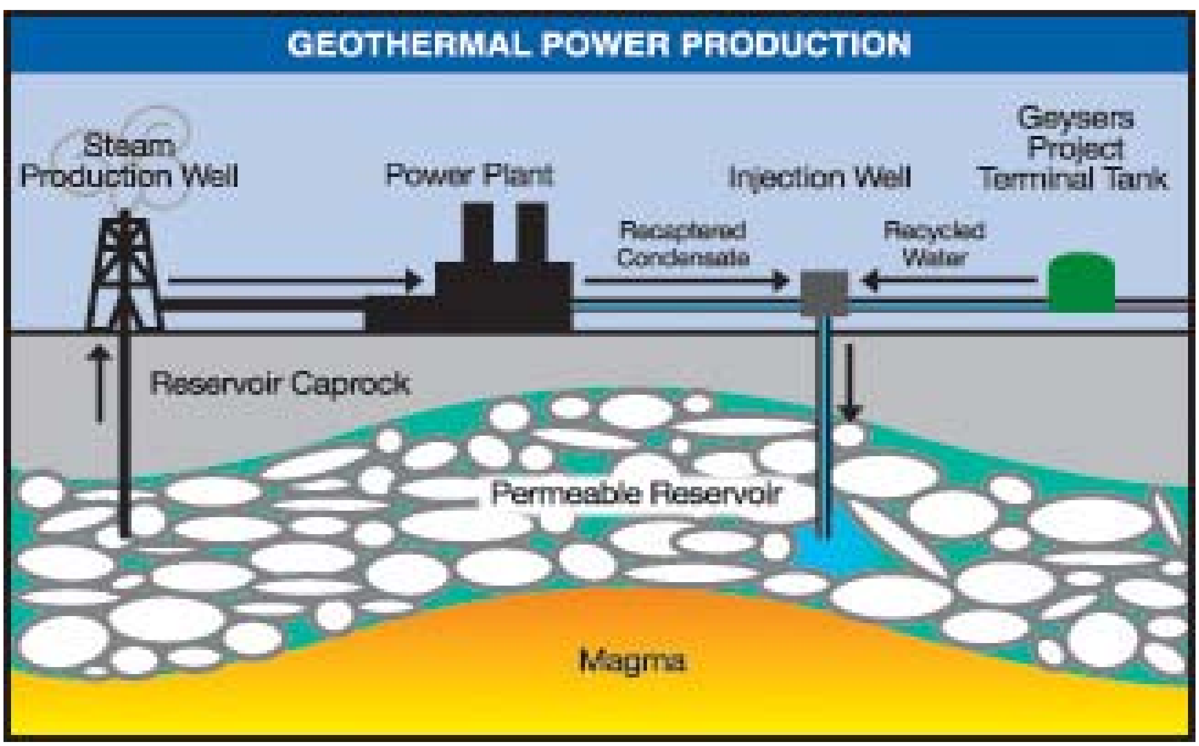
## Laguna Wastewater Treatment Plant

**a. Details of the Subregional Recycling System (Courtesy: City Website, City of Santa Rosa)**

Subregional Operations comprises of eight sections that operate and maintain- The Laguna Treatment Plant, the Oakmont Treatment Plant, the Subregional Compost Facility and the Reclamation system. Laguna Treatment Plant is a tertiary-level treatment facility that has an average daily dry weather flow of 17.5 million gallons per day. This facility serves the Subregional partners including the Cities of Santa Rosa, Sebastopol, Cotati, Rohnert Park and the Sonoma County South Park Sanitation District. The Oakmont Treatment Plant has an average flow of .5 to .6 MGD and operates between April and October. The Subregional Compost Facility is an agitated, aerobic, naturally heated, biological process that produces approximately 20,000 cubic yards of compost annually. The Reclamation system comprises 6,130 acres, utilizing 45 pump stations that deliver reclaimed water to buried pipe and aboveground irrigation systems.




***b.*** **Details of the Geysers Recharge Project (Courtesy: City Website, City of Santa Rosa)**



**c. Total flow at Laguna WWTP**

| Date | Total Flow | Total Flow | |
|---|---|---|---|
| | ave. daily flow | Monthly | |
| Month/Year | MGD | MG | MG/Yr |
| Jan-00 | 21.55 | 668.05 | 7607.41 |
| Feb-00 | 33.59 | 940.52 | |
| Mar-00 | 28.01 | 868.31 | |
| Apr-00 | 21.22 | 636.60 | |
| May-00 | 20.02 | 620.62 | |
| Jun-00 | 18.07 | 542.10 | |
| Jul-00 | 17.60 | 545.60 | |
| Aug-00 | 17.80 | 551.80 | |
| Sep-00 | 17.51 | 525.30 | |
| Oct-00 | 18.22 | 564.82 | |
| Nov-00 | 18.81 | 564.30 | |
| Dec-00 | 18.69 | 579.39 | |
| Jan-01 | 21.12 | 654.72 | 7382.01 |
| Feb-01 | 26.03 | 728.84 | |
| Mar-01 | 23.17 | 718.27 | |
| Apr-01 | 19.47 | 584.10 | |
| May-01 | 17.70 | 548.70 | |
| Jun-01 | 16.79 | 503.70 | |
| Jul-01 | 16.37 | 507.47 | |
| Aug-01 | 16.47 | 510.57 | |
| Sep-01 | 16.45 | 493.50 | |
| Oct-01 | 16.47 | 510.57 | |
| Nov-01 | 20.81 | 624.30 | |
| Dec-01 | 32.17 | 997.27 | |
| Jan-02 | 29.55 | 916.05 | 7382.34 |
| Feb-02 | 22.01 | 616.28 | |
| Mar-02 | 22.43 | 695.33 | |
| Apr-02 | 19.28 | 578.40 | |
| May-02 | 18.11 | 561.41 | |
| Jun-02 | 17.15 | 514.50 | |
| Jul-02 | 16.32 | 505.92 | |
| Aug-02 | 16.36 | 507.16 | |
| Sep-02 | 16.20 | 486.00 | |
| Oct-02 | 16.30 | 505.30 | |
| Nov-02 | 17.74 | 532.20 | |
| Dec-02 | 31.09 | 963.79 | |
| Jan-03 | 28.46 | 882.26 | 7509.01 |
| Feb-03 | 22.51 | 630.28 | |
| Mar-03 | 21.86 | 677.66 | |
| Apr-03 | 22.41 | 672.30 | |
| May-03 | 21.96 | 680.76 | |
| Jun-03 | 18.28 | 548.40 | |
| Jul-03 | 17.25 | 534.75 | |

| | | | |
|---|---|---|---|
| Aug-03 | 17.26 | 535.06 | |
| Sep-03 | 16.94 | 508.20 | |
| Oct-03 | 16.71 | 518.01 | |
| Nov-03 | 17.87 | 536.10 | |
| Dec-03 | 25.33 | 785.23 | |
| Jan-04 | 25.68 | 796.08 | 7371.38 |
| Feb-04 | 30.42 | 851.76 | |
| Mar-04 | 22.66 | 702.46 | |
| Apr-04 | 19.71 | 591.30 | |
| May-04 | 17.73 | 549.63 | |
| Jun-04 | 17.17 | 515.10 | |
| Jul-04 | 16.84 | 522.04 | |
| Aug-04 | 16.73 | 518.63 | |
| Sep-04 | 16.55 | 496.50 | |
| Oct-04 | 17.59 | 545.29 | |
| Nov-04 | 17.86 | 535.80 | |
| Dec-04 | 24.09 | 746.79 | |
| Jan-05 | 27.88 | 864.28 | 8056.49 |
| Feb-05 | 24.26 | 679.28 | |
| Mar-05 | 28.68 | 889.08 | |
| Apr-05 | 22.92 | 687.60 | |
| May-05 | 24.38 | 755.78 | |
| Jun-05 | 19.76 | 592.80 | |
| Jul-05 | 18.15 | 562.65 | |
| Aug-05 | 17.62 | 546.22 | |
| Sep-05 | 17.30 | 519.00 | |
| Oct-05 | 16.65 | 516.15 | |
| Nov-05 | 17.69 | 530.70 | |
| Dec-05 | 29.45 | 912.95 | |

## d. Electricity Consumption at the Laguna WWTP

| Date | Electricity Consumption | | | | | Electricity supplied from the Grid | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Grid | | Generator | | Total | | | | | |
| Month/ Year | kWh/ month | % of Total | kWh/ month | % of Total | kWh | kWh/ MG | GJ | GJ/ Yr | GJ/ MG | GJ/ MG-Yr |
| Jan-00 | 1709991.00 | 59.12 | 1182433.00 | 40.88 | 2892424.00 | 2559.68 | 6155.97 | 71341.19 | 9.21 | 9.38 |
| Feb-00 | 2078054.00 | 63.09 | 1097992.00 | 36.91 | 2974944.00 | 2209.47 | 7480.99 | | 7.95 | |
| Mar-00 | 1880987.00 | 60.62 | 1221865.00 | 39.38 | 3102852.00 | 2166.26 | 6771.55 | | 7.80 | |
| Apr-00 | 1743750.00 | 60.85 | 1085730.00 | 39.15 | 2773230.00 | 2739.16 | 6277.50 | | 9.86 | |
| May-00 | 1736992.00 | 57.64 | 1276642.00 | 42.36 | 3013634.00 | 2798.80 | 6253.17 | | 10.08 | |
| Jun-00 | 1683300.00 | 58.89 | 1137270.00 | 41.11 | 2766270.00 | 3105.15 | 6059.88 | | 11.18 | |
| Jul-00 | 1494014.00 | 54.00 | 1272612.00 | 46.00 | 2766626.00 | 2738.30 | 5378.45 | | 9.86 | |
| Aug-00 | 1484745.00 | 53.58 | 1286314.00 | 46.42 | 2771059.00 | 2690.73 | 5345.08 | | 9.69 | |
| Sep-00 | 1308045.00 | 50.88 | 1222260.00 | 49.12 | 2488110.00 | 2490.09 | 4708.96 | | 8.96 | |
| Oct-00 | 1312664.00 | 50.40 | 1292049.00 | 49.60 | 2604713.00 | 2324.04 | 4725.59 | | 8.37 | |
| Nov-00 | 1703450.00 | 59.59 | 1117920.00 | 40.41 | 2766420.00 | 3018.70 | 6132.42 | | 10.87 | |
| Dec-00 | 1681006.00 | 59.03 | 1166499.00 | 40.97 | 2847505.00 | 2901.34 | 6051.62 | | 10.44 | |
| Jan-01 | 1764551.00 | 59.14 | 1219075.00 | 40.86 | 2983626.00 | 2695.12 | 6352.38 | 74249.83 | 9.70 | 10.06 |
| Feb-01 | 2160142.00 | 70.71 | 808360.00 | 29.29 | 2759456.00 | 2963.81 | 7776.51 | | 10.67 | |
| Mar-01 | 2447730.00 | 82.00 | 555117.00 | 18.00 | 3084438.00 | 3407.81 | 8811.83 | | 12.27 | |
| Apr-01 | 2145293.00 | 78.87 | 556110.00 | 21.13 | 2632200.00 | 3672.82 | 7723.05 | | 13.22 | |
| May-01 | 1860496.00 | 71.71 | 733894.00 | 28.29 | 2594390.00 | 3390.73 | 6697.79 | | 12.21 | |
| Jun-01 | 1347600.00 | 54.54 | 1123320.00 | 45.46 | 2470920.00 | 2675.40 | 4851.36 | | 9.63 | |
| Jul-01 | 1365054.00 | 52.18 | 1250912.00 | 47.82 | 2615966.00 | 2689.92 | 4914.19 | | 9.68 | |
| Aug-01 | 1399898.00 | 52.02 | 1291181.00 | 47.98 | 2691079.00 | 2741.83 | 5039.63 | | 9.87 | |
| Sep-01 | 1157640.00 | 48.64 | 1222230.00 | 51.36 | 2379870.00 | 2345.78 | 4167.50 | | 8.44 | |
| Oct-01 | 1171304.00 | 47.98 | 1269915.00 | 52.02 | 2441219.00 | 2294.11 | 4216.69 | | 8.26 | |
| Nov-01 | 1506780.00 | 57.31 | 1122570.00 | 42.69 | 2629350.00 | 2413.55 | 5424.41 | | 8.69 | |
| Dec-01 | 2298464.00 | 69.94 | 987753.00 | 30.06 | 3286217.00 | 2304.76 | 8274.47 | | 8.30 | |
| Jan-02 | 2012737.00 | 64.29 | 1117953.00 | 35.71 | 3130690.00 | 2197.19 | 7245.85 | 69847.49 | 7.91 | 9.46 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Feb-02 | 1547336.00 | 59.81 | 1039892.00 | 40.19 | 2587228.00 | 2510.77 | 5570.41 | | 9.04 | |
| Mar-02 | 2023308.00 | 70.13 | 861769.00 | 29.87 | 2885077.00 | 2909.85 | 7283.91 | | 10.48 | |
| Apr-02 | 1577130.00 | 58.28 | 1128930.00 | 41.72 | 2706060.00 | 2726.71 | 5677.67 | | 9.82 | |
| May-02 | 1513606.00 | 56.65 | 1158346.00 | 43.35 | 2671952.00 | 2696.08 | 5448.98 | | 9.71 | |
| Jun-02 | 1404780.00 | 55.94 | 1106670.00 | 44.06 | 2511450.00 | 2730.38 | 5057.21 | | 9.83 | |
| Jul-02 | 1424450.00 | 55.28 | 1152518.00 | 44.72 | 2576968.00 | 2815.56 | 5128.02 | | 10.14 | |
| Aug-02 | 1575730.00 | 58.23 | 1130136.00 | 41.77 | 2618580.00 | 3106.97 | 5672.63 | | 11.19 | |
| Sep-02 | 1285170.00 | 51.31 | 1219590.00 | 48.69 | 2504760.00 | 2644.38 | 4626.61 | | 9.52 | |
| Oct-02 | 1374602.00 | 52.55 | 1240992.00 | 47.45 | 2615594.00 | 2720.37 | 4948.57 | | 9.79 | |
| Nov-02 | 1519860.00 | 57.56 | 1120500.00 | 42.44 | 2640360.00 | 2855.81 | 5471.50 | | 10.28 | |
| Dec-02 | 2143371.00 | 64.79 | 1164763.00 | 35.21 | 3308134.00 | 2223.90 | 7716.14 | | 8.01 | |
| Jan-03 | 1989611.00 | 63.54 | 1141823.00 | 36.46 | 3131434.00 | 2255.13 | 7162.60 | 66801.07 | 8.12 | 8.90 |
| Feb-03 | 1550388.00 | 59.37 | 1061004.00 | 40.63 | 2611392.00 | 2459.84 | 5581.40 | | 8.86 | |
| Mar-03 | 1852560.00 | 62.18 | 1126695.00 | 37.82 | 2979255.00 | 2733.76 | 6669.22 | | 9.84 | |
| Apr-03 | 1654080.00 | 59.76 | 1113630.00 | 40.24 | 2767710.00 | 2460.33 | 5954.69 | | 8.86 | |
| May-03 | 1466517.00 | 53.18 | 1290902.00 | 46.82 | 2757419.00 | 2154.23 | 5279.46 | | 7.76 | |
| Jun-03 | 1249920.00 | 50.05 | 1247460.00 | 49.95 | 2497380.00 | 2279.21 | 4499.71 | | 8.21 | |
| Jul-03 | 1347539.00 | 51.20 | 1284206.00 | 48.80 | 2631745.00 | 2519.94 | 4851.14 | | 9.07 | |
| Aug-03 | 1348810.00 | 51.92 | 1249238.00 | 48.08 | 2598048.00 | 2520.86 | 4855.72 | | 9.08 | |
| Sep-03 | 1342500.00 | 52.04 | 1237350.00 | 47.96 | 2579850.00 | 2641.68 | 4833.00 | | 9.51 | |
| Oct-03 | 1316415.00 | 50.71 | 1279556.00 | 49.29 | 2595971.00 | 2541.29 | 4739.09 | | 9.15 | |
| Nov-03 | 1436400.00 | 56.16 | 1121100.00 | 43.84 | 2557500.00 | 2679.35 | 5171.04 | | 9.65 | |
| Dec-03 | 2001112.00 | 63.20 | 1165321.00 | 36.80 | 3166433.00 | 2548.44 | 7204.00 | | 9.17 | |
| Jan-04 | 2131684.00 | 64.97 | 1149356.00 | 35.03 | 3281040.00 | 2677.73 | 7674.06 | 82022.10 | 9.64 | 11.13 |
| Feb-04 | 2306108.00 | 72.25 | 885724.00 | 27.75 | 3191832.00 | 2707.46 | 8301.99 | | 9.75 | |
| Mar-04 | 2038312.00 | 63.75 | 1159183.00 | 36.25 | 3197495.00 | 2901.68 | 7337.92 | | 10.45 | |
| Apr-04 | 1672080.00 | 60.45 | 1094130.00 | 39.55 | 2766210.00 | 2827.80 | 6019.49 | | 10.18 | |
| May-04 | 1665847.00 | 57.57 | 1227693.00 | 42.43 | 2893540.00 | 3030.85 | 5997.05 | | 10.91 | |
| Jun-04 | 1635120.00 | 57.82 | 1192650.00 | 42.18 | 2827770.00 | 3174.37 | 5886.43 | | 11.43 | |
| Jul-04 | 1614418.00 | 56.91 | 1222547.00 | 43.09 | 2836965.00 | 3092.52 | 5811.90 | | 11.13 | |
| Aug-04 | 1726545.00 | 58.73 | 1213092.00 | 41.27 | 2939637.00 | 3329.05 | 6215.56 | | 11.98 | |
| Sep-04 | 1482000.00 | 55.14 | 1205880.00 | 44.86 | 2687880.00 | 2984.89 | 5335.20 | | 10.75 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Oct-04 | 2105489.00 | 63.25 | 1223167.00 | 36.75 | 3328656.00 | 3861.23 | 7579.76 | | 13.90 | |
| Nov-04 | 2108160.00 | 66.59 | 1057770.00 | 33.41 | 3165930.00 | 3934.60 | 7589.38 | | 14.16 | |
| Dec-04 | 2298154.00 | 67.31 | 1116310.00 | 32.69 | 3414464.00 | 3077.38 | 8273.35 | | 11.08 | |
| Jan-05 | 2431237.00 | 68.05 | 1141606.00 | 31.95 | 3572843.00 | 2813.02 | 8752.45 | 82730.24 | 10.13 | 10.27 |
| Feb-05 | 1828792.00 | 63.56 | 1048600.00 | 36.44 | 2877392.00 | 2692.25 | 6583.65 | | 9.69 | |
| Mar-05 | 2250228.00 | 66.04 | 1156982.00 | 33.96 | 3407210.00 | 2530.96 | 8100.82 | | 9.11 | |
| Apr-05 | 1858620.00 | 63.16 | 1084050.00 | 36.84 | 2942670.00 | 2703.05 | 6691.03 | | 9.73 | |
| May-05 | 1894813.00 | 59.26 | 1302744.00 | 40.74 | 3197557.00 | 2507.10 | 6821.33 | | 9.03 | |
| Jun-05 | 1527840.00 | 54.90 | 1254990.00 | 45.10 | 2782830.00 | 2577.33 | 5500.22 | | 9.28 | |
| Jul-05 | 1702551.00 | 57.90 | 1238202.00 | 42.10 | 2940753.00 | 3025.95 | 6129.18 | | 10.89 | |
| Aug-05 | 1793040.00 | 59.15 | 1238202.00 | 40.85 | 3031242.00 | 3282.63 | 6454.94 | | 11.82 | |
| Sep-05 | 1638480.00 | 58.22 | 1175940.00 | 41.78 | 2814420.00 | 3156.99 | 5898.53 | | 11.37 | |
| Oct-05 | 1701528.00 | 59.51 | 1157912.00 | 40.49 | 2859440.00 | 3296.58 | 6125.50 | | 11.87 | |
| Nov-05 | 1853280.00 | 66.40 | 937650.00 | 33.60 | 2790930.00 | 3492.14 | 6671.81 | | 12.57 | |
| Dec-05 | 2500212.00 | 73.45 | 903712.00 | 26.55 | 3403924.00 | 2738.61 | 9000.76 | | 9.86 | |

## e. Natural Gas Consumption at the Laguna WWTP

| Date | Total Flow | Natural Gas Consumption | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | WW Treated | Cogeneration | | | | | | |
| Month/Year | MG | CCF | cuft | cuft/MG | GJ | GJ/Yr | GJ/MG | GJ/MG-Yr |
| Jan-00 | 668.05 | 2100.00 | 210000.00 | 314.35 | 0.252 | 3.379 | 0.0004 | 0.0004 |
| Feb-00 | 940.52 | 2184.00 | 218400.00 | 232.21 | 0.262 | | 0.0003 | |
| Mar-00 | 868.31 | 2150.00 | 215000.00 | 247.61 | 0.258 | | 0.0003 | |
| Apr-00 | 636.60 | 2122.00 | 212200.00 | 333.33 | 0.255 | | 0.0004 | |
| May-00 | 620.62 | 2531.00 | 253100.00 | 407.82 | 0.304 | | 0.0005 | |
| Jun-00 | 542.10 | 2284.00 | 228400.00 | 421.32 | 0.274 | | 0.0005 | |
| Jul-00 | 545.60 | 2599.00 | 259900.00 | 476.36 | 0.312 | | 0.0006 | |
| Aug-00 | 551.80 | 2642.00 | 264200.00 | 478.80 | 0.317 | | 0.0006 | |
| Sep-00 | 525.30 | 2619.00 | 261900.00 | 498.57 | 0.314 | | 0.0006 | |
| Oct-00 | 564.82 | 2717.00 | 271700.00 | 481.04 | 0.326 | | 0.0006 | |
| Nov-00 | 564.30 | 2137.00 | 213700.00 | 378.70 | 0.256 | | 0.0005 | |
| Dec-00 | 579.39 | 2072.00 | 207200.00 | 357.62 | 0.249 | | 0.0004 | |
| Jan-01 | 654.72 | 2224.00 | 222400.00 | 339.69 | 0.267 | 2.433 | 0.0004 | 0.0003 |
| Feb-01 | 728.84 | 1185.00 | 118500.00 | 162.59 | 0.142 | | 0.0002 | |
| Mar-01 | 718.27 | 45.00 | 4500.00 | 6.27 | 0.005 | | 0.0000 | |
| Apr-01 | 584.10 | 110.00 | 11000.00 | 18.83 | 0.013 | | 0.0000 | |
| May-01 | 548.70 | 590.00 | 59000.00 | 107.53 | 0.071 | | 0.0001 | |
| Jun-01 | 503.70 | 2021.00 | 202100.00 | 401.23 | 0.243 | | 0.0005 | |
| Jul-01 | 507.47 | 2531.00 | 253100.00 | 498.75 | 0.304 | | 0.0006 | |
| Aug-01 | 510.57 | 2792.00 | 279200.00 | 546.84 | 0.335 | | 0.0007 | |
| Sep-01 | 493.50 | 2710.00 | 271000.00 | 549.14 | 0.325 | | 0.0007 | |
| Oct-01 | 510.57 | 2589.00 | 258900.00 | 507.08 | 0.311 | | 0.0006 | |
| Nov-01 | 624.30 | 2037.00 | 203700.00 | 326.29 | 0.244 | | 0.0004 | |
| Dec-01 | 997.27 | 1445.00 | 144500.00 | 144.90 | 0.173 | | 0.0002 | |
| Jan-02 | 916.05 | 1887.00 | 188700.00 | 205.99 | 0.226 | 3.040 | 0.0002 | 0.0004 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Feb-02 | 616.28 | 2057.00 | 205700.00 | 333.78 | 0.247 | | 0.0004 | |
| Mar-02 | 695.33 | 1077.00 | 107700.00 | 154.89 | 0.129 | | 0.0002 | |
| Apr-02 | 578.40 | 2096.00 | 209600.00 | 362.38 | 0.252 | | 0.0004 | |
| May-02 | 561.41 | 2090.00 | 209000.00 | 372.28 | 0.251 | | 0.0004 | |
| Jun-02 | 514.50 | 2142.00 | 214200.00 | 416.33 | 0.257 | | 0.0005 | |
| Jul-02 | 505.92 | 2266.00 | 226600.00 | 447.90 | 0.272 | | 0.0005 | |
| Aug-02 | 507.16 | 2213.00 | 221300.00 | 436.35 | 0.266 | | 0.0005 | |
| Sep-02 | 486.00 | 2605.00 | 260500.00 | 536.01 | 0.313 | | 0.0006 | |
| Oct-02 | 505.30 | 2559.00 | 255900.00 | 506.43 | 0.307 | | 0.0006 | |
| Nov-02 | 532.20 | 2204.00 | 220400.00 | 414.13 | 0.264 | | 0.0005 | |
| Dec-02 | 963.79 | 2140.00 | 214000.00 | 222.04 | 0.257 | | 0.0003 | |
| Jan-03 | 882.26 | 1992.00 | 199200.00 | 225.78 | 0.239 | 3.375 | 0.0003 | 0.0004 |
| Feb-03 | 630.28 | 2017.00 | 201700.00 | 320.02 | 0.242 | | 0.0004 | |
| Mar-03 | 677.66 | 1957.00 | 195700.00 | 288.79 | 0.235 | | 0.0003 | |
| Apr-03 | 672.30 | 1986.00 | 198600.00 | 295.40 | 0.238 | | 0.0004 | |
| May-03 | 680.76 | 2460.00 | 246000.00 | 361.36 | 0.295 | | 0.0004 | |
| Jun-03 | 548.40 | 2609.00 | 260900.00 | 475.75 | 0.313 | | 0.0006 | |
| Jul-03 | 534.75 | 2677.00 | 267700.00 | 500.61 | 0.321 | | 0.0006 | |
| Aug-03 | 535.06 | 2602.00 | 260200.00 | 486.30 | 0.312 | | 0.0006 | |
| Sep-03 | 508.20 | 2727.00 | 272700.00 | 536.60 | 0.327 | | 0.0006 | |
| Oct-03 | 518.01 | 2675.00 | 267500.00 | 516.40 | 0.321 | | 0.0006 | |
| Nov-03 | 536.10 | 2229.00 | 222900.00 | 415.78 | 0.267 | | 0.0005 | |
| Dec-03 | 785.23 | 2196.00 | 219600.00 | 279.66 | 0.264 | | 0.0003 | |
| Jan-04 | 796.08 | 2054.00 | 205400.00 | 258.01 | 0.246 | 3.162 | 0.0003 | 0.0004 |
| Feb-04 | 851.76 | 1549.00 | 154900.00 | 181.86 | 0.186 | | 0.0002 | |
| Mar-04 | 702.46 | 2129.00 | 212900.00 | 303.08 | 0.255 | | 0.0004 | |
| Apr-04 | 591.30 | 1999.00 | 199900.00 | 338.07 | 0.240 | | 0.0004 | |
| May-04 | 549.63 | 2384.00 | 238400.00 | 433.75 | 0.286 | | 0.0005 | |
| Jun-04 | 515.10 | 2409.00 | 240900.00 | 467.68 | 0.289 | | 0.0006 | |
| Jul-04 | 522.04 | 2449.00 | 244900.00 | 469.12 | 0.294 | | 0.0006 | |
| Aug-04 | 518.63 | 2493.00 | 249300.00 | 480.69 | 0.299 | | 0.0006 | |
| Sep-04 | 496.50 | 2521.00 | 252100.00 | 507.75 | 0.302 | | 0.0006 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Oct-04 | 545.29 | 2474.00 | 247400.00 | 453.70 | 0.297 | | 0.0005 | |
| Nov-04 | 535.80 | 1906.00 | 190600.00 | 355.73 | 0.229 | | 0.0004 | |
| Dec-04 | 746.79 | 1988.00 | 198800.00 | 266.21 | 0.239 | | 0.0003 | |
| Jan-05 | 864.28 | 2065.00 | 206500.00 | 238.93 | 0.248 | 3.361 | 0.0003 | 0.0004 |
| Feb-05 | 679.28 | 2066.00 | 206600.00 | 304.15 | 0.248 | | 0.0004 | |
| Mar-05 | 889.08 | 2117.00 | 211700.00 | 238.11 | 0.254 | | 0.0003 | |
| Apr-05 | 687.60 | 2008.00 | 200800.00 | 292.03 | 0.241 | | 0.0004 | |
| May-05 | 755.78 | 2566.00 | 256600.00 | 339.52 | 0.308 | | 0.0004 | |
| Jun-05 | 592.80 | 2635.00 | 263500.00 | 444.50 | 0.316 | | 0.0005 | |
| Jul-05 | 562.65 | 2518.00 | 251800.00 | 447.53 | 0.302 | | 0.0005 | |
| Aug-05 | 546.22 | 2738.00 | 273800.00 | 501.26 | 0.329 | | 0.0006 | |
| Sep-05 | 519.00 | 2890.00 | 289000.00 | 556.84 | 0.347 | | 0.0007 | |
| Oct-05 | 516.15 | 2890.00 | 289000.00 | 559.91 | 0.347 | | 0.0007 | |
| Nov-05 | 530.70 | 2060.00 | 206000.00 | 388.17 | 0.247 | | 0.0005 | |
| Dec-05 | 912.95 | 1458.00 | 145800.00 | 159.70 | 0.175 | | 0.0002 | |

## f. Chemicals Utilized for Treatment at the Laguna WWTP

| Date | Ferrous Chloride (FeCl3-) | | Alum | | Hypochlorite | |
|---|---|---|---|---|---|---|
| | 24% Ferrous (or Ferric) | | 47% Al2(SO4)2 | | | |
| | Lbs | Lbs/MG | Lbs | Lbs/MG | Lbs | Lbs/ MG |
| Jan-00 | 54095.00 | 80.97 | 25513.00 | 38.19 | 16000.21 | 23.95 |
| Feb-00 | 47628.00 | 50.64 | 37520.00 | 39.89 | 16000.21 | 17.01 |
| Mar-00 | 61597.00 | 70.94 | 34379.00 | 39.59 | 16000.21 | 18.43 |
| Apr-00 | 42540.00 | 66.82 | 26820.00 | 42.13 | 16000.21 | 25.13 |
| May-00 | 41726.00 | 67.23 | 29481.00 | 47.50 | 16000.21 | 25.78 |
| Jun-00 | 48450.00 | 89.37 | 26400.00 | 48.70 | 16000.21 | 29.52 |
| Jul-00 | 48000.00 | 87.98 | 24490.00 | 44.89 | 16000.21 | 29.33 |
| Aug-00 | 50747.00 | 91.97 | 26164.00 | 47.42 | 16000.21 | 29.00 |
| Sep-00 | 50640.00 | 96.40 | 22890.00 | 43.58 | 16000.21 | 30.46 |
| Oct-00 | 54312.00 | 96.16 | 24242.00 | 42.92 | 16000.21 | 28.33 |
| Nov-00 | 48030.00 | 85.11 | 21870.00 | 38.76 | 16000.21 | 28.35 |
| Dec-00 | 59179.00 | 102.14 | 25296.00 | 43.66 | 16000.21 | 27.62 |
| Jan-01 | 55738.00 | 85.13 | 30659.00 | 46.83 | 35509.94 | 54.24 |
| Feb-01 | 55832.00 | 76.60 | 31136.00 | 42.72 | 35509.94 | 48.72 |
| Mar-01 | 77779.00 | 108.29 | 44919.00 | 62.54 | 35509.94 | 49.44 |
| Apr-01 | 61659.00 | 105.56 | 26940.00 | 46.12 | 35509.94 | 60.79 |
| May-01 | 45539.00 | 82.99 | 26877.00 | 48.98 | 35509.94 | 64.72 |
| Jun-01 | 49080.00 | 97.44 | 45720.00 | 90.77 | 35509.94 | 70.50 |
| Jul-01 | 45539.00 | 89.74 | 48856.00 | 96.27 | 35509.94 | 69.97 |
| Aug-01 | 49848.00 | 97.63 | 29357.00 | 57.50 | 35509.94 | 69.55 |
| Sep-01 | 55950.00 | 113.37 | 22770.00 | 46.14 | 35509.94 | 71.96 |
| Oct-01 | 62434.00 | 122.28 | 24087.00 | 47.18 | 35509.94 | 69.55 |
| Nov-01 | 775620.00 | 1242.38 | 40980.00 | 65.64 | 35509.94 | 56.88 |
| Dec-01 | 126914.00 | 127.26 | 55087.00 | 55.24 | 35509.94 | 35.61 |
| Jan-02 | 100595.00 | 109.81 | 58156.00 | 63.49 | 39335.04 | 42.94 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Feb-02 | 55076.00 | 89.37 | 40152.00 | 65.15 | 39335.04 | 63.83 |
| Mar-02 | 66185.00 | 95.19 | 43059.00 | 61.93 | 39335.04 | 56.57 |
| Apr-02 | 73800.00 | 127.59 | 40200.00 | 69.50 | 39335.04 | 68.01 |
| May-02 | 75671.00 | 134.79 | 35681.00 | 63.56 | 39335.04 | 70.06 |
| Jun-02 | 54240.00 | 105.42 | 36840.00 | 71.60 | 39335.04 | 76.45 |
| Jul-02 | 53816.00 | 106.37 | 32395.00 | 64.03 | 39335.04 | 77.75 |
| Aug-02 | 51584.00 | 101.71 | 34317.00 | 67.67 | 39335.04 | 77.56 |
| Sep-02 | 51840.00 | 106.67 | 31950.00 | 65.74 | 39335.04 | 80.94 |
| Oct-02 | 57381.00 | 113.56 | 33728.00 | 66.75 | 39335.04 | 77.84 |
| Nov-02 | 44550.00 | 83.71 | 33480.00 | 62.91 | 39335.04 | 73.91 |
| Dec-02 | 118265.00 | 122.71 | 50964.00 | 52.88 | 39335.04 | 40.81 |
| Jan-03 | 62930.00 | 71.33 | 47554.00 | 53.90 | 24203.75 | 27.43 |
| Feb-03 | 43344.00 | 68.77 | 39732.00 | 63.04 | 24203.75 | 38.40 |
| Mar-03 | 47895.00 | 70.68 | 40548.00 | 59.84 | 24203.75 | 35.72 |
| Apr-03 | 41370.00 | 61.54 | 37950.00 | 56.45 | 24203.75 | 36.00 |
| May-03 | 47926.00 | 70.40 | 31093.00 | 45.67 | 24203.75 | 35.55 |
| Jun-03 | 42090.00 | 76.75 | 26100.00 | 47.59 | 24203.75 | 44.14 |
| Jul-03 | 43772.00 | 81.86 | 24986.00 | 46.72 | 24203.75 | 45.26 |
| Aug-03 | 45477.00 | 84.99 | 24180.00 | 45.19 | 24203.75 | 45.24 |
| Sep-03 | 50190.00 | 98.76 | 24060.00 | 47.34 | 24203.75 | 47.63 |
| Oct-03 | 57164.00 | 110.35 | 33418.00 | 64.51 | 24203.75 | 46.72 |
| Nov-03 | 47820.00 | 89.20 | 34140.00 | 63.68 | 24203.75 | 45.15 |
| Dec-03 | 68448.00 | 87.17 | 32829.00 | 41.81 | 24203.75 | 30.82 |
| Jan-04 | 61969.00 | 77.84 | 32333.00 | 40.62 | 14738.50 | 18.51 |
| Feb-04 | 44660.00 | 52.43 | 84084.00 | 98.72 | 14738.50 | 17.30 |
| Mar-04 | 47151.00 | 67.12 | 60264.00 | 85.79 | 14738.50 | 20.98 |
| Apr-04 | 46050.00 | 77.88 | 110280.00 | 186.50 | 14738.50 | 24.93 |
| May-04 | 45663.00 | 83.08 | 23870.00 | 43.43 | 14738.50 | 26.82 |
| Jun-04 | 51510.00 | 100.00 | 22170.00 | 43.04 | 14738.50 | 28.61 |
| Jul-04 | 66061.00 | 126.54 | 33232.00 | 63.66 | 14738.50 | 28.23 |
| Aug-04 | 67363.00 | 129.89 | 40796.00 | 78.66 | 14738.50 | 28.42 |
| Sep-04 | 57840.00 | 116.50 | 23850.00 | 48.04 | 14738.50 | 29.68 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Oct-04 | 74400.00 | 136.44 | 24211.00 | 44.40 | 14738.50 | 27.03 |
| Nov-04 | 54030.00 | 100.84 | 26700.00 | 49.83 | 14738.50 | 27.51 |
| Dec-04 | 39897.00 | 53.42 | 58249.00 | 78.00 | 14738.50 | 19.74 |
| Jan-05 | 88071.00 | 101.90 | 43090.00 | 49.86 | 18076.42 | 20.92 |
| Feb-05 | 45472.00 | 66.94 | 26348.00 | 38.79 | 18076.42 | 26.61 |
| Mar-05 | 74369.00 | 83.65 | 63426.00 | 71.34 | 18076.42 | 20.33 |
| Apr-05 | 51600.00 | 75.04 | 30270.00 | 44.02 | 18076.42 | 26.29 |
| May-05 | 42749.00 | 56.56 | 31682.00 | 41.92 | 18076.42 | 23.92 |
| Jun-05 | 51660.00 | 87.15 | 27990.00 | 47.22 | 18076.42 | 30.49 |
| Jul-05 | 32581.00 | 57.91 | 28241.00 | 50.19 | 18076.42 | 32.13 |
| Aug-05 | 49011.00 | 89.73 | 26257.00 | 48.07 | 18076.42 | 33.09 |
| Sep-05 | 56730.00 | 109.31 | 27390.00 | 52.77 | 18076.42 | 34.83 |
| Oct-05 | 49600.00 | 96.10 | 30380.00 | 58.86 | 18076.42 | 35.02 |
| Nov-05 | 45420.00 | 85.59 | 26640.00 | 50.20 | 18076.42 | 34.06 |
| Dec-05 | 73780.00 | 80.81 | 77035.00 | 84.38 | 18076.42 | 19.80 |

| **Date** | **Total Energy for Producing Chemicals** | | | | |
|---|---|---|---|---|---|
| | MJ | GJ | GJ/Yr | GJ/MG | GJ/MG-Yr |
| Jan-00 | 534242.57 | 534.24 | 6441.89 | 0.80 | 0.85 |
| Feb-00 | 564979.63 | 564.98 | | 0.60 | |
| Mar-00 | 563621.54 | 563.62 | | 0.65 | |
| Apr-00 | 531682.05 | 531.68 | | 0.84 | |
| May-00 | 538831.07 | 538.83 | | 0.87 | |
| Jun-00 | 533700.63 | 533.70 | | 0.98 | |
| Jul-00 | 528006.27 | 528.01 | | 0.97 | |
| Aug-00 | 534277.58 | 534.28 | | 0.97 | |
| Sep-00 | 524878.30 | 524.88 | | 1.00 | |
| Oct-00 | 530734.40 | 530.73 | | 0.94 | |
| Nov-00 | 520547.49 | 520.55 | | 0.92 | |
| Dec-00 | 536390.72 | 536.39 | | 0.93 | |
| Jan-01 | 1076583.30 | 1076.58 | 13520.38 | 1.64 | 1.83 |

| | | | | | |
|---|---|---|---|---|---|
| Feb-01 | 1077995.39 | 1078.00 | | 1.48 | |
| Mar-01 | 1129265.61 | 1129.27 | | 1.57 | |
| Apr-01 | 1069195.50 | 1069.20 | | 1.83 | |
| May-01 | 1060241.46 | 1060.24 | | 1.93 | |
| Jun-01 | 1115929.76 | 1115.93 | | 2.22 | |
| Jul-01 | 1122949.66 | 1122.95 | | 2.21 | |
| Aug-01 | 1069662.58 | 1069.66 | | 2.10 | |
| Sep-01 | 1054190.62 | 1054.19 | | 2.14 | |
| Oct-01 | 1061477.46 | 1061.48 | | 2.08 | |
| Nov-01 | 1497869.71 | 1497.87 | | 2.40 | |
| Dec-01 | 1185020.60 | 1185.02 | | 1.19 | |
| Jan-02 | 1282729.19 | 1282.73 | 14525.26 | 1.40 | 1.97 |
| Feb-02 | 1206585.56 | 1206.59 | | 1.96 | |
| Mar-02 | 1220926.26 | 1220.93 | | 1.76 | |
| Apr-02 | 1216914.18 | 1216.91 | | 2.10 | |
| May-02 | 1205039.45 | 1205.04 | | 2.15 | |
| Jun-02 | 1196681.06 | 1196.68 | | 2.33 | |
| Jul-02 | 1183768.26 | 1183.77 | | 2.34 | |
| Aug-02 | 1188037.01 | 1188.04 | | 2.34 | |
| Sep-02 | 1181423.07 | 1181.42 | | 2.43 | |
| Oct-02 | 1189511.90 | 1189.51 | | 2.35 | |
| Nov-02 | 1181820.28 | 1181.82 | | 2.22 | |
| Dec-02 | 1271827.69 | 1271.83 | | 1.32 | |
| Jan-03 | 823432.99 | 823.43 | 9299.28 | 0.93 | 1.24 |
| Feb-03 | 790455.20 | 790.46 | | 1.25 | |
| Mar-03 | 795260.48 | 795.26 | | 1.17 | |
| Apr-03 | 784296.51 | 784.30 | | 1.17 | |
| May-03 | 768301.33 | 768.30 | | 1.13 | |
| Jun-03 | 750879.23 | 750.88 | | 1.37 | |
| Jul-03 | 748616.41 | 748.62 | | 1.40 | |
| Aug-03 | 747244.86 | 747.24 | | 1.40 | |
| Sep-03 | 749467.83 | 749.47 | | 1.47 | |

| | | | | | |
|---|---|---|---|---|---|
| Oct-03 | 779963.13 | 779.96 | | 1.51 | |
| Nov-03 | 776937.02 | 776.94 | | 1.45 | |
| Dec-03 | 784424.66 | 784.42 | | 1.00 | |
| Jan-04 | 523920.35 | 523.92 | 6673.46 | 0.66 | 0.91 |
| Feb-04 | 662149.46 | 662.15 | | 0.78 | |
| Mar-04 | 595544.58 | 595.54 | | 0.85 | |
| Apr-04 | 737645.76 | 737.65 | | 1.25 | |
| May-04 | 490899.07 | 490.90 | | 0.89 | |
| Jun-04 | 489231.39 | 489.23 | | 0.95 | |
| Jul-04 | 528712.61 | 528.71 | | 1.01 | |
| Aug-04 | 551002.12 | 551.00 | | 1.06 | |
| Sep-04 | 497470.08 | 497.47 | | 1.00 | |
| Oct-04 | 507513.83 | 507.51 | | 0.93 | |
| Nov-04 | 503527.58 | 503.53 | | 0.94 | |
| Dec-04 | 585847.16 | 585.85 | | 0.78 | |
| Jan-05 | 658942.75 | 658.94 | 7468.38 | 0.76 | 0.93 |
| Feb-05 | 587989.12 | 587.99 | | 0.87 | |
| Mar-05 | 709505.17 | 709.51 | | 0.80 | |
| Apr-05 | 602514.50 | 602.51 | | 0.88 | |
| May-05 | 601725.37 | 601.73 | | 0.80 | |
| Jun-05 | 596042.10 | 596.04 | | 1.01 | |
| Jul-05 | 586373.32 | 586.37 | | 1.04 | |
| Aug-05 | 589655.80 | 589.66 | | 1.08 | |
| Sep-05 | 597089.89 | 597.09 | | 1.15 | |
| Oct-05 | 601739.72 | 601.74 | | 1.17 | |
| Nov-05 | 588793.92 | 588.79 | | 1.11 | |
| Dec-05 | 748012.36 | 748.01 | | 0.82 | |

# Appendix C-II

## Laguna Wastewater Treatment Plant – Emissions from the Plant

### a. Global Warming Potential

| Global Warming Potential for 2000 - Electricity | | | | |
|---|---|---|---|---|
| | ***g/MJe*** | **Total for 2000** | ***g $CO_2$ eq.//MG*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 183 | 13936873872 | 1832013 | 1832 |
| Non-fossil Carbon Dioxide | 0.000297 | 22619 | 3 | 0.003 |
| Methane CH4 | 0.313 | 23837385 | 72069 | 72 |
| Nitrous Oxide | 0.0102 | 776809 | 30634 | 31 |
| **Total GWP** | | | 1934719 | 1935 |

| Global Warming Potential for 2001 - Electricity | | | | |
|---|---|---|---|---|
| | ***g/MJe*** | **Total for 2001** | ***g $CO_2$ eq.//MG*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 183 | 14669394495 | 1987182 | 1987 |
| Non-fossil Carbon Dioxide | 0.0003 | 23808 | 3 | 0.003 |
| Methane CH4 | 0.313 | 25090276 | 78173 | 78 |
| Nitrous Oxide | 0.010 | 817638 | 33228 | 33 |
| **Total GWP** | | | 2098586 | 2099 |

| Global Warming Potential for 2002 - Electricity | | | | |
|---|---|---|---|---|
| | ***g/MJe*** | **Total for 2002** | ***g $CO_2$ eq.//MG*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 183 | 13932478431 | 1887271 | 1887 |
| Non-fossil Carbon Dioxide | 0.0003 | 22612 | 3 | 0.003 |
| Methane CH4 | 0.313 | 23829867 | 74243 | 74 |
| Nitrous Oxide | 0.0102 | 776564 | 31558 | 32 |
| **Total GWP** | | | 1993075 | 1993 |

| Global Warming Potential for 2003 - Electricity | | | | |
|---|---|---|---|---|
| | ***g/MJe*** | **Total for 2003** | ***g $CO_2$ eq.//MG*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 183 | 13324808874 | 1774509 | 1775 |
| Non-fossil Carbon Dioxide | 0.0003 | 21626 | 3 | 0.003 |
| Methane CH4 | 0.313 | 22790520 | 69807 | 70 |
| Nitrous Oxide | 0.0102 | 742694 | 29672 | 30 |
| **Total GWP** | | | 1873991 | 1874 |

| Global Warming Potential for 2004 - Electricity | | | | |
|---|---|---|---|---|
| | ***g/MJe*** | **Total for 2004** | ***g $CO_2$ eq.//MG*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 183 | 16360948526 | 2219523 | 2220 |
| Non-fossil Carbon Dioxide | 0.0003 | 26553 | 4 | 0.004 |
| Methane CH4 | 0.313 | 27983480 | 87313 | 87 |
| Nitrous Oxide | 0.0102 | 911922 | 37113 | 37 |
| **Total GWP** | | | 2343953 | 2344 |

| Global Warming Potential for 2005 - Electricity | | | | |
|---|---|---|---|---|
| | ***g/MJe*** | **Total for 2004** | ***g $CO_2$ eq.//MG*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 183 | 16502200095 | 2048311 | 2048 |
| Non-fossil Carbon Dioxide | 0.0003 | 26782 | 3 | 0.003 |
| Methane CH4 | 0.313 | 28225074 | 80578 | 81 |
| Nitrous Oxide | 0.0102 | 919795 | 34250 | 34 |
| **Total GWP** | | | 2163143 | 2163 |

| Global Warming Potential for 2000- Natural Gas | | | | |
|---|---|---|---|---|
| | ***g/1000cuft*** | ***Total in 2000*** | ***g $CO_2$ eq.//MG*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 62142 | 174973652 | 23000 | 23 |
| Non-fossil Carbon Dioxide | 13 | 35762 | 5 | 0.005 |
| Methane CH4 | 172 | 485328 | 1467 | 1 |
| Nitrous Oxide | 0.005 | 14 | 0.555 | 0.001 |
| **Total GWP** | | | 24473 | 24 |

| Global Warming Potential for 2001- Natural Gas | | | | |
|---|---|---|---|---|
| | ***g/1000cuft*** | ***Total in 2001*** | ***g $CO_2$ eq.//MG*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 62142 | 126018066 | 17071 | 17 |
| Non-fossil Carbon Dioxide | 13 | 25756 | 3 | 0.003 |
| Methane CH4 | 172 | 349539 | 1089 | 1.089 |
| Nitrous Oxide | 0.005 | 10 | 0.412 | 0.000 |
| **Total GWP** | | | 18164 | 18 |

| Global Warming Potential for 2002- Natural Gas | | | | |
|---|---|---|---|---|
| | ***g/1000cuft*** | ***Total in 2002*** | ***g $CO_2$ eq.//MG*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 62142 | 157443351 | 21327 | 21 |
| Non-fossil Carbon Dioxide | 13 | 32179 | 4 | 0.004 |
| Methane CH4 | 172 | 436704 | 1361 | 1 |
| Nitrous Oxide | 0.005 | 13 | 0.515 | 0.001 |
| **Total GWP** | | | 22692 | 23 |

| Global Warming Potential for 2003- Natural Gas | | | | |
|---|---|---|---|---|
| | ***g/1000cuft*** | ***Total in 2003*** | ***g $CO_2$ eq.//MG*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 62142 | 174787225 | 23277 | 23.277 |
| Non-fossil Carbon Dioxide | 13 | 35724 | 5 | 0.005 |
| Methane CH4 | 172 | 484811 | 1485 | 1 |
| Nitrous Oxide | 0.005 | 14 | 0.562 | 0.001 |
| **Total GWP** | | | 24767 | 25 |

| Global Warming Potential for 2004- Natural Gas | | | | |
|---|---|---|---|---|
| | ***g/1000cuft*** | ***Total in 2004*** | ***g $CO_2$ eq.//MG*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 62142 | 163775636 | 22218 | 22 |
| Non-fossil Carbon Dioxide | 13 | 33473 | 5 | 0.005 |
| Methane CH4 | 172 | 454268 | 1417 | 1 |
| Nitrous Oxide | 0.005 | 13 | 0.536 | 0.001 |
| **Total GWP** | | | 23640 | 24 |

| Global Warming Potential for 2005- Natural Gas Combustion | | | | |
|---|---|---|---|---|
| | ***g/1000cuft*** | ***Total in 2005*** | ***g $CO_2$ eq.//MG*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 54885 | 153737477 | 19082 | 19 |
| Non-fossil Carbon Dioxide | 0 | 0 | 0 | 0 |
| Methane CH4 | 0.1360 | 381 | 1 | 0.001 |
| Nitrous Oxide | 2.268 | 6353 | 236.563 | 0.24 |
| **Total GWP** | | | 19320 | 19.32 |

| Global Warming Potential for 2005- Diesel | | | | |
|---|---|---|---|---|
| | ***g/1000cuft*** | ***Total in 2005*** | ***g $CO_2$ eq.//MG*** | ***kg $CO_2$ eq./MG*** |
| Fossil Carbon Dioxide | 11626480.00 | 60612543.27 | 7523.443 | 7.523 |
| Non-fossil Carbon Dioxide | 2766.913 | 14424.80 | 1.790 | 0.002 |
| Methane CH4 | 1837.049 | 9577.12 | 27.341 | 0.027 |
| Nitrous Oxide | 0.007 | 0.04 | 0.001 | 0.000001 |
| **Total GWP** | | | 7552.58 | 7.553 |

| Global Warming Potential for 2005- Chemicals | | |
|---|---|---|
| | ***kg Co2/Yr*** | ***kg Co2/MG*** |
| Carbon Dioxide | 17756 | 2.2 |
| Methane CH4 | 744 | 0.09 |
| Nitrous Oxide | 240 | 0.03 |
| **Total GWP** | | 2.3 |

## b. Eutrophication Potential

| Eutrophication Potential for 2005- Electricity | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/MJe* | *Total in 2005* | kg N eq./MG | | *g/MJe* | *Total in 2005* | kg N eq./MG |
| NOx | 0.475 | 39296861.910 | 0.195 | N | | | |
| $NH_3$ | 0.00035 | 28955.582 | 0.0004 | $NH_3$ | 0.000151 | 12385.337 | 0.0012 |
| $NH_4$+ | | | | COD | 0.00466 | 382222.992 | 0.00237 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.0000473 | 3879.645 | 0.000048 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.000000002 | 0.152 | 0.00000014 |
| P | | | | P | | | |
| Total | | | 196 | g | | | 4 |

| Eutrophication Potential for 2005- Natural Gas Combustion | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/1000 cuft.* | *Total in 2004* | g N eq./MG | | *g/1000 cuft.* | *Total in 2004* | g N eq./MG |
| NOx | 176.9 | 495514.590 | 2.460 | N | | | |
| $NH_3$ | 1.361 | 3812.297 | 0.0568 | $NH_3$ | 0.0245 | 68.627 | 0.006644 |
| $NH_4$+ | | | | COD | 10.886 | 30492.775 | 0.18924 |
| $NO_3^-$ | | | | $NO_3^-$ | 0 | 0.000 | 0.00000 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0 | 0.000 | 0.00000 |
| P | | | | P | | | |
| Total | | | 2.517 | | | | 0.2 |

| Eutrophication Potential for 2005- Chemicals | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g N eq./Yr* | | g N eq./MG | | *g N eq./Yr* | | g N eq./MG |
| NOx | 1398.98 | | 0.174 | N | | | |
| $NH_3$ | 3.09 | | 0.000 | $NH_3$ | 0.03 | | 0.000004 |
| $NH_4$+ | | | | COD | 17.15 | | 0.002129 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.35 | | 0.000044 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 0.21 | | 0.000026 |
| P | | | | P | | | |
| Total | | | 0.174 | | | | 0.002 |

| Eutrophication Potential for 2005- Diesel | | | | | | | |
|---|---|---|---|---|---|---|---|
| Atmospheric | | | | Aquatic | | | |
| | *g/1000 cuft.* | *Total in 2005* | kg N eq./MG | | *g/1000 cuft.* | *Total in 2005* | kg N eq./MG |
| NOx | 216950.400 | 1131031.53 | 0.006 | N | | | |
| $NH_3$ | 18.144 | 94.59 | 0.000001 | $NH_3$ | 6.35 | 33.105 | 0.000003 |
| $NH_4$+ | | | | COD | 39.463 | 205.733 | 0.000001 |
| $NO_3^-$ | | | | $NO_3^-$ | 0.018 | 0.094 | 0.000000001 |
| $PO_4^{3-}$ | | | | $PO_4^{3-}$ | 1.588 | 8.279 | 0.000002 |
| P | | | | P | | | |
| Total | | | 6 | | | | 0.007 |

## c. Acidification Potential

| Acidification Potential for 2000- Electricity | | | | Acidification Potential for 2001- Electricity | | | |
|---|---|---|---|---|---|---|---|
| | g/MJe | Total in 2000 | g $SO_2$ equiv./MG | | g/MJe | Total in 2001 | g $SO_2$ equiv./MG |
| $SO_2$ | 38 | 2897172209 | 381 | $SO_2$ | 38 | 3049447275 | 413 |
| HCl | 3 | 255588406 | 34 | HCl | 3 | 269022106 | 36 |
| NOx | 19 | 1448444832 | 190 | NOx | 19 | 1524574939 | 207 |
| $NH_3$ | 0.03 | 2545307 | 0 | $NH_3$ | 0.03 | 2679088 | 0 |
| Total | | | 605 | Total | | | 656 |
| | | | | | | | |
| Acidification Potential for 2002- Electricity | | | | Acidification Potential for 2003- Electricity | | | |
| | g/MJe | Total in 2002 | kg $SO_2$ equiv./MG | | g/MJe | Total in 2003 | kg $SO_2$ equiv./MG |
| $SO_2$ | 38 | 2896258492 | 392 | $SO_2$ | 38 | 2769937240 | 369 |
| HCl | 3 | 255507798 | 35 | HCl | 3 | 244363743 | 33 |
| NOx | 19 | 1447988018 | 196 | NOx | 19 | 1384833552 | 184 |
| $NH_3$ | 0 | 2544505 | 0 | $NH_3$ | 0.03 | 2433525 | 0 |
| Total | | | 623 | Total | | | 586 |
| | | | | | | | |
| Acidification Potential for 2004- Electricity | | | | Acidification Potential for 2005- Electricity | | | |
| | g/MJe | Total in 2004 | kg $SO_2$ equiv./MG | | g/MJe | Total in 2005 | kg $SO_2$ equiv./MG |
| $SO_2$ | 38 | 3120260987 | 423 | $SO_2$ | 38 | 3147199631 | 391 |
| HCl | 3 | 275269288 | 37 | HCl | 3 | 277645814 | 34 |
| NOx | 19 | 1559978343 | 212 | NOx | 19 | 1573446351 | 195 |
| $NH_3$ | 0.03 | 2741302 | 0 | $NH_3$ | 0.03 | 2764969 | 0 |
| Total | | | 673 | Total | | | 621 |

| Acidification Potential for 2005- Diesel | | | |
|---|---|---|---|
| | g/1000 gallons | Total in 2005 | kg $SO_2$ equiv./MG |
| Sulfur Dioxide | 25854.77 | 134789.1508 | 0.017 |
| Hydrochloric Acid | 11.34 | 59.11903179 | 0.00001 |
| Nitrous Oxides | 216590.4 | 1129154.739 | 0.098 |
| Ammonia | 18.144 | 94.59045086 | 0.000 |
| Total | | | 0.11 |

| Acidification Potential for 2005- Chemicals | | |
|---|---|---|
| | moles H+/Yr | moles H+ eq./MG |
| Sulfur Dioxide | 14357 | 1.782 |
| Hydrochloric Acid | 296 | 0.037 |
| Nitrous Oxides | 2121 | 0.263 |
| Ammonia | 3 | 0.000 |
| Total | | 2.08 |

# Appendix D

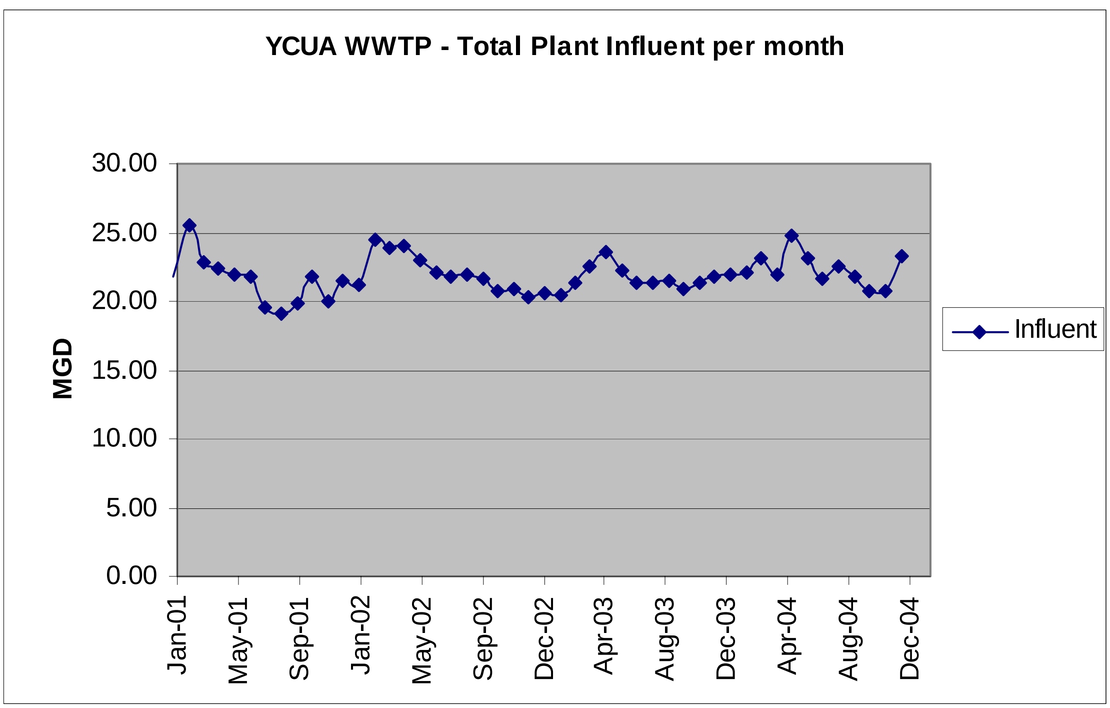
## Details of YCUA Wastewater Treatment plant

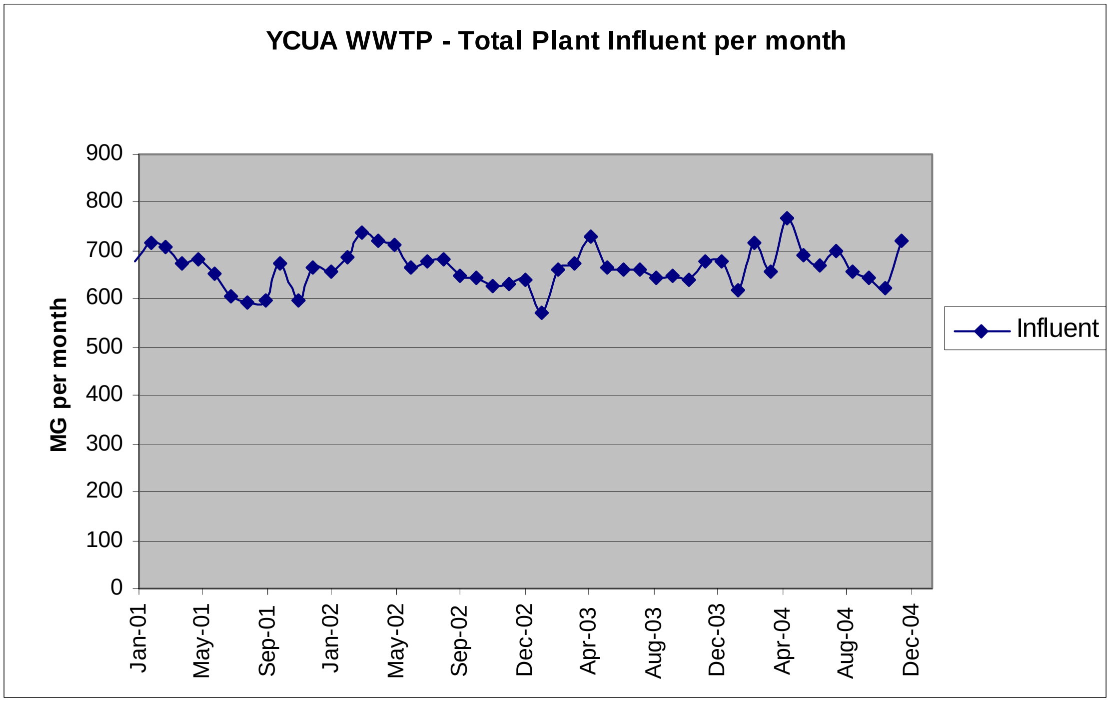
### a. Background

The Ypsilanti Community Utilities Authority WWTP is a tertiary treatment plant with a capacity of 29 MGD. The details of the case study have already been compiled in the ongoing 'Preliminary Application of Life Cycle Assessment to U.S. Water and Wastewater Treatment Facilities' conducted by Center for Sustainable Systems at the University of Michigan, Ann Arbor. For the purpose of comparisons with recent case studies of Ann Arbor and Laguna WWTPs some of the calculations have been upgraded or further calculations have been made as required.

### b. Plant Influent

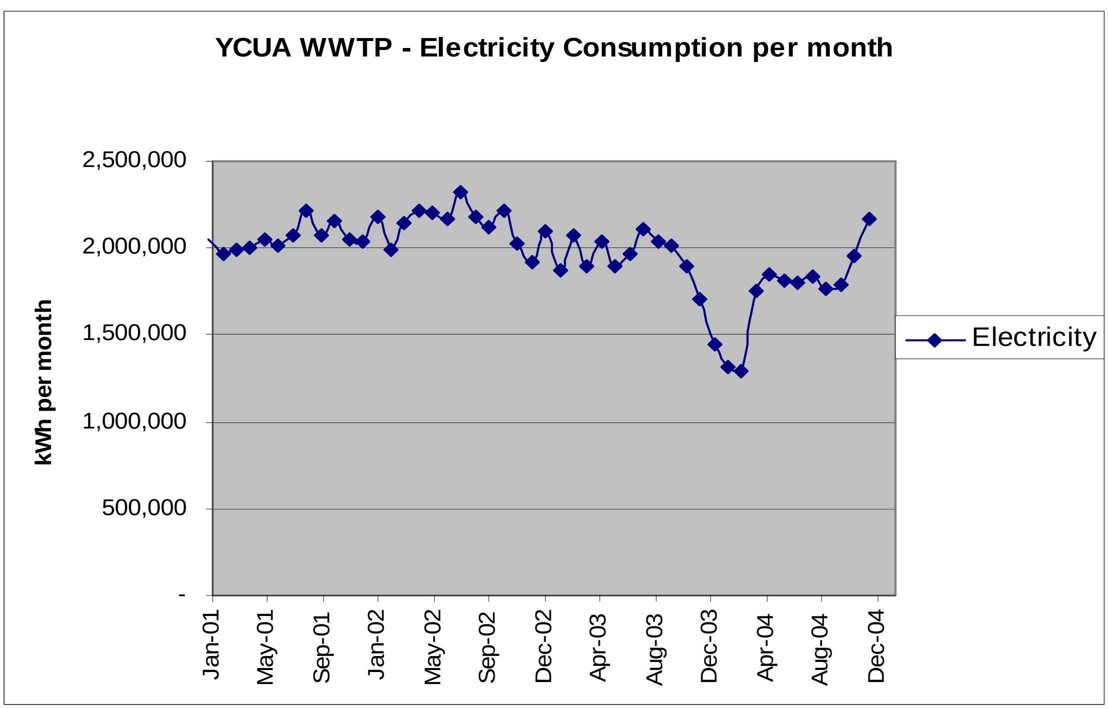
The influent quantity at YCUA WWTP is generally lower in winters and a little higher during summers. The total quantity of influent does not fluctuate drastically and ranges from 18 MGD to 25 MGD

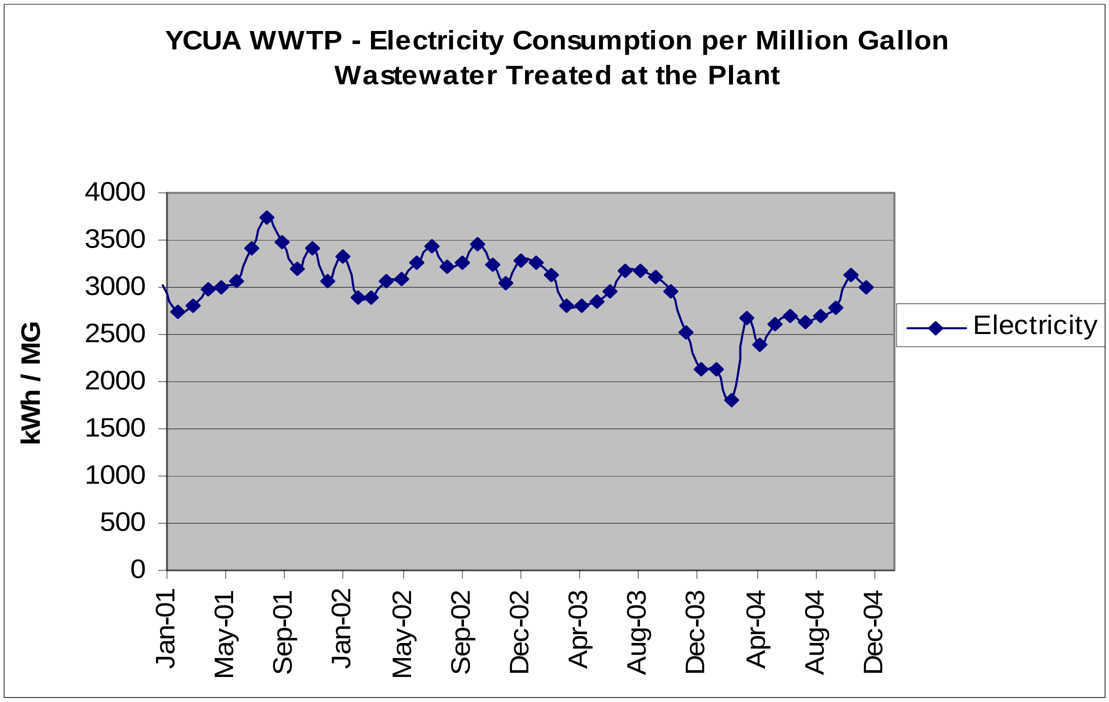





c. **Electricity Consumption**

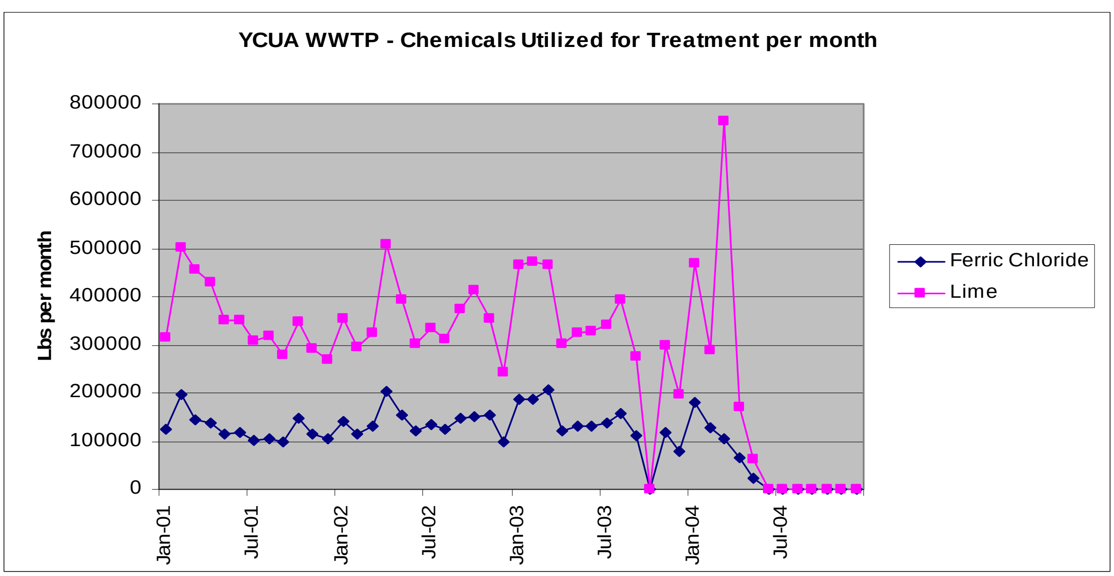
The electricity consumption at YCUA includes in-plant electricity disinfection and electricity consumed within buildings. There is a sudden drop in electricity usage at the plant from Dec-03 to April 04.



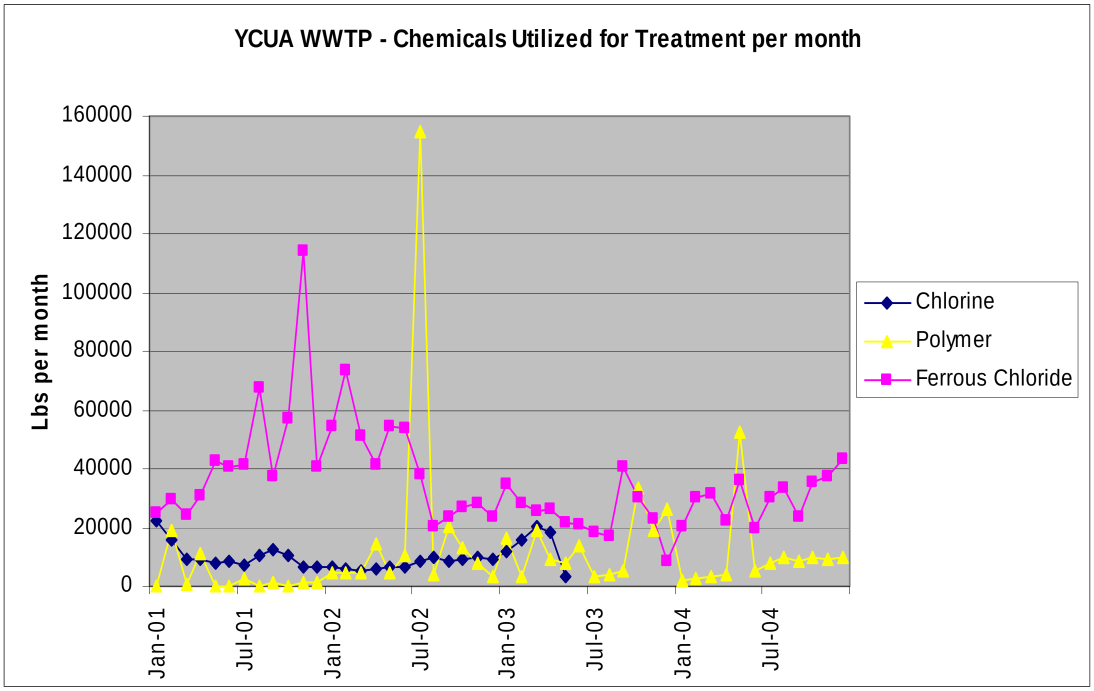



## d. Chemicals Utilized for Treatment

Chlorine, Ferric Chloride, Ferrous Chloride, Lime, and a polymer are used for treatment at YCUA WWTP. The average consumption of lime during Jan-01 to may-04 was 342,448 Lbs per month. Average consumption of Ferric Chloride for the same period was 127,910 Lbs per month



The average consumption of Chlorine from Jan-01 to may-03 was 9964 Lbs per month. The average consumption of Polymer was 11852 Lbs per month. An exceptionally high amount was consumed in Jul-02. The average consumption of ferrous Chloride was 35,362 Lbs month.



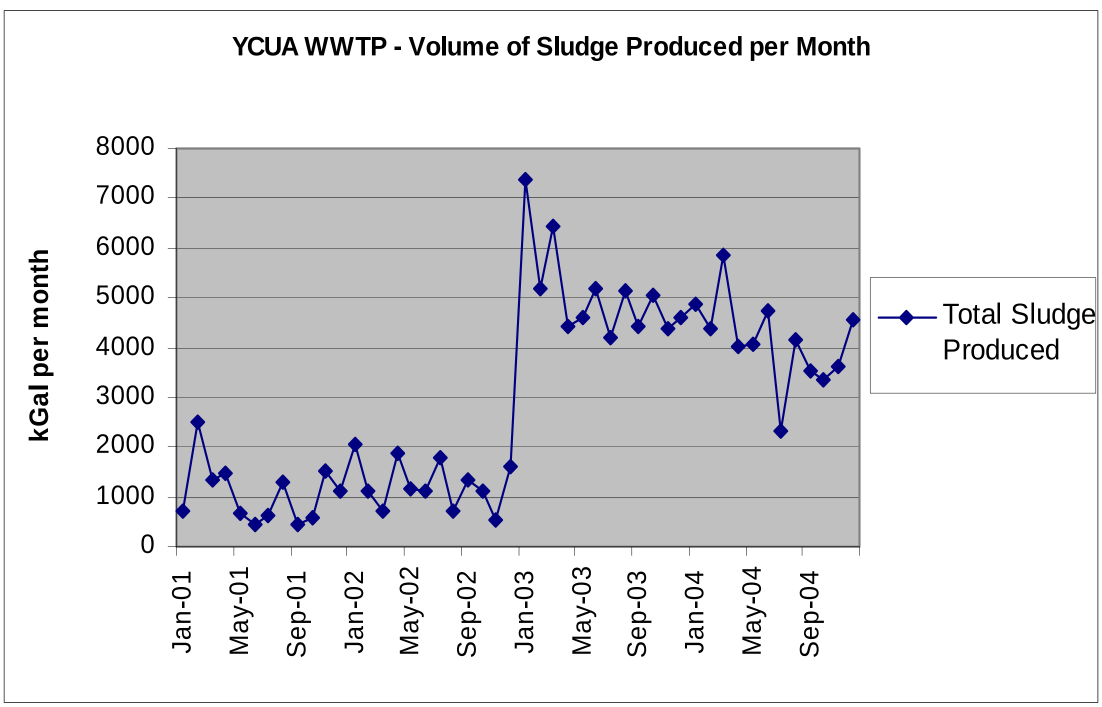

The total energy consumed per month in the form of chemicals used at the plant- Chlorine, Ferric Chloride, Ferrous Chloride, Lime, and a polymer.

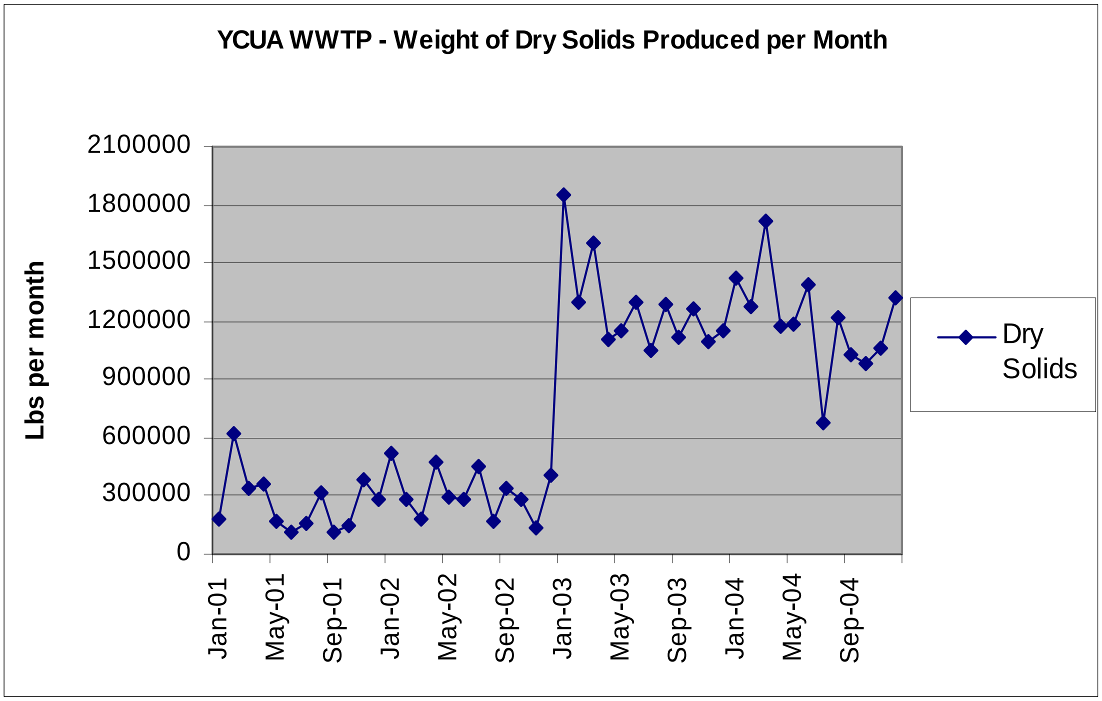
### e. Sludge Handling

On an average, more than 75% of the total sludge was incinerated at the plant from Jan' 01 to March' 04. No Incineration was reported after April' 04.

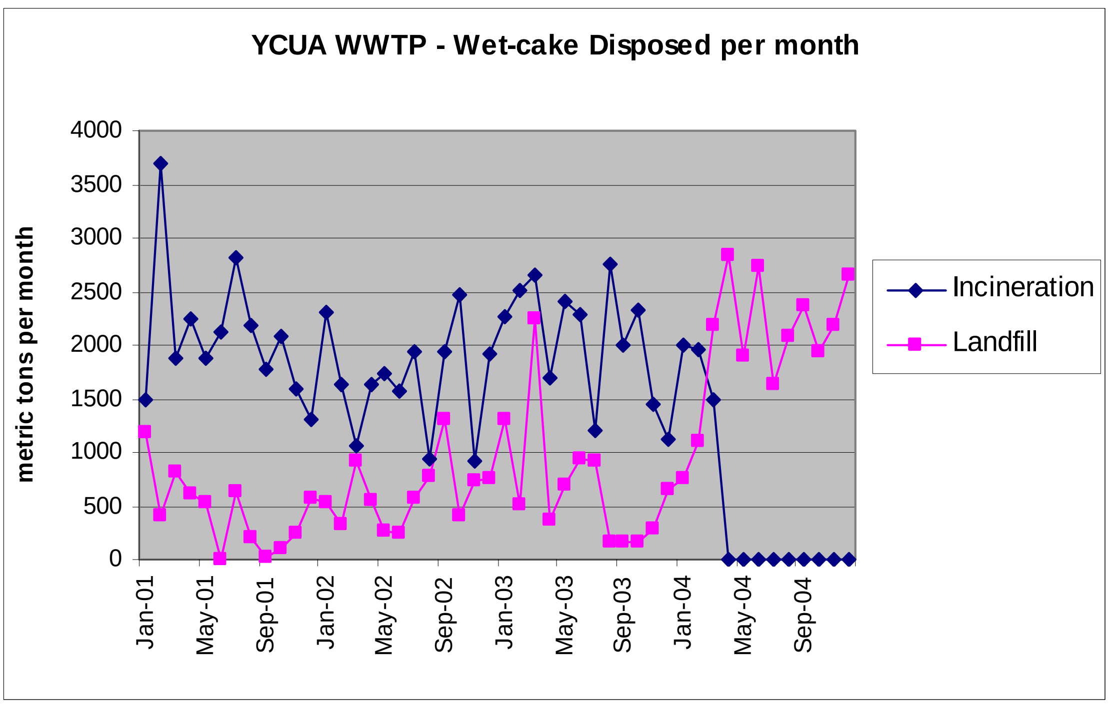
| Year | Total Sludge | Incineration | | | Landfill | | | | Total Energy |
|---|---|---|---|---|---|---|---|---|---|
| | Wet | Sludge | Ash | Nat. Gas | Sludge | Sludge and Ash | | Diesel | Nat.gas+ diesel |
| | Metric tons | Metric tons | Metric tons | GJ | Metric tons | Metric tons | metric ton-miles | GJ | GJ |
| 2001 | 30,377 | 25,036 | 5,829 | 84,779 | 5,341 | 11,169 | 207,957 | 919 | 85,698 |
| 2002 | 27,459 | 20,081 | 8,037 | 89,982 | 6,840 | 14,876 | 284,363 | 1,256 | 91,238 |
| 2003 | 33,063 | 24,684 | 6,020 | 82,723 | 8,380 | 14,399 | 374,451 | 1,685 | 84,409 |
| 2004 | 31,555 | 6,559 | 3,616 | 10,232 | 24,996 | 28,612 | 575,323 | 2,542 | 12,774 |

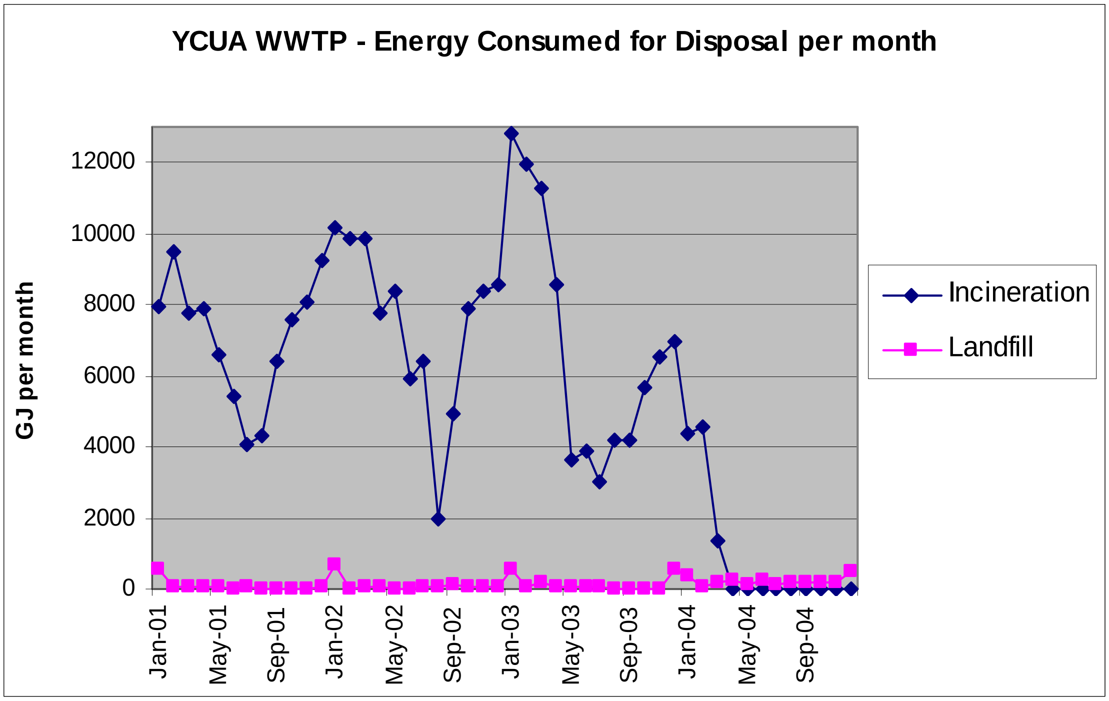
When the quantity of waste incinerated is reduced significantly in 2004, the energy consumed in GJ reduces significantly as well. Further, the volume of sludge produced per month and the weight of the dry solids at YCUA WWTP shows a sudden increase in Jan-03.

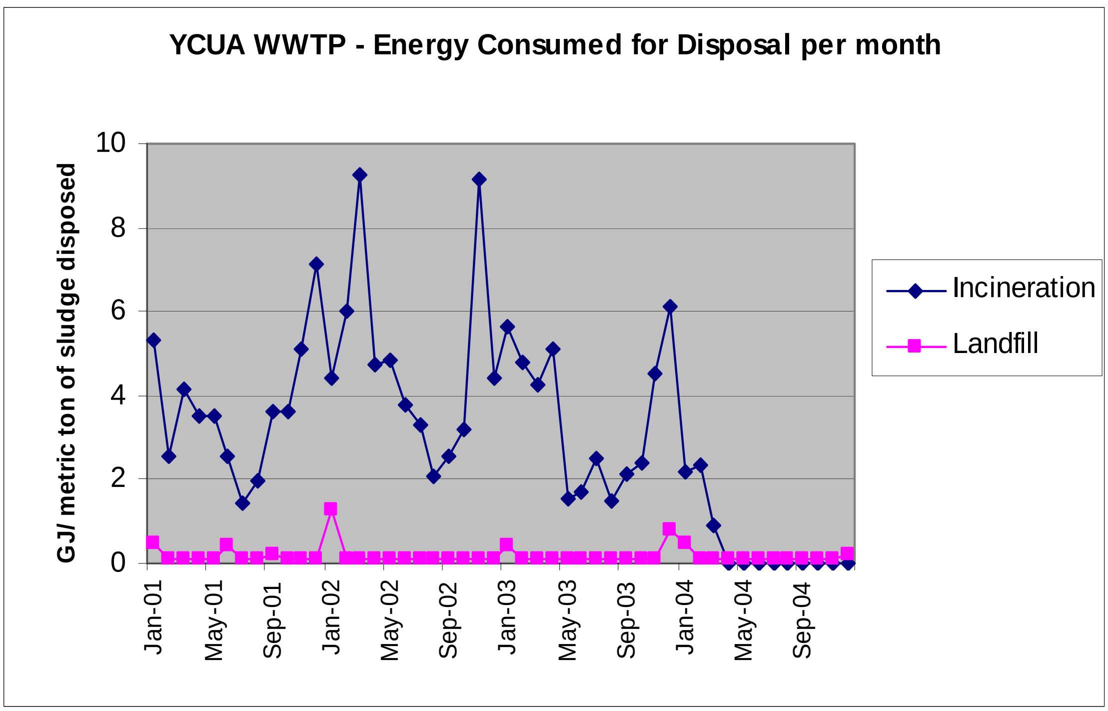





Since natural gas has higher energy intensity than diesel the energy consumption for incineration is significantly higher than land-filling.



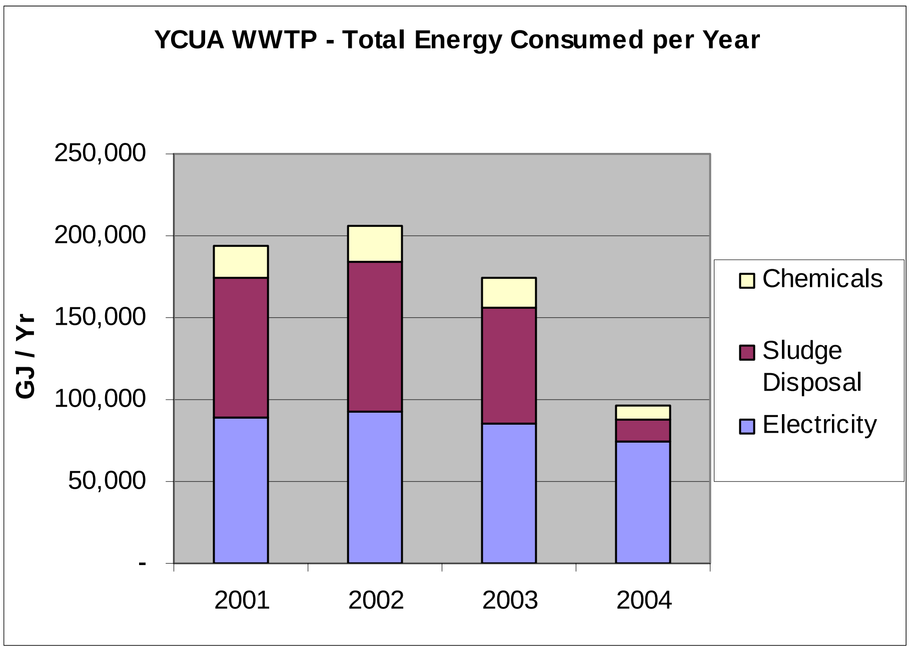

YCUA WWTP - Energy Consumed for Disposal per month
GJ per month
12000
10000
8000
6000
4000
2000
0
Jan-01
May-01
Sep-01
Jan-02
May-02
Sep-02
Jan-03
May-03
Sep-03
Jan-04
May-04
Sep-04
Incineration
Landfill

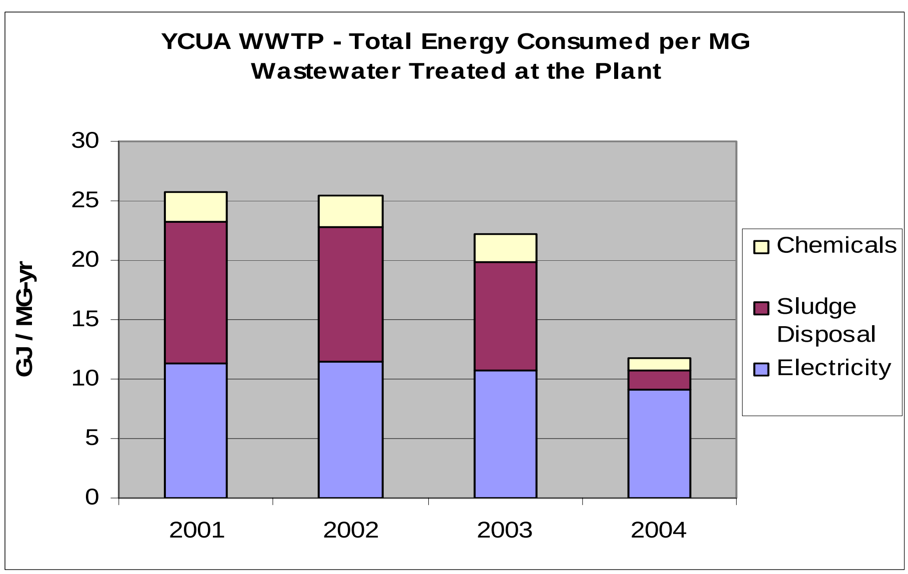

YCUA WWTP - Energy Consumed for Disposal per month
GJ/ metric ton of sludge disposed
10
8
6
4
2
0
Jan-01
May-01
Sep-01
Jan-02
May-02
Sep-02
Jan-03
May-03
Sep-03
Jan-04
May-04
Sep-04
Incineration
Landfill

## f. Life-cycle Energy for Operation of YCUA WWTP

| Year | Electricity | | | Sludge Disposal | | | Chemicals | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | GJ | GJ/MG | % | GJ | GJ/MG | % | GJ | GJ/MG | % | GJ | GJ/MG |
| 2001 | 88794 | 11 | 44 | 85698 | 12 | 46 | 19429 | 2 | 10 | 193921 | 26 |
| 2002 | 92561 | 11 | 45 | 91238 | 11 | 44 | 22271 | 3 | 11 | 206070 | 25 |
| 2003 | 84978 | 11 | 49 | 70986 | 9 | 41 | 18896 | 2 | 11 | 174861 | 22 |
| 2004 | 74817 | 9 | 78 | 12774 | 2 | 13 | 8679 | 1 | 9 | 96270 | 12 |

The average Life Cycle Energy for the YCUA WWTP from 2001 to 2004 is around 21 GJ/MG.



## g. Life-cycle Impacts from Operation of YCUA WWTP

| Global Warming Potential for YCUA WWTP (kgs of CO2 eq./MG) | | | | | |
|---|---|---|---|---|---|
| | 2001 | | | | |
| | ***Electricity*** | ***Nat. Gas*** | ***Diesel*** | ***Chemicals*** | ***Total*** |
| Carbon Dioxide | 2258 | 549 | 8 | 27 | 2842 |
| Methane CH4 | 89 | 35 | 0.03 | 0.49 | 124 |
| Nitrous Oxide | 38 | 0.01 | 0.000001 | 0.04 | 38 |
| **Total GWP/MG** | 2385 | 584 | 8 | 28 | 3004 |
| % of Total GWP/MG | 79 | 19 | 0 | 1 | |
| | 2002 | | | | |
| | ***Electricity*** | ***Nat. Gas*** | ***Diesel*** | ***Chemicals*** | ***Total*** |
| Carbon Dioxide | 2283 | 565 | 11 | 26 | 2885 |
| Methane CH4 | 90 | 36 | 0.04 | 0.48 | 126 |
| Nitrous Oxide | 38 | 0.01 | 0.000002 | 0.04 | 38 |
| **Total GWP/MG** | 2411 | 601 | 11 | 27 | 3050 |
| % of Total GWP/MG | 79 | 20 | 0 | 1 | |
| | 2003 | | | | |
| | ***Electricity*** | ***Nat. Gas*** | ***Diesel*** | ***Chemicals*** | ***Total*** |
| Carbon Dioxide | 2151 | 533 | 15 | 27 | 2726 |
| Methane CH4 | 85 | 34 | 0.05 | 0.49 | 119 |
| Nitrous Oxide | 36 | 0.01 | 0.000003 | 0.04 | 36 |
| **Total GWP/MG** | 2272 | 567 | 15 | 27 | 2881 |
| % of Total GWP/MG | 79 | 19.69 | 0.51 | 0.95 | |
| | 2004 | | | | |
| | ***Electricity*** | ***Nat. Gas*** | ***Diesel*** | ***Chemicals*** | ***Total*** |
| Carbon Dioxide | 1833 | 64 | 22 | 26 | 1944 |
| Methane CH4 | 72 | 4 | 0.08 | 0.48 | 77 |
| Nitrous Oxide | 31 | 0.002 | 0.000004 | 0.04 | 31 |
| **Total GWP/MG** | 1935 | 68 | 22 | 27 | 2052 |
| % of Total GWP/MG | 94 | 3 | 1 | 1 | |

| Eutrophication Potential for YCUA WWTP | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2001 | | | | 2002 | | | |
| ***Atmospheric*** | | ***Aquatic*** | | ***Atmospheric*** | | ***Aquatic*** | |
| ***g N eq./MG*** | | ***g N eq./MG*** | | ***g N eq./MG*** | | ***g N eq./MG*** | |
| NOx | 234.609 | N | | NOx | 237.182 | N | |
| $NH_3$ | 0.520 | $NH_3$ | 1.454 | $NH_3$ | 0.526 | $NH_3$ | 1.469 |
| $NH_4$+ | | COD | 2.885 | $NH_4$+ | | COD | 2.916 |
| $NO_3^-$ | | $NO_3^-$ | 0.0584 | $NO_3^-$ | | $NO_3^-$ | 0.0590 |
| $PO_4^{3-}$ | | $PO_4^{3-}$ | 0.0003 | $PO_4^{3-}$ | | $PO_4^{3-}$ | 0.0003 |
| P | | P | | P | | P | |
| **Total** | 235.129 | | 4.397 | **Total** | 237.707 | | 4.445 |

| 2003 | | | | 2004 | | | |
|---|---|---|---|---|---|---|---|
| ***Atmospheric*** | | ***Aquatic*** | | ***Atmospheric*** | | ***Aquatic*** | |
| ***g N eq./MG*** | | ***g N eq./MG*** | | ***g N eq./MG*** | | ***g N eq./MG*** | |
| NOx | 223.498 | N | | NOx | 190.361 | N | |
| $NH_3$ | 0.495 | $NH_3$ | 1.385 | $NH_3$ | 0.421 | $NH_3$ | 1.180 |
| $NH_4$+ | | COD | 2.748 | $NH_4$+ | | COD | 2.335 |
| $NO_3^-$ | | $NO_3^-$ | 0.0556 | $NO_3^-$ | | $NO_3^-$ | 0.0474 |
| $PO_4^{3-}$ | | $PO_4^{3-}$ | 0.0003 | $PO_4^{3-}$ | | $PO_4^{3-}$ | 0.0002 |
| P | | P | | P | | P | |
| **Total** | 223.993 | | 4.189 | **Total** | 190.782 | | 3.562 |

| Acidification Potential for YCUA WWTP | | | | |
|---|---|---|---|---|
| | **2001** | **2002** | **2003** | **2004** |
| | ***g SO2 equiv./MG*** | | | |
| $SO_2$ | 872 | 889 | 839 | 431 |
| HCl | 41 | 42 | 40 | 34 |
| NOx | 323 | 330 | 315 | 217 |
| $NH_3$ | 2 | 2 | 2 | 0.5 |
| Total/MG | 1238 | 1263 | 1194 | 682 |

| YCUA Wastewater Treatment Plant- Emissions from Electricity and Fuels | | | | |
|---|---|---|---|---|
| **Year** | **Global Warming Potential** | **Eutrophication Potential** | | **Acidification Potential** |
| | kg CO2 equiv / MG | kg Phosphate equiv / MG | | kg SO2 equiv / MG |
| | | ***Atmospheric*** | ***Aquatic*** | |
| 2001 | 3004.465 | 235.129 | 4.397 | 1238.083 |
| 2002 | 3049.588 | 237.707 | 4.445 | 1262.705 |
| 2003 | 2880.999 | 223.993 | 4.1886 | 1194.365 |
| 2004 | 2051.637 | 190.782 | 3.5622 | 681.597 |

# Appendix E

## Water Quality Information on Ann Arbor WWTP

| Date | Influent | pH | BOD 5 | BOD 5 | SS | SS | Total | Total | Vol. SS | Vol. SS | NH3-N | Org-N | Alkalinity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temp. | | | | | | Phosphorous | Phosphorous | | | | | |
| Month/Yr | Degree F | SU | mg/l | Lbs | mg/l | Lbs | mg/l | Lbs | mg/l | Lbs | mg/l | mg/l | mg/l |
| Jan-00 | 56.70 | 7.10 | 265.00 | 1173109.00 | 335.00 | 1498667.00 | 6.10 | 27062.00 | 265.00 | 839788.00 | 18.40 | 10.90 | 224.00 |
| Feb-00 | 54.80 | 7.10 | 268.00 | 1121545.00 | 454.00 | 1893316.00 | 6.30 | 26483.00 | 322.00 | 973989.00 | 17.20 | 12.10 | 214.00 |
| Mar-00 | 56.60 | 7.10 | 243.00 | 1091883.00 | 305.00 | 1374680.00 | 5.70 | 25508.00 | 250.00 | 695815.00 | 15.70 | 11.30 | 207.00 |
| Apr-00 | 58.80 | 7.10 | 260.00 | 1175230.00 | 330.00 | 1495053.00 | 5.90 | 25713.00 | 286.00 | 901554.00 | 16.00 | 14.20 | 205.00 |
| May-00 | 62.90 | 7.10 | 182.00 | 907448.00 | 283.00 | 1397109.00 | 5.00 | 24747.00 | 264.00 | 917762.00 | 12.60 | 11.00 | 225.00 |
| Jun-00 | 66.40 | 7.10 | 193.00 | 977698.00 | 289.00 | 1496746.00 | 4.80 | 24195.00 | 262.00 | 974766.00 | 10.80 | 11.00 | 210.00 |
| Jul-00 | 69.00 | 7.00 | 191.00 | 946820.00 | 257.00 | 1273823.00 | 4.90 | 24166.00 | 231.00 | 662948.00 | 10.50 | 8.90 | 205.00 |
| Aug-00 | 70.30 | 7.00 | 168.00 | 856549.00 | 273.00 | 1389199.00 | 4.80 | 24315.00 | 237.00 | 749272.00 | 10.40 | 9.80 | 206.00 |
| Sep-00 | 70.90 | 7.00 | 210.00 | 1047156.00 | 366.00 | 1824045.00 | 6.20 | 31003.00 | 273.00 | 791596.00 | 16.00 | 12.90 | |
| Oct-00 | 68.20 | 7.00 | 230.00 | 1125460.00 | 327.00 | 1604297.00 | 6.20 | 30435.00 | 285.00 | 858754.00 | 16.90 | 13.70 | |
| Nov-00 | 64.50 | 7.10 | 252.00 | 1131072.00 | 349.00 | 1566899.00 | 6.20 | 27717.00 | 285.00 | 699462.00 | 15.50 | 13.50 | |
| Dec-00 | 58.30 | 7.10 | 232.00 | 1057153.00 | 317.00 | 1447384.00 | 5.90 | 26769.00 | 261.00 | 552432.00 | 15.10 | 12.20 | |
| Jan-01 | 54.90 | 7.30 | 209.00 | 999999.00 | 279.00 | 1333439.00 | 5.40 | 25749.00 | 240.00 | 708126.00 | 15.70 | 11.80 | |
| Feb-01 | 52.90 | 7.50 | 146.00 | 746839.00 | 184.00 | 947674.00 | 4.30 | 21960.00 | 131.00 | 452875.00 | 13.30 | 7.80 | |
| Mar-01 | 53.10 | 7.30 | 173.00 | 866169.00 | 195.00 | 972681.00 | 4.80 | 24128.00 | 160.00 | 444525.00 | 14.80 | 9.80 | |
| Apr-01 | 55.80 | 7.40 | 176.00 | 871154.00 | 222.00 | 1098458.00 | 4.70 | 23169.00 | 166.00 | 468645.00 | 15.20 | 10.90 | |
| May-01 | 60.80 | 7.30 | 154.00 | 765333.00 | 187.00 | 930774.00 | 4.50 | 22236.00 | 141.00 | 341653.00 | 13.40 | 8.90 | |
| Jun-01 | 64.40 | 7.00 | 146.00 | 715646.00 | 185.00 | 905621.00 | 4.30 | 21352.00 | 147.00 | 451651.00 | 13.50 | 9.90 | |
| Jul-01 | 69.80 | 7.10 | 149.00 | 684832.00 | 199.00 | 915045.00 | 5.30 | 24590.00 | 154.00 | 458643.00 | 13.40 | 9.60 | |
| Aug-01 | 72.30 | 7.10 | 152.00 | 718519.00 | 188.00 | 891559.00 | 5.60 | 26567.00 | 151.00 | 461849.00 | 14.90 | 10.60 | |
| Sep-01 | 70.80 | 7.20 | 175.00 | 817435.00 | 210.00 | 982689.00 | 5.20 | 24470.00 | 163.00 | 387793.00 | 17.40 | 9.90 | |
| Oct-01 | 66.60 | 7.30 | 188.00 | 993286.00 | 262.00 | 1438648.00 | 5.30 | 29005.00 | 229.00 | 840996.00 | 18.50 | 15.30 | |
| Nov-01 | | 7.40 | 55.00 | 972360.00 | 229.00 | 1062976.00 | 6.70 | 31183.00 | 191.00 | 566229.00 | 19.90 | 12.10 | |
| Dec-01 | 59.50 | 7.40 | 175.00 | 840669.00 | 222.00 | 1062866.00 | 5.00 | 24429.00 | 180.00 | 329520.00 | 18.30 | 13.40 | |
| Jan-02 | 56.10 | 7.40 | 186.00 | 860458.00 | 237.00 | 1094805.00 | 5.30 | 24530.00 | 188.00 | 565829.00 | 17.90 | 11.6 | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb-02 | 55.60 | 7.50 | 165.00 | 832147.00 | 204.00 | 1036722.00 | 4.80 | 24448.00 | 165.00 | 450093.00 | 12.20 | 8.70 | |
| Mar-02 | 53.70 | 7.50 | 176.00 | 890765.00 | 185.00 | 978659.00 | 4.90 | 26022.00 | 155.00 | 293408.00 | 13.80 | 10.00 | 264.00 |
| Apr-02 | 57.60 | 7.50 | 166.00 | 881642.00 | 193.00 | 1023421.00 | 4.80 | 25521.00 | 167.00 | 592394.00 | 14.30 | 9.50 | 272.00 |
| May-02 | 59.10 | 7.20 | 160.00 | 793288.00 | 155.00 | 769438.00 | 4.80 | 23773.00 | 124.00 | 406355.00 | 13.80 | 8.60 | 299.00 |
| Jun-02 | 65.00 | 7.00 | 158.00 | 716052.00 | 173.00 | 785811.00 | 4.90 | 22481.00 | 156.00 | 475760.00 | 14.50 | 9.70 | 232.00 |
| Jul-02 | 70.80 | 7.00 | 156.00 | 682057.00 | 172.00 | 752558.00 | 4.80 | 21214.00 | 140.00 | 320603.00 | 14.90 | 10.20 | 217.00 |
| Aug-02 | 72.00 | 6.90 | 156.00 | 735697.00 | 172.00 | 811475.00 | 5.10 | 23992.00 | 141.00 | 406301.00 | 14.20 | 9.40 | 203.00 |
| Sep-02 | 72.80 | 7.00 | 173.00 | 820028.00 | 189.00 | 896693.00 | 5.60 | 26507.00 | 177.00 | 526611.00 | 17.00 | 11.10 | 211.00 |
| Oct-02 | 68.80 | 7.10 | 183.00 | 826246.00 | 191.00 | 892296.00 | 5.80 | 26869.00 | 167.00 | 398956.00 | 18.00 | 10.80 | 212.00 |
| Nov-02 | 63.30 | 7.40 | 204.00 | 776273.00 | 208.00 | 925710.00 | 6.00 | 26712.00 | 191.00 | 400760.00 | 18.00 | 11.60 | 207.00 |
| Dec-02 | 58.00 | 7.00 | 218.00 | 913623.00 | 284.00 | 1215392.00 | 5.80 | 24595.00 | 194.00 | 434971.00 | 19.60 | 9.00 | 224.00 |
| Jan-03 | 55.70 | 7.10 | 228.00 | 980847.00 | 243.00 | 1048301.00 | 6.20 | 26688.00 | 220.00 | 614468.00 | 17.50 | 10.80 | 231.00 |
| Feb-03 | 53.60 | 7.20 | 210.00 | 692961.00 | 210.00 | 797568.00 | 6.10 | 22972.00 | 191.00 | 490646.00 | 17.30 | 10.80 | 226.00 |
| Mar-03 | 52.90 | 7.20 | 216.00 | 1006971.00 | 210.00 | 972728.00 | 5.70 | 26890.00 | 193.00 | 513053.00 | 16.70 | 10.40 | 233.00 |
| Apr-03 | 56.10 | 7.20 | 201.00 | 982978.00 | 187.00 | 915589.00 | 5.40 | 26518.00 | 169.00 | 543037.00 | 17.90 | 12.70 | 232.00 |
| May-03 | 59.40 | 7.10 | 168.00 | 846855.00 | 164.00 | 824466.00 | 4.80 | 24092.00 | 154.00 | 399516.00 | 13.30 | 8.40 | 238.00 |
| Jun-03 | 63.90 | 7.30 | 188.00 | 710877.00 | 224.00 | 1010014.00 | 5.40 | 24389.00 | 207.00 | 437900.00 | 16.80 | 11.20 | 231.00 |
| Jul-03 | 69.00 | 7.30 | 179.00 | 818841.00 | 207.00 | 948465.00 | 5.30 | 24005.00 | 188.00 | 587922.00 | 16.50 | 10.40 | 216.00 |
| Aug-03 | 71.10 | 7.30 | 177.00 | 829220.00 | 208.00 | 976364.00 | 5.00 | 23658.00 | 186.00 | 505614.00 | 15.50 | 11.20 | 212.00 |
| Sep-03 | 71.00 | 7.30 | 208.00 | 943988.00 | 262.00 | 1236779.00 | 5.80 | 27303.00 | 244.00 | 853065.00 | | | 230.00 |
| Oct-03 | 67.30 | 7.10 | 271.00 | 1149500.00 | 370.00 | 1678644.00 | 6.70 | 30450.00 | 355.00 | 938822.00 | | | 255.00 |
| Nov-03 | 63.40 | 7.40 | 240.00 | 1088031.00 | 280.00 | 1261932.00 | 6.20 | 28112.00 | 256.00 | 590769.00 | | | 245.00 |
| Dec-03 | 58.80 | 7.20 | 190.00 | 739889.00 | 188.00 | 838417.00 | 5.30 | 23847.00 | 159.00 | 394829.00 | | | 251.00 |
| Jan-04 | 55.80 | 7.20 | 184.00 | 830063.00 | 194.00 | 876027.00 | 5.70 | 25667.00 | 159.00 | 354870.00 | | | 253.00 |
| Feb-04 | 54.30 | 7.20 | 204.00 | 702625.00 | 187.00 | 777605.00 | 5.60 | 23400.00 | 166.00 | 474202.00 | | | 249.00 |
| Mar-04 | 54.10 | 7.20 | 167.00 | 762344.00 | 173.00 | 944919.00 | 5.00 | 26426.00 | 152.00 | 469779.00 | | | 264.00 |
| Apr-04 | 57.40 | 7.20 | 188.00 | 860621.00 | 207.00 | 943591.00 | 5.60 | 25755.00 | 173.00 | 427659.00 | | | 242.00 |
| May-04 | 62.60 | 7.20 | 151.00 | 796377.00 | 188.00 | 1013370.00 | 4.60 | 24740.00 | 151.00 | 455487.00 | | | 267.00 |
| Jun-04 | 70.60 | 7.50 | 142.00 | 566650.00 | 162.00 | 762690.00 | 4.80 | 22531.00 | 143.00 | 351778.00 | | | 251.00 |
| Jul-04 | 74.90 | 7.30 | 156.00 | 717086.00 | 173.00 | 788217.00 | 5.00 | 22909.00 | 147.00 | 325410.00 | | | 229.00 |
| Aug-04 | 75.90 | 7.30 | 151.00 | 690362.00 | 160.00 | 736452.00 | 5.10 | 23596.00 | 136.00 | 373262.00 | | | 232.00 |
| Sep-04 | 77.60 | 7.10 | 182.00 | 826513.00 | 181.00 | 823285.00 | 5.90 | 26852.00 | 175.00 | 531688.00 | | | 238.00 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct-04 | 73.70 | 7.60 | 201.00 | 897573.00 | 187.00 | 836705.00 | 6.20 | 27517.00 | 177.00 | 455944.00 | | | 246.00 |
| Nov-04 | 70.10 | 7.70 | 200.00 | 856754.00 | 197.00 | 841303.00 | 6.00 | 25655.00 | 182.00 | 394879.00 | | | 233.00 |
| Dec-04 | 66.20 | 7.60 | 186.00 | 836466.00 | 191.00 | 866179.00 | 5.50 | 25005.00 | 176.00 | 471057.00 | | | 240.00 |
| Jan-05 | 60.90 | 7.20 | 163.00 | 808694.00 | 176.00 | 880107.00 | 4.70 | 23589.00 | 166.00 | 498295.00 | 10.10 | 6.40 | 260.00 |
| Feb-05 | 63.10 | 7.30 | 165.00 | 756903.00 | 145.00 | 674136.00 | 4.40 | 20094.00 | 126.00 | 326751.00 | | | 212.00 |
| Mar-05 | 63.00 | 7.10 | 165.00 | 830342.00 | 150.00 | 749663.00 | 4.30 | 20957.00 | 130.00 | 501985.00 | | | 256.00 |
| Apr-05 | 62.90 | 7.10 | 183.00 | 833797.00 | 199.00 | 910598.00 | 5.00 | 22844.00 | 170.00 | 645726.00 | | | 232.00 |
| May-05 | 65.90 | 7.10 | 211.00 | 897621.00 | 242.00 | 1059944.00 | 5.40 | 23816.00 | 211.00 | 778175.00 | | | 247.00 |
| Jun-05 | 72.30 | 7.10 | 193.00 | 843618.00 | 227.00 | 1028159.00 | 4.70 | 21128.00 | 202.00 | 707062.00 | | | 228.00 |
| Jul-05 | 76.60 | 7.10 | 169.00 | 849685.00 | 217.00 | 1090980.00 | 4.50 | 22563.00 | 188.00 | 818005.00 | | | 205.00 |
| Aug-05 | 78.60 | 7.00 | 210.00 | 934017.00 | 253.00 | 1164778.00 | 5.00 | 22859.00 | 214.00 | 826823.00 | | | 245.00 |
| Sep-05 | 79.10 | 7.00 | 226.00 | 1026008.00 | 295.00 | 1340160.00 | 5.50 | 24338.00 | 240.00 | 878786.00 | | | |
| Oct-05 | 75.10 | 7.10 | 205.00 | 782350.00 | 251.00 | 1134021.00 | 5.40 | 23737.00 | 223.00 | 785083.00 | | | |
| Nov-05 | 71.20 | 7.10 | 226.00 | 766748.00 | 219.00 | 900723.00 | 5.20 | 20435.00 | 181.00 | 540041.00 | | | |
| Dec-05 | 64.70 | 7.10 | 227.00 | 962228.00 | 234.00 | 989533.00 | 5.70 | 24171.00 | 225.00 | 676141.00 | | | |

# Appendix F-I

## Energy Calculations for Chemicals

### a. Energy Factors and Values for Chemicals

| Material Production Energy for Chemicals | | Source | Description |
|---|---|---|---|
| | **MJ/metric ton** | | |
| **Aluminum Sulfate (Alum)** | **6290** | Simapro 6.0- BUWAL250, Eco-indicator 99 (I) | Production of aluminum sulphate (17% Al2O3) from sulfuric acid and aluminum hydroxide. |
| **Ferric Chloride** | **1200** | Owen William F. 'Energy in Wastewater Treatment' | Addition of upstream energy to the production energy |
| **Ferrous Chloride** | **1200** | Owen William F. 'Energy in Wastewater Treatment' | Addition of upstream energy to the production energy |
| **Chlorine** | **20130** | APME, Eco-profiles of the European plastic Industry, July 2006 | Total primary energy |
| **Sodium Hypochlorite** | **59525** | Owen William F. 'Energy in Wastewater Treatment' | Addition of upstream energy to the production energy |
| **Lime** | **6500** | Simapro 6.0- BUWAL250, Eco-indicator 99 (I) | Production of CaO by calcination of calcium carbonate (limestone) in a lime kiln. The energy use is between 3500 and 7800 MJ per metric ton CaO. Data are derived from Ullman (1990) and Franklin (1989). No water emissions occur and waste is not specified. |
| **Polymers** | **44682** | Owen William F. 'Energy in Wastewater Treatment' | Addition of upstream energy to the production energy |
| **Carbon Dioxide** | **12900** | Simapro 6.0- BUWAL250, Eco-indicator 99 (I) | Production of ammonia from natural gas and water in the steam-reformer process. CO2 is formed as a co-product in the ratio of 1.15 to 1.Data are taken from Coray (1993). |
| **Oxygen** | **5590** | Simapro 6.0- BUWAL250, Eco-indicator 99 (I) | Production of oxygen from air. Air is compressed (6-7 bar) and oxygen, hydrogen and argon are separated in a gas separation column. |
| **Sodium Hydroxide** | **22040** | APME, Eco-profiles of the European plastic Industry, March 2005 | Total primary energy |
| **Sodium Hexametaphosphate** | **12800** | Life Cycle Inventory of Biodeisel and Petroleum Diesel. Final Report, May 1998. NREL. | Total primary energy |
| **Ammonia** | **35760** | APME, Eco-profiles of the European plastic Industry, March 2005 | Total primary energy |
| **Sodium Silico Fluoride** | **12800** | Life Cycle Inventory of Biodeisel and Petroleum Diesel. Final Report, May 1998. NREL. | Total primary energy |

## b. Energy Calculation for Fluoride

Fluorosilicic acid produced as a by product from wet process for phosphoric acid production= 20-40kg / tonne of P2O5
(The quantity of fluosilicic acid obtained as a by-product in phosphoric acid production is normally in the range 20 to 40 Kg (as H2SiF6 100%) per ton of P2O5 produced. http://www.fluoridealert.org/fertilizer-waste.htm)

Energy for production of P2O5 = 12.8 MJ/kg (Life Cycle Inventory of Biodiesel and Petroleum Diesel. Final Report, May 1998. NREL. Page 202, table 121.)

12.8 MJ/kg * 1000kg/tonne = 12800 MJ/tonne

Mass of H2SiF6 to total mass = 30 kg / 1030 kg
= 3/103
= 0.029
Mass of P2O5 to total mass = 1000 kg / 1030 kg
= 0.97
= approximately equal to 1

Hence, the energy intensity for H2SiF6 will be the same as P2O5 = 12800 MJ/tonne
= 12800 MJ/2204.623 lbs
= 1.613 kWh/lb

## c. Energy Calculation for Sodium Hexametaphosphate

Basic information:
1) Chemical formula: (NaPO3)6
2) Molecular weight: 611.82

Food grade:
1) Total phosphate (as P2O5):68% min.
2) Inactive phosphate (as P2O5):7.5% max.
3) Solubility: Pass
4) Insoluble matter in water: 0.05% max.
5) Iron (Fe):0.05% max.
6) pH value: 5.8 - 7.0
7) Heavy metals (as Pb):0.001% max.
8) Arsenic (As):0.0003% max.
9) Fluoride (as F):0.003% max.

Since more than 68% of it is P2O5, the energy intensity for (NaPO3)6 would be more or less the same as that of P2O5 = 12.8 MJ/kg
Hence, energy for (NaPO3)6 = 12.8 MJ/kg = 12800 MJ/ tonne = 12800 MJ/2204.623 lbs

# Appendix F-II

## Emissions calculations

### a. Emissions from Electricity

*Source: Kim, Seungdo. Dale, Bruce E. 'Life Cycle Inventory Information of the United States Electricity System' International Journal of Life Cycle Assessment, 10 (4). 2005.*
*Appendix B: Environmental Burdens associated with generating1 MJe electricity in the US in 2000 (based on generation)*

| Global Warming Potential | |
|---|---|
| | ***g/MJe*** |
| Fossil $CO_2$ | 183 |
| Non-Fossil $CO_3$ | 0.000297 |
| $CH_4$ | 0.313 |
| $N_2O$ | 0.0102 |

| Eutrophication Potential | |
|---|---|
| ***Atmospheric*** | ***g/MJe*** |
| NOx | 0.475 |
| $NH_3$ | 0.00035 |
| $NH_4$+ | |
| $NO_3^-$ | |
| $PO_4^{3-}$ | |
| P | |
| ***Aquatic*** | ***g/MJe*** |
| N | |
| $NH_3$ | 0.000151 |
| COD | 0.00466 |
| $NO_3^-$ | 0.0000473 |
| $PO_4^{3-}$ | 1.85E-09 |
| P | |

| Acidification Potential | |
|---|---|
| | ***g/MJe*** |
| $SO_2$ | 0.749 |
| HCl | 0.0413 |
| NOx | 0.475 |
| $NH_3$ | 0.00035 |

## b. Emissions from Natural Gas

*Source: Franklin's Appendix A. Table A-20*

| Global Warming Potential | | |
|---|---|---|
| | ***lbs/1000cuft*** | ***g/cuft*** |
| Fossil $CO_2$ | 137 | 62142.15 |
| Non-Fossil $CO_2$ | 0.028 | 12.701 |
| $CH_4$ | 0.38 | 172.365 |
| $N_2O$ | 0.000012 | 0.0054 |

| Eutrophication Potential | | |
|---|---|---|
| ***Atmospheric*** | ***lbs/1000cuft*** | **g/1000cuft** |
| NOx | 0.51 | 231.332 |
| $NH_3$ | 0.003 | 1.361 |
| $NH_4$+ | | |
| $NO_3^-$ | | |
| $PO_4^{3-}$ | | |
| P | | |
| ***Aquatic*** | ***lbs/1000cuft*** | **g/1000cuft** |
| N | | |
| $NH_3$ | 0.000059 | 0.027 |
| COD | 0.043 | 19.504 |
| $NO_3^-$ | 0.00000018 | 0.000082 |
| $PO_4^{3-}$ | 0.000011 | 0.005 |
| P | | |

| Acidification Potential | | |
|---|---|---|
| | ***lbs/1000cuft*** | **g/1000cuft** |
| $SO_2$ | 1.97 | 893.577 |
| HCl | 0.000098 | 0.044 |
| NOx | 0.51 | 231.332 |
| $NH_3$ | 0.003 | 1.361 |

## c. Emissions from Diesel

*Source: Franklin's Appendix A. Table A-23*

| Global Warming Potential | | |
|---|---|---|
| | ***lbs/1000gal.*** | **g/1000gal** |
| Fossil $CO_2$ | 25632 | 11626480.00 |
| Non-Fossil $CO_2$ | 6.1 | 2766.913 |
| $CH_4$ | 4.05 | 1837.049 |
| $N_2O$ | 0.000015 | 0.007 |

| Eutrophication Potential | | |
|---|---|---|
| ***Atmospheric*** | ***lbs/1000gal.*** | **g/1000gal** |
| NOx | 477.5 | 216950.400 |
| $NH_3$ | 0.04 | 18.144 |
| $NH_4$+ | | |
| $NO_3^-$ | | |
| $PO_4^{3-}$ | | |
| P | | |
| ***Aquatic*** | ***lbs/1000gal.*** | **g/1000gal** |
| N | | |
| $NH_3$ | 0.014 | 6.35 |
| COD | 0.87 | 39.463 |
| $NO_3^-$ | 0.000039 | 0.018 |
| $PO_4^{3-}$ | 0.0035 | 1.588 |
| P | | |

| Acidification Potential | | |
|---|---|---|
| | ***lbs/1000gal.*** | **g/1000gal** |
| $SO_2$ | 57 | 25854.77 |
| HCl | 0.025 | 11.34 |
| NOx | 477.5 | 216590.4 |
| $NH_3$ | 0.04 | 18.144 |

## Bibliography


1. UNO. ‘International Decade for Action: Water for Life, 2005-2025’. Factsheet on Water and Sanitation. United Nations Organization. Extracted on January 10, 2006. <http://www.un.org/waterforlifedecade/factsheet.html>

2. Seckler, David. Amarisinghe, Upali. Molden, David. De Silva, Radhika. Barker, Randolph. ‘World Water Demand and Supply, 1990 to 2025: Scenarios and Isuues’. International Water Management Institute. Research Report 19. IWMI, 1998.

3. UNEP, 2002. Global Environmental Outlook, Nairobi, Kenya.

4. Baker M.N., Taras M.J., 1981, The quest for pure water – The history of the twentieth century, volume I and II, Denver: AWWA

5. James, Kevin. Campbell, Stephanie L. Godlove, Christopher E. ‘Watergy: Taking Advantage of Untapped Energy and Water Efficiency Opportunities in Municipal Water Systems’. Alliance to Save Energy and USAID.

6. Center for Sustainable Systems. ‘U.S. Water Supply and Distribution’ Factsheet. August 2005.

7. EPRI. ‘Water and Sustainability: U.S. Electricity Consumption for Water Supply and Treatment- The Next Half Century’. Vol.4, Electric Power Research Institute, 2002

8. Center for Sustainable Systems. ‘US Wastewater Treatment’ Factsheet. August 2005.

9. Energy Information Administration. ‘Electric Power Annual 2005 – Data Tables’. Extracted on January 5, 2007. <http://www.eia.doe.gov/cneaf/electricity/epa/generation_state.xls>

10. USEPA, ‘Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2004, 2004’. April 15, 2006. US Environmental Protection Agency. 1200 Pennsylvania Avenue, N.W. Washington, DC 20460. USA

11. ISO 14040. ‘Environmental Management- life-cycle Assessment- Principles and Framework’. 1997

12. SETAC. ‘Guidelines for Life-Cycle Assessment: A Code of Practice’. Society for Environmental Toxicology and Chemistry. 1993.

13. Franklin Associates ‘Appendix A- Energy Requirements and Environment Emissions for Fuel Consumption. December 2000. Table A-9. page A-24.

14. Kim, Seungdo. Dale, Bruce E. ‘Life-cycle Inventory Information of the United States Electricity System’ International Journal of Life-cycle Assessment,10 (4). 2005

15. Franklin Associates ‘Appendix A- Energy Requirements and Environment Emissions for Fuel Consumption. December 2000.Table A-20. page A-55

16. Franklin Associates ‘Appendix A- Energy Requirements and Environment Emissions for Fuel Consumption. December 2000.Table A-23. page A-61

17. IPCC. ‘Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories’. Intergovernmental Panel on Climate Change. 2000

18. EPA. ‘The History of Drinking Water Treatment’ Factsheet. United States Environmental Protection Agency. EPA-816-F-00-006. February 2000.

19. Owen William F. ‘Energy in Wastewater Treatment’. Englewoods Cliffs, N.J. Prentice-Hall. 1982

20. Fuller, Jennifer. ‘Energy Efficient Alternatives for the Fortuna Wastewater Treatment facility’. The Community Clean Water Institute, Fortuna Water Quality Project. 2002

21. Raluy, Gemma R. Serra, Luis. Uche Javier. “Life-cycle Assessment of Water Production Technologies” International Journal of Life-cycle Assessments 10 (4) 285. 2005

22. Stokes, Jenifer. Horvath, Arpad. “Life-cycle Energy Assessment of Alternative Water Supply Systems”. International Journal of Life-cycle Assessments 11 (5) 335-343. 2006

23. City Website. City of Ann Arbor. ‘Water Treatment Plant- Dams and Hydros’. Extracted on November 06, 2006. <http://www.ci.ann-arbor.mi.us/PublicServices/Water/WTP/int-Dams.html>

24. NREL. “Life-cycle Inventory of Biodiesel fuel and Petroleum Diesel fuel”. Final Report, May 1998. Page 202, table 121.

25. City Website. City of Santa Rosa. ‘Recycled Water Overview’. Extracted on November 02, 2006. <http://ci.santa-rosa.ca.us/default.aspx?PageId=2219>

26. Deslauriers, Sarah. Kanzaki Mazayuki. Kumar, Akshay. Bulkley Jonathan. Tripathi, Malavika. ‘Preliminary Application of Life-cycle Assessment to U.S. Water and Wastewater Treatment Facilities’. Center for Sustainable Systems. University of Michigan. Ann Arbor. CSS05-12

27. ‘Epstein et al. ‘City of Ann Arbor Greenhouse Gas Emissions Reduction Strategy’. University of Michigan. May 2003

28. Keoleian, Gregory A. Spitzley, David V. “Life-cycle based Sustainability Metrics”. Published by Elsevier B.V. 2006