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ENVIRONMENTAL IMPACTS OF ADVANCED WASTEWATER TREATMENT AT ELY, MINNESOTA

Environmental Research Laboratory
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ENVIRONMENTAL IMPACTS OF ADVANCED WASTEWATER TREATMENT AT ELY, MINNESOTA

by

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DISCLAIMER

FOREWORD

Effective regulatory and enforcement actions by the Environmental Protection Agency would be virtually impossible without sound scientific data on pollutants and their impact on environmental stability and human health. Responsibility for building this data base has been assigned to EPA's Office of Research and Development and its 15 major field installations, one of which is the Corvallis Environmental Research Laboratory (CERL).

The primary mission of the Corvallis laboratory is research on the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects and control of pollutants in lake systems; and the development of predictive models on the movement of pollutants in the biosphere.

This report describes some of the resources used and pollutants generated as a result of operating an advanced wastewater treatment plant which includes phosphorus removal. Other reports are being prepared which describe the improvement in the Shagawa Lake ecosystem due to the reduction in phosphorus loading, and the social and economic consequences of operating the advanced wastewater treatment plant.

A.F. Bartsch
Director, CERL

ABSTRACT

The results presented in this report give an indication of the pollutants that would be generated and the resources consumed in operating a treatment facility similar to the one at Ely, Minnesota. The study analyzes not only the facility itself, but also those industries that supply products to the treatment plant. It was found that the total energy requirement of the advanced wastewater treatment plant was 50×10^6 Btu/million gallons of water treated.

CONTENTS

ACKNOWLEDGEMENTS

The authors wish to thank R. M. Brice at Ely for his enormous amount of help in supplying data on the operation of the treatment facility. Without his help, this paper would not have been possible. In addition, we would like to thank Mr. C. LaLiberte, Cutler-Magner Corporation; Mr. M. Pressman, Betz Laboratories; Mr. C. Vorel, Cardox Products; and Mr. J. Sharp, Dow Chemical, for supplying us with information on their respective industries, and for reviewing the draft manuscript. Additionally, Dr. John Sheehy provided useful comments on the manuscript.

SECTION I

INTRODUCTION

The environmental effects of wastewater treatment include more than the improvements in water quality that result from operating the treatment facility. To understand the total environmental effects of a facility, it is necessary to know the environmental tradeoffs that have occurred as a result of construction and operation. For example: What are the social and economic costs and benefits associated with treating wastewater? What pollutants are generated in the manufacture of products used at the treatment facility? How much energy is consumed both directly and indirectly in the construction and operation of the plant? What changes have occurred in receiving water quality as a result of reduced pollutant loadings to the system? What effect has the disposal of sludge had on nearby terrestrial ecosystems?

These are but a few of the questions to be answered by an environmental assessment being conducted by the Corvallis Environmental Research Laboratory of the Shagawa Lake Demonstration Project. It is hoped that this environmental assessment will aid in understanding the types of significant environmental effects that may occur if similar technology were transferred elsewhere. The reader must be congizant that the Shagawa Project was a research effort, not simply a state-of-the-art application. Consequently, the costs and benefits of the project cannot be developed into a traditional C/B ratio. For example, a primary benefit has been an increase in both limnological and technological knowledge. This increase in knowledge is unquantifiable in any traditional sense and no attempt is made to place a numerical value on this commodity.

The purpose of this part of the overall environmental assessment is to examine only one aspect of the environmental impact of the Advanced Wastewater Treatment (AWT) facility at Ely, Minnesota, namely resource utilization and pollutant generation resulting from the operation and maintenance of the AWT plant. These results give an indication of the pollutants that would be generated and the resources consumed if the technologies developed at Ely were transferred to another location. Further, the results may be compared to those of a similiar AWT study at South Lake Tahoe (Antonucci and Schaumberg, 1975).

Boundaries for the area of consideration need to be carefully defined in order to assess the resources used and pollutants generated as a result of the operation and maintenance of the Ely AWT plant. The following assumptions and limitations imposed on the study were due to both data restrictions and manpower constraints: 1) Only the operation and maintenance of the AWT plant has been considered. Resources utilized and pollutants generated during the construction of the plant have not been considered. 2) Consideration has been given only to the utilization of resources and pollutants generated at the AWT plant and in first order industries. A first order industry is any industry that supplies products directly to the AWT plant at Ely. Resources utilized or pollutants generated by second order industries (i.e. those industries supplying products to first order industries) have not been considered. As an example, pollutants generated as a result of providing electricity to the AWT plant are considered; pollutants generated as a result of supplying electricity for the manufacturing of lime are not considered. 3) The city of Ely was operating a secondary treatment plant. The phosphorus removal facility was added to the existing plant. Consequently, an environmental assessment of advanced wastewater treatment might cover only the tertiary phase, or that portion of treatment beyond secondary treatment. This study, however, examined the entire treatment process - primary, secondary and tertiary. The reasons for studying the entire plant, instead of just the tertiary phase are: a) the tertiary phase of the facility cannot operate without primary and secondary treatment, and b) water quality improvements in Shagawa Lake result from the treatment provided by the entire plant, not just the tertiary plant.

To put the present study into proper perspective, a brief history of the initiation of the AWT plant and a description of the plant itself is necessary. Prior to the operation of the AWT, phosphorus entering the lake was discharged from the secondary facility operated by the City of Ely. The U.S. Environmental Protection Agency (EPA), in cooperation with the City of Ely, funded construction of an advanced wastewater treatment facility to demonstrate that a reduction in phosphorus from a point source could reduce the trophic status of Shagawa Lake (Malueg *et al*, 1975). The tertiary plant which began operation in the spring of 1973, was designed to limit the phosphorus content of the effluent to 50 Mg/m^3 (0.05 mg/l^{-1}) or less. Operating data since that time indicate that the effluent from the plant does indeed meet design criteria. Both the improvement in water quality and the limnological characteristics of Shagawa Lake have been reported in the literature by Malueg *et al* (1975) and by Larsen *et al* (1975) and will not be discussed here.

SECTION II

WASTEWATER TREATMENT PLANT

Prior to construction of the tertiary treatment plant, the Ely, Minnesota, waste treatment facility consisted of a conventional secondary treatment operation. Wastewater entered the facility, passed through two parallel grit chambers and then through a bar screen and comminuter. The waste proceeded through a primary clarifier, trickling filter and secondary clarifier. After the effluent left the secondary clarifier, it was chlorinated and discharged into Shagawa Lake (Brice 1975).

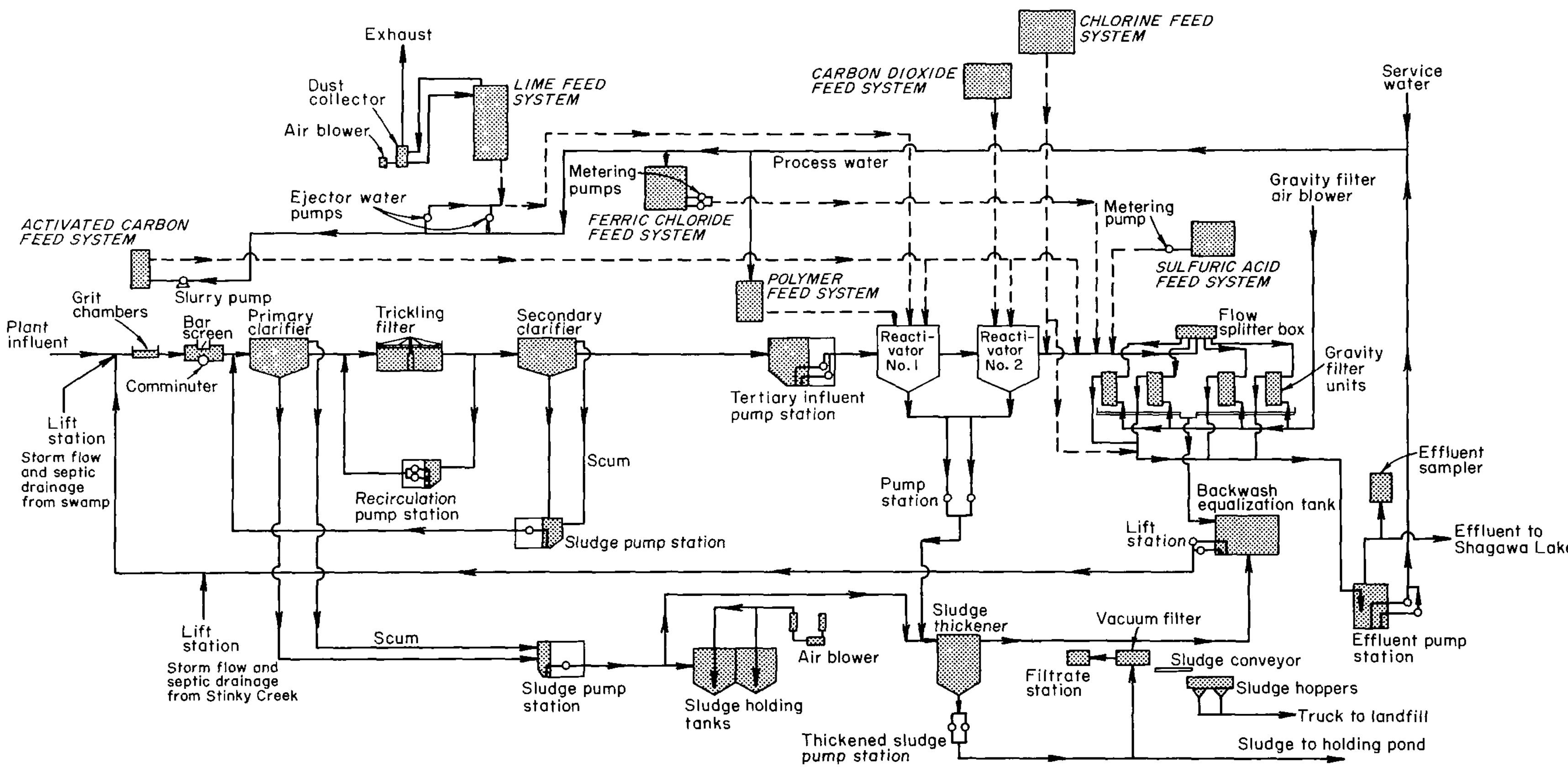
Historically, sludge from the secondary clarifier was returned to the influent line of the primary clarifier and sludge from the primary clarifier was digested and discharged to sludge drying beds. The plant was designed to use digester gas in the plant boiler burner. However, it was necessary to use supplemental gas to heat the digester (Brice 1975).

The tertiary treatment system was constructed as a research facility with a maximum of operational flexibility. Because of this, it is possible to pump almost any part of the waste "from anywhere to anywhere". Chemicals can also be introduced at many points in the system. However, much of this capability is not used and a standard procedure which is working quite satisfactorily, was developed. It is this normal operating procedure which will be described. A plant flow schematic is shown in Figure 1.

The effluent from the secondary treatment facility is pumped to a solids-contact clarifier at a rate of 4164 m^3/day (1.1 mgd), Sheehy and Evans (1976). Flow from this clarifier goes to a second, similar clarifier and then to a flow splitter box which feeds by gravity to four dual media filters.

The filters polish the effluent by removal of suspended solids containing phosphorous. Use of dual media (anthracite and sand) permits longer filter runs while still retaining excellent solids retention capability. Backwash water is returned to the secondary plant influent line. The filter effluent is chlorinated and discharged to Shagawa Lake or pumped back to the plant for use as process water.

It should be noted that an activated carbon feed capability is available for the removal of soluble organic phosphorous, or other uses as indicated. However, due to normal plant efficiency activated carbon



ELY, MINNESOTA

WASTEWATER TREATMENT PLANT
NORMAL FLOW SCHEMATIC

MODIFIED FROM
TOLTZ, KING, DUVALL, ANDERSON AND ASSOCIATES SCHEMATIC

——— *Process piping*
– – – *Chemical feed piping*

is seldom used, consequently the analyses which follow do not include an assessment of the activated carbon system.

Chemical sludge is withdrawn from the tertiary system at both clarifiers and pumped to a gravity sludge thickener. Organic sludge from the primary and secondary clarifiers goes to the sludge thickener where it is mixed with the chemical sludge from the tertiary plant. From the sludge thickener, the sludge is pumped to a rotary belt vacuum filter and trucked to an approved sanitary landfill. In the event of equipment failure, the sludge can bypass any given treatment facility and be discharged to a sludge holding pond. Filtrate from the vacuum filter and slurry from the vacuum are discharged to the equilization tank and returned to the head of the plant.

The tertiary treatment plant was designed to treat 5,678 m^3/day (1.5 mgd) and from April 1, 1973 - March 31, 1974 was treating 4,164 m^3/day (1.1 mgd). Overall plant performance relative to certain parameters is presented in Table 1 (Sheehy and Evans, 1976).

TABLE 1. ELY AWT PLANT PERFORMANCE

	Influent g/m^3	Effluent g/m^3	Removal %	g/m^3	kg/d	Mg/yr
Total P	7.1	0.05	99.4	7.02	29.2	10.7
Suspended Solids	202.0	1.30	99.4	201.0	837.0	306.0
Alkalinity (as $CaCO_3$)	181.0	41.90	76.9	139.0	579.0	211.0
BOD	90.0	12.30	86.3	78.0	325.0	119.0

SECTION III

RESOURCE UTILIZATION AND POLLUTANT GENERATION

As discussed in the Introduction, the operation and maintenance of the Ely AWT requires resources and the production of these resources generates pollutants. This section describes and quantifies the major resources utilized both directly (Table 2) and indirectly by the AWT. In addition to the resources discussed below, there is the human resource which will be discussed in a later paper on socioeconomic factors. However, it should be noted here that at present there are eleven people employed directly in the operation of the treatment facility. The significant pollutants caused by the production of these resources are also identified and quantified. These data will allow an assessment of the trade-offs which exist between the benefits accrued to the AWT through improved effluent quality and the costs incurred by the AWT through resources employed and pollutants generated.

TABLE 2. RESOURCES USED DIRECTLY AT ELY PER YEAR
SHEEHY AND EVANS (1975), BRICE (1975)

1. Lime Mg (Tons)	488 (538)
2. CO_2 Mg (Tons)	152 (168)
3. Chlorine Mg (Tons)	4.7 (5.2)
4. Electricity (kwh)	780,000
5. Fuel Oil m^3 (gals)	238 (63,000)
6. $FeCl_3$ Mg (Tons)	39.9 (44)
7. Sulfuric Acid Mg (Tons)	74.4 (82)
8. Polymer kg (lbs)	304 (670)

ENERGY

Electricity

On an average annual basis approximately 65 MWh (65,000 kWh) are used monthly at the wastewater treatment facility at Ely, Minnesota. This electricity is purchased from the City of Ely, who in turn buys electricity from Minnesota Power and Light (MP&L). The environmental analysis which follows is based on the fuel mix for the base load of MP&L, which is approximately 80% low sulfur western coal, 12% hydroelectric, and 8% residual fuel oil (Rutka, 1975). The following assumptions were made with regard to the fuels: 1) coal = 0.65% sulfur, 19.77 MJ/kg (8500 BTU's/lb), ash content = 7%; 2) Fuel oil = 1% sulfur and 0.5% ash; and 3) hydroelectric - no environmental insults are assigned to production of electricity by hydroelectric generation.

It is recognized that production of electricity by hydroelectric generation creates environmental alteration such as changing a free flowing stream to a standing water reservoir. This in turn alters **recreational** opportunities and species composition of the aquatic ecosystem. Further, dams can and do create other potential environmental effects, such as gas bubble disease. However, with present assessment techniques it is not possible to allocate a percentage of these types of effects to the AWT at Ely. It must simply be recognized that the AWT at Ely contributed to the demand for electricity and that demand is being partially satisfied by hydroelectric power.

The resources consumed and pollutants generated, as shown in Tables 3 and 4 respectively, were calculated from Pigford et al (1975). While Pigford et al have included pollutants generated throughout the entire fuel cycle of both fuel oil and coal, this analysis includes only pollutants generated at the power plant. This paper has not included an analysis of potential environmental effects associated with the extraction, transportation, or processing of fuels prior to burning in the power plant.

TABLE 3. RESOURCE REQUIREMENTS FOR PRODUCTION OF ELECTRICITY FOR AWT AT ELY, MINNESOTA

	Per MWh	Per year (780 MWh)
Fuel oil (8%) m^3 (gals)	0.020 (5.2)	15.4 (4070)
Coal (80%), Mg (ton)	0.420 (0.46)	328 (359)
Hydro-electric (12%)	---	---

TABLE 4. POLLUTANT DISCHARGE DUE TO PRODUCTION OF ELECTRICITY FOR AWT AT ELY, MINNESOTA 780 MWh/year[1]

		kg (lbs) of pollutant per MWh		kg (lbs) of pollutant per year	
To Air	SO_2	5.56	(12.3)	4.34×10^3	(9.6×10^3)
	NO_x	4.04	(8.91)	3.15×10^3	(6.95×10^3)
	CO	0.25	(0.55)	193	(426.0)
	HC	0.045	(0.10)	34.9	(77.0)
	Particulates	2.31	(5.09)	1.80×10^3	(3.97×10^3)
To Water	Suspended Solids	0.053	(0.116)	41.2	(90.8)
	H_2SO_4	0.009	(0.020)	7.02	(15.5)
	Cl_2	0.003	(0.006)	2.3	(5.1)
	Phosphates	0.005	(0.010)	3.6	(7.9)
	Boron	0.036	(0.080)	28.3	(62.4)
	BOD	Negligible		Negligible	
To Land	Fly Ash	2.72	(6.00)	21.2×10^3	(46.7×10^3)

[1] Assumes fuel mix of 80% coal, 12% hydro and 8% fuel oil.

It is emphasized that the data in Table 3 indicate the pollutants generated as a consequence of electric energy use by the Ely AWT. However, it must be recognized that these pollutants are discharged to the environment at the generating location, not at Ely. Consequently, as with all indirect pollutants generated as a result of operating the AWT, the environmental costs are being borne not by the users of Shagawa Lake or the residents of Ely, but by the residents living near, and the people using the environment at another location.

Fuel Oil and Gasoline

Significant quantities of pollutants are generated by burning fuel oil and gasoline at the AWT facility. Further, the oil refineries required to produce these products are the most significant indirect source of pollution that can be assigned to the operation of the AWT at Ely.

The direct pollutants generated and energy consumed as a result of burning these fuels may be accounted for as follows. The trucks which haul sludge from the AWT to a sanitary landfill consume 9.273 m^3 (2450 gallons) of gasoline per year. This is a direct energy consumption of 3.30×10^5 MJ (31.3×10^7 BTU's). In addition, based on air pollution emission factors (EPA, 1972) this study assumes the following air pollutants are emitted from these trucks: 1) carbon monoxide, 1838 kg; 2) hydrocarbons, 183 kg; 3) Nitrous Oxide (NO_x), 150 kg. Based on assumptions shown in Table 2, the burning of 238.5 m^3 (63,000 gallons) of fuel oil at Ely may be expected to emit the following air pollutants: 1) SO_x, 4113 kg; 2) CO, 6 kg; 3) HC, 83 kg; 4) NO_x, 1145 kg; 5) particulates, 429 kg; and an undetermined amount of fly ash (EPA, 1972). This results in a direct energy consumption of 1.01×10^7 MJ (957×10^7 BTU's).

As noted above, the refining of the fuel oil and gasoline constitutes the largest indirect source of pollutants and energy consumption required for the operation of the AWT. To allocate pollutants generated and resources consumed at an oil refinery it is necessary to know the percentage of gasoline and fuel oil produced by the total refinery process. For this analysis, it is assumed that gasoline represents 44.7% of the crude input and fuel oil represents 21.7% (Pigford et al, 1975). Tables 5 and 6 show the resources consumed and pollutants emitted in refining the fuel oil and gasoline consumed at Ely. This information has been taken from Pigford et al, (1975), and it should be noted that it represents industry-wide data for 1969. Thus it does not represent the most modern technology; rather is indicative of existing operations in the United States. It is interesting to note that of the total amount of energy consumed as a result of operating the AWT at Ely 65% can be assigned to the direct use of fuel oil and gasoline, and/or the refining of these products. In a wastewater treatment plant that uses digester gas in the boilers, significant savings in energy and pollutant discharges, both directly and indirectly, would be realized.

LIME

The Ely AWT facility uses 488 Mg (537 tons) of lime per year. Lime is fed into the clarifier at an average dosage of 275 g/m^3 (mg/l) as CaO to maintain a pH of 11.8 - 12.2 and to react with the ortho-phosphate to form calcium hydroxyapatite. This is the primary mechanism by which phosphorus is removed from the wastewater. Magnesium hydroxide

TABLE 5. RESOURCE REQUIREMENTS FOR PRODUCTION OF PETROLEUM PRODUCTS FOR AWT AT ELY, MINNESOTA
9.273 m^3 (2450 gal) Gasoline and 238.5 m^3 (63,000 gal) Fuel Oil per Year

	Per m^3 Gasoline	Per 1000 gal Gasoline	Per m^3 Fuel Oil	Per 1000 gal Fuel Oil	Per year Total	
Water, m^3 (gal)	6.19×10^{7}	(6.19×10^{10})	3.01×10^{7}	(3.01×10^{10})	7.76×10^{9}	(2.05×10^{12})
Natural Gas, m^3 (cu ft)	0.748	(100)	0.364	(48.6)	93.5	(3304)
Propane and Butane m^3 (gal)	1.028	(1020)	0.538	(538)	138.	(36400)
Crude Oil, m^3 (gal)	6.29×10^{-3}	(6.29)	3.05×10^{-3}	(3.05)	0.786	(208.)

TABLE 6. POLLUTANT DISCHARGE DUE TO PRODUCTION OF PETROLEUM PRODUCTS FOR AWT AT ELY, MINNESOTA
9.273 m^3 (2450 gal) Gasoline and 238.5 m^3 (63,000 gal) Fuel Oil/year

	kg per m^3 Gasoline	lbs per 1000 gal Gasoline	kg per m^3 Fuel Oil	lbs per 1000 gal Fuel Oil	Per Year kg	Per Year lbs
To Air						
Particulates	15.9	(133)	7.8	(64.7)	1993	(4394)
Organic	127.6	(1065)	61.8	(516)	15930	(35,000)
NO_x	99.4	(830)	48.3	(403)	12440	(27,000)
SO_x	118.0	(985)	57.3	(478)	14760	(33,000)
CO	24.1	(201)	11.7	(97.6)	3014	(6650)
To Water						
Chlorides	134.9	(1126)	65.4	(546)	16850	(37157)
Grease	0.34	(2.8)	0.17	(1.4)	43.1	(95.1)
NH_3 - N	0.34	(2.8)	0.17	(1.4)	43.1	(95.1)
Phosphate	0.02	(0.14)	0.01	(0.07)	2.2	(4.8)
BOD	0.56	(4.7)	0.28	(2.3)	70.9	(156.4)
COD	36.40	(304)	17.70	(148)	4567	(10,100)
Suspended Solids	1.13	(9.4)	0.55	(4.6)	142	(313)
Dissolved Solids	618.0	(5160)	300.10	(2505)	77320	(170,000)

and calcium carbonate are also formed and serve as coagulants to assist in removing the gelatinous calcium hydroxyapatite. In addition, lime is used when necessary as a sludge conditioner.

The analysis and documentation of environmental alterations which are assigned to the Ely AWT plant as a result of using lime include only those associated directly with the processing of limestone. Both the mining of limestone and the transporting of the limestone to the processing plant generate pollutants which are not considered here. All lime used at the AWT plant is purchased from the Cutler-Magner Company of Duluth, Minnesota. The calcining data in this paper is based largely on information supplied by Cutler-Magner Company (LaLiberte 1975). Lime is produced by calcining limestone at temperatures in excess of 1093°C (2000°F) in rotary kilns fired 37% of the time by #6 fuel oil and 63% of the time by natural gas. In the analysis which follows, the calculations are based on the fact that it requires 7,500,000 Btu's of oil to produce one ton of lime and 8,000,000 Btu's of natural gas. The difference between natural gas and fuel oil is that the kilns are more efficient when fired with fuel oil. It takes approximately 2Mg of limestone to produce 1Mg of lime. In this operation, power is required to drive the rotary kilns, induced draft fans, water cooling pumps, feeders, compressors, crushers, screens, conveying equipment and to generate high D.C. voltage in the electrostatic precipitators. Water is required for cooling kiln bearnings and cleaning the exit gas samples going to the continuous gas analyzers which record levels of oxygen and combustibles in the exit gases of the three kilns. The resources utilized and the pollutants generated as a result of producing lime are presented in Tables 7 and 8. Other literature (EPA, 1974; Lewis and Crocker, 1969, Boynton, 1966) all indicate that the Cutler-Magner data are generally representative of the industry as a whole.

TABLE 7. RESOURCE REQUIREMENT FOR PRODUCTION OF LIME
FOR AWT AT ELY, MINNESOTA*
488 Mg (537 Tons)/year

	Per Mg Lime	Per Ton Lime	Per Year
Limestone, Mg (tons)	2	(2)	976 (1070)
Fuel Oil, m^3 (gal)	0.209	(50)	38 (9935)*
Natural Gas, m^3 (cu ft)	237	(7619)	73,200 (2.58×10^6)*
Electricity, MWh (kWh)	0.055	(50)	27 (26900)
Water, m^3 (gal)	0.334	(88)	148 (42700)

* Based on fact that 37% of the time kilns are fired with #6 fuel oil therefore it was assumed 37% of the total lime consumed at Ely was produced by this fuel and 63% was produced by natural gas.

TABLE 8. ATMOSPHERIC POLLUTANT DISCHARGE DUE TO PRODUCTION OF LIME FOR AWT AT ELY, MINNESOTA
488 Mg (537 Tons)/year

	Per Mg Lime	Per Ton Lime	Per Year
To Air			
SO_x kg (lbs)	2.04	(4.1)	996 (2196)
Particulates, kg (lbs)	0.16	(0.32)	78 (172)
Heat, GJ (BTU)	5.20	(4.5×10^6)	$2500\ (24.0 \times 10^8)$
*NO_x, kg (lbs)	0.61	(1.23)	299 (661)
*CO, kg (lbs)	0.05	(0.10)	24.6 (54)
*HC, kg (lbs)	0.035	(0.07)	17.1 (37.8)

* NO_x, CO, and HC are calculated from "Compilation of Air Pollution Emission Factors" (EPA 1972) and are based on the fact that approximately 209 dm^3 (liter) of fuel oil are burned to produce 1 Mg of lime (50 gallons/ton). Sulphur content of fuel oil was assumed to be 1.6%. Kilns are fired 37% of the time by fuel oil and 63% of the time by natural gas.

POLYMER

In addition to the lime, a cationic polymer (Betz 1150) is used as a coagulant aid and added at a dosage of 0.1-0.2 (mg/l). This results in 299 kg (659 lbs) of polymer being used each year. Betz polymer 1150 is "actually a co-polymer of acrymlamide with a portion of quaternary ethyl acrylate included in the structure" (Pressman, 1975). However, since this polymer is only one of several products being manufactured simultaneously, Betz Laboratories could not furnish detailed information on resource utilization such as energy consumption. The company claims no waste products are given off during the manufacturing process. All constituents which are not used are recycled and used in other production (Pressman, 1975). The resources utilized and energy costs of transporting 299 kg (659 lbs) of polymer from Trevose, Pennsylvania to Ely, Minnesota, are insignificant compared to other energy and resource requirements of the AWT plant. As a result of these findings, even though the cost of the product, \$8367 per Mg (\$7606/ton) would indicate that the process of producing Betz 1150 may be highly energy consuming, no environmental impacts are assigned to the utilization of the polymer at Ely.

CARBON DIOXIDE

Commercial grade carbon dioxide is added to the second clarifier at a level of 100 g/m^3 (mg/l). This reduces the excess calcium by forming calcium carbonate resulting in an annual usage of 152.4 Mg (167.6 tons) of CO_2. Carbon dioxide is generally obtained as a by-product of some other reaction and is either emitted to the atmosphere or diverted to a purification and liquefaction plant. There are only two resources required to produce liquefied CO_2 - electrical energy and cooling water (Vorel, 1975). The information on electrical consumption and pollutants generated, as supplied by Cardox products (Vorel, 1975) is shown in Table 9. This information is valid only for gas produced as a byproduct of another reaction, and not appropriate if gas were produced in an inert gas generator.

TABLE 9. RESOURCE REQUIREMENT FOR AND POLLUTANT DISCHARGE DUE TO PRODUCTION OF CO_2 FOR AWT AT ELY, MINNESOTA
152 Mg (168 Tons)/year

	Per Mg CO_2	Per Ton CO_2	Total Per Year
Electricity, kWH	176	160.	26800
Waste Heat to Cooling Water, GJ (BTU)	0.32	(3.0×10^5)	53.1 (503×10^5)

FERRIC CHLORIDE

Ferric chloride is added to the processes at two points. First it is added to the second stage lime clarifier at the rate of approximately 6 g/m^3 (mg/l) of iron. This serves to form complex insoluble phosphorous salts which are precipitated or filtered out.

Second, after the effluent leaves the second stage lime clarifier, chlorine, ferric chloride and sulfuric acid are added. Ferric chloride, at a level of 1.0 - 2.0 g/m^3 (mg/l) of iron, provides a floc blanket which improves filter efficiency and extends filter runs. There is an annual usage of 39.8 Mg (43.8 tons) of ferric chloride.

There are several different techniques and processes for producing ferric chloride. The analysis which follows is based upon information supplied by Dow Chemical Company (Sharp, 1975) and information contained in the Development Document for Effluent Limitation Guidelines and Proposed New Source Performance Standards for the Significant Inorganic Products (EPA, 1975). The manufacturing of ferric chloride utilizes mostly waste products from the steel industry - scrap steel and/or waste pickle liquor (WPL) (Table 10). Chlorine is added to the iron solution in a reactor and ferric chloride is formed. In some processing plants, additional hydrochloric acid is added to the reactor. However, since the facility at Shagawa has been using Dow or DuPont ferric chloride, neither of which use HCl, it has not been included in this analysis. While the reaction $2\ FeCl_2 + Cl_2 \rightarrow 2\ FeCl_3$ is basically exothermic, external heat is used at times to concentrate the final product. The quantity of energy utilized for this step is insignificant (Sharp, 1975) and is not counted in this analysis.

TABLE 10. RESOURCE REQUIREMENTS FOR PRODUCTION OF FERRIC CHLORIDE USED AT AWT AT ELY, MINNESOTA
40 Mg (44 Tons)/year

	Mg Per Mg Ferric Chloride	Ton Per Ton Ferric Chloride	Total Per Year Mg	Total Per Year Tons
Waste Pickle Liquor (as Fe)	0.34	0.34	13.7	15.1
Chlorine	0.66	0.66	26.2	28.9

In the manufacturing of $FeCl_3$, there are no waste products produced that are either discharged to the water or emitted to the air (Sharp, 1975). There are, however, a total of approximately 17.7 kg of sludge produced for every Mg of product ferric chloride (35.4 lbs/ton). This means that the amount of solid waste produced each year as a result of using $FeCl_3$ at Ely is approximately 706.5 kg (1558 lbs). There is no detailed information on the chemical composition of the sludge but it is expected that it would contain grease, silica, sand, ferric chloride, and iron oxide and hydioxide (EPA, 1975). No environmental insult has been assigned to the chemicals contained in the sludge.

CHLORINE

Chlorine is added at a dosage of approximately 3.0 g/m^3 (mg/l) to provide a final effluent residual of 0.2 g/m^3 (mg/l). This serves as a control for potential pathogenic bacteria and results in the use of 4.7 Mg (5.17 tons) of chlorine per year.

The industrial process and energy requirements for the production of chlorine has been detailed by Saxton et al (1974) and EPA (1974). The electrolytic processing of brine by either diaphram or mercury cells accounts for 96% of the total chlorine production in the United States. The remaining 4% is presently produced as a by-product of other industrial processes. In this study it has been assumed that the chlorine used at Ely has been produced by the electrolytic process. The following information and assumptions are important in analyzing resource requirements of the chlorine industry: 1) 75% of the installed electrolytic capacity in chlor-alkali plants consist of diaphram cells and 25% of the capacity consists of mercury cells; 2) 41% of the cells use graphite anodes, and 59% use metal anodes; 3) for every megagram (Mg) of chlorine produced, 1.13 Mg of caustic soda (NaoH) are produced (1 ton chlorine/1.13 ton caustic soda). Since most available raw data that are for the co-production of chlorine and sodium hydroxide, this last fact could lead to misinterpretation of data. This study has allocated resources between chlorine and caustic soda on a weight basis. For example, if the co-production of 1 Mg of chlorine and 1.13 Mg of caustic soda requires 3197 kwh of electricity, 1500 kWh are assigned to the production of 1 Mg of chlorine. In this case, it is legitimate to allocate energy resources between chlorine and caustic soda because both products are in high demand and the dollar value of both products is high. In other words, caustic is not necessarily just a by-product of chlorine production, or vice versa. If caustic was simply a by-product with little or no economic value, it would not be legitimate to allocate resources between the two products. Further, the total process yields hydrogen gas as a by-product which is sold. However, this paper does not allocate any of the resources to the production of hydrogen (i.e., it was considered solely as a by-product of producing chlorine and caustic soda).

The net and gross energy costs of producing chlorine by different technologies are shown in Table 11. In this analysis, net electrical use, rather than gross electrical use, has been used in calculating

TABLE 11. ENERGY REQUIREMENT FOR THE PRODUCTION OF CHLORINE
(Modified from Saxton et al, 1974)

	Net Electrical[1] Energy		Gross Electrical[2] Energy		Process Steam		Total Net[3] Energy	
	GJ/Mg	BTU/Ton	GJ/Mg	BTU/Ton	GJ/Mg	BTU/Ton	GJ/Mg	BTU/Ton
Mercury Cell								
Graphite Anode	6.1 (1700 kWh)	52.6×10^5	19	164×10^5	1.3	11.2×10^5	7.4	63.8×10^5
Metal Anode	5.2 (1445 kWh)	44.8×10^5	16	138×10^5	1.3	11.2×10^5	6.5	56×10^5
Diaphragm Cell								
Graphite Anode	5.5 (1527 kWh)	47.4×10^5	17	147×10^5	5.6	48.3×10^5	11.1	95.7×10^5
Metal Anode	4.7 (1300 kWh)	40.5×10^5	15	129×10^5	5.6	48.3×10^5	10.3	88.8×10^5

[1] Power consumed directly in the electrolytic cell and elsewhere in the chlorine plant.

[2] Fuel required to generate the net electricity (in some instances electric power is generated on-site).

[3] Total of Net Electrical Energy and Process Steam.

pollutant emissions and energy consumption. This is done because the entire analysis is limited to first order industries. The gross energy figures represent the energy required to produce the electricity. However, nearly 50% of the electrical consumption by the chlor-alkali industry is generated on site, therefore, gross energy values are given in Table 11 so that (if desired) the reader may recalculate energy values for the production of chlorine.

In addition to electrical energy, the production of chlorine requires large amounts of process steam in the evaporators. Natural gas is the primary fuel used in the boilers to produce steam. However, there are no data on the specific fuel mix used in the boilers. Therefore, the emissions generated from producing chlorine have been calculated using the same fossil fuel mix as utilized by the alkalies and chlorine industry (SIC 2812) as a whole (5% fuel oil, 18% coal, 77% natural gas). It has been assumed that these fuels have the following heat content: fuel oil, 39.8 GJ/m^3 (143 x 10^3 BTU/gal); coal, 30.24 MJ/kg (13 x 10^3 BTU/lb); and natural gas 39.12 MJ/m^3 (1056 BTU ft^3). Based on these assumptions, Table 12 shows the resources consumed in producing 1 Mg (and 1 ton) of chlorine, as well as the resources utilized in producing the 4.72 Mg (5.20 ton) of chlorine that is used yearly at the AWT plant in Ely.

TABLE 12. RESOURCE REQUIREMENTS FOR PRODUCTION OF CHLORINE FOR AWT AT ELY, MINNESOTA
4.72 Mg (5.20 tons)/year

	Per Mg Cl	Per Ton Cl	Per Year	
Electrical, MWh (kwh)	1.4	(1250)	6.5	(6.45x10^3)
Steam[1], GJ (BTU)	4.8	(41.6x10^5)	22.8	(21.6x10^6)
Fuel Oil, dm^3 (gal)	6.3	(1.51)	29.7	(7.7)
Coal, kg (lbs)	28.9	(58.0)	136.	(300.)
Natural Gas, m^3 (cu ft)	95.0	(3050)	448	(15.8x10^3)
Rock Salt[2], Mg (tons)	1.1	(1.25)	5.3	(6.5)
Sulfuric Acid, kg (lbs)	6.1	(12.2)	28.8	(63.5)
Sodium Carbonate, kg (lbs)	8.2	(16.4)	38.7	(85.3)

[1] Steam includes fuel oil, coal and natural gas.

[2] Rock Salt was allocated on a molecular weight basis between chlorine and caustic soda.

Table 13 shows the atmospheric and aquatic emissions that result from the manufacture of chlorine. To calculate these numbers, additional assumptions were made: ash content of coal = 12%; ash content of fuel oil = 0.5%; sulfur content of coal and fuel oil = 1%; and emission controls = 98% particulate removal.

TABLE 13. POLLUTANT DISCHARGE DUE TO PRODUCTION OF CHLORINE FOR AWT AT ELY, MINNESOTA 4.72 Mg (5.20 Tons)/year

		gm per Mg Chlorine	lbs per Ton Chlorine	Per Year gm	Per Year lbs
To Air					
	Particulates	45	9	210	47
	SO_2	590	118	2780	614
	CO	45	9	210	47
	HC	20	4	94	207
	NO_x	540	108	2550	561
	Cl_2	9070	1800	42800	9360
	CO_2	15900	3180	75000	16500
To Water[1]					
	Suspended Solids	320	64	1510	330
	Lead	2.5	0.5	10	2.60
	Hg[2]	Negligible	Negligible	Negligible	Negligible

[1] Based upon effluent guidelines for best practical control technology.

[2] Allowable discharge of Hg from chlorine plants using mercury cells is 0.14 g/kg of chlorine produced. Since this analysis is based upon the assumption that only 25% of Ely's chlorine comes from mercury cells, the discharge of mercury is 0.0315 g/kg of chlorine produced.

SULFURIC ACID

As the wastewater leaves the second stage lime clarifier, sulfuric acid is added at a dosage of approximately 37 g/m^3 (mg/l) which is sufficient to maintain a final effluent pH of 7.0-7.5. This results in the use of 74.5 Mg (82 tons) per year. Sulfuric acid is produced primarily by burning sulfur to produce SO_2, followed by oxidation to yield SO_3, which is reacted with water to produce H_2SO_4. This process consumes insignificant quantities of energy, 174.4 kJ/kg (75 BTU/lb) (Saxton et al, 1974), and, in many cases, much of the excess steam is utilized either internally or in a nearby plant. For these reasons, this paper does not include a detailed analysis of the fuels required to produce the 174.4 kJ/kg (75 BTU/lb) of H_2SO_4. The total energy requirement, 13.0 GJ (1.23×10^7 BTU's), is counted in the energy consumption of the facility at Shagawa. The processes produce an emission of 20 g of SO_2 per kg of H_2SO_4 (0.02 lb/lb) (EPA, 1972). Acid mist is produced and emitted to the air. If the H_2SO_4 facility has acid mist eliminators, then from 0.01 to 0.1 g/kg of H_2SO_4 is emitted. If there are no eliminators then from 0.15 to 3.75 g/kg are emitted. The following assumption was made: acid mist eliminators are present at the facility supplying Ely and 0.1 g/kg (1×10^{-4} lb/lb) are emitted. This results in the assignment of 7.45 kg (16.4 lbs) per year of acid mist emissions due to the production of H_2SO_4 used at the Ely AWT.

SECTION IV

DISCUSSION AND SUMMARY

The total pollutants generated and resources consumed for treating 1.616 hm^3 (427 million gallons) per year of wastewater at the AWT facility in Ely are summarized in Tables 14, 15, and 16. Of the total energy requirement of 26.34 TJ (24.96 x 10^9 BTU's) (Table 14), 10.1 TJ (9.57 x 10^9 BTU's) are contained in the fuel oil burned at the AWT plant. The major indirect energy sources are for refining gasoline and fuel oil and in the energy content of the fuel required to produce the electricity used for the AWT. The operation of the oil refinery was the single largest contributor of pollutants generated as a result of operating the Ely AWT.

When the values for the AWT at Ely are compared to those of the AWT at Lake Tahoe (Antonucci and Shaumberg, 1975) there are some apparent differences (Table 17):

1) At Ely, chlorine is consumed both directly and indirectly in the manufacturing of $FeCl_3$. At Tahoe, since alum is used instead of $FeCl_3$, chlorine is only consumed directly. Because of this difference in operational procedure, chlorine consumed at Ely is 1.5 times that used at Tahoe. However, when direct consumption of chlorine is considered then the chlorine consumed at Ely is only 0.25 times that used at Tahoe. Likewise, salt and sodium carbonate, used in chlorine manufacturing, values are much higher at Tahoe. The difference in these values is due to: 1) the chlorine dosage at Tahoe is 12 g/m^3 (mg/l), and 3 g/m^3 (mg/l) at Ely; and 2) in this study, the resources used in chlorine production were allocated between chlorine and its co-product, caustic soda.

2) Lime is used in greater quantities at the Ely facility primarily because there is a lime recovery system at Tahoe, whereas at Ely the lime sludge is trucked to a sanitary landfill. This must be balanced against energy cost at Tahoe of 3.8 x10^{10} kJ (35.7 x 10^6 Btu's) to recover lime.

3) Finally, it is apparent from Table 17 that it takes twice as much total energy, per million gallons of effluent to operate the Tahoe facility. Of the 111.8 GJ (106 million BTU's) used at Tahoe over 36.9 GJ (35 million BTU's) are used in recalcining lime, which is not done at

TABLE 14. TOTAL ENERGY[1] REQUIREMENTS PER YEAR FOR AWT AT ELY, MINNESOTA

	Indirect		Direct		Total		Converted to TJ	Converted to BTU
Electricity, MWh (kWh)	60.2	(60200)	780.	(780,000)	840.2	(840,200)	3.03	(287x10^7)
Fuel Oil, m^3 (gal)	38	(9,935)	238.5	(63,000)	276.5	(72,935)	11.7	(1109x10^7)
Gasoline, m^3 (gal)	--	--	9.27	(2450)	9.27	(2450)	0.330	(31.3x10^7)
Natural Gas, m^3 (cu ft)	73,200	(2.58x10^6)	-0-	-0-	73,200	(2.58x10^6)	3.10	(271x10^7)
Propane & Butane, m^3 (gal)	138	(36,400)	-0-	-0-	138	(36,400)	3.67	(348x10^7)
Crude Oil, m^3 (gal)	0.79	(208)	-0-	-0-	0.79	(208)	0.03	(2.87x10^7)
Misc. GJ (BTU's)	35.8	(33.9x10^6)	-0-	-0-	35.8	(33.9x10^6)	0.04	(3.39x10^7)
					Sub Total		21.6	(205.3x10^8)
			Gross TJ	Gross BTU	Net TJ	Net BTU		
[2]Fuel Oil, m^3 (gal)	115.2	(4069)	0.65	6.18x10^8	0.43	4.08x10^8	0.43	(4.08x10^8)
[2]Coal, Mg (Tons)	326.4	(359)	6.43	6.10x10^9	4.24	4.02x10^9	4.24	(40.2x10^8)
					Grand Total		26.34	(249.6x10^8)

[1] Energy Factors Used:

Electricity	= 3413 BTU/kWh
Fuel Oil	= 19,000 BTU/lb (8 lb/gal)
Gasoline	= 20,750 BTU/lb (6.152 lb/gal)
Natural Gas	= 1050 BTU/cu ft
Propane & Butane	= 95,500 BTU/gal
Crude Oil	= 138,100 BTU/gal
Coal	= 8,500 BTU/lb

[2] Fuel required to produce direct electricity shown on 1st line of table. In these lines, gross refers to energy content of fuel, and net refers to energy after the energy content of electricity has been subtracted - assuming 33% thermal efficiency.

TABLE 15. SUMMARY OF MAJOR POLLUTANT DISCHARGES PER YEAR DUE TO OPERATION OF AWT AT ELY, MINNESOTA

	Indirect		Direct		Total	
	Mg	Tons	Mg	Tons	Mg	Tons
To Air						
Particulates	3.88	5.23	0.43	0.4*	4.31	5.71
SO_x	20.6	22.74	4.08	4.50	24.7	27.2
CO^x	3.20	3.59	1.84	2.03	5.10	5.62
HC	0.15	0.16	0.27	0.29	0.42	0.45
NO_x	15.88	17.5	1.29	1.43	17.15	18.9
Cl_2	4.28	4.70	--	--	4.28	4.70
To Water						
Suspended Solids	0.33	0.37	--	--	0.33	0.37
H_2SO_4	0.007	0.01	--	--	0.007	0.01
Phosphates	0.007	0.01	--	--	0.007	0.01
BOD and COD	4.6	5.1	--	--	4.6	5.1
To Land						
Sludge	0.78	0.78	893.0	984.	894.	985.
Fly Ash	2.12	2.34	--	--	2.12	2.34

TABLE 16. RESOURCE REQUIREMENTS PER YEAR FOR OPERATION OF AWT AT ELY, MINNESOTA

	Indirect		Direct		Total	
	Mg	Tons	Mg	Tons	Mg	Tons
Chlorine	26.2	28.9	4.7	5.2	30.9	34.1
Lime	--	--	488.1	538.1	488.1	538.
$FeCl_3$	--	--	39.9	44.0	39.9	44.
H_2SO_4	0.03	0.03	74.4	82.0	74.4	82.0
Polymer	--	--	0.15	0.17	0.15	0.17
Salt	5.30	5.80	--	--	5.3	5.8
Sodium Carbonate	0.04	0.04	--	--	0.04	0.04
Limestone	971×10^3	1070.	--	--	971.	1070.0

TABLE 17. COMPARISON OF RESOURCE REQUIREMENTS FOR AWT AT ELY, MINNESOTA AND LAKE TAHOE, CALIFORNIA

	ELY		TAHOE	
	Per 1000 m^3	Per Million Gallons	Per 1000 m^3	Per Million Gallons
Chlorine, kg (lbs)	19	(160)	12.7	(106)
Salt, kg (lbs)	3.26	(27.2)	33.6	(280)
Sodium Carbonate, kg (lbs)	0.02	(0.19)	0.31	(2.6)
Lime, kg (lbs)	302.0	(2520)	192.0	(1600)
Limestone, kg (lbs)	600.5	(5011)	383.5	(3200)
Energy, GJ (BTU)	16.19	(58.1×10^6)	29.5	(106×10^6)

Ely. Secondly, the AWT at Ely does not incinerate its organic solids, but mixes them with the lime sludge and hauls them to a landfill. At Tahoe the incineration of these solids results in an energy cost of 6.64 kJ/m^3 (23,800 BTU's per million gallons). The only energy value that was calculated differently in the two studies was the amount of energy required to produce chlorine. In this study the energy consumed in producing chlorine and caustic soda was allocated between the two end products, whereas Antonucci and Schaumberg (1975) assigned all of the energy in the production of chlorine and caustic soda to chlorine. This difference is insignificant when compared to other energy requirements of the AWT plants.

In order to put the resource consumption due to the operation of Ely's AWT in perspective, one can compare this consumption with a common "baseline", for example, home consumption of energy. On the average an all-electric home, 111.5 m^2 (1200 sq ft), in Ely, Minnesota, consumes approximately 3240 kWh/mo which is equivalent to 11,065,000 BTU's. The AWT plant at Ely uses 65,000 kWh per month (221,980,000 BTU's) plus another 798 million BTU's in fuel oil. Thus the direct energy consumption at the AWT facility is equal to the direct energy consumed in 74 all-electric homes. Using another comparison, the 2450 gals of gasoline used in the trucks for hauling sludge would drive an automobile (getting 20 mpg) approximately 49,000 miles, about what four average families would drive in one year.

Based on 1975 emission standards, which are more stringent than the emissions from an average auto, it is possible to compute the number of miles of auto travel that would create the equivalant grams of certain pollutants as does the operation of the AWT at Ely: 1) CO, 337,200 miles; 2) HC, 224,000 miles; and 3) NO_x, 57,950,000 miles.

Other comparisons can be made. However, the purpose of this paper is not to evaluate operation of the Ely AWT facility by comparing its operation to other activities of man. The purpose of this study is to assess what pollutants have been emitted and what resources have been consumed as a result of operating the AWT at Ely. Ideally, it would be desirable to carry this analysis a step further and discuss the effect these pollutants have on human health and natural ecosystems. This is not possible using techniques available today.

Consequently, we are faced with the situation where it is possible to quantify, to some extent, the unquestionable improvement of the Shagawa Lake ecosystem, and compare this improvement to unquantifiable environmental effects that are being borne, not by the users of Shagawa Lake and the residents of Ely, Minnesota, but by others who live in the area of the oil refineries, chlorine plants and other support industries. While we cannot quantify these tradeoffs it is important to understand that they do exist and because of this technology fixes may not necessarily be the solution to all environmental pollution problems.

SECTION V

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SECTION VI
SI UNITS AND CONVERSION FACTORS USED

UNITS

length	metre (m)	energy	joule (J)
mass	kilogram (kg)	volume	cubic metre (m^3)
area	square metre (m^2)		

SI PREFIXES

Multiplication Factors	Prefix	SI Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

CONVERSIONS

To Convert From	to	Multiply By
BTU	joules (J)	1.055×10^{3}
$foot^2$	$metre^2$ (m^2)	9.290×10^{-2}
$foot^3$	$metre^3$ (m^3)	2.832×10^{-2}
gallon (U.S. liquid)	metre (m^3)	3.785×10^{-3}
kilowatt-hour (kWh)	joules (J)	3.600×10^{6}
mile (U.S. statute)	kilometer (km)	1.609
pounds (lb avoirdupois)	kilogram (kg)	4.536×10^{-1}
ton (short-2000 lbm)	megagrams (Mg)	0.907
barrel (bbl)	gallon (U.S. liquid)	4.2 x 10

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(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The results presented in this report give an indication of the pollutants that would be generated and the resources consumed in operating a treatment facility similar to the one at Ely, Minnesota. The study analyzes not only the facility itself, but also those industries that supply products to the treatment plant. It was found that the total energy requirement of the advanced wastewater treatment plant was $50x10^6$ Btu/million gallons of water treated.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Environmental Assessment Resource Consumption	Advanced Wastewater Treatment.	

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