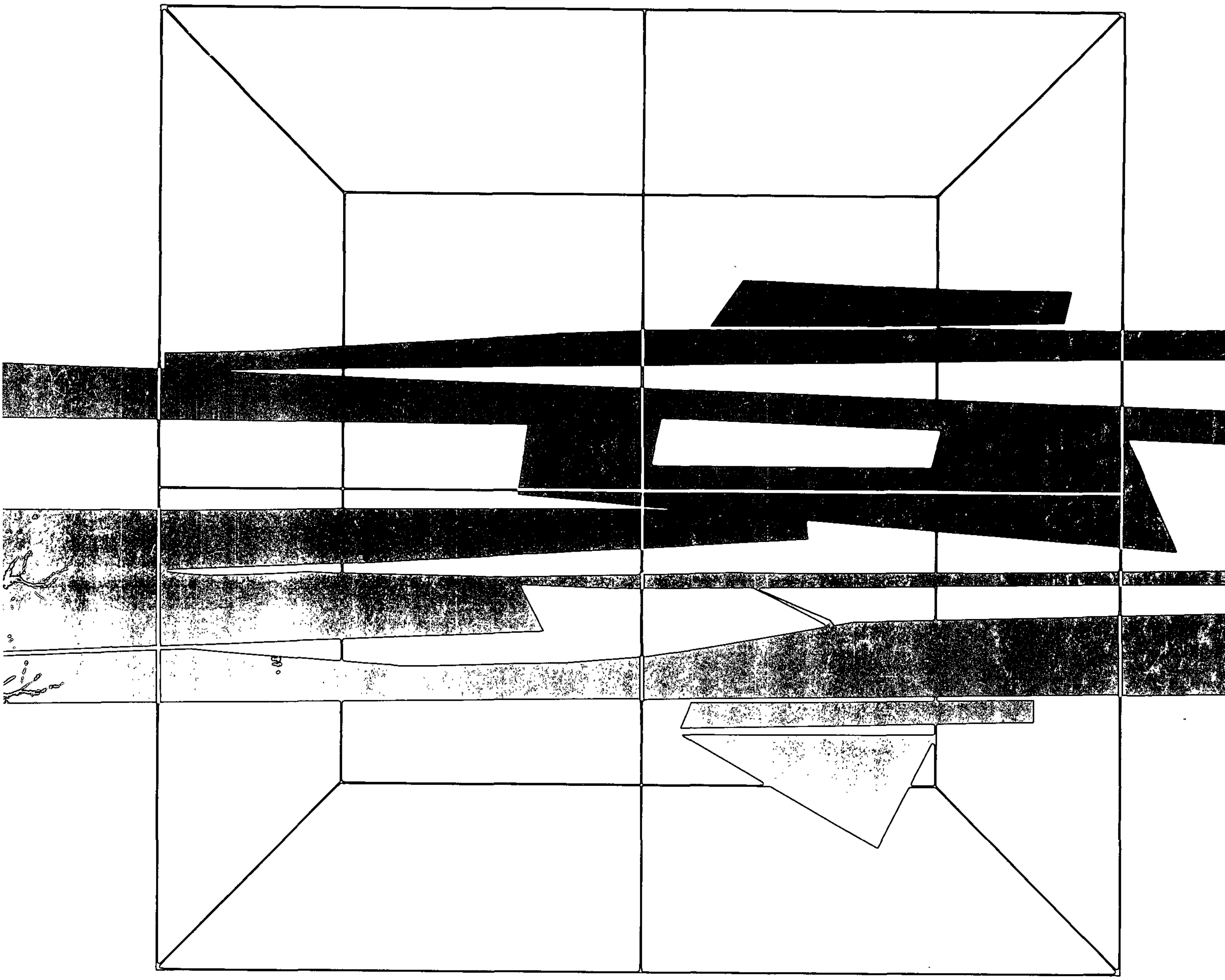
Operation and Maintenance Costs for Municipal Wastewater Treatment Facilities in Canada - 1980

Report EPS 5/UP/1
December 1984



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OPERATION AND MAINTENANCE COSTS FOR MUNICIPAL WASTEWATER TREATMENT FACILITIES IN CANADA - 1980

by

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ABSTRACT

Operating and maintenance cost data were collected at 52 municipal wastewater treatment facilities in Canada in 1981. Facilities surveyed included primary treatment plants, secondary treatment plants and aerated and facultative lagoon systems. Cost data presented in this report are in 1980 dollars.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The success or failure of the performance of a municipal wastewater treatment plant depends upon three important factors:

1) planning and design;
2) construction; and
3) operation and maintenance.

If any one of these factors is inadequately or improperly done, it is unlikely that the facility will provide satisfactory results. While a significant effort is made during the planning, designing and construction stage of a project to meet budget estimates on capital items and provide a useful end product, the same is not always true for operation and maintenance (O & M) of the facility. Rough estimates of personnel and budget needs are made during project planning, but the O & M funding commitment to sewage treatment often is not fully appreciated until a facility has been operating for some time.

A national data base of O & M costs would assist the prediction of budget requirements for municipal wastewater treatment facilities. To initiate the development of such a data base, a national survey was conducted in 1981. Data were collected from 52 municipal wastewater treatment facilities in various regions of Canada on the basis of 1980 O & M records and dollar values. This report summarizes information collected during the survey. To improve upon the accuracy or to update these data, more intensive review of facilities of a specific process-type or size group will be required. Comprehensive coverage of this nature should occur as needs are identified.

1.1 Background

In Canada, municipal sewage is discharged to sanitary collectors at a rate of approximately 11 x 10^6 m^3/d. About 55% (6 x 10^6 m^3/d) of this wastewater receives some form of treatment. The following processes are used for approximately 90-95% of the treated wastewater: 60% by activated sludge; 20% by primary treatment; 6% by aerated lagoons; and 5-10% by facultative lagoons.

There are approximately 450 activated sludge plants (or modified versions of activated sludge), 74 primary plants, and 746 aerated or facultative lagoons operating in Canada. The majority of the mechanical plants, i.e., activated sludge and primary plants, have capacities of 50 000 m^3/d or less. Between 85-90% of facultative and aerated lagoons have design capacities that are less than 10 000 m^3/d.

During the summer of 1981, the survey of 52 municipal wastewater treatment facilities was completed by an engineering consultant under contract to EPS (Environmental Protection Service). The survey included the examination of 1980 operational records at various facilities across the country including: 25 conventional activated sludge plants; 9 primary plants; 8 aerated lagoon systems; and 10 facultative lagoon systems. Seven activated sludge plants, 3 primary plants, 1 aerated lagoon and 2 facultative lagoons included in the survey used phosphorus removal processes.

1.2 Objectives

The specific objectives of the project included:

1) collection of O & M cost information at selected sewage treatment facilities;
2) development of an O & M cost information resource manual;
3) examination of the significant components of O & M costs at sewage treatment plants;
4) development of relationships between O & M costs and common sewage treatment parameters such as average daily flow and pollutant removal rates for various types of facilities.

2 METHODOLOGY

2.1 Survey

Data presented in this report were obtained during site visits to sewage treatment plants in various regions of Canada. For the purpose of this survey, regions were defined as follows:

Western: British Columbia, Alberta, Saskatchewan, Manitoba

Central: Ontario

Eastern: Quebec, New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland.

Responsible individuals associated with the 52 plants surveyed were interviewed. Data on the facility and its operation and maintenance costs were obtained from 1980 records, whenever possible. In some situations it was necessary to use pre-1980 information and update to a common dollar value (1980 dollars) using cost indexes.

The plants in each region were selected on the basis of process type and size. The types of plants considered were categorized as:

Levels of Treatment	Process type
1) Primary Treatment	Primary clarification
2) Secondary Treatment	Conventional Activated Sludge
	Extended Aeration
	Contact Stabilization
	Step Aeration
3) Lagoons	Aerated
	Facultative

Primary treatment typically removes about 60% of the raw sewage suspended solids (SS) and about 35% of the biochemical oxygen demand (BOD). At the primary facilities surveyed SS removal efficiencies ranged from 55% to 89% (average 72%) and BOD removal efficiencies ranged from 35% to 70% (average 52%).

Secondary treatment processes are designed to remove 85% to 90% of the BOD and SS. For the 25 plants surveyed, BOD removals varied from 70% to 97% (87% average) and SS removal efficiencies ranged from 65% to 95% (88% average). Wide variations in removal efficiencies were experienced in the lagoon systems surveyed. BOD and SS removal rates varied from 66% to 97% and from 19% to 93%, respectively, for aerated lagoons, and from 41% to 98% and 22% to 95%, respectively, for facultative lagoons.

In addition to treatment levels, plants were selected and grouped according to size. Size categories included:

Small	< 1000 m^3/d and 1000-5000 m^3/d
Medium	5000-50 000 m^3/d
Large	> 50 000 m^3/d

Seven of the 52 plants surveyed were in the large category, i.e., 5 secondary and 2 primary systems. Twenty-one plants in the survey were small, i.e., 11 lagoons, 2 primary, and 8 secondary systems; while 5 primary , 12 secondary and 7 lagoon systems were in the 5000 to 50 000 m^3/d category.

General information on the surveyed plants is included in the Appendix.

2.2 Data Analysis

Data analysis was completed on the basis of four considerations:

- level of treatment
- operational capacity;
- component costs; and
- pollutant removal efficiency.

2.2.1 Level of Treatment. Data was initially collated on the basis of level of treatment, i.e., primary, secondary, and lagoons. For secondary systems, no distinction was made between the processes employed (i.e., conventional activated sludge or modified versions). Aerated and facultative lagoon data were considered in separate analyses.

2.2.2 Operational Capacity. Cost data on plant-types were categorized on the basis of plant size, as outlined previously, and then analyzed according to operational capacity. Operational capacity was assessed on the basis of average daily flow versus design daily flow. A facility was considered to be design loaded if average daily flows were in the range of 90% to 110% of design flow. Treatment facilities with actual daily flows greater than 110% of the design flow were defined as overloaded. Underloaded plants were defined as those plants with average daily loading of less than 90% of the design flow.

2.2.3 Component Costs. Component costs are general budgetary categories which collectively make up the total O & M costs of municipal wastewater treatment facilities. The major component costs assessed in this investigation were:

1) electrical - all expenditures for electrical power other than sewage pumping station requirements.

2) personnel - wages and fringe benefits for operating staff and supervisory personnel.
3) chemicals - costs for process chemicals including chlorine for disinfection and/or odour control, precipitant chemicals for phosphorus removal, and miscellaneous chemicals used around the plant, such as air sweeteners. Chemicals associated with sludge treatment are incorporated into sludge costs.
4) sludge - expenditures for digester heating, sludge dewatering chemicals, off-site haulage, contracts for disposal, and where applicable, incineration (fuel) costs.
5) administration and miscellaneous - administrative and support activities related to the daily operation and maintenance of a plant. Other miscellaneous costs included are vehicle maintenance, municipal taxes, insurance premiums, outside service costs for materials and labour, outside laboratory costs and heating (fuel) costs. These costs were often inconsistent from plant to plant.

2.2.4 Pollutant Removal Efficiency. Pollutant removal efficiencies were determined on the basis of annual average influent and effluent concentrations and average daily flows. Biochemical oxygen demand, suspended solids and phosphorus removals were calculated in kilograms removed per day. This information was then used to analyze operational costs for levels of treatment.

2.2.5 Cost Updating Procedures. Cost data in this report are presented in 1980 Canadian dollars. To convert these costs to the present, cost indexes must be used. A cost index is simply a ratio of cost at a given time relative to a specified base time. Because the cost was known for the time these data were collected, the index equivalent cost at the present time can be determined by using the following equation:

$$\text{PRESENT COST} = \text{ORIGINAL COST} \times \frac{\text{INDEX VALUE AT PRESENT TIME}}{\text{INDEX VALUE AT TIME ORIGINAL DATA WERE OBTAINED}}$$

$$\text{PRESENT COST} = \text{ORGINAL COST} \times \text{INDEX RATIO}$$

Several such cost indexes are published regularly. The U.S. Environmental Protection Agency (EPA) prepares a quarterly operation, maintenance and repair index for American wastewater treatment facilities.(1) It is a very complete cost index that includes labour, chemical, power, maintenance, administration and other cost indexes. However, it reflects U.S. price trends, and might not be completely satisfactory for updating Canadian cost data. Some Canadian cost indexes may be used for updating the O & M cost information. These include:

a) Electrical Costs. The Statistics Canada publication, Industry Price Indexes(2), presents a Non-Residential Electric Power Selling Price Index. This index is determined monthly for each province, and on a national basis, and for two different electric demand categories (> 5000 kW and < 5000 kW).

b) Labor Costs. The Statistics Canada monthly publication, Employment, Earnings and Hours(3, 4), presents the results of national wage surveys for several activity sectors. Activity sector no. 576 "Water Systems" appears to provide the best estimate of salaries paid at sewage treatment plants. Although these data are presented in the form of weekly salaries and not in a cost index form (dimensionless data with base year), current and historical data may be used to update wages and salaries in exactly the same manner as cost indexes.

c) Chemical Costs. Cost indexes for a few chemicals such as chlorine and sodium hydroxide are provided in the publication, Industry Price Indexes(2). Another source of chemical cost data would be the Corpus Chemical Report(5), a weekly market letter on Canada's chemical process industries. It contains cost data on chlorine, aluminium sulphate, lime, methanol and other chemicals. Again, these are actual market prices, not cost indexes, but they may be used in the same manner as cost indexes in the updating equation.

d) Sludge Costs. The sludge costs reported in this document include the following:

- sludge dewatering chemical costs,
- digester heating costs,
- incineration (fuel) costs,
- sludge haulage costs.

It is difficult to determine an index that will appropriately describe the effect of inflation on all these costs. However, since all these costs (especially the last three) are affected by fuel costs, the fuel cost indexes in the Statistics Canada publication Industry Price Indexes(2) may be a good approximation.

e) Administrative and Miscellaneous Costs. This is the most diverse cost category, and the one for which appropriate cost index selection is most difficult. An average of the index ratios for the electrical, labour, chemical and sludge costs was considered a reasonable approximation for updating this cost group.

Table 1 presents the updating of the cost data for plant no. 26 from 1980 to 1983 (August). The equivalent total O & M cost for 1983 obtained is \$53.50 per 1000 m^3 of actual flow, an increase of about 25%.

TABLE 1 UPDATING OF COST DATA FOR PLANT NO. 26 (Activated Sludge Plant/Central Region)

Component Cost	1980 Cost $/1000 m^3 Actual Flow	Index Used for Updating	Index Value Component 1980 (Average) (1)	August 1983 (2)	Index Ratio (2)/(1)	1983 Cost $/1000 m^3 Actual Flow
Electrical Costs	5.65	Stats. Canada Electric Power Selling Price Index • Prov: Ontario • Demand < 5000 kW	226.4	290.5	1.283	7.25
Personnel Costs	20.86	Stats. Canada Wage Survey • Activity Sector: Water Systems • Prov: Ontario • Data in $/week	464.3	482.6	1.039	21.67
Sludge Costs	7.25	Stats. Canada Fuel Cost Index	438.8	696.0	1.586	11.50
Chemical Costs	5.88	Stats. Canada Chlorine Cost Index	248.4	376.3	1.515	8.91
Additional Costs	3.10	Average Index Ratio	----	----	1.356	4.20
Total O & M Costs	42.75	----	----	----	----	53.53
Total O & M Costs	42.75	EPA - Operation Maintenance Repair Index for STP'S	2.94	3.61	1.228	52.50

If the U.S. EPA operation and maintenance index for wastewater treatment facilities were used instead, the equivalent calculated total O & M cost for 1983 would be \$52.50 per 1000 m^3 of actual flow, an increase of 23%.

For the sewage treatment plants surveyed in this study, it was estimated that O & M costs for 1983 were an average of 26% higher than those for 1980.

3 SURVEY RESULTS AND FINDINGS

3.1 Regional Breakdown of Plants Surveyed

Table 2 illustrates the distribution of plants surveyed by region and according to plant size. The minimum number of plants surveyed in any one region was 14, in the eastern region. Plants in the 5000 m^3/d to 50 000 m^3/d size range were visited more than any other group; the least surveyed size group was the group in the greater than 50 000 m^3/d category with only seven plant visits. Seven of the plants surveyed in the eastern region did not have actual daily flow information available.

TABLE 2 NUMBER OF PLANTS SURVEYED BY REGION AND SIZE GROUPS

	Region			
Plant Size (m^3/d)	Eastern	Central	Western	Total
< 1000	-	4	1	5
1000 - 5000	1	6	4	11
5000 - 50 000	6	7	9	22
> 50 000	-	3	4	7
N/A*	7	-	-	7
Total	14	20	18	52

* No information available on average daily flow.

The distribution of wastewater treatment plants surveyed by level of treatment is shown in Table 3. Secondary plants were visited more often than other facilities, followed by lagoons and primary plants. Phosphorus removal processes were included at 13 of the plants surveyed, seven of which were secondary systems. Only one of the 13 surveyed plants providing phosphorus removal was located outside of the central region.

3.2 Operational Capacity

3.2.1 Annual Hydraulic Loading. Table 4 presents average O & M costs according to level of treatment and plant size. Costs (1980) are based on dollars per 1000 m^3 of wastewater treated. Table 4 shows that the cost of treating wastewater increases as the level of treatment increases. Excluding all systems treating less than 1000 m^3/d from consideration, facultative lagoons average \$3/1000 m^3, aerated lagoons \$30, primary

TABLE 3 NUMBER OF PLANTS SURVEYED BY REGION AND LEVEL OF TREATMENT

	Region			
Level of treatment*	Eastern	Central	Western	Total
Primary	2	4 (3)	3	9 (3)
Secondary	6	10 (6)	9 (1)	25 (7)
Aerated lagoons	3	3 (1)	3	9 (1)
Facultative lagoons	3	3 (2)	3	9 (2)
Total	14	20 (12)	18 (1)	52 (13)

* Numbers in brackets indicate plants with phosphorus removal.

TABLE 4 AVERAGE O & M COST PER 1000 m^3 TREATED ($/1000 m^3)*

	Level of Treatment			
Plant Size (m^3/d)	Primary	Secondary	Aerated Lagoons	Facultative Lagoons
< 1000	-	222 (n=2)	-	72 (n=3)
1000-5000	38 (n=2)	71 (n=4)	37 (n=3)	4 (n=1)
5000-50 000	49 (n=4)	58 (n=11)	26 (n=5)	2 (n=2)
> 50 000	41 (n=2)	27 (n=4)	-	-
All plants**	44 (n=8)	54 (n=19)	30 (n=8)	3 (n=3)

n = number of plants included in calculation of averages.

$$\text{* Average Cost/1000 m}^3 = \frac{\text{Total Annual Operation and Maintenance Costs}}{\text{Actual Flow (1000 m}^3\text{/d) x 365}}$$

** Plants < 1000 m^3/d excluded; costs in 1980 Canadian dollars.

plants \$44, and secondary plants \$54. If small systems are considered in the averaging, the cost of operating the surveyed facultative lagoons increases to \$32/1000 m^3, while secondary treatment costs rise to \$104/1000 m^3. The former set of costs are probably more representative of average operational costs than the latter.

For all levels of treatment except primary, the average cost per 1000 m^3 of treated sewage decreases as the plant size increases. The exception among the primary plants surveyed was a plant treating greater than 50 000 m^3/d (\$55 per 1000 m^3). Phosphorus removal was practiced at this particular plant. One other primary treatment facility in the same size category, but operating without phosphorus removal processes, was found to have an average O & M cost of \$27 per 1000 m^3 treated.

Figures 1, 2, 3, and 4 are graphical presentations of annual O & M costs versus average daily flows at primary, secondary, aerated lagoon and facultative lagoon facilities respectively. Generally, the figures illustrate that costs increase as the level of treatment progresses from lagoons, to primary, to secondary processes. Secondly, with the exception of primary plants, economies of scale are found because exponents in cost correlations are smaller than one. This means that, as flow rates increase, annual operating costs per unit of flow decrease for secondary plants and aerated lagoons. On the other hand, as flows to primary plants increase, costs per unit flow increase.

3.2.2 Average Daily Flow versus Design Daily Flow. Table 5 summarizes data on the basis of average daily flow versus design daily flow. The data are presented to illustrate the hydraulic operating conditions at the plants surveyed. In this review, a plant is described as being underloaded with respect to flow capacity when the average daily flow is less than 90% of the design daily flow capacity of the plant (i.e. $A/D < 0.9$). With the exception of lagoons, the majority of the plants surveyed were reported as operating in an underloaded state. Twenty-two percent of the plants surveyed were operating within 90% to 110% of the design flow; 7 of the 10 facilities in this category were secondary treatment plants. Twenty-two percent of the facilities were reported to have average daily flows exceeding the design requirements by more than 10%. Lagoons account for 60% of the plants in the overloaded operating condition.

The "National Inventory of Municipal Waterworks and Wastewater Systems"(6) provides inventory information on 74 primary plants, 454 activated sludge (or modified versions of the activated sludge process) systems, 140 aerated lagoons and 586 facultative lagoon facilities. A search of Mundat, the computer-based data management system for the national inventory, revealed that for these facilities, design flow and actual flow information was available for 52 primary, 331 secondary, 68 aerated lagoon and 191

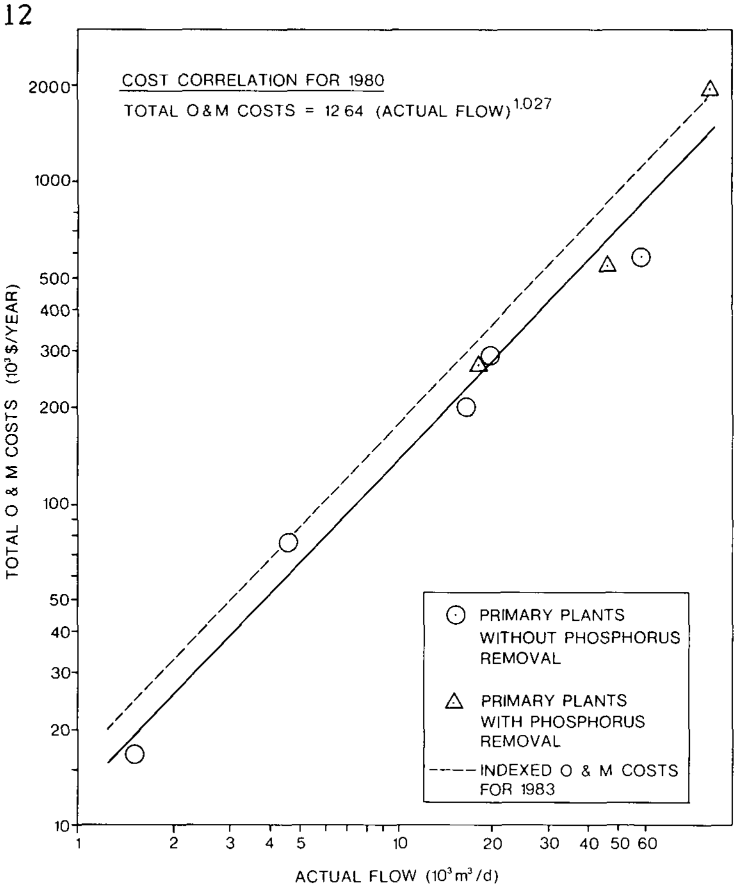

FIGURE 1 O & M COSTS (10^3 \$/YEAR) VERSUS FLOW RATE FOR PRIMARY SEWAGE TREATMENT PLANTS

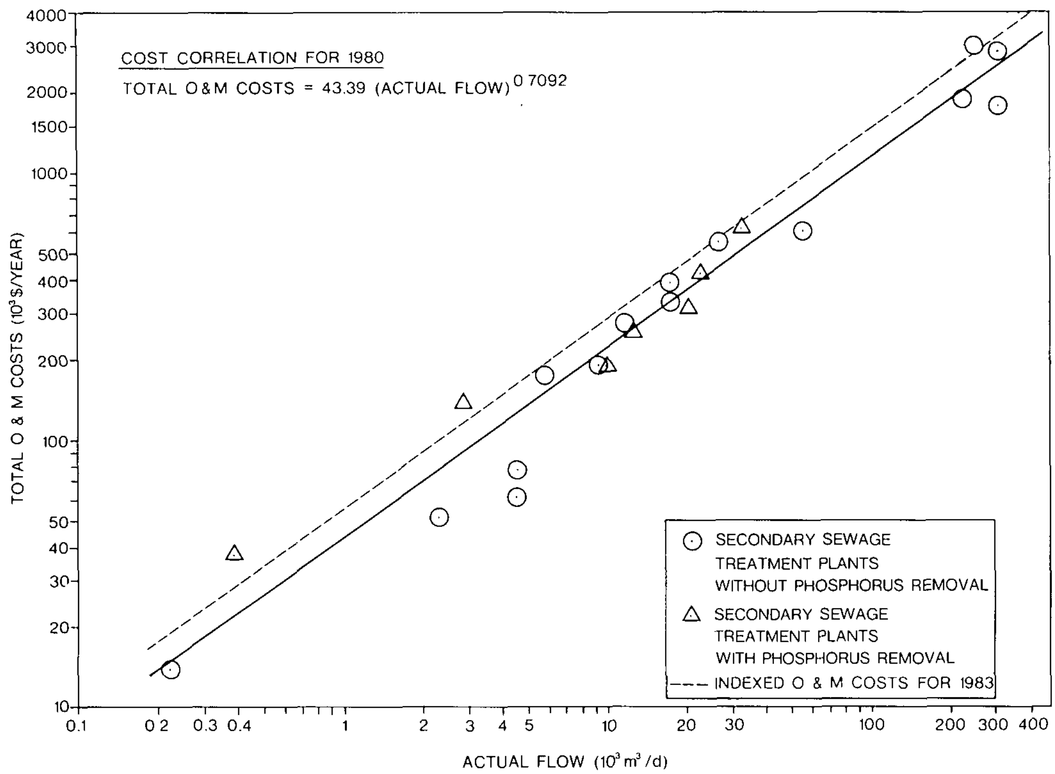

FIGURE 2 O & M COSTS (10^3 \$/YEAR) VERSUS FLOW RATE FOR SECONDARY SEWAGE TREATMENT PLANTS

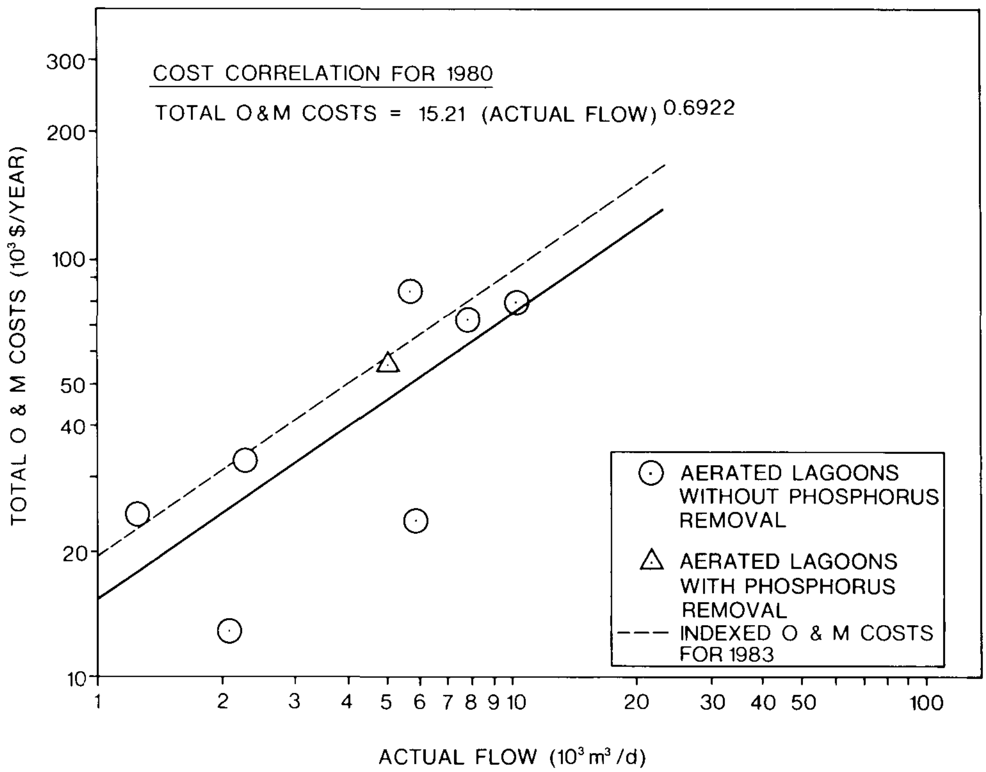

FIGURE 3 O & M COSTS (10^3 \$/YEAR) VERSUS FLOW RATE FOR AERATED LAGOONS

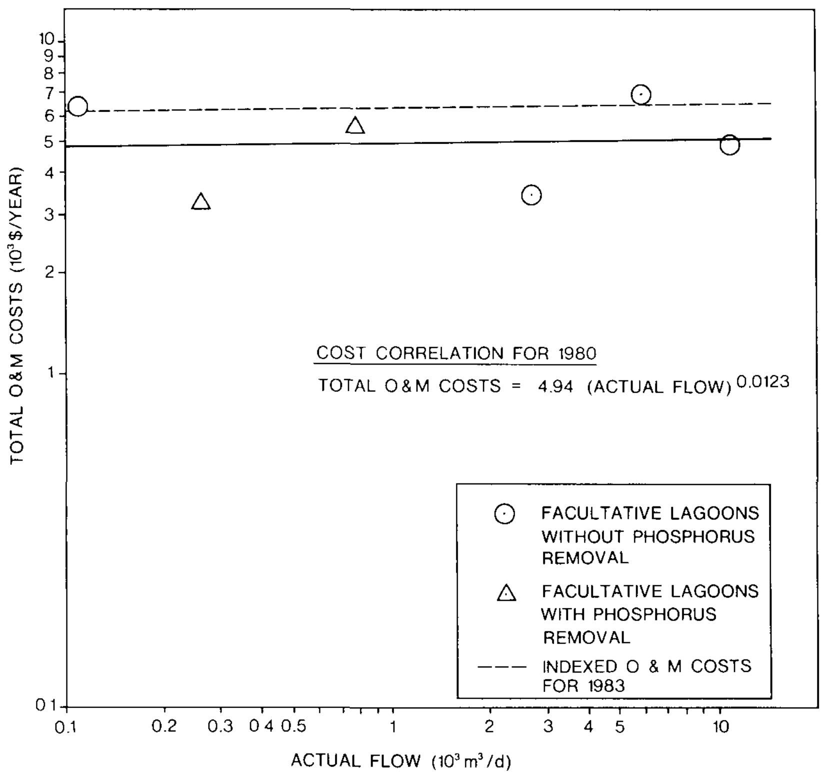

FIGURE 4 O & M COSTS (10^3 \$/YEAR) VERSUS FLOW RATE FOR FACULTATIVE LAGOONS

TABLE 5 HYDRAULIC LOADING CONDITIONS AT SURVEYED FACILITIES (number of plants and their hydraulic operating conditions)*

Plant Type	Hydraulic Underload (A/D<0.9)	Hydraulic Design Load (0.9 >A/D<1.1)	Hydraulic Overload (A/D >1.1)
Primary	5 (63)	1 (12)	2 (25)
Secondary	13 (59)	7 (32)	2 (9)
Aerated lagoon	4 (50)	1 (12)	3 (38)
Facultative lagoon	3 (43)	1 (14)	3 (43)
Totals	25 (56)	10 (22)	10 (22)

* Numbers in brackets represent the percentage of surveyed plant types within a hydraulic operating category.

facultative lagoon facilities (Mundat, 1983). Seventy-one percent of all facilities were being operated at less than 90% of their design flow, 14% were operating within 10% of their design flow, and the remainder were in an overload state. For secondary plants the figures were 73%, 12%, and 15% for underloaded, design and overloaded hydraulic conditions respectively. Thus, while the numbers for this O & M survey do not coincide with Mundat information, the trend toward underloaded conditions appears to be valid.

The impact of hydraulic loading conditions on operational costs at sewage treatment facilities may be examined by comparing Table 4 data with data in Table 6. The average cost for operating an activated sludge plant, based on a 19-plant survey and disregarding plant capacities less than 1000 m^3/day, was $54 per 1000 m^3 of wastewater treated (Table 4). Costs associated with six plants in this same survey operating at design hydraulic conditions were $46 per 1000 m^3 (Table 6). Eleven of the plants were hydraulically underloaded at the time of the survey and were costing an average of $60 per 1000 m^3 to operate; two plants in a hydraulically overloaded condition were costing $46 per 1000 m^3. From these data it is apparent that plants operating at less than their design capacity have higher unit operating costs than plants treating wastes at or near design flows. Cost data on primary plants and lagoons are quite limited and trends are not so obvious. For example, the survey showed that the average cost for primary plant operation was $44 per 1000 m^3 of sewage treated (Table 4). Table 6 indicates that these costs for primary treatment are skewed to the hydraulic overload condition, in contrast to cost information for secondary plants. The raw data in the appendix indicate that the two primary plants in the overload condition also provide phosphorus removal. This additional

TABLE 6 AVERAGE COST PER 1000 m^3 TREATED BY OPERATIONAL CAPACITY (1980 Canadian $/1000 m^3)

Ratio of Actual Flow to Design Flow	Level of Treatment		Lagoons	
	Primary	Secondary	Aerated	Facultative
A/D <0.9	40 (n=5)	60 (n=11)	31 (n=4)	-
0.9 <A/D <1.10	31 (n=1)	46 (n=6)	54 (n=1)	3 (n=1)
A/D >1.10	61 (n=2)	46 (n=2)	21 (n=3)	2 (n=2)

process may influence an increase in operational costs compared to costs of other primary plants in the same size category without phosphorus removal processes. Aerated lagoon cost trends for underloaded versus overloaded facilities are consistent with the information on secondary plants in Table 6.

3.3 Component Costs

The analysis of total O & M costs on the basis of five budgetory categories is presented in Tables 7, 8, 9 and 10. Electrical, personnel, sludge handling, chemical and administration and miscellaneous cost components are examined according to process-type and flow range and are defined as being a percentage of the total annual O & M cost. Data presented in these tables are averages. Definitions of the cost categories are as outlined in Section 2 of this report.

From the tables it is clear that personnel costs are the major fraction of operating expense for all sizes of primary and secondary plants and facultative lagoons. Typically, wages and benefits for operating and supervisory personnel accounted for 40% to 50% of the total operational cost. On the other hand, aerated lagoon systems experienced personnel costs in the 20% to 40% range.

The cost for electrical power in a secondary sewage treatment operation ranged from 20% to 30% of the total annual expenditure. This compares to a 5% to 10% range for primary plants and a 40% to 45% range for aerated lagoons. Power consumption, and the associated electrical costs, followed no discernible trend that could be associated with plant flow. The combined influence of plants operating at flow capacities outside their design range and inconsistencies in operational characteristics among plants of the same process-type could be the reason for the lack of correlation.

Costs associated with the treatment and disposal of sludges were reported for primary and secondary treatment facilities. Of the nine primary plants surveyed, only

TABLE 7 COMPONENT O & M COSTS (% of total O & M) FOR PLANTS WITH ACTUAL FLOWS LESS THAN 1000 m^3/d

Level of Treatment	No. of Plants	Components Costs (% of Total O&M Costs)				
		Electrical	Personnel	Sludge	Chemical	Administrative
Primary	--	--	--	--	--	--
Secondary	2	22	54	2	5	16
Aerated Lagoons	1	41	23	0	0	35
Facultative Lagoons	4	0	47	0	35	18

TABLE 8 COMPONENT O & M COSTS (% of total O & M) FOR PLANTS WITH ACTUAL FLOWS 1000 to 5000 m^3/d

Level of Treatment	No. of Plants	Components Costs (% of Total O&M Costs)				
		Electrical	Personnel	Sludge	Chemical	Administrative
Primary	2	10	57	0	2	32
Secondary	6	29	34	3	8	26
Aerated Lagoons	3	39	43	0	0	18
Facultative Lagoons	1	0	82	0	0	18

four plants identified budgetary expenditures in this category. Three of those plants were medium-sized (i.e., 5000 to 50 000 m^3/d), for which sludge processing represented an average of 6% of the total annual O & M budget. The fourth plant, with a flow of greater than 50 000 m^3/d and with a P-removal process, had a significantly higher budget expenditure for sludge processing (i.e., 27%). With secondary plants, the proportion of sludge handling costs ranged from 2% to 11%. Budgetary allocations to sludge handling increased with plant size, i.e., in the 1000 m^3/d plants costing was a minimum at 2%, whereas in the large facilities (greater than 50 000 m^3/d) the average was 11%. Five of 24 secondary facilities did not report sludge costs.

TABLE 9 COMPONENT O & M COSTS (% of total O & M) FOR PLANTS WITH ACTUAL FLOWS 5000 to 50 000 m^3/d

Level of Treatment	No. of Plants	Components Costs (% of Total O&M Cost)				
		Electrical	Personnel	Sludge	Chemical	Administrative
Primary	5	8	37	4	11	40
Secondary	11	18	48	9	6	20
Aerated Lagoons	5	44	23	0	12	21
Facultative Lagoons	2	12	24	0	2	63

TABLE 10 COMPONENT O & M COSTS (% of total O & M) FOR PLANTS WITH ACTUAL DAILY FLOWS GREATER THAN 50 000 m^3/d

Level of Treatment	No. of Plants	Components Costs (% of Total O&M Cost)				
		Electrical	Personnel	Sludge	Chemical	Administrative
Primary	2	5	50	13	14	19
Secondary	5	21	55	11	2	12
Aerated Lagoons	0	--	--	--	--	--
Facultative Lagoons	0	--	--	--	--	--

The fraction of annual operating costs that may be attributed to the purchase of chemicals is presented in Tables 7 through 10. For secondary systems in the 5000 m^3/d to 50 000 m^3/d flow range with P-removal processes, a five-plant average for chemical costs was 10% of the total annual operating cost; six plants in this same flow range, but without P-removal processes, had an average chemical cost of 2%. Two primary plants in the 5000 to 50 000 m^3/d flow range with P-removal utilized an average of 26% of their operating budget for chemical purchase; two similar-sized primary plants without P-removal had chemical costs that averaged 2% of their operating expenditures. Three small facultative lagoons employed chemicals, presumably for disinfection and/or P-removal purposes. The costs represented a significant portion (35%) of the total operating budget.

The budget category "Administrative and Miscellaneous Costs" showed that in general the fractional cost decreased as plant size increased.

3.4 Pollutant Removal Costs

Operating costs are analyzed on the basis of BOD, SS and P removals at surveyed plants and presented in Tables 11, 12 and 13.

In Table 11, costs associated with BOD removal are shown for primary, secondary and lagoon facilities. Primary plants have high unit costs for BOD removal, compared to the secondary plants and lagoon processes. Although the data base for primary plants is small, the results of this analysis appear quite reasonable. Primary treatment processes are designed and operated principally for the removal of solids. Any BOD removal that occurs as a result of this process is a function of the solids association.

Secondary plants exhibit the next highest average BOD removal costs, followed by lagoon facilities. Again, these relative costs may be expected given the greater complexity of secondary facilities (and thus operating requirements) compared to lagoon systems.

Table 12 presents pollutant removal costs as they relate to suspended solids. These data illustrate a similar trend to that seen in Table 11. Disregarding plant size, SS removal cost appears to be least for lagoon systems. Primary facilities represent the highest operational costs with respect to removal of this pollutant, followed closely by secondary facilities. Secondary plants in the 5000 to 50 000 m^3/d flow range are indicated as the most expensive facilities to operate for SS removal. A larger sampling of plants in the various flow ranges is required to confirm these results.

Table 13 summarizes average costs for P-removal at the various treatment facilities. No distinction can be made between plants with P-removal processes and plants where P-removal occurs as a function of solids removal or biological processes. Aerated lagoons have the highest average cost per kilogram P removed ($23) followed by primary plants ($20), secondary plants ($16), and facultative lagoons ($2).

3.5 Per Capita Operating Costs

Table 14 presents average costs per capita for operating various types of treatment processes at various flow ratings. In general, secondary plants, with the most complex treatment processes, are presented as the most expensive to operate on a per capita basis at $10. Primary plants at $9 per capita, aerated lagoons at $8 per capita, and

TABLE 11 AVERAGE COST PER kg BOD REMOVED (1980 Canadian $/kg BOD removed)

Flow Category (m^3/d)	Primary	Secondary	Aerated Lagoons	Facultative Lagoons
< 1000	-	4.00 (n=1)	-	0.18 (n=2)
1000-5000	0.54 (n=2)	0.50 (n=3)	0.12 (n=3)	0.05 (n=1)
5000-50 000	0.61 (n=4)	0.47 (n=11)	0.23 (n=5)	0.13 (n=1)
> 50 000	0.53 (n=2)	0.20 (n=5)	-	-
All plants*	0.57 (n=8)	0.40 (n=19)	0.19 (n=8)	0.09 (n=2)

*Plants < 1000 m^3/d excluded.
n = number of plants included in calculation of average.

TABLE 12 AVERAGE COST PER kg SS REMOVED (1980 Canadian $/kg SS removed)

Flow Category	Primary	Secondary	Aerated Lagoons	Facultative Lagoons
< 1000	-	3.00 (n=1)	-	0.17 (n=2)
1000-5000	0.37 (n=1)	0.28 (n=3)	0.30 (n=3)	0.07 (n=1)
5000-50 000	0.31 (n=4)	0.44 (n=9)	0.10 (n=3)	0.09 (n=1)
> 50 000	0.36 (n=2)	0.14 (n=5)	-	-
All plants*	0.33 (n=7)	0.32 (n=17)	0.20 (n=6)	0.08 (n=2)

*Plants < 1000 m^3/d excluded.
n = number of plants included in calculation average.

TABLE 13 AVERAGE COST PER kg P REMOVED (1980 Canadian $/kg P removed)

Flow Category	Primary	Secondary	Aerated Lagoons	Facultative Lagoons
< 1000	-	84 (n=1)	-	5 (n=2)
1000-5000	20 (n=1)	14 (n=2)	29 (n=2)	1 (n=1)
5000-50 000	24 (n=2)	22 (n=6)	17 (n=2)	2 (n=1)
> 50 000	16 (n=2)	8 (n=4)	-	-
All plants*	20 (n=5)	16 (n=12)	23 (n=4)	2 (n=2)

*Plants < 1000 m^3/d excluded.
n = number of plants included in calculation of averages.

TABLE 14 AVERAGE COST PER CAPITA (1980 Canadian $/capita/annum)

Flow Category (m^3/d)	Primary	Secondary	Aerated Lagoons	Facultative Lagoons
< 1000	-	45 (n=2)	-	13 (n=3)
1000-5000	9 (n=2)	11 (n=6)	11 (n=2)	1 (n=1)
5000-50 000	9 (n=4)	11 (n=11)	7 (n=5)	1 (n=2)
> 50 000	10 (n=2)	7 (n=5)	-	-
All plants*	9 (n=8)	10 (n=22)	8 (n=7)	1 (n=3)

*Plants < 1000 m^3/d excluded.
n = number of plants included in calculation of averages.

facultative lagoons at $1 per capita follow secondary plants in this analysis. Further, on a per capita basis, the smaller plants appear to be more costly to operate than larger plants of the same process type. The exception to this trend is the primary plant category. Per capita costs for primary plants were $9 and $10 for the plants surveyed. A larger sample group should be surveyed in order to verify these results.

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APPENDIX

Raw Data on Wastewater Treatment Plants

TABLE A.1 TREATMENT PLANTS LISTED BY LEVEL OF TREATMENT

Plant No.	Region	Phosphorus Removal	Design Flow $10^3 m^3/d$	Actual Flow $10^3 m^3/d$	% Design Flow	Total Annual O & M Costs (1980 Canadian $) $/1000 m^3 Design Flow	$/1000 m^3 Actual Flow	$10^3$$/year
Primary Treatment Plants								
14	C	--	1.64	1.50	91	28.00	30.62	16.76
16	W	--	5.16	4.55	88	40.58	46.02	76.43
13	E	--	22.72	16.36	72	24.32	33.77	201.7
4	C	Yes	13.64	18.15	133	54.96	41.30	273.6
34	W	--	27.28	19.55	72	29.07	40.56	289.4
19	C	Yes	36.37	46.38	128	41.24	32.33	547.3
3	W	--	90.92	59.1	65	17.60	27.08	584.2
37	C	Yes	109.11	97.29	89	48.94	54.89	1949
11*	E	--	5.71	--	--	12.72	--	26.51
Secondary Treatment Plants								
53	C	--	0.45	0.22	49	86.04	175.99	14.13
1	C	Yes	0.50	0.39	78	209.14	268.13	38.17
42	W	--	2.29	2.30	100	63.48	63.20	53.06
41	C	Yes	3.64	2.86	79	106.55	135.61	141.6
45	W	--	2.95	4.54	150	57.45	37.33	61.86
47	C	--	6.82	4.55	67	31.76	47.61	79.07
38	W	--	7.00	5.75	82	70.73	86.11	180.7
6	E	--	9.46	9.46	100	56.38	56.38	194.7
36	W	Yes	8.18	9.72	119	65.55	55.16	195.7
39	E	--	13.63	11.73	86	56.16	65.26	279.4
9	C	Yes	13.64	12.55	92	52.27	56.81	260.2
52	W	--	22.73	17.25	76	40.32	53.13	334.5
44	E	--	22.72	17.41	76.6	47.86	62.46	396.9
26	C	Yes	27.28	20.52	75	32.15	42.75	320.2
31	C	Yes	29.55	22.65	77	40.09	52.31	432.5
40	W	--	29.51	26.5	90	51.99	57.90	560.0
17	C	Yes	61.37	32.51	53	28.18	53.20	631.3
50	C	--	68.19	56.01	82	25.00	30.44	622.3
28	W	--	250.00	225	90	21.34	23.71	1947
20	C	--	409.15	245.58	50	20.36	33.92	3040
29	W	--	313.26	302.73	96.6	25.43	26.32	2908
12	W	--	295.1	303.81	103	17.00	16.51	1831
43*	E	--	1.14	--	--	46.17	--	19.21
21*	E	--	2.27	--	--	24.00	--	19.89
25*	E	--	7.56	--	--	--	--	--
Aerated Lagoons								
8	C	--	1.27	1.25	98	53.36	54.22	24.74
48	C	--	5.46	2.07	38	6.48	17.10	12.92
27	E	--	13.57	2.27	23	6.72	40.17	33.28
30	C	Yes	4.54	5.06	111	34.17	30.66	56.63
51	E	--	11.35	5.68	50	20.48	40.92	84.84
22	W	--	4.54	5.86	130	14.41	11.17	23.89
23	W	--	10.28	7.88	80	19.39	25.29	72.74
5	W	--	6.82	10.23	150	32.07	21.38	79.83
33*	E	--	0.57	--	--	32.51	--	6.76
Facultative Lagoons								
10	W	--	0.07	0.11	160	255.95	162.88	6.54
15	C	Yes	0.73	0.26	36	12.33	34.62	3.29
35	C	Yes	0.98	0.78	80	15.69	19.72	5.61
49	C	--	2.39	2.72	114	3.99	3.51	3.48
32	W	--	6.36	5.91	93	3.02	3.25	7.01
18	E	--	0.73	11.36	1600	18.83	1.21	5.02
2*	E	--	0.20	--	--	--	--	--
46*	E	--	0.32	--	--	4.04	--	0.47
7*	W	--	3.64	1.59	44	--	--	--

*Plants with incomplete data

TABLE A.2 TREATMENT PLANTS AND THEIR COMPONENT COSTS (1980 Canadian $)

Plant	Region	Pop. Served 10^3	Electrical Costs $/1000 m^3 Actual Flow	Electrical Costs % Total	Personnel Costs $/1000 m^3 Actual Flow	Personnel Costs % Total	Sludge Costs $/1000 m^3 Actual Flow	Sludge Costs % Total	Chemical Costs $/1000 m^3 Actual Flow	Chemical Costs % Total	Additional Costs $/1000 m^3 Actual Flow	Additional Costs % Total
Primary Treatment Plants												
14	C	2.2	3.20	10.5	20.84	68.1	0.0	0.0	0.0	0.0	6.58	21.5
16	W	8.0	4.19	9.1	20.81	45.2	0.0	0.0	1.81	3.9	19.21	41.7
13	E	30.0	2.38	7.0	18.15	53.7	0.0	0.0	0.0	0.0	13.24	39.2
4	C	28.6	3.58	8.7	16.58	40.1	4.88	11.8	14.65	35.5	1.60	3.9
34	W	40.0	4.46	11.0	20.74	51.1	0.60	1.5	0.0	0.0	14.76	36.4
19	C	49.0	0.74	2.3	8.65	26.8	1.82	5.6	5.20	16.1	15.93	49.3
3	W	135.7	1.29	4.8	17.79	65.7	0.0	0.0	2.27	8.4	5.73	21.2
37	C	130.0	2.68	4.9	18.82	34.3	14.52	26.5	10.25	18.7	8.61	15.7
11*	E	4.0	1.14**	9.0	1.84**	14.5	0.0**	0.0	0.53**	4.2	9.21**	72.4
Secondary Treatment Plants												
53	C	0.3	55.73	31.7	89.21	50.7	0.00	0.0	3.66	2.1	27.40	15.6
1	C	0.9	32.30	12.0	155.31	57.9	12.32	4.6	22.47	8.4	45.73	17.1
42	W	5.7	26.13	41.3	22.15	35.0	0.00	0.0	0.00	0.0	14.93	23.6
41	C	7.1	27.39	20.2	59.52	43.9	16.28	12.0	19.29	14.2	13.12	9.7
45	W	4.5	4.21	11.3	11.18	29.9	0.33	0.9	1.60	4.3	20.01	53.6
47	C	6.7	15.99	33.6	22.59	47.4	2.82	5.9	0.66	1.4	5.56	11.7
38	W	15.0	19.27	22.4	63.57	73.8	2.19	2.5	0.00	0.0	1.07	1.2
6	E	30.0	5.27	9.3	23.28	41.3	4.94	8.8	2.03	3.6	20.85	37.0
36	W	22.0	5.46	9.9	33.44	60.6	1.67	3.0	1.86	3.4	12.72	23.1
39	E	25.0	15.46	23.7	21.67	33.2	1.51	2.3	2.29	3.5	24.33	37.3
9	C	32.0	6.69	11.8	21.58	38.0	12.58	22.1	5.71	10.1	10.26	18.1
52	W	50.0	16.87	31.8	28.00	52.7	0.00	0.0	1.20	2.3	7.05	13.3
44	E	41.4	19.09	30.6	21.78	34.9	14.84	23.8	0.52	0.8	6.23	10.0
26	C	26.5	5.65	13.2	20.86	48.8	7.25	17.0	5.88	13.8	3.10	7.3
31	C	45.0	6.71	12.8	28.40	54.3	0.25	0.5	6.36	12.2	10.58	20.2
40	W	21.0	9.90	17.1	36.67	63.3	0.82	1.4	0.83	1.4	9.67	16.7
17	C	59.7	7.35	13.8	16.83	31.6	8.02	15.5	4.83	9.1	16.16	30.4
50	C	85.0	10.75	35.3	11.05	36.3	5.11	16.8	0.67	2.2	2.85	9.4
28	W	365.0	5.20	21.9	12.01	50.7	3.27	13.8	0.86	3.6	2.37	10.0
20	C	360.0	4.58	13.5	19.31	56.9	3.77	11.1	0.36	1.1	5.90	17.4
29	W	400.0	7.07	15.5	17.76	67.5	1.44	5.5	0.27	1.0	2.79	10.6
12	W	425.2	2.90	17.6	10.19	61.7	1.10	6.7	0.02	0.1	2.30	13.9
43*	E	2.5	20.42**	44.2	12.65**	27.4	0.00**	0.0	8.41**	18.2	4.69**	10.2
21*	E	3.2	5.48**	22.8	5.44**	22.7	0.00**	0.0	2.40**	10.0	10.68**	44.5
25*	E	75.8	--	--	98.94**	--	0.00**	0.0	0.00**	--	2.17**	--
Aerated Lagoons												
8	C	1.4	27.51	50.7	22.01	40.6	0.0	0.0	0.0	0.0	4.69	8.6
48	C	3.8	0.21	1.2	13.63	79.7	0.0	0.0	0.0	0.0	3.26	19.1
27	E	0.2	26.21	65.2	3.95	9.8	0.0	0.0	0.0	0.0	10.01	24.9
30	C	5.0	8.98	29.3	11.03	36.0	0.0	0.0	6.78	22.1	3.87	12.6
51	E	6.5	12.58	30.7	17.10	41.8	0.0	0.0	5.16	12.6	6.09	14.9
22	W	9.3	5.88	52.6	1.62	14.5	0.0	0.0	0.47	4.2	3.20	28.6
23	W	30.0	15.83	62.6	4.52	17.9	0.0	0.0	0.0	0.0	4.94	19.5
5	W	13.5	9.10	42.6	0.63	2.9	0.0	0.0	4.95	23.2	6.70	31.3
33*	E	1.4	13.41**	41.2	7.61**	23.4	0.0**	0.0	0.0**	0.0	11.49**	35.3
Facultative Lagoons												
10	W	0.2	0.0	0.0	68.74	42.2	0.0	0.0	25.89	15.9	68.24	41.9
15	C	0.8	0.0	0.0	9.65	27.9	0.0	0.0	18.02	52.1	6.95	20.1
35	C	1.7	0.0	0.0	3.60	18.3	0.0	0.0	14.01	71.0	2.11	10.7
49	C	6.3	0.0	0.0	2.88	82.1	0.0	0.0	0.0	0.0	0.62	17.7
32	W	14.0	0.0	0.0	0.75	23.1	0.0	0.0	0.0	0.0	2.50	76.9
18	E	2.8	0.28	23.1	0.30	24.8	0.0	0.0	0.04	3.3	0.60	49.6
2*	E	0.9	0.0**	--	--	--	0.0**	--	0.0**	--	2.74**	--
46*	E	0.9	0.0**	0.0	4.04**	100	0.0**	0.0	0.0**	0.0	0.0**	0.0
7	W	5.1	--	--	0.87	--	0.0	--	0.0	--	0.65	--

* Design flow only (10^3 m^3/d)
** $/1000 m^3 design flow