International Joint Commission (IJC) Digital Archive

1978-07-01

Relative Costs of Achieving Various Levels of Phosphorus Control at Municipal Wasterwater Treatment Plants in the Great Lakes Basin: A Technical Report

International Joint Commission. Great Lakes Regional Office

W. R. Drynan

INTERNATIONAL REFERENCE GROUP ON GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES

INTERNATIONAL JOINT COMMISSION

RELATIVE COSTS OF ACHIEVING VARIOUS LEVELS OF PHOSPHORUS CONTROL AT MUNICIPAL WASTEWATER TREATMENT PLANTS IN THE GREAT LAKES BASIN

DISCLAIMER

The work discussed in this document was carried out in support of the efforts of the Pollution from Land Use Activities Reference Group, an organization of the International Joint Commission, established under the Canada-United States Great Lakes Water Quality Agreement of 1972. Funding was provided for the contract with James F. MacLaren Ltd. by the IJC Great Lakes Regional Office.

Findings and conclusions are those of the author and do not necessarily reflect the views of the Reference Group or its recommendations to the Commission.

TABLE OF CONTENTS

TABLE OF CONTENTS

PAGE NO.

DISCLAIMER i

LIST OF TABLES v

LIST OF FIGURES vii

INTRODUCTION 1

DESCRIPTION OF COMPUTER MODEL 3

    Liquid Treatment Schemes and Process Design Parameters ... 4

    Chemical Requirements for Phosphorus Removal 6

    Sludge Treatment Schemes and Process Design Parameters ... 7

    Input Information 8

    Output Information 9

RELATIVE COSTS TO ACHIEVE PHOSPHORUS REDUCTIONS IN MUNICIPAL WASTEWATER TREATMENT PLANT DISCHARGES 11

VALIDITY OF COST ESTIMATES 15

CONCLUSIONS 19

RECOMMENDATIONS 21

REFERENCES 23

APPENDIX A - TREATMENT PLANT INPUT DATA AND OUTPUT SUMMARIES ... A

APPENDIX B - SUMMARY OF SANITARY ENGINEERING CRITERIA RELATING TO PHOSPHORUS REMOVAL .... B

APPENDIX C - LISTING OF PLANT SPECIFIC VARIABLES C

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

INTRODUCTION

Under the terms of the Great Lakes Water Quality Agreement, the Governments of Canada and the United States agreed to develop and implement programs and measures to reduce inputs of phosphorus to the Great Lakes System. These programs were to include construction and operation of waste treatment facilities to remove phosphorus from municipal sewage and could include regulations limiting or eliminating phosphorus from detergents sold for use within the Great Lakes Basin. It was further agreed that the total phosphorus concentrations in the effluents from municipal waste treatment plants discharging in excess of one million gallons per day, shall not exceed a daily average of one milligram per litre into Lake Erie, Lake Ontario and the International Section of the St. Lawrence River.

During the past five years, the various jurisdictions in the Great Lakes Basin have adopted a range of different strategies for the control of phosphorus inputs within the general guidelines of the Agreement. While all of these programs are not yet fully implemented, concerns have been expressed that, even when fully implemented, they will not achieve the objectives for control of eutrophication in the Great Lakes and more stringent controls may be necessary.

In addition, many of the jurisdictions are currently reviewing the cost-effectiveness of their present programs. As a result, experience gained in implementing the existing programs, complemented with findings of continuing applied research, should provide a base of information upon which to assess the implications of future and alternate phosphorus control strategies.

The International Joint Commission suggested that a study be carried out to determine the impact of phosphorus control programs on municipal wastewater treatment, particularly with respect to sludge production and attendant costs for treatment and disposal. At the same time, the Research Advisory Board's committee on Water and Wastewater Treatment was given a referral from the Water Quality Board to determine the feasibility of achieving concentrations of less than 1.0 mg/L "P" (total phosphorus) and as low as 0.1 mg/L "P" in the municipal wastewater treatment plant effluents. Consequently, this study was undertaken to evaluate, in as rigorous a manner as practical, the implications of alternative legislative restrictions on the allowable concentrations of phosphorus in detergents and in the effluents of municipal wastewater treatment plants on the cost of building and operating these plants.

A contract was awarded by the International Joint Commission's Great Lakes Regional Office to James F. MacLaren Ltd.,* to develop, utilizing computer model simulation technology, the relative capital and operating costs to achieve various levels of phosphorus removal at 43 major municipal wastewater treatment facilities in the Lake Erie and Lake Ontario drainage basins.

Present sewered populations, wastewater flow and characteristics, and waste and sludge treatment processes in use or planned were used as initial conditions. Treatment facilities were designed and operated, using standard sanitary engineering design parameters, assuming (a) no requirement for phosphorus removal, and (b) phosphorus removal to achieve effluent concentrations of 1.0, 0.5, 0.3 and 0.1 mg/L as "P".

1

A computer model was used to simulate wastewater treatment facilities, including sludge treatment and disposal, for each of the 43 municipalities, under various phosphorus final effluent requirements. Capital costs required to build the facilities in 1975, expand them as necessary over a 25 year period were simulated (1). Some of the more significant engineering assumptions related to phosphorus removal technology used in the simulation model are discussed in Appendix B.

The total phosphorus loads which would be discharged to the Great Lakes System under each assumed scenario were also determined.

The results for the plants in the Lake Erie and Lake Ontario Basins are summarized in Tables A2 and A3 respectively in Appendix A. These results were then used to determine per capita costs for use in the PLUARG Overview modelling activities to estimate costs for point source reductions in phosphorus loads to the Great Lakes to compare with costs to reduce inputs from land runoff.

2

DESCRIPTION OF COMPUTER MODEL

In October 1973, the United States Environmental Protection Agency published a report of Yeaple, Barnes and DiGiano entitled, "A Computer Model for Evaluating Community Phosphorus Removal Strategies" (2). The model described within this report is known as "REMOVE". "REMOVE", after suitable modification for the specific requirements of this study, was used as the base model.

REMOVE was built upon earlier work by Smith (3) which involved the simulation of conventional wastewater treatment schemes, and by Patterson and Banker (4) where construction, operating and maintenance costs associated with wastewater treatment processes are further defined. These cost functions have been adapted for computer use by Eilers and Smith (5).

The capabilities and costs of unit processes used more recently for sewage treatment, such as coagulating chemical addition systems, tertiary filtration and settling equipment and air flotation sludge thickening have been added to the model.

All unit processes so defined have then been used to establish "liquid-phase treatment system options" and "sludge handling system options". Using these functions REMOVE is capable of providing data which gives an indication of the phosphorus removal cost-effectiveness of wastewater treatment schemes.

The nature of the program allows input of a significant amount of plant specific information for the simulations. Lacking plant specific information, the program will revert to preprogrammed values of required parameters. Consequently, the model is sufficiently sophisticated to allow a fairly complete fitting to both the sewage and sludge characteristics and the physical components of many wastewater treatment facilities.

The characteristics of the model in simulating sewage treatment plant costs are investigated to a degree in "Sensitivity Analysis of a Phosphorus Removal Strategy Computer Model" (6). In this study, model predicted treatment costs are documented as a function of each of eighteen individual input variables for each of five specific sewage treatment plants. Based upon information generated in this manner, the study report ranks the eighteen input variables by their significance in altering predicted treatment costs. The report also comments that there is a need for further refining the model by more specifically defining the role of electricity costs and a need for updating other cost functions because of the limitations of the indexing approach.

Unfortunately, historical information regarding the extent to which the model has been used by municipalities or others has not been found. As a consequence, commentaries on how well the model simulates and evaluates treatment alternatives are not available.

3

REMOVE was developed for use by individual municipalities in the preliminary evaluation of alternatives for attaining required degrees of phosphorus removal in sewage treatment plant effluents.

New input and output formats, to suit the specific objectives of this project, were necessary.

Additional information regarding the technology of phosphorus removal at domestic sewage treatment plants has become available since REMOVE was formulated in the lates 1960's. Consequently, significant revisions and updating of this type were made in the sanitary engineering criteria used in the model.

In addition, it was found that many of the 43 plants to be simulated have liquid and sludge treatment schemes which are not included in REMOVE. Consequently, new process schemes were added.

LIQUID TREATMENT SCHEMES AND PROCESS DESIGN PARAMETERS

The following types of treatment plants exist in the study area:

Primary (Canada)
Secondary (Activated sludge and trickling filter)
Physical/Chemical (U.S.A. only)
Enriched oxygen

Based on current technology, liquid schemes were delineated to achieve 1.0, 0.5, 0.3, 0.1 mg/L effluent phosphorus. A listing of the schemes and rationale for their selection appears in Appendix B.

The following points are worthy of note in the consideration of liquid schemes:

Primary Plants: The original model presumed that any primary plant was already being upgraded to a secondary, according to requirements of United States law (PL 92-500). Such is not the case in Canada and liquid schemes directly applicable to primary plants for 1.0 and 0.5 mg/L effluent "P" have been specified. The 1.0 mg/L "P" objective is met by chemical addition alone, the 0.5 mg/L "P" objective by chemical addition and effluent filtration. A primary plant with the addition of two stage lime clarification and filtration is considered to be the only means by which an existing primary plant can attain 0.1 mg/L "P". It is assumed that in the primary plants considered there is no ongoing requirement for upgrading to secondary for reasons of improved removals of BOD₅, suspended solids or other pollutants; therefore, all costs of the upgrading, plus the tertiary lime clarification are considered part of the cost of attaining 0.1 mg/L "P".

Secondary Plants: Existing secondary plants have been demonstrated to be capable of achieving both 1.0 and 0.5 mg/L effluent "P" through the use of metal salts, the lower residual phosphorus being obtained by increasing chemical doses (alum or ferric chloride) over those required for 1 mg/L "P". Effluent levels of 0.3 mg/L "P" require the higher chemical doses, as just noted, plus the tertiary process of effluent filtration.

Two-stage lime clarification following the existing secondary plant is specified as the process capable of achieving 0.1 mg/L "P".

Physical/Chemical Plants: These plants, normally having the major unit processes of chemical coagulation, flocculation, primary settling and activated carbon adsorption, with or without prior filtration, were not modelled in the original program.

Three such plants exist or are proposed in the study area. Sizing and cost equations for several of the unit processes required (e.g. preliminary treatment, flocculation basins, primary treatment) were already available in the model. To complete the model, the following changes were made to existing sizing and cost equations:

a) sludge incinerator costs were used to simulate activated carbon regeneration facilities

b) costs relating to effluent filtration were used to simulate activated carbon contactors.

To effectively treat wastewater, a physical/chemical plant must have the basic operations of chemical coagulation, primary settling and activated carbon adsorption. A consequence of these processes is a certain degree of phosphorus removal, whether or not the plant is under regulatory requirement to reduce phosphorus discharges. Noting that the activated carbon columns act as effluent filters, it is considered that as a minimum, an effluent phosphorus level of 0.5 mg/L will be available from the plant in the "as-designed" condition. (This is the effluent quality available from a primary plant with effluent filtration, which has unit processes similar to physical/chemical plants). Accordingly, no additional cost was assigned to the physical/chemical plants for achieving 0.5 mg/L "P". To achieve 0.3 mg/L effluent "P", under the criteria set out for primary plants would require two-stage lime clarification as an additional process. It is suggested that such an addition would be impractical to a plant already designed for physical/chemical operation and therefore the achievement of 0.3 mg/L "P" may well require extensive rebuilding of the existing plant.

To achieve 0.1 mg/L would require the construction of a secondary treatment plant, followed by two-stage lime clarification. Physical/chemical plants are constructed for such reasons as lack of space for conventional facilities, or raw sewage unsuitable for biological treatment.

On this basis, it is concluded that it is impractical to reduce the effluent "P" level from a physical/chemical plant to below the "as-designed" condition, in this case assumed to be 0.5 mg/L "P". Irrespective of the particular effluent objective specified in the simulations, all physical/chemical plants are modelled as always discharging 0.5 mg/L effluent "P".

Enriched Oxygen Plants: There is still considerable debate over the relative merits and operating conditions between enriched oxygen systems and conventional secondary treatment plants. There are indications, however, that total treatment costs for the two are similar. It was therefore decided to simulate enriched oxygen plants as conventional activated sludge plants.

CHEMICAL REQUIREMENT FOR PHOSPHORUS REMOVAL

A critical step in the phosphorus removal process by chemical addition
is the precipitation of soluble phosphate species by the chemical added.
With lime additions, the precipitation is pH dependent only; the quantity
of lime required is therefore independent of initial phosphorus present.
Mineral addition (alum or ferric chloride) involves a pseudo-stoichiometric
relationship with initial phosphorus present. In pure solutions, aluminum
or ferric ion would enter into a precipitiation reaction with orthophos-
phorus on a 1:1 molar basis. This cannot be applied to precipitation in
sewage because the total phosphorus initially present is in several forms
(i.e. soluble, insoluble, ortho-, poly-, and organic phosphates). In
secondary plants conversion of species to the ortho- form occurs in the
aeration section of the plant; this may occur to varying degrees, depend-
ing upon plant design and operation. To further detract from stoichio-
metric relationships, the cation added enters into competing reactions
with other sewage constituents, generally to form aluminum or ferric hydrox-
ide. When expressing chemical requirements in terms of influent phosphorus
therefore, it is necessary to take an empirical approach based on data
generated from plant studies.

It is emphasized that realistic simulations of chemical requirements are
necessary because:

a) the cost of chemical is a major contributing factor to the overall
    cost of phosphorus removal;

b) the quantity of chemical sludges generated by precipitation is a
    function of chemical dose. The chemical dose selected will there-
    fore ultimately affect capital, operating and maintenance costs of
    plant sludge handling facilities.

A detailed discussion of the approach taken to establish relationships
between incoming phosphorus and chemical required for various effluent levels
of phosphorus is presented in Appendix B. A brief summary is given here to
indicate the methodology.

When dealing with alum or ferric addition, the opinion has been expressed
(7) that the incoming phosphorus levels have no effect on chemical demand.
In this study, no data from full-scale plant operation supporting this con-
tention has been found. In fact, studies by Environment Canada (8) indicate that
reducing initial phosphorus by 50 per cent, results in a 50 per cent saving
in chemical. This is considered a "strong" dependence of chemical on phos-
phorus levels and therefore the concept that influent phosphorus levels do not
affect chemical demand is not considered further.

A differing opinion has been expressed by Barth (9) on the matter
of the available savings. It is suggested that a 50 percent reduction
in initial phosphorus results in a 30 per cent saving of chemical. The
rationale for this is as follows: a portion of the chemicals added
reacts with extraneous ion; chemical must be added to ensure coagulation –
not simply enough to precipitate phosphorus; and finally, a slight
excess of chemical is necessary to ensure the solubility product of the
metal/phosphorus compound.

The Barth approach which is considered a "moderate" dependence of
chemical demand on incoming phosphorus and therefore, more conservative
was used in comparing the effects of various detergent control scenarios.
However, simulations were done for secondary plants using both approaches,
as sensitivity analysis, to determine the overall effect of the two
types of correlations. These analyses indicated that using the Environment
Canada relationships for the 1.0 mg/L requirement predicted total operating
and maintenance costs 1.9% lower than those obtained using the Barth
relationship. However, at the 0.5 and 0.3 mg/L requirement the Environment
Canada relationships predicted 4.9% greater operating and maintenance
costs.

SLUDGE TREATMENT SCHEMES AND PROCESS DESIGN PARAMETERS

The manual for the original model (2) documents five sludge handling
options. When the model is used to fulfill its original objective, i.e.
to select the optimum phosphorus removal process for a particular plan,
the sludge handling option best suited to the existing unit processes
for sludge handling is selected. If no facilities exist, it is the
user's option to select a sludge scheme.

When considering the plants in the study area, individual sludge
schemes appropriate to existing or intended facilities were specified,
giving a total of 21 different schemes.

Appendix "C" of the manual, documents sludge processing design criteria
for sizing various unit processes. These were reviewed and updated from
recent literature.

It should be noted that three of the forty-three plants included in
the study, will have wet air oxidation as a sludge process. This is not
modelled in the REMOVE program and accordingly the sludge schemes for
these plants do not include this process. The model should be updated
when the opportunity arises to include this process.

Appendix B of this report documents the derivation of equations
used for predicting excess sludge quantities due to chemical addition.
Generally, in both primary and secondary plants, excess sludge is formed
by precipitation of metal/phosphate or metal/hydroxide compounds.
Additional sewage sludge is formed in a primary plant due to improved
sedimentation and solids capture.

Plants employing lime clarification as a tertiary step generate a
large quantity of chemical sludge (approximately 7,600 lbs/MIG), but the
quantity of excess sludge to be purged from the system is reduced because
the chemical sludge is re-calcined to calcium oxide and re-used.

7

ESTIMATE OF PHOSPHORUS DISCHARGES FROM PLANTS WHEN NOT PRACTICING CHEMICAL ADDITION

To provide a reference point for this study, it was necessary to calculate the phosphorus loadings to the Lower Great Lakes under uncontrolled conditions (i.e. no chemical addition). The existing model does not compute this output.

With physical/chemical plants, chemical addition is necessary for proper plant operation overall. Therefore, there would be no "uncontrolled discharge" condition for these plants and the uncontrolled loading has been computed on the basis of 0.5 mg/L effluent "P".

For primary and secondary plants, a simplified program was written to simulate phosphorus removal across the facilities and computed phosphorus discharge under controlled conditions. The equations used are sensitive to influent phosphorus and therefore reflect lower uncontrolled mass discharges of phosphorus as influent phosphorus concentrations decrease due to reductions in detergent phosphorus levels.

INPUT INFORMATION

The prime independent variables in this study consisted of the phosphorus concentration of the raw sewage and the phosphorus concentration of the treated effluent.

The phosphorus concentration of raw sewage has decreased in recent years due to voluntary and legislated reductions in the phosphate concentration of detergents. The average raw sewage values used were obtained from plant records and are listed in Table A-1, Appendix A.

Discrete treated effluent phosphorus concentrations of 1.0, 0.5, 0.3 and 0.1 mg/L were identified as treatment objectives. Appropriate liquid treatment schemes for attaining these objectives were assigned.

The plant specific data used for each simulation included the following:

a) Existing unit operations.

b) Existing characteristics of the raw sewage at each plant (including BOD, SS, P).

c) Existing and future plant flows and the existing plant design flow.

d) Plant specific chemical costs.

e) Plant specific sludge characteristics and plant specific values of unit process design parameters (design variables) were not used in the simulation. Instead, normal values of design parameters were used in all cases.

Data coding sheets were prepared for items a) to d) to replace the interactive form used in REMOVE. The parameters contained on these coding sheets and typical values are identified in Appendix C.

8

OUTPUT INFORMATION

Computer printouts containing the detailed information generated by this study are available at the IJC Great Lakes Regional Office, 100 Ouellette Avenue, Windsor, Ontario N9A 6T3.

Treatment costs have been simulated for the 25-year period 1976 - 2000, subdivided into five-year increments. The computer program, determines the nature of unit process expansions required by the year 2000 and the incremental time period during which the expansion is required. Capital, operating and maintenance costs for each time period are calculated accordingly. Consequently, information is generated which indicates, in present-day values, the cost of present and future wastewater treatment facilities.

For comparison purposes, the replacement value of existing plants, and the continuing costs of plants as they are simulated both with and without phosphorus removal facilities are computed. The total phosphorus in the effluent, sludge quantities produced and simulated future flows are also calculated.

Two output formats have been provided to present the computed information. The first provides a detailed description of each wastewater facility. The printout consists of five pages for each plant:

Page 1   -   identification of plant and liquid and sludge treatment schemes.
          -    identification of chemical dosage equation.
          -    listing of plant specific variables used in the run.
          -    listing of unit processes used by plant in the run.

Page 2   -   table showing size and capital cost of each unit process in the plant both for the conditions of its existing design flow, and for the future capacity required to the year 2000, with and without phosphorus removal facilities, and the time period during which the expansion would be needed.

Page 3   -   table showing total plant operating and maintenance costs with and without phosphorus removal facilities for each unit process, for the first time period (1976 - 1980), by its components of operating man-hours, maintenance man-hours, total labour cost and material and supply cost.

Page 4   -   summary report showing effluent phosphorus and total capital and operating and maintenance costs with and without phosphorus removal facilities, for each time period; maximum average flow for each time period is also indicated.

Page 5   -   identifies estimated sludge quantities for ultimate disposal both with and without phosphorus removal facilities, for each time period.

A subsequent printout form summarizes simulation data for all plants in the run on a form similar to each plant summary report.

The total capital and operating and maintenance costs for the Canadian and United States plants in the Lake Erie and Lake Ontario drainage basins are summarized in Appendix A, Tables A-2 and A-3 respectively.

9

RELATIVE COSTS TO ACHIEVE PHOSPHORUS REDUCTIONS IN MUNICIPAL
WASTEWATER TREATMENT DISCHARGES

Capital and operating and maintenance costs for 43 selected municipal wastewater treatment plants were simulated with the computer model described above.

This computer output was then used to develop estimated annual costs to achieve various effluent phosphorus concentrations on a per capita sewered population basis for the "Overview Model" (10) developed for use in the International Reference Group on Pollution of the Great Lakes from Land Use Activities (PLUARG). The per capita costs, as developed below, were used in the "overview model" to estimate total costs for phosphorus reductions from municipal point sources to compare with computer generated costs to reduce loads from non-point sources.

It must be emphasized that these are generalized cost estimates developed from computer outputs. However, as shown in the next section, the cost estimates developed are believed to be close approximations to present costs on a general basin-wide basis. Estimated costs for specific communities, or even for single watersheds, may be at least an order of magnitude different from real costs. Refinement of the model, more plant specific inputs, and comparison of the computer cost estimates with real costs will be needed if the model is to be used to develop costs for smaller geographical units than a Great Lakes drainage basin.

The total population served by the plants used in the simulation is 12.15 millions. The estimated total sewage flow to be treated over the 25 year period was 3,124.4 MGD (U.S.). The present design flow for the 43 plants is a total of 3,055.1 MGD (U.S.).

The treatment plants used for the simulation are all located in the lower Great Lakes Basin and range in size from 6.0 to 950 MGD and represent a balanced cross section of plants in both the U.S. and Canada. There are 5 Primary Treatment Plants, 2 Trickling Filter Plants, 33 Secondary (activated sludge) Plants (two of which have tertiary multi-media filtration) and 3 Physical-Chemical Plants.

The computer model developed the capital and operating costs for each of the existing plants given the population served, an estimate of population growth, the influent sewage characteristics and the treatment processes included at the plant. Operating and maintenance costs were computed for a 25 year period (1975 - 2000) and the capital facilities of the plant were expanded as required by population growth.

Additional treatment processes were then designed to achieve a specified level of phosphorus in the effluent. The computer again simulated the capital cost, including expansions, and operating and maintenance costs. These total costs for all the plants are listed in Table A-2 and A-3.

The relative simulated annual costs, on a per capita basis, to achieve various phosphorus concentrations in treated municipal wastewater effluents, as shown in Table 1, were calculated from the computer output and populations served as listed in Appendix A.

11

TABLE 1
COMPUTER SIMULATED COSTS TO ACHIEVE VARIOUS EFFLUENT PHOSPHORUS CONCENTRATIONS

Effluent Total Phosphorus Concentration (mg/L)	Annual Cost (Dollars per Capita)		
	Capital[b]	O & M[c]	Total
4.0[a]	10.70	5.84	16.54
1.0	11.24	7.65	18.89
0.5	11.61	8.27	19.88
0.3	15.87	10.04	25.91
0.1	15.51	31.06	46.57

[a] Average concentration which would be achieved with existing Primary or Secondary treatment at all plants.

[b] Capital Costs: Simulated Capital Costs to build and expand plant as required over a 25 year period. The per capita cost is the total simulated capital costs divided by the present population served, and the annual per Capita Cost (R) is the amount needed at an interest rate of 10% (i) to recover the investment (P) in 25 years (n).

$$R = P \left[\frac{i}{1 - (1+i)^{-n}} \right]$$

[c] O & M Costs: The operating and maintenance costs are the total O & M costs simulated for the first 5 years and divided by the present population served on an annual basis.

The simulated capital costs are the sum required at an interest rate of 10% to recover in 25 years, the total capital requirements, including expansion capital. The present population being served by each plant was used to calculate the per capita costs.

The operating and maintenance costs are those simulated by the computer for the first 5 years of operation divided by five and the population served.

VALIDITY OF COST ESTIMATES

The base model "REMOVE" is a relatively sophisticated tool for simulating individual wastewater treatment facilities which can be fitted to specific conditions by setting design variables to appropriate values.

A review was made of the accuracy of the model in sizing and costing wastewater treatment facilities. It has been confirmed that the model predicts realistic capital and operating and maintenance costs both for unit processes and for total treatment facilities. The observed accuracy of prediction will improve when dealing with summations for many plants as errors of prediction for specific plants offset one another.

It can, however, be argued that the model is incomplete in many ways. The simulation of the kinetics of biological oxidation, for instance does not account for the presence of any solids recycled to liquid treatment schemes from sludge treatment schemes. Operating cost curves, for example, generally do not include specific terms involving energy costs, and consequently can be adjusted for inflation only by more general indices. Total predicted capital costs do not include specific items for yard work, land costs or specific allowances for construction problems which could occur at a particular site.

Validity of the simulations is also dependent upon the reliability of assumptions regarding the technology of phosphorus removal. The technology for removing phosphorus to concentrations as low as 0.3 mg/L is well developed. It is unlikely that liquid treatment schemes defined for these levels of treatment will change greatly within the study period. It is clear, however, that the simulated costs at these levels of treatment are a direct and significant function of the defined cationic chemical dosage and resulting extra quantity of sludge.

The technology for removal of phosphorus to 0.1 mg/L is not as well proven. The simulation at this treatment level is built upon the two-stage lime clarification of secondary effluent. This process appears at the present time to be the most practical treatment scheme. It is possible, however, that other methods for attaining this objective will be developed through improvements in the performance of existing unit processes, or perhaps through new technology.

One potential source of error which has been difficult to avoid and to assess quantitatively occurs periodically in the sizing of new equipment. When "building" once to meet unit process requirements to the year 2000, sizing parameters sometimes exceed the range for which the capital cost curves have been verified. Such occurences are automatically identified on the long printouts. As unit process construction costs generally vary almost linearly with size at the high end of the range, errors introduced by exceeding the verified range in this direction are considered to be minimal. Where only small additions to

15

unit process capacities are required by the year 2000, the verified range for cost curves may be exceeded on the low end. When this occurs, costs are simulated for a process addition of small capacity and associated high unit cost. That is, the assumed addition may be smaller than practical, and the diseconomies of small size could be significant. Upon review of the long form printouts, it appears that the frequency of exceeding the range of cost curves on the low side is not great. Also, this condition can occur in all sumulations in a generally random manner, hence when comparing differences in simulated costs between runs on a total drainage area basis, the effect is reduced in significance.

Finally, in order to assess the validity of the simulations, some comparisons were made with actual costs experienced at several wastewater treatment plants where phosphorus removal is practiced. The observations are summarized as follows:

OPERATING COSTS
(Dollars/Million Gallons Treated)

	Simulated	Reported
Sarnia	125	101 *
Windsor Little River	159	180 +
Windsor Westerly	104	158 +
Rocky River	241	300 o

o   Data reported by Moss et al. WPCF Conference, Minneapolis
*   Plant records 1975, cost adjusted to current levels
+   Water and Pollution Control, Nov. 1976. Costs adjusted to current levels.

In a more general analysis, a recent report (11) on municipal water and wastewater treatment plants in Canada, indicates that, for wastewater treatment plants in Ontario with flows greater than 1 MGD, the mean annual operating costs was about $50 per year/1000 gpd of treatment capacity. The computer simulated operating and maintenance costs for the three plants in the Canadian Lake Erie basin, with a total flow of 46 MGD, were determined to $24 per year/1000 gpd without phosphorus removal and $44 per year/1000 gpd with phosphorus removal to 1.0 mg/L. Similarly, in the Lake Ontario basin, 17 plants with a total flow of over 600 MGD, were simulated, and the estimated average operating and maintenance costs for these plants was calculated at $28 and $38 per year/1000 gpd without and with phosphorus removal respectively.

It is difficult to obtain actual capital costs for sewage treatment plant construction which can be used to compare with the computer simulated costs. In 1976 the Great Lakes Water Quality Board (12) estimated that the total funds committed for sewerage construction in the Great Lakes Basin between 1971 and 1976 to be $3,640 million. The total capital cost simulated for the 43 plants serving a sewered population of 12.15 million persons was $1,180 million without phosphorus removal and $1,240 million with phosphorus removal to 1.0 mg/L. Extrapolating this to a total basin sewered population pf 20.2 million persons indicates capital costs of $1,960 million and $2,060 million without and with phosphorus removal, respectively.

16

The model only computes the total capital required to build the various unit processes and does not include land, office space, interceptor sewers, etc. Many of these items are included in the Water Quality Board's total capital expenditures. Considering the differences in the items included in both estimates it is apparent that the model results are providing realistic figures for comparison purposes.

Thus, while it must be emphasized that the costs developed in this study are computer simulated estimates which are subject to the accuracy of the assumptions and input data used to generate them, they are well within reasonable limits of known costs and are appropriate for broad planning purposes on a basin-wide basis to compare alternate strategies for phosphorus control in the Great Lakes.

17

CONCLUSIONS

1. The computer model provides a useful tool for determing the relative
    costs for various requirements for phosphorus removal at municipal
    wastewater treatment plants.

2. When water quality management plans are being developed for watersheds
    on a site specific basis the model can be used for developing
    relative costs for the larger treatment plants in the basin.
    (Design flows greater than 10 MGD).

3. The model could be used to evaluate the impact of further limitations
    on the phosphate content of detergents on the costs of sewage
    treatment.

4. With suitable modifications and refinements the model could be
    applied to analysis of the impact of changing municipal sewage
    treatment requirements on energy and other resources of the Great
    Lakes Basin.

19

RECOMMENDATIONS

The computer model should be further developed and used considering the following:

1. Further verification of the model output with existing plant information would be most useful.

2. Resolution of the chemical dosages needed for various effluent requirements at the full-scale operating level. The use of site specific dosage relationships may be required.

3. Determination of the impacts of detergent reformulations on phosphorus content of municipal sewage.

4. The practicality of implementing technology at municipal treatment plants to achieve 0.3 and particularly 0.1 mg/L need to be demonstrated and costs developed.

5. The present model cannot be used for smaller treatment facilities. An extension to the REMOVE model or a separate program should be developed for plants at least down to 1.0 MGD capacity.

6. Operating costs for physical-chemical plants need to be developed.

7. Some of the technical assumptions in the model need to be re-evaluated and refined, for example:

    i)   impact of addition of chemicals for phosphorus removal on sludge characteristics such as filterability, digestibility.

    ii) impact of phosphorus removal chemicals on mixed liquor characteristics such as density and settleability.

    iii) improved removals of suspended solids, heavy metals and organics which occur concurrent with phosphorus removal should be incorporated in the model.

    iv) design parameters and cost curves for anaerobic digestion and carbon regeneration.

    v)   components for operating and capital costs curves could be expanded to include items such as energy costs, land costs, and costs resulting from abnormal construction problems.

    vi) expansion of the number of liquid and sludge treatment schemes.

    vii) long-term practicality of achieving 0.5 mg/L P by chemical additions at existing secondary treatment plants without adding effluent filtration.

RECOMMENDATIONS

The computer model should be further developed and used considering the following:

1. Further verification of the model output with existing plant information would be most useful.

2. Resolution of the chemical dosages needed for various effluent requirements at the full-scale operating level. The use of site specific dosage relationships may be required.

3. Determination of the impacts of detergent reformulations on phosphorus content of municipal sewage.

4. The practicality of implementing technology at municipal treatment plants to achieve 0.3 and particularly 0.1 mg/l need to be demonstrated and costs developed.

5. The present model cannot be used for smaller treatment facilities. An extension to the RENOVR model or a separate program should be developed for plants at least down to 1.0 MGD capacity.

6. Operating costs for physical-chemical plants need to be developed.

7. Some of the technical assumptions in the model need to be re-evaluated and refined, for example:

   i) Impact of addition of chemicals for phosphorus removal on sludge characteristics such as filterability, digestibility.

   ii) Impact of phosphorus removal chemicals on mixed liquor characteristics such as density and settleability.

   iii) Improved removals of suspended solids, heavy metals and organics which occur concurrent with phosphorus removal should be incorporated in the model.

   iv) Design parameters and cost curves for anaerobic digestion and carbon regeneration.

   v) Components for operating and capital costs curves could be expanded to include items such as energy costs, land costs, and costs resulting from abnormal construction problems.

   vi) Expansion of the number of liquid and sludge treatment schemes.

   vii) Long-term practicality of achieving 0.3 mg/l P by chemical additions at existing secondary treatment plants without adding effluent filtration.

REFERENCES

1) "Report to the IJC on Capital and Operating Cost Analysis of Municipal Phosphorus Control Strategies" James F. MacLaren Ltd., Consulting Engineers, 320 Adelaide St., South, London, Ontario, (March 1977).

2) "A Computer Model for Evaluating Community Phosphorus Removal Strategies" U.S. EPA Report 400/9-73-001 (October 1973).

3) Preliminary Design and Simulation of Conventional Wastewater Renovation Systems Using the Digital Computer. R. Smith, U.S. Department of the Interior. March 1968.

4) Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities. Patterson and Banker, EPA Report 17090 DAN 10/71.

5) Wastewater Treatment Plant Cost Estimating Programme Documentation. R. Eilers and R. Smith, EPA Report PB-222 762 (NTIS).

6) Sensitivity Analysis for a Phosphorus Removal Strategy Computer Model. J.B.F. Scientific Corporation. EPS Report PB 259-415 (NTIS).

7) Phosphorus Removal Design Seminar; Canada/Ontario Agreement on Great Lakes Water Quality, Toronto, Ontario. 1973.

8) Development of Predictive Models for Chemical Phosphorus Removal. Environment Canada (CCIW) Report in Press.

9) Statement of EPA Region V in the Matter of Phosphorus Control Technology. E.F. Barth. 1976.

10) "Management Information Base and Overview Modelling". M.G. Johnson, J. Comeau, W. Sonzogni, T. Heidtke and B. Stahlbaum. Technical Report prepared for International Reference on Great Lakes Pollution from Land Use Activities (July 1978).

11) National Inventory of Municipal Waterworks and Wastewater Systems in Canada - 1975. Prepared jointly by federal, provincial and municipal government agencies with the assistance of the Federation of Associations on the Canadian Environment (FACE).

12) Great Lakes Water Quality Board 1976 Annual Report to the IJC (July 1977).

REFERENCES

1) "Report to the IJC on Capital and Operating Cost Analysis of Municipal Phosphorus Control Strategies." James F. MacLaren Ltd., Consulting Engineers, 120 Adelaide St., South, London, Ontario, (March 1977).

2) "A Computer Model for Evaluating Community Phosphorus Removal Strategies" U.S. EPA Report 600/9-73-001 (October 1973).

3) Preliminary Design and Simulation of Conventional Wastewater Renovation Systems Using the Digital Computer, R. Smith, U.S. Department of the Interior, March 1968.

4) Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities. Patterson and Banker, EPA Report 17090 DAN 10/71.

5) Wastewater Treatment Plant Cost Estimating Programme Documentation. R. Eilers and R. Smith, EPA Report PB-242 762 (NTIS).

6) Sensitivity Analysis for a Phosphorus Removal Strategy Computer Model. J.M.P. Scientific Corporation. EPS Report PB 254 615 (NTIS).

7) Phosphorus Removal Design Seminar; Canada/Ontario Agreement on Great Lakes Water Quality, Toronto, Ontario. 1973.

8) Development of Predictive Models for Chemical Phosphorus Removal. Environment Canada (CCIW) Report in Press.

9) Statement of EPA Region V in the Matter of Phosphorus Control Technology. E.E. Berth. 1976.

10) "Management Information Base and Overview Modelling." M.G. Johnson, J. Cannan, W. Sonzogni, T. Heidtke and R. Stahlbaum. Technical Report prepared for International Reference on Great Lakes Pollution from Land Use Activities (July 1976).

11) National Inventory of Municipal Waterworks and Wastewater Systems in Canada - 1975. Prepared jointly by federal, provincial and municipal government agencies with the assistance of the Federation of Associations on the Canadian Environment (FACE).

12) Great Lakes Water Quality Board 1976 Annual Report to the IJC (July 1977).

APPENDIX A

TREATMENT PLANT INPUT DATA
AND
OUTPUT SUMMARIES

TABLE A-1 —   Treatment Plant Input Data (1975)

TABLE A-2 —   Computer Simulated Total Phosphorus Loads and
                Municipal Wastewater Treatment Plant Costs over
                a 25 Year Period (1975-2000) for Selected Plants
                in the Lake Erie Drainage Basin

TABLE A-3 —   Computer Simulated Total Phosphorus Loads and
                Municipal Wastewater Treatment Plant Costs over
                a 25 Year Period (1975-2000) for Selected Plants
                in the Lake Ontario Drainage Basin

FIGURE A-1   Total Phosphorus Loads and Wastewater Treatment
                Costs over a 25 Year Period (1975-2000) for 43
                Selected Municipal Wastewater Treatment
                Facilities in the Lake Erie and Lake Ontario
                Drainage Basins

APPENDIX A

TREATMENT PLANT INPUT DATA
AND
OUTPUT SUMMARIES

A

PLANT	SEWERED POPULATION (SPOP)	PRESENT FLOW (MGD) (QAVE)	DESIGN FLOW (MGD) (QADSGN)	TYPE OF TREATMENT	INFLUENT CONCENTRATIONS (mg/L) BOD$_5$	SS	Total P
LAKE ERIE U.S.A.							
Cheektowaga S.D., N.Y.	80,417	9.6	7.5	Trickling Filter	137	143	2.3
Akron, OH	378,000	80.5	90.0	Activated Sludge	97	121	2.9
Cleveland, OH Easterly	000	115.8	170.0	Activated Sludge	123	113	6.2
Southerly	,000	94.6	200.0	Activated Sludge	208	291	7.2
Westerly	160,000	34.7	50.0	Physical-Chemical	200	242	6.2
Euclid, OH	120,300	19.1	17.0	Activated Sludge	200	242	8.8
Lakewood, OH	78,400	13.4	13.0	Activated Sludge	120	150	7.2
Lorain, OH	78,100	16.3	15.0	Activated Sludge	120	150	6.2
Rocky River, OH	78,000	8.5	10.0	Physical-Chemical	120	150	9.0
Sandusky, OH	42,800	11.3	12.5	Activated Sludge	160	188	4.0
Toledo, OH	445,000	86.0	102.0	Activated Sludge	149	263	14.0
Monroe, MI	28,690	13.0	24.0	Activated Sludge	160	188	2.0
Port Huron, MI	36,831	15.0	20.0	Activated Sludge	160	188	5.0
Wayne City-Wyandotte, MI	252,787	74.0	100.0	Activated Sludge	240	756	6.7
Fort Wayne, IND	177,671	46.4	60.0	Activated Sludge	148	260	2.3
Erie, PA	190,000	46.4	65.0	Activated Sludge	131	260	4.8
Detroit, MI	3,128,897	946.0	950.0	Activated Sludge	107	211	5.2
LAKE ERIE - CANADA							
Sarnia, ONT	65,000	10.6	17.4	Primary	107	191	5.5
Windsor, ONT Little River	60,000	7.7	14.4	Activated Sludge	71	151	4.9
Westerly	160,000	26.4	28.8	Primary	116	192	3.9
LAKE ONTARIO - U.S.A.							
Buffalo, NY	847,000	173.5	180.0	Activated Sludge	87	107	2.6
Monroe City, NY	59,531	7.8	15.0	Activated Sludge	145	188	5.0
Niagara Falls, NY	85,000	34.0	48.0	Physical-Chemical	150	250	2.2
Rochester, NY	362,231	74.8	100.0	Activated Sludge	161	127	2.7
Syracuse, NY	293,480	72.3	80.0	Activated Sludge	206	185	1.6
Tonawanda, NY S.D. #2	95,653	17.7	30.0	Activated Sludge	78	85	3.8
LAKE ONTARIO - CANADA							
Belleville, ONT	33,600	10.8	9.6	Activated Sludge	84	88	9.1
Burlington, ONT	72,684	14.3	24.0	Activated Sludge	128	216	7.1
Cornwall, ONT	45,900	13.9	9.9	Primary	177	171	3.4
Hamilton, ONT	309,870	67.4	72.0	Activated Sludge	143	365	8.0
Kingston, ONT	60,471	15.7	16.2	Primary	86	113	3.4
Toronto, ONT Humber	612,000	90.0	90.0	Activated Sludge	264	369	10.0
Main	1,560,000	220.8	216.0	Activated Sludge	124	179	5.2
Highland Creek	193,800	32.0	38.4	Activated Sludge	164	216	5.8
North Toronto	107,447	10.4	10.2	Activated Sludge	109	167	11.8
Mississauga, ONT Clarkson	80,000	9.6	12.0	Activated Sludge	115	191	8.7
Lakeview	352,660	47.3	60.0	Activated Sludge	286	233	9.4
Niagara Falls, ONT	70,380	10.1	12.0	Primary	89	139	4.3
Oakville, ONT	49,776	9.2	7.8	Activated Sludge	140	170	6.7
Oshawa, ONT Plant 1	57,600	7.1	9.0	Trickling Filter	102	145	5.4
Plant 2	38,400	4.8	6.0	Activated Sludge	110	194	6.7
Port Dalhousie, ONT	53,620	9.5	16.2	Activated Sludge	63	95	4.2
Port Weller, ONT	63,648	9.2	16.2	Activated Sludge	84	157	5.8

TABLE A-2

COMPUTER SIMULATED TOTAL PHOSPHORUS LOADS AND MUNICIPAL WASTEWATER TREATMENT PLANT COSTS
OVER A 25 YEAR PERIOD (1975-2000) FOR SELECTED PLANTS IN THE LAKE ERIE DRAINAGE BASIN

Phosphorus Effluent Limitation (mg/L)	Jurisdiction	Number of Plants	Simulated Total Phosphorus Load (metric tons)	Simulated Wastewater Treatment Plant Costs (Millions of Dollars)		
				Capital	Operation & Maintenance	Total
None	Canada	3	7,080	13.1	30.2	43.3
	U.S.A.	17	274,780	719.1	1,208.4	1,927.5
	Total	20	281,860	732.2	1,238.6	1,960.8
1.0	Canada	3	1,870	15.5	56.3	71.8
	U.S.A.	17	65,790	758.5	1,572.0	2,330.5
	Total	20	67,860	774.0	1,628.3	2,402.3
0.5	Canada	3	935	24.8	69.6	94.4
	U.S.A.	17	33,290	771.1	1,686.2	2,457.3
	Total	20	34,225	795.9	1,745.8	2,551.7
0.3	Canada	3	560	36.2	186.0	222.0
	U.S.A.	17	20,280	1,049.4	1,883.5	2,932.9
	Total	20	20,840	1,085.6	2,069.5	3,154.9
0.1	Canada	3	187	34.9	216.1	251.0
	U.S.A.	17	7,260	1,014.5	6,769.1	7,783.6
	Total	20	7,447	1,049.4	6,985.2	8,034.6

TABLE A-3

COMPUTER SIMULATED TOTAL PHOSPHORUS LOADS AND MUNICIPAL WASTEWATER TREATMENT PLANT COSTS
OVER A 25 YEAR PERIOD (1975-2000) FOR SELECTED PLANTS IN THE LAKE ONTARIO DRAINAGE BASIN

Phosphorus Effluent Limitation (mg/L)	Jurisdiction	Number of Plants	Simulated Total Phosphorus Load (metric tons)	Simulated Wastewater Treatment Plant Costs (Millions of Dollars)		
				Capital	Operation & Maintenance	Total
None	Canada	17	118,090	298.6	472.7	771.3
	U.S.A.	6	20,740	150.4	301.3	451.7
	Total	23	138,830	449.0	774.0	1,223.0
1.0	Canada	17	24,580	306.3	645.6	951.9
	U.S.A.	6	14,210	155.0	380.0	535.0
	Total	23	38,790	461.3	1,025.6	1,486.9
0.5	Canada	17	12,250	322.9	723.1	1,046.0
	U.S.A.	6	7,480	157.1	396.6	553.7
	Total	23	19,730	480.0	1,119.7	1,599.7
0.3	Canada	17	7,370	452.3	950.8	1,403.1
	U.S.A.	6	4,800	216.7	440.4	657.1
	Total	23	12,170	669.0	1,391.2	2,060.2
0.1	Canada	17	2,450	446.4	2,603.9	3,050.3
	U.S.A.	6	2,120	212.3	1,438.1	1,650.4
	Total	23	4,570	658.7	4,042.0	4,700.7
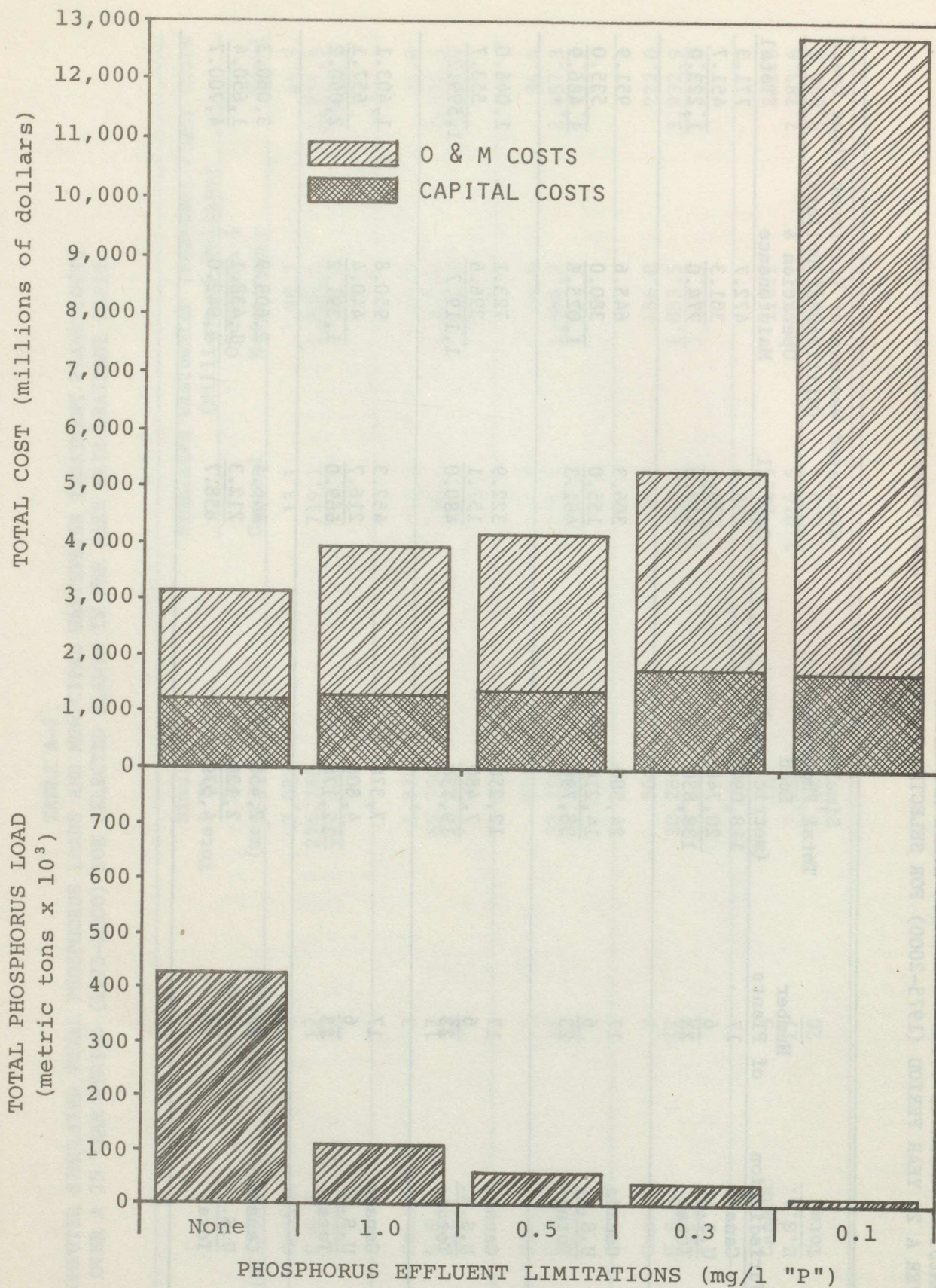
FIGURE A-1   TOTAL PHOSPHORUS LOADS AND WASTEWATER
TREATMENT COSTS OVER A 25 YEAR PERIOD
(1975 - 2000) FOR 43 SELECTED MUNICIPAL WASTEWATER
TREATMENT FACILITIES IN THE LAKE ONTARIO AND
LAKE ERIE BASINS.

APPENDIX B

SUMMARY OF SANITARY ENGINEERING CRITERIA

RELATING TO PHOSPHORUS REMOVAL

NOTE: THIS APPENDIX WAS PREPARED BY J.F. MACLAREN LTD. AND ISSUED ON MARCH 1, 1977 TO THE IJC GREAT LAKES REGIONAL OFFICE WHICH DISTRIBUTED IT FOR COMMENT TO THE REMEDIAL PROGRAMS SUBCOMMITTEE OF THE GREAT LAKES WATER QUALITY BOARD AND THE ENGINEERING AND TECHNOLOGICAL ASPECTS COMMITTEE OF THE RESEARCH ADVISORY BOARD. THE ORIGINAL DOCUMENT WAS REVISED TO INCORPORATE THE VALUABLE SUGGESTIONS MADE.

TABLE OF CONTENTS

PAGE

ABBREVIATIONS AND SYMBOLS

Fe	ferric or ferrous ion
Al	aluminum ion
P	phosphorus
P_T	phosphorus total
Po	ortho-phosphorus
P_{IN}	influent phosphorus (total)
P_{OUT}	effluent phosphorus (total)
mg/l	milligrams per litre
mm/l	millimoles per litre
S.T.P.	sewage treatment plant
MIG	Million Imperial Gallons
MUSG	Million U.S. Gallons

1.   PROCESS SELECTION FOR PHOSPHORUS REMOVAL OBJECTIVES

1.1   PRIMARY PLANTS (CANADA ONLY)

Schemes in use: Fe, or Al to raw sewage, plus polymer.

<u>Objective:</u> 1 mg/L P

Process Scheme: See Schemes 1 and 2.   (Figure B-1)

Chemical doses: Polymer: 0.5 mg/L anionic polymer.
                 Cation: See Section 2.1.1 for derivation.
                          Doses will be "moderate"

<u>Objective:</u> 0.5 mg/L P

No current practice data available.

Recommended process: See Schemes 3 and 4.   (Figure B-1)

<u>NOTES:</u>

1. Review of Sarnia data (1) indicates 0.5 mg/L cannot be obtained
    more than 30% of the time, at "high" (20 mg/L Fe) chemical doses.

2. From (1), ortho-P levels are 0.25>Po, at 20 mg/L Fe, hence with
    effective solids capture, 0.5 mg/1 residual P would be achieveable.

3. Low solids levels in primary effluent (30 mg/L +) obtainable –
    suitable to apply to effluent filter.

4. Review of West Windsor S.T.P. Data (2) indicates 0.5 mg/L P
    was reached by settling with chemical addition over one 9 day test
    period. No indication of long-term consistency of 0.5 mg/L objective.

    Chemical doses: Polymer: 0.5 mg/L anionic polymer.
                        Cation: See Section 2.2.1 for derivation.
                                 To ensure more complete precipitation
                                 of P, chemical doses will be higher than
                                 for 1 mg/L objective.

<u>Objective:</u> 0.3 mg/L P

Recommended process scheme: See Schemes 5 and 6.   (Figure B-1)

<u>NOTES:</u>

Process selected as per O'Farrell and Bishop, as reported by Stepko (3).

FIGURE B-4.

0·5 mg/l P OBJECTIVE

ALUM TO MIXED LIQUOR

Alum DOSE   mg/l as Alum $Al_2(SO_4)_3 \cdot 14 H_2O$

P_T mg/l INFLUENT SEWAGE

EPA REPORT 400/9 (10)

73/00 (101)

ENVIRONMENT CANADA (9)

BARTH POSITION 1976 (12)
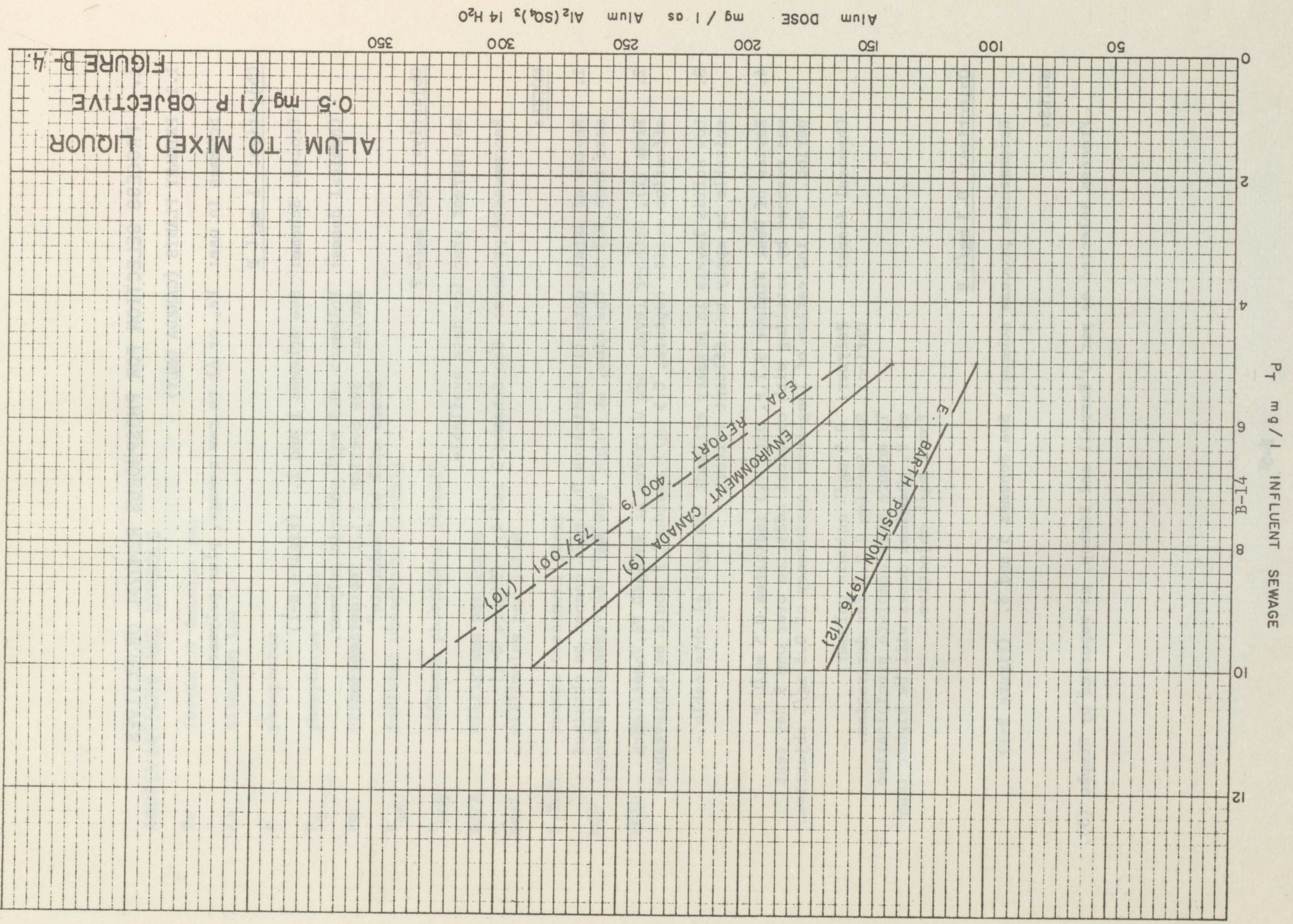
FERRIC / FERROUS ION
TO MIXED LIQUOR
0.5 mg / l P OBJECTIVE

FIGURE B-5

ENVIRONMENT CANADA (9)

E. BARTH POSITION 1976 (12)

Fe^{3+} / Fe^{2+} DOSE mg / l

P_T mg/l INFLUENT SEWAGE

B-15

<u>NOTES</u>:

1. Pickle liquor effectiveness established in Milwaukee (5).

2. Iron from ferrous source will be considered equivalent to that from ferric source for P removal.

   Chemical doses: Refer to Section 2.1.2. Doses will be "moderate", reflecting current experience for this effluent objective.

<u>Objective: 0.5 mg/L P</u>

Recent literature (3) documents experience with secondary plants and chemical addition attaining <0.3 mg/L residual P. General requirement was for chemical dose to be twice level required for 1 mg/L P objective.

Caution expressed that, to obtain <0.3 mg/L P consistency, effluent filtration would probably be required.

On this basis, with the increased chemical doses as noted above, 0.5 mg/L P should be attainable <u>without filtration</u>.

Recommended process scheme: See Schemes 11, 12, 13 and 14. (Figure B-1)

Chemical doses: Will be higher (factor of two, approximately) than for 1 mg/L P objective. (Refer to Section 2.2.2)

<u>Objective: 0.3 mg/L P</u>

Reference (3) data suggests that the process option for obtaining 0.5 mg/L may be employed for <0.3 mg/L with the addition of effluent filtration to provide a <u>consistent</u> quality of effluent.

Confirmation exists (6) based on prolonged involvement by chemical suppliers in the phosphorus removal programme, and data on filtration of nitrified/denitrified effluents (7).

Recommended process scheme: See Schemes 15, 16, 17 and 18. (Figure B-1)

<u>NOTES</u>:

1. Total chemical dose could be split between pre-settling and pre-filtration as shown, although caution must be exercised with Fe before filtration due to discolouring of effluent by Fe ion.

2. Distinct possibility exists that this scheme would give effluents less
    than 0.3 mg/L. In th P loading curves to the Great Lakes, this <u>possible</u>
    reduction, representing, say, 0.2 mg/L, should be shown as an improvement
    available at no extra cost beyond the cost incurred for 0.3 mg/L objective
    option.

    Chemical doses: Cation dose will be as per 0.5 mg/L objective.

<u>Objective: 0.1 mg/L P</u>

    The only recent fully documented case available is Ely, Minn. (4). For
    this objective two stage lime clarification and recarbonation would be
    required, without filtration.

    Opinion is divided on whether 0.1 mg/L may be achieved with metallic
    ion and filtration alone.

    Recommended for simulation is that two stage lime clarification be
    considered the option for 0.1 mg/L residual P; the sensitivity analysis
    on this would be made by comparing this total process cost with the
    costs for tertiary metal salt addition and filtration derived to
    achieve the 0.3 mg/L objective, in view of the possibility of obtaining
    0.1 mg/L with this latter process.

    Recommended process scheme: See Schemes 19 and 20. (Figure B-1)

    Chemical doses: Assuming secondary effluent alkalinity
                          of 200 mg/L $CaCO_3$ lime dose 300 mg/L CaO
                          recommended for simulations.

                          Add supplementary cation (2 mg/L Al^{3+} or
                          4 mg/L Fe^{3+}) to prevent precipitated phosphorus
                          dissolution during recarbonation.

1.3 PHYSICAL CHEMICAL PLANTS (U.S. ONLY)

    See Schemes 21, 22 and 23, Figure B-1

    Generally, physical/chemical (P-C) installations have, as a minimum, the
    unit processes of chemical coagulation and sedimentation, followed by
    activated carbon adsorption. The latter may or may not be preceeded by
    filtration. In either case (active carbon plus filtration, or active
    carbon alone) an effluent of quality <u>at least equivalent</u> to that predicted
    from a primary plant with chemical coagulation and effluent filtration
    is expected.

    Hence: proposal for simulations is that all P-C plants, <u>as designed</u>,
    will provide an effluent of 0.5 mg/L residual phosphorus.

    Reductions to lower levels (0.3 - 0.1 mg/L) may not be possible in P-C
    plants. P-C plants have been constructed in the U.S.A. for reasons such
    as: lack of space for construction of biological facilities (Rocky
    River, Ohio), or raw sewage characteristics not being suitable for
    biological treatment, due to a high industrial waste component
    (Niagara Falls, N.Y.).

Accordingly, the simulations include capital and operating costs appropriate to 0.5 mg/L effluent P irrespective of the overall effluent objectives specified in the particular scenario. Phosphorus loadings to the Lake from these plants reflect 0.5 mg/L effluent, again irrespective of the overall effluent objective specified in the scenario.

2. RELATIONSHIPS BETWEEN CHEMICAL REQUIREMENTS AND INCOMING P LEVELS FOR VARIOUS EFFLUENT PHOSPHORUS LEVELS

2.1 OBJECTIVE 1 mg/L

2.1.1 *Primary Plants (Canada Only)*

Up-to-date literature (9) reports insufficient data for a regression to provide chemical dose as a funciton of P_{IN}.

Because process is sedimentation only, it is suggested that, for a given chemical dose, effluent P would be a function of influent P; further, testing at Sarnia (1) indicates a relationship between P_{IN}; P_{OUT}; and chemical dose.

Therefore, it is presumed that all three parameters, P_{IN}, P_{OUT}, and chemical dose are inter-related.

Ferric addition

Reference 9:   7 observations

    Average Fe   16.0 mg/L

    Average P_{IN} 5.3 mg/L

    Fe: P_{IN} 3:1 mg/L

    for : 1 mg/L residual phosphorus

    In view of lack of other data, assume 1 mg/L effluent P:

$$Fe: \ P_{IN} = 3:1$$

    (Original computer programme (10) indicates a ration of 3.1:1)

Proposal: Compute chemical requirements on basis of Fe:P of 3:1, and include a polymer at 0.5 mg/L, as per Ontario experience.

Alum addition   (Figure B-2)

Reference 9:   5 observations

    Average Al   10.3 mg/L

    Average P_{IN} 6.2 mg/L

    Al:P_{IN} 1.7:1
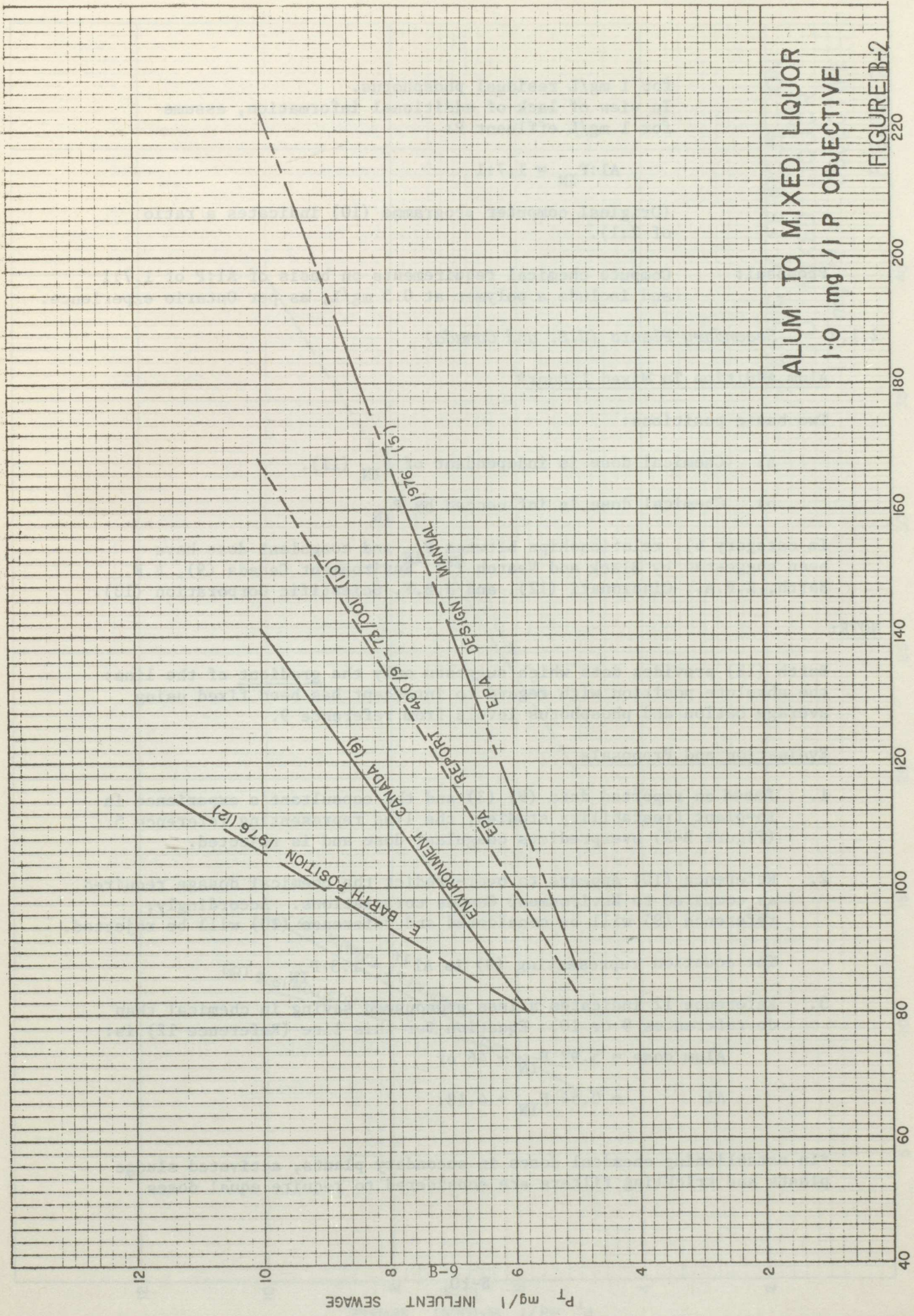
ALUM TO MIXED LIQUOR
1·0 mg /l P OBJECTIVE
FIGURE B-2

Alum DOSE ; mg/l as Alum. $Al_2(SO_4)_3 \cdot 14 H_2O$

P_T mg/l INFLUENT SEWAGE

B-9

EPA DESIGN MANUAL 1976 (5)

EPA REPORT 400/9-73/001 (10)

ENVIRONMENT CANADA (9)

E. BARTH POSITION 1976 (12)

for 1 mg/L residual phosphorus.
In view of lack of additional information, assume
for 1 mg/L effluent P:

$$Al:P_{IN} = 1.7:1$$

(Original computer programme (10) indicates a ratio
of 2:1).

Proposal: Compute chemical requirements on basis of Al:P of 1.7:1
and include a polymer at 0.5 mg/L, as per Ontario experience.

2.1.2   *Secondary Plants (U.S. and Canada)*

Alum Addition To Mixed Liquor*

Two basic positions:

a)   Chemical dose is independant of P_{IN} (11).

b)   Chemical dose is influenced by P_{IN}.

In category b), relationships between P_{IN} and coagulant dose have
been suggested by Black and Veatch (5), Environment Canada (9), E.F.
Barth, E.P.A., Cincinnati (12), and J.B.F. Scientific Corporation (10).

NOTE:

Barth (12) provides data which suggests only the gradient of the line:
the absolute position with regard to intercept has been fixed using
average cation and phosphorus levels from reference 9.

Evaluation and Proposals

1.   Based on reported data (9) (3) and the consultant's experience in
in-plant treatability studies, the line representing reference 5
(Figure B-2) overpredicts coagulant dose and is rejected.

2.   Reference (10) appears to over-predict the chemical dosage required,
as compared to Environment Canada correlations. Accordingly,
reference (9) will be considered and reference (10) will be rejected.

The equation representing (9) is $Al^{3+} = 1.3\ P_{IN}$

3.   Reference 12 indicates a less pronounced saving in chemical than
do references 9 or 10. Equation for this line (Reference 12) is:

Alum dose = $5.97\ P_{IN} + 46$ or

Al   = $0.54\ P_{IN} + 4.18$.

*In establishing chemical doses in secondary plants, activated sludge
plants and trickling filters are considered to require equal doses.
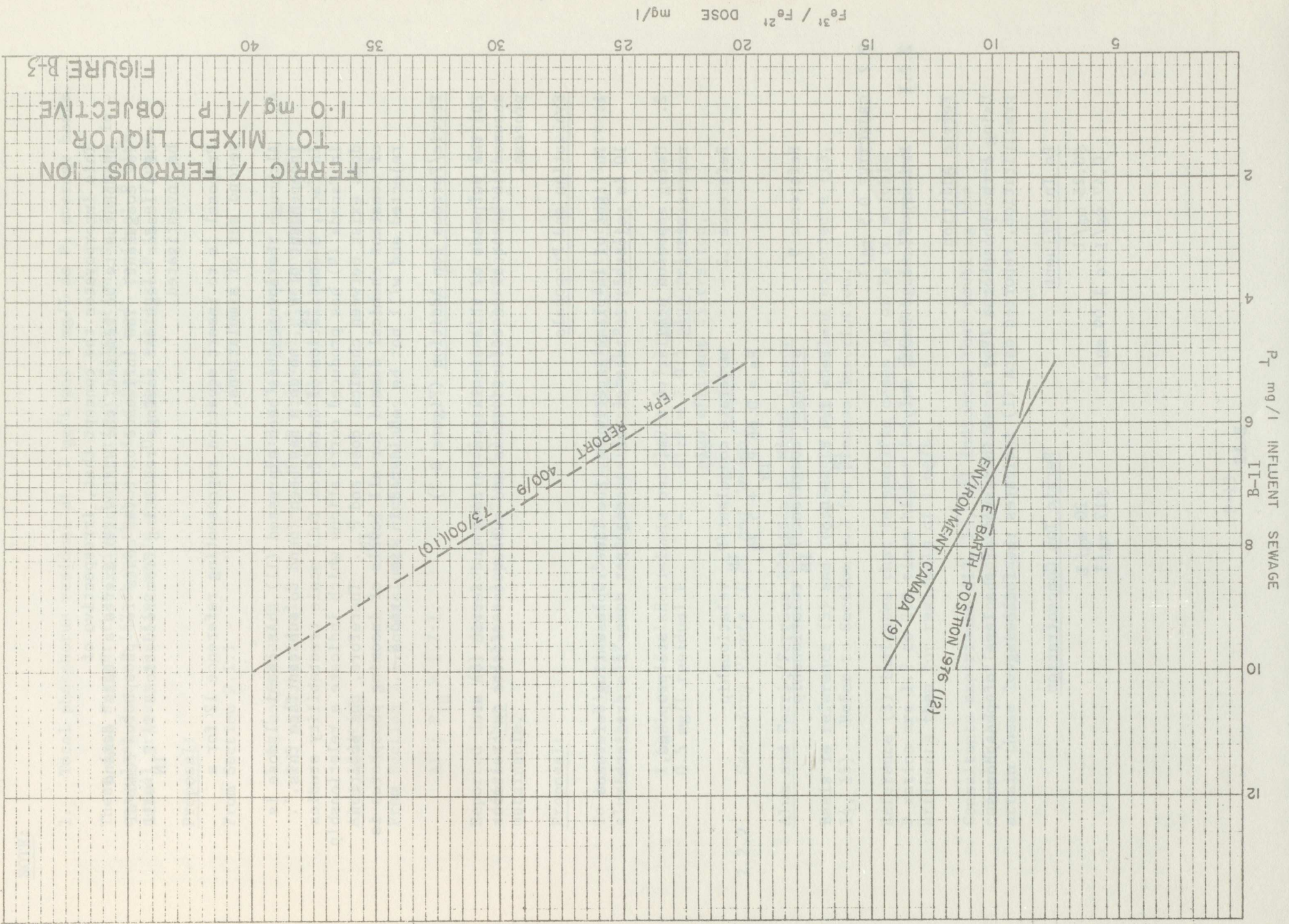
FIGURE B·3

FERRIC / FERROUS ION
TO MIXED LIQUOR
1·0 mg / l P OBJECTIVE

Fe^{3+} / Fe^{2+} DOSE mg / l

P_T mg / l INFLUENT SEWAGE

EPA REPORT 400/9 73/001(10)

ENVIRONMENT CANADA (9)

E. BARTH POSITION 1976 (12)

This incorporates the concept that, irrespective of phosphorus to be removed, the wastewater exerts a "base" demand for coagulant. The influence on total costs for phosphorus removal of a lesser coagulant savings resulting from reductions in P_{IN} will be investigated.

Proposal is to insert equation representing reference 12 for a second set of simulations.

4. Although the opinion has been expressed (11) that chemical dose is independant of P_{IN}, no data has been found to substantiate this. In fact, a compilation of data from full scale treatability studies in Canada (9) has produced correlations which indicate a relationship does exist between chemical dose and P_{IN}. Therefore, the position of constant chemical demand for all levels of incoming phosphorus is rejected and will not be considered in simulations.

Ferric/Ferrous Ion Addition (Figure B-3)

For the purposes of this simulation ferrous and ferric ion are assumed to be equal in effectiveness and subsequent effects on treatment process.

Evaluation and Proposals

1. In light of in-plant experience, the line representing reference 10 is _rejected_, in that excessive coagulant doses are predicted.

2. Using approach similar to alum, two simulations are proposed, representing:

Reference 12 -   _moderate_ coagulant/P_{IN} relationship

$$Fe = 0.66 \ P_{IN} + 5.24$$

Reference 9 -   _stronger_ coagulant/P_{IN} relationship

$$Fe = 1.4 \ P_{IN} + 0.5$$

2.2 OBJECTIVE 0.5 mg/L

2.2.1   _Primary Plants (Canada Only)_

Ferric Addition

Using ortho-phosphorus (Po) as an indicator of the level of phosphorus precipitation, reported data (1) indicates the following:

Po In Effluent	Ferric Ion Concentration
≤ 0.25 mg/L	20 mg/L
0.47 mg/L to 1.09 mg/L	≤ 17 mg/L

NOTE:

1. Total phosphorus residual at 17 mg/L was 1 mg/L as P, average basis.

These data suggest that, given post-primary filtration, an increase in coagulant dose of 15% above that required for 1 mg/L residual P with normal primary settling would ensure 0.5 mg/L residual P in effluent.

Proposal:

From Section 2.1.1

 1 mg/L residual P   -   Fe:P = 3:1 plus polymer
∴ 0.5 mg/L residual P   -   Fe:P = 3.45:1 plus polymer
              plus effluent filtration.

Alum Addition

From Section 2.1.2 for 1 mg/L residual P:

$$Al : P_{IN} = 1.7:1.$$

Reported data (2) does not permit evaluation similar to that for ferric addition but indicates low (<0.2 mg/L) ortho-phosphorus residuals obtainable.

Proposal:

To ensure objective of 0.5 mg/L, given post-primary filtration, increase alum dosage by 15% over requirements for 1 mg/L P residual.

 1 mg/L residual P   -   Al:P = 1.7:1 plus polymer
 0.5 mg/L residual P   -   Al:P = 2.0:1 plus polymer,
              plus effluent filtration.

2.2.2   *Secondary Plants (U.S. and Canada)*

Alum and Ferric/Ferrous Addition to Mixed Liquor

Basis is reference (3) and consultants own in-plant experience (13, 14, 15). Refer to Section 1.2 for process description.

Reference (3) indicates that in specific cases Al or Fe to soluble P ratios are 1.3 to 2.0 times higher for low (<0.3 mg/L) phosphorus effluents than for residuals of 1 mg/L.

Consultants experience (13, 14, 15) indicates that doubling the concentration of cation normally used (for 1 mg/L residual P) will attain these low residuals.

LIQUID SCHEME NUMBER	EFFLUENT P mg/L	EXCESS SLUDGE GENERATED (two components are additive)		EXCESS SLUDGE PRODUCED FROM PROCESS	CHEMICAL REQUIREMENTS mg/L	PROCESS UNITS
		CHEMICAL	SEW. SOLIDS			
1, 2	1·0	6·10 lb/lb AL 3·65 lb/lb Fe	500 lbs./M.I.G. 420 lbs./M.U.S.G.	QUANTITY EQUALS EXCESS SLUDGE GENERATED	Fe : P = 3 : 1 AL : P = 1·7 : 1	PRELIMINARY TREATMENT → PRIMARY SETTLING → 1 mg/L P (Fe/AL SALT, POLYMER)
3, 4	0·5	6·10 lb/lb AL 3·65 lb/lb Fe	800 lbs./M.I.G. 660 lbs./M.U.S.G.	QUANTITY EQUALS EXCESS SLUDGE GENERATED	Fe : P = 3·45 : 1 AL : P = 2·00 : 1	PRELIMINARY TREATMENT → PRIMARY SETTLING → FILTRATION → 0·5 mg/L P (Fe/AL SALT, POLYMER)
5, 6	0·3	7611 lbs/M.I.G. 6343 lbs/M.U.S.G.	800 lbs./M.I.G. 660 lbs./M.U.S.G.	1076 lbs./M.I.G. 895 lbs./M.U.S.G	300 CaO	PRIMARY EFFLUENT → TWO STAGE LIME CLARIFICATION AND RECARBONATION → FILTRATION → 0·3 mg/L P
19 (ACTIVATED SLUDGE), 20 (TRICKLING FILTER)	0·1	7677 lbs/M.I.G. 6397 lbs/M.U.S.G.	AS ABOVE (SCHEMES 5 and 6)	966 lbs./M.I.G. 805 lbs./M.U.S.G.	300 CaO 2 AL 4 Fe	SECONDARY EFFLUENT FROM UPGRADED PLANT → TWO STAGE LIME CLARIFICATION AND RECARBONATION → 0·1 mg/L P
7,8 (ACTIVATED SLUDGE), 9,10 (TRICKLING FILTER)	1·0	1·4P + 2·89 AL (mg/L) 1·4P + 1·91 Fe	0	QUANTITY EQUALS EXCESS SLUDGE GENERATED	AL = 1·3 P − 0·3 AL = 0·54P + 4·18 Fe = 1·4 P + 0·5 Fe = 0·66P + 5·24	PRIMARY TREATMENT → AERATION OR TRICKLING FILTER → FINAL SETTLING → 1 mg/L P (Fe/AL SALT)
11,12 (ACTIVATED SLUDGE), 13,14 (TRICKLING FILTER)	0·5	AS ABOVE (SCHEMES 7–10)	0	QUANTITY EQUALS EXCESS SLUDGE GENERATED	AL = 2·6P − 0·3 AL = 1·08P + 4·18 Fe = 2·8P + 0·5 Fe = 1·32P + 5·24	PRIMARY TREATMENT → AERATION OR TRICKLING FILTER → FINAL SETTLING → 0·5 mg/L P (Fe/AL SALT)
15,16 (ACTIVATED SLUDGE), 17,18 (TRICKLING FILTER)	0·3	AS ABOVE (SCHEMES 7–10)	100 lbs/M.I.G 83 lbs./M.U.S.G	QUANTITY EQUALS EXCESS SLUDGE GENERATED	AS FOR SCHEME 6 ABOVE	PRIMARY TREATMENT → AERATION OR TRICKLING FILTER → FINAL SETTLING → FILTRATION → 0·3 mg/L P (Fe/AL SALT)
19 (ACTIVATED SLUDGE), 20 (TRICKLING FILTER)	0·1	7677 lbs/M.I.G. 6397 lbs/M.U.S.G	0	966 lbs/M.I.G 805 lbs/M.U.S.G.	300 CaO 2 AL 4 Fe	SECONDARY EFFLUENT FROM EXISTING PLANT → TWO STAGE LIME CLARIFICATION AND RECARBONATION → 0·1 mg/L P
21, 22 PHYSICAL — CHEMICAL PLANT	0·5	0	0	0	12·5 AL Fe = 3·45 P ACTIVATED CARBON MAKE-UP : 50 lbs/M.U.S.G.	PRELIMINARY TREATMENT → FLOCCULATION → PRIMARY SETTLING → ACTIVATED CARBON FILTER → 0·5 mg/L P (Fe/AL SALT, POLYMER)
23 PHYSICAL — CHEMICAL PLANT	0·5	0	0	0	165 CaO ACTIVATED CARBON MAKE-UP : 50 lbs./M.U.S.G.	PRELIMINARY TREATMENT → FLOCCULATION → PRIMARY SETTLING → FILTRATION → ACTIVATED CARBON FILTER → 0·5 mg/L P (CaO, POLYMER)

NOTES

1. IN LIQUID SCHEMES 5,6,19,20, EXCESS SLUDGE PRODUCED FROM PROCESS IS DISPOSED OF DIRECTLY. QUANTITIES INDICATED ARE FOR DIRECT DISPOSAL. IN ALL OTHER SCHEMES EXCESS SLUDGE PRODUCED FROM PROCESS, TOGETHER WITH SLUDGES NORMALLY PRODUCED ARE PASSED ON TO SLUDGE PROCESSING (DIGESTION, FILTRATION, ETC.)

2. LIQUID SCHEME 22, FERRIC DOSING OF A PHYSICAL CHEMICAL PLANT IS NOT SIMULATED IN THIS STUDY

3. PHYSICAL – CHEMICAL PLANTS OPERATE AT ASSIGNED EFFLUENT OF 0·5 mg/L P, IRRESPECTIVE OF SCENARIO SPECIFIED. NO EXCESS SLUDGE IS ATTRIBUTED TO P REMOVAL.

TREATMENT SCHEMES FOR 'P' REMOVAL

Figure No. B-1

Chemical doses: Two stage lime clarification using <u>300 mg/L CaO</u>.
                              See following section for derivation of dose.

<u>Objective: 0.1 mg/L P</u>

No known experience meeting this objective with primary effluents.

EPA data (4) indicates that on trickling filter effluent:

	After two stage lime clarification	After filtration
P_T -	0.089 mg/L	0.045 mg/L

Recommend, for computer simulation:

(a) upgrade primary plant to secondary
(b) no chemical addition in secondary process train
(c) two stage lime clarification of secondary effluent
       without effluent filtration, to obtain 0.1 mg/L residual P.

Recommended process scheme: See Schemes 19 and 20 (Figure B-1)

Chemical doses: Assuming secondary effluent alkalinity of
                              200 mg/L $CaCo_3$, lime doses required as per
                              literature
                            -   300 mg/L CaO(5), (3)
                            -   260 to 340 mg/L CaO (4)

                         Recommend <u>300 mg/L CaO</u> for simulations.

                         To prevent redissolution of precipitated phosphorus
                         during recarbonation, add supplementary cation
                         at 2 mg/L Al^{3+} or 4 mg/L Fe^{3+}.

1.2 SECONDARY PLANTS

Existing Canadian Plants with secondary treatment. All U.S. Plants
as per P.L. 92-500.

<u>Objective: 1 mg/L P</u>

Canadian experience on comparing liquid treatment schemes indicates that
chemical addition to mixed liquor is more economical than addition to raw
sewage.

Processes will be pre-selected to reflect existing installed equipment
and chemical used: chemical addition to mixed liquor (no lime schemes used).

Recommended Process Scheme: See Schemes 7, 8, 9 and 10. (Figure B-1)

Proposal:

Alum Addition

Apply a factor of $\underline{two}$ to relationships derived from references (10) and (12), as follows:

Reference	1 mg/L P	0.5 mg/L P
(10)	$Al = 1.3 \, P_{IN} - 0.3$	$Al = 2.6 \, P_{IN} - 0.3$
(12)	$Al = 0.54 \, P_{In} + 4.18$	$Al = 1.08 \, P_{IN} + 4.18*$

Relationships shown of Figure B-4.

Ferric/Ferrous Addition

Apply a factor of $\underline{two}$ to relationships derived from references (9) and (12).

Reference	1 mg/L P	0.5 mg/L P
(9)	$Fe = 1.4 \, P_{IN} + 0.5$	$Fe = 2.8 \, P_{IN} + 0.5*$
(12)	$Fe = 0.66 \, P_{IN} + 5.24$	$Fe = 1.32 \, P_{IN} + 5.24*$

Relationships shown on Figure B-5.

*Constant in these equations related to "base" demand of wastewater for coagulant, exclusive of phosphorus precipitation. Factor of two does not apply to this constant.

Simulations will be done for each chemical, where applicable using the two functions shown.

2.3 OBJECTIVE 0.3 mg/L

2.3.1 *Primary Plants (Canada Only)*

Use two stage lime clarification at 300 mg/L CaO in the tertiary step.

2.3.2 *Secondary Plants (U.S. and Canada)*

Chemical doses (Al or Fe) determined as for 0.5 mg/L objective discussed previously (Section 2.2.2) post-secondary filtration added.

2.4 OBJECTIVE 0.1 mg/L

Only secondary plants presumed capable of this objective. Two stage lime clarification as post-secondary treatment.

Lime dose: 300 mg/L as CaO.

Supplementary cation addition, as noted previously.

3. EXCESS SLUDGE PRODUCTION FROM CHEMICAL ADDITION

3.1 PRIMARY PLANTS (CANADA ONLY)

3.1.1 *Objective: 1 mg/L P*

Existing computer programme will be modified to take into account
additional solids capture from chemical addition. Basis for this:

Typical Primary Plant (no chemical addition)

- influent suspended solids: 175 mg/L
- effluent suspended solids (no chemical addition): 90 mg/L

    (50% removal of influent solids)

From this, solids production is 850 lbs/M.I.G.

Primary Plant With Chemical Addition

- influent suspended solids: 175 mg/L
- effluent suspended solids: 40 mg/L (max.)

    (77% removal of influent solids say 80%)

From this, solids production (settleable only, excluding chemical
sludge): 1350 lbs/M.I.G.

To this must be added chemical sludge formed.

Stoichiometric: Alum Addition

For Al precipitated as $AlPO_4$, sludge production
is 4.52 lbs/lb. aluminum added.

For Al precipitated as $Al(OH)_3$, sludge production
is 2.89 lbs/lb. aluminum added.

Ferric Addition

For Fe precipitated as $FePO_4$, sludge production
is 2.69 lbs/lb. iron added.

For Fe precipitated as $Fe(OH)_3$, sludge production
is 1.91 lbs/lb. iron added.

Following a review of available information, reference (5) indicates
that when computing stoichiometric sludge produciton, as above,
an additional 35% should be added.

In preparing this document it was determined that, in view of the fact
that a large amount of sludge would be produced from additional sewage
solids (and would therefore be largely independent of chemical quantities
added), it is permissable to assume that all chemical sludges were formed
as the phosphate. On this basis, the following factors are recommended:

Chemical sludge: 6.10 lbs/lb. aluminum added.
                              3.65 lbs/lb. iron added.

Solids removal across the primary; chemical addition: 80%.

Check: Average rates of cation addition to primary plants (9).

Fe : 16.0 mg/L
Al : 10.3 mg/L

	Al	Fe
Additional chemical sludge lb/MIG (Using factors above)	628	584
Additional settleable sludge lb/MIG (1350 lbs-850 lbs, from previous calculation)	500	500
	1128	1084
Sludge production without chemical addition	850	850
Sludge production with chemical addition (lbs/MIG)	1978	1934

Reference (11) indicates the following sludge production:

Before chemical addition : 700-1200 lbs/MIG
After chemical addition   : 1500-2500 ln/MIG

3.1.2   *Objective 0.5 mg/L P*

Chemical sludges   –   as presented for 1 mg/L objective
                           (NOTE: 15% more chemical will be added
                           for lower P objective).

Sewage sludges   –   80% removal across primary, plus reduction
                           from 40 mg/L to 10 mg/L suspended solids
                           across filter, i.e. 300 lbs/MIG.

3.1.3   *Objective 0.3 mg/L P*

Two stage lime clarification plus filtration.

Estimated sludge production from tertiary process: (see following notes)	7611 lb/MIG
Estimated sludge production from additional solids capture:	800 lb/MIG
	8411 lbs/MIG

Processes employing lime clarification are simulated as having lime recalcination for lime recovery by conversion of calcium carbonate in the sludge to calcium oxide. The figures noted above are therefore used in process sizing calculations.

The _excess_ sludge generated for ultimate disposal is equal to the quantity of recalcined material which must be purged from the system to ensure that inert matter does not accumulate in the process. In this primary plant application these inert components are made up of non-volatile sewage sludge solids present in the 800 lb/MIG excess solids captured in the lime clarification, together with the non-calcinable portion of the chemical sludges formed by lime addition.

These components are estimated as follows:

1.   Non-volatile sewage solids, corresponding to a volatile fraction of 78% in incoming sewage solids –

         800 x 0.22 = 176 lb/MIG or 145 lbs/MUSG.

2.   Non-calcinable chemical sludge: 900 lbs MIG or 750 lbs/MUSG. (Based on inerts formed in lime sludges – Section 3.1.4, cross-checked with Lake Tahoe operating data).

Of the 8411 lb/MIG (7003 lbs MUSG) excess sludge produced (see below), the amount purged from the recalcination process is therefore 1076 lbs/MIG, or 895 lbs/MUSG. This is in addition to the sludges formed by the normal operation of the primary plant.

3.1.4   _Objective 0.1 mg/L P_

Plant assumed upgraded to secondary treatment followed by two stage lime clarification.

Estimated sludge production from tertiary process and additional solids capture is 8411 lbs/MIG (7009 lbs/MUSG) as above plus 66 lbs/MIG (55 lbs/MUSG) from supplementary cation as detailed in the following notes, for a total of 8477 lbs/MIG (7064 lbs/MUSG).

NOTES:

1.   Original (10) estimate of sludge production 7000 lbs/MUSG (8400 lbs/MIG) without the addition of supplementary cation.

2.   Basis for computation of 7611 lbs/MIG excess chemical sludge:

     Reference (5), page 11-27 et seq.

     In view of lack of specific data on plant effluents with respect to the components listed, assume the following secondary effluent properties:

P_T (no prior chemical treatment)   7 mg/L

Alkalinity, As $CaCO_3$ 200 mg/L

Calcium ion   100 mg/L

Magnesium ion   20 mg/L

Sludge components

(a) Neglect inerts in lime.

(b) Hydroxyapatite sludge, assuming removal of P from
     7 to 0.1 mg/L: 38 mg/L

(c) Magnesium hydroxide precipitation, assuming entire
     20 mg/L Mg precipitated: 48 mg/L

(d) Calcium carbonate precipitated: from calcium
     balance 250 mg/L Ca is precipitated, equivalent
     to, as calcium carbonate: 625 mg/L

(e) Calcium carbonate produced from recarbonation,
     assuming reduction in Ca from 50 to 30 mg/L: 50 mg/L

     Total sludge produced from lime addition   761 mg/L

                      OR   7611 lbs/MIG

                      OR   6342 lbs/MUSG

When operating at effluent P levels of 0.1 mg/L the chemical
precipitates resulting from the addition of 2 to 4 mg/L of cation,
to prevent phosphate redissolution, just be added, estimated at 48
lbs/MUSG for alum addition and 64 lbs/MUSG for ferric addition, say,   55 lbs/MUSG

               Total sludge produced   6397 lbs/MUSG

(In sizing unit process the model uses the exact quantities of sludge
appropriate to either alum or ferric; the 55 lbs/MUSG figure is used
here only for ease of presentation of this table and Figure B-1).

As previously discussed in Section 3.1.3, the excess sludge for ultimate
disposal to be purged from the lime process is 750 lbs/MUSG. To this
must be added the chemical sludges produced by supplementary cation
addition for alum or ferric chloride, 48 and 64 lbs/MUSG
respectively.

Hence, in computing excess sludge for direct disposal from the
recalcination process, the model uses the following factors:

Supplementary cation   Excess sludge

     Aluminum   798 lbs/MUSG
     Ferric   814 lbs/MUSG

This sludge is additional to the sludge formed by normal plant operation.

3.2 SECONDARY PLANTS (U.S. AND CANADA)

3.2.1   *Objective: 1 mg/L and 0.5 mg/L P*

Processes for each objective differ only in quantity of chemical to
be used. Majority of input phosphorus will be hydrolysed to ortho-
form through aeration section and precipitated as aluminum or ferric
phosphate. Balance of chemical will be consumed as hydroxide of
cation added. At lower (0.5 mg/L P) objective, proportionately more
cation will be in excess of stiochiometric requirements for phosphate
precipitation than at 1 mg/L objective. Therefore, the mathematical
function to express sludge must account for both types of precipitate.

Basis: Alum Addition To Mixed Liquor

Influent concentration P_{IN} mg/L or 0.032 P_{IN} mm/L.

Assume all P_{IN} is precipitated as $AlPO_4$.

Sludge production ($AlPO_4$): 0.032 P_{IN} mm/L

OR   390 P_{IN} mg/L.................I

Aluminum added at aeration tank: Al_{IN} mg/L

OR   0.037Al_{IN} mm/L

Aluminum available for hydroxide precipitation:

(0.037 Al_{IN} - 0.032 P_{IN}) mm/L

Sludge production $[Al(OH)_3]$: $(0.037Al_{IN} - 0.032P_{IN})$ x 78

$= (2.89Al_{IN} - 2.50P_{IN})$ mg/L..II

Total sludge production (stoichiometric), by adding
equations I and II:

$$(1.4\ P_{IN} + 2.89Al_{IN})\ mg/L$$

Validation: Consider E. Barth (12) corellation (Figure B-2)

P_{IN}	Alum	Aluminum	Excess Sludge
10	114	10.3	59.1
5	80	7.2	37.6

(all units mg/L)

Assume rate of sludge production, conventional secondary plant, no
chemical addition is 200 mg/L (or 2000 lbs/MIG). Rate of excess sludge
production is:

At P_{IN} = 10 mg/L : 30% above base of 200 mg/L

P_{IN} = 5 mg/L : 19% above base of 200 mg/L

A review of secondary plant sludge production in Ontario studies with chemical addition (11) indicates a 5%-25% increase in solids production attributable to chemical addition. Noting that 10 mg/L influent P is somewhat higher than experienced after detergent reformulation in Ontario (9), with a consequent increase in prime coagulation required (according to Barth correlation chosen for this example), predicted range of excess sludge production is reasonable, and therefore will be predicted in simulations according to:

Excess sludge produced (mg/L) = $1.4\ P_{IN} + 2.89\ Al_{IN}$

(units of P_{IN}, Al_{IN} : mg/L)

Ferric/Ferrous Addition To Mixed Liquor

An approach similar to the above, but for iron salts, yields the equation:

Excess sludge production (mg/L) = $1.91\ Fe_{IN} + 1.4\ P_{IN}$

(units of P_{IN}, Fe_{IN} : mg/L)

Validation: Consider Barth (12) Correlation (Figure B-2)

P_{IN}	Fe	Excess Sludge
10	11.5	32.12
5	7.5	21.41

(all units mg/L)

Taking a datum sludge production of 200 mg/L, rate of excess sludge production is:

At P_{IN} = 10 mg/L : 18% above base of 200 mg/L

P_{IN} = 5 mg/L : 11% above base of 200 mg/L

Again, a reasonable fit with 5%-25% previously cited (11) is noted.

The use of the equation below for excess sludge production is recommended for simulations.

Excess sludge produced (mg/L) = $1.91\ Fe_{IN} + 1.4\ P_{IN}$

(units of Fe_{IN}, P_{IN} : mg/L)

3.2.2   *Objective: 0.3 mg/L P*

Chemical sludges   —   derived according to equations set forth for 0.5 mg/L P objective.

Sewage sludges   —   additional solids removed across tertiary filter. Assuming a normal quality secondary effluent (15 mg/L suspended solids) is applied to the filters and reduced to 5 mg/L suspended solids, additional sludge load is:

$$(15-5) \times 10 = 100 \text{ lbs/MIG}$$
$$\text{or } 83 \text{ lbs/MUSG}$$

3.2.3   *Objective: 0.1 mg/L P*

Estimated sludge production from tertiary (two stage lime clarification) process:

7688 lbs/MIG;   6390 lbs/MUSG - Al addition

7687 lbs/MIG;   6406 lbs/MUSG - Fe addition

Excess sludge for ultimate disposal:

958 lbs/MIG;   798 lbs/MUSG - Al addition

977 lbs/MIG;   814 lbs/MUSG - Fe addition

REFERENCES

(1)   Canada/Ontario Agreement – Research Report 14. Phosphorus Removal Study at the Sarnia W.P.C.P.

(2)   Nutrient Removal at Windsor Sewage Treatment Plants – 1972.

(3)   Design Considerations to Attain Less than 0.3 mg/L Effluent Phosphorus. Stepko, W.E. and Schroeder. High Quality Effluent Seminar, Toronto, 1975.

(4)   Tertiary Treatment for Phosphorus Removal at Ely, Minnesota. EPA Report 600/2-76-082, March, 1976.

(5)   EPA Process Design Manual for Phosphorus Removal; April, 1976.

(6)   Personal Communication from R.W. Ockershausen, Allied Chemical Corporation, February, 1977.

(7)   Carbon, Nitrogen and Phosphorus Removal in Staged Nitrification-Denitrification Treatment. EPA Report 670/2-75-052, June 1975.

(8)   Culp and Culp. Advanced Wastewater Treatment, Van Nostrand Reinhold Company.

(9)   Development of Predictive Models for Chemical Phosphorus Removal. Environment Canada Report in Press.

(10)   Computer Model for Evaluating Community Phosphorus Removal Strategies.
         EPA Report 400/9-73-001.

(11)   Phosphorus Removal Design Seminar; Canada/Ontario Agreement on
         Great Lakes Water Quality. Toronto, Ontario, 1973.

(12)   Statement for EPA Region V in the Matter of Phosphorus Control
         Technology. E.F. Barth, 1976.

(13)   Phosphorus Removal at the Tillsonburg W.P.C.P., James F.
         MacLaren Limited, April, 1976.

(14)   Phosphorus Removal at the City of Woodstock Water Pollution
         Control Center, James F. MacLaren Limited, August, 1973.

(15)   Phosphorus Removal at the Westminster Township Pollution Control
         Plant, James F. MacLaren Limited, September, 1973.

APPENDIX "C"

LISTING OF PLANT SPECIFIC VARIABLES

TABLE C-1

LISTING OF PLANT SPECIFIC VARIABLES

Listed below are those variables in the programme which could be set on an individual plant basis, and an indication of the range of values used in the simulations.

VARIABLE	SIGNIFICANCE	VALUE
CNSTRC	(WQO-STP Construction Cost Index) $\div$ 100	2.757
DHR	Direct hourly labour rate	$7.50/hour
ELECOS	Electrical power cost	$0.025/KWHR
GOVFF	Government financial fraction of consruction cost	0.0
IDFRAC	Indirect labour fraction	0.35
MATRLS	(Wholesale Price Index for Industrial Commodities) $\div$ 100	1.899
SOLSNK (Cap)	Capacity of solid sink for sludge disposal	set at a large number
SOLSNK (Dist)	Distance to solid sink	1 mile
TRNCST	Transportation cost for solid wastes	$1.40/ton mile
FNCTYP	Function type for interpolation of population	Linear inter-polation
SPOPIN	Projected population by year (2 variables)	from local population projections
ALKIPS	Alkalinity into primary settler	201 mg/L
ASD	Activated sludge density	0.01
BODIPS	BOD_5 into primary settler	from existing plant records
FLOTUD	Floated sludge density	0.05
GRAVUD	Thickened sludge density	0.08
HPDFT	Hours per day flotation operation	16 hours/day
HPDVF	Hours per day vacuum filter operation	16 hours/day
MLSSAR	MLSS concentration	2,000 mg/L
NH31AR	NH_3 into aeration process	25 mg/L
PINPS	Phosphorus into the primary settler	derived from existing plant data for each condition
PSETUD	Density of settled primary sludge	0.05
PSRMVE	Fraction S.S. removed in primary settler	0.50

TABLE C-1

LISTING OF PLANT SPECIFIC VARIABLES

VARIABLE	SIGNIFICANCE	VALUE
QAVE	Average daily flow	from operating data of existing plant
QPEAK	Peak diurnal flow	not used in this study (peak flow calculated by Harmon formulae)
SSINPS	S.S. into primary settler	from operating data of existing plant
TBODAR	Change in BOD_5 across aeration process	0.85
VFPSLG	Volatile fraction of primary sludge	0.78
VSANRM	Volatile fraction of anaerobically digested sludge	0.50
VSARM	Volatile fraction of aerobically-digested sludge	0.50
AMRATE	Amortization rate	N/A in this study
AMLIFE	Amortization life	N/A in this study
DESIGN CAP	Design capacity of existing facilities	stated capacity of existing plant
PROCESS	Unit processes for wastewater treatment	from existing plant information
ALUMFS	Cost of alum	$0.043/lb. alum
FECLFS	Cost of ferric chloride	$0.079/lb. ferric chloride
LIMEFS	Cost of lime	$0.025/lb. lime
POLYFS	Cost of polymer	$2.00/lb. polymer
COZFS	Cost of carbon dioxide	$0.038/lb. carbon dioxide
NAALFS	Altered from REMOVE to indicate cost of granular activated carbon	$0.50/lb activated carbon
PCKLFS	Cost of pickle liquor	$0.04/lb. ferrous chloride
NAOHFS	Cost of sodium hydroxide	N/A in this study

INTERNATIONAL JOINT COMMISSION
GREAT LAKES REGIONAL OFFICE
100 Ouellette Avenue
Windsor, Ontario N9A 6T3