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# Advanced Wastewater Treatment Technology in Canada (1979)



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Economic and Technical Review  
Report EPS 4-WP 79-5

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August 1979

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ADVANCED WASTEWATER TREATMENT TECHNOLOGY IN CANADA (1979)

by

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## ABSTRACT

Information is presented on the use of Advanced Wastewater Treatment (AWT) technology in Canada for the treatment of municipal wastewaters. AWT in the Canadian context is defined, specific requirements for the application of AWT are identified, and examples of the systems in use are described. In addition, Canadian pilot scale research and development efforts of recent years are discussed.

Specific applications dealt with are the use of AWT for phosphorus removal, nitrogen conversion and removal, post filtration for BOD<sub>5</sub> and suspended solids removal, studies on the use of ozone, reverse osmosis and the physical-chemical treatment of municipal wastewaters.

In Canada, different approaches to AWT have been taken to resolve specific problems. The principal applications are physical-chemical treatment for phosphorus removal at over 140 mechanical plants, mainly in the Province of Ontario. The most popular method for phosphorus removal is accomplished by "in plant" modifications to existing treatment systems. Effluent filtration to meet more stringent BOD<sub>5</sub> and SS effluent criteria is practiced at a limited number of Canadian plants.

## RESUME

Cet ouvrage fournit des renseignements sur l'utilisation de techniques de pointe pour l'épuration des eaux usées municipales au Canada. On y trouve une définition de ces techniques dans un contexte canadien, les conditions spécifiques de leur application, et des exemples de systèmes couramment utilisés. Les efforts de recherche et de développement effectués ces dernières années, à titre de projets pilotes canadiens, y sont examinés.

Les applications spécifiques traitées comprennent la déphosphatation, la transformation et l'élimination de l'azote, la postfiltration en vue d'éliminer la DBO<sub>5</sub> et les matières en suspension, les études sur l'utilisation de l'ozone, l'exosmose et le traitement physico-chimique des eaux usées municipales.

Au Canada, ces techniques ont été utilisées de diverses façons pour résoudre des problèmes précis. Ainsi, dans plus de 140 installations mécaniques situées pour la plupart en Ontario, la déphosphatation est effectuée grâce à des traitements physico-chimiques. La méthode retenue consiste à apporter des modifications "sur mesure" au dispositif d'épuration de l'installation. Un petit nombre d'installations filtrent les effluents de façon à satisfaire à des critères plus stricts touchant la DBO<sub>5</sub> et les matières en suspension.

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## 1 INTRODUCTION

The purpose of this report is to present information on the use of Advanced Wastewater Treatment (AWT) technology in Canada for the treatment of municipal wastewaters.

This report is intended to define AWT in the Canadian context, identify specific requirements for the application of AWT, and provide some examples of the types of systems used in Canada. In addition, some of the considerable amount of pilot scale AWT research and development efforts undertaken in Canada in recent years are discussed. The most extensive use of AWT technology is for the removal of the nutrient phosphorus; several hundred plants in Canada currently have this capability. There are considerably fewer examples of the uses of AWT technology to remove other constituents - principally BOD<sub>5</sub> and suspended solids.

1.1 AWT Defined

One definition of AWT technology is "...any treatment process or combination of processes not currently employed (or employed rarely) at operational wastewater treatment works..." (Best and Banks, 1978).

The author's preference is, however, to define AWT in terms of the ability of a particular system to remove specific wastewater constituents to levels not normally achieved by conventional biological treatment systems. The performance data for an AWT system (or systems) are set out in Table 1 and compared to the typical effluent from a reasonably well-operated activated sludge (AS) sewage treatment plant.

TABLE 1. PERFORMANCE DATA FOR AN AWT SYSTEM

Parameter	Effluent Quality	
	AWT Technology mg/L	AS Plant mg/L
BOD <sub>5</sub>	<5	15
Suspended Solids	<5	15
Phosphorus (as P)	<1	3-11
Total Nitrogen (as N)	5	9-20

The AWT effluent concentrations shown cannot be achieved even in a well-run standard activated sludge sewage treatment plant. However, these values might be obtained with in-plant modification, process changes, with tertiary treatment unit operations, or with changes in operating strategies.

## 1.2 The Need for AWT

Within the past decade a number of water quality studies on lakes and river systems in Canada have been completed (IJC, 1970; Canada Water Year Book, 1976; Salbach, 1976). One of the main problems identified has been cultural or man-made eutrophication caused by enrichment of water with nutrients derived from human activities. Principal nutrients involved are compounds of phosphorus and nitrogen derived primarily from municipal sewage and, to a lesser extent, from drainage of urban areas, and agricultural and other rural land use areas. Some of the symptoms of eutrophication are blooms of planktonic algae or excessive growths of aquatic weeds and filamentous attached algae, drinking water quality problems, ruined bathing areas and depleted dissolved oxygen levels in affected waters. Additional problems have been described in the reports mentioned previously.

Several examples of problem areas and the actions taken or contemplated will be used to illustrate Canadian concerns for water quality degradation resulting from man's activities. Figure 1 is a map of Canada indicating the particular watersheds or lakes to which reference will be made.

### 1.2.1 Okanagan Basin - British Columbia (B.C.)

The Okanagan Basin, in the heart of British Columbia, is noted for its mild climate and beautiful lakes. The basin is a prime tourist and retirement area although it also has a reasonable industrial base. In 1971, the population was 114 500.

For many years there were problems with water quantity and by the mid 1960's deterioration in water quality was evident. In response, detailed water management studies were carried out from 1969 to 1974.

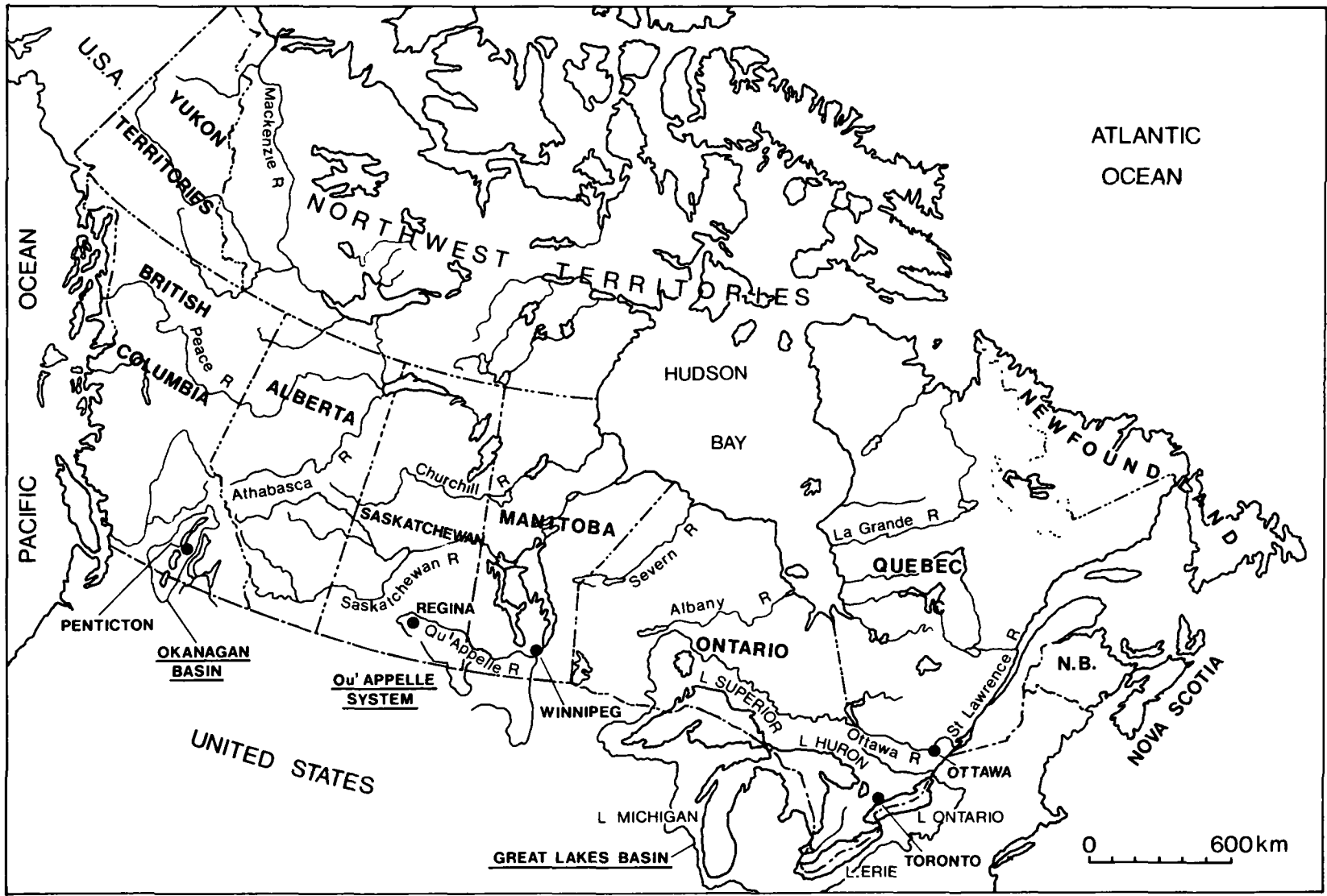


FIGURE 1. CANADIAN WATERSHEDS

Implementation of the recommended measures was to be undertaken between 1976 and 1981 (Canada Water Year Book, 1976).

Most streams in the basin had at least one constituent, such as colour, turbidity, phosphorus, nitrogen, or coliforms whose concentration exceeded acceptable health standards for drinking water. Varying degrees of nutrient enrichment, resulting in aquatic plant and algal growth, existed in all of the bottom valley lakes. The major sources of these nutrients were tributary streams and municipal outfalls, but septic tank systems and agricultural runoff were also adversely affecting local shoreline areas. Phosphorus was identified as the nutrient which could be most successfully controlled to limit algal and aquatic plant growth.

The removal of phosphorus through advanced waste treatment processes was considered the most effective means to control aquatic plant and algal growth in the main valley lakes and provide maximum recreational and aesthetic benefits. The location of outfall discharges and green belts in combination with phosphorus removal was also to be considered in the long term management of water quality in these lakes. The removal of 80% of the phosphorus by chemical treatment or spray irrigation of some municipal effluents was recommended (Canada Water Year Book, 1976). Subsequently, phosphorus removal was implemented at two plants and spray irrigation at a third plant.

#### 1.2.2 Qu'Appelle River Basin - Saskatchewan

The Qu'Appelle River Basin in eastern Saskatchewan and part of Manitoba encompasses an area of 51 800 square kilometres (20 000 square miles), with agriculture (wheat) being the most important industry. It is one of the major watersheds in southern Saskatchewan.

A water management study was carried out from August 1970 to March 1972 because of the importance of this river system to the region. The principal water quality problems in the Qu'Appelle basin were the highly eutrophic condition of the lakes, and the low dissolved oxygen levels in some parts of the system. To a large extent, these problems reflected the amount and nature of nutrients discharged into the system.

Phosphorus, nitrogen and carbon are the major nutrients which support the growth of algae in water bodies. The concentrations of

phosphorus and nitrogen required to support algal growth are exceeded in all Qu'Appelle basin lakes, and the levels of total organic carbon are also more than adequate to support abundant growths.

The majority of urban centres in the basin with sewage treatment systems dispose of their effluent in tributaries of the Qu'Appelle River. Nearly 70% of the total amount of phosphorus and nitrogen in the water originates from municipal sewage systems; the City of Regina, the provincial capital, contributes 56%, and the city of Moose Jaw 13% of the total amounts. The remainder is derived from other sources such as eroded soils, agricultural wastes and groundwater.

Under the terms of the implementation agreement (1975 to 1985) wastewater treatment facilities were to be constructed at Moose Jaw, Regina, and other urban centres. The City of Regina has implemented a phosphorus removal system, which is described later in this report.

### 1.2.3 Great Lakes System - Ontario

One-third of Canada's population lives within the Great Lakes - St. Lawrence River watershed. In the United States, some 30 million people share the same waters for drinking, recreation, commerce and wastewater disposal.

After a six-year study, initiated in 1964, the International Joint Commission described the conditions of Lakes Erie and Ontario as follows:

"On the basis of a collective evaluation of the foregoing categories (physical, chemical and biological parameters), it is obvious that the western basin of Lake Erie is eutrophic; the central basin moderately eutrophic, and the eastern basin mesotrophic with some oligotrophic characteristics. Lake Ontario is presently in a stage between oligotrophy and mesotrophy."

The cause was attributed to phosphorus, principally from sewage effluents, and to a lesser extent non-point sources. Up to 50% of the phosphorus in effluents was attributed to detergents (IJC, 1970).

Further evidence of the deteriorated condition of Lake Erie was provided by the Joint Canada-United States "Project Hypolimnion" (Burns and Ross, 1971). This intensive study of the hypolimnion of the central basin

of Lake Erie, in 1970, showed that the area of complete oxygen depletion by the end of the summer reached an extent of 6000 sq km or 40% of the whole central basin. The major cause of the oxygen depletion was attributed to massive algal blooms, which were still found to be phosphorus-limited, and which sank to the bottom consuming the available oxygen in the decay process.

Subsequent to the studies on Lakes Erie and Ontario, studies were conducted on Lakes Huron and Superior. These have been completed and recommendations have been made for controlling phosphorus inputs because of identified and potential eutrophication problems (Upper Lakes Reference Group, 1976).

In addition to problems in the Great Lakes, Ontario had, through previous studies, identified eutrophication as a serious problem and recognized the need for phosphorus control on the Ottawa River system and many inland recreational lakes (Van Fleet, 1973).

A specific study on the Thames River watershed, initiated in 1972, identified that impairment of surface water quality was caused primarily by excessive inputs of nutrients, oxygen consuming materials (carbonaceous and nitrogenous), bacteria and suspended solids (Salbach, 1976). Major sources included sewage treatment plant effluents, storm and combined sewer discharges, surface runoff from fertilized fields, drainage from intensive feedlot operations and other land use sources.

In summary, a significant need has been identified in Canada for AWT technology for phosphorus removal, and to a much lesser extent for reduction of oxygen consuming components of wastewaters through reducing carbon (BOD), suspended solids, and the conversion of nitrogen (nitrification) in wastewater discharges.



## 2 PHOSPHORUS - THE APPROACH TO CONTROL AND THE DEVELOPMENT OF AWT

### 2.1 The Challenge

To meet the challenge of phosphorus removal nationally, Canada opted for a double-pronged attack combining legislation and technology development to reduce phosphorus concentrations in wastewater discharges. Thus, the Canadian Government, under the provisions of the Canada Water Act (1970), legislated a policy calling for a staged reduction in the phosphorus content of detergents to a limit of 20%, by weight as  $P_2O_5$ , by August, 1970, and 5% by December 31, 1972. Establishment and support of the framework for the development of technical means to reduce the nutrient content of municipal wastewater discharges to the Great Lakes system was recognized as a joint Federal-Provincial responsibility.

### 2.2 The Ontario Scene

In August, 1971, the Federal government and the government of Ontario reached an agreement to ensure that the water quality of the Great Lakes would be restored and protected. The "Canada-Ontario Agreement on Great Lakes Water Quality" was signed in response to the recommendations of the IJC (IJC, 1970) and in anticipation of the Canada-U.S. Agreement on Great Lakes Water Quality (Anon, 1972), which called for an effluent objective of 1 mg/L total phosphorus from municipal sewage treatment plants. Under the terms of the Canada-Ontario Agreement on Great Lakes Water Quality, the construction of water pollution control facilities in the Lower Lakes Basin was to be accelerated. Furthermore, for a five-year period ending in 1976, six million dollars were committed for phosphorus removal treatability studies and research designed to develop or improve pollution control technology. This funding was subsequently increased by one million dollars and the program extended for two years until 1978. A further two-year extension until 1980 was also negotiated.

A schedule for the implementation of phosphorus removal facilities was developed in Ontario. It was anticipated that by the end of 1975 some 200 plants serving a population of 4 700 000 could have operational phosphorus removal facilities. As of 1977, 211 out of 349 sewage treatment plants had phosphorus removal facilities in operation (Archer, 1978a).

### 2.2.1 Treatability studies approach

The approach to AWT (with respect to phosphorus removal) in Ontario was to integrate chemical treatment into existing plant processes. This contrasts with the addition of "add-on" processes or tertiary units to conventional systems. The basic idea was to precipitate the phosphorus with calcium, iron or aluminum salts and remove the precipitate as part of the "normal sludges" from conventional wastewater treatment systems.

An integral part of the program was a two-phase treatability study consisting initially of extensive jar testing followed by six to eight weeks of full scale testing. The objective was to establish the optimum chemical and dosage range required at each treatment plant. By 1972, engineering consultants, the Ontario Ministry of the Environment Environment Canada had collected a large amount of jar test and full scale phosphorus removal data. It became evident that such a large data base would be useful in developing trends, cost data and other information that could lead to possible elimination or reduction in the scope of jar testing (full scale testing would still be required) in subsequent stages of the Canada-Ontario Agreement program or in future programs of a similar nature.

As a result of analyses of these data, the following equations were developed to predict full scale chemical precipitant dosages based on the concentration of the influent phosphorus (Prested et al, 1977) with the goal of achieving an effluent total phosphorus (TP) concentration of 1 mg/L.

$$\begin{aligned} \text{Fe}^{+3} &= 0.5 + 1.4 (\text{TP}) && (\text{Ave } \text{Fe}^{+3} = 9.2 \text{ mg/L}) \\ \text{Al}^{+3} &= -0.3 + 1.3 (\text{TP}) && (\text{Ave. } \text{Al}^{+3} = 7.2 \text{ mg/L}) \\ &&& (\text{where } \text{Fe}^{+3}, \text{Al}^{+3} \text{ and TP are all in mg/L}) \end{aligned}$$

These equations were found to be capable of predicting dosages for a particular wastewater to within  $\pm 30\%$ . No useful correlation for calcium salts was determined. Subsequently, a more extensive analysis of the data was conducted using more influent parameters (Prested et al, 1978). Even though this technique proved to be slightly better in predicting the

actual precipitant dosage requirement, it was concluded that the degree of improvement did not warrant the extra effort and expense involved in additional data collection and analysis.

### 2.2.2 The processes

Canadian studies and operational experience have clearly demonstrated that an effluent level of 1 mg/L of total phosphorus is technically feasible with the addition of chemicals to either primary or secondary treatment facilities.

Schematics of the various options for chemical addition are shown in Figure 2, and are typical for primary and secondary plants. Satisfactory mixing can generally be obtained if the chemicals are injected in the suction side of raw sewage pumps, or added to pre-aeration tanks or into the channel between the aeration tank and the final clarifier, provided additional mechanical agitation or air mixing is available (Boyko and Rupke, 1976).

Of the 211 Ontario wastewater treatment plants with phosphorus removal, 65 are lagoons and use alum as the precipitant. The remaining 146 are mechanical plants; 59% use iron, 40% alum and 1% lime (Archer, 1978a).

Typical chemical dosages used based on a 1975 survey (Archer, 1978b) are given in Table 2.

### 2.2.3 Sludge production

The chemicals added for phosphorus precipitation increase both the sludge volume and weight of solids. These changes have recently been summarized (Table 3) based on the results of a survey conducted in 1975 and presented by Schmidtke and Cohen (1977).

Data collected by Archer (1978b) on 40 secondary and eight primary plants indicated similar increases in sludge volumes.

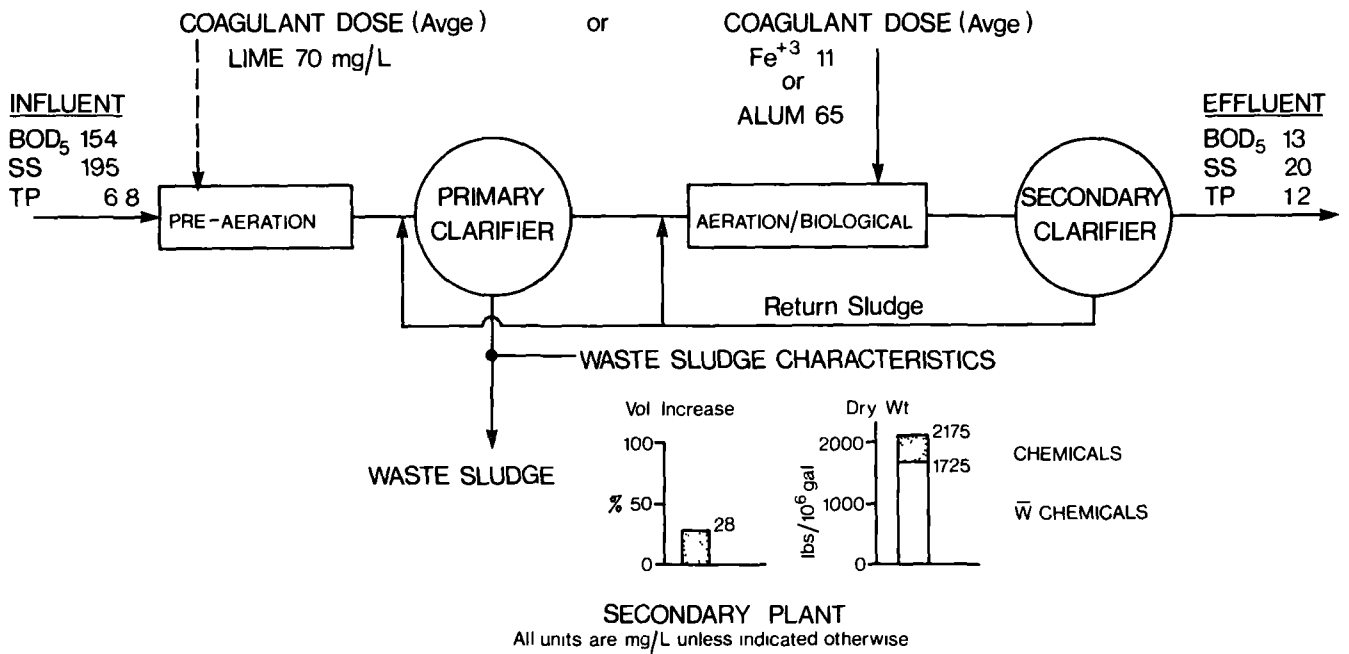
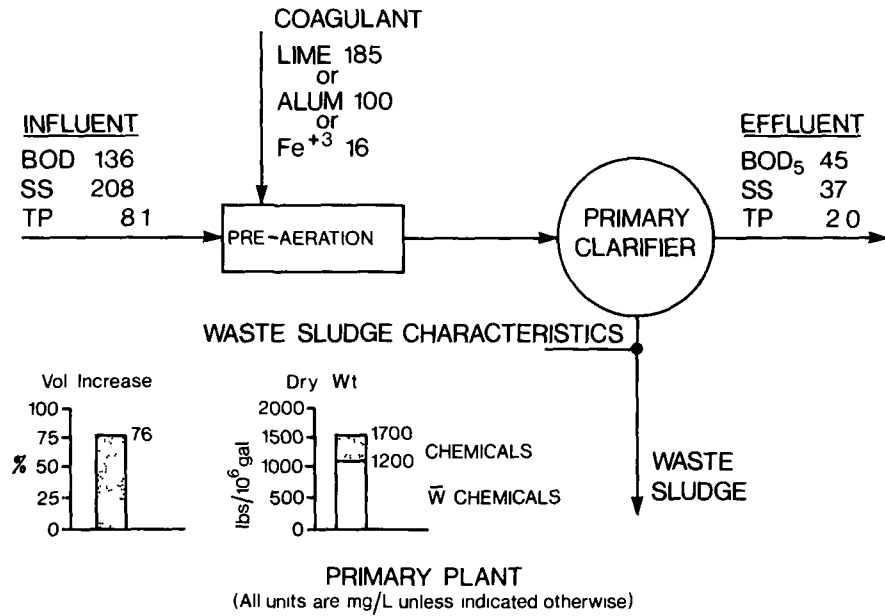


FIGURE 2 TYPICAL PHOSPHORUS REMOVAL PROCESSES  
(after Schmidtke and Cohen, 1977)

TABLE 2. TYPICAL DOSAGE RESULTS FOR PHOSPHORUS REMOVAL IN ONTARIO (1975)

Type of Treatment	Chemical	Number of Plants	Dosage mg/L	
			Range	Mean
Primary	Lime	3	167-200	185
	Alum	1	100	100
	Iron Salts (as Fe <sup>+3</sup> )	9	6-30	16
Secondary	Lime	2	40-100	70
	Alum	15	30-150	65
	Iron Salts (as Fe <sup>+3</sup> )	32	2-30	11

TABLE 3. SLUDGE PRODUCTION

System	Sludge Quantity*							
	Weight per capita			Dry Solids			Volume	
	lbs pcd	gm pcd	% Inc	lbs/10 <sup>6</sup> gal	kg/m <sup>3</sup>	% Inc	% Infl	% Inc
Conventional Primary	0.17	77		1200	0.12		0.20	
Upgraded Primary	0.24	109	42	1700	0.17	42	0.32	60
Conventional AS	0.25	114		1725	0.17		0.38	
Upgraded AS	0.32	145	27	2175	0.22	26	0.51	34

\* Based on Q (flow) = 145 gpcd or 658 L pcd.

pcd = per capita per day.

% Inc. = % increase between conventional and upgraded systems.

Upgraded systems are those with phosphorus removal.

#### 2.2.4 System costs

Archer (1978b) presented data on the costs of the various systems installed as of the date of the survey. The average capital cost for these plants is shown in Figure 3. These costs do not include any costs for plant enlargement or expansion of sludge handling facilities.

Operating costs, with the exception of chemical costs, are shown in Figure 4.

Chemical costs vary significantly throughout Ontario and are therefore not included in Figure 4, although these are the largest portion of the total process cost. Chemical costs during the summer of 1976 for the municipalities surveyed were:

Alum	- \$78.05 to \$92.11 (per tonne of dry alum) (\$70.95 to \$83.74 [per ton])
Iron Salts	- \$0.26 to \$0.46 (per kg Fe) (\$0.12 to \$0.21 [per lb Fe])
Lime	- \$37.95 to \$48.79 (per tonne of bulk hydrated lime) (\$34.50 to \$44.35 [per ton])

These costs ranged from \$0.55 to \$16.92 per 1000 m<sup>3</sup> (\$2.48 to \$76.88 per million gallons) of sewage treated, with the average being approximately \$5.06 per 1000 m<sup>3</sup> (\$23.00 per MG).

#### 2.2.5 Related research

Through funding provided under the Canada-Ontario agreement, research programs on phosphorus removal were expanded and intensified to explore concepts proposed by municipalities, universities, industries and consulting firms. In addition, long-term full scale and laboratory studies were initiated by both Environment Canada and the Ontario Ministry of the Environment in an attempt to refine the technology of phosphorus removal. In some cases, the treatability and research studies were integrated. The long-term research studies have provided an opportunity to assess specific process phenomenon, including sludge treatment and disposal, under the influence of varying quantities and types of prime coagulants.

The sludges produced are being used for laboratory and field investigations of the various aspects of sludge utilization and disposal. These studies are designed to establish the maximum rates of sludge

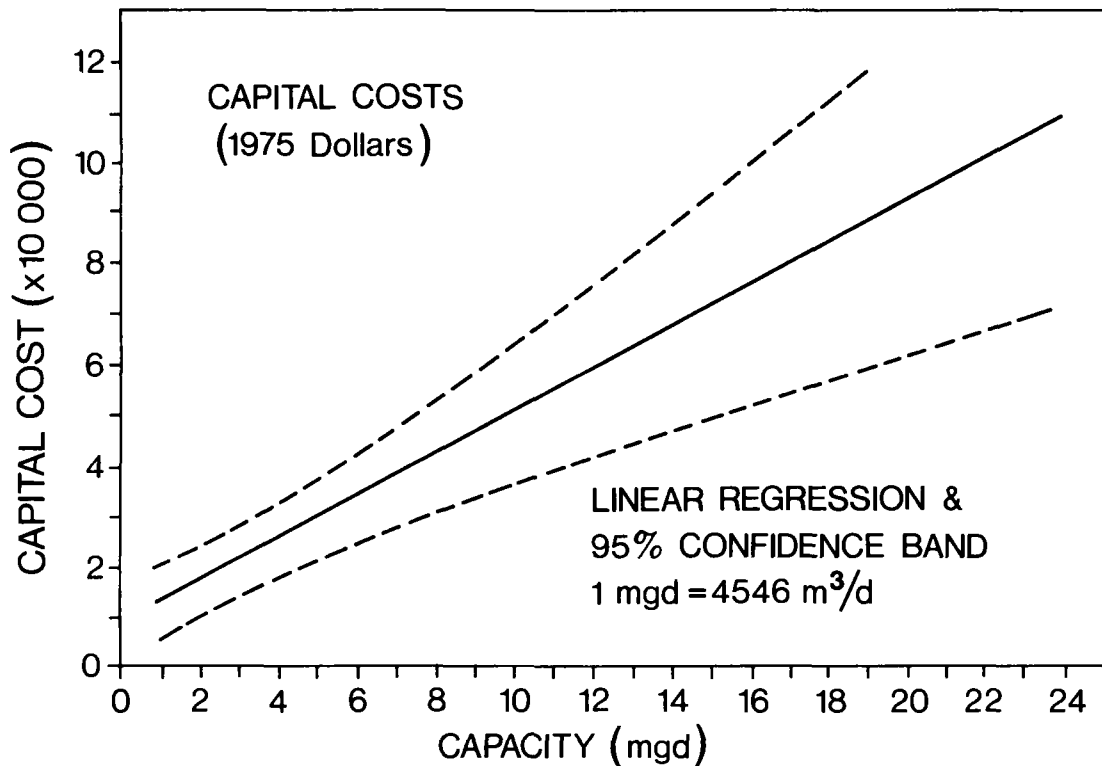
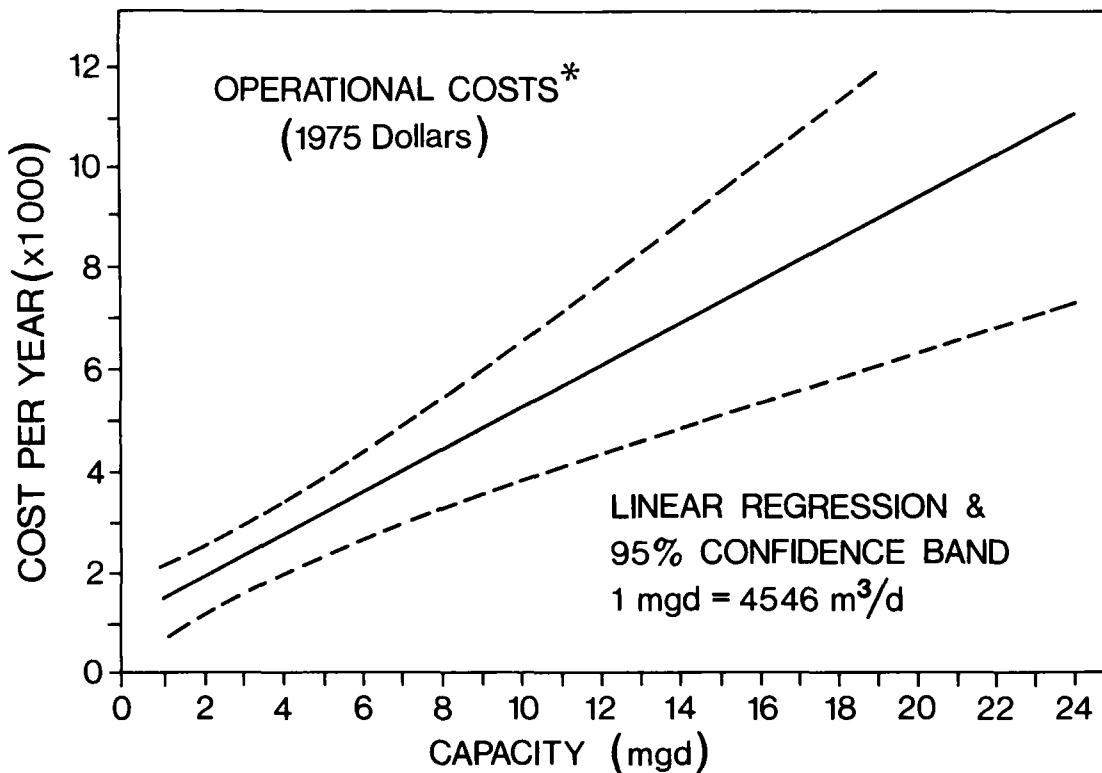


FIGURE 3. PHOSPHORUS REMOVAL EQUIPMENT-CAPITAL COSTS



\*Costs Exclude Chemical Costs

FIGURE 4. PHOSPHORUS REMOVAL-OPERATIONAL COSTS

application to agricultural soils without polluting ground and surface water or reducing the quantity and quality of the crops produced. The behaviour of chemical sludges in soils is also under investigation to determine the effects of the sludges on the physical, chemical and biological properties of the soils. Tentative conclusions at this time are that, in general, heavy metals and viruses are not a significant problem in the utilization of sewage sludges on agricultural lands (Cohen and Bryant, 1978).

The whole spectrum of related research studies has been categorized and is given in Table 4 with some highlights presented in the following paragraphs.

A number of potentially useful prime coagulants which may reduce the cost of phosphorus removal were also examined. Projects were carried out at two treatment plants on the use of waste pickle liquor from steel product manufacturing operations. The utilization of aluminized red mud solids (ARMS) from the aluminum industry has been examined with promising results.

A spray irrigation and spray runoff study, irrigating lands with and without crop cover, is in progress at Smithville. The objective is to assess the effectiveness of this process to remove organics and phosphorus. The project, involving irrigation of a wheat crop, was begun in 1972. The evaluation of runoff from a nearby cropped plot indicated a 60 to 70% reduction of phosphorus with little effect on the receiving stream. For small municipalities this may be a clear alternative to chemical treatment.

Many other investigations have been undertaken and have only recently been completed. These include investigations of the settling behaviour of physical-chemical flocs, effluent polishing processes, factors influencing chemical addition rates and other studies which will provide a greater insight into phosphorus removal and associated process implications.



TABLE 4. PHOSPHORUS - AWT RELATED STUDIES

Project Title	Report Number*
<u>TOPIC - 1. Phosphorus Removal - Primary and Secondary Treatment Plants</u>	
Phosphorus Removal at the Sarnia Water Pollution Control Plant	14
The Use of Lime in the Treatment of Municipal Wastewaters	21
Phosphorus Removal Treatability Studies at CFB Borden, Petawawa, Trenton and Uplands	EPS 4-WP-73-5
Full Scale Phosphorus Removal at CFB Petawawa (Primary Plant)	EPS 4-WP-74-3
Phosphorus Removal Demonstration Study Using Ferric Chloride and Alum at CFB Uplands	EPS 4-WP-74-5
Phosphorus Removal Within Existing Wastewater Treatment Facilities	44
Phosphorus Removal Demonstration Studies at CFB Trenton Phase I	EPS 4-WP-74-9
Phase II	EPS 4-WP-76-4
Phosphorus Removal Demonstration Studies Using Lime, Alum and Ferric Chloride at CFB Borden	EPS 4-WP-78-2
Phosphorus Removal Design Seminar, Toronto, 1973	1 (Conf. Proc.)
Integration of Physico-Chemical and Biological Wastewater Treatment Processes	7
<u>TOPIC - 2. Phosphorus Removal - Lagoons</u>	
Nutrient Control in Sewage Lagoons Volume I	8
Volume II	23
Phosphorus Removal in Seasonal Retention Lagoons by Batch Chemical Precipitation	13
Spray Runoff Disposal of Waste Stabilization Pond Effluent	22
Phosphorus Reduction from Continuous Overflow Lagoons by Addition of Coagulants to Influent Sewage	65
<u>TOPIC - 3. Process Control</u>	
Chemical Control for Phosphorus Removal	4

\* Individual numbers refer to reports published in the Canada-Ontario Agreement Research Report and Conference Proceedings (Conf. Proc.) Series.

EPS numbers are reports published in the Environmental Protection Service, Environment Canada, Report Series.

TABLE 4 (CONT'D). PHOSPHORUS - AWT RELATED STUDIES

Project Title	Report Number*
<u>TOPIC - 4. Prediction Models</u>	
Development of Prediction Models for Chemical Phosphorus Removal	
Volume I	68
Volume II	78
<u>TOPIC 5. Sources of Chemicals</u>	
Use and Production of Iron Salts for Phosphorus Removal	5
Utilization of Industrial Wastes and Waste By-products for Phosphorus Removal: An Inventory and Assessment	6
Utilization of Aluminized Red Mud Solids (ARMS) for Phosphorus Removal	EPS 4-WP-75-2
<u>TOPIC 6. Chemical Aids</u>	
Assessment of Polyelectrolytes for Phosphorus Removal	37
<u>TOPIC 7. Process Studies</u>	
Design and Performance Criteria for Settling Tanks for the Removal of Physical Chemical Floccs	
Volume I	10
Volume II	56
<u>TOPIC 8. Polishing Processes</u>	
Effluent Polishing by Filtration Through Activated Alumina	
Volume I	39
Volume II	40
Tertiary Phosphorus Removal and Limiting Nutrient Studies at CFS Lac St. Denis	EPS 4-WP-74-1
The Welland Canal Water Quality Experiments	EPS 4-WP-74-10

\* Individual numbers refer to reports published in the Canada-Ontario Agreement Research Report and Conference Proceedings (Conf. Proc.) Series.

EPS numbers are reports published in the Environmental Protection Service, Environment Canada, Report Series.

TABLE 4 (CONT'D). PHOSPHORUS - AWT RELATED STUDIES

Project Title	Report Number*
<b>TOPIC - 9. <u>Detergent Substitution Studies</u></b>	
Effect of Citrate and Carbonate Based Detergents on Wastewater Characteristics and Treatment	61
A Study of NTA Degradation in a Receiving Stream	EPS 4-WP-74-7
Detergent Substitution Studies at CFS Gloucester	EPS 4-WP-73-3
Impact of Nitrilotriacetic Acid (NTA) on an Activated Sludge Plant	91
Activated Sludge Degradation of Nitrilotriacetic Acid (NTA) - Metal Complexes	EPS 4-WP-78-5
<b>TOPIC 10. <u>Sludges</u></b>	
a) <u>Dewatering/Conditioning</u>	
Sludge Dewatering Design Manual	72
b) <u>Digestion Processes</u>	
Aerobic Digestion of Organic Sludges Containing Inorganic Phosphorus Precipitates	
Phase I	3
Volume I	58
Anaerobic Digestion of Lime Sewage Sludge	50
c) <u>Application to Land</u>	
Land Application of Sewage Sludge	1
Heavy Metals in Agricultural Lands Receiving Chemical Sewage Sludges	
Volume I	9
Volume II	25
Volume III	30
Volume IV	51
Land Disposal of Sewage Sludge (Field Studies)	
Volume I	16
Volume II	24
Volume III	35
Volume IV	60
Volume V	73
Volume VI	90
Land Application of Digested Sludge Under Adverse Conditions	53
Chemical Sewage Sludge Disposal on Land (Lysimeter Studies)	
Volume I	67
Volume II	79

\* Individual numbers refer to reports published in the Canada-Ontario Agreement Research Report and Conference Proceedings (Conf. Proc.) Series.

EPS numbers are reports published in the Environmental Protection Service, Environment Canada, Report Series.

TABLE 4 (CONT'D). PHOSPHORUS - AWT RELATED STUDIES

Project Title	Report Number*
d) <u>Heat Processes</u>	
Wet Air Oxidation of Chemical Sludges	12
Evaluation of the Barber-Coleman Wetox Process for Sewage Sludge Disposal	20
Sludge Incineration and Precipitant Recovery Volume I	31
Volume II	74
Volume III	75
e) <u>Recovery of Materials from Process Residuals</u>	
Recycling of Incinerator Ash	19
Removal of Phosphates and Metals from Sewage Sludge	28
The Removal and Recovery of Metals from Sludge and Sludge Incinerator Ash	33
Reuse of Waste SO <sub>2</sub> and Phosphate Sewage Sludge by Solidification with Lime and Fly Ash	69
f) <u>Health Hazards</u>	
Examination of Sewage and Sewage Sludge for Enteroviruses	
Volume I	27
Volume II	52
g) <u>Computer-aided Planning of Regional Sludge Disposal Systems</u>	46
h) <u>Analysis</u>	
The Analysis of Chemical Digester Sludges for Metals by Several Laboratory Groups	EPS 4-WP-78-1
i) <u>Sludge Handling and Disposal Seminar, Toronto, 1974 and 1978</u>	2 & 6 (Conf. Proc.)

\* Individual numbers refer to reports published in the Canada-Ontario Agreement Research Report and Conference Proceedings (Conf. Proc.) Series.

EPS numbers are reports published in the Environmental Protection Service, Environment Canada, Report Series.

### 2.3 Saskatchewan - City of Regina

The Province of Ontario, in cooperation with the Federal Government, has had the most active program for phosphorus removal in Canada. Although most of the R & D was done in Ontario, a rather unique situation existed in the City of Regina, and for this reason its treatment system is briefly described herein.

The City of Regina (population 150 610) has installed a system for phosphorus removal at its treatment plant. The "treatment system" consists of five partially aerated lagoons with an area of about 500 hectares (200 acres). The AWT system is a tertiary facility treating 45 450 m<sup>3</sup>/d (10 mgd) with lime (at a dosage of 400 mg/L), and 36 360 m<sup>3</sup>/d (8 mgd) with alum (at a dosage of 200 to 300 mg/L) and polymer (0.3 to 0.6 mg/L). The plant consists of the necessary chemical storage tanks, feed tanks, mixers, and feed lines to two reactor-clarifiers with sloping tubes. The clarified effluent is discharged to a small stream, tributary to the Qu'Appelle River. Typical effluent results are presented in Table 5 (Moisuk, 1978).

TABLE 5. TYPICAL EFFLUENT RESULTS

Parameter	Value
Phosphorus (Total)	1 mg/L
Chlorophyll 'a'	80 µg/L (90% removal)
BOD <sub>5</sub>	<10 mg/L
SS	<20 mg/L
pH	<8.8 - 9

### 3 AWT - NITROGEN CONVERSION AND REMOVAL

#### 3.1 Introduction

Requirements for nitrogen conversion exist primarily to alleviate the nitrogenous oxygen demand in aquatic systems, and for total nitrogen removal.

There are no municipal systems operational in Canada exclusively for nitrogen removal, but a number of systems for nitrogen conversion are operating in Ontario. Information on these systems and the requirements for nitrogen conversion (nitrification) in Ontario are presented in Table 6. However, one industrial operation with biological nitrogen removal is operating in Ontario.

##### 3.1.1 R & D studies

Under the Canada-Ontario Agreement, research programs on nitrogen removal were initiated by the Ontario Ministry of the Environment (MOE) and the Wastewater Technology Centre (WTC), Environment Canada.

As reported by Smith (1976), the initial thrust of the MOE studies was an evaluation of a full scale system at Newmarket, Ontario. Although valuable information was obtained, it was decided, because of bulking sludge problems, to undertake pilot scale studies at several other locations in Ontario. An extensive program was carried out at the Ontario Experimental Facility at Brampton with encouraging results; however, bulking sludges continued to be a problem.

At the Wastewater Technology Centre, a pilot scale nitrogen conversion/removal program was initiated in 1972 to provide design information for a variety of system configurations, including single-sludge systems for carbon oxidation - nitrification and denitrification. The highlights of this program, which was completed late in 1977, are presented in Table 7.

TABLE 6. REQUIREMENTS FOR NITRIFICATION IN ONTARIO

Nitrification required at the following locations when the existing plant is expanded or a new one constructed.				
Period	Location	Flow		Comments
		m <sup>3</sup> /d	Imgd	
a) Summer only	Milton	12 900	2.84	(Expansion)
	Mount Albert	680 - 1 360	0.15 - 0.30	(New Plant)
	Alliston	3 600	0.77	(Expansion)
	Guelph <sup>1</sup>	54 000	12	32 shaft RBC Ave. loading 0.11 m <sup>3</sup> /d/m <sup>2</sup> Peak loading 0.16 m <sup>3</sup> /d/m <sup>2</sup>
b) All year	1. Woodstock <sup>2</sup>	20 400	4.5	(5 plants)
	2. London <sup>2</sup>	180 000	≈40	
	3. Stratford <sup>2,3</sup>	27 100	6.0	
	4. Chatham <sup>2,3</sup>	20 400	4.5	
	5. Elmira <sup>3</sup>	3 080	0.68	

<sup>1</sup> RBC installed as tertiary system for nitrification.

<sup>2</sup> Thames River watershed.

<sup>3</sup> Tentative requirement.

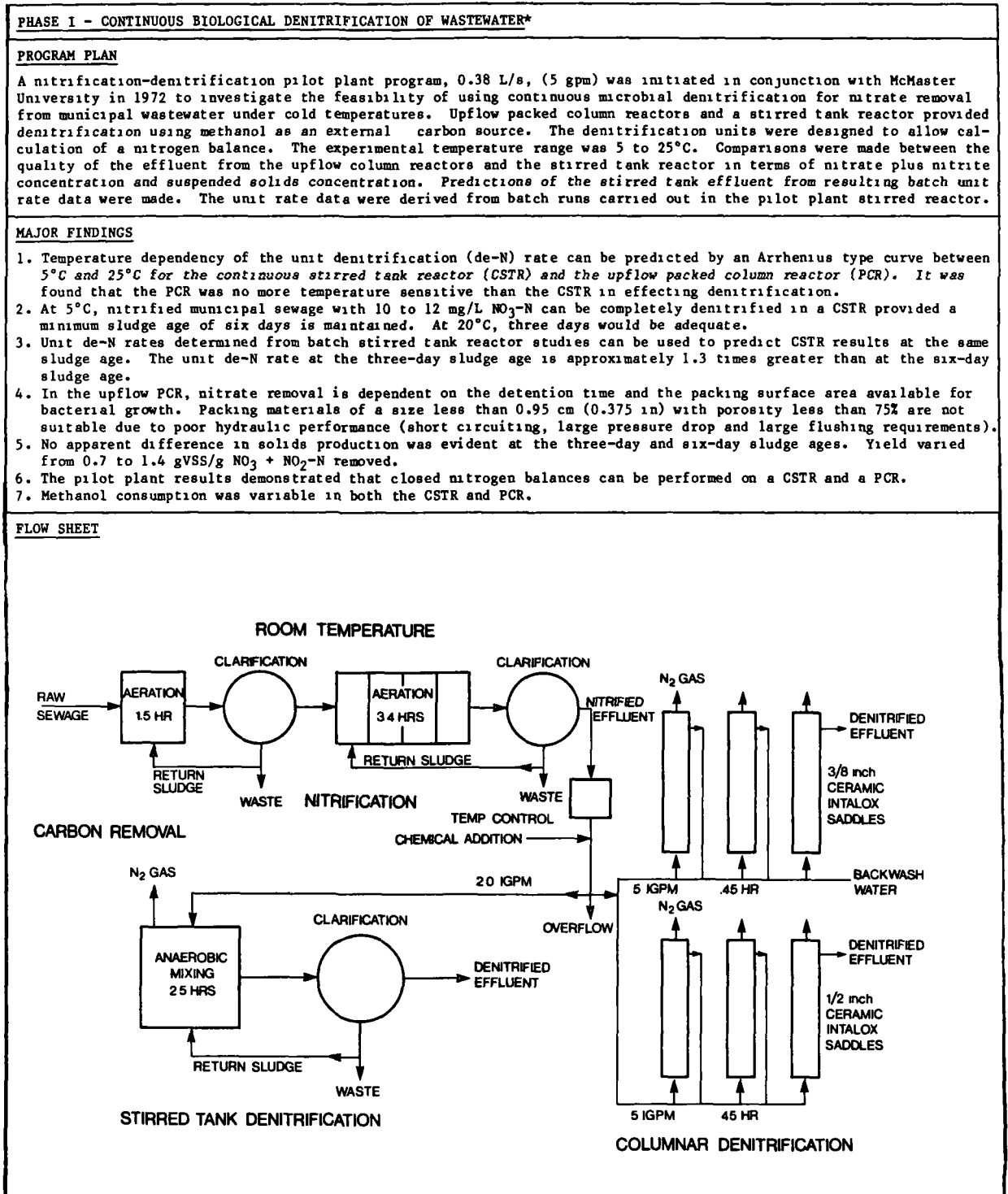
Note: According to the 1975 operating summaries for Ministry of the Environment plants, 80% of the extended aeration plants and 38% of the conventional plants attain year-round nitrification (i.e., effluent NH<sub>3</sub> < 3 mg/L).

(Information from S. Black and R. Rush, personal communication.)

### 3.1.2 Full scale feasibility study

Following the completion of the WTC program, a feasibility study was conducted for a full scale facility at Penticton, British Columbia. The results are presented in Section 3.2. The findings of the WTC studies were used extensively in this full scale exercise. In addition, general cost data were developed for plants of different sizes.

TABLE 7. WASTEWATER TECHNOLOGY CENTRE NITROGEN PROGRAM - A BRIEF SUMMARY



\* Murphy and Sutton, 1975, Sutton, Murphy and Dawson, 1975.



TABLE 7 (CONT'D). WASTEWATER TECHNOLOGY CENTRE NITROGEN PROGRAM - A BRIEF SUMMARY

PHASE II - CARBON OXIDATION - NITRIFICATION - DENITRIFICATION*	
<b>PROGRAM PLAN</b>	
Results from the earlier studies established that the critical link in a low temperature biological nitrification/denitrification system was in the nitrification step. Consequently, a pilot program was initiated in 1973 to examine various flow and process configurations for biological nitrification systems.	
<b>Objectives</b>	
<ol style="list-style-type: none"> <li>Evaluation of pilot scale parallel systems of combined and separate sludge, carbon removal nitrification systems operated at pseudo steady-state conditions over a range of loading conditions and temperatures               <ul style="list-style-type: none"> <li>- single stage combined sludge,</li> <li>- two-stage combined sludge, and</li> <li>- two-stage separate sludge.</li> </ul> </li> <li>Establish the kinetics and operational data for rotating biological contactors during both nitrification and denitrification to allow a comparison with suspended growth systems.</li> <li>Evaluate the performance of a fluidized bed reactor and upflow submerged packed columns having a high porosity for denitrification.</li> </ol>	
<b>MAJOR FINDINGS</b>	
<b>Nitrification</b>	
<b>Suspended Growth Systems</b>	
<ol style="list-style-type: none"> <li>For nitrogen levels commonly found in domestic wastewater, the rate of nitrification (filterable TKN removed per unit mass of activated sludge) is independent of the concentration of filterable TKN.</li> <li>No significant difference in filterable TKN removal or temperature sensitivity may be expected between systems with separate nitrifying sludges compared to combined carbon removal-nitrification sludges under similar operating conditions (i.e., temperature, solids retention time, etc.).</li> <li>Nitrification can be accomplished over a range of solids retention times with temperature sensitivity decreasing with increasing SRT.</li> <li>No appreciable difference in settleability was evident between the combined and separate nitrifying sludge systems. Even with complete nitrification, slightly less than 1 mg/L of filterable organic nitrogen together with an average of 1 mg/L of TKN may be expected in the suspended fraction of the effluent.</li> <li>A significantly higher quantity of sludge will be produced from a separate sludge carbon removal-nitrification system than from a combined sludge system.</li> </ol>	
<b>Supported Growth System (RBC)</b>	
<ol style="list-style-type: none"> <li>The rate of nitrification on the RBC is independent of concentration of filterable TKN and can be expressed as a function of the disc surface area within the limits of BOD<sub>5</sub> and filterable TKN loadings in this study.</li> <li>The temperature sensitivity of nitrification on the RBC is comparable to combined sludge carbon removal-nitrification systems at high SRT's.</li> <li>In cold climates, wastewater cooling as a result of heat transfer between the RBC and the atmosphere will be significant. The resulting effect on efficiency will necessitate either the installation of the RBC's in a partially heated building, or the placement of covers on all units.</li> </ol>	
<b>Denitrification</b>	
<b>Suspended Growth Systems</b>	
<ol style="list-style-type: none"> <li>For levels of nitrogen commonly found in nitrified domestic waste, the rate of denitrification (nitrate plus nitrite removed per unit mass of activated sludge) is independent of the concentration of NO<sub>3</sub> + NO<sub>2</sub>-N.</li> <li>Temperature sensitivity of the process is essentially independent of solids retention time over the range of three to nine days.</li> <li>The incorporation of an aerobic stabilization chamber with a retention time of 30 minutes will reduce leakage of residual methanol from the process without affecting the denitrification rate. The settleability of the denitrifying sludge is improved.</li> <li>Nitrogen contributed by effluent suspended solids resulted in a mean effluent TKN of 1.2 mg/L. To consistently attain a total nitrogen effluent requirement of 1 mg/L, some form of additional suspended solids removal will be required.</li> </ol>	
<b>Supported Growth Systems</b>	
<ol style="list-style-type: none"> <li>Fixed bed upflow packed column reactors developing minor pressure gradients will exhibit non-steady hydraulic behaviour resulting in variable denitrification rates, although variable, significant quantities of nitrate can be removed.</li> <li>For packed columns of the type investigated in this study, some form of additional effluent suspended solids removal would be required.</li> <li>Supported growth denitrification systems appear to be less temperature sensitive than suspended growth systems.</li> </ol>	
<b>FLOW SHEET</b>	
<p style="text-align: center;"><b>FLOW DIAGRAM OF SUSPENDED AND SUPPORTED GROWTH NITRIFICATION-DENITRIFICATION PILOT PLANT</b></p>	
* Sutton et al, 1975, Murphy et al, 1977, Sutton et al, 1977, Sutton et al, 1977a, Sutton and Jank, 1976a, Sutton and Jank, 1976b, Murphy et al, 1976, Sutton et al, 1978a.	

TABLE 7 (CONT'D). WASTEWATER TECHNOLOGY CENTRE NITROGEN PROGRAM - A BRIEF SUMMARY

PHASE III - BIOLOGICAL NITRIFICATION-DENITRIFICATION SINGLE SLUDGE SYSTEMS*	
<p><b>PROGRAM PLAN</b></p> <p>The final phase of the pilot scale program was the development of design criteria for single sludge nitrification-denitrification systems. The single sludge systems combine the processes of carbon oxidation, nitrification, and denitrification in a system having no intermediate clarification. Nitrate reduction is provided either by using the organics (carbon source) present in the wastewater or by the endogenous respiration of the biological sludge. Many combined sludge process configurations have been proposed. Although it has been demonstrated for some systems that high nitrogen removal can be obtained, there is little kinetic rate data available to permit the determination of the fundamental design parameter values and, thus, development of the optimal combined sludge process configuration under any given loading and temperature conditions. To obtain the information necessary to design combined sludge carbon oxidation (Co) - nitrification (Nit) - denitrification (Denit) systems, an extensive pilot plant program was undertaken. Five different combined sludge systems were under investigation with nitrate reduction relying on</p> <ol style="list-style-type: none"> <li>1) the endogenous respiration of the biological sludge, system A,</li> <li>2) the supply of an external carbon source-methanol, system B,</li> <li>3) the organics present in the wastewater and an external carbon source, system C, and</li> <li>4) the organics present in the wastewater, systems D and E.</li> </ol> <p>This experimental program was divided into two phases. In Phase 1, three parallel pilot plants permitted the operation of systems A, B and C or D. In Phase 2, systems A and E were operated in parallel and additional information obtained for process configurations C and D.</p>	
<p><b>MAJOR FINDINGS</b></p> <p><u>Nitrification in Single Sludge Systems</u></p> <ol style="list-style-type: none"> <li>1. The degree of nitrification in single sludge systems, whether expressed as the fraction of ammonia or filterable TKN removal, will be dependent on the aerobic SRT.</li> <li>2. The maximum fraction of filterable TKN removal, 0.90 to 0.95, will be limited by a residual filterable organic nitrogen in the effluent. The mean value of the residual filterable organic nitrogen can be estimated at 1.2 mg/L.</li> <li>3. Under variable influent conditions, the capacity for filterable TKN or ammonia removal will increase as the operating aerobic SRT increases beyond the minimum necessary for nitrification.</li> <li>4. Periods of up to 4.0 h of anoxic conditions will have no effect on nitrifying organisms.</li> <li>5. The growth rate and temperature sensitivity of nitrifiers in aerobic-anoxic single sludge systems and in purely aerobic systems will be comparable.</li> </ol> <p><u>Denitrification in Single Sludge Systems</u></p> <ol style="list-style-type: none"> <li>1. Under non-carbon limiting conditions, the denitrification rates, expressed as mg of oxidized nitrogen removed per mg of MLVSS per day in separate sludge systems will be significantly larger than in single sludge systems. The temperature sensitivity of the rate of denitrification under these conditions will be no different in separate or single sludge systems.</li> <li>2. The organics present in the influent sewage fed to the single sludge systems in this study were comparable to methanol as an organic carbon and energy source for denitrification.</li> <li>3. In separate and single sludge post-denitrification systems, the methanol requirements to ensure that denitrification proceeds under non-carbon limiting conditions will be similar. In single sludge pre-denitrification and step-feed denitrification systems, the methanol requirements will be more than double that required in separate sludge systems.</li> <li>4. Under carbon limiting conditions, complete denitrification can be achieved in an anoxic reactor by relying on endogenous denitrification to complete nitrate removal.</li> <li>5. The endogenous denitrification rates expressed as mg of <math>\text{NO}_3^-</math>-N removed per mg of MLVSS per day will be dependent on the system SRT. The denitrification rates will decrease with increasing SRT.</li> <li>6. Little or no temperature sensitivity may be expected for denitrification proceeding under carbon limiting conditions.</li> </ol> <p><u>Single Sludge System Performance</u></p> <ol style="list-style-type: none"> <li>1. The mean value of the yield coefficient for single sludge systems in which no external carbon source is added or in which methanol is added but only in sufficient quantities to prevent an organic carbon limitation on the denitrification rate, can be expected to be 0.57 mg VSS per mg COD removed.</li> <li>2. The mean value for the ratio of the observed to theoretical alkalinity consumption in single sludge systems will vary between 0.8 for the post-denitrification systems and 1.5 for the pre-denitrification systems.</li> <li>3. In a single sludge pre-denitrification/nitrification system, an enhanced degree of P removal may be expected when anaerobic conditions are achieved in the anoxic reactor.</li> <li>4. The minimum effluent nitrogen level attainable in single sludge nitrogen removal systems will be 2 to 3 mg/L of total N. Depending on the single sludge process configuration, these effluent values may not be attainable.</li> </ol>	
<p><b>FLOW SHEET</b></p> <div style="display: flex; justify-content: space-around;"> <div style="width: 45%;"> <p><u>CARBON OXIDATION-NITRIFICATION POST-DENITRIFICATION</u></p> <p>NO EXTERNAL CARBON SOURCE ADDITION (SYSTEM A)</p> <p>EXTERNAL CARBON SOURCE ADDITION (SYSTEM B)</p> </div> <div style="width: 45%;"> <p><u>PRE-DENITRIFICATION NITRIFICATION</u></p> <p>EXTERNAL CARBON SOURCE ADDITION (SYSTEM C)</p> <p>NO EXTERNAL CARBON SOURCE ADDITION (SYSTEM D)</p> </div> </div> <p><u>STEP-FEED NITRIFICATION - DENITRIFICATION</u></p> <p>(SYSTEM E)</p> <p>Note Co refers to carbon oxidation, Nit to nitrification, Denit to denitrification, F to feed, RS to return sludge, and ML to mixed liquor</p>	

\* Sutton et al, 1977b; Sutton et al, 1978b.

### 3.1.3 Identification of alternate sources of methanol for denitrification

In Section 3.3, the results of a study conducted to identify alternate carbon sources to replace methanol in the denitrification process are briefly presented.

A full scale system for nitrogen removal from municipal wastewaters has yet to be demonstrated in Canada. However, these studies have provided researchers with the complementary opportunity to solve industrial nitrogen removal problems. Table 8 presents data on effluent quality attainable from various nitrogen removal options.

TABLE 8. EFFLUENT QUALITY ATTAINABLE FROM MUNICIPAL NITROGEN REMOVAL SYSTEMS

<p><u>ALTERNATIVE A</u> - Combined or separate sludge suspended growth system with filtration excluding a pre-denitrification system.</p> <p>SS - 5 mg/L</p> <p>TKN - 1 to 2 mg/L</p> <p><math>\text{NH}_4^+</math>-N - Trace</p> <p><math>\text{NO}_3\text{-N} + \text{NO}_2\text{-N}</math> - Trace</p> <p>Total N - 2 mg/L</p>
<p><u>ALTERNATIVE B</u> - Same as Alternative A without filtration (post-de-N).</p> <p>SS - 20 mg/L</p> <p>TKN - 2 to 3 mg/L</p> <p><math>\text{NH}_4^+</math>-N - Trace</p> <p><math>\text{NO}_3\text{-N} + \text{NO}_2\text{-N}</math> - Trace</p>
<p><u>ALTERNATIVE C</u> - Pre-denitrification single sludge with <math>\text{NH}_4^+</math>-N in influent of 20 mg/L and anoxic reactor <math>\text{NO}_3\text{-N} + \text{NO}_2\text{-N}</math> approaching zero.</p> <p>SS - 20 mg/L</p> <p>TKN - 2 to 3 mg/L</p> <p><math>\text{NH}_4^+</math>-N - Trace</p> <p><math>\text{NO}_3\text{-N}</math> - 4 mg/L</p>

### 3.2 Feasibility Study for Full Scale Nitrogen Removal

To develop cost data on AWT systems for nutrient removal, the City of Penticton, British Columbia, with a population of 22 000, was selected for a feasibility study. Three biological nitrogen removal processes were selected for detailed evaluation (Murphy and Wilson, 1978). These were the two-sludge post-denitrification process, the one-sludge post-denitrification process, and the one-sludge pre-denitrification process. Schematics of each of these process alternatives are presented in Figure 5.

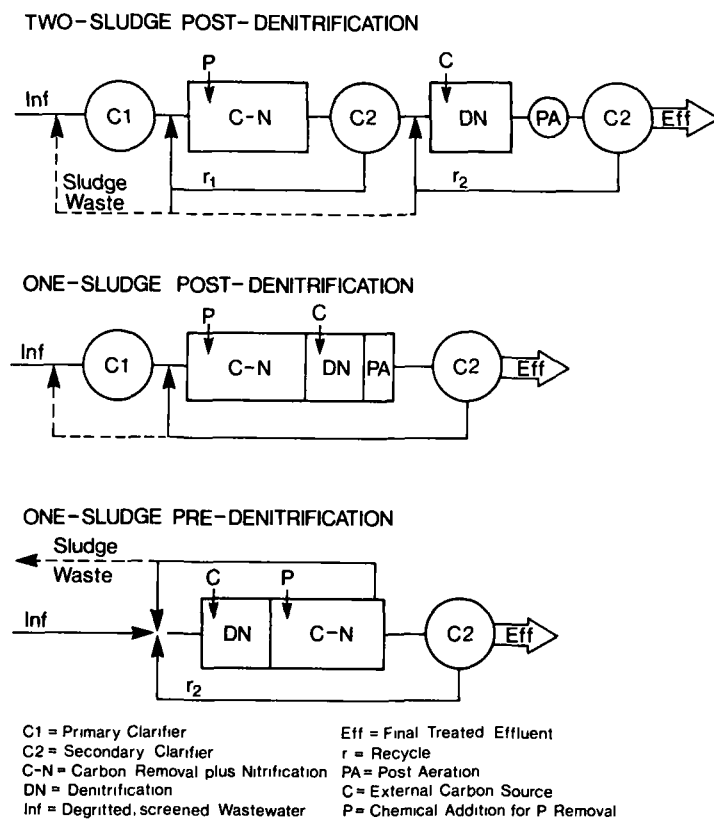


FIGURE 5 NITROGEN REMOVAL PROCESSES

In the two-sludge process, primary clarified wastewater enters an aerated basin where organic carbon and ammonia are oxidized. Following clarification, the nitrified wastewater enters the stirred tank denitrification basin. An external carbon source, typically methanol, is added to provide an electron donor for the reduction of the nitrate to nitrogen gas. Subsequently, the wastewater enters a short detention

aerated basin where entrained gases are stripped and residual methanol is removed before final clarification.

One-sludge post-denitrification is similar to the two-sludge process except that the intermediate clarifier is eliminated. This combines the carbon removal, the nitrifying, and the denitrifying organisms in a common mixed liquor. There is a potential economy in this process compared to the two-sludge system since fewer clarifiers are needed. However, this saving is partially offset by increased volumes for the denitrification basin as the relative concentration of denitrifying organisms is decreased.

The once-sludge pre-denitrification process utilizes the oxidizable organic substances in the raw wastewater as electron donors for the denitrification process. Depending on the ratio of oxidized material to  $\text{NO}_3\text{-N}$ , this process configuration can reduce or perhaps even eliminate the requirement for methanol addition. Oxygen requirements are less than for the other two processes since most of the oxidizable organics are removed during pre-denitrification before the wastewater enters the aerated portion of the basin.

Table 9 summarizes cost estimates for nitrification and denitrification facilities. The cost for nitrogen removal is approximately twice the cost of carbon removal. (Note: These costs are for the biological portion of the Water Pollution Control Plant only).

The following alternative nitrogen removal processes were also assessed: ion exchange (clinoptilolite), ammonia stripping, and land disposal. Performance expectations for these processes are presented in Table 10 and cost comparisons in Table 11. Performance and cost expectations are related to conventional activated sludge systems.

A series of more general cost curves (Murphy and Wilson, 1978) were also prepared on the data developed for systems for this municipality. The four separate process systems considered were: two-sludge nitrification-denitrification, one-sludge pre-denitrification, nitrification alone, and activated sludge treatment. The curves were prepared from separate cost estimates for a  $0.45 \times 10^4 \text{ m}^3/\text{d}$  (1.0 Imgd), a  $1.5 \times 10^4 \text{ m}^3/\text{d}$  (3.4 Imgd) and a  $4.5 \times 10^4 \text{ m}^3/\text{d}$  (10 Imgd) plant. Equipment, power, chemical and labour costs were also based on the values used in the development of the previous tables.

TABLE 9. ECONOMIC COMPARISON OF BIOLOGICAL NITROGEN REMOVAL PROCESSES

Present Worth <sup>1</sup>	Activated	Nitrification	Two-Sludge	One-Sludge	One-Sludge
	Sludge		Post-DN	Post-DN	Pre-DN
Capital	\$2 618 000	\$3 268 000	\$4 802 000	\$4 180 000	\$4 327 000
Present worth of annual O&M	1 103 000	1 679 000	3 366 000	2 996 000	2 477 000
Total present worth	3 721 000	4 947 000	8 168 000	7 176 000	6 804 000
Comparative rating	0.55	0.73	1.20	1.05	1.00
<u>Annual Cost</u>					
Amortized capital <sup>1</sup>	318 000	397 000	583 000	508 000	526 000
O&M	134 000	204 000	409 000	364 000	301 000
Total annual cost	452 000	601 000	992 000	872 000	827 000
Comparative rating	0.55	0.73	1.20	1.05	1.00

<sup>1</sup> Based on a 10.5% discount/interest rate for 20 years.

Note: Costs are in January, 1979 dollars (Canadian).

TABLE 10. SUMMARY OF PERFORMANCE FOR VARIOUS NITROGEN REMOVAL METHODS

Method	Concentration in Effluent (mg/L)			
	Total Nitrogen <sup>1</sup> (as N)	BOD <sub>5</sub>	TSS	Total Phosphorus (as P)
Activated Sludge	26-30	≈20	≈20	0.6
Activated Sludge with Nitrification	26-30	≈20	≈20	0.6
Biological Nitrogen Removal	≤6	≈20	≈20	0.6
Other Methods:				
- Ion Exchange	2-3	<5	<5	<0.5
- Ammonia Stripping	4-18	<10	<10	<0.5
- Land Disposal	0	0	0	0

<sup>1</sup> Based on influent total nitrogen of 35 mg/L as N.

TABLE 11. COST COMPARISON OF BIOLOGICAL NITROGEN REMOVAL WITH OTHER METHODS

			Biological Nitrogen Removal (x \$1 000)			Other Methods (x \$1 000)		
	Activated Sludge (x \$1 000)	Nitrification (x \$1 000)	Two-Sludge Post-DN	One-Sludge Post-DN	One-Sludge Pre-DN	Clinopti- lolite Ion Exch.	Ammonia Stripping	Land Disposal
Capital	\$7 513	\$8 600	\$10 134	\$9 512	\$9 659	\$15 980	\$12 561	\$19 434
Annual O&M	421	485	600	555	492	629	679	162
Present Worth of O&M <sup>1</sup>	3 456	3 992	4 938	4 568	4 050	5 177	5 589	1 333
Total Present Worth	\$10 969	\$12 592	\$15 072	\$14 080	\$13 709	\$21 157	\$18 150	\$19 712 <sup>2</sup>
Comparative Rating	0.80	0.92	1.10	1.03	1.00	1.54	1.32	1.44

<sup>1</sup> Based on a discount rate of 10.5% for 20 years.

<sup>2</sup> Includes pipeline salvage value of \$365 000 based on straight-line depreciation and a 40-year pipeline life, land salvage value of \$690 000 based on 3% compound appreciation in land value for 20 years and 10.5% discount rate.

Note: Costs are in January, 1979 dollars (Canadian) for a complete treatment facility at Penticton, B.C., with capacity of 18 000 m<sup>3</sup>/d (4.0 Imgd), 4 540 kg/d (10 000 lb/d) BOD, and average annual flow of 15 400 m<sup>3</sup>/d (3.4 Imgd).

Capital and O&M costs for new facilities presented in Figure 6 were prepared using a design basis similar to that used for the development of the previous estimates. The costs include only those portions of the treatment plants associated with carbon removal and nitrogen removal. This excludes headworks, primary clarifiers, sludge processing and disinfection. The capital costs in Figure 6 do not include the 20% contingency included in previous cost estimates, but do allow for yardwork and engineering.

Figure 7 presents curves for the costs of "add-on" facilities for existing activated sludge treatment plants. The "add-on" capital costs were prepared by estimating the cost of additional basin volume, aeration, mixing and chemical feed equipment. It was assumed that no major renovations would be necessary to the existing final clarifiers and that they would be able to handle the increased solids loading caused by plant conversion. The capital cost includes yardwork and engineering. A 15% contingency was added because of the uncertainties in predicting costs for renovations to existing plants.

### 3.3 Waste Carbon Sources for Biological Denitrification

As part of the extensive nitrogen removal program conducted at the WTC over the past six years, a project to identify and evaluate industrial wastes or waste by-products which could be used as less expensive replacements for methanol in the denitrification process was initiated (Monteith et al, 1979). The first phase of the project involved contacting a wide variety of processing and manufacturing industries (petrochemical, organic chemical, pulp and paper, food and beverage, etc.) to identify potentially suitable wastes. Forty-one waste samples were collected and chemically analyzed to determine organic carbon and nitrogen concentrations. Bench scale testing followed, with the determination of batch denitrification rates for 30 of the characterized wastes.

As identified in Table 12, 24 of the wastes exhibited denitrification rates equal to or greater than those observed using methanol. A distillery fusel oil exhibited the highest denitrification rate which was 2.38 times that for methanol.



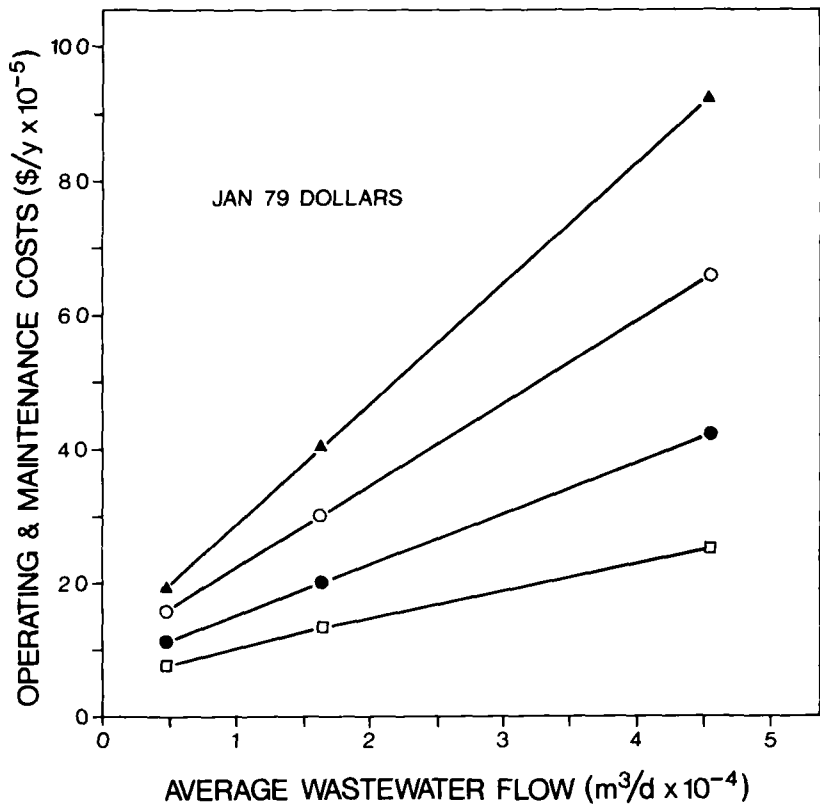
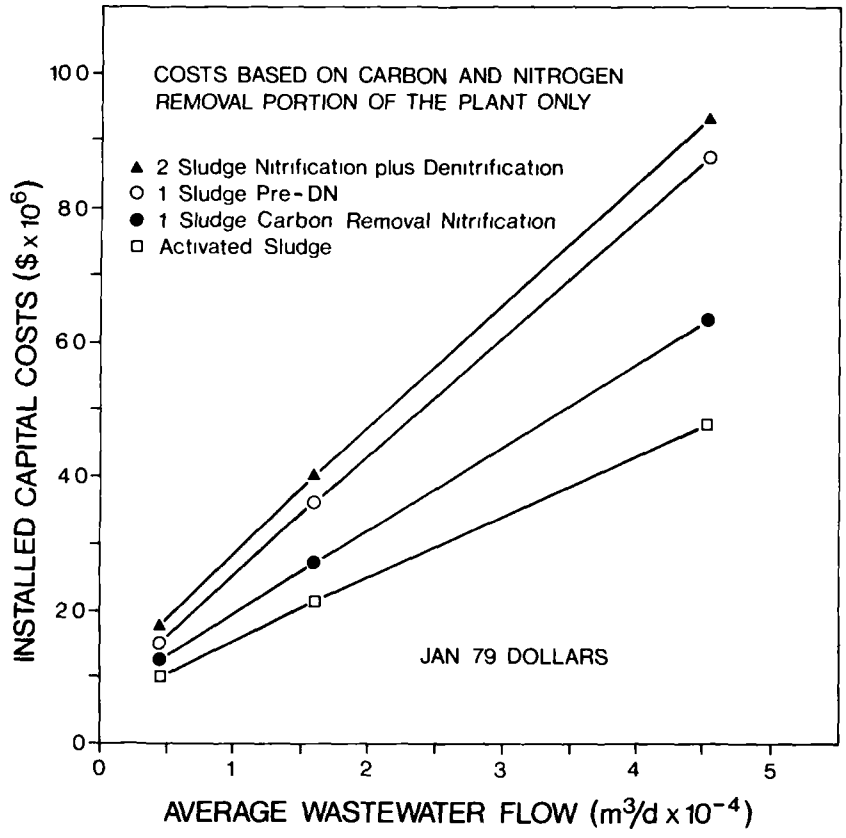


FIGURE 6. COSTS FOR CARBON AND NITROGEN REMOVAL PROCESSES

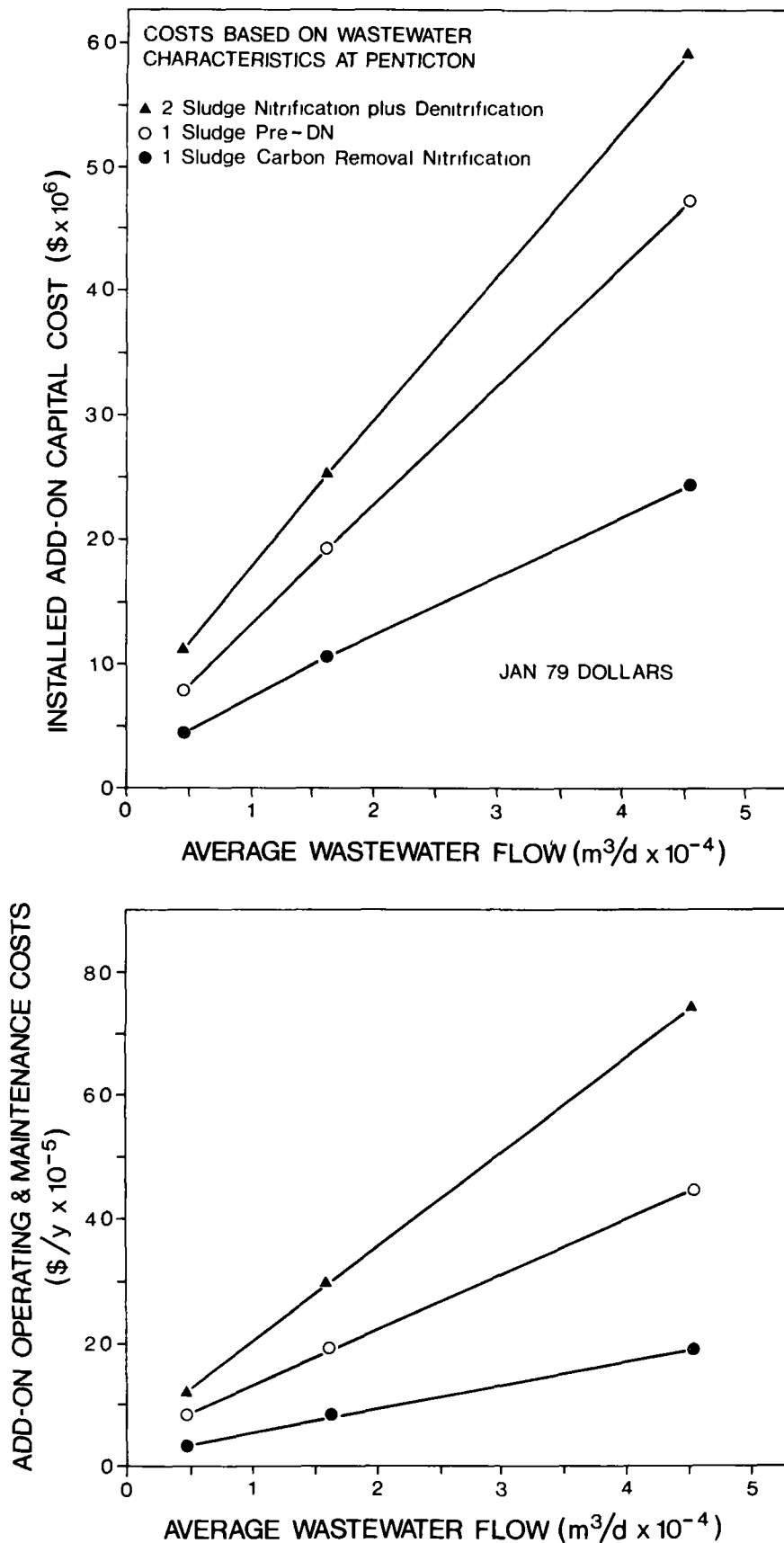


FIGURE 7. COSTS FOR "ADD-ON" CARBON AND NITROGEN REMOVAL PROCESSES

TABLE 12. DENITRIFICATION RATES USING INDUSTRIAL WASTES AS CARBON SOURCE

Waste	Initial FOC:N	Temp. (°C)	DN Rate (d <sup>-1</sup> )	DN Rate Relative to MeOH Control Run on Same Day	Substrate Consumption Ratios		Comments*
					kg FCOD Consumed kg NO <sub>T</sub> -N Removed	kg FOC Consumed kg NO <sub>T</sub> -N Removed	
<b>GROUP 1: The following wastes exhibited rates above the 95% confidence interval for methanol:</b>							
Rieder Distillery Fusel Oils	3.19	20.5	0.331	2.38	2.22	0.77	
Pea Blanchwater (Food Processor 'A')	3.27	18.5	0.261	2.08	5.71		
Jordan Wines Sludge Centrate	2.70	20.5	0.207	1.62	7.30	2.28	1
Labatt's Brewery Spent Grain Extract	3.18	20	0.197	2.40	5.48	2.46	1
Molson's Brewery Last Runnings	2.53	20.5	0.191	1.49	6.67	1.83	
Molson's Brewery Wort	4.29	21	0.187	2.27	6.17	1.35	1
McGuinness Distillers Thin Stillage	2.71	21	0.184	1.44	6.07	2.18	1
Methanol Still Bottoms (Org. Manuf. 'A')	1.49	20	0.170	0.86	3.66	0.71	1
National Starch Process Effluent	2.97	18	0.160	1.54	3.26		
Tomato Sludge (Food Processor 'A')	1.72	18	0.160	1.31	2.54	0.80	
McGuinness Distillers Fusel Oils	3.17	20	0.159	1.29	5.32	1.46	1
Molson's Brewery Beer	4.16	20.5	0.159	1.41	8.57	2.54	1
Du Pont Organic Acids Waste	2.61	21	0.142	1.29	5.14	1.65	1
Spent Sulphite Liquor (Can. Int. Paper)	1.77	19	0.137	1.24	3.94	0.79	2,3
Domtar Packaging Whitewater	3.72	21	0.137	2.13	5.74	1.48	1,3
Vulcan-Cincinnati Methyl Fuel	4.07	21	0.135	1.22	6.18	1.83	
Celanese Light Ends (Tray 25)	3.48	21	0.129	1.17	5.23	1.36	
Methanol Heads (Ontario Paper Co.)	1.53	18	0.128	1.06	2.45	0.82	
Rieder Distillery Grape Slops	3.21	20	0.125	1.94	5.00	1.42	1
Acetic Acid Waste (Dow Chemical Co.)	1.76	20	0.123	0.62	3.87	1.71	1
Du Pont High Boiling Organic Waste	2.53	19	0.119	1.07	6.02	1.36	2
McGuinness Distillers Light Distillate	9.91	20	0.117	1.61	10.16	1.52	
<b>GROUP 2: The following wastes exhibited rates within the 95% confidence interval for methanol:</b>							
Jordan Wines Pomace Extract	3.43	19	0.112	1.74	5.69	2.6	1
Millhaven Fibres Glycol Waste	2.94	20	0.103	1.60	5.98	0.92	(DN is
METHANOL CONTROL	2.87	20	0.097†	-	5.41†	1.17†	(Mean of
Molson's Brewery Trub	4.73	20	0.093	1.28	6.40	3.7	(14 Runs
Isopropanol Waste (Norwich)	4.40	20	0.090	1.40	3.64	1.82	2
Gos and Gris Cheese Whey	2.50	20	0.084	1.31	9.65	0.91	1
<b>GROUP 3: The following wastes exhibited rates below the 95% confidence interval for methanol:</b>							
Domtar Packaging Black Liquor	2.24	18	0.080	1.25	6.02	1.76	1,3
Waste Dextrose (Baxter Travenol Labs)	2.65	20	0.071	0.57	8.19	2.57	1
Formaldehyde Waste (University of Guelph)	3.62	20	0.042	0.37	6.21	1.38	

† Mean Value. \*LEGEND: 1)Wastes cause nitrite production. 2)Waste adds to TKN concentration. 3)Waste adds colour to clarified effluent.

A second objective of the project was to determine whether it was economically feasible to use the industrial wastes in place of methanol in biological denitrification. The factors considered in the assessment of the wastes were organic strength, uniformity of composition, denitrification rates achieved, volumes of wastes available on a regular basis, and transportation and storage costs. It was concluded that only those wastes having a filterable COD greater than 50 000 mg/L could be considered as economically feasible alternatives to methanol. Approximately 50% of the wastes tested had this required carbon concentration and were available continuously or in sufficient quantities to provide constant supply.

## 4 AWT - FILTRATION - BOD AND SS REMOVAL

In some Ontario locations the requirement exists for discharging very low levels of oxygen demanding substances. Upgrading existing plants with "add-on" process technology, such as filtration to reduce both BOD<sub>5</sub> and suspended solids loadings and, to a lesser extent phosphorus, has been a popular solution to this requirement.

In 1978, there were some 16 polishing filter installations operating in Ontario (Table 13). Rupke et al (1978) recently reported experiences with five tertiary filters in the York Region, just west of Toronto.

A variety of filter types are used, all operating in a downflow mode. A description of the five installations is presented in Table 14. The operating results, compared with the Ontario Ministry of the Environment guidelines, are set out in Table 15.

The effluent discharge levels of BOD<sub>5</sub>, SS and total phosphorus (total P) met the Ontario Ministry of the Environment's stringent guidelines in almost all cases. A notable exception was the Newmarket Water Pollution Control Plant [with a 5.4 mg/L BOD<sub>5</sub> at 900 m<sup>3</sup>/d (2.4 lmgd)] which discharged approximately 59 kg (130 lbs) of BOD<sub>5</sub>/d, when allowed only 45 kg/d (100 lbs/d).

To date, few significant operational problems have been experienced with the York Region's filters. Indeed, even though both the Stouffville (when operating) and John Street filters were hydraulically overloaded, they produced satisfactory effluents consistently.

TABLE 13. TERTIARY FILTER INSTALLATIONS\* IN ONTARIO (Black, 1978)

Location	Capacity		Comments
	m <sup>3</sup> /d	mgd	
Acton	2 830	0.625	Slow sand, underdrain
Caloden	4 545	1.0	Hardinge**
Cochrane	2 720	0.6	
Dysard Twp.	950	0.21	Slow sand, underdrain
Eramosa Twp.	770	0.17	Slow sand, underdrain
Georgetown	13 600	3.0	Hardinge**
Markham	3 400	0.75	Hardinge**
Newmarket	13 600	3.0	Hardinge**
North Don	6 350	1.4	Dual media
Orangeville	6 800	1.5	Hardinge**
Simcoe	9 950	2.2	Hardinge**
Stouffville	2 500	0.55	Slow sand, underdrain
Stratford	36 400	8.0	Down flow, four, anthracite and sand, 12.3 m <sup>3</sup> /m <sup>2</sup> ·h (5 U.S. gpm/ft <sup>2</sup> )
Terrace Bay	454	0.1	Slow sand, underdrain
Thornhill (John St)	3 400	0.75	
Unionville	3 640	0.8	

\* Effluent quality is generally expected to be:  
BOD<sub>5</sub> 5 mg/L; SS 5 mg/L, total P 0.2 to 0.5 mg/L.

\*\* Hardinge filter - continuous backwash, low head,  
- 20.4 to 38.2 cm (8 to 15") sand,  
- average feed rate 1.92 m<sup>3</sup>/m<sup>2</sup>·h (0.65 Igpm/ft<sup>2</sup>),  
- peak feed rate 6.9 m<sup>3</sup>/m<sup>2</sup>·h (2.34 Igpm/ft<sup>2</sup>).

TABLE 14. FILTER SPECIFICATIONS

Location	Average Daily Flow m <sup>3</sup> /d (Imgd)	Filter Type (Number)	Total Design Capacity m <sup>3</sup> /d (Imgd)	Dimensions: 1 Unit				Media/Unit	
				Configuration/ Dimensions m (ft)	Filter Head m (ft)	Filter Area m <sup>2</sup> (ft) <sup>2</sup>	Filter Rate (Design) m <sup>3</sup> /m <sup>2</sup> ·h (l/gpm/ft <sup>2</sup> )	Type and Depth m (ft)	Volume (Media) m <sup>3</sup> (ft <sup>3</sup> )
North Don WPCP (Richmond Hill)	3 140 (0.69)	Pressure (2)	6 400 (1.4)	Circular Dia. 6.4 (21)	7.6 (25)	32.2 (346.8)	0.48 (1.4)	Mixed 1) Anthracilt 0.6 (2) 2) Filter Sand 0.3 (1.0)	29.4 (1 040)
Newmarket WPCP	10 900 (2.40)	Gravity (2)	13 200 (2.9)	Rectangular 3.8x15 (12.5x48.67)	0.46 (1.5)	57 (608.4)	0.57 (1.67)	Single Sand 0.28 (0.92)	15.8 (559.7)
John St. WPCP (Thornhill)	3 900 (0.86)	Gravity (1)	3 400 (0.75)	Rectangular 3.8x15.3 (12.5x50)	0.46 (1.5)	58 (625)	0.28 (0.83) (1966)	Single Sand 0.28 (0.92)	16.3 (575)
Unionville WPCP	2 000 (0.44)	Pressure (1)	3 640 (0.8)	Rectangular 3.7x8.3 (11.25x25.25)	3.2 (10.5)	23.6 (255)	1.1 (3.2) (Using 0.67 Area)	Mixed 1) Anthracite 0.45 (1.5) 2) Sand 0.3 (1.0)	18.2 (638)
Stouffville WPCP	2 360 (0.52)	Gravity (1)	2 500 (0.55)	Rectangular 61x30.5 (200x100)	0.13 (0.42)	1 850 (20 000)	0.007 (0.02)	Mixed 1) Gravel 2) Sand 1.0 (3.0)	1 730 (60 000)

TABLE 15. OPERATING DATA AND COMPARISON TO MOE REQUIREMENTS

Location	BOD <sub>5</sub> Required	BOD <sub>5</sub> Results	Suspended Solids Required (mg/L)	SS Results (mg/L)	Total P Required (mg/L)	Total P Results (mg/L)	Total Nitrogen as N Required (mg/L)	Total Nitrogen as N Results (mg/L)
North Don WPCP	5 mg/L	2.6 mg/L	5	<5.3	1.0	0.89	8	12.6
Newmarket WPCP	45 kg/d (100 lbs/d)	59 kg/d (129.6 lbs/d)	15	<9.0	1.0	0.78	-	-
John St. WPCP (Thornhill)	10 mg/L)	6.3 mg/L	10	<7.5	1.0	0.85	-	-
Unionville WPCP	6.5-7 mg/L	4.8 mg/L	6.5-7	<7.4	1.0	1.3	-	-
Stouffville WPCP *	41 kg/d (90 lbs/d)	11 kg/d (24 lbs/d)	15	<5.8	1.0	1.05	Filtered Results *	69% Year *

\* Filter is not operated for 31% of year (i.e., during freezing weather).



## 5 AWT - OZONE

In Canada, there are no full scale wastewater treatment plants using ozone as a specific wastewater treatment unit process. However, several pilot scale studies have been undertaken using ozone for effluent disinfection (Tonelli et al, 1979; Smith and Given, 1978).

Another preliminary pilot scale study was undertaken by Jones and Dufort (1976) on the direct physico-chemical treatment of sewage with ozone. The wastewater treated was raw sewage from the Centre Hospitalier Universitaire (CHU) of the Université de Sherbrooke. The raw sewage was trucked to the university and stored in six stirred reservoirs with a total capacity of  $11.4 \text{ m}^3$  (2500 Igal). Normal flowrate for the plant was 11.4 L/min (2.5 Igpm), providing three to nine-hour batch runs. Capacity of the pilot plant was 22.8 L/min (5 Igpm).

The pilot plant consisted of:

- 1) A chemical clarification unit (coagulation/flocculation/sedimentation) with provision for the addition of ferric chloride and lime (Figure 8).
- 2) An ozonation unit consisting of four ozone contact stages with ozone produced from oxygen (Figure 9). The average ozone feed rate was 26 g/h. Ozone consumed averaged 25 mg/L.
- 3) A dual media filter.

Forty-two runs were made using this system. The results of several selected runs when the complete system was operating are presented in Table 16.

One run was conducted using the effluent from this system and re-running it through the ozone contactors to determine if the  $\text{BOD}_5$  could be further reduced. From this run the following results were obtained:  $\text{BOD}_5$  - 16 mg/L; SS - 1.2 mg/L; total P - 0.40 mg/L; and total N - 8.3 mg/L.

On the basis of the results from this one run, the authors developed a total cost for a  $35.8 \times 10^3 \text{ m}^3/\text{d}$  (7.9 Imgd) plant and estimated this to be 6.7 cents/ $\text{m}^3$ . This was compared with the cost for equivalent activated carbon treatment which was estimated to be 5.8 cents/ $\text{m}^3$ .

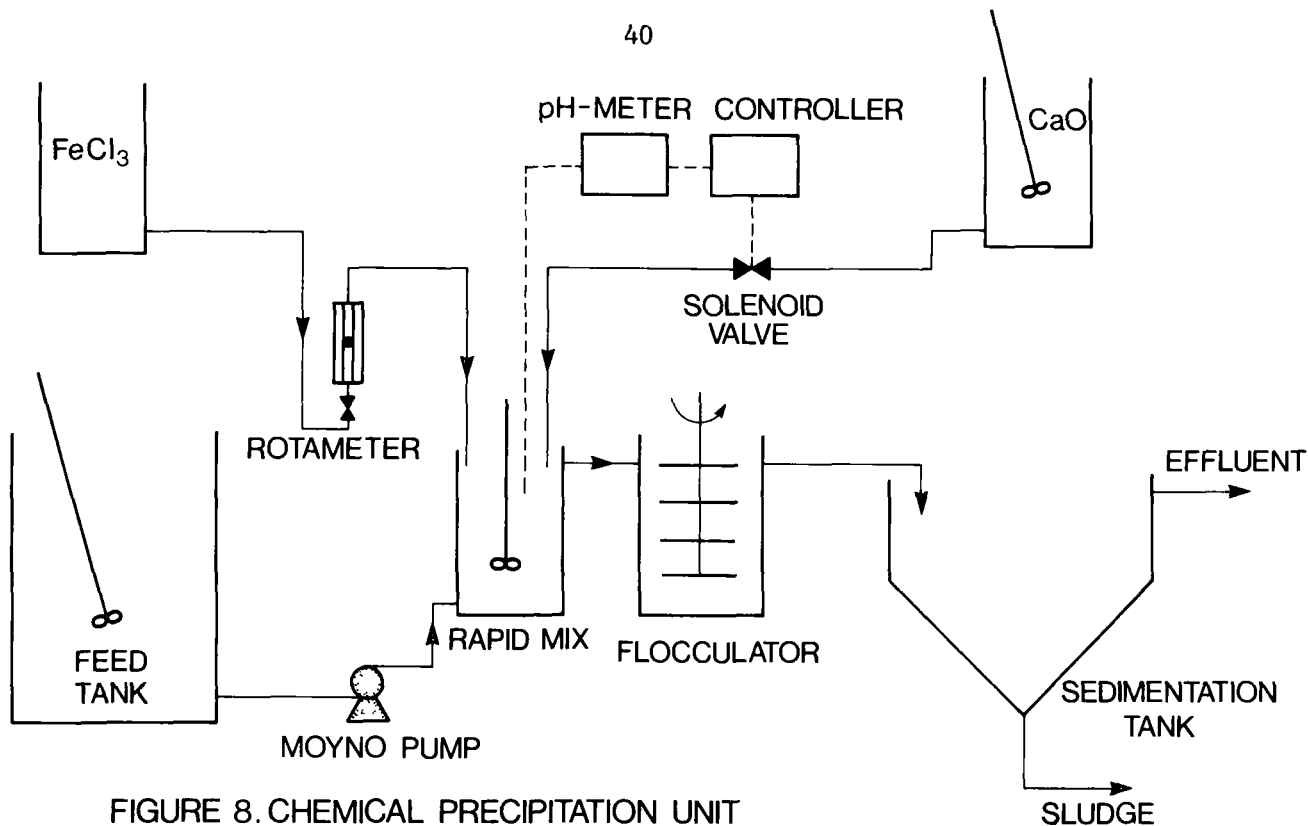


FIGURE 8. CHEMICAL PRECIPITATION UNIT

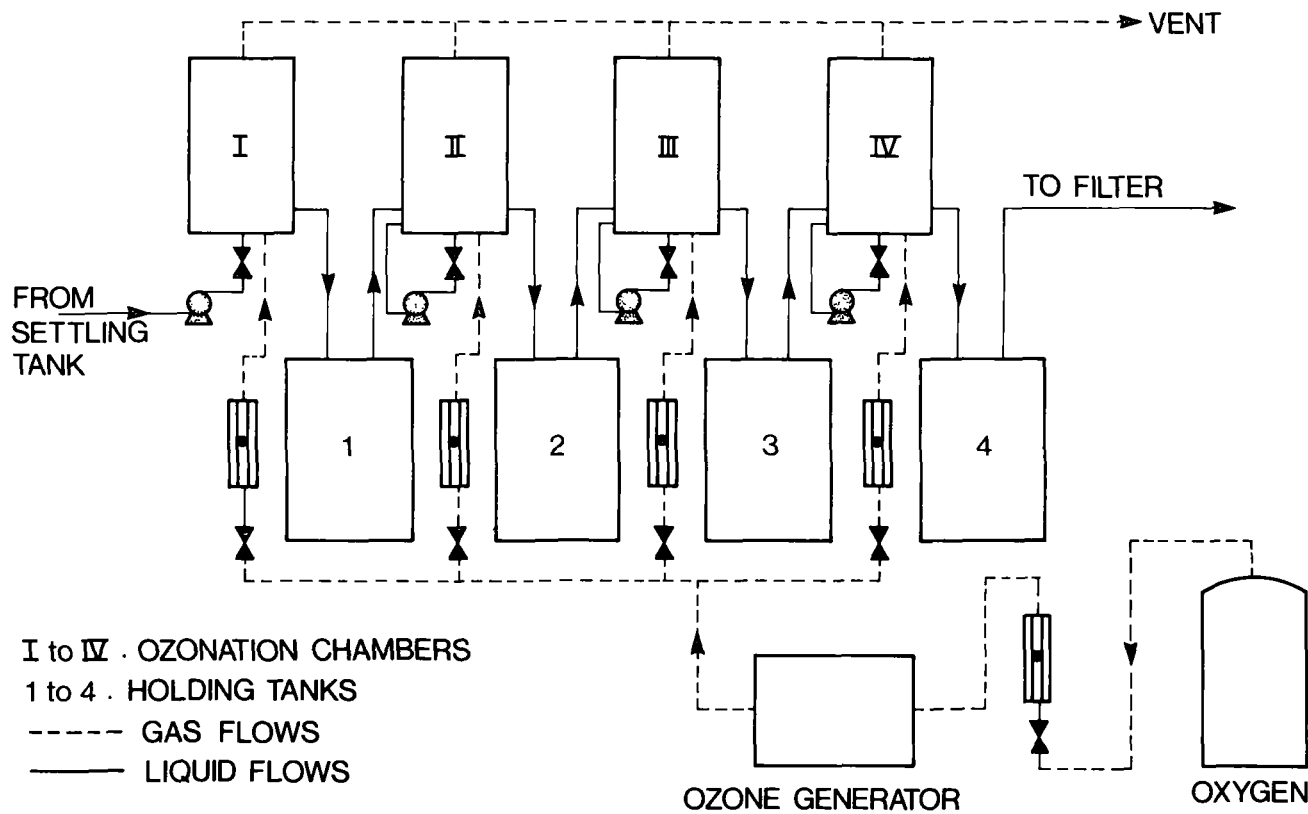


FIGURE 9. OZONATION PILOT PLANT

TABLE 16. SUMMARY OF PHYSICO-CHEMICAL TREATMENT WITH OZONE

Stage Parameter	Influent Conc. (mg/L)	Post Coagulation		Post Ozonation		Post Filtration*	
		Conc. (mg/L)	Overall Removal (%)	Conc. (mg/L)	Overall Removal (%)	Conc. (mg/L)	Overall Removal (%)
BOD <sub>5</sub>	213	93	56	70	67	63	70
SS	91	21	77	28	69	9	90
Total P	8.1	2.3	72	2.2	73	1.2	85
Total N	22	18.1	18	13.7	38	13.3	40

\* Final system effluent.

## 6 AWT - REVERSE OSMOSIS

There are no full scale reverse osmosis (RO) systems treating municipal wastes in Canada. A limited amount of work was conducted at the WTC (Johnston and Lim, 1978a; Johnston and Lim, 1978b) using laboratory and pilot scale systems (Figures 10, 11 and 12) for the treatment of municipal wastes and simulated industrial wastes. A two-stage research program was undertaken in 1974 and is summarized in the following paragraphs.

The first stage of the program was designed to examine the effectiveness of RO as an advanced wastewater treatment process. The effectiveness of this technique for the removal of nutrients, bacteria and various chemical constituents was examined. Laboratory test cells and eight tubular modules\* were employed to treat nutrient solutions, various secondary sewage treatment plant effluents, nutrient spiked sewage and raw sewage. Cellulose acetate membranes with 75% and 90% salt rejection were employed. Optimum operating conditions for the pilot plant were determined and chemical cleaning techniques were applied to restore permeate flux levels. Even though flux was adversely affected by membrane fouling, results indicated high and stable removals for most constituents. Although not yet economically competitive, especially for the treatment of municipal wastes, RO represents a potentially advantageous advanced wastewater treatment technique. Typical results are presented in Tables 17 and 18.

One advantage of RO is its ability to remove specific substances. The second phase of the study determined the effectiveness of RO in the removal of the toxic substances: arsenic; selenium, cyanide (simple and complex salts), nitrilotriacetic acids (NTA), phenols, aldrin, dichlorodiphenyltrichloroethane (DDT), chlordane, endrin, malathion, and parathion. Experiments were conducted in the laboratory and a specially equipped mobile pilot plant (Figure 10). Data on constituent removal efficiencies are presented along with RO system permeation rates and variations in those rates with time (Figure 13). Membrane fouling problems and cleaning methods were examined.

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\* Westinghouse Electric Corporation, U.S.A.

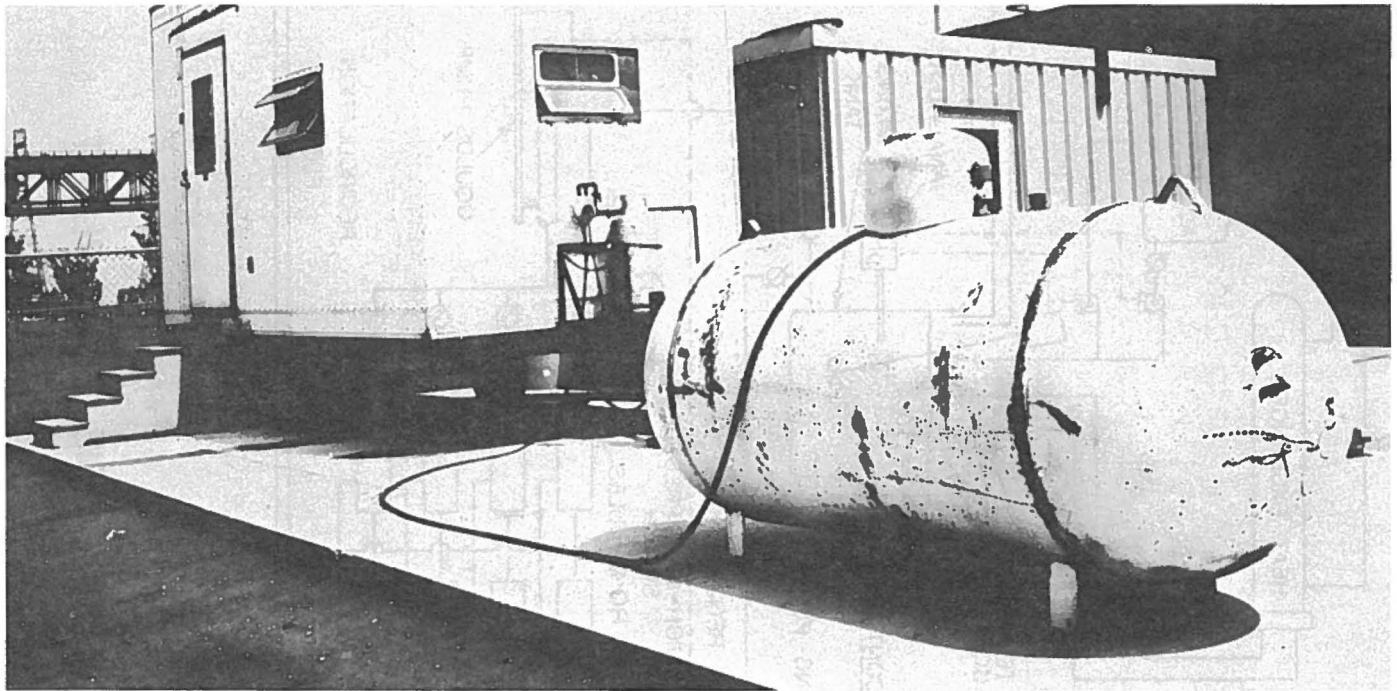


FIGURE 10. MOBILE REVERSE OSMOSIS PILOT PLANT

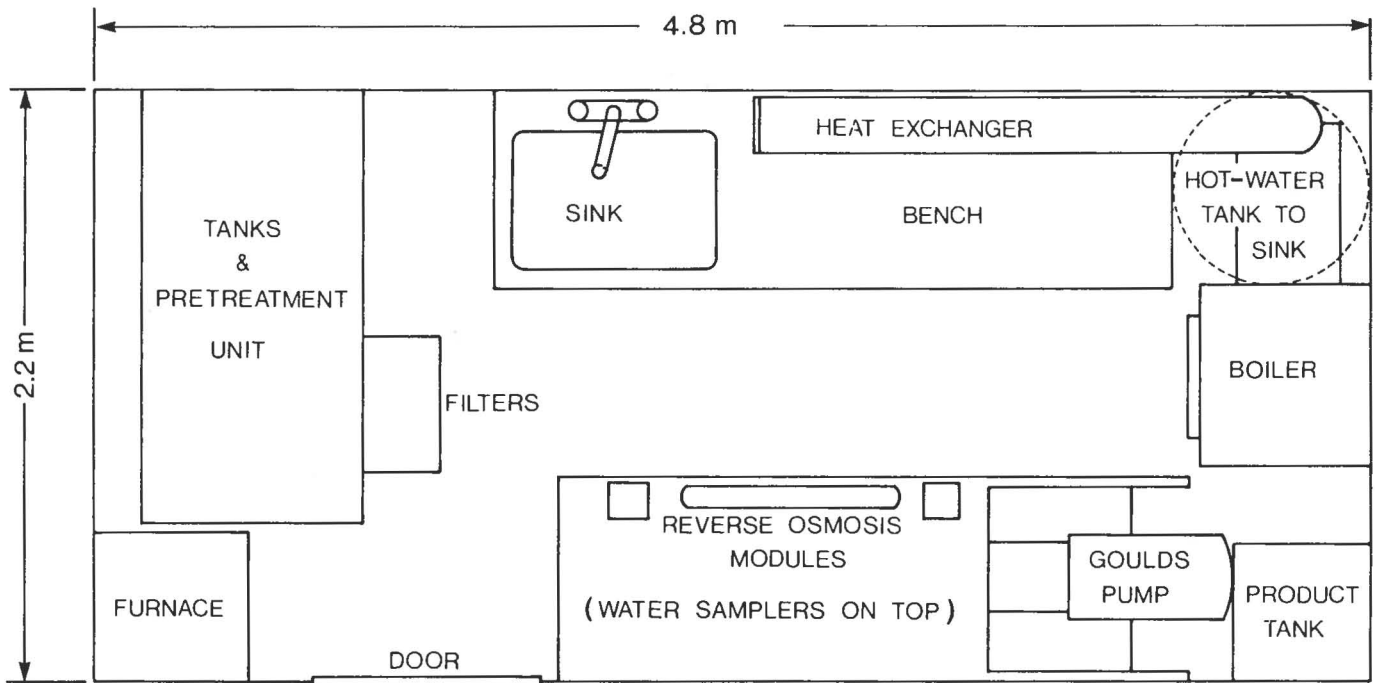


FIGURE 11. EQUIPMENT LAYOUT IN TRAILER

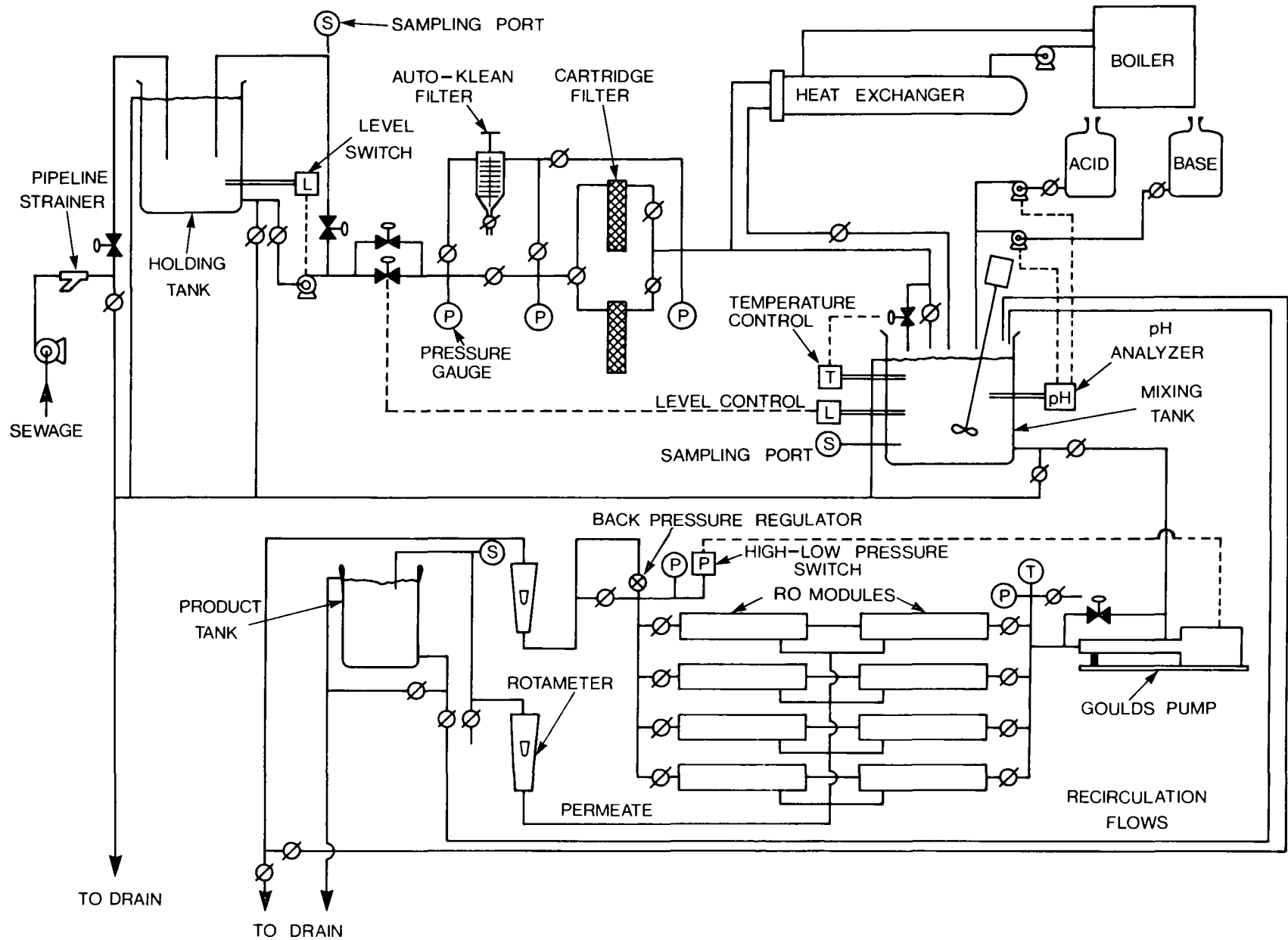


FIGURE 12. FLOW DIAGRAM FOR REVERSE OSMOSIS PILOT PLANT

TABLE 17. REPRESENTATIVE REVERSE OSMOSIS EFFLUENT PARAMETERS

Parameter	WTC Pilot Plant		Burlington Skyway Plant		Detection Limit	Sensitivity (mg/L)
	Feed (mg/L)	Permeate (mg/L)	Feed (mg/L)	Permeate (mg/L)		
TOC	4.0 - 12.0	<0.1 - 3.0	6.9 - 15.0	1.9 - 2.0	0.5 0.1 <sup>3</sup>	0.5 0.1
TIC	19.4 - 37.0	1.0 - 7.0	30.5 - 33.1	3.0	0.5 0.1 <sup>3</sup>	0.5 0.1
NH <sub>3</sub> (N)	0.01 - 0.17	0.01 - 0.17	0.6 - 0.7	0.05 - 0.3	0.005	0.001
NO <sub>3</sub> + NO <sub>2</sub> (N)	10.2 - 18.8	4.6 - 9.0	7.6 - 9.7	3.4 - 4.6	0.005	0.001
DIP (P)	0.1 - 2.5 <sup>1</sup> 0.03 - 0.12 <sup>2</sup>	<0.001 - 0.04 <sup>1</sup> <0.001 - 0.002 <sup>2</sup>	1.6 - 3.5	0.05 - 0.07	0.001	0.001
TP (P)	0.18 - 2.6 <sup>1</sup> 0.19 - 0.38 <sup>2</sup>	<0.001 - 0.18 <sup>1</sup> <0.001 - 0.38 <sup>2</sup>	2.2 - 3.5	0.05 - 0.07	0.001	0.001
COD	9.9 - 42.6	1.0 - 5.0	24.2 - 41.0	1.8 - 4.8	1.0	0.1
BOD <sub>5</sub>	<5	<5		<5	5	1.0
Colour (CU)	10 - 30	<5 - 10	10 - 20	5	5	5.0
Turbidity (JTU)	0.5 - 2.0	<0.1 - 1.2	2.8 - 7.8	0.2 - 0.3	0.1	0.1
Total Hardness	246.0 - 319.4	18.0 - 40.0	232 - 241	23.6 - 28.1	0.5	0.5
TDS	591 - 755 611 - 739	87 - 150 113 - 152	527 - 596	93.2 - 94.4	1	0.5
FDS	470 - 608 515 - 638	40.4 - 97.5 83.2 - 104.0	440 - 503	72.4 - 73.2	1	0.5
SS	1.2 - 6.0	<1.0	8.4 - 10.8	<1.0	1	0.1
FSS	<1.0 - 3.2 2.8 - 4.4	<1.0	1.2 - 4.0	<1.0	1	0.1
Cl <sup>-</sup>	108 - 158	18.1 - 28.2	105 - 115	21.4	0.1	0.1
SO <sub>4</sub> <sup>=</sup>	100 - 174 215 - 250	1.0 - 3.0 3.5 - 5.0	72 - 90	2.0	2.0	1.0

<sup>1</sup> Baseline operation.

<sup>2</sup> Alum.

<sup>3</sup> Two methods were used.

TABLE 18. TYPICAL REMOVAL EFFICIENCIES BY  
THE REVERSE OSMOSIS SYSTEM

Parameter	% Removal	
	Initial	Final*
TOC	50-90	50-90
TIC	96	88
NH <sub>3</sub> (N)	55-90	45-80
NO <sub>3</sub> + NO <sub>2</sub> (N)	56	47
DIP (P)	99.5	98.5
TP (P)	99.5	98.5
COD	>95	94
BOD <sub>5</sub>	-	-
Colour (CU)	50->75	50->75
Turbidity (JTU)	50->95	50->95
T. Hardness (CaCO <sub>3</sub> )	92	92
TDS	85	81
FDS (550°C)	85	82
SS	-	95
FSS	-	>94
Cl <sup>-</sup>	83	80
SO <sub>4</sub> <sup>-</sup>	98	98

\* After four months of operation.

Note: Initial and final salt rejections  
were 81.3% and 70.0%, respectively.

It was determined that pesticides and organic phosphates are almost completely removed by RO, while the heavy metal removal rate was consistently greater than 95% (Table 19). The removal rates for other substances examined, such as complex cyanide, NTA, selenium, arsenic and phenols, varied between 43% and 90%.



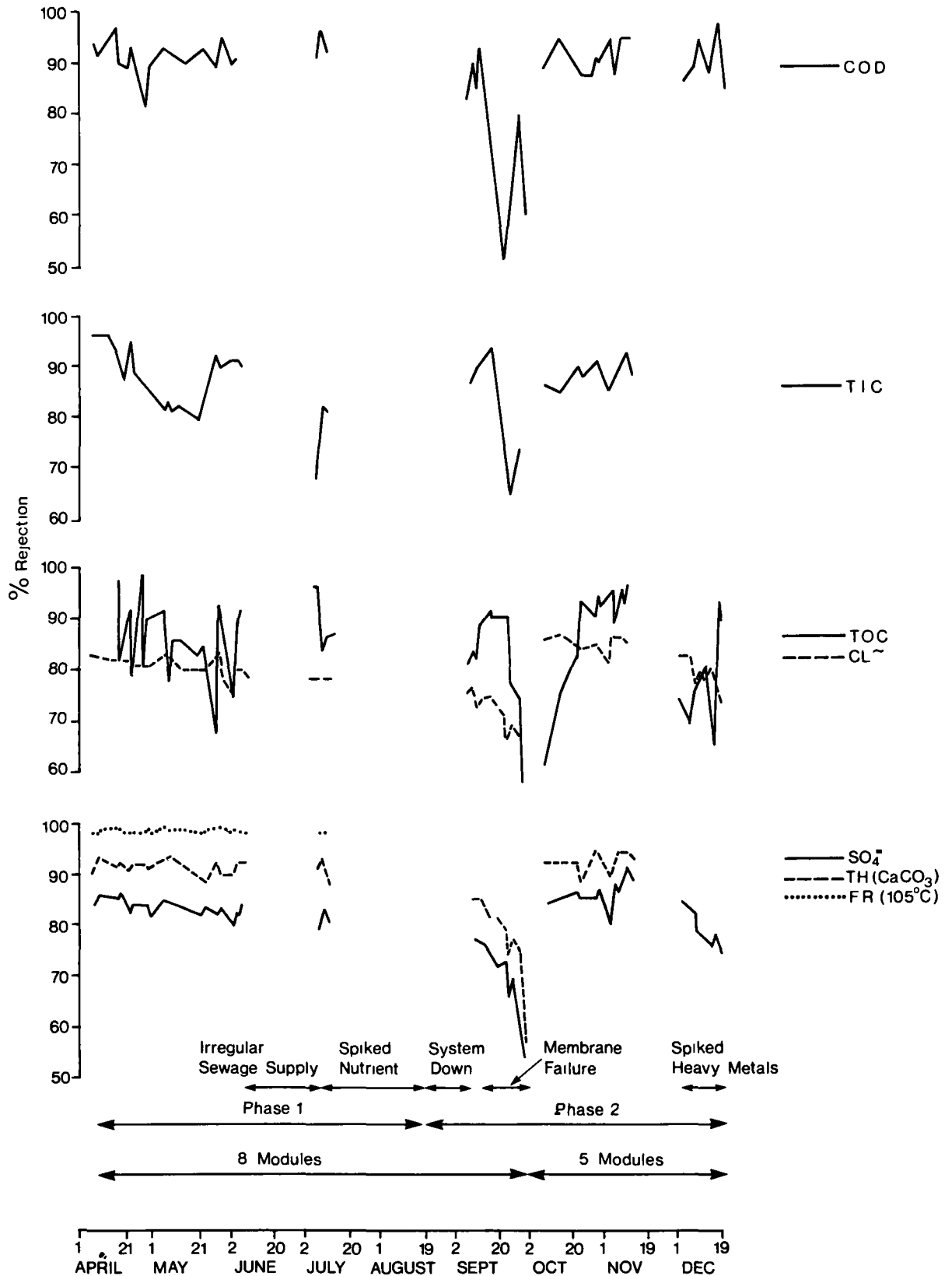


FIGURE 13. VARIATION OF REMOVAL EFFICIENCIES WITH TIME

While RO is an excellent AWT technology, its application will probably be limited to industrial waste treatment problems, specifically those which result in the recovery of a usable (commercially valuable) by-product. A pilot project is currently underway at a Canadian dairy for the treatment of its wastes and the recovery of whey for by-product utilization.

TABLE 19. METAL REMOVAL EFFICIENCIES BY REVERSE OSMOSIS

Metal Chloride	pH of 10 mg/L Solution	Percent Metal Removal*	
		NaCl <sub>70</sub>	NaCl <sub>90</sub>
(1) K <sup>+1</sup>	6.3	88.1	94.0
(2) Ba <sup>+2</sup>	5.8	88.3	100.0
(3) Be <sup>+2</sup>	4.3	83.8	97.0
(4) Ca <sup>+2</sup>	5.9	80.8	94.1
(5) Cd <sup>+2</sup>	5.5	85.1	98.3
(6) Co <sup>+2</sup>	5.8	81.9	96.0
(7) Cu <sup>+2</sup>	5.4	84.1	98.6
(8) Fe <sup>+2</sup>	5.1	82.0	96.2
(9) Mg <sup>+2</sup>	6.1	73.5	90.0
(10) Mn <sup>+2</sup>	5.8	84.2	97.5
(11) Ni <sup>+2</sup>	5.9	81.8	95.2
(12) Pb <sup>+2</sup>	5.2	85.5	97.6
(13) Sn <sup>+2</sup>	4.0	99.3	100.0
(14) Sr <sup>+2</sup>	5.9	84.1	96.3
(15) Zn <sup>+2</sup>	5.6	83.4	97.3
(16) Al <sup>+3</sup>	4.4	97.3	100.0
(17) Cr <sup>+3</sup>	4.2	99.1	100.0
(18) Fe <sup>+3</sup>	3.4	100.0	100.0

\* 10 mg/L solutions tested at 1724 kPa (250 psi)

Separations noted are for metal removals from a 10 mg/L solution when permeated through the reverse osmosis static test cell.

## 7 PHYSICAL-CHEMICAL WASTE TREATMENT

One of the investigations at the WTC addressed the potential application of physical-chemical waste treatment to small, isolated communities of a few thousand people or less. The unique design and operational problems associated with small treatment systems are well-known and are not normally encountered in large plants. Many of the problems are related to the variable organic and hydraulic loads under which small plants must operate. Problems can also be attributed to the fact that these small plants often receive inadequate maintenance and operator attention.

To meet the treatment requirements of small communities, a project was initiated in 1973 to develop and demonstrate physical-chemical treatment systems with the potential of ensuring improved effluent quality and consistency of treatment. Two processes were studied at pilot scale, 91 L/min (20 Igpm):

- 1) an integrated coagulation-adsorption process using aluminum sulphate and powdered activated carbon; and
- 2) a lime-coagulation (to pH 11.5) process, including two-stage recarbonation, followed by pressure filtration and adsorption on granular activated carbon.

The integrated coagulation-adsorption process operated successfully with respect to effluent quality and process reliability in experiments conducted between mid-1973 and mid-1975 (Table 20). Although the overall treatment efficiency was relatively high, with BOD<sub>5</sub> and SS concentrations of less than 15 mg/L, the limited improvement in treatment efficiency resulting from the use of powdered activated carbon did not justify its use on a once-through basis.

The high-lime granular activated carbon (GAC) adsorption process produced a high quality effluent with BOD<sub>5</sub> and SS concentrations of less than 10 mg/L (Table 21).

TABLE 20. COAGULATION-ADSORPTION PROCESS RESULTS

Parameter	Influent (mg/L)	Effluent (mg/L)	Removal (%)
BOD <sub>5</sub> - total	163	13	92
COD - total	633	54	91
TOC - filtered	35	17	51
SS - total	448	12	97
- volatile	315	11	97
P - total	13.0	1.3	90
Al - total	3.96	0.45	89
Cu - total	0.55	0.03	95
Alkalinity - total	109	80	27

Note: Operating conditions include 100 mg/L powdered activated carbon, 150 mg/L alum, 0.5 mg/L anionic polymer, 5% volumetric sludge recycle.

TABLE 21. HIGH LIME - GAC ADSORPTION PROCESS RESULTS

Parameter	Influent (mg/L)	Effluent (mg/L)	Removal (%)
BOD <sub>5</sub> - total	125	8	94
- filtered	25	7	72
COD - total	415	30	93
- filtered	93	26	72
TOC - filtered	33	10	70
SS - total	308	6	98
- volatile	244	6	98
P - total	7.7	0.3	96
- filtered	2.9	0.2	93
Hardness - total	278	175	37
Alkalinity - total	270	110	59

Total phosphorus was reduced to 0.3 mg/L in the effluent. However, during the experimental program in 1975, this process suffered from an inordinate number of operational problems. These were investigated in 1976 through laboratory experiments and pilot plant modifications. The recarbonation system was extensively modified and tested. Additional studies included effluent toxicity to fish, disinfection effectiveness at high pH, and heavy metal removal.

The final reports on both pilot scale studies are expected to be available in 1980 (Averill and Stickney, 1980a; Averill and Stickney, 1980b). The tentative conclusion drawn from these experiments was that a simple independent physical-chemical process, consisting of chemical coagulation, flocculation, sedimentation and filtration may be the most practical solution to the problem of treating wastewater under the conditions peculiar to small treatment plants while still producing a high quality effluent. Further comparative field studies, however, are required to validate this conclusion.

## 8 CONCLUDING REMARKS

The use of AWT technology in Canada has been briefly reviewed. Different approaches have been taken to resolve specific problems. In Ontario, physical-chemical treatment for phosphorus removal has been accomplished by in-plant modifications to existing treatment facilities. For nitrogen conversion, in-plant modifications will likely be used where appropriate, although one municipality is proposing an "add-on" facility: a rotating biological contactor. Polishing filters are being utilized for further suspended solids and BOD<sub>5</sub> reductions.

In the one system referred to in Saskatchewan, an "add-on" physical-chemical tertiary treatment system for phosphorus removal and concurrent reduction of other constituents is in operation.

In the Okanagan Basin, one community selected a tertiary spray irrigation system for the complete removal of contaminants, while in-plant modifications for phosphorus removal are used by two other municipalities.

Thus, in Canada, there is no "across-the-board" requirement for the application of sophisticated AWT technologies; rather, approaches to AWT technology are tailored to meet the specific needs for high quality effluents.

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