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UPPER GREAT LAKES WASTE LOADINGS TRENDS SIMULATION MODEL:

CONCEPTS AND METHODOLOGY

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INTRODUCTION

Following the 1972 signing of the Canada-United States Great Lakes Water Quality Agreement, the two countries requested the International Joint Commission to undertake a comprehensive study of Lake Superior and Lake Huron and the connecting waters. The I.J.C. prepared a set of Reference Questions[1] and appointed the Upper Lakes Reference Group to undertake appropriate studies. These included an examination of the possible demographic and economic developments which could influence water quality[2].

The study plan emphasized the need to better understand fundamental sources of pollution, to develop and evaluate pollution abatement and preventive programs, and to determine future trends in activities which could cause additional pollution problems, in the Upper Great Lakes. It was proposed that demographic and economic projections would be formulated with the program of Working Group A, and that procedures for converting these projections into predictions for future point source waste loadings would be developed with Working Group C. Working Group A chose to develop a computer simulation model to study loadings data and to simulate results from various sets of alternative assumptions. Monitoring data provided by Working Group C would serve to coordinate and validate the theoretical mathematical model. The present report is a description of that model.

For technical and operational reasons, a small Technical Committee of Working Group A was assigned the task of preparing the conceptual framework and the model-mechanism, under direction of the Canadian and U.S.A. Co-chairmen, Mr. J.P.H. Batteke and Mr. E. Pinkstaff. The personnel of this committee is given in Appendix 1.

THE PURPOSE AND SCOPE OF THE MODEL

The aim of the present project was to comply with the stated purpose of Working Group A to build a computer simulation model to coordinate the present and the predicted interrelationships of geographic, economic and demographic characteristics of the Upper Great Lakes Basin with waste loadings and their discharge to the Lakes. Specifically, the model attempts to estimate the municipal and industrial non point source of waste loadings in the Basin, to indicate the rate of growth of the needs and costs of pollution treatment capacity.

The model also attempts to set up a framework for exploring the consequences of possible changes in technology in the production and treatment of sewage, as well as for examining the costs and benefits of various investment policies.

The regions covered by the study were the following geographical areas:

Canada (a) 7 River Basin Groups:

1. Kaministikwia River
2. Nipigon River
Ogoki Diversion
Longlac Diversion
White River
3. Magpie River
Montreal River
4. Mississagi River
5. Spanish River
French River
6. Severn
Muskoka
Lake Simcoe
7. Saugeen River
Maitland River

(b) 3 C.M.A.'s

Thunder Bay
Sault Ste. Marie
Sudbury

U. S. (a) 4 Economic Sub-areas
(1.1)
(1.2)
(3.1)
(3.2)

(b) 4 SMSA's
Duluth - Superior
Flint, Michigan
Saginaw, Michigan
Bay City, Michigan

The model considered the size of the population and its municipal - rural distribution in order to compute municipal waste loadings.

The industries examined for their waste loadings were those listed in the Canadian Major Industrial Group Classification as listed in the Candide Model[3] and the Standard Industrial Classification as listed in OBERS E[4].

METHODOLOGY

Joint Canada - U.S. Conceptual Approach

While the model aspires to process a large volume of statistical data from both countries, an ever present problem inherent in this task is the different format of Canadian and United States information. Nevertheless, it was decided at the outset to build similar conceptual model structures wherever possible for both countries. This is particularly apparent in the sectoral modular structure of the entire work, showing the interaction between population, economic activities, technological changes, sociological factors and legislation, to integrate into a coordinated whole which produces a given waste loading impact upon the tributaries and the lake. The principle involved in deciding to follow this procedure is emphasized by Mr. J.P.H. Batteke:

> "The rationale for that decision is based on the realization that different methodologies, in such complex matters as long term estimates of wasteloadings, could cause critical variations in these estimates, which would render impossible a proper interpretation of the Reference Question regarding possible future transboundary pollution."[5].

Interactive Simulation Modelling

Such modelling has a number of advantages over linear statistical projection[6]. It allows for the organization of large amounts of data in an interrelated manner. It emphasizes the need for continuous communication with decision makers and permits the latter to see the consequences of recommended policies and strategies. It helps develop a better understanding of the behaviour of the system and of the sectors of the overall problem which still need to be researched It allows the combination of facts and opinions in an orderly and systematic fashion.

The forecasting of the waste loadings has two aspects - objective and subjective. The objective aspects are those based on cause and effect relationships which permit scientific analysis. For example, through experience it has been established that the waste loading of phosphorus effluent per capita is 2.5 lb/per year.

The subjective aspects refer to the uncertainty that is always present when attempting to forecast which requires opinion and judgemental inputs. In demographic and economic considerations, uncertainty exists in such factors as growth rates and availability of resources. In technological considerations, there is uncertainty about the availability, performance and costs of waste treatment systems. There are also political and administrative uncertainties including financial and budgetary decisions, and new legal conditions. The model attempts to cope with such uncertainties by allowing the model user to assess a variety of opinions in the scenarios.

The objective aspects of the model are represented coherently and systematically by means of equations of the relevant relationships[7].

The subjective aspects of estimating the waste loadings are incorporated into the model by allowing that assumptions will have to be made regarding future events, choices, and value judgments. Such assumptions may be expressed through a sequence of possible events, or a mixture of options and events, composed into a scenario[8][9]. The parameters provided by the scenario complete the model, and permit the computer to analyze the consequences of making whatever assumption or policies proposed by the decision maker.

In analyzing the hypothetical future of the system in terms of a set of scenarios, there is no forecasting in the literal sense of that word. Instead, a framework is provided for experimenting with alternative future developments on the basis of "if this is assumed, then this will follow".

In view of the above, it is apparent that the main modelling effort consisted of building the causal framework, upon which scenario analysis becomes possible. To build such a framework, it was necessary to obtain data about the regions on the Canadian and U.S. side of the Upper Great Lakes Basin concerning population, urbanization, municipal effluent production, extent of municipal effluent, industrial production, municipal and industrial effluent treatment capacity and costs. Much of the technical data and estimates have been supplied by the Canadian and the United States sections of Working Group C[10] [11]. Physical and economic background information was supplied by the members of Working Group A[12].

The simulations concerning expected changes in population growth, technological changes, alterations in sociological lifestyles and legislative and corporate policies are carried out by means of variables to which the decision maker may assign exploratory values in order to ascertain their consequences. Such are called "simulation variables".

OVERVIEW OF THE MODEL

A great many factors are involved in trying to estimate the demographic, sociological, technological and industrial developments which will evolve in the next 50 years to influence man's impact on water quality in the Upper Lakes through waste loading. The total impact is further complicated by the synergistic relations between these factors. Hence the first step in any effort to look ahead is to reduce the number of critical variables to be considered. The lack of thorough and consistent data and the need to keep the field of inquiry within manageable proportions are further considerations in economising on the number of variables.
The basic variables of the model are population and economic activity. Their development, and the extent to which they produce their respective wasteloads, and cope with them, constitute the main theme of the model. Other interdependent forces are social, technological and legislative factors. The relationship between these factors are depicted in Figure 1.

The conceptual structure of the model consists of estimating the municipal waste, produced by the urban population, and the industrial waste, produced by the various industries. In each respective case, the primary discharges of wastes were computed by multiplying the population by per capita waste coefficients, and the industrial output by appropriate coefficients. This procedure yielded the loads produced in suitable units and in iterative sequence for all the regions, the municipalities, the industries and the parameters as desired.

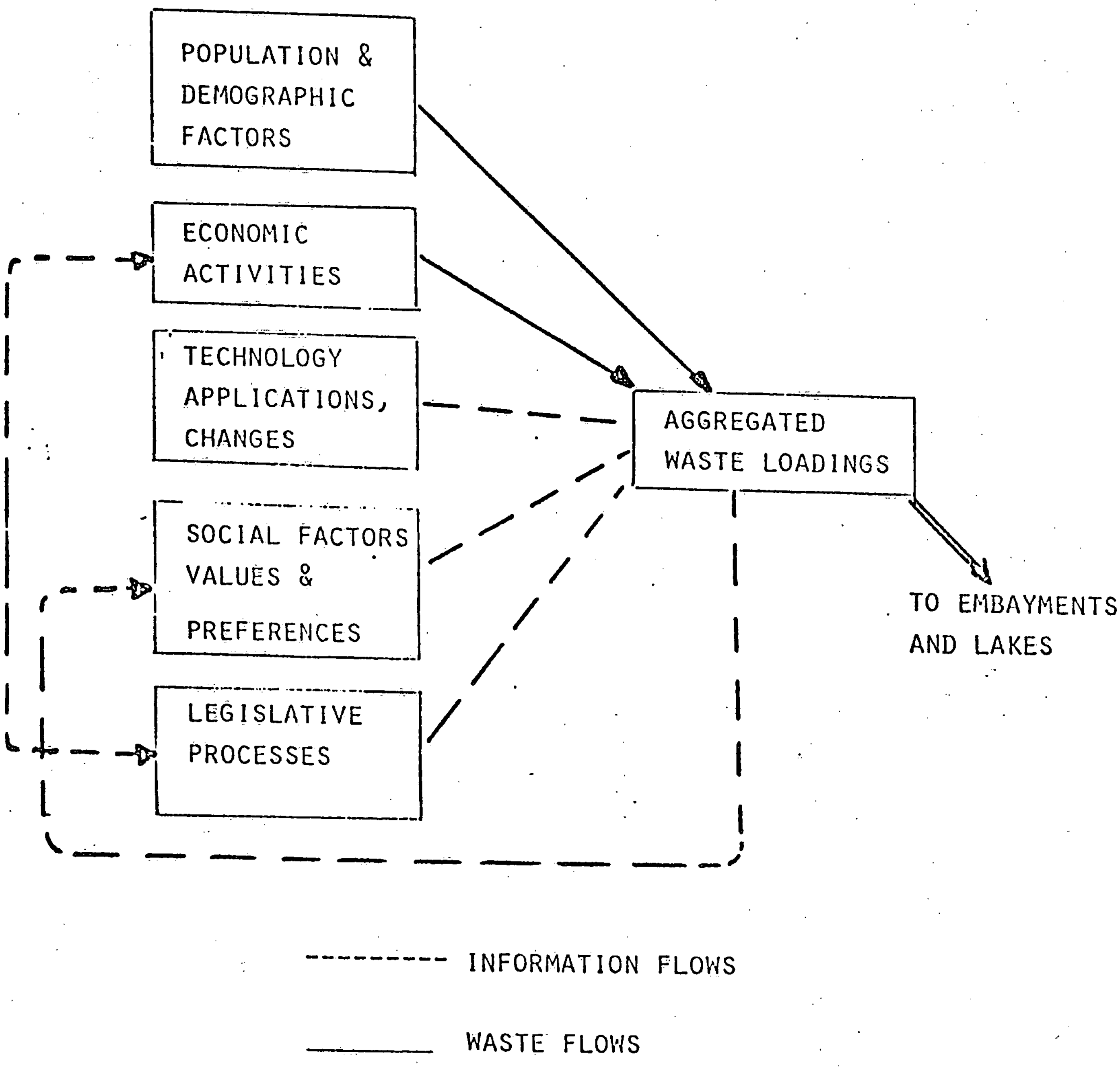


Figure 1. The Modular Structure of the Model.

The wastes produced were subject to treatment by the municipal and industrial treatment capacity respectively. The rates of growth of the treatment capacity plant, and the required investment, were incorporated into the model as simulation variables, allowing users of the model to set parameter values for these variables.

The treatment of the wastes from municipalities and industries falls short of its thorough treatment on two counts. First, some flows might not enter the treatment plant because of inadequate capacity.
Second, some wastes emerge from the treatment plant through which it passes because the level of treatment set by the operator of the plant might be less than 100% effective for budgetary or technological reasons.

The sum of the two amounts of wastes is taken as the waste loading added to the lake.

This quantity is checked against the measured value obtained by monitoring. The difference between the computed and the observed value of wasteloading is ascribed to factors which were not taken into account in the building of the model, such as inputs from atmospheric and land drainage sources,* or absorption by soils and benthic vegetation.
The discrepancies, noted as "calibration factors", were incorporated into the final equation showing the amount of waste loading added to the lake in the computed time scale.

*Another IJC study undertaken by the Pollution from Land Use Activities Reference Group (PLUARG) will focus on non point sources.

A MORE DETAILED DESCRIPTION OF THE VARIABLES AND ALGORITHMS OF THE MODEL

Urbanized Population

Canadian demographic data were obtained from the Ontario Government who supplied statistical information about the present population in the Basin, and its urban-rural distribution. This source also provided population projections to the year 2020.

U.S. demographic data were obtained from OBERS E* which provides population projections to the year 2020.

In the present model, the algorithm for population growth contains a simulation variable to permit the operator to introduce his own proposed value for experimental purposes to see the consequences of various growth rates upon the reference problem.

The variables and the equation for the urbanized population on the Canadian side is as follows:-

10. Urbanized Population

	Terms	
10.1	ESTM01	Ontario Population Estimates. Persons, by region, by year.
10.2	URBP02	Urban Population. Persons, by region, by year.
10.3	ADJT01	Adjustment Factor, used to simulate the fluctuations around the original population estimates. Dimensionless, by region, by year... Simulation variable.
10.4	URBA01	Urbanization Ratio, the fraction of the population living in urban areas. Dimensionless, by region, by year.

* OBERS E is contraction of the Office of Business Economics and the Economic Research Service.

10.5 ADJTO2 Adjustment Factor, used to simulate the fluctuations around the original fraction urbanized.

Dimensionless, by region, by year. Simulation variable.

Algorithm

10.6 URBPO2 = ESTMO1*URBAO1*ADJTO1*ADJTO2

See Appendix for details about the notation used for the computer naming of the variables and constants.

Municipal Waste Coefficients

These coefficients, estimates of the per capita loadings of the waste parameters, were obtained from both Canadian and U.S. sources. The Canadian source was the Ontario Ministry of the Environment, and the U.S. source was the EPA. They are quite comparable in most cases.

20. Municipal Waste Production Coefficient

Terms

20.1 MFACO1 Municipal Waste Production Coefficients. These are coefficients used in the computation of municipal wastes.

Pounds per capita per year, by parameter, for the base year.

20.2 MFACO2 Municipal Waste Production Coefficients. These are also coefficients as above, modified by any technological change in municipal waste production.

Pounds per capita per year, by parameter, for the base year.

20.3 CHMFAC Change Factor Matrix reflecting technological change in the MFACO1.

Dimensionless, by year, by parameter. Simulation variable.

Algorithm

20.4 MFACO2 = MFACO1*CHMFAC

Allowing for the possibility that the coefficients might undergo a change due, say, to changing technology, a simulation variable CHMFAC was introduced to serve as a potential multiplier.

Municipal Raw Sewage Production

This is obtained by multiplying the urban population by the municipal waste coefficients.

30. Municipal Raw Sewage Production

Terms

30.1 RAWS02 — Municipal Raw Sewage.
The weight of the various chemical parameters present in the municipal raw wastes production.

Pounds per year by parameter, by region, by year.

30.2 URBP02 — Urban Population.

Persons, by region, by year.

30.3 MFAC02 — Municipal Waste Production Coefficients.
These are coefficients modified by any technological change in municipal waste production.

Pounds per capita per year, by parameter, for the base year.

Algorithm

30.4 RAWS02 = MFAC02*URBP02 (pounds/year by parameter, by region, by year).

MUNICIPAL SEWAGE TREATMENT, RESIDUALS AND WASTELOADING

Having calculated the municipal production of raw sewage, the model proceeds to compute the amount of sewage which obtains treatment, and the amount which does not. Hence the variables "Treated Municipal Sewage" (MSTR02) and "Untreated Municipal Sewage" (RESS02).

However, the final municipal wasteloading which is eventually added to the tributary or the lake is greater than the untreated portion. The model takes into account that the efficiency of treatment is less than 100%. Hence the need to consider the "Municipal Treatment Inefficiency" (TIFF02).

Having calculated the Municipal Wasteloading from both sources described above, the model sums up the entire course of waste production, treatment, and eventual wasteloading. This summation yields the "Municipal Total Basin Loading" (TBLD).

These quantities are now discussed as variables and algorithms, and then they are represented in a tree structure.

TREATED MUNICIPAL SEWAGE

This variable, representing the amount of municipal sewage treated in any given year, is computed as the sum of two parts.

i) The first part is obtained by multiplying the raw sewage produced in any given year by the proportion of sewage treated in the base year* (ZC01).

ii) The second part is the proportion treated in any given year in excess of the proportion treated in the base year. This is represented by the term MXSIM defined below.

It is assumed that the base year proportion of treatment has become institutionalized in the budgetary allocation in any given region. This assumption is based on the implicit inclusion of pollution treatment plant expenditures within government spending in CANDIDE[3] [16] [17] [18] and OBERS E[4]. These are referred to as non-impacting investments[20].

The second component is known as the impact-creating component[20] in this report.

40. Treated Municipal Sewage

Terms		
40.1	ZB01	The base year proportion of municipal sewage treated. Dimensionless, by region.
40.2	ZC01	The base year proportion of municipal sewage untreated. Dimensionless, by region.
40.3	ZZ02	The current year proportion of sewage treated. Dimensionless, by region, by year.
40.4	MXSIM	The proportion additional to the base year proportion to be treated. Dimensionless, by region, by year. Simulation variable.

*The term base year refers to 1973 for the Canadian data; and 1972 for the United States data.

40.5 RAWS02 Raw Sewage Production.
Pounds per year, by region, by year.

40.6 MSTR02 Treated Municipal Sewage.
Tons by parameter, by region, by year.

Algorithms

40.7 ZC01 = 1.-ZB01

40.8 ZZ02 = ZB01 + (MXSIM*ZC01)

40.9 MSTR02 = RAWS02*ZZ02/2000.

Untreated Municipal Sewage

This quantity represents the weight of sewage which bypasses any treatment whatsoever simply because the municipal capacity is inadequate for receiving the total sewage produced(14)(15). By subtracting the proportion of municipal sewage treated, computed previously, from one and multiplying by the weight of raw municipal sewage, the untreated municipal sewage is obtained.

50. Untreated Municipal Sewage

Terms

50.1 ZZ02 The Proportion of Municipal Sewage Treated.
Dimensionless, by region, by year.

50.2 ZN02 The Proportion of Municipal Sewage Untreated.
Dimensionless, by region, by year.

50.3 RAWS02 Raw Sewage Production.
Pounds per year, by region, by year.

50.4 RESS02 Residue of Untreated Municipal Sewage.
Tons per year, by region, by year.

Algorithms

50.5 ZN02 = 1 - ZZ02.

50.6 RESS02 = ZN02*RAWS02/2000.

MUNICIPAL TREATMENT INEFFICIENCY

This term is needed for calculating the waste residue left unchanged in the sewage which passes through the treatment process(19). (See 70. "Municipal Treatment Residuals"). The treatmentinefficiency multiplier expresses the fraction of the sewage left unaltered. However, it may be simulated by the model operator who might wish to explore the possibility of technological improvement of treatment efficiency. This can be done by changing the value of CHTIFF, a simulation variable, introduced to serve this purpose.

60. Municipal Treatment Inefficiency

Terms

60.1 TIFF02 Treatment Inefficiency Multiplier for different types of municipal treatment plants.
Dimensionless, by parameter, by region, by year.

60.2 TIFF01 Base year value for TIFF02.
Dimensionless, by parameter, by region, by year.

60.3 CHTIFF Simulation Factor reflecting technological change for TIFF01.
Dimensionless, by type of treatment plant, by parameter, by year.
Simulation variable.

Algorithm

60.4 TIFF02 = TIFF01*CHTIFF

Municipal Treatment Residuals

As mentioned above, this represents the waste residue left unchanged in the sewage despite its passage through the treatment process. It is computed by multiplying the weight of sewage passing through the treatment plant by the treatment inefficiency multiplier. The municipal treatment residual is another component of the waste load which eventually adds to the tributaries and the lake.

70. Municipal Treatment Residuals

Terms

70.1 TRDS02 Municipal Treatment Residuals in Canadian basins.

Tons per year, by parameter, by region, by year.

70.2 TIFF02 Treatment Inefficiency Multiplier for different types of municipal treatment plants.

Dimensionless, by parameter, by region, by year.

70.3 MSTR02 Treated Municipal Sewage.

Tons per parameter, by region, by year.

Algorithm

70.4 TRDS02 = MSTR02*TIFF02

TREE STRUCTURE FOR THE MUNICIPAL WASTELOADING

The structure of this sector consists of the following branches:

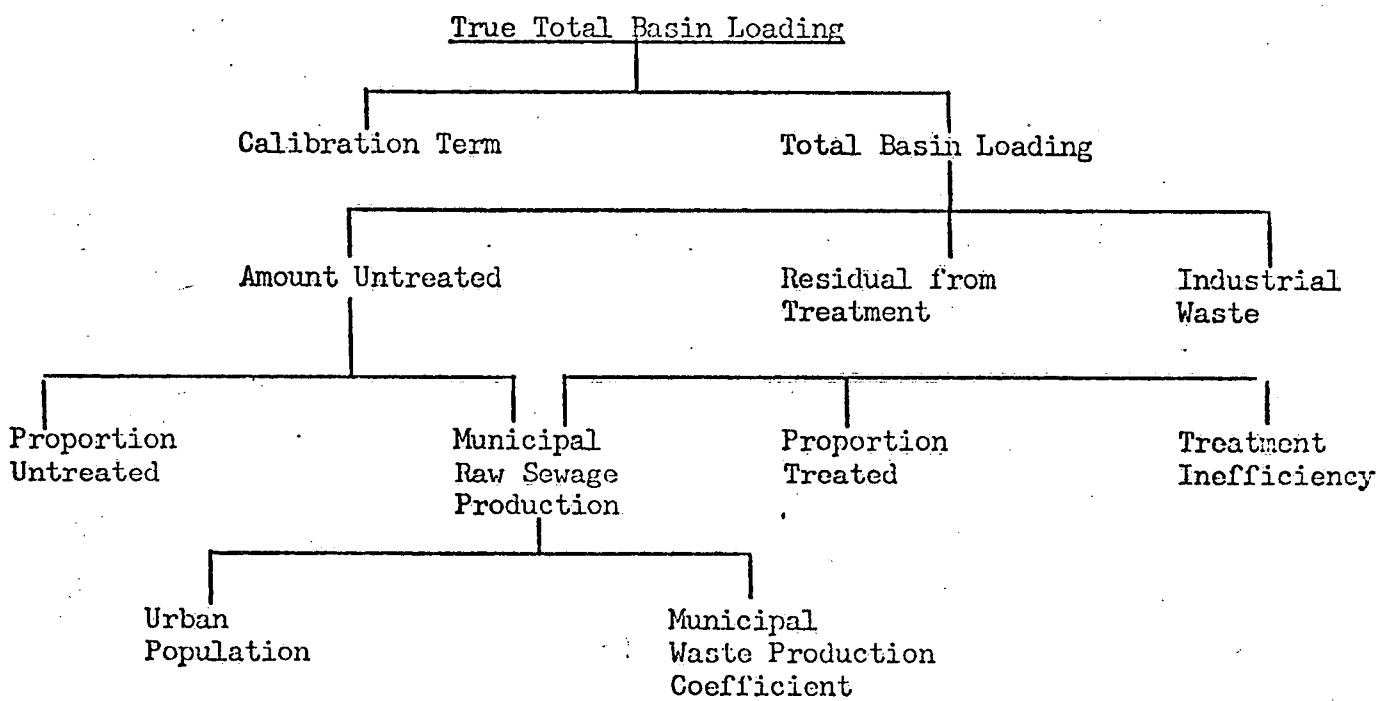
(i) The product of the urban population and the municipal wasteloading coefficient yields the municipal wasteloading.

(ii) Part of this goes into waste treatment plants where it is processed at predetermined levels, generally less than 100% efficiency.

(iii) The effluent output from the treatment plants is joined by the portion which had not gone through any treatment plant at all, as well as by the residuals of industrial treatment to become the total basin loading.

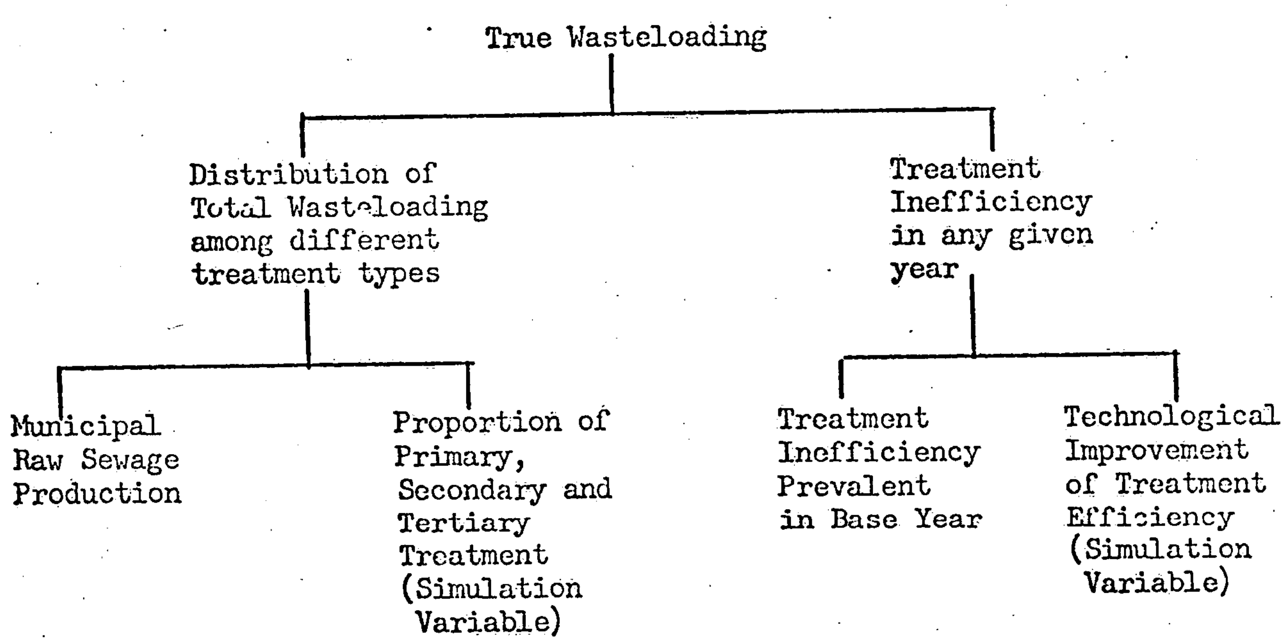
(iv) This quantity, calculated by the model, is compared with the observed quantity, as monitored.

(v) The difference, referred to as a calibration term, is used to provide the final result, the true total basin loading.



THE ALLOCATION OF THE MUNICIPAL WASTELOADING AMONG PRIMARY, SECONDARY AND TERTIARY TREATMENT PLANTS

The municipal wasteloading is given primary, secondary and/or tertiary treatment in accordance with a schedule given by a simulation variable PRPCAP which permits the model user to select the proportion of primary, secondary and tertiary treatment levels[21]. While this determines the amount of load in each type of treatment, one needs to consider the efficiency in each case. From the extent of the amount treated and the efficiency of the process, one obtains the "true wasteloading" of the residuals left in the effluent even after treatment.



MUNICIPAL EXPENDITURES AND AGGREGATE CAPACITY

Having computed the amount of wastes treated, and the level of treatment, the model proceeds to calculate the Municipal Expenditures (MTMI03). This variable expresses the total costs[20] on the basis of the aggregate volume of sewage treated (MGAL02), the cost per unit volume treated (MTCOST)[14][15][19], the fraction of the produced waste being treated (MXSIM), and the proportion of the waste being treated in the primary, secondary and tertiary levels of treatment (PRPCAP).[21]

The details will now be presented.

Municipal Expenditures

This represents the annual expenditures in constant dollars on municipal treatment. It is the expenditures of a capital nature to increase the municipal treatment capacity. The additional expenditure reflects the willingness to treat more sewage, and it is expressed by increasing the simulation variable MXSIM. Furthermore, it is also expected that the efficiency of treatment will improve with changing technology.

80. Municipal Expenditures

	Terms	
80.1	MTMI03	Total expenditures in constant dollars on municipal treatment. Dollars per year, by region, by year.
80.2	MTMI02	Non-impact creating expenditures for municipal treatment. Dollars per year, by region, by year.
80.3	MTMI02	Additional expenditures for municipal treatment as simulated. Dollars per year, by region, by year. Simulation variable.
80.4	DLOD02	The absolute increase in raw sewage relative to the previous year. Tons by parameter, by region, by year.

80.5 EFF$01 Efficiency of treatment expenditures for municipal and industrial facilities compared with base year.

Dimensionless, by parameter, by year.
Simulation variable.

80.6 MTCOST Unit cost of Treatment of Municipal Sewage.

Dollars per gallon, per day, by region, by year.*

80.7 ZC01 Proportion of wastes not treated in base year.

Dimensionless, by region, by year.

80.8 MXSIM The proportion of ZC01 which is treated through additional investment policies.

Dimensionless, by region, by year.
Simulation variable.

80.9 ZB01 The base year proportion of municipal sewage treated.

Dimensionless, by region.

Algorithms

80.10 $MTMI03 = MTMI01 + MTMI02$

80.11 $MTMI01 = (DLOD02 * ZB01) * MTCOST * EFF\$01$

80.12 $DLOD02 = RAWS02_t - RAWS02_{t-1}$

80.13 $MTMI02 = ((DLOD02 * ZC01 * MXSIM) + (MXSIM * RESS02_{t-1})) * MTCOST$

* Worked out by Tom Muir and Pat Deutscher, Internal Paper, Canada Centre for Inland Waters

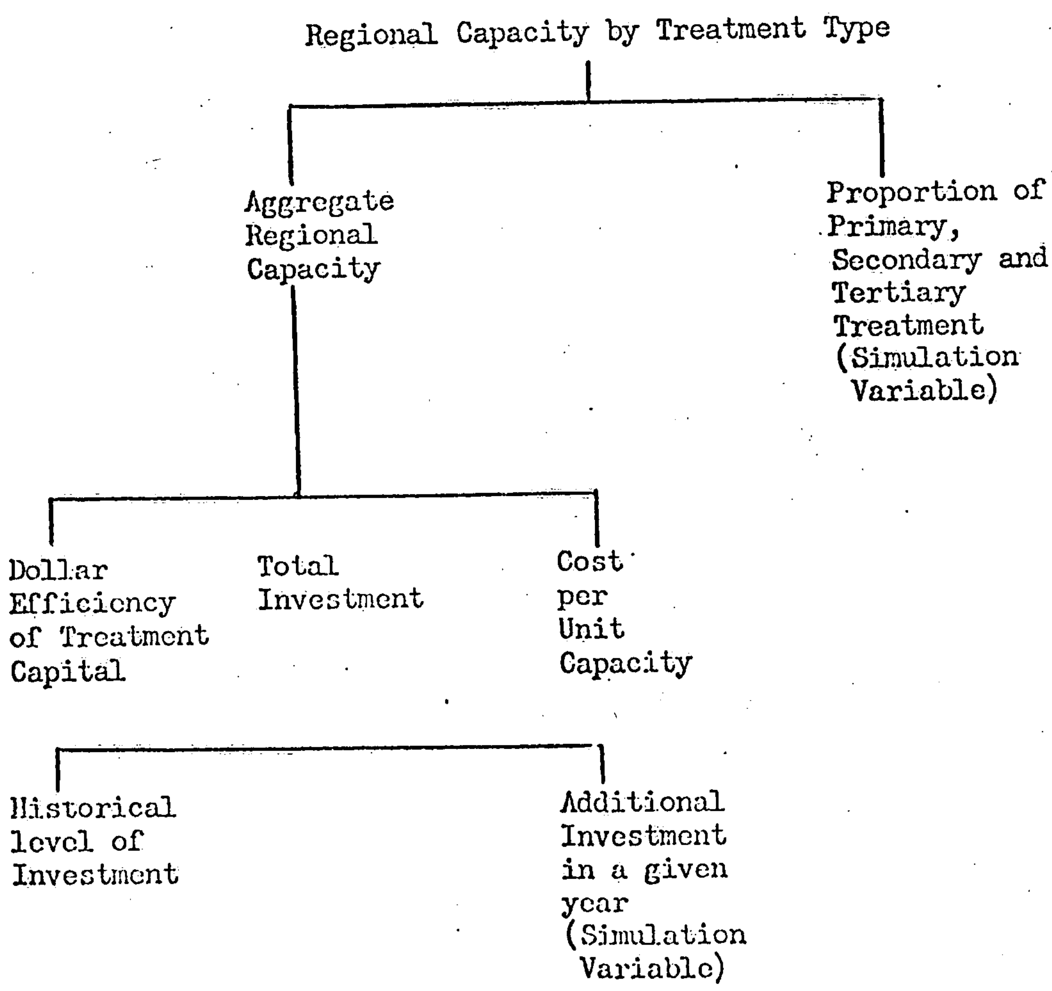
MUNICIPAL CAPACITY AND INVESTMENT

The regional capacity in gallons (MGAL02)[21][22] is multiplied by the proportion of the wasteloading to be allocated among the primary, secondary and tertiary treatment levels. The aggregate regional capacity is determined by investment. The latter consists of two parts:-

> one part is institutionalized, necessary for continuation of existing treatment service (MTMI01)[20],

> and the other is an additional amount in accordance with a policy decision to increase services (MTMI02).

Their sum MTMI03, the annual budget in any given year, is modified by the capital effectiveness at the time, as well as the actual unit cost of treating the sewage.



ECONOMIC ACTIVITIES AND INDUSTRIAL WASTELOADINGS

Both in the real world as well as in the model, industrial wasteloading is a more varied problem than municipal waste loads. Industrial effluent tends to be more damaging to health and environment and more difficult to remove by treatment methods. For modelling purposes, the data base and the causal structures interrelating industrial production, waste loading, treatment technology, effluent standards, funding for capacity and for treatment levels, all seem to be more intertwined than for municipal consideration.

In addition, public reaction seems to be more ambivalent about industrial than municipal effluent. While the results of industrial pollution are conspicuously damaging, the public seems to be divided on the issue of how stringent the pollution abatement standards should be, lest the economic viability of industry is jeopardized, and the jobs which industry provides threatened.

The basic data about the economic activity of the regions were taken from the CANDIDE[3][16][17][18] model for the Canadian side and OBERS E[4][23] for the U.S. While both are national forecasts, their approaches differ. The CANDIDE model generates national data which need to be multiplied by regional coefficients to obtain such regional data as output, while OBERS provides regional output directly. On the other hand, the CANDIDE model permits the computation of the national consequences of pollution abatement policies in terms of such variables as G.N.P. and unemployment.

INDUSTRIAL WASTE LOADING COEFFICIENTS

Industrial Waste Loading coefficients are the link between the level of industrial activity and industrial output of water borne wastes. The waste loading coefficient can be defined as the weight of a waste parameter produced by an industry in a given period divided by the 'value added' by that industry in the same period.

Value added can be considered net output measured by the value of gross output less the cost of commodity inputs and the value of contract work carried out by others. It is analogous to the domestic product concept of national income accounting.

U.S. data on total industrial waste loads in the American Upper Lakes Region were obtained from the U.S. section of the ULRG Working Group C[10][11][15]. These data are from NPDES[24] files summarized by Industry Group (U.S. S.I.C. basis) by Basin Group. The information upon which these compilations were based was collected between 1970 and 1974.

Canadian data on 1973 waste loads were obtained from the Ontario Ministry of the Environment Industrial Waste Discharges on Drainage Basin 1973. Waste loadings were aggregated for each basin to the major group level of the Canadian Standard Industrial Classification[3][14].

Example of Coefficient Calculation

U.S. Primary Metals Industry

Measurements of waste loadings for this industry were obtained in the Subareas 1.1 (Western Lake Superior) and 3.2 (Southwestern Lake Huron).

For this example, calculation will be only carried out for the first four parameters; Total Phosphorus, Total Nitrogen, Total Dissolved Solids and Total Chlorides.

The total waste loads in lbs./year for this industry in each basin were in the base year*[15] :-

	401	408
Total P	13,505	11,315
Total N	2,967,085	485,813
TDS	27,630,500	45,382,275
Total Chloride	1,423,500	8,140,595

*Values in these examples might differ from up-dated values used in the model[10][11].

The earnings in 1967 dollars in the Water Resources subareas (whose boundaries do not correspond precisely to the basin boundaries) for the primary metals industry group in 1969 is obtained and adjusted to the base year:

Subarea 401	$22,903,000
Subarea 408	$143,242,000

By applying the ratio of domestic product to earnings, a multiplier of 1.35, the gross product originating from the industry was estimated as:

Subarea 401	$30,919,050
Subarea 408	$193,376,700

Basic specific waste loading coefficients are the ratio of the total annual waste loads by parameter to the value of gross product:

	Lbs./1967 $ gross product	
	401	408
Total P	.000437	.0000585
Total N	.0960	.00251
TDS	.894	.235
Total Chloride	.0460	.0421

The unweighted averages of these coefficients were used as the industrial waste loading coefficients for the primary metal industry group in the entire American Upper Lakes:

	Lbs./1967 $ gross product
Total P	.00024775
Total N	.04925
TDS	.5645
Total Chloride	.04405

American industrial waste loading coefficients were obtained from calculations using OBERS E production data and NPDES monitoring data. Wherever possible, Canadian coefficients were calculated in a similar way from Candide production data and Ontario's Ministry of Environment monitoring data. Otherwise American coefficients adjusted for monetary differences were used in Canadian waste loading coefficients. A detailed report on these calculations is provided by Deutscher[14].

INDUSTRIAL WASTELOADING (IWL)

In order to compute this quantity it was decided to employ coefficients for industrial waste production (IWLFAC). These coefficients give the amount of waste for each parameter for each industry. The industrial effluent is then obtained by multiplying the regional dollar output (RO) by the appropriate coefficient.

However, the coefficients themselves had to be worked out. This was done by using the effluent monitoring data furnished by NPDES[24] and the data about output furnished by the national statistics. Inasmuch as the monitored data reported the effluent as it was present in the tributary or lake, it was taken to be the residue after whatever treatment the waste had received at the plant. The latter quantity was termed the Base Year Treatment Level (BASTRL). The fraction of effluent which remained untreated is expressed as 1 - BASTRL[20].

In any given year, the treatment level is expected to be specified by the model user. This is termed the Desired Treatment Level (DESTRL), and it serves as a simulation variable. Again, by implication, the untreated fraction of effluent would be given by 1 - DESTRL. With the use of these concepts, the industrial waste production was expressed as the algorithm which follows:

90. Industrial Wasteloading

Terms

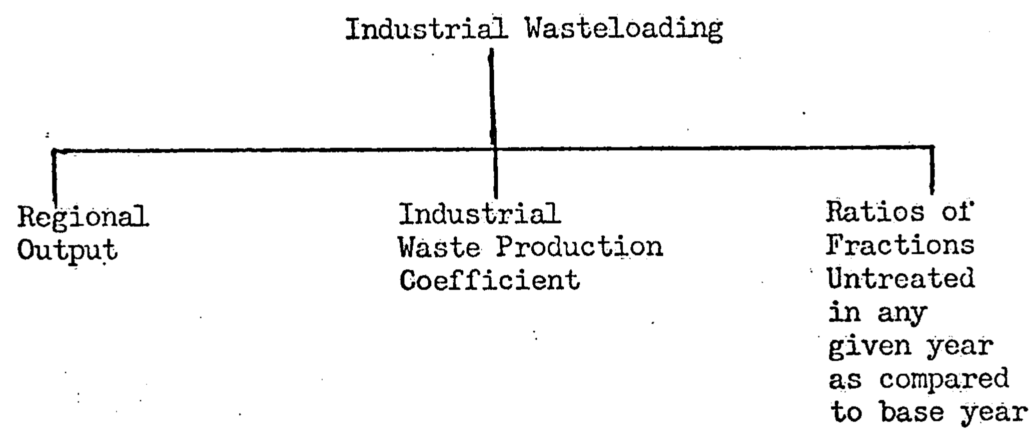
90.1	IWL	Industrial Wasteloading. Tons per year, by industry, by parameter, by region, by year.
90.2	RO	Regional Output. Dollars per year, by industry, by region, by year.
90.3	IWLFAC	Industrial Wasteloading Coefficient. Pounds per dollar per year by industry, by parameter, by region, by year.
90.4	DESTRL	Desired Treatment Level. Dimensionless, by industry, by year. Simulation variable.
90.5	BASTRL	Base Year Treatment Level Dimensionless, by industry, by year.

Algorithm

90.6 IWL = $\frac{RO*IWLFAC*(1-DESTRL)}{(1-BASTRL)(2000)}$

TREE STRUCTURE FOR INDUSTRIAL WASTELOADING

This structure shows the determinants of the industrial wasteloading as discussed on the previous page.



REGIONAL INDUSTRIAL WASTELOADING

This represents the summations from all industries of a given region for a given effluent parameter. For example, the total amount of phosphorus added by chemical, food, pulp and paper, and other industries.

110. Regional Industrial Wasteloading

	Terms	
110.1	IWLSUM	Regional Industrial Wasteloading. Tons per year, by industry, by parameter, by region, by year.
110.2	IWL	Industrial Wasteloading. Tons per year, by industry, by parameter, by region, by year.

Algorithm

110.3 IWLSUM = IWLSUM + IWL

The Regional Industrial Wasteloading becomes an input to the Total Basin Loading as shown on page 16.

INDUSTRIAL WASTE TREATMENT INVESTMENT SECTOR

An analysis of investment problems in the programming of the industrial waste treatment sector was carried out by T. Muir[20]. In view of the complexity of the problem and the inadequacy of comprehensive hard data on either actual expenditures on effluent treatment, or the extent to which pollutants are removed, it was deemed appropriate to make the following assumptions:

(1) That investment is determined by a capital-output model.

(2) That desired and actual capital stocks are equal; implying instantaneous adjustment and no investment lags.

(3) That desired stocks, and therefore net investment, respond symmetrically to both output changes and treatment level changes.

(4) Beyond the point of increasing marginal cost, the stock requirements increase exponentially.

For the present modelling purposes, investment flows were differentiated into two types; one characterizing a first approximation to maintaining the baseline or 1973 treatment levels, and the other designed to provide simulation capabilities for investigating different assumption sets concerning the specification of future water quality and effluent discharge regulations. These equations are now presented in turn.

For simulation it was assumed that up to a certain level of treatment, say 90 percent for example, the capital stock to output ratio increases in the same proportion as the desired treatment level. For example, to increase the removal of a certain pollutant by 10 percent, say from 40 percent removal level, to a 50 percent level, the stock of pollution capital would have to rise by 10 percent given no change in output. Above the 90 percent treatment level, it was assumed that the pollution capital stock has to rise by more than in proportion. This relationship is assumed to be an exponential one.

The investment flows needed to satisfy the increase would be equal to the baseline investment, plus that amount needed to increase the pollution capital to output ratio by the necessary amount. The augmented stock in the current year becomes the lagged stock the next year. As such, it grows with output and is replaced on depreciation.

100. Industrial Expenditures

Baseline Investment

This is the investment required to maintain, at a constant, the base year (1973) level of treatment.* This implies that the ratio of pollution capital stock to industry output must remain constant and that the capital grows by the same proportion as output.

Terms

100.1 EFF$01 Efficiency of treatment expenditures for municipal and industrial facilities compared with base year.

Dimensionless, by parameter, by year.
Simulation variable.

100.2 ITMI01 Industrial investment (non-impact creating) for pollution abatement treatment.

Real 1961 dollars, by region, by year.

100.3 STOCK1 Pollution abatement capital stock (non-impact creating), needed to maintain the 1973 ratio of pollution abatement capital to output.

Real 1961 dollars, by region, by year.

100.4 RDP Regional domestic product.

Dollars per year, by region, by year.

100.5 DEP Depreciation rate.

1/year, by industry, by year.

Algorithm

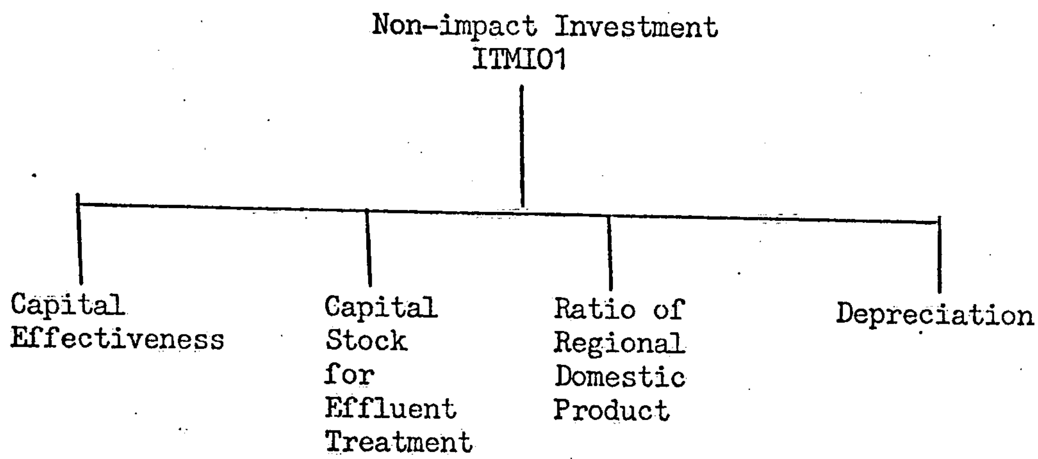
100.6 $$ITMI01_t = EFF\$01 * (STOCK1_{t-1} * \frac{RDP_t}{RDP_{t-1}} + DEP * STOCK1_{t-1}) - STOCK1_{t-1}$$

100.7 $$STOCK1_t = STOCK1_{t-1} + ITMI01_{t-1} - DEP * STOCK1_{t-1}$$

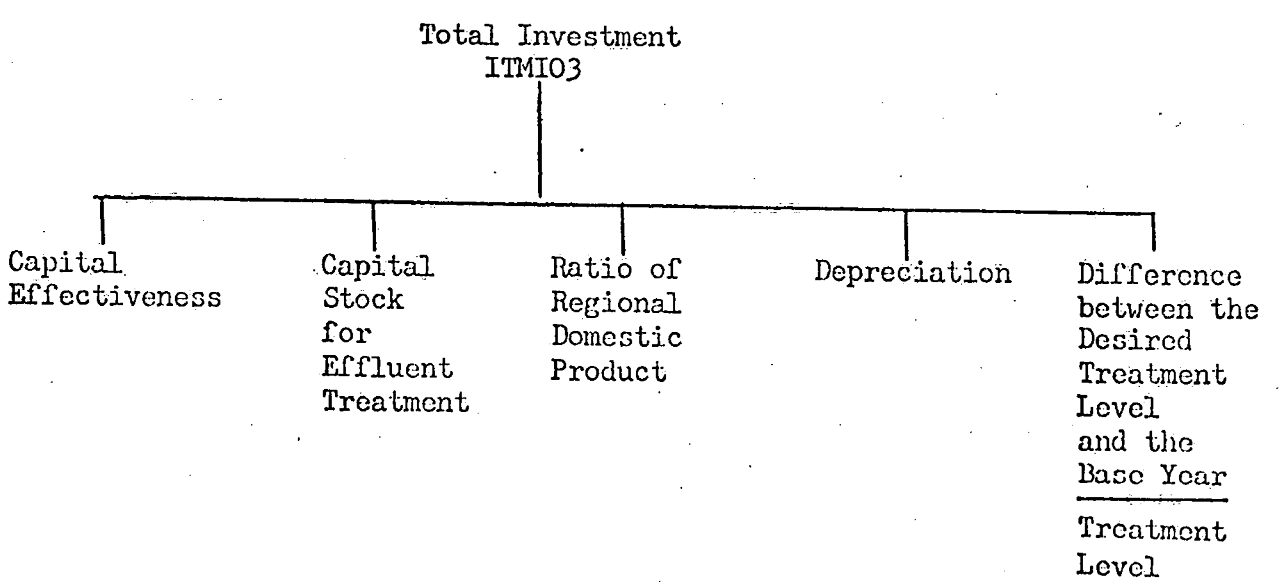
* The only consistent figures available on waste-flows related to 1973. It was, therefore, decided that the pollution capital stock calculated for that year would be related to industry output in the same year to form a pollution capital to output ratio. It was further assumed that this ratio was the desired and actual one required to achieve the given level of pollution loadings per unit of output as measured in the same year, 1973[20].

INDUSTRIAL WASTELOADING TREATMENT INVESTMENT

The industrial wasteloading investment sector is structured on the assumption that while this sum must grow in proportion to region domestic product, it may also be increased by policy decision to raise the treatment to some desired level. The present structure will show the fundamental component of the investment which consists of the interaction between the exisiting capital stock for effluent treatment, the ratio of the regional domestic product in two successive years, and the allowance for depreciation.



If in a given year, a decision is taken to increase the desired treatment level, the total investment would then be represented as follows:-



INTEGRATION

The municipal and industrial wasteloadings are calculated in the model for each tributary basin to yield the Total Basin Loading TBLD. This calculated quantity is then compared with the monitored results from the Ontario Ministry of the Environment, NPDES and Working Group C, and the difference between the calculated and the observed amounts are taken as a calibration term CALIBR. This term is then used in further calculations to provide the Calibrated Total Basin Loading TTBLD.

Subsequently, two further integrations are carried out beyond the tributary stage. The municipal and the industrial wasteloadings are summed for each of Lake Superior and Lake Huron on both the Canadian and U.S. sides.

Basin Loading

TBLD — Total Basin Wasteloading for each of the tributaries. Tons/year.

CALIBR — Calibration term. Tons/year.

TTBLD — Calibrated Total Basin Wasteloading for each of the tributaries. Tons/year.

TTBLD = CALIBR + TBLD.

Lake Superior and Lake Huron Loading

MUNSUP — Municipal Wasteloading of the tributaries into Lake Superior. Tons/year.

IWLSUP — Industrial Wasteloading of the tributaries into Lake Superior. Tons/year.

TBLSUP — Total Basin Loading into Lake Superior. Tons/year.

TTBSUP — Calibrated Total Basin Loading into Lake Superior. Tons/year.

TBLSUP = MUNSUP + IWLSUP.

TTBSUP = TBLSUP + CALIBR.

The data for Lake Huron are treated similarly.

DISCUSSION

The waste loadings computed in the model are strongly determined by the projections of CANDIDE[3] and OBERS E[4]. A brief description of these models follows:

The population and industrial activity on the U.S. side were taken from OBERS E, an acronym which signifies a unified effort by the Bureau of Economic Analysis (formerly the Office of Business Economics OBE), U. S. Department of Commerce and the Economic Research Service (ERS), U. S. Department of Agriculture. The work has been pursued under a cooperative agreement with the Water Resources Council (WRC).

The OBERS projections are intended as conditional forecasts of the future. The projections represent estimates of economic activity expected to develop if all the assumed conditions materialize.
OBERS C, D and E are respectively high, medium and low projections, the latter being the version used in the present model. The general assumptions are presented.

GENERAL ASSUMPTIONS

The OBERS projections are based on longrun or secular trends and ignore the cyclical fluctuations which characterize the shortrun path of the economy. The general assumptions that underlie the projections are:-

(1) Growth of population will be conditioned by a decline of fertility rates from those of the 1962-1965 period.

(2) Nationally, reasonably full employment, represented by a 4 percent unemployment rate, will prevail at the points for which projections are made; as in the past, unemployment will be disproportionately distributed regionally; but the extent of disproportionality will diminish.

(3) No foreign conflicts are assumed to occur at the projection dates.

(4) Continued technological progress and capital accumulation will support a growth in private output per manhour of 3 percent annually.

(5) The new products that will appear will be accommodated within the existing industrial classification system, and, therefore, no new industrial classifications are necessary.

(6) Growth in output can be achieved without ecological disaster or serious deterioration, although diversion of resources for pollution control will cause changes in the industrial mix of output.

The regional projections are based on the following additional assumptions:

(1) Most factors that have influenced historical shifts in regional "export" industry location will continue into the future with varying degrees of intensity.

(2) Trends toward economic area self-sufficiency in local-service industries will continue.

(3) Workers will migrate to areas of economic opportunities and away from slow-growth or declining areas.

(4) Regional earnings per worker and income per capita will continue to converge toward the national average.

(5) Regional employment/population ratios will tend to move toward the national ratio.

CANADIAN INDUSTRIAL PROJECTIONS

The projection of economic activity on the Canadian side was made by using a forecast of national economic activity which was then distributed to the regions of concern. The distribution mechanism is based on the assumption that the share of each region in the output of each industry in 1971 remains the same throughout the projection period. For example, 5.6% of the output of Primary Metals manufacturers occurred in Region IV in 1971. The same 5.6% of Canadian Metals manufacturing was distributed in 2020 to Region IV.

An econometric model(16)(17)(18) (a variant of CANDIDE(3)) of the Canadian economy has been used to derive the forecasted national aggregates. As compared to projections based on the simple extrapolation of previous trends of individual measures of economic activity, use of this analytical tool for forecasting offers a number of advantages. Perhaps the most important is the ability to project activity on the basis of a consistent economic theory as well as a consistent accounting framework. It should be recognized that CANDIDE is itself a systems view of economic behaviour (which is sensitive to sociological and other assumptions), and in its use, it has been possible to exercise key judgements that the model then "translates" into such measures of economic activity as industrial output. Thus, in the course of developing this set of benchmarks, it was assumed that governments in the next half century will continue to view full employment with moderate price increases as a key policy objective.

Further, use of this model has enabled a projection of economic activity on the basis of demand as well as supply considerations. The impact of demographic assumptions may help to illustrate the point. At least, with respect to major trends, it is judged with considerable confidence that fertility rates, which have declined steadily over the last two decades, will continue to decline over the next 15 years and will then level off at what is considered, by usual standards, a low rate.

This has obvious implications for the supply side of the economy in that, over time, the labour force can be expected to grow much more slowly than has been the case recently. Consequently, the potential for maintaining the rates of economic growth that have prevailed in the recent past (and are available in the near future) will be reduced. This key demographic assumption also affects demand in that the mix of commodities and services needed to fulfill private consumption requirements will vary with the growth of population as a whole as well as with the changing age structure of the population. Moreover, given the slowing growth of population, investment in housing can be expected to grow more slowly than has been the case in the last decade. This, in turn, implies a different pattern in the growth and mix of industrial output than if recent rapid population growth were simply extrapolated.

Finally, it should be noted that CANDIDE is an extremely large system of equations that incorporates means of projecting industrial output in considerable detail. Consequently, it has been unnecessary to link projections of industrial output to such aggregate measures of economic activity as Gross National Product through any independent mechanism.

Having noted these advantages, a number of cautions are emphasized. These projections are conditional on the assumptions made (and on those that implicitly are in the model). Obviously, there are an infinite number of forecasts since options available in so long a period as 50 years are innumerable. Thus, the tabulated projections should be thought of as the middle points of a band of projections about which some confidence is held. That band widens over time. Finally, it should be noted that these projections are in no sense meant to represent targets to which public policy should be directed.

POPULATION PROJECTIONS

Since population projections are critically important in this study, it would be instructive to see how they were treated.

On the U. S. side, population projections were taken from OBERS E[4] whose methodology consists of projecting the national population, and then deriving the regional population by means of suitable multipliers. Projections of national population are prepared by the Bureau of the Census and are based on assumptions regarding three factors:

(1) The amount of net immigration, and its age, sex, and race composition;

(2) Age specific survival rates for mortality; and

(3) Age specific birth rates for fertility. In OBERS E, it is projected that the United States population will attain zero growth in 2036.

There is little disagreement concerning expectations for the first two factors. Concerning the third, the declining birth rate, there is some variation in demographic opinion about the long-term downtrend in fertility. The data used in this report reflect the trend showing the most intense drop in fertility.

The population projections for the Canadian side were obtained from the Ontario Statistical Review, whose methodology is described as follows:

> Population projections to the year 2001 were obtained from the 1973 Ontario Statistical Review published by the Economic Analysis Branch, TEIGA. These figures represent a demographic trend projection only, and do not embody the impact resulting from any proposed and committed private and public development projects. The Branch provided provincial projections down to the county level, employing the 'cohort-survival' method which takes into account the combined impact of births, deaths, and immigration. Specifically, a medium fertility rate (about 1.97 children/woman), 50,000 net external migration/year, and an internal migration at 0.27% of Ontario's population were assumed.

ALTERNATIVE FORECASTS

It can be seen that both models tend to assume continuous economic and demographic growth to the year 2020, with relatively low inflation and unemployment rates. Furthermore, the models do not consider the possibility that there might be an energy shortage in the time span under consideration. The impact of alternative forecasts would cause a considerable change on the rate of economic growth as well as on the availability of capital for the extension of treatment capacity.

Following the economic projections of OBERS and CANDIDE, the present model yields an output which shows a corresponding growth in the production of waste loading.

Furthermore, the model has not made due allowance for the legislation already passed in both the U.S. and Canada with regard to municipal and industrial effluents, as described briefly in the following account:

MODEL SCENARIOS

The model was designed to serve interactively with the user who might wish to explore the possibilities, costs and benefits of various policies.

Three scenarios were examined in the course of building the model. The first consisted of the policy of continuing to treat effluent at the same level as in the base year. The second scenario attempted to maintain a constant level of loadings by postulating a higher level of treatment than occurred in the base year. The third scenario raised the question of what needs to be done to bring about a condition of zero loadings by a given year. It is expected that the optimal use will be made by the decision maker seeking to evaluate policies which are consonant with projected legislation and possible technological innovation[21].

POLLUTION FROM MUNICIPAL SOURCES

Construction and Operation of Waste Treatment Facilities - United States

Under the Federal Water Pollution Control Act, the Environmental Protection Agency is authorized to make grants to municipalities to assist in the construction of publicly owned treatment plants to a maximum of 75% of the estimated costs. It is anticipated that municipal projects discharging to the Great Lakes will continue to receive increased funds to assist in the construction of needed facilities with emphasis on municipal phosphorus removal facilities. ...

"The establishment of construction and operating standards will be an across-the-board agency implementation responsibility. The amended statute sets forth many deadlines for individual requirements such as secondary treatment, industrial pre-treatment, effluent limitations, best practicable technology, best available technology, etc."

The States plans for treatment facilities and operation basically follow the Ten States Standards for Sewage Works.
These require that

all municipalities prepare a wastewater management plan considered on a watershed basis;

the plan should present the best mix of action to abate pollution, wastewater management economy and consistency with long-range needs.

Canada

The Ontario Ministry of the Environment is involved in many aspects of construction and regulation of municipal waste water treatment plants including definition of problem areas, guidelines for sewage collection and treatment processes, stream or lake loading criteria, financing and design review.

POLLUTION FROM INDUSTRIAL SOURCES

A survey of the problems associated with pollution from industrial sources and the governmental measures being taken on both the Canadian and U.S. sides is given in the Great Lakes Water Quality Annual Report to the IJC [25].

In Canada, national effluent regulations incorporating the principles of "best practicable technology" have been developed for the pulp and paper industry, for mercury discharges from the chloralkali industry, and for the petroleum refining industry, while regulations for many other industries are under development by a joint Federal/Provincial/Industrial task force. The report states that this type of cooperative approach has been successful to date and has resulted in realistic yet stringent environmental protection measures. More stringent measures may be imposed as required by local or regional conditions to provide adequate environmental protection.

In the United States, the Federal Water Pollution Control Act Amendments of 1972 established a National Pollution Discharge Evaluation System (NPDES) [24] Permit Program and authorizes the Administrator of the Environmental Protection Agency, after opportunity for public hearing, to issue a permit for the discharge of any pollutant to the navigable water of the United States.

The law is predicated on two national goals: the elimination of discharge of pollutants into navigable waters by 1985, and the interim attainment by 1983 of water quality which provides for protection of fish and wildlife and for recreation.

UPPER LAKES WASTELOADING SIMULATION MODEL

TECHNICAL PERSONNEL

J. P. H. Batteke,	DOE	- Canadian Co-chairman of ULRG, Working Group A.
E. Pinkstaff,	EPA	- U.S.A. Co-chairman of ULRG, Working Group A.
D. E. Coleman,	DOE	- Overall Responsibility For Programming, Model Operation and Data Inputs.
L. D'Amore,	Canada	- Social and Technological Trend Analysis.
P. Deutscher,	DOE	- Data Collection.
P. Jacobson,	Canada	- Economic Forecasts.
E. Jeracki,	GLBC	- Planning Studies.
S. Ma,	York University	- Programming Assistant to Dr. Madras.
Dr. S. Madras,	York University	- Modelling Concepts Formulation.
J. J. McGuire,	EPA	- Data Collection.
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APPENDIX 2

NOTATION

The notation used in naming and indexing the acronyms for the variables may be illustrated by reference to a typical listing such as that for Urbanized Population, page 9.

Each term ends in two digits-- a zero followed by another digit.

The zero indicates Canadian data (U.S. data have a 1 in the corresponding position). The final digit may be a 1, usually indicating a reference constant, or a 2 or higher digit, indicating a variable.

ESTM01 represents the estimate by the Ontario Ministry of the Environment of the population, for each of the seven Canadian regions, in each of the years at the beginning of the decades from 1970 to 2020. The corresponding US population, ESTM11, would be obtained from OBERS E.

ADJT01, called a "simulation variable", hase the value of 1 if the operator is willing to use the given population estimates. If, however, he wishes to simulate higher or lower population estimates, he may assign corresponding values to ADJT01 treating it as an adjustment multiplier.

The urban population is thus derived by the equation or algorithm 10.5 as indicated.

In this presentation of variables and algorithms, only the Canadian equations will be used since both the Canadian and the U.S. population sectors are structured similarly.

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