G. T.

CHLORINE

GREAT LAKES
WATER QUALITY BOARD

INTERNATIONAL
JOINT
COMMISSION

ALTERNATIVES FOR MANAGING CHLORINE RESIDUALS:
A SOCIAL AND ECONOMIC ASSESSMENT

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A SOCIAL AND ECONOMIC ASSESSMENT

FINAL REPORT
OF THE
CHLORINE OBJECTIVE TASK FORCE

TO THE
GREAT LAKES
WATER QUALITY BOARD

APRIL 1980
WINDSOR, ONTARIO

Statements and views presented in this report are totally those of the Task Force and do not necessarily reflect the views and policies of the International Joint Commission or its Water Quality Board. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

INTERNATIONAL JOINT COMMISSION
GREAT LAKES WATER QUALITY BOARD

May 9, 1980

International Joint Commission
Canada and United States

The Great Lakes Water Quality Board has accepted the report of the Chlorine Objective Task Force and is pleased to submit it to the International Joint Commission.

We wish to point out to the Commission that the process developed by the Task Force for socio-economic assessments appears to have benefit for use by the jurisdictions, but not for application on a basinwide basis (Recommendation 8). Also, Recommendation 10, which calls for the IJC and Water Quality Board to assist the jurisdictions in their assessments seems to be inconsistent with Recommendation 8 and the cost to the IJC and the Board to carry out the recommendation would be excessive. The suggestion was made that the Regional Office might monitor the application of such socio-economic procedures, where they are feasible, by the jurisdictions and report periodically on these activities.

Since this report represents a pioneering effort for this type of evaluation, it might be helpful to review the reasons for initiating this study.

The Great Lakes Water Quality Agreement of 1972 was based on a concept of adopting water quality objectives to achieve improved water quality in the Great Lakes System. These objectives were goals to be maintained or achieved in the boundary waters through effective pollution control programs in both countries. The Agreement listed General and Specific Water Quality Objectives, and made provision for modifying existing objectives and adopting new ones. These provisions were continued in the 1978 Great Lakes Water Quality Agreement.

Proposed new and revised water quality objectives were recommended to the International Joint Commission by the Great Lakes Water Quality Board in the Board's Annual Reports for 1974, 1975 and 1976. Most of these objectives were the subject of public hearings by the IJC and were included in the 1978 Agreement by the Parties. Not included in the Agreement were the objectives for chlorine, cyanide, silver and temperature. The Water Quality Board was asked to continue its consideration of these objectives.

These water quality objectives were developed on the basis of scientifically defensible data to protect the most sensitive beneficial use. No consideration was given to the socio-economic implications of achieving the objective. It was assumed that the jurisdictions would consider designated uses, social and economic factors, and technical capability in translating the objectives into their water quality standards and other regulatory requirements.

Concern for the socio-economic implication of achieving the objectives has been expressed on several occasions by the IJC and others and was discussed during the Commission's hearings on objectives.

In an attempt to answer these questions, the Water Quality Board decided to examine the practicality of reviewing the socio-economic impact of one water quality objective. The chlorine objective was chosen for the test because it would be applied on a broad basis throughout the Great Lakes Basin. Accordingly, the Water Quality Board established the Chlorine Objective Task Force early in 1978 to assess the socio-economic impact of the proposed chlorine objective and the practicality of implementing and monitoring regulatory actions. This is the first time that IJC has sponsored such an economic and social assessment of an ambient water quality objective.

This report is the result of the Task Force's efforts. We trust that it will provide helpful guidance for carrying out socio-economic assessments of water quality objectives.

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SUMMARY

The Chlorine Objective Task Force was established to assess the social and economic implications of approaching or achieving the proposed ambient objective for total residual chlorine of 0.002 mg/L in surface waters receiving effluent from municipal sewage treatment plants, industrial establishments and any other source of continuous chlorine discharge. An additional objective of the Task Force has been to determine the extent to which chlorine disinfection practices contribute to potentially hazardous chlorinated organic chemicals in the Great Lakes and in drinking water supplies. A third major effort involved the identification and evaluation of alternative technologies and strategies for the disinfection of sewage treatment plant effluents in the Basin.

This is the first such socio-economic assessment ever undertaken for the Water Quality Board. The methodological framework used in this analysis identified the various social and economic consequences that might result in the course of achieving a proposed objective. Quantitative measures of these consequences, together with knowledge of how they are distributed among different groups or sectors, are necessary to make assessments that will lead to choices about which actions to take.

The Task Force did not undertake a traditional economic cost-benefit analysis exercise because neither quantitative biological data nor dollar value estimates of certain key consequences, i.e. the changes in damages to aquatic life and the changes in risk to human health, were available. Nevertheless, the study specified the kinds of data and information that jurisdictional agencies should compile in order to make social and economic assessments of this nature.

A review of chlorine production and use data for the United States and Canada was undertaken to gain an economic overview of the industry. The sources and relative importance of free and combined chlorine residuals were also examined. Sewage treatment plants constitute the major continuous source of combined chlorine residual. The amounts of chlorinated organic residues generated at sewage treatment plants are miniscule compared with the chlorinated residuals discharged by industry. However, very little of these residues find their way into drinking water supplies. The primary source of chlorinated organic compounds in municipal water supplies is the result of in-plant chlorination which combines with humic matter in the raw source of water.

To the extent that achievement of the objective will entail changes in sewage treatment plant effluent disinfection and cooling water biofouling control practices, three interrelated consequences of effects are most pertinent:

1. the protection of public health from bacterial contamination in raw water supplies and recreational waters;
2. the protection of aquatic life, especially from chlorine toxicity and
3. the financial costs of disinfecting effluents or biofouling control.

Microbiological objectives, disinfection practices and policies that are current for the Great Lakes jurisdictions are reviewed. The uncertainties about current disinfection practices and the debate among relevant authorities about sewage treatment plant effluents are summarized.

The problems involved in defining mixing or limited use zones are explained. Different sizes of mixing zones were not explicitly considered in the evaluation of disinfection options, primarily because there is no single, accepted criterion or parameter for determining the size of such a zone.

Chlorination for biofouling control in industrial and power plant cooling water results in a less problematic intermittent discharge of residual chlorine. Nevertheless, there appears to be adequate technical and relatively low cost methods of reducing the use of chlorine or eliminating the residuals altogether from these sources where local conditions require it.

The train derailment in Mississauga, Ontario on November 10, 1979 and the subsequent evacuation of 250,000 residents because of the release of chlorine gas from a single railway tank car illustrates the magnitude of risks associated with the transportation, storage and use of chlorine. However, the actual amounts of chlorine used for sewage treatment effluent disinfection appears to be small relative to the total. Risk of transit accidents would probably not be significantly altered by a reduction in chlorine use in this sector.

Various sewage treatment plant effluent disinfection technologies and systems are identified and evaluated. Of those considered, only ozonation and ultraviolet light are sufficiently developed to be installed in appropriate existing or new sewage treatment plants and appear to generate no problematic by-products. To date there is no published evidence as to the degree of toxicity of these by-products. Researchers are, however, endeavouring to find the answers. It is also noted that bacterial contamination of surface waters could result from a variety of sources of which only sewage treatment plant effluents are presently disinfected.

Seven disinfection strategies are identified which could be implemented to help move toward or achieve the chlorine objective. These strategies could be implemented by jurisdictions or over the entire Basin. Assuming implementation over the entire Basin, the strategies were then evaluated in terms of six key criteria:

1. progress toward meeting the objective;
2. financial implications for operators of existing sewage treatment plants;
3. effects on aquatic life;
4. public health risk;
5. government enforcement activities and
6. possible employment implications.

Finally, the implications for new and expanded sewage treatment plants are noted along with several comments on the implementation of the strategies by the relevant jurisdictions.

CONCLUSIONS

1. Economic and social assessments of environmental objectives can be helpful in setting project priorities, identifying least cost technologies and justifying regulatory or enforcement actions.

2. North American chlorine production totals approximately 11 million tonnes per annum. Only about 5% of this production is used for purposes of water and wastewater disinfection. Power plant intermittent usage is significantly smaller than municipal usage.

3. There is little documentation of identified residual chlorine problem areas in the Great Lakes. Consequently, the benefits of approaching or achieving the chlorine objective in terms of protecting aquatic life are difficult to determine with any accuracy.

4. The contribution of chlorinated organics due to chlorination by sewage treatment and power plants is insignificant when compared with industrial discharges.

5. Industrial contributions of residual chlorine discharges are minimal compared with municipal and power plant sources.

6. There is substantial evidence to indicate that most of the halomethanes and other chloro-organics found in treated drinking water are formed by the chlorination of humic matter during actual drinking water treatment and that they do not enter the plant from industrial or municipal waste discharges.

7. Health and sanitary engineering authorities are not unanimous about the need for disinfection of wastewaters or about the health risks associated with reduced disinfection or its relevance to breaking cycles of potential water borne infectious diseases. The Task Force concludes that the elimination of disinfection year-round is a viable option to be considered.

8. Jurisdictions can make their own assessment of mixing zone size. Allowance for mixing zones will then mitigate or otherwise alter certain consequences, i.e. possibly result in lower financial costs of achieving the objective or in an increase in the risk and damage to aquatic life.

9. Although the proposed chlorine objective is not intended for intermittent chlorine discharges from power plants, there is scope for minimizing the application of chlorine. Hence, the reduction in chlorine residual loadings in a number of power plants. Where problems and damages to aquatic life warrant, dechlorination appears to be a feasible means of eliminating hazards to aquatic life until other mechanisms for biofouling control that do not use chlorine are developed.

10. Some 150 chlorine related accidents are reported annually in Canada and the United States. The potential for accidents and significant damage to

people and property will continue to exist wherever chlorine is transported, stored or used in large amounts. Reducing or eliminating sewage treatment plant effluent chlorination would not likely significantly reduce the frequency of transportation accidents because of the relatively small chlorine usage for purposes of disinfection.

11. For existing sewage treatment plants in the Basin, the alternative technologies to chlorine disinfection cannot be retrofitted at the present time with certainty of effectiveness and without upgrading effluent quality in most plants. Ozone and ultraviolet radiation technologies may be applied in <u>new</u> plants or where plants are expanded or are producing upgraded effluents.

12. Strategies considered relevant for moving toward and/or achieving the chlorine objective in sewage treatment plants include:

    a) improve the efficiency of present chlorine disinfection practices;

    b) implement seasonal disinfection in all Great Lakes plants;

    c) add dechlorination to present chlorine disinfection processes and practices;

    d) install alternative disinfection technologies;

    e) eliminate disinfection altogether and

    f) improve outfall diffusion structures.

13. The following are summaries of the consequences of each disinfection strategy based on a qualitative evaluation by Task Force members:

    a) Continuation of current practices would result in annual expenditures in the order of $4.2 million in Canada and the United States for chlorine used in disinfection. Damages to aquatic life and habitat are presumed to be occurring although there are no systematic or aggregate data to illustrate the magnitude of effects.

    b) More efficient chlorination could be undertaken at many locations with little or no financial cost, with presumed reductions in damages to aquatic life and habitat and with no change in public health risk.

    c) Seasonal chlorination could be implemented on a wider basis in the United States jurisdictions with a maximum potential financial saving of about $1.5 million per year, with reduced damages to aquatic life and habitat during the non-chlorination season and with no perceived changes in public health risk.

    d) Dechlorination with sulphur dioxide could be installed on about 116 Great Lakes Basin plants in the United States and Canada at an approximate capital cost of $23.8 million. These facilities would cost approximately an additional $5 million per year to operate. Damages to aquatic life and habitat from chlorine would be reduced and there would be no perceived change in health risks.

   e) If wastewater disinfection were to be eliminated entirely throughout the Basin, the chlorine objective would be achieved and there would be an approximate saving of $4.2 million per year. Aquatic life and habitat would be protected year-round but risks to public health would be perceived to be increased, especially in terms of recreational waters.

14. The feasibility of installing diffusers will have to be determined on a case-by-case basis. Diffusers are, in any event, more appropriate for new and upgraded plants.

15. Evaluations of the strategies lead the Task Force to conclude that more efficient chlorination and seasonal chlorination in the United States plants could be implemented immediately with substantial benefit and little or no added cost.

16. Decisions about changes in disinfection practices will be made at the state, provincial and sometimes at the local level. It is, therefore, clear to the Task Force that the detailed, quantitative field and case studies necessary to make these decisions are more appropriately accomplished by the relevant agencies of these jurisdictions.

RECOMMENDATIONS

The Task Force recommends that:

Technological

1. All jurisdictions undertake to improve the efficiency of present chlorination practices where cost savings warrant.
2. The United States jurisdictions consider implementing seasonal disinfection as is permitted in Ontario under defined circumstances.
3. Before embarking on new and refined wastewater disinfection technologies, resources should be devoted to improving and upgrading municipal wastewater treatment facilities.
4. Dechlorination facilities be considered only for those locations where documentation shows substantive damages to aquatic life.
5. For projected new and expanded sewage treatment plants, jurisdictions should
   a) design the facilities to achieve better effluent quality than is presently the norm;
   b) incorporate non-chlorine disinfection technologies, including diffusers if warranted and
   c) study methods and the feasibility of implementing no disinfection.

Socio-economic

6. The Water Quality Board and the constituent jurisdictions use the report:

   a) as a framework for conducting assessment of other water quality objectives;

   b) as a guide in making informed decisions as to how, where, when and to what extent the chlorine objective might be achieved;

   c) as a guide for municipal authorities in developing implementation programs and

   d) as evidence in support of relevant regulatory actions by state, provincial or federal authorities.

7. Where changes in disinfection practices and policies other than those noted in Recommendations 1 and 2 are contemplated, agencies in the jurisdictions should undertake the necessary social, economic and risk assessments.

8. Future socio-economic assessments of proposed objectives should be carried out by the jurisdictions.

9. All jurisdictions undertake (as is feasible) to document environmental effects and damages to aquatic life and habitat in a quantitative, systematic and comparable manner.

10. The IJC and the Water Quality Board assist the jurisdictions by:

    a) establishing a list of the personnel that would be available from the member jurisdictions to provide expertise on these topics;

    b) developing criteria upon which to base a recommendation to undertake a socio-economic assessment;

    c) identifying to the relevant jurisdictions where social, economic and risk assessments should be undertaken;

    d) developing methods for measuring environmental effects and damages to aquatic life and habitat;

    e) disseminating the results of these studies and

    f) incorporating social and economic factors into other relevant committees, subcommittees and task forces. For example, the Aquatic Ecosystem Objectives Committee could identify and review the various consequences of several possible objective levels for a given contaminant.

11. The following recommendation of the Remedial Programs Subcommittee be acted upon:

> "The Water Quality Board supports the development of guidelines by the jurisdictions for selection of sites where chlorination requirements can be relaxed without adversely affecting public health." (Remedial Programs Subcommittee, 1975, p. 2)

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1

BACKGROUND AND STUDY OBJECTIVES

In the 1974 Annual Report, the Water Quality Objectives Subcommittee proposed that the maximum ambient concentration of total residual chlorine be 0.002mg/L in the boundary waters of the Great Lakes. The Water Quality Board subsequently directed the Surveillance and the Remedial Programs Subcommittees to report on the technical capabilities for monitoring such low concentrations of chlorine in water and to investigate methods for achieving the proposed objective. A Chlorine Objective Task Force was constituted in 1975 to study these issues in detail.

The first Chlorine Objective Task Force submitted its report in 1976 (Chlorine Objective Task Force, 1976). The key findings were that disinfection of sewage treatment plant discharges were required to protect public health and that it would be technically impossible to achieve the proposed chlorine objective at all times and in all locations. Some procedural guidelines to help effect reductions in the use of chlorine at municipal wastewater treatment plants were also presented. The first Task Force noted that there were several technical issues that needed further study and it emphasized that the costs of implementing the objective could be very high.

It should be noted here that, traditionally, the Water Quality Objectives Subcommittee based its recommendations entirely on technical and biological criteria. That is, a target ambient concentration was chosen such that there would be no known effects on aquatic life. Economic and social implications were not explicitly considered. However, in addition to the findings of the Chlorine Objective Task Force, other parties have expressed concerns to the IJC and the Water Quality Board about the costs of achieving various water quality objectives.

Consequently, in early 1978 the Water Quality Board decided to address these economic concerns and it directed that an assessment of the economic and social implications of achieving the chlorine objective be undertaken. It further directed that the formation of an Objective Assessment Subcommittee be considered. It was envisioned that this Subcommittee could provide economic and social input in setting objectives and it could assess the economic feasibility of achieving objectives already established on the basis of scientific or human health criteria.

The present Chlorine Objective Task Force is, therefore, seen as a test case for undertaking social and economic assessments of proposed water quality objectives under the aegis of the Great Lakes Water Quality Board.

The Terms of Reference for this present Task Force are as follows:

> *The Chlorine Objective Task Force will assist the Objectives Assessment Subcommittee (OAS) in assessing the economic, social and regulatory aspects of water quality objectives by assessing the specifically proposed chlorine objective and interacting with the Aquatic Ecosystem Objectives Committee (AEOC).*
>
> *The former Chlorine Objective Task Force was able to carry out the first six of its seven terms of reference. This seventh item is the basis for this set of references to examine the socio-economic and technical implications involved in the achievement of the objective. The new terms of reference were specifically developed to extend the study of the chlorine objective to include the study of socio-economic and technical aspects of adopting the objective.*
>
> 1. *By how much and by what means could the operation of municipal wastewater treatment plants and industrial processes be changed to minimize the discharge of chlorine to the Great Lakes?*
> 2. *Determine the costs associated with alternatives to the process of chlorination.*
> 3. *Determine the practicability of such alternatives given the present technology in use in the Basin.*
> 4. *Consideration of the above by making explicit assumptions regarding effluent limitations and/or mixing zones.*
> 5. *Determine the above by studying two or more specific sites in the Great Lakes which would allow the full examination of the above factors.*

The primary objective of the Task Force is to assess the social and economic implications of approaching or achieving the ambient objective for total residual chlorine of 0.002 mg/L by controlling and/or altering continuous chlorine exposure from any source, particularly municipal sewage treatment plants. The general interpretation of this objective is that it is not meant to refer to intermittent discharges by industry or power plants. An additional objective of this study has been to determine the extent to which chlorine disinfection practices contribute to potentially hazardous chlorinated organic chemicals in the Great Lakes and in drinking water supplies.

The Task Force has confined its efforts to discharges that went directly into the Great Lakes, their interconnecting channels and the first five kilometers of certain tributary rivers.

The present report completes all Terms of Reference except the case studies. Case studies were not carried out because the Task Force concluded that they would not alter or result in any substantive changes in Task Force conclusions or recommendations. Such detailed case studies are more appropriately carried out by the jurisdictions. Suggestions for such studies are noted in Chapters 2, 9 and in the Summary, Conclusions and Recommendations.

It is recommended that the Water Quality Board and the constituent jurisdictions use the report:

1. as a framework for conducting assessments of other ambient water quality objectives; ✗
2. as a guide in making informed decisions as to how, where, when and to what extent the chlorine objective ought to be achieved; ✓
3. as a guide to municipal authorities in developing implementation programs and ✓
4. as evidence in support of relevant regulatory actions by state, provincial or federal authorities. ✓

2

COMMENTS ON METHODOLOGY

Introduction

This is the first economic and social assessment of achieving an ambient water quality objective sponsored by the IJC. The concepts and methods that have been used in this study may also be applied to future socio-economic assessments of other water quality objectives and will, therefore, be explained in some detail.

Explanation of the Methodology

The achievement of specific ambient levels of chlorine or mixing zone configurations may require that the discharge of chlorine residuals from certain sources, e.g. industrial facilities, sewage treatment plants or power plants be curtailed. The technical methods of implementing these curtailments can be specified. The consequences of undertaking the actions necessary to achieve the objective will include one or more of the following:

a) changes in direct financial costs of wastewater disinfection or biofouling control;

b) changes in the sales and revenues to the chlorine production and packaging industries that result from the changes in chlorine demand;

c) changes in sales and revenues to sectors that produce alternative disinfection technologies;

d) changes in employment in all sectors directly affected;

e) changes in government effort required to implement the objective;

f) changes in state, provincial and federal government effort to implement the objective and monitor the ambient conditions;

g) changes in the risk[1] and damages[2] from pathogens found in sewage;

h) changes in risk and damages from chlorinated organic compounds;

i) changes in risk caused by accidents that occur during the transportation and use of chlorine;

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[1] Chance or probability of exposure to pathogens, chemicals and their adverse effects.

[2] Damages refer to the actual disease and deaths as well as to property damages that can be attributed to the consequence.

j) changes in the risk and damages to fish populations and other aquatic life due to chlorine and

k) public perception of and reaction to the risks and damages and to the alternatives for achieving the objective and to other consequences.

The consequences listed above are summarized in Table 1. The relevant quantifiers for each consequence are noted in the table and the group or party that is potentially affected by the consequence is noted as well. There are two types of "quantifiers" specified in Table 1. First, there are data that are quantitative, factual and basically value-free, such as tons of chlorine, numbers of fish killed, numbers of people at risk, numbers of man-hours or years worked, etc. Second, there are data that are quantitative but are subjective and evaluative. These include prices, the dollar values of materials and of different activities and people's preferences. Finally, qualitative insights can be gained on consequences about which there is otherwise little quantitative data. The direction of the changes and who bears the consequence are examples of these qualitative insights.

These consequences may be broadly classified as either benefits or costs. Benefits refer to those consequences which are viewed as contributions to human well-being. Costs refer to those consequences that constitute the expenditure of resources or otherwise diminish human well being. Each of these consequences also has a distributional perspective in that someone or some group bears the consequence. Consequences may be classified as a benefit or a cost depending on this distributional perspective. Therefore, a cost (expenditure of resources) to one party will constitute a benefit (an increase in revenue or a saving) to a receiving party. For this reason, it is often not possible to immediately classify all the consequences listed in Table 1 as either benefits or costs. They become benefits and costs as one evaluates specific programs or alternatives and identifies losers and gainers.

In order to make unambiguous comparisons or evaluations, each of the consequences should be measured using commensurable units. Money or dollar values are widely used to compare and evaluate both public and private investment projects or activities in order to make planning decisions. Money values not only provide common units to the various pertinent consequences, but they also give relative weights to each consequence; the more expensive something is or the more revenue it yields, the more significance or weight it has in the context of the market economy.

However, not all of the consequences specified in Table 1 can be measured directly in monetary units. This is an important, but not an insurmountable, impediment to a systematic assessment of the benefits and costs of environmental objectives and environmental protection activities. Where the consequences cannot easily be expressed in dollars, other appropriate physical units or quantifiers can be used. Costs and benefits can still be systematically tabulated in these appropriate units; comparisons and evaluations can be systematically made on the basis of clearly defined criteria, and rational decisions can be made with the explicit use of judgement. Moreover, the consequences listed in Table 1 have varying degrees of significance in different situations. Empirical study may reveal that only two or three of the consequences are important for making decisions. This eases the task of comparing different types of consequences and physical units.

TABLE 1

POTENTIAL CONSEQUENCES OF ACHIEVING THE PROPOSED
CHLORINE OBJECTIVE, QUANTIFIERS AND GROUPS DIRECTLY AFFECTED

CONSEQUENCE	QUANTIFIERS[1]	GROUPS DIRECTLY AFFECTED
1. Changes in Direct Costs of Chlorine use	$	Municipalities Industrial Groups Power Plants
2. Changes in Sales and Revenues of Chlorine	Tons of Chlorine $	Chlorine Industry Primary Producers Packagers or Merchandisers
3. Changes in Sales and Revenues of alternative technologies	$	Other industries and companies
4. Changes in Employment	Number of Employees - Man Years	Industry, municipalities, tourist industry
5. Changes in government regulatory effort - Implementation - Regulation - Monitoring	Man Years $	U.S. & Canada Federal Governments State Governments Province of Ontario
6. Changes in damages[2] & risk[3] from pathogens in sewage - in drinking water - in recreational water	Risk of disease Mortality Morbidity	Population consuming water Population swimming in recreational water Tourist Industry
7. Changes in damages[2] & risk[3] from chlorinated organics - in drinking water - in fish	Mortality Morbidity Risk of disease	Population consuming water Population who eat contaminated fish
8. Changes in damages[2] caused by accidents that occur during transportation and use of chlorine	Mortality Injuries Property damages Compensation payments $	Individuals
9. Changes in the damages[2] & risk[3] to fish populations and other aquatic life due to chlorine in sewage	Fish mortality Presence or absence of species $ value of sport or commercial fishery affected Fish and spawning habitat improvement	Sport & Commercial fishermen Tourist Industry
10. Public perception and reaction to different disinfection alternatives	Complaints	"Public" Government Agencies IJC

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[1] There are two types of "quantifiers". First, there are factual value-free quantifiers such as tons of chlorine or numbers of people sick or who have died. Second, there are subjective and evaluative quantifiers such as dollar value prices and complaints.

[2] Damages refer to the actual disease and deaths as well as to property damages that can be attributed to the consequence.

[3] Risk is the chance or probability of experiencing a consequence such as the disease. The greater the exposure to pathogens or exotic chemicals, the greater the probability that one person (or more people in a given population) will experience adverse effects, i.e. disease, poisoning.

If all consequences could be expressed in dollars and the benefits and costs of each strategy or alternative could be clearly defined, then explicit comparisons could be made and the alternative yielding the maximum net benefits or lowest net cost could be unequivocally determined. However, because it is not possible to determine dollar values of all of the relevant consequences, a rigorous economic benefit cost analysis has not been performed by the Task Force. Rather, the approach in this study has been to assemble and display the relevant cost and other data along with any assumptions used in estimations for all to see and to criticize. At the very least, the low cost methods or strategies for achieving specific objectives can be determined. Important gaps in quantitative information needed for policy development and evaluation can also be identified.

Decisions may not be any easier to make, but by using the procedures outlined here, they will be more informed and, perhaps, unanimous.

Social and Economic Assessments

The proposed chlorine objective is based on the most sensitive use by aquatic life from an analysis of data on the effects of continuous exposure of aquatic life to chlorine. It was determined without explicit consideration of the costs of achieving the objective or of taking steps to move toward it. It also appears that the benefits of achieving the objective were not systematically enumerated and explicitly compared with the costs.

By setting environmental objectives in this manner, it is implied that the most sensitive use or species of aquatic life that is preserved is worth whatever costs must be incurred to achieve the objective. If financial and other resources were limitless, then the question of costs to achieve this and other environmental objectives would be irrelevant. But, of course, resources are not limitless so that individuals and governments must make choices about allocating scarce money and time among the many important problems and worthy social goals that compete for these resources. Economic principles provide useful rules and guidelines for making these choices.

Social-economic assessments are intended primarily to show, as clearly as possible, the magnitude and the distribution of the costs and benefits of alternative policy choices. Furthermore, such assessments indicate which alternative or courses of action are the most cost-effective or are the most equitable. The information generated by a social-economic assessment will, however, constitute only a part of the considerations in making decisions or choices. While the choices may not be any easier, the information provided by social-economic assessments, if used, will help people make more informed choices.

Socio-economic assessments ask two fundamental and reasonable questions: What does it cost to achieve specific environmental improvements, and what is gained or achieved in the way of environmental improvement from specific environmental protection efforts?

Ideally, in order for society to use its resources productively, the environmental benefits derived from achieving an environmental quality objective should be valued by society as equal to or greater than the costs of the goods and services that are given up by society to achieve it. If money and effort must be spent to achieve the chlorine objective in the receiving waters of the Great Lakes, other activities such as the reduction of phosphorus, research on hazardous chemicals or the upgrading of sewage treatment plants may have to be foregone. It is legitimate to ask whether the benefits of achieving the chlorine objective are worth more to society than the benefits obtained by using the money and effort for some other activity.

Since the discharge loadings of chlorine and many other contaminants are already rather low, the benefits of further curtailment of loadings or of ambient concentrations tend to be subtle and sometimes obscure. Furthermore, some ways of achieving the objective may result in an increase in the risk of adverse human health effects. One cannot, therefore, conclude a priori that achieving the chlorine objective will necessarily result in a net benefit to society in all situations. It is necessary, therefore, to identify explicitly and measure empirically the magnitude of the costs and benefits to determine whether the method or activity in question is rational, i.e. whether the benefits are reasonably commensurate with the costs.

Even if the benefits of achieving the objective are indeterminate or if a "political" decision is made to achieve the objective, a socio-economic assessment can still yield additional useful information. For example, an explicit assessment of the costs alone will help to determine the least-cost method of achieving specific levels of protection so that the costs of achieving specific objectives can be evaluated.

In addition to knowing the magnitudes involved, it is important to know which groups or sectors of the economy will bear the costs and enjoy the benefits of environmental protection. This information will help to preserve equity in the implementation of environmental protection.

The Usefulness of Socio-Economic Assessments

In practical terms, the discussion above means that economic and social assessments of water quality objectives aid in:

1. deciding which locations and problem areas are most important;
2. setting priorities for abatement projects, for the allocation of enforcement efforts and for setting implementation timetables;
3. identifying the least-cost technologies for abatement and protection;
4. justifying implementation of abatement and protection activities and
5. justifying not taking actions or not enforcing compliance in certain locations.

Single-Valued Objectives versus Incremental Changes

Achievement of the proposed objective of 0.002 mg/L throughout the Basin may be seen as an extreme situation while the existing levels of chlorine discharges and ambient concentrations constitute the opposite situation. It is important to recognize that there are a number of efforts and changes that can be made to achieve intermediate patterns of discharge control and ambient quality conditions. This could mean that the objective can be achieved only in certain locations or at certain times of the year. Varying the size of mixing zones is another way in which intermediate levels of ambient quality can be achieved.

As already noted, it is not certain that reaching the chlorine objective in receiving waters throughout the Great Lakes will yield to society benefits that are necessarily valued greater than the money and effort that must be expended to achieve it. Ideally, resources should be expended on an activity such as achieving the chlorine objective up to the point where the extra costs incurred are just equal to the extra or incremental benefits obtained. This level of environmental quality or protection is considered by economists to be most efficient for society as a whole.

It is often very costly to acquire all the information necessary to determine the optimal or ideal environmental quality objective. A more practical approach is one that includes setting desired objectives as is done by the Water Quality Board now. Authorities could then enumerate, in a quantitative manner, the effects or the damages that would be avoided by moving to one or two intermediate steps between existing ambient levels and the ultimate objectives. An explicit assessment of the added risks and costs of implementing these intermediate quality levels could then be carried out and used, along with the information about the incremental benefits of intermediate levels, in the development and scheduling of remedial programs by the relevant jurisdictions. These data and assessments could even be used in establishing proposed objectives for contaminants whose control costs are high or whose effects are relatively well known. If these analyses are accomplished, the authorities concerned will have more pertinent and organized information with which to make better informed and defensible policy decisions.

3

CHLORINE PRODUCTION, USE AND RESIDUALS - AN OVERVIEW

Chlorine Production and Use

Chlorine is one of the 10 largest volume products in the chemical industry. It is produced by electrolysis with caustic soda (sodium hydroxide) as a co-product. During 1978 approximately 10 million tonnes (11 million short tons) of chlorine gas were produced in the United States amounting to a $1.3 billion industry (Chemical & Engineering News, 1979). Production in all of Canada totalled about 910,000 tonnes (one million short tons) during that same year. Production statistics for the United States are presented in Table 2. Canadian production and trade data are tabulated in Table 3.

About 1.2 - 1.4 million tonnes (1.3 - 1.5 million short tons) of the 10 million tonnes of chlorine produced in the United States is manufactured in plants located in New York, Michigan and Ohio. Regional production figures are not available for Canada. A total of 19 chlor-alkali plants are located in the Great Lakes region of the United States and Canada. These are listed in Table 4; locations are given in Figure 1. Four of these plants are not located directly on the Great Lakes or their interconnecting channels. A total of 36 firms produce chlorine (and caustic soda) in the United States and 10 different companies in Canada presently manufacture this product for internal use or for sale on the market. The pulp and paper industry uses approximately 60% of the chlorine consumed in Canada, while various industrial chemical users account for about 35%.

According to Statistics Canada approximately 1% of total chlorine consumption or about 8,000 metric tonnes in 1976 were used by water and wastewater treatment plants in Canada. Data on chlorine consumption by user group in Canada are presented in Table 5. The Ontario Ministry of the Environment estimates that about 4,200 tonnes (4,600 short tons) per year are used by municipal water treatment facilities and approximately 2,000 tonnes (2,200 short tons) are used for wastewater disinfection annually in Ontario which encompasses the Canadian portion of the Great Lakes Basin. Ontario Hydro uses about 24.6 tonnes (27.0 short tons) each year for antifouling and the disinfection of service water in their six thermal generating stations and one of their four nuclear establishments.

Consumption patterns in the United States are somewhat different as indicated by the following data:

Ontario	tonnes
Munic wastewater	4200
Water intakes	2000
Hydro	27

TABLE 2

CHLORINE CAPACITY AND PRODUCTION IN THE UNITED STATES PRICES, EXPORTS AND IMPORTS (metric tonnes)

YEAR	DAILY CAPACITY	GAS PRODUCTION		LIQUID PRODUCTION		PRICE TANK CARS ¢/lb.	EXPORTS	IMPORTS
		ANNUAL TOTAL	DAILY AVERAGE	LIQUIFIED (% OF TOTAL GAS PROD.)	TOTAL			
1969	22,793	8,505,822	23,303	46.7	3,974,512	3.70		
1970	25,652	8,857,630	24,268	45.4	4,017,963	3.75	24,811	
1971	26,428	8,484,531	23,245	47.9	4,060,847	3.75	38,820	35,295
1972	25,935	8,939,816	24,426	50.9	4,549,615	3.75	14,801	22,623
1973	26,892	9,437,004	25,855	52.2	4,922,290	2.75-4.00	11,936	45,513
1974	27,497	9,755,220	26,727	54.4	5,309,083	3.75-8.90	14,732	76,473
1975	30,854	8,316,416	22,784	58.0	4,823,508	5.75-7.50	15,190	67,142
1976	31,786	9,415,314	25,725	58.7	5,525,659	6.25-7.50	22,510	75,151
1977	32,413	9,591,838	26,279	60.0	5,752,860	6.75-7.50	37,491	93,367
1978								
1979								

SOURCE: Chlorine Institute Inc. *North American Chlor-Alkali Industry Plants and Production. Data Book, January 1979.* Chlorine Institute Pamphlet 10. p. 12 and p. 13.

TABLE 3

CHLORINE PRODUCTION, IMPORTS, EXPORTS IN CANADA
(metric tonnes)

YEAR	PRODUCTION	IMPORTS	EXPORTS
1971	772,921	975	30,498
1972	817,373	1,610	32,411
1973	889,948	3,720	42,098
1974	954,358	6,214	69,535
1975	748,894	4,894	71,500
1976	898,336	11,101	76,465
1977	888,324^p	17,000^p	90,882^p
1978	940,712^p	17,269^p	79,606^p

p = Preliminary data

SOURCE: Statistics Canada, Catalogue 46-004, (1977 March) Service Bulletin, Chemicals, Manufacturing and Primary Industries Div., Vol. 3, No. 9, Sulfuric Acid, Caustic Soda and Chlorine-Annual.

TABLE 4

CHLOR-ALKALI MANUFACTURING PLANTS IN THE GREAT LAKES REGION UNITED STATES AND CANADA

LOCATION	COMPANY	ELECTROLYTIC PRODUCTION CELLS	CONTAINERS FILLED[1]
Michigan			
Midland	Dow Chemical	Dow (diaph)	s
Montague	Hooker Chemical & Plastics	Hooker (diaph)	s
Wyandotte	BASF Corp., Wyandotte		s
Wyandotte	Pennwalt Corp.		c & s
New York			
Niagara Falls	DuPont	Downs (fused salt)	-
Niagara Falls	Hooker Chemical	Hooker (diaph)	s
Niagara Falls	Hooker - IMC Joint Venture	Uhde (merc.)	s
Niagara Falls	Olin Corp.	Oil (merc.)	s
Syracuse	Allied Chemical	Solvay (merc.) Hooker (diaph)	s
Ohio			
Ashtabula	IMC Chemical Group, Inc.	Olin E11F (merc.)	s
Ashtabula	RMI Company	Downs (fused salt)	s
Barberton	PPG Industries Inc.	Columbia (diaph)	s
Wisconsin			
Green Bay	Fort Howard Paper Co.	Hooker (diaph)	-
Ontario			
Cornwall	Canadian Industries Ltd.	ICI (merc.)	cts
Dryden[2]	Reed Ltd.	Hooker (membrane)	ts
Hamilton[2]	Canadian Industries Ltd.	-	-
Marathon[2]	American Can	-	-
Sarnia	Dow Chemical of Canada	Dow (diaph)	s
Thunder Bay[2]	Dow Chemical of Canada	-	-
Amherstburg[3]	Allied Chemical	-	s

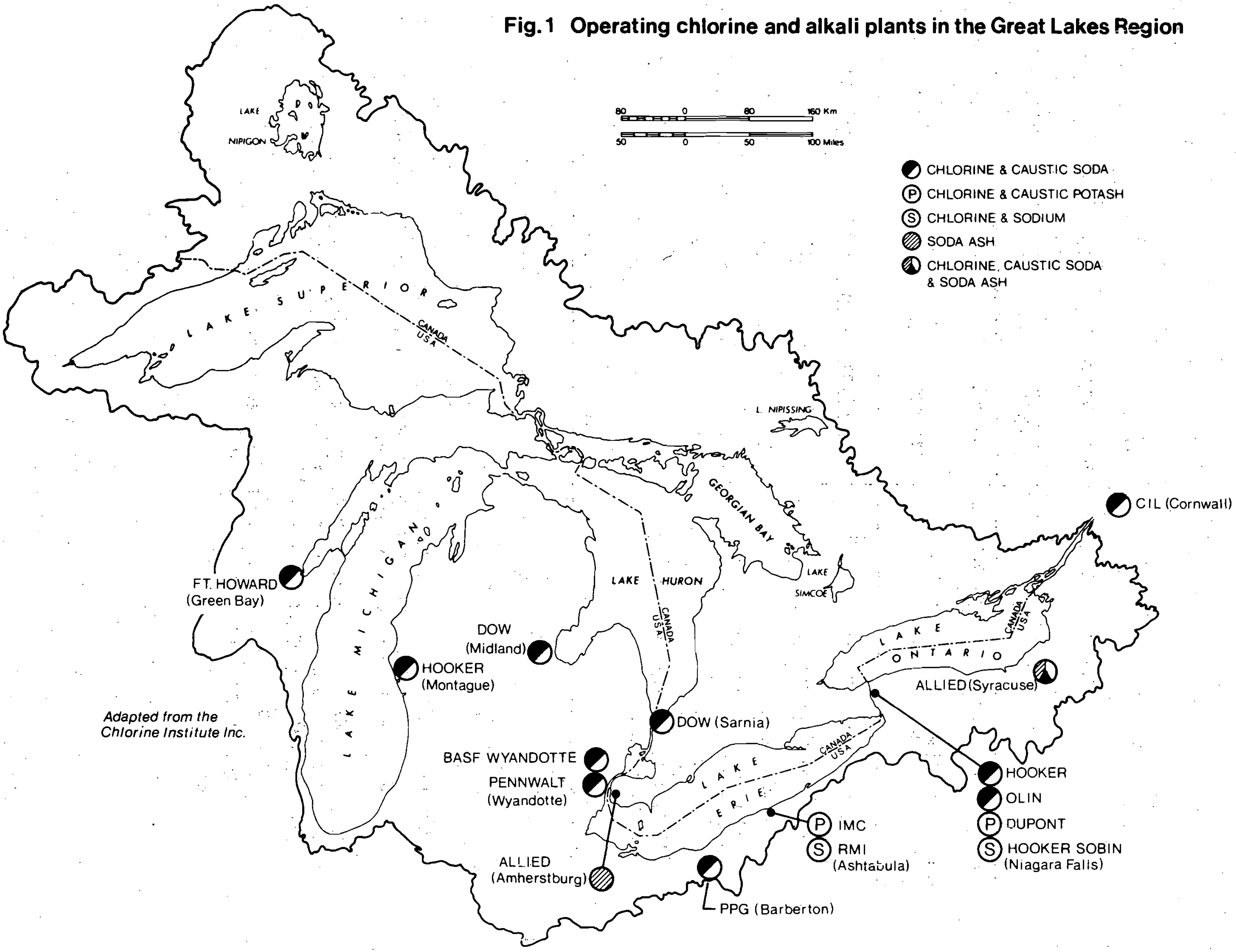
[1] s - single unit tank cars
c - cylinders
t - ton cylinders

[2] No longer in operation.

[3] Produces soda ash by solvay process.

SOURCE: Chlorine Institute, North American Chlor-Alkali Industry Plants and Production. Data Book, January 1979, pp. 2-3.

Fig. 1 Operating chlorine and alkali plants in the Great Lakes Region



Adapted from the Chlorine Institute Inc.

TABLE 5

CHLORINE PRODUCTION AND CONSUMPTION IN CANADA

	1973[1]	1975[1]	1976[2]
Total Production (metric tonnes)	889,948	748,894	898,336
Total Consumption of Industries Surveyed (metric tonnes)	818,330	604,787	792,815
Consuming Sectors	% Consumption by Industries Surveyed*		
Municipal Waterworks	.7	1.0	-
Mining	.6	0.8	-
Pulp and Paper	57.3	83.5	62.4
Smelting and Refining	.9	1.2	-
Soap and Cleaning Compounds	1.1	1.2	0.9
Industrial Chemicals	39.4	12.0	36.6
Fish Processing	-	-	0.02
Miscellaneous Food Industries	-	-	0.01
Miscellaneous	0.1	0.3	0.07
	100.0	100.0	100.4

*Only certain users are surveyed each year. In 1976, municipal waterworks, mining, and smelting and refining were not surveyed. These users did, however, use chlorine during that year.

[1] Statistics Canada, Catalogue 46-004, Service Bulletin, Chemicals, Manufacturing and Primary Industries Division, Vol. 3, No. 9, Caustic Soda and Chlorine-Annual, March 1977.

[2] Dornan, J. (1979), Statistics Canada, Manufacturing and Primary Industries Division, Ottawa. Personal Communication.

USER	APPROXIMATE PERCENT OF TOTAL CONSUMPTION
Various chemicals	40%
Plastics (PVC)	20
Solvents	15
Pulp and Paper	15
Water Treatment	5

Source: Chemical and Engineering News, Feb. 26, 1979, p. 11.

The amount of chlorine used in the United States for "water treatment", which presumably includes both wastewater and water supply disinfection, amounts to about 500,000 tonnes (550,000 short tons) annually (5% of 11 million short tons). The proportion of this consumption that is used only for wastewater disinfection and/or in the Great Lakes region is not known. The total amount of chlorine used by the 64 power plants in the United States located on the Great Lakes is also unavailable at this time.

Chlorine gas is sold to users by rail and truck tank car and in 1-ton or less sized cylinders. Large users may buy in tank-car lots directly from primary producers. However, the major proportion of the chlorine that is used for sewage and water disinfection is purchased in 1-ton or smaller cylinders from chlorine packaging companies. In 1978, there were 46 of these companies in the United States and five in Canada. Some primary producers also sold chlorine in smaller cylinders (The Chlorine Institute, Inc., 1979).

Assuming that the total chlorine consumption in Canada is 16,000 tonnes (2 x the 8,000 tonnes used for water and wastewater treatment noted on page 19), the total amounts of chlorine used for water and wastewater disinfection in both the United States and Canada amounts to about 516,000 metric tonnes per year. This amounts to about 4.7% of the annual total of 11 million tonnes of chlorine that have been produced during recent years.

Some of the alternatives to be considered in this study involve the reduction or the elimination altogether of chlorine as a disinfectant. It is, therefore, important to try to determine what effect the resulting reduction in chlorine demand would have on the industry. Because the amounts used for sewage disinfection are so small, the losses to primary producers would not be significant in the long run under normal conditions of steady growth. However, chlorine demand has declined somewhat since 1975 and the industry has some excess capacity (Chemical & Engineering News, 1979). If this underutilization of capacity persists, the industry will perceive the reduced demand and revenues more acutely than if market demand were growing more consistently.

Reductions in the demand for chlorine for disinfection could more seriously affect the smaller chlorine packagers that market chlorine to municipalities. Discussions with such packagers indicate that they have been diversifying their customers in recent years because chlorine demand from municipalities has been declining. While the packaging section of the industry is not likely to welcome further declines in chlorine demand, it does not appear that the chlorine industry would be seriously damaged by actions that would reduce or eliminate the use of chlorine as a disinfectant in the Great Lakes.

Sources of Residual Chlorine and Chlorinated Organics

There are three major sources of residual chlorine discharges to the Great Lakes: industry, power plants and sewage treatment plants. However, because data concerning the actual residual chlorine discharges are limited, estimates must be based on chlorine use and knowledge of the processes involving chlorine. In addition, it is important to note that the proposed objective is generally intended for continuous discharges of chlorine from sources like sewage treatment plants and some industrial establishments. Although the proposed chlorine objective is not intended for intermittent sources such as power plants, the implications for further reductions in chlorine use and discharges from this source were investigated in the course of this study.

The pulp and paper industry is a major industrial user of chlorine, especially in Canada where it is used as a bleaching agent. The wastewater discharges of chlorine bleaching processes, where they occur, primarily include inorganic chlorides and chlorinated organic compounds with little or no residual chlorine. Some of the chlorinated organic compounds are acutely toxic to fish and other aquatic life and there is concern that they may have chronic effects as well. Toxicity studies have only begun on these compounds so the relative significance of their effects on aquatic life cannot be evaluated at this time.

Chlorine is used extensively in the chemical industry for the manufacture of chlorinated organic compounds as well as the manufacture of non-chlorine containing compounds or products. Some chlorinated compounds may be discarded into waste streams. The actual loading of chlorinated organics to the Great Lakes from the organic chemical industry is not known although studies are under way to get more information on these discharges.

The manufacture of chlorine and caustic soda results in the discharge of residual chlorine in plant effluents. Sources of residual chlorine in the effluent of these plants are due mainly to overflows, spills and leaks occurring in the manufacturing process. The use of carbon electrodes in the chlorine manufacturing process results in the formation of trace amounts of chloro-organics such as hexachlorobenzene. Because of their bioaccumulation potential, these compounds are in sufficient quantities to cause environmental contamination.

Other industries, including the iron and steel and petroleum industries, chlorinate their intake waters for use in cooling systems and service waters for biocidal purposes. These waters are potential sources of residual chlorine loadings to the Great Lakes; but when combined with the total plant effluent, the final effluent concentration often is negligible. Chlorine is also used in phenol and cyanide destruct systems by these industries. However, no chlorine residuals have been attributed to their use. The extent of chloro-organic formation by these processes is unknown.

Chlorine is used in power plants primarily to control biofouling of cooling system condenser tubes, condenser water intake delivery systems and to control algae in cooling towers. Application of chlorine differs at each plant according to the quality of intake water and the amount of water flowing through the plant. Only four out of six thermal generating stations use chlorine to control biofouling of condenser tubes in Ontario. The four nuclear establishments in Ontario do not chlorinate cooling water. In the United States, 54 of the 64 power plants on the Great Lakes chlorinate intake waters to their condenser cooling systems.

In the summer, the most common method to control biofouling in power plants is intermittent dosing with chlorine in concentrations of 1 to 3 mg/L of total chlorine residual for five to 60 minutes, two or three times every 24 hours. Winter operational practices normally entail a decrease in the frequency of chlorine applications. (Power plants operating in Ontario are restricted to total chlorine residual discharges of less than 0.5 mg/L).

The amounts of chlorine used and the estimated quantities of total residual chlorine and chlorinated organic loadings from all major sources are summarized in Table 6.

Although these data are rather sparse, it is apparent from these and other sources that industry is the largest source of chlorinated organic loadings. However, except for chlor-alkali plants, industry process wastewaters are not important sources of residual chlorine. Power plants are a source of residual chlorine on an intermittent basis as well as some volatile chlorinated organics. Sewage treatment plants (Figure 2) are a source of residual chlorine and chlorinated organics although the quantities of the latter are virtually insignificant compared with industrial sources.

Residual Chlorine Problems

There is little documentation of identified residual chlorine problem areas in the Great Lakes. Efforts made by Task Force members to compile statistics on the number and magnitude of actual problems caused by residual chlorine yielded little in the way of data. Some fish kills have been documented in the Great Lakes, but there are biologists who contend that these data understate the effects of residual chlorine because:

- many kills are unobserved;
- many areas are not studied;
- fish avoid chlorinated discharges and
- chlorine affects food organisms.

The effects of residual chlorine are further complicated by the fact that other contaminants or stressful conditions, e.g. ammonia and temperature are almost always present with residual chlorine. Also, fish kills caused by residual chlorine in discharges from sewage treatment plants have not been shown to occur. Fish have been shown to avoid continuously occurring concentrations well below lethal concentrations (Tsai and Fava, 1975; Fava and Tsai, 1976). Avoidance, while it might protect mobile aquatic populations from direct mortality, does result in a loss of habitat. Factors, such as avoidance, make the quantification of benefits difficult to determine with any precision.

TABLE 6

SUMMARY OF CHLORINE USE AND RESIDUALS FROM MAJOR SOURCES ON THE GREAT LAKES

(tonnes/year)

RECEIVING WATER	SOURCE	UNITED STATES			CANADA		
		CHLORINE USE	RESIDUAL CHLORINE LOADINGS*	CHLORINATED ORGANIC LOADINGS	CHLORINE USE	RESIDUAL CHLORINE LOADINGS*	CHLORINATED ORGANIC LOADINGS
Superior	Pulp & Paper				35,035[a]		7,011[b]
	Iron & Steel						
	Power Plants		10.4	10.4		8.7[c] (CCW & SW)[d]	
	Sewage Treatment Plants					.02 (STP)[e]	
Michigan	Power Plants		128.8	128.8			
	Sewage Treatment Plants						
Huron	Pulp & Paper				5,215		1,043
	Power Plants		10.2	10.2		.25 (STP)	
	Sewage Treatment Plants						
St. Clair River	Organic Chemical						717.5
	Inorganic Chemical					53	
Lake St. Clair	Power Plants		10.2				
Detroit River	Power Plants		57.3				
Erie	Petroleum						
	Power Plants		181.9			.39 (SW)	
	Sewage Treatment Plants						
	Ferrometals	4.9		Unknown			
Ontario	Organic Chemical						
	Iron & Steel						
	Petroleum						
	Power Plants		4.2		24.6	5.97 (CCW & SW)	
St. Lawrence River	Pulp & Paper				7,770		1,558
	Inorganic Chemical					6	

---

*Total residual chlorine

[a] Calculated usage rate assuming 7% chlorine application rate by weight of bleached pulp.

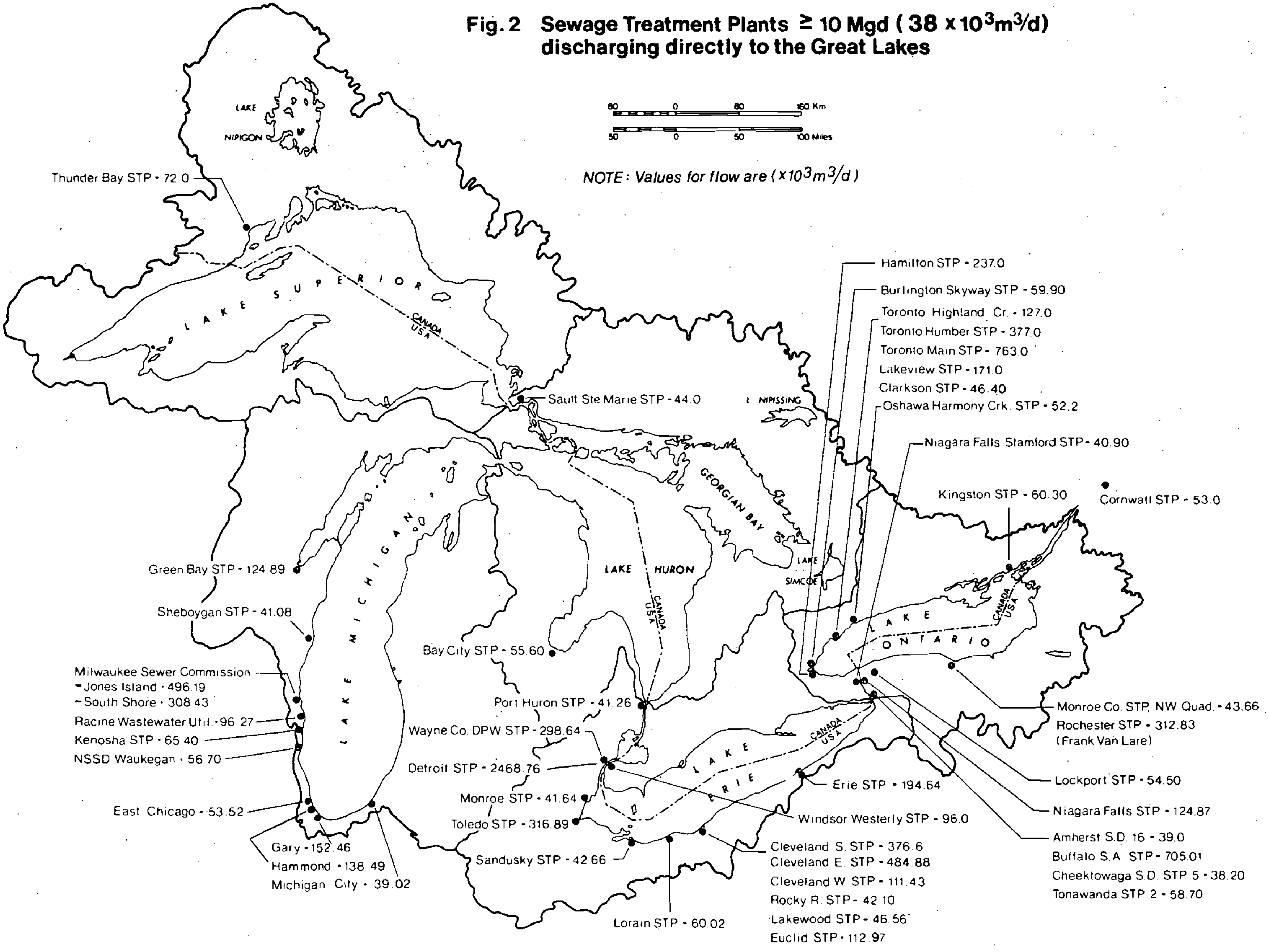
[b] Calculated chlorinated organic loading assuming 20% of the applied chlorine is substituted into organic compounds, as Cl.

[c] Power plants - 1978 monitoring information from Ontario Hydro.

[d] CCW - Condenser cooling water discharge.
SW - Service water discharge.

[e] STP - On-site sewage treatment plant discharge.

Fig. 2 Sewage Treatment Plants ≥ 10 Mgd (38 x $10^3 m^3/d$) discharging directly to the Great Lakes



4

CHLORO-ORGANICS - PROBLEMS AND SIGNIFICANCE

In wastewater all three of the active species, Cl_2, HOCl and OCl^- are strong oxidizing agents and will react strongly with any reducing compounds, such as hydrogen sulphide, carbohydrates, etc. present in the wastewater. When such oxidations have proceeded to virtual completion the active species start to react with ammonia or organic nitrogen containing compounds to form chloramines (combined chlorine). When the weight ratio of chlorine to ammonia is less than 5:1, monochloramine is the predominant product. With a ratio of between 5:1 and 10:1, disproportionation occurs and dichloramine is formed and above 10:1 (the approximate ratio for break point chlorination), some trichloramine may be formed. Only after all these reactions have occurred will continued addition of chlorine produce free residual chlorine which will be available for disinfection.

The nature and concentrations of the reactive chlorine containing species are of primary importance in determining the formation and yield of chlorinated organic compounds. Lee and Morris (1962) have reported on the potential chlorinating ability of HOCl and Morris (1967) has estimated that it is more effective than NH_2Cl by about four orders of magnitude. Since HOCl appears to be the major chlorinating species, the possible chemical reactions with organic constituents in aqueous solution must be examined. According to Jolley (1973) these reactions may be grouped into three general categories: a) oxidation, b) substitution, c) addition.

Jolley (1973) has proposed that oxidation reactions may be the predominant type of reactions to occur in natural waters or effluents, although this has been disputed by Zaloum and Murphy (1974), who quote unchanged values of total organic carbon (TOC) and chemical oxygen demand (COD) before and after chlorination in support of their argument. However, they appear to be considering chloramines only since they assume all the chlorine to be in the combined form. Jolley et al. (1976) lists more than 20 carbohydrates, polyols and aliphatic organic acids which have been identified in primary domestic sewage and which would readily oxidize in the presence of HOCl. Most of these compounds were identified in the low μgL^{-1} range. Although these compounds probably contribute to the overall chlorine demand of effluents or cooling waters, they are unlikely to result in appreciable formation of chloro-organic compounds.

Substitution reactions can be conveniently divided into two groups:

i) those resulting in formation of N-chlorinated compounds and

ii) those resulting in formation of C-chlorinated compounds.

The formation of N-chlorinated compounds has been reported by Morris (1967). Pitt et al. (1975) have identified numerous amides, amino acids, indoles, pyridine derivatives, purine derivatives and pyrimidine derivatives in sewage effluents. These compounds would be expected to react with aqueous chlorine in a similar way to ammonia. However, amines would be expected to react much faster to form N-chloro-derivatives than amides (Morris 1967).

Substitution of chlorine into organic compounds to form C-chlorinated derivatives has been summarized by Jolley (1973), Carlson et al. (1975) and Morris (1973). These reactions can either be conventional substitution, i.e. substitution of chlorine into aromatic or heterocyclic compounds, or of the haloform reaction type. The latter reaction has been studied in detail in recent years in the chlorination of water (Rook 1974 and 1976), cooling water (Jolley et al. 1978) and wastewater (Glaze and Henderson 1975). The major precursors of the haloform reaction are now considered to be m-dihydroxy aromatic compounds - common building blocks of humic materials and low molecular weight methyl ketones (Stevens et al.).

During the past six years, studies of the formation of chlorinated organics during water and wastewater disinfection have proceeded in three directions:

a) chlorination of model organic compounds in the laboratory;

b) chlorination of sewage effluents or cooling waters in the laboratory and

c) chlorination of effluents in sewage treatment plants under normal operating conditions.

These three areas will now be reviewed in turn. Unfortunately, (a) and (b) above have received considerably more attention than (c).

a) Chlorination of Model Organic Compounds

For a recent review of general chlorination reactions, the reader is referred to a report by Pierce (1978). Numerous studies have been made on the chlorination of organic compounds (other than chloramines), which have either been identified as components of sewage effluents or predicted as possible components. Carlson et al. (1975) examined the interaction of several monosubstituted aromatics with low concentrations (7×10^{-4} M) of aqueous chlorine. The reactions followed recognized trends (Morris 1976), i.e. aromatics containing activating substituents such as hydroxyl, ether, amine groups undergo electrophilic aromatic substitution faster than those containing electron withdrawing groups such as nitro, chloro, nitrile and carboxyl groups (De LaMare and Ridd 1959; Gaffney 1974; and Rockwell and Larson, 1978). Phenol was shown to be an exception to this general rule in that it is readily chlorinated at high pH due to the formation of the phenolate anion.

The chlorination of biphenyl (Carlson et al. 1975 and Smith et al. 1977) and naphthalene (Smith et al. 1977) has also been studied in detail due to relatively easy recognition of chlorinated isomers and the concern over possible PCB and PNC formation in treatment plants known to receive biphenyl and naphthalene (Gaffney 1974 and Smith et al. 1977). Smith et al. (1977) reported that chlorinated biphenyls and chlorinated naphthalenes formed readily at room temperature with the extent of reaction depending upon pH and the molar ratio of hydrocarbon:chlorine. In a 500 mgL^{-1} non-homogeneous suspension of biphenyl they identified the predominant products as 2-chlorobiphenyl, 4-chlorobiphenyl, 2,2'-dichlorobiphenyl and 2,4'-dichlorobiphenyl. In 50% saturated solutions of biphenyl, Carlson and Caple (1976) reported the above products and significant concentrations of 3,4-dichlorobiphenyl and 4,4'-dichlorobiphenyl at low or neutral pH. Unfortunately, neither author extended his study to true treatment plant conditions. In the case of naphthalene, Smith et al. (1977) identified the 1,2-dichloro- and 1,4-dichloro-isomers plus four other undefined products (isomers?) and an undefined tetrachloro-naphthalene. Similar products were observed in both 500 mgL^{-1} suspensions and 10 mgL^{-1} solutions.

Murphy et al. (1975) and Usenik and Murphy have grouped representative organics into groups which are "easily chlorinated", "chlorinated under vigorous conditions" and "not chlorinated" as follows:

TABLE 7

EASE OF CHLORINATION OF SELECTED ORGANICS

EASILY CHLORINATED	CHLORINATED UNDER VIGOROUS CONDITIONS	NOT CHLORINATED
Phenols	Carboxylic Acids	Alcohols
Amines	Nitrobenzene	Methyl Ketone
Aldehydes	Benzonitrile	Urea
Ketones		Furan
Pyrrole		Thiophene

Compounds in the table were evaluated by measurement of chlorine uptake during aqueous chlorination rather than by identification of specific chlorinated product. Molar ratios of between 1:1 and 3:5 were used. The conclusions drawn supported those of Carlson et al. (1975) in that only those ring structures with electron activating substituents are likely to be chlorinated under conditions employed during wastewater disinfection. The presence of ammonia retarded the uptake of chlorine through the formation of less oxidative chloramines but given sufficient contact time, both aromatic structures and amino acids could be chlorinated in the presence of ammonia. With sufficient contact period, ring structures were both chlorinated and oxidized even by NH_2Cl but excess free chlorine was required for the oxidation of amino acids.

Reinhard et al. (1976) have examined the possibility of chlorinated hydrocarbons originating from the chlorination of petroleum-derived compounds in aqueous solution. Specifically, they studied the aqueous chlorination of aromatic fraction of diesel fuel over 1, 30 and 70 hours. Products were identified using gas-chromatographic-mass spectrometric analysis. Major products include 2-chloromesitylene and chloronaphthalene derivatives after one hour chlorination, chlorinated benzene derivatives, 2,5-dichloromesitylene and chlorinated indane derivatives after 30 hours and chlorinated benzene derivatives, 2-chloromesitylene and dichlorobenzene derivatives after 70 hours chlorination. In addition, some other non-chlorinated oxidation products were generated.

The formation of halomethanes by the haloform reaction has been studied in detail by a number of researchers (Rook 1976; Stevens et al.; Christman et al. 1976; Oliver and Lawrence 1979; and Youssefi et al. 1978). The general concensus is that most compounds containing the m-dihydroxy aromatic moiety or low molecular weight methyl ketones will form haloforms upon chlorination. Since many natural organic compounds (or their degradation products) contain m-dihydroxy groupings, the formation of volatile halomethanes can be expected during chlorination of many natural waters and effluents. Compounds which have been shown to produce chloroform, bromodichloromethane, chlorodibromomethane, carbon tetrachloride, or bromoform, include humic acid (Rook 1976; Oliver and Lawrence 1979; and Youssefi et al. 1978), fulvic acid (Rook 1976 and Oliver and Lawrence 1979), tannic acid (Oliver and Lawrence 1979 and Youssefi et al. 1978), glucose, vanillic acid, gallic acid (Youssefi et al. 1978), lignosulphonic acid and amino acids (Oliver and Lawrence 1979). Of these precursors, humic and fulvic acids are the most abundant in effluent and hence contribute most to the total volatile organo-halogens. The brominated compounds arise from traces of bromide which become oxidized by chlorine to bromine and then via the haloform reaction to brominated or chlorobrominated methanes. The haloform reaction is strongly pH dependent, the total yield at pH 11 being approximately three times that at pH 7 (Oliver and Lawrence 1979).

While it has been shown that many organic compounds react with chlorine at near neutral pH and ambient temperature, a large number do not react or react very slowly under these conditions (Kobayashi and Okuda 1972). However, when illuminated with ultraviolet light, many of these compounds which do not react with chlorine under strictly thermal conditions, will form chlorinated compounds. Oliver and Carey (1977) showed that in the case of ethanol, the primary hydroxyl radical attack occurs at the α - carbon atom. Hence, acetic acid and acetaldehyde were the major products with only small amounts of 2-chloroethanol and 2-chloroacethaldehyde being formed. For n-butanol, however, only 34% of the hydroxyl radical attack was at the α - carbon and consequently more chlorinated products were formed, such as 2-chloro-n-butanol.

Kobayashi and Okuda (1972) list about 50 organic compounds and group them in terms of relative reactivity with chlorine in the presence and absence of UV irradiation. These photolysis reactions could be quite significant since many sewage treatment plants disinfect their effluents in open-air tanks exposed to sunlight.

From the above discussion of laboratory studies of the chlorination of organic compounds, it is evident that the potential exists for many chlorinated organic compounds to be formed during wastewater disinfection. It is also evident that in many instances the chemical mechanisms involved are little understood. Is it $HOCl$, OCl^-, H_2OCl^+, Cl^+, or $Cl\cdot$, which is the active species or some combination of these? The pH of the reaction plays a major role in the type and degree of reaction since many of the reactions are acid catalysed while the haloform reaction is base catalysed.

b) Laboratory Chlorination of Effluents and Cooling Waters

Many studies have been carried out in which secondary sewage treatment plant effluents have been chlorinated in the laboratory and the products examined. Although such experiments could be expected to represent 'real life' chlorination, the conditions chosen by many of the authors are far in excess of those used in secondary treatment.

Glaze and Peyton (1978) reported that chlorination of wastewater results in a decrease of the mean molecular weight of the organic constituents of about one-half. They also found a similar reduction during raw-water chlorination (analogous to cooling water). The chlorination condition used in these experiments was 740 mgL^{-1} residual of chlorine and a contact time of two weeks at 5°C. It is, therefore, unlikely that sewage treatment plant conditions would produce anything like the 50% reduction reported here, although super-chlorination has been suggested for specific applications, such as the oxidative stabilization of wastewater and sludge by-products (Puriface Inc. 1969).

Both Glaze et al. (1973, 1975 and 1976) and Jolley et al. (1973, 1975, 1976^a and 1976^b) have reported the formation of chlorinated organic compounds resulting from the disinfection of sewage effluents. While initial studies tended to identify chlorinated products in terms of the number of gaschromatographic peaks obtained, more recent studies have identified the peaks either by matching GC retention times or by confirmation with mass spectrometry. Glaze and Henderson (1975) obtained well in excess of 100 gas chromatogram peaks when they chlorinated a secondary effluent from Denton, Texas, with 1,500 mgL^{-1} chlorine. Many of the peaks they predicted were mixtures of two or more compounds and 36 of these peaks were not present before chlorination. These compounds range from chloroform to substituted aromatics. However, it is evident that not all of the chlorinated aromatics are derived from "activated" aromatics as predicted by Morris (1976). Glaze and Henderson (1973) cite the chloroderivatives of benzene, toluene and benzyl alcohol as examples of "inactivated" aromatic moieties. Although these products resulted from the super-chlorination of effluents, some of them were the same as those generated by chlorination with 10 mgL^{-1} chlorine. Jolley (1975, et al. 1976^a) also identified numerous specific chlorinated products during chlorination of effluents from the Oak Ridge Municipal Sewage Treatment Plant.

Sievers et al. (1978) have reported on the generation of volatile organic compounds by treatment of secondary sewage effluent with chlorine but note that there is often a marked difference between plant and laboratory chlorination. In some cases plant chlorination resulted in increased levels of aromatic hydrocarbons, i.e. toluene, o-, mand p-xylenes and styrene, whereas laboratory chlorination resulted in chlorotoluene and chloroxylene species.

The above discussion illustrates that laboratory chlorination of sewage effluents and cooling waters (especially super-chlorination) results in a multitude of halogenated compounds, many of which do not appear to be found at appreciable concentrations under actual treatment plant chlorination conditions. The next section will deal only with those compounds that have been identified in plant disinfected effluents or cooling waters.

c) Plant Chlorination of Effluents and Cooling Waters

Studies of the chlorinated organic component of effluents and cooling water which have undergone disinfection with chlorine under normal plant operating conditions are, unfortunately, far fewer than those involving laboratory chlorination (Jolley). Laboratory super-chlorination leads to much higher concentrations of halogen-containing species which, in turn, make detailed analysis more feasible. Obviously, some of the investigations discussed in the previous section in which the chlorination conditions were realistic (Jolley 1975) should be representative of real plant situations.

The presence of low volatility chloro-organics in cooling towers and once-through systems has been reported by Jolley et al. (1978). Three cooling water systems were evaluated: the cooling tower at Oak Ridge Gaseous Diffusion Plant (ORGDP), the cooling tower of the High Flux Isotope Reactor (HFIR) at Oak Ridge and the once-through cooling system at the Kingston (Tennessee) Steam Generating Plant (KSGP). Both the ORGDP and the HFIR units operate under closed-cycle conditions with make-up water contributing only about 3% of the total flow.

The KSGP uses 100,000 to 125,000 gpm cooling water through each of its nine condensers. The water is chlorinated 30 minutes daily with 0.2 ppm free chlorine residual (0.5 ppm total residual). The condensers are chlorinated sequentially so that the discharged chlorinated coolant is diluted with unchlorinated water within the discharge canal. The concentration of haloforms in the discharge channel was 5 ppm as opposed to 1 ppm in the feed water. The authors estimated the annual production of chloroform at about one ton. They then extrapolated the results on a national basis and estimated a total production of 100-200 tons per year in the United States from all electric power stations.

Garrison et al. (1976) carried out a detailed analysis of many of the organic components in domestic wastewaters. The only reported effect of chlorination (in terms of generation of chloro-organics) was the formation of chlorocyclohexane, 1,1,1,2-tetrachloromethane, pentachloroethane, hexachloroethane and five other unidentified compounds. No indication of the concentrations involved were included in the report and indeed the identification of some of the components was not confirmed.

The processing of textile wastes in a municipal sewage treatment plant was studied by Tincher (1978). Textile processing facilities use and discharge a wide range of organic and inorganic compounds which come in contact with chlorine or chlorine-containing compounds either during waste treatment or in textile processing operations. Reported experiments suggest that chlorination of some species can occur, but the only significant increase between influent and effluent was for the 2-monochloroisomer of biphenyl. The other isomers either did not change or decreased within the chlorination unit. Concentrations for the 2-monochloro isomer were 2.8 $\mu g L^{-1}$ for the influent and 17.2 $\mu g L^{-1}$ for the effluent.

Discussion and Conclusions

Conservative estimates, based on laboratory chlorination studies, indicate that sewage treatment plants on the Great Lakes are responsible for an annual discharge of approximately 100 tonnes of chlorinated organic compounds (approx. 16.5 and 83.5 tonnes from Canadian and American cities, respectively). Similar estimates for power plant cooling waters yield a total discharge of 38.5 tonnes annually. (Approx. 3.5 tonnes from Canadian power plants and 35 tonnes from American plants.) Hence, the total discharge from both cooling waters and sewage treatment plants amounts to about 135 tonnes annually.

Industrial contributions of chloro-organics to the Great Lakes have been crudely estimated as 600-12,000 tonnes annually[1] (500-10,000 tonnes/yr from Canadian sources and 100-2,000 from American sources). The major fraction of these compounds arises from wood pulp processing in the paper industry. Hence, the contribution of chloro-organics from sewage treatment plants and cooling waters appear to be insignificant in relation to the large industrial discharges.

Very little is known concerning environmental and public health significance of chloro-organics in lakes and rivers, although it is well established that hydrophobic chlorinated compounds tend to biomagnify along the food chain. It is also not known for sure whether the compounds remain in solution or are adsorbed onto sediments, although one would expect much of the material to readily adsorb onto sediments or suspended particulates. Reliable analytical data are needed on the discharge and ultimate fate of chloro-organics, together with an assessment of the toxicological effects to both aquatic and terrestrial organisms. There is substantial evidence to indicate that most of the halomethanes and other chloro-organics found in treated drinking water are formed by the chlorination of humic matter during actual drinking water treatment and that they do not enter the plant from industrial or municipal waste discharges (Morris, 1975).

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[1] Based on estimates of total consumption of chlorine and 1% to 20% conversion to chloro-organics of medium molecular weight. The 1% to 20% conversion is for the pulp and paper industry, the exact value depending on the bleaching process employed and the efficiency of the operation.

5

PROTECTING SURFACE WATERS FOR RECREATION, WATER SUPPLIES AND FISH LIFE

The Issues

As noted in Table 1 of Chapter 2, there are about nine different consequences that can result from the achievement of the residual chlorine objective. To the extent that achievement of the objective will entail changes in sewage effluent disinfection and cooling water biofouling control practices, three interrelated consequences or effects are most pertinent:

1. the protection of public health from bacterial contamination in
   (a) raw water supplies and
   (b) surface water used for swimming and other recreational purposes;
2. the protection of aquatic life, especially from chlorine toxicity and
3. the financial costs of disinfecting effluents or controlling biofouling in power and industrial cooling water.

It is well established that coliform (total and fecal) bacteria in wastewater and in surface waters are indicators of the possible presence of pathogens. Based on this relationship, the reduction in coliform levels implies a reduction in the numbers of pathogens as well. Most importantly, a reduction in coliform levels is assumed to imply a reduction in the probability of human contact with pathogenic organisms.

The disinfection of sewage treatment plant effluent is considered to be the primary method of controlling the numbers of indicator organisms and their associated pathogens in effluents and in receiving waters. Chlorination is presently the most commonly used method for both sewage effluent disinfection and biofouling control in utility and industrial cooling water facilities. Although treatment of water supplies is the primary method of eliminating pathogens from drinking water, many authorities view sewage disinfection as desirable added protection for municipal water supplies.

There appears to be a three-way tradeoff involved in achieving the chlorine objective - the elimination or reduction in chlorination would reduce the potential for chlorine toxicity effects in fish and aquatic life and would result in financial savings to municipalities who operate sewage treatment plants. However, there is substantial concern that health risks, especially to those engaged in swimming and other contact recreation activities, would be increased. On the other hand, the technical alternatives to chlorination for disinfection appear to be very costly to sewage treatment plant operators. The magnitude of these tradeoffs and the extent to which they are unavoidable are examined in this report.

Both disinfection practices and the coliform bacteria objectives that are established by the various jurisdictions throughout the Great Lakes Basin are predicated on the protection of human health. Nevertheless, these practices and objectives vary from one jurisdiction to another around the Great Lakes region. These practices are, therefore, summarized in the following section.

Current Microbiological Objectives, Disinfection Practices and Policies

In the United States, individual states have different microbiological guidelines and standards, although many follow those found in Quality Criteria for Water (U.S. Environmental Protection Agency, 1976). For public water supplies, "it is recommended that the geometric means of fecal coliform and total coliform densities in raw surface water sources not exceed 2,000/100 mL and 20,000/100 mL, respectively" (p. 42). For contact recreational waters, "based on a minimum of not less than five samples taken over not more than a 30-day period, the fecal coliform content of primary contact recreational waters shall not exceed a log mean of 200/100 mL, nor shall more than 10 percent of total samples during any 30-day period exceed 400/100 mL" (p. 53).

Current microbiological objectives for Ontario are found in Water Management Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment (Ontario Ministry of the Environment, 1978). According to this document, "a potential health hazard exists if the fecal coliform geometric mean density for a series (at least ten samples per month) of water samples exceeds 100 per 100 mL". Furthermore, "... water is considered impaired when the total coliform geometric mean density for a series of water samples exceeds 1000 per 100 mL" (p. 43).

Wastewater disinfection practices in each jurisdiction are, to a large extent, governed by the relevant bacteria objectives that have been adopted. In the United States, all states bordering the Great Lakes require disinfection of sewage effluents by means of chlorination throughout the year. Chlorination practices in these jurisdictions are generally aimed at maintaining total chlorine residuals of between 0.5 and 2.0 mg/L. Several states (Minnesota, Wisconsin, New York, Illinois, Indiana and Michigan) have considered changing to seasonal disinfection. To date, only Indiana has implemented seasonal chlorination requiring that sewage treatment plants meet fecal coliform limits of 200/100mL, May to October and 1,000/100 mL from November to April.

The current Water Quality Criteria for coliform bacteria in the receiving waters of the states bordering the Great Lakes are summarized in Table 8 according to use and coliform type. The minimum level of treatment prior to disinfection is secondary, as prescribed by federal law. Control and enforcement of the coliform standards is left up to the individual jurisdictional localities, and this is one reason for the varied coliform criteria as presented in Table 8.

Implications of Achieving the Microbiological Criteria

The total coliform bacterial densities of typical, well-treated nondisinfected secondary effluents usually fall in the range of approximately 5×10^5 to 5×10^6 organisms/100 mL. The fecal coliform densities typically average 10 to 20 percent of the total coliforms. Thus, to achieve

TABLE 8

STATE AND PROVINCIAL MICROBIOLOGICAL CRITERIA ACCORDING TO USE AND COLIFORM TYPE (FC = FECAL, TC = TOTAL)

Coliform Numbers/100 mL

STATE & PROVINCE	RAW WATER SUPPLY FOR HIGH QUALITY DRINKING H_2O		RAW WATER SUPPLY FOR REGULAR QUALITY DRINKING H_2O[a]		PRIMARY CONTACT RECREATION		SECONDARY CONTACT RECREATION		GREAT LAKES WATERS	
	TC	FC	TC	FC	TC	FC	TC	FC	TC	FC
Minnesota	-	-	-	10[b]	-	200[b]	-	200[b]	-	-
Wisconsin	-	-	-	200[b]	-	200[b]	-	200[b]	-	200[b]
Illinois	-	-	-	200[b] (400)	-	200[b] (400)	-	1,000[b] (2,000)	-	20[b]
Indiana	-	-	5,000[b]	-	-	200[b] (400)	-	1,000[b] (2,000)	-	200[b,c] (400)
Michigan	-	-	-	1,000[b]	-	100[b]	-	1,000[b]	-	-
Ohio	-	-	-	-	-	1,000[d] (2,000)	-	5,000[b]	-	-
Pennsylvania	-	-	-	-	-	200	-	-	-	-
New York[e]	- 50[f] (240)	-	5,000[f] (20,000)	200[b]	2,400[f] (5,000)	200[b]	10,000[b]	2,000[b]	1,000[b]	200[b]
Ontario[g]	-	-	-	-	1,000	100	-	-	-	-

[a] Some states in process of revising - Pa., Ind., Ill. has passed; N.Y., Ohio pending.

[b] Monthly Geometric Mean.

[c] Shore waters. For open waters, 20 FC/100 mL ( ) = maximum value in not more than 20% of the samples; minimum 5 samples.

- = no criteria specified.

[d] Bathing = 20 FC/100 (400 FC/100 max.).

[e] Criteria for Primary and Secondary Contact Recreation is to be met during all periods when disinfection is practised. Time period is not specified.

[f] Monthly Median.

[g] "Water which meets the water quality criteria for aquatic life and recreation, will be suitable for most other beneficial uses, such as drinking water and agriculture." (Ontario Ministry of the Environment, Water Management, 1978, p. 4).

the highest coliform limitation noted in Table 8, i.e. State of New York, secondary contact recreation, 10,000 total coliforms and 2,000 fecal coliforms/100 mL would require only about 1.7 to 2.0 $\log_{10}$ reduction. This can easily be achieved with a minimal amount of chlorine. To meet the lowest coliform limitation, i.e. State of Minnesota, raw drinking water supplies, 10 fecal coliforms/100 mL would require at least 4 $\log_{10}$ reduction. This would necessitate substantially more chlorine and longer contact times. Achieving the 200 fecal coliform criterion (approximately 3 $\log_{10}$ reduction) would typically require some intermediate dose level, thus an intermediate disinfection cost. It is difficult to indicate actual chlorine dose levels required in each instance because of the extremely variable wastewater quality among treatment plants. Conservative ranges can be estimated if it is assumed that the effluent quality is high, i.e. biochemical oxygen demand and total suspended solids each less than 15 mg/L and the chlorine contact time is a minimum of 30 minutes at peak flow. The chlorine dose for <2 log coliform reduction would likely be 1 to 3 mg/L; for 3 log reduction, 3 to 8 mg/L; for ≥ 4 log reduction, 8 to 12 mg/L.

The Province of Ontario, which borders all of the Great Lakes except Lake Michigan, requires that all sewage treatment facilities (other than lagoons) chlorinate their effluents for a 30-minute average contact period and to a minimum of 0.5 mg/L total residual in all cases where there is a downstream use potential for a water supply source or for contact recreation. Where it can be shown that there are no downstream recreational or withdrawal water uses and where dilution is deemed adequate, no disinfection is required by Ontario authorities between November 15 and May 15. No disinfection at all is required for sewage lagoons unless the effluent is used for spray irrigation near human or domestic animal habitations. Present Ontario disinfection guidelines are under review following adoption of Provincial Water Quality Objectives which stipulate that, as a goal, all surface water be entirely fit for aquatic life and for recreational use, except within the mixing zone.

The most recent United States-Canada Great Lakes Water Quality Agreement (International Joint Commission, 1978) specifies only that waters used for body contact recreation should be substantially free from bacteria and other microorganisms that may produce diseases. No numerical objectives for bacteria are specified in the Agreement nor is wastewater disinfection specifically required. This is an important change from the previous Agreement which included numerical bacterial objectives.

Interpretation of the "substantially free" objective is being reviewed by the Microbiology Work Group of the Aquatic Ecosystem Objectives Committee (AEOC) of the Science Advisory Board. Their draft recommendations suggest a "non-degredation" objective for midlake.

It must be stressed that the final decisions about bacterial objectives and disinfection practices lie with the various federal, state, provincial and, in some instances, local jurisdictions.

Uncertainties About the Need for Disinfection

Progress toward the residual chlorine objective may be achieved in four basic ways:

(a) by more efficient and effective use of chlorine as a disinfectant;

(b) by the chemical destruction of residual chlorine;

(c) by the installation of disinfection technologies that do not involve chlorine and

(d) by the reduction or elimination of disinfection altogether.

As noted, there appears to be a three-way tradeoff in choosing one or more of these methods of achieving the objective: financial costs of disinfection _versus_ the protection of human health _versus_ the damage to aquatic life.

The first three options can be implemented to achieve desired disinfection levels, i.e. protection of human health so that only the financial costs of disinfection and the damages to aquatic life will vary. The adoption of seasonal disinfection is both logical and practical where the sewage effluents discharge into recreational waters. There is obviously no health threat from swimming or contact recreational activities during the winter months. However, where receiving waters constitute a source of water supply, local authorities may view the year-round disinfection of sewage as desirable extra protection against disease transmission even though the water is treated prior to distribution. There also appears to be scope for chlorinating sewage treatment plant effluent more efficiently without reducing the degree of disinfection. Finally, improvements in the efficiency of sewage treatment will result in lower chlorine demands during disinfection.

Dechlorination and the use of chlorine-free disinfection processes will likely involve added financial costs to the relevant authorities. However, the actual magnitude of these costs must be determined empirically in order to ascertain whether they are commensurate with the reduction in damages to aquatic life due to chlorine toxicity.

The last option, reduction or elimination of any disinfection, could change the risk to public health. There are, however, several reasons why the elimination of sewage effluent disinfection altogether can be seriously considered in certain instances.

The degree of wastewater treatment is also relevant to the need for disinfection. The poorer the effluent quality, the more difficult and expensive it is to disinfect. In addition, high levels of BOD_5 and suspended solids in the effluents will promote regrowth of microorganisms in receiving waters. Therefore, as adjudged on a site-by-site basis, resources should be devoted to improving and upgrading municipal wastewater treatment facilities before embarking on new and refined wastewater disinfection practices.

A variety of pathogenic microorganisms is found in the feces of actively infected cases or carriers and, hence, in wastewaters containing the fecal wastes from such individuals. Transmission of pathogenic microorganisms to man is possible if a sufficient number of such organisms is present in a given receiving stream or body of water designated for primary contact recreation. However, the relationship of discharging secondary wastewater effluent with disease transmission via the receiving stream used for recreational purposes has been the subject of considerable debate in recent years. Prominent among the antithetical views is a report to Congress by the Comptroller General of the United States (1977) criticizing the practice of wastewater disinfection, specifically chlorination. The following report summary succinctly expresses the concern and conclusions of the Comptroller General:

> "Chlorine is frequently used to disinfect domestic sewage, and it is also used in industry and is discharged in various industrial wastes. Chlorinated discharges have been shown to be harmful to the aquatic environment, but they are still largely uncontrolled. In many situations the use of chlorine is not needed. Except in areas of shellfish-harvesting or of unrestricted irrigation, disinfection of treated wastes usually is not needed to protect
>
> -- swimmable waters in cold weather months,
> -- waters rarely used for swimming, or
> -- drinking water.
>
> When sewage disinfection is needed, present sewage chlorination practices generally result in excessive amounts of chlorine being discharged into waterways. More should be done to limit residuals and to promote the efficient use of chlorine in sewage disinfection (p. 7)."

At the First International Symposium on Ozone for Water and Wastewater Treatment, Lue-Hing, Lynam and Zenz (1977) presented a paper entitled "Wastewater Disinfection: The Case Against Chlorination." The paper discussed a specific case where continued chlorination was, in the authors' opinion, not a justifiable practice. The case was the 1200 MGD West-Southwest (WSW) plant of the Metropolitan Sanitary District of Greater Chicago. The plant had been continuously chlorinating its secondary effluent since July, 1972. The effluent discharged into the man-made canal system which directs wastewater effluents away from Lake Michigan and into the Illinois River system.

The following arguments were put forth by the authors to support their views: (1) the District's waterways were never intended for primary contact recreational activities, and indeed, no such activities take place; (2) total chlorine residual is toxic to aquatic life and its presence has precluded the existence of fish and other aquatic life in the waterways; (3) concern was expressed over the carcinogenic compounds produced by reaction of chlorine with precursors in water and wastewater; (4) evidence was cited (Sproul, 1969; Shuval et al., 1967) which indicated little inactivation of viruses by chloramines, the major form of chlorine in secondary effluents containing ammoniumnitrogen; (5) when the coliform levels in the main waterways in the year 1966, when no chlorination was practised, were compared with the same waterways in 1974 after effluent chlorination was instituted, the coliform levels near the final discharge point of the District waterway system were not significantly different when the major plants were chlorinating compared to when they were not; and (6) the costs of chlorination for the WSW plant in 1975 were shown to be approximately $3,210 per day and total District costs were about $6,000 per day. The authors concluded from the evidence presented that chlorination of the WSW effluent and other major effluents of the District waterway system did not justify the cost:

> "There is no measurable benefit from such chlorination; and indeed, the possible harm to the environment and to citizens is significant. No harm will result with the discontinuance of chlorination and the taxpayers will be saved an expenditure approaching 1.2 million dollars per year for the WSW plant alone."

Henderson (1968) evaluated the coliform index adopted by the Federal Water Pollution Control Administration. The index had as its basis protection of users from enteric diseases in natural recreational waters of the 50 states. After considering the evidence, Henderson concluded: (1) the numerical fecal coliform criteria for primary contact water and general recreational use adopted by the FWPCA are considered inappropriate; (2) the standards are excessively low in their ceilings from the standpoint of realistic public health risk of contracting enteric disease, based on the negative United States and British epidemiological experience and (3) no index organism test based on fecal discharges should be used as a self-supporting standard without supportive, quantitative epidemiological findings.

In a review of the British experience, Barrows (1977) pointed out that, despite extensive work over several years investigating the possibility of a causal relationship between poliomyelitis and bathing in wastewater polluted seawater, a working party of the Public Health Laboratory Service, formulated in 1953, was unable to find any significant association. The only evidence of health hazards from sea bathing were four cases of paratyphoid fever all associated with beaches grossly polluted with fecal matter (Working Party of the Public Health Laboratory Service, 1959). Moore (1954, 1970 and 1971) reviewed the international literature on health hazards from bathing and concluded that the risk of contracting serious disease is minimal. In his study of poliomyelitis among children residing near the seashore in England and Wales, Moore (1959) was unable to produce data suggestive of an increased incidence of illness associated with swimming in "polluted" marine waters as defined by the coliform densities reported.

Until recently the most well-known epidemiological study supporting the need to establish microbial discharge standards to protect public health at bathing beaches in the vicinity of a sewage outfall was the Stevenson investigation (Stevenson, 1953). In his fresh water studies, one comparing two beaches on Lake Michigan and the other comparing a swimming pool to a beach on the Ohio River, he reported two instances suggesting health effects associated with swimming in waters having a coliform density of approximately 2,000/100 mL. In another comparison of illness rates at two bathing beaches in Westchester, New York, Stevenson was unable to find a significant correlation between illness and coliform density.

Cabelli et al. (1975) rejected the approaches taken by Stevenson (1953) and Moore (1959) in designing their prospective epidemiological-microbiological study. The pitfalls in Moore's approach, as enunciated by Cabelli et al. (1975) are given as follows: (1) Moore presupposed (1959), possibly with justification at the time, which diseases are or are not significant in establishing criteria; (2) a protracted interval of time elapsed between the bathing experience and the inquiries made concerning its nature and circumstances and (3) because of the extreme day-to-day variability in pollution due to hydrographic and meterological factors, i.e. tide, rainfall, wind, etc., bathing experiences could not be accurately associated with the quality of the water. Cabelli et al. (1975) rigorously defined swimmers as those who actually immersed their heads in the water; non-swimmer controls were those who went to the beach but merely sunbathed or waded. Stevenson's non-bathing controls were individuals who did not go to the beach. Thus, in the latter case, beach-going but not swimming-associated illnesses could be erroneously included in calculating the illness rates of swimmers and non-swimmers. In Stevenson's (1975) study the use of "calendars" to record illness made it necessary to limit the study to seashore residents. This maximized the probability of multiple exposures. Cabelli et al. (1975) limited their study periods to Saturdays and Sundays only, testing individuals who had a single (one-day) swimming experience. Finally, Cabelli et al. (1975) included demographic considerations in their study, in addition to age and sex.

The Cabelli et al. study (1976) was limited to two salt-water bathing beaches in New York. One beach was "relatively unpolluted" and the other was "barely acceptable" from a microbiological standpoint. A consistent finding from the study was that gastrointestinal symptoms (vomiting, diarrhea, nausea or stomach ache) were significantly higher for swimmers than non-swimmers at the "barely acceptable" beach, but not at the "relatively unpolluted" beach. When the mean indicator densities at each beach for the 1973 and 1974 data were plotted against the corresponding differential (swimmers minus non-swimmers) gastrointestinal symptom rates, four points were obtained for each indicator. High correlation coefficients (0.95) were obtained for Escherichia coli and fecal streptococci, indicating a significant correlation between gastrointestinal disease symptomatology and indicator density. Preliminary findings (Cabelli, unpublished) from multi-year epidemiological studies being conducted at marine beaches in the vicinity of Alexandria, Egypt and a brackish water beach on Lake Pontchartrain in New Orleans resemble and appear to confirm Cabelli's previous findings.

Other recent reports have positively attributed outbreaks of serious diseases to exposure to natural recreational waters. In Dubuque, Iowa an outbreak of shigellosis occurred among swimmers bathing in fecally polluted Mississippi River water (Rosenberg, 1976). This was strong evidence that gastrointestinal disease transmission can occur by swimming in such waters, although the source(s) of the Shigella and indicator organisms in the water could not be unequivocally established. Other reported diseases include typhoid (Center for Disease Control, 1972), infectious hepatitis (Bryan et al., 1974), amebic meningoencephalitis (Wellings et al., 1977), external otitis (Hoadley and Knight, 1975), coxsackievirus B infection (Hawley et al., 1973), skin granuloma caused by Mycobacterium marinum (balnei) (Evan-Paz et al., 1976) and gastrointeritis in Macomb County, Michigan (Center for Disease Control, 1979). Other examples are cited by Pipes (1978).

In a recent report prepared by the National Research Council of the National Academy of Sciences (1979) it was concluded that:

> "Despite the potential error of the coliform criterion having been based on the presumed coincidence of Salmonella, the criterion remains a reasonable predictor for gastroenteric illness and, possibly, infections from non-coliform agents.

In its review of the present techniques for monitoring the microbiological quality of recreational water, the committee further concluded that

> ". . . bacterial monitoring of recreational waters, when used, has served to hold disease transmission to reasonable levels, thereby providing valid justification for continuing use of a bacterial criterion for recreational waters and for further extensive efforts to improve procedures. The fecal coliform test is acceptable for protecting the public health until additional epidemiologic data, improved laboratory procedures, and a better understanding of aquatic microbial ecology are attained. It provides a useful interim criterion that is superior to the other suggested microbiological indicators, and its use certainly is better than abandoning microbiological criteria altogether."

The foregoing discussion points out the fact that evidence supporting the need to control the discharge of pathogenic microorganisms to receiving waters is controversial. In view of the fact that a strong case can be built for either point of view, depending on the individual circumstances, it is the Task Force's opinion that the seasonal disinfection option and, even in some cases, a no disinfection option could be viable candidate strategies worthy of consideration. The final public health decisions pertaining to the discharge of a particular wastewater effluent and the degree of protection judged to be pertinent to the users of the receiving stream must be made by the specific local jurisdictions. Consequently, the seasonal and no disinfection options will be addressed in this report.

Protection of Aquatic Life

Laboratory and field studies have documented the adverse effects of residual chlorine on aquatic life at selected locations. Data or studies on the magnitude of these effects around the Great Lakes, however, are not available for various reasons as noted in Chapter 3. Indeed, it is not clear how many Great Lakes sewage treatment or power plant discharges are considered to be even potential problems. Although the adverse impacts on aquatic life have been documented for some areas, it is possible that chlorine is not an important problem in the Great Lakes because:

a. existing data show fish can tolerate short-term exposures to fairly high concentrations of chlorine without apparent adverse effects;

b. although the existing data have been contradictory, some species of fish have been shown to avoid chlorine in both laboratory and field studies and

c. there are sometimes stressful levels of contaminants other than chlorine in sewage treatment plant effluents. These contaminants may be more detrimental than chlorine depending on the concentrations and durations of exposure to both chlorine and the other toxicants.

Implications for Disinfection Strategies to be Assessed

The following microbiological guidelines are summarized from the current policies of the relevant Great Lakes jurisdictions:

OBJECTIVE	PURPOSE AND/OR JURISDICTION
1. One fecal coliform per 100 mL objective	- Non-degradation objective.
2. 10 fecal coliforms per 100 mL 100 total coliforms per 100 mL	- IJC Microbiology Work Group Draft Recommendation for Recreational Waters.
3. 200/400 fecal coliforms per 100 mL	- U.S. States' Objective for Recreational Waters.
4. 2,000 fecal coliforms per 100 mL	- U.S. and Canadian Objectives for Water.
5. 20,000 total coliforms per 100 mL	- U.S. and Canadian Objectives for Water Supply intakes.

These objectives would theoretically apply at the edge of a mixing zone, but for the purposes of this study, it will be assumed that these objectives are to be met at the end-of-pipe. This Task Force does not recommend any specific bacterial objectives, but will identify the implications for achieving each microbiological objective level in terms of the type and degree of sewage treatment required. These treatment requirements will be used in the evaluation of the alternative methods of moving toward or achieving the chlorine objective. The assumption of meeting objectives at the end-of-pipe will indicate the maximum consequences that can be expected when alternatives are implemented.

The elimination of disinfection year-round appears to be a viable option under certain circumstances, e.g. where effluents have BOD and TSS concentrations of 15 mg/L or better, where the outfall is submerged and distant from shore and where the effluent does not directly impinge on drinking water supplies or contact recreation areas.

The achievement of at least 2,000 fecal coliforms/100 mL and 20,000 total coliforms/100 mL could be reliably achieved in most primary and secondary plants with chlorination or other disinfection methods.

Reduction of total coliforms to less than 200/100 mL would require that effluents receive at least secondary treatment, i.e. activated sludge and aeration. The achievement of less than 100 total coliforms per 100 mL would require a very efficient degree of advanced secondary treatment and the bacterial density would vary considerably with effluent quality despite chlorination. A density of less than one fecal coliform per 100 mL cannot be achieved by disinfection methods without tertiary filtration and treatment.

6

MIXING AND LIMITED USE ZONES

Definitions

The initial conception of a mixing zone was engineering oriented. It is that area or volume of dilution water necessary to reduce contaminant concentrations to some target level or to a totally mixed condition and defined in terms of plume shape, size and depth. This concept of a mixing zone did not incorporate any consideration of the biological effect of that discharge.

A more recent interpretation of the term mixing zone is by regulatory agencies responsible for the development and enforcement of water quality standards in receiving waters. In the parlance of regulatory agencies, a mixing zone is that area or volume of water in which water quality standards could be exceeded. In most instances, a physical mixing zone and a regulatory mixing zone differed significantly in size.

The concept of a "limited use zone" was introduced into the Great Lakes Water Quality Agreement (International Joint Commission, 1978). Limited use zones are areas in the vicinity of present and future municipal, industrial and tributary point source discharges within which some specific objectives may not apply and are not protective of certain uses. It is that area or volume where an effluent and ambient water mix. Limited use zones represent the maximum area where less than objective quality would be allowed. Harbours and certain bays may be encompassed by a limited use zone.

As referred to in the Agreement, the limited use zone is virtually synonymous with the mixing zone. Limited use zones and mixing zones are currently under review, but for this present study the terms refer to that zone around a point source discharge within which ambient water quality objectives for receiving waters do not apply.

The Determination of Mixing and Limited Use Zones

There are a number of factors that make the designation of mixing or limited use zones difficult. The sequential addition of loadings over time sometimes makes it necessary to redesignate the mixing zone to permit new discharges. It is also important to distinguish between conservative, bio-accumulative and bio- or chemo-degradable contaminants. Some substances may be so toxic as to preclude the allowance of a mixing zone.

One of the earlier attempts to incorporate environmental considerations into the development of mixing zones was based on zones of passage. This was devised to ensure that contaminants would not block the migration or the drifting of aquatic species. In these passageways, concentrations of waste materials should meet the requirements for the receiving water. Generally, mixing should be accomplished as quickly as possible through devices such as diffusers.

Current Policies

Mixing zones are not clearly defined in state statutory and administrative policies. Fifteen states had no statement whatsoever about these zones. Twelve others had vague statements applicable only to cooling waters or sewage treatment plant effluents. Very general statements were used by 19 states and most of these used mixing zones to justify not monitoring effluents close to the point of discharge. Only four states had specific numerical limitations and these only applied to zones of passage.

The United States Environmental Protection Agency has noted that "limited use zones" provide an excuse for dilution or pollution which is contrary to United States laws. In Ontario the concept of a mixing zone or limited use zone is accepted, but is applied on a case-by-case basis subject to the various constraints and guidelines as set out in the 1978 Agreement (International Joint Commission, 1978).

Implications Concerning Mixing Zones

Mixing or limited use zones are relevant to this study because different sizes or areas of mixing zones:

a) imply different costs to achieve them and

b) imply a willingness to accept specific levels of environmental damage in receiving waters.

However, different sizes of mixing zones will not be explicity considered in the evaluation of disinfection options in this study for the following reasons:

a) the concepts of mixing and limited use zones are currently under review and may be substantially revised;

b) there is no clear, objective criterion for determining the size of a mixing zone and

c) regulatory agencies currently determine sizes and characteristics of mixing zones on a case-by-case basis. In this study, the options will be evaluated on an aggregate basis.

As noted earlier all evaluations will be made on the basis of meeting objectives at the end-of-pipe. The expected consequences will represent the maximum possible. To estimate consequences of different strategies, the Task Force assumed that there were no mixing zones because there are no preferred criteria for the establishment of mixing zones. Consequently, jurisdictions can make their own assessment of mixing zone size. Allowance for mixing zones will then mitigate or otherwise alter these consequences, i.e. possibly result in lower financial costs for achieving the objective or in an increase in the risk and damages to aquatic life.

7

ACHIEVING THE OBJECTIVE BY INDUSTRY AND POWER PLANTS

Chlorine Residuals from Industrial Sources

Other than the chlor-alkali plants already noted, there are relatively few major industrial sources of free available chlorine residual. There are many large industrial users of chlorine who discharge chlorine residuals along with liquid wastes into the Great Lakes, their tributaries and their interconnecting channels. However, residual chlorine is either not discharged, not considered a problem or the effects are masked by other more noxious and problematic components.

Because residual chlorine is usually not the most serious contaminant from industrial dischargers, it is often not monitored, consequently data on residual chlorine from industrial sources are rather sparse. Industrial sources for which residual chlorine is measured are listed in Table 9. It is important to remember that each source discharges other contaminants. Those sources whose chlorine loadings exceed "requirements" would certainly warrant further investigation. However, those data corroborate our conclusion that industrial sources are not an important source of residual chlorine.

Chlorine Residuals from Power Plants

Intermittent chlorination is necessary in many power plants to maintain condenser tube cleanliness for proper heat transfer in the condensers but not for any health reasons. The Canadian and United States power plants that discharge cooling water into the Great Lakes are listed individually in Appendix 1 and displayed in Figure 3. Data on residual chlorine loadings are not available for all power plants.

Many of the power companies included in Appendix 1 report that they are reducing their chlorine usage by optimizing chlorine dosages. At present power plants operating in Ontario are restricted to total chlorine residual discharges of less than 0.5 mg/L.

In plants where anti-biofouling practices are employed, the following measures can be implemented to reduce or eliminate total chlorine residuals:

1. undertake studies to determine the minimum amounts of chlorine required to achieve biofouling control (Schumacker and Lingle, 1979);
2. automated mechanical cleaning without chlorination or supplemented by chlorination;
3. dechlorination of discharges from condensers by chemical feed;

TABLE 9

KNOWN INDUSTRIAL DISCHARGERS OF CHLORINE TO THE GREAT LAKES

SOURCE FACILITY	LOCATION	FLOW (1,000 m^3/d)	CHLORINE LOAD (Kg/d)	REQUIREMENT (Kg/d)	DIRECT	IN-DIRECT
American Maize	Indiana Hammond	58.82	-	-	X	
Hooker Chemicals & Plastics	Michigan Montague	35.43	24.36	7.09	X	
E. I. Dupont de Nemours Co.	Montague	27.91	1.45	1.23	X	
Abitibi Corp.	Alpena	15.90	1.52	3.80	X	
Renaissance Center Manage Co.	Detroit	90.46	48.63	-	X	
Uniroyal Tire Co.	Detroit	44.59	-	22.32	X	
BASF Wyandotte Corp.	Wyandotte	205.11	16.30	88.23	X	
BASF Wyandotte Corp.	Wyandotte	147.46	168.30	73.75	X	
Parke Davis & Co.	Detroit	45.99	3.95	20.28	X	
Ford SSECO	Dearborn	1,936.40	466.30	698.54		X
Chrysler	Ann Arbor	0.36	0.16	0.25		X
Ford Motor Co. SSECO	Dearborn	34.67	10.71	34.67		X
C-B Foods	New York Rochester	0.58	0.5 mg/L	0.85 mg/L	X	
IMC Chem (Chlor-Alkali PLT)	Ohio Ashtabula	10.06	Unknown	1.00	X	
Union Carbide Corp. (Metals Div.)	Ashtabula	147.54	3.27	-	X	

SOURCE: International Joint Commission - (July 1979), Inventory of Major Municipal and Industrial Point Source Dischargers in Great Lakes Basin.

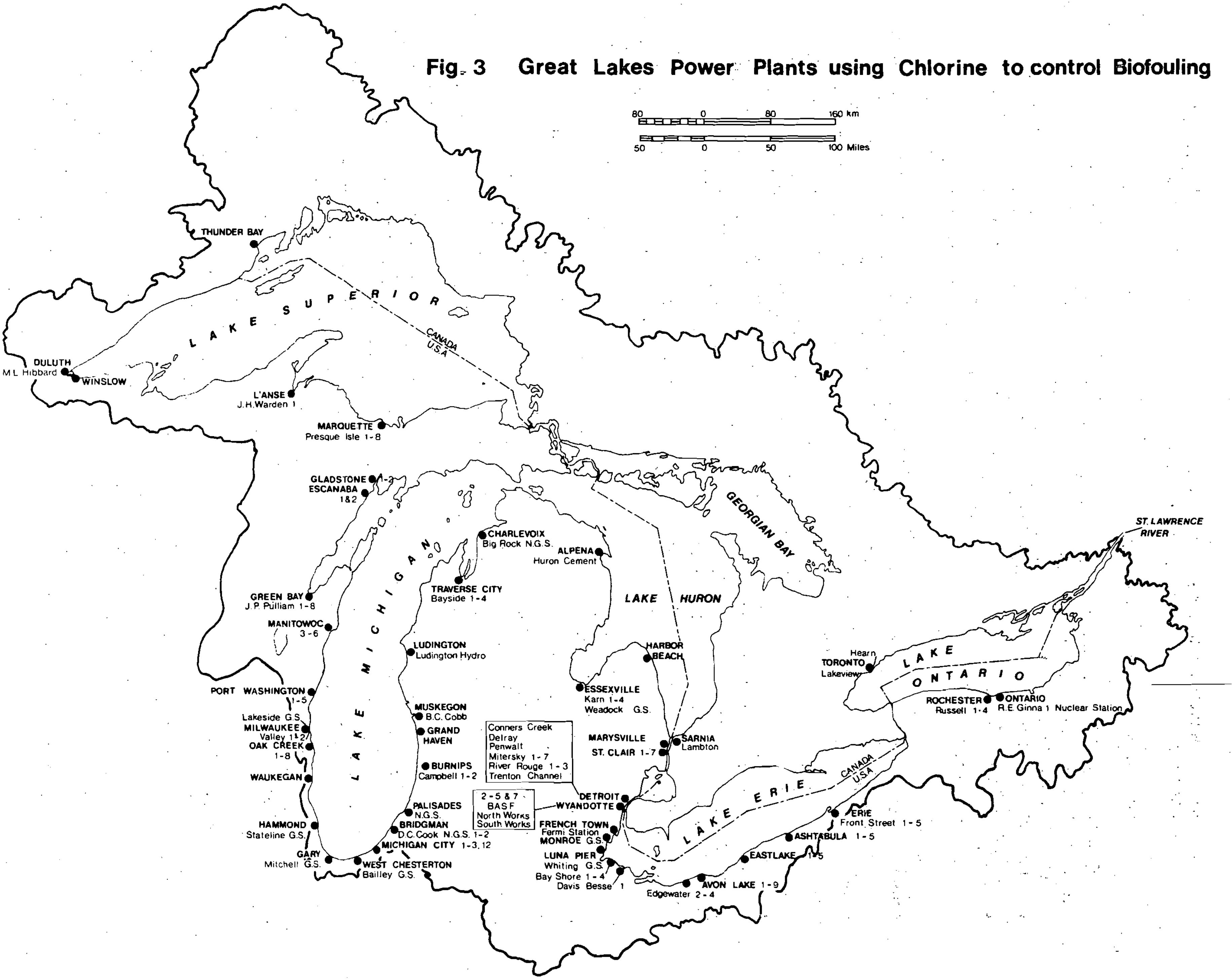

Fig. 3 Great Lakes Power Plants using Chlorine to control Biofouling

4. use of water from other condensers to both dilute and react with waste chlorine discharged from the condenser under chlorination and

5. new chemical "chlorine aids".

Electric utility companies and various agencies are investigating the above mentioned alternatives to current biofouling control practices or are following such research. However, the utilities claim that the alternatives are not yet technically proven on a large scale or that retrofitting onto existing plants would raise biofouling control costs substantially greater than chlorination. The most significant cost appears to be the production penalty that could occur if the plant had to be shut down for manual cleaning.

These claims notwithstanding, dechlorination systems for power plants appear to be technically and economically feasible on the basis of experience and recent literature. The data in Table 2 of Appendix 1 show that eight Great Lakes facilities in the United States dechlorinate regularly. Beals, et al. (1979) provide an informative review of dechlorination practices by power utilities. They note that reducing (dechlorinating) agents such as sulphur dioxide, sodium sulfite and sodium bisulfite can be added to water systems by using standard commercially available equipment. No new equipment or systems need be developed for the successful application of the reducing agents to condenser cooling water discharges. These authors further assert that "sulfur dioxide systems are usually composed of equipment components essentially identical to those used for chlorine, except for (a smaller) size". Smaller sized equipment can be used because it is the chlorine residual, not the dose, that must be destroyed.

According to Beals et al. (1979), equipment costs for dechlorination systems range from $60,000 to $150,000, about the same as the chlorination system, depending on plant capacity, unit arrangements and cooling water system features. Chemical costs for once through system dechlorination run about $0.165/d/mg/L total residual chlorine for each 1,000 U.S. GPM of cooling water flow which is chlorinated for one hour per day.

Because power generating facilities vary so much and because no biofouling control alternative is preferred at this time, it was not possible for the Task Force to estimate the financial costs of expressly meeting the chlorine objective. Although the proposed chlorine objective is not intended for intermittent chlorine discharges from power plants, there is scope for minimizing the application of chlorine. Hence, the reduction in chlorine residual loadings in a number of power plants. Where problems and damages to aquatic life warrant, dechlorination appears to be a feasible means of reducing hazards to aquatic life until other mechanisms for biofouling control that do not use chlorine are developed.

8

CHLORINE INCIDENTS

Even though chlorine is widely used in home and public swimming pools as well as by water and wastewater treatment plants, relatively small quantities of chlorine gas in air can be extremely toxic. A concentration of 1,000 mg/L in air can be fatal after only a few breaths. Any accidental, uncontrolled release of chlorine gas must be treated as an emergency. Risk of accidental release of chlorine during its transportation, handling, application and storage is a source of social and economic concern.

Chlorine is transported by means of small cylinders, ton containers, tank trucks, rail cars, barges and pipelines. Bulk chlorine shipments follow a general pattern as follows: rail, 68-70%; water, 7-8%; highway, 1-2% and pipeline about 20%. It is roughly estimated that about one-half million tons are annually shipped in cylinders and ton containers (almost exclusively from packagers). Much of this chlorine is used in water and sewage disinfection (Laubusch, 1979).

The number of chlorine-related incidents during 1973 and 1974, their locations and types of containers are summarized in Table 10. The data show that about 60% of all incidents occur at the consumer's facility, while only about 10% occur at the producer or packager's facility. Approximately 25% of all incidents occur in transit of which about 80% are rail. A little over 60% of all incidents involve shipping containers as opposed to stationary equipment. Despite the number of accidents, their significance in terms of human injury, death and property damages appears to be low.

Table 11 shows those Reported Chlorine Incidents occurring in the Great Lakes Basin during the three-year period 1972-74. Incidents pertaining to swimming pools or hypochlorite and bleach were not included. Of the 62 incidents listed in the Great Lakes Basin, 36% occurred in industry, 21% in transit, 8% at sewage treatment plants, 8% at water treatment facilities, 5% at paper companies, 3% at power plants and 19% were defined as other.

The "disinfectant" users (STPs, water treatment and power plants) together account for 19% of all incidents. It is not known how many of the transit incidents were related to STPs or power plants. The disinfectant users do not account for large amounts of chlorine used, but there seems to be a disproportionate number of related incidents because these users require more handling of the chemical.

On November 10, 1979 a train carrying propane and chlorine was derailed in Mississauga, Ontario. The resulting explosion, fires and rupture of a single railway tank car of chlorine prompted the evacuation of over 250,000 people for one week. This was the largest evacuation ever to take place in North

TABLE 10

SUMMARY OF REPORTED CHLORINE INCIDENTS[1]

CLASSIFICATION	1973		1974	
CLASSIFIED BY LOCATION				
At Facility				
Producer	9		11	
Packager	11		2	
Consumer	89		105	
Other	1	110	12	130
Transit				
Highway	8		2	
Rail	26		37	
Water	1		4	
		35		43
Unknown		1		1
Total		146		174
CLASSIFIED BY CONTAINER				
Shipping Containers				
Cylinder	31		41	
Ton Containers	15		8	
Tank Cars	43		54	
Cargo Tank	1		-	
Barge	1		3	
		91		106
Stationary Equipment		36		41
Unknown		19		27
Total		146		174

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[1] Adapted from The Chlorine Institute, Inc. (1979) (N.B. - Data are not exclusively for the Great Lakes).

TABLE 11

REPORTED CHLORINE INCIDENTS[1]
GREAT LAKES BASIN
(1972-1974)

LOCATION	DATE	FACILITY				TRANSIT			CONTAINER				OTHER	LEAK	REMARKS
		Producer	Packager	Consumer	Other	Highway	Rail	Water	Cylinder	Ton Ctr.	Tank Car	Barge			
Midland, Mi.	1/29/72													Yes	Chlor Cells
Homewood, Il.	2/ 7/72			X						X				Yes	Village
Grand Rapids, Mi.	6/ ?/72			X									Pipeline	Yes	Factory
Mount Clemens, Mi.	7/11/72			X									Str. Tk.	Yes	STP
Chagrin Falls, Oh.	7/22/72			X					X					Yes	Water Dept.
Cleveland, Oh.	7/25/72			X							X			Yes	Filter Plant
Norwalk, Oh.	9/14/72			X									Str. Tk.	Yes	Water Plant
Muskegon, Mi.	11/ 5/72			X(	?)								?	Yes	Chemical Co.
E. Chicago, In.	11/24/72			X									Pipeline	Yes	Sec. Smelting Plant
Bay City, Mi.	1/18/73			X						X				Yes	STP
Ashtabula, Oh.	1/18/73	X											Pipe	Yes	Detrex
N. Tonawanda, N.Y.	2/13/73			X									Valve Gasket	Yes	Paper Mill
Green Island, N.Y.*	2/ 1/73			X									Pipeline	Yes	Paper Mill
Ashtabula, Oh.	2/23/73			X										Yes	Zinc Plant (Chem. React.)
Tonawanda, N.Y.	4/26/73			X							X			Yes	
Cleveland, Oh.	5/13/73														$SiCl_4$
Sauget, Il.*	5/22/73	X											Compress	Yes	Monsanto
Cleveland, Oh.	6/15/73										X			Yes	
Lake Odessa, Mi.	6/28/73						X				X			No	Derailment
Chicago, Il.	6/28/73					X				X				No	
Clay, N.Y.*	6/29/73						X			X				Yes	Water Works
Berwyn, Il.	6/ ?/73			X						X			Pipeline	Yes	
London, Ont.	6/19/73 6/22/73			X					X					Yes	
Sudbury, Ont.	7/ 5/73			X										Yes	Iron Ore Plant -Lab
Lemont, Il.	7/31/73		X											Yes	
Fort Wayne, In.	7/21/73						X				X			No	Derailment
Midland, Mi.	8/ 3/73	X											Scrubber	Yes	Dow
Green Bay, Wi.	8/ 9/73			X							X			No	Power Plant
Sarnia, Ont.	8/16/73	X											Valve	Yes	Dow
Lemont, Il.	8/ 8/73		X								X			Yes	Dome Gasket Leak
Sarnia, Ont.	8/20/73													Yes	Dow
Flint, Mi.	10/ 7/73			X						X				Yes	STP
Niagara Falls, N.Y.	11/15/73	X											Line	Yes	Hooker Chemical
Rochester, N.Y.	11/30/73						X				X			No	

Table 11 - cont'd.

LOCATION	DATE	FACILITY				TRANSIT			CONTAINER				OTHER	LEAK	REMARKS
		Producer	Packager	Consumer	Other	Highway	Rail	Water	Cylinder	Ton Ctr.	Tank Car	Barge			
(Cont'd.)															
Niagara Falls, N.Y.	11/25/73	X												Yes	Hooker Chemical
R.deBeaudette, Ont.*	11/24/73			X		X				X				Yes	
Midland, Mi.	12/20/73									X				Yes	Dow Corning
Ashtabula, Oh.	1/18/74	X									X			Yes	Detrex Chem.
Cuyahoga Hts., Oh.	1/26/74													Yes	Burning Plastic
Detroit, Mi.	2/12/74						X				X			No	Derailment
Belleview, Oh.	3/15/74			X							X			No	Derailment
E. Syracuse, N.Y.	4/ 4/74						X				X			No	Derailment
Toronto, Oh.*	4/27/74				X				X					Yes	Distributor
Wheatfield, N.Y.	4/27/74			X					X					Yes	Cylinder as Septic tank
Chicago, Il.	4/30/74						X				X			Yes	Derailment
Erie, Pa.	4/29/74			X							X			Yes	Paper Co.
Racine, Wi.	5/11/74			X						X				Yes	STP
Chicago Hts., Il.	5/21/74			X									Pipeline	Yes	Al. Co.
Sarnia, Ont.	5/15/74 5/16/74						X				X				RR yard
Toledo, Oh.	5/15/74			X							X			No	Mfg. Co.
Marysville, Mi.	6/18/74			X						X				Yes	Power Plant
Clinton, Ont.	6/21/74			X					X					Yes	P.U.C.
Enola, Pa.*	7/ 7/74						X				X			Yes	RR yard
Syracuse, N.Y.	7/16/74			X					X					Yes	Prest-o-Lite Corp.
Niagara Falls, N.Y.	7/ 6/74				X									Yes	Sewer
Solvay, N.Y.	8/ 1/74	X											Pipeline	Yes	Allied Chemical
N. Tonawanda, N.Y.	11/21/74														Thionyl chloride break in
Wyandotte, Mi.	11/ 2/74	X												Yes	Press Lines
Lake Odessa, Mi.	11/14/74						X				X			No	Derailment
Grand Rapids, Mi.	11/ 5/74		X										Pipeline	Yes	Mfg. Co.
Miles, Oh.*	12/ 7/74		X								X			No	Derailment
Plankton, Oh.*	12/13/74						X				X			No	Derailment

* Location not determined, therefore, may be outside of Great Lakes Basin.

[1] The Chlorine Institute, Inc. (1979).

America and while there were no deaths or injuries attributable to the chlorine, the costs of the evacuation, inconvenience and interruptions that the threat of this chemical caused will doubtless run into the millions of dollars.

It is difficult to quantify the actual accidents and risk attributable to chlorine that is used for disinfection, but the potential for accidents and significant damage to persons and property will continue to exist wherever chlorine is transported, stored and used in large amounts. However, reducing or eliminating sewage treatment plant effluent chlorination would not likely reduce the frequency of transportation accidents because of the relatively small chlorine usage for purposes of disinfection.

9

ALTERNATIVE WASTEWATER DISINFECTION PRACTICES

Introduction

Municipal sewage treatment plants constitute the major source of residual chlorine in the aquatic environment along with power plant cooling water antifouling practices. In this chapter several different strategies for reducing the levels of residual chlorine in existing sewage treatment plant effluents are identified and are evaluated using criteria derived from Table 1. These strategies range from continuing present practices with minor operational improvements to eliminating sewage disinfection altogether. The strategies identified and evaluated represent specific points along a continuum of alternatives that could be implemented.

The evaluations will primarily be qualitative and will indicate which criteria or consequences are most important or significant, the nature and the direction of the changes that are likely to occur and what operational measures should be used for empirical evaluations. Some quantitative estimates of the consequences of different strategies are presented as well. However, a complete and comprehensive empirical evaluation of even the few strategies identified here is beyond the resources of the Task Force. Nevertheless, the qualitative assessments presented will provide some valuable insights and the procedures outlined in this chapter will enable jurisdictional authorities to undertake their own, more intensive, empirical evaluations of strategies of programs for their own locations.

Alternative disinfection technologies were also studied and evaluated by the Task Force. The conclusions of this technical assessment are presented in this chapter with a more detailed report in Appendix 2.

In addition to these evaluations, the chapter will include some further perspectives on the extent to which the proposed ambient chlorine objective is currently being achieved, the relative importance of sewage treatment plant effluents to total pollution loadings and comments on the implications of implementing these various strategies in present and future treatment plants. Research and information needs will be identified throughout.

Alternative Disinfection Systems

The various new and old technologies for terminal disinfection at sewage treatment plants discharging into the Great Lakes were reviewed in terms of environmental consequences, practicability and cost. A report of this review is presented in Appendix 2 while the results of these evaluations are summarized in Table 12. Only those techniques that appear to achieve disinfection without generating questionable chemical by-products were

TABLE 12

PRACTICABILITY OF ALTERNATIVE DISINFECTION TECHNOLOGIES AND SYSTEMS

TECHNOLOGY/ SYSTEM	EXISTING FULL-SCALE FACILITIES	RELATIVE COMPLEXITY OF TECHNOLOGY	EQUIPMENT RELIABILITY	PROCESS CONTROL	PROCESS DESIGN PROCEDURES	COMMERCIAL AVAILABILITY	
						EQUIPMENT	CHEMICALS
Chlorine/SO_2 Dechlorination	Yes	Moderate	Fair	Well Developed	Well Developed	Yes	Yes
BrCl	No	Moderate	Poor	Problematic	Insufficient experience	No	Yes
Ozone	Yes	Complex	Variable (Poor to Good)	Poor	Underdeveloped	Yes	N/A
ClO_2	No	Moderate	Insufficient experience	Not known	Insufficient experience	Yes	Uncertain
UV	Yes	Simple	Good[1]	Not known	Insufficient experience	Yes	N/A

[1] Based on prototype demonstration facility.

considered for basinwide application. This is not to say that agents such as bromine chloride should not be tested by jurisdictional authorities. Time and resource limitations permitted the Task Force to evaluate only a few technologies in detail.

Although other oxidizing agents can be used, dechlorination is most commonly achieved through the use of sulphur dioxide. For small plants, one day's storage of a chlorinated effluent will substantially reduce the chlorine residuals. Dechlorination with sulphur dioxide may result in the reduction of dissolved oxygen in receiving waters, but in either case chloro-organics will be produced. Dechlorination agents such as sulphur dioxide, however, are toxic to aquatic life and may also exacerbate the delicate pH conditions of some waters.

Only ozone and ultraviolet (UV) light appear to meet the no problematic by-product criterion. To date there is no published evidence as to the degree of toxicity of the by-products. Researchers are, however, endeavouring to find the answers. Ozone technology is relatively well-developed and some large-scale facilities are operational in the United States. While some aspects of ozone technology require improvement, facilities may presently be designed and built with the assurance of achieving satisfactory disinfection of filtered, secondary or higher quality effluent. New or expanded sewage treatment plants should use ozone or ultraviolet provided the effluent will be sufficiently polished to allow disinfection using these methods. Although an increase in disinfection costs would likely result (see Appendix 2), the potential for economies of scale in larger facilities appears to be substantial.

The broad applicability of ozone to the present population of treatment plants was estimated on the basis of the information provided in Table 13. Most of the alternative technologies can be used only on effluents that are of secondary treatment level quality or better. However, not all secondary treatment plants presently have a quality sufficient for these techniques or there may be other reasons why the technology is not applicable.

The application of ultraviolet radiation to sewage disinfection is not as well developed as the application of ozone. Operating experience on fullsized plants is limited to a secondary treatment plant at Northwest Bergen County, N.J., where a secondary (BOD and Solids of less than 10 mL/L) level sewage treatment with a good quality effluent is disinfected with ultraviolet radiation. The lower limits of effluent quality for which effective performance can be expected is not well defined. For these reasons the implications of wide-spread application of ultraviolet radiation to plants in the Basin has not been considered in these evaluations.

For existing sewage treatment plants in the Basin, the alternative technologies to chlorine disinfection that meet the "no by-products" criterion cannot be retrofitted in most plants at the present time with certainty of effectiveness and without upgrading effluent quality. Ozone technology may be applied in new plants or where plants are expanded or upgraded, especially with respect to suspended solids. Furthermore, research and development currently underway on ultraviolet technology may facilitate the application in the near future of these devices in new or upgraded plants.

TABLE 13

MICROBIOLOGICAL, ECOLOGICAL AND CHEMICAL EFFECTS OF ALTERNATIVE DISINFECTION TECHNOLOGIES AND SYSTEMS

TECHNOLOGY/ SYSTEM	MICROBIOLOGICAL OBJECTIVE			INCREMENTAL FISH TOXICITY RELATIVE TO CL_2	HAZARDOUS BY-PRODUCTS	SAFETY PROBLEMS		RELATIVE[2] COST	ADDITIONAL REMARKS
	MIN. LEVEL OF TREATMENT	BACTERI-CIDAL	VIRU-CIDAL			TRANSPOR-TATION	ON-SITE		
Chlorine	Primary	Yes	Poor	Toxic	Yes	Yes	++++	1.0	Good economy of scale
Chlorine/SO_2 Dechlorination	Primary	Yes	Poor	Non-toxic	Yes	Yes	++++	1.1 to 1.3	SO_2 application more difficult at smaller plants
BrCl	Secondary	Yes	Fair	Slight to moderate	Yes	Yes	+++	1.5	
Ozone	Filtered Secondary	Yes	Good	Non-toxic	None demonstrated	No	++	2.0 to 3.0[3]	Good economy of scale. More efficient with oxygen
ClO_2	Secondary	Yes	Good	Toxic	Not expected	Yes[1]	++++	4.0	
UV	Secondary (?)	Yes	Good	Non-toxic	No	No	+	≤1.0[4]	Scale-up is more linear

[1] Due to the chlorine needed for on-site generation.
[2] Plant with 5 x 10^3 m^3/d flow; the ratio will change with size plant.
[3] Ozone generated from air.
[4] Based on results from NW Bergen County, New Jersey.
+ = Minimal Safety Problem.
++ = Slight Safety Problem.
+++ = Moderate Safety Problem.
++++ = Substantial Safety Problem.

Some Perspectives on Sewage Treatment Plant Disinfection

As noted in Chapter 5, the key consequences of changes in chlorination practices appear to be disinfection costs and bacterial loadings which give rise to health risk and damages to aquatic life. In addition, it is necessary to consider the extent to which each strategy will actually achieve or move toward the ambient chlorine objective as well as the degree to which government enforcement activities are required.

The Task Force has attempted to obtain an inventory of those locations on the Great Lakes and interconnecting channels where ambient chlorine levels are not achieved or where chlorine concentrations are considered to cause damages to aquatic life. So far no jurisdiction has completed such a survey. It is not known precisely where treated and chlorinated effluent volumes are such that total residual chlorine concentrations are consistently above the proposed ambient levels in receiving water. Moreover, no jurisdiction has actually required that sewage treatment plants dechlorinate their discharges as a general policy. Two sewage treatment facilities, eight power plants and at least eight industrial facilities in the Great Lakes already dechlorinate their effluents at the behest of their respective environmental agencies.

Consequently, the various jurisdictions should document the actual and potential damages to aquatic life in a more systematic manner in order to make quantitative comparisons with changes in bacterial loadings and disinfection costs resulting from different strategies. One approach would be to review sewage treatment plant effluents and receiving water dilution ratios to determine where the resulting concentrations of chlorine and other contaminants have the potential to exceed objective levels. Problem areas can then be identified after adjustments are made for outflow devices, plume patterns, water-use patterns and contaminant decay rates.

Chlorination is practised primarily to reduce or eliminate pathogenic organisms from sewage effluents which might otherwise cause diseases. These organisms include bacteria, viruses and protozoans. Chlorination is, however, less effective against viruses than it is against bacteria and there are other sources of bacteria and pathogenic contamination in the water body that, in some instances, makes sewage treatment plant disinfection ineffectual in controlling surface water bacterial populations.

Bacterial contamination in surface waters can result from:

- runoff, particularly from intensive livestock rearing or finishing yards and areas where wildlife congregate;
- meat and poultry processing facilities;
- leachate from landfill sites;
- discharges from septic tanks and tile beds;
- raw sewage by-passed up stream of sewage treatment plants;
- storm flows from combined sewers and

- discharges from pulp and paper mills and sawmills.

These sources are summarized in Figure 4.

The volume of discharges from these sources is undoubtedly significant but difficult to quantify basinwide. Studies in Ontario have yielded a data base from which the relative volume of (untreated) stormflows and (treated) sewage discharges may be estimated (Waller and Novak 1979). Figure 5 provides a quantitative overview of the various types of discharges from Ontario communities to the Great Lakes. The combined volume of stormwater discharges and combined sewer overflows is about 40% of that from treated sewage.

Thus, sewage treatment plant disinfection is only a partial barrier to the control of bacterial contamination. Disinfection of sewage effluents may be a waste of money in some areas unless other, more diffuse, sources of bacterial contamination are brought under control. It is, of course, up to the various jurisdictions to identify and to make the appropriate decisions about these situations.

Strategies for Achieving the Chlorine Objective

An almost infinite combination of feasible wastewater disinfection technologies and practices could be implemented at sewage treatment plants throughout the Great Lakes Basin. In addition, there are several things that could be done, unrelated to disinfection, that would also help to achieve the ambient objective. It is impossible, therefore, to evaluate in detail all possible disinfection programs or degrees of implementation. Nevertheless, several classes of alternatives or strategies can be identified and the expected consequences evaluated on the basis of the most relevant criteria derived from Table 1. Although the programs specified below represent extreme assumptions in some cases, they permit the nature and the incidence of the consequences to be defined.

The strategies concerning sewage treatment plant effluents include:

a) CONTINUE CURRENT PRACTICES AND PROCEDURES

These practices include seasonal chlorination in Ontario; year-round chlorination in the United States; no retrofitting of new disinfection technologies; installation of chlorination facilities at new plants; changes in individual plant practices as problems are identified.

b) IMPROVE THE EFFICIENCY OF PRESENT CHLORINE DISINFECTION PRACTICES

Specific changes that would improve the efficiency of chlorine use include more systematic testing of effluents, chlorine minimization studies and the installation of automatic equipment in some locations.

c) SEASONAL DISINFECTION

All Great Lakes sewage treatment plants undertake six-month disinfection unless in close proximity to drinking water intakes.

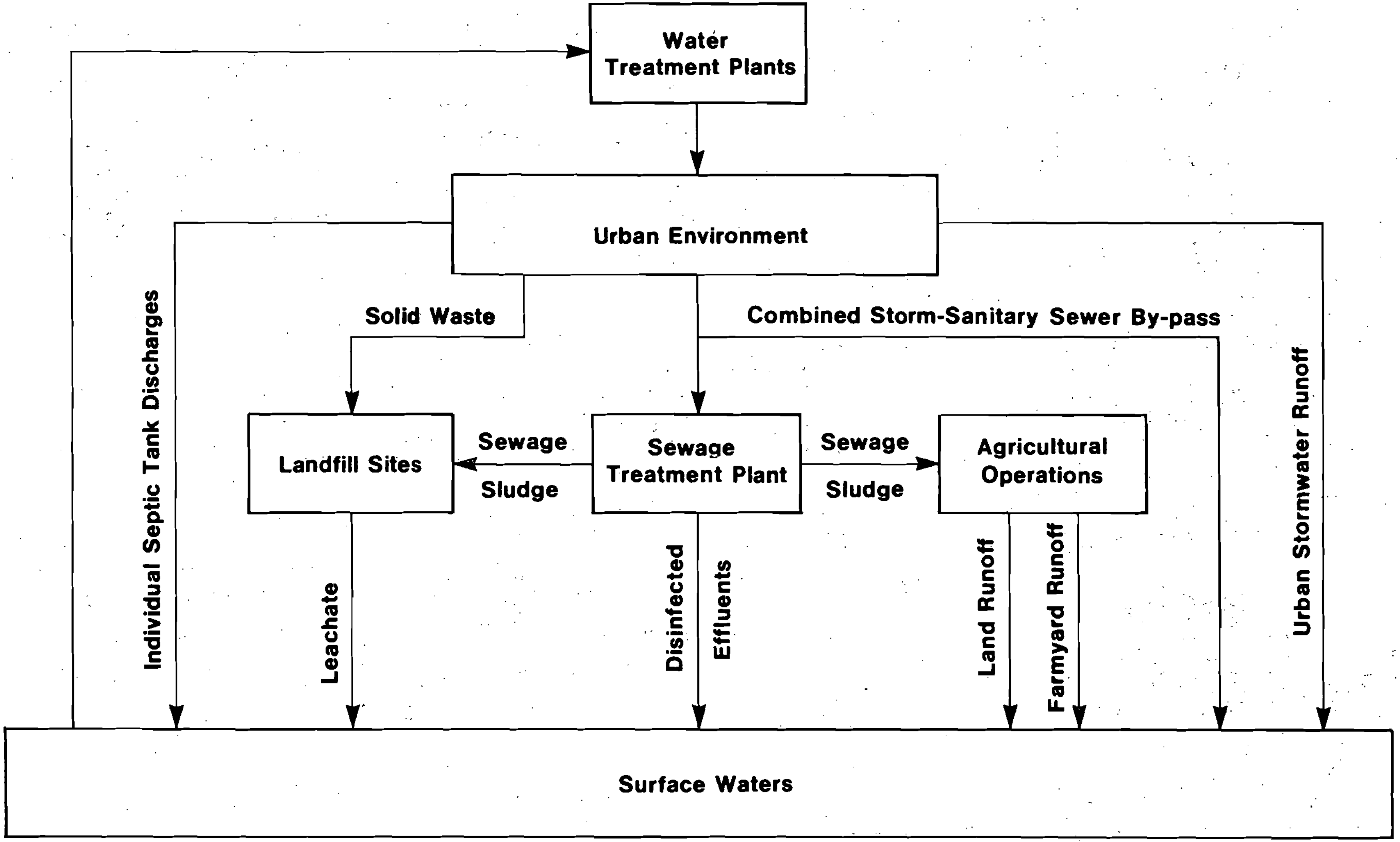
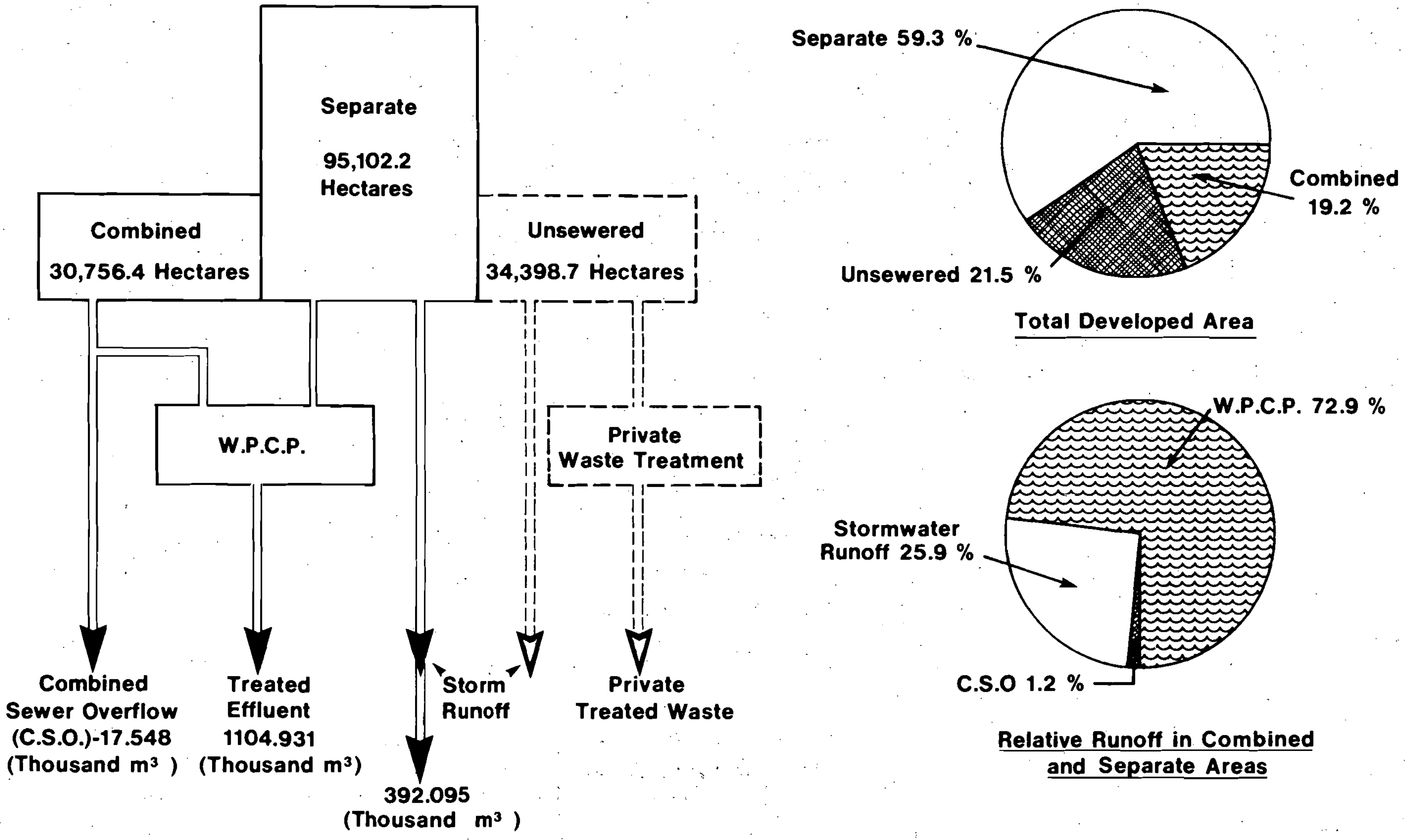


Fig. 4 Sources of Bacterial Contamination to Surface Waters

Fig. 5 Developed Urban Area and Runoff in Ontario



d) ADD DECHLORINATION TO PRESENT CHLORINE DISINFECTION PROCESSES AND PRACTICES

Plants in the United States continue to disinfect 12 months per year. Most plants in Ontario disinfect seasonally. Capital and operating cost estimates are estimated from the assumptions presented in Appendix 4.

e) INSTALL ALTERNATIVE DISINFECTION TECHNOLOGIES

Only estimates of the qualitative consequences of this strategy could be developed (summary in Table 14, detail in Appendix 2).

f) ELIMINATE DISINFECTION ALTOGETHER

This strategy would be considered in the absence of a proximate water supply intake or recreational use.

g) IMPROVE OUTFALL DIFFUSION STRUCTURES WHERE FEASIBLE

The chlorine objective may be achieved through dilution without any in-plant changes. The degree of dilution depends on the initial mixing from the diffuser parts or outlets and water movement. In a lake context with little water movement, effluents must be discharged into depths of 6-10 meters which require rather large offshore distances in shallower lakes. However, even with the use of a multiport diffuser, the maximum dilution anticipated is in the range of 50:1. At this dilution rate, the proposed chlorine objective cannot be achieved without a mixing zone given a typical chlorine discharge residual concentration. However, chlorine concentrations at "end of pipe" will be well below the 24-hour LC_{50} objective specified by the latest Canada - United States Water Quality Agreement.

Diffuser structures would only be relevant to new plants, to plants that are scheduled to be substantially upgraded or expanded and where dilution is required for other contaminants besides chlorine.

Evaluation of Strategies for Achieving the Proposed Chlorine Objective

The strategies mentioned above were evaluated in terms of:

a) Financial Implications for Existing Plants

- Initial capital costs of new equipment and retrofitting and
- Annual cost of chlorine used.

b) Effects on Aquatic Life

Quantitative documentation of specific effects on fish or other aquatic organisms is not available. Evaluation is based on judgements of Task Force members.

c) Public Health Risk

Ideally, it would be necessary to have data on sewage treatment plants whose effluents constitute a public health risk

- to raw water supplies and
- to contact recreational waters.

However, evaluation was based on the judgements of Task Force members as to the perceived change in health risk.

d) Extent of Achieving Chlorine Objective

Ideally, it would be necessary to have data on sewage treatment plants where total residual chlorine is in excess of the proposed objective or is otherwise considered to be a problem in the receiving waters adjacent to the plant. The estimated proportion of the year during which the chlorine objective is achieved is indicated for three of the strategies. Some progress toward the objective is indicated for the remaining three strategies.

e) Government Enforcement Activities

In order to make a quantitative assessment:

- for initial implementation it is necessary to determine the man-years of effort and the provincial, state and local government expenditure.
- for monitoring it is necessary to determine man-years of effort and the provincial, state or federal government expenditure to monitor plant operations, ambient water quality, damages and effluent qualities.

Table 14 summarizes the expected consequences of each strategy in qualitative terms. This evaluation could be undertaken on a more quantitative basis by a state or province for a specific drainage area or population of plants. The Task Force was not able to compile detailed quantitative data on each of these evaluation criteria for the entire Great Lakes Basin. Table 14 is, therefore, an example of the kind of analysis that could be carried out by jurisdictional authorities where data requirements are less formidable.

Nevertheless, Table 14 does indicate that seasonal chlorination is an attractive strategy. Gains in terms of achieving the chlorine objective and reduced potential damages to aquatic life can be achieved with a reduction in the financial costs of disinfection by means of this strategy. Presumably such a policy can be implemented so as to avoid increases in health risks. Seasonal chlorination and efforts to achieve more efficient chlorination could, therefore, be recommended without much additional empirical analysis.

TABLE 14

EVALUATION OF STRATEGIES FOR ACHIEVING Cl_2 OBJECTIVE IN STPs

STRATEGIES	FINANCIAL IMPLICATIONS ON EXISTING PLANTS		EFFECTS ON AQUATIC LIFE	PUBLIC HEALTH RISK		EXTENT OF ACHIEVING Cl_2 OBJ.	GOV'T. ENFORCEMENT ACTIVITIES		REMARKS
	CAP. $	O&M $		WATER SUPPLY	RECREATION		INITIAL IMPLEMENTATION	MONITORING	
1. More efficient Chlorination	▲	▲ ▼	▼	0	0	▲	▲	▲	
2. Seasonal Chlorination	0	▼	▼	0	0	40-60% of year	▲	0	Subject to receiving water uses.
3. Dechlorination	▲	▲	▼	0	0	100%	▲	▲	
4. Alternative Disinfection Technology	▲	▲	▼	0	0	▲	▲	0	Primarily relevant to new or expanded plants.
5. No Disinfection	0	▼	▼	▲	▲	100%	▲	▲	Health risk perceived to be increased.
6. Improve Outfall Structures	▲	0	▼	0	▼	▲	▲	0	Option is very site-specific.

▲ - Increase
▼ - Decrease
0 - No Change

However, the remaining strategies require the development of empirical information before any further decisions or choices can be made. Additional comments on the consequences of each strategy are noted below.

a. Continue Current Practices and Procedures

- There are no data from the jurisdictions or the IJC on the extent to which chlorine is a problem in sewage treatment plant effluent. (Chlorine Objective Task Force 1976).
- According to Appendix 4, Table 11 for Canada and Table 14 for the United States, the following amounts are spent annually on chlorine chemicals for disinfection:

-Ontario Sewage Treatment Plants	$ 481,900 for 6-months chlorination/yr.
-United States Sewage Treatment Plants	3,684,800 for 12-months chlorination/yr.
Total	$4,166,700

- No systematic or aggregate data on the effects on aquatic life.

  (Chlorine Objective Task Force 1976).
- Not chlorinating can have significant impact on operation and maintenance costs at smaller faccilities (U.S. Environmental Protection Agency, 1975).
- Monitoring costs are likely to rise in the future in any event.

b. Improve the Efficiency of Present Chlorine Disinfection Practices

- Chlorine objective may be achieved in an unknown number of locations.
- Capital costs must be incurred to achieve more efficient chlorination - unknown for entire Basin.
- Operation and maintenance costs will decrease because less chlorine is used and increase because more maintenance will be required.
- Presumably reduces effects on aquatic life with no change in public health risks.
- Senior (state and provincial) governments will likely have to induce municipalities (at a cost) to implement and maintain more efficient practices by means of more frequent monitoring.

c. Seasonal Disinfection

- The chlorine objective will be achieved in most locations at least five months per year.

- No capital cost will be incurred.

- Assuming all plants adopt seasonal chlorination, annual chlorination costs at United States plants will be reduced by 5/12 of total expenditure or $1,535,300 per year.

- Effects on aquatic life will be reduced during non-chlorination season.

- No change in public health risk is expected.

- Little senior government effort will be required to implement but, more frequent monitoring is likely to be required.

- Not all treatment plants may be able to implement seasonal disinfection because of receiving water uses.

d. Add Dechlorination to Present Chlorine Disinfection Processes and Practices

- Information on the location of plants with chlorine problems will be useful in determining where dechlorination should be implemented.

- Based on Figures 1 and 2 in Appendix 3:

  - o The approximate capital costs of installing dechlorination:

    in 73 U.S. plants will be $16.0 million;
    in 43 Ontario plants will be 7.8 million.

  - o The annual operation costs of dechlorination:

    in 73 U.S. plants will be $3.8 million for year-round operation and $2.9 million on a seasonal basis;
    in 43 Ontario plants will be $1.5 million per year on a seasonal basis.[1]

- Effects on aquatic life will be reduced by an unknown extent and no change will result in health risks.

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[1] In both countries the costs of dechlorination were estimated only for plants between 5,000 and 1 million m^3/d design capacity or actual flow with the exception of Detroit for which the costs of the 1,000,000 M^3/D plant were multiplied by 3. These U.S. estimates are, therefore, likely to be an overestimate of the actual cost.

- Additional senior level government effort and expenditure will be required to implement and monitor these practices.

e. Install Alternative Disinfection Technologies

- Ozone or ultraviolet should be considered explicitly for installation with new treatment plants, major expansions and upgrading of treatment.

f. Eliminate Disinfection Altogether

- The Chlorine Objective will be achieved.

- No change will occur in capital costs.

- A saving of:
  $ 481,900 per year in Ontario and
  3,684,800 per year in the United States
  by operators of sewage treatment plants, i.e. municipalities.

- The aggregate benefits in terms of reduced damages to aquatic life are not known.

- Public health risks will be perceived to be increased, especially in terms of recreational waters. The degree to which risk is increased should be verified empirically. This is most emphatically a site specific issue (Chlorine Objective Task Force 1976).

- Bacterial monitoring activities at all government levels would have to be increased substantially. The cost of these activities would be borne by state and provincial governments.

g. Improve Outfall Diffusion Structures Where Feasible

- In some locations a diffuser would achieve desired dilution of chlorine and other contaminants without reducing disinfection. The feasibility of installing diffusers would have to be determined on a case-by-case basis.

These findings and implications corroborate some of the conclusions of the first Chlorine Objective Task Force, especially in that there is a general lack of information about actual chlorine toxicity to aquatic life and the loss of habitat and beneficial water uses in the vicinity of sewage outfalls. These effects are attributable to residual chlorine levels (Remedial Programs Subcommittee 1975). This information is needed for policy evaluation and decisions.

The foregoing evaluations lead the Task Force to conclude that more efficient chlorination and seasonal chlorination in United States plants could be implemented immediately with substantial benefit and little or no added cost. Where chlorine is an acute problem in receiving waters, dechlorination can be installed at a relatively modest cost. The elimination of disinfection of wastewaters altogether would likely result in an increase in perceived health risks and would probably meet strong resistance from health authorities. This measure could be implemented on a site-specific basis. Finally, ozone, ultraviolet diffusers and the further elimination of disinfection are more appropriate considerations for new, expanded or upgraded plants.

Implications for Future Sewage Treatment Plants and The Implementation of Strategies

The strategies discussed and evaluated in this chapter were concerned primarily with existing sewage treatment plants. Where new or substantially expanded plants are being planned and designed, there would appear to be greater flexibility and scope for:

a) incorporating non-chlorine disinfection technologies;
b) incorporating a higher level of treatment;
c) incorporating diffusers and
d) significant changes in the institutional organization and management of these plants to achieve greater effectiveness, efficiency and reduced costs.

There may also be some scope for locating and designing effluent outfalls in a manner that maximizes dispersion or removes the effluents from water supply or recreational use areas.

The riparian jurisdictions might be advised to study the technical feasibility of implementing the no-disinfection strategy as well as the nonchlorine disinfection technologies when designing the major new treatment plants.

What can the senior governments do to implement any of these strategies? An understanding of the economic and other incentives facing the parties that must actually bear the consequences of these strategies is essential to the development of effective policy instruments. Implementation incentives are policies or actions that induce or otherwise motivate people or companies to an action. Individuals, firms and municipalities are inclined to act in their own best interests. Lack of action or change usually means that organizations or individuals deem that actions desired by others will yield <u>no</u> net benefit to them. Where compliance costs are high, and the social sanctions of non-compliance are low, these parties will perceive incentives to delay or refuse compliance in order to maintain a better position for themselves. Thus, municipalities and other authorities may not want to change disinfection practices because of the perceived social costs to be incurred, i.e. increased health risks are deemed greater than the financial savings (in chlorine costs) that might result.

All of the public policy instruments that can be used to give individuals or organizations an incentive to do something can be classified either as a "carrot" or a "stick". "Carrots" are policies or actions that enhance the regulated party's position. He may increase profits or reduce costs; he may obtain something he needs such as approval or a licence; he may gain satisfaction or prestige; he may win an election. On the other hand, people will try to avoid the discomforts imposed by punitive "sticks" such as prosecutions, financial penalties or public indignation. A fundamental problem with environmental management under existing institutions is the dearth of "carrots" and the reluctance of governments to wield effective "sticks".

A crucial element of any implementation strategy is the identification and ultimate use of policies and instruments that give the correct economic incentives or signals to municipalities and other regulated parties.

Federal, provincial and state governments in both the United States and Canada have generally opted to implement municipal sewage treatment programs through massive financial subsidies. Only recently have "sticks" been applied in the form of litigation and court orders against municipalities as in the case of Detroit. The incorporation of phosphorus removal practices and processes in sewage treatment plants has met with little opposition because the changes did not add substantially to costs, they were technically simple and they involved no highly contentious effects such as human health risks.

There do not seem to be strong economic or institutional barriers to the implementation of more efficient and seasonal chlorination although such programs may require federal or provincial subsidies to cover capital costs. What is more problematic and requires imaginative and innovative thinking is the development of incentive systems to maintain the efficient operation of sewage treatment plants and processes once they are installed. American and Canadian federal, state and provincial programs to build wastewater treatment facilities have generally concentrated on constructing plants and have tended to neglect operation. Moreover, the management and operation of water treatment and distribution systems and that of sewage treatment systems are usually under separate authorities. This contributes to the technical and economic inefficiencies associated with these facilities.

Decisions about changes in disinfection practices will be made at the state, provincial and sometimes at the local level. It is clear to the Task Force that such detailed, quantitative field and case studies are more appropriately accomplished by the relevant agencies of the member jurisdictions. The results and findings of these studies can then be disseminated by the International Joint Commission. In addition, the IJC and its associated Boards and Committees can provide stimuli and guidance for such work, especially in the area of social and economic assessment. Finally, the agencies and jurisdictions themselves should move toward making such assessments a more routine part of their overall programs.

REFERENCES

Barrows, G. I. "Bacterial Indicators and Standards of Water Quality in Britain," in Bacterial Indicators/ Health Hazards Associated With Water, A. W. Hoadley and B. J. Dutka, eds. Philadelphia, American Society for Testing and Materials, 1977, pp. 289-337.

Beals, J. L., R. J. Baker and P. K. Brandon. "Dechlorination of Condenser Cooling Water Discharges by Chemical Reduction." Paper presented at the Condenser Biofouling Control Symposium, March 26-28, 1979, p. 2.

Bryan, J. A. et al. "An Outbreak of Hepatitis-Associated with Recreational Lakewater." Am. J. Epidemiol., Vol. 99, 1974, pp. 145-154.

Cabelli, V. J. "Evaluation of Recreational Water Quality, the EPA Approach." Presented at the International Symposium on the Discharge of Sewage from Sea Outfalls, Stevenage, England, 1974.

__________ et al. "The Impact of Pollution on Marine Bathing Beaches: An Epidemiological Study", Am. Soc. Limnol. Oceanogr. Spec. Symp., Vol. 2, 1976, pp. 424-432.

__________. "The Development of Criteria for Recreational Waters" in Discharge of Sewage from Sea Outfalls, Oxford, Pergamon Press, 1975.

Carlson, R. M. and R. Caple. "Organo-chemical Implications of Water Chlorination" in Proc. of Conference on Environmental Impact of Water Chlorination, 1975, R. L. Jolley, ed., Oak Ridge, Tennessee, Oak Ridge National Laboratory, 1976, p. 73.

__________ et al. "Facile Incorporation of Chlorine Into Aromatic Systems During Aqueous Chlorination Processes", Env. Sci. and Tech., Vol. 9, 1975, pp. 674-675.

Center for Disease Control. "Typhoid Fever Alabama Morbid." Mortal Weekly Reports, Vol. 21, 1972, p. 280.

__________. "Gastroenteritis Associated with Lake Swimming - Michigan", Morbid. Mortal. Weekly Report, Vol. 28, No. 35, 1979, pp. 413-416.

Chemical and Engineering News, Feb. 26, 1979, p. 11.

The Chlorine Institute, Inc. North American Chlor-Alkali Industry Plants and Production Data Book, Pamphlet 10, 1979.

Chlorine Objective Task Force. Final Report of the Chlorine Objective Task Force. International Joint Commission, Water Quality Board, 1976.

Christman, R. F. et al. "Natural and Model Aquatic Humics: Reactions with Chlorine" in Proc. of Conference Water Chlorination: Environmental Impact and Health Effects, 1977, Vol. 2, R. L. Jolley et al., eds. Ann Arbor, Michigan, Ann Arbor Science, 1976, p. 15.

Committee on Microbiological Standards for Recreational Water. Microbiological Measures of Recreational Water Quality. Washington, D.C., Board on Toxicology and Environmental Health Hazards, National Academy of Sciences, 1979.

Comptroller General of the United States. "Unncessary and Harmful Levels of Domestic Sewage Chlorination Should be Stopped", Report to the Congress Washington, D.C., General Accounting Office, 1977.

De LaMare, P. B. D. and J. H. Ridd. Aromatic Substitution Nitration and Halogenation, New York, Academic Press, 1959.

Dornan, J. Personal communication to the author by J. Dornan of Statistics Canada, Manufacturing and Primary Industries Division, Ottawa, 1979.

Environment Canada. Wastewater Disinfection in Canada. A Background Paper, 1978. (EPS 3-WP-78-4).

Evan-Paz, Z. et al. "Mycobacterium Marinum Skin Infections Mimicking Cutaneous Leishmaniasis", Brit. J. Dermatol., Vol. 94, 1976, pp. 435-442.

Fava, J. A. and C. F. Tsai. "Immediate Behavior Reactions of Blacknose Dace Rhinichthys atratulus to Domestic Sewage and Its Toxic Constituents", Trans. Am. Fish. Soc., Vol. 105, 1976, pp. 430-441.

Gaffney, D. E. "PCB: Another Source", Science, Vol. 183, 1974, p. 367.

Garrison, A. W., J. D. Pope and F. R. Allen. "GC-MS Analaysis of Organic Compounds in Domestic Wastewaters" in Proc. of Conference Identification and Analysis of Organic Pollutants in Water, L. H. Keith, ed. Ann Arbor, Michigan, Ann Arbor Science, 1976, p. 517.

Geldreich, E. E. "Applying Bacteriological Parameters to Recreational Water Quality", J. Am. Water Works. Assn., Vol. 62, No. 2, 1970, pp. 113-120.

Glaze, W. H. and J. E. Henderson. "Formation of Organochlorine Compounds From the Chlorination of Municipal Secondary Effluent", J. Wat. Poll. Contr. Fed., Vol. 47, 1975, p. 2511.

__________ and G. R. Peyton. "Soluble Organic Constituents of Natural Water and Wastewater Before and After Chlorination" in Proc. of Conference on Water Chlorination: Environmental Impact and Health Effects, Vol. 2, R. L. Jolley et al., eds. Ann Arbor, Michigan, Ann Arbor Science, 1978, p. 3.

__________ J. E. Henderson IV and G. Smith. "Analysis of New Chlorinated Organic Compounds in Municipal Wastewaters After Terminal Chlorination" in Proc. of Conference Identification and Analysis of Organic Pollutants in Water, L. H. Keith, ed. Ann Arbor, Michigan, Ann Arbor Science, 1976, pp. 247-254.

__________ *et al.* "Analysis of Organic Materials in Wastewater Effluents After Chlorination", *J. Chromatog. Science*, Vol. 11, 1973, p. 580.

Hawley, H. B. *et al.* "Coxsackievirus B Epidemic at a Boy's Summer Camp", *J. Am. Med. Assn.*, Vol. 226, 1973, pp. 33-36.

Henderson, J. M. "Enteric Disease Criteria for Recreational Waters", *J. Sanit. Eng. Div. Proc. Am. Soc. Civ. Eng.*, Vol. 94, 1968, pp. 1253-1276.

Hoadley, A. W. and D. E. Knight. "External Otitis Among Swimmers and Nonswimmers", *Arch. Environ. Health*, Vol. 30, 1975, pp. 445-448.

International Joint Commission. *Great Lakes Water Quality Agreement of 1978*, Annex 1, p. 6.

__________. *Inventory of Major and Industrial Point Source Dischargers in Great Lakes Basin*, 1979.

Jolley, R. L. Private communication with author by R. L. Jolley, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

__________. *Chlorination Effects on Organic Constituents in Effluents From Domestic Sanitary Sewage Treatment Plants.* Ph.D. Dissertation, Oak Ridge, Tennessee, University of Tennessee, 1973. (ORNL/TM 4290).

__________. "Chlorine Containing Organic Constituents in Chlorinated Effluents", *J. Wat. Poll. Contr. Fed.*, Vol. 47, No. 3, 1975, pp. 601-618.

__________ *et al.* "Chlorination of Organics in Cooling Waters and Process of Effluents" in *Proc. of Conference on Environmental Impact of Water Chlorination, 1975*, Vol. 1. Ann Arbor, Michigan, Ann Arbor Science, 1976, p. 115.

__________ *et al.* "Determination of Chlorination Effects on Organic Constituents in Natural and Process Waters Using High-Pressure Liquid Chromatography" in *Identification and Analysis of Organic Pollutants in Water*, L. H. Keith, ed. Ann Arbor, Michigan, Ann Arbor Science, 1976, p. 233.

__________ *et al.* "An Experimental Assessment of Halogenated Organics in Water from Cooling Towers & Once Through Systems" in *Proc. of Conf. on Water Chlorination: Environmental Impact and Health Effects, 1977*, Vol. 2. Ann Arbor, Michigan, Ann Arbor Science, 1978, p. 695.

Joseph, S. W. *et al.* "*Aeromonas* Primary Wound Infection of a Diver in Polluted Water", *J. Clin. Microbiol.* (In press).

Kobayaski, T. and T. Okuda. "A Continuous Method of Monitoring Water Quality", *Water Res.*, Vol. 6, 1972, p. 197.

Laubusch, E. J. Personal communication with the author by E. J. Laubusch, The Chlorine Institute, Inc., March 6, 1979.

Lee, G. F. and J. C. Morris. "Kinetics of Chlorination of Phenolchlorophenolic Tastes and Odours", *Int. J. Air Wat. Poll.*, Vol. 6, 1962, p. 419.

Lothrop, T. L. and O. J. Sproul. *J. Wat. Poll. Contr. Fed.*, Vol. 41, 1969, p. 67.

Lue-Hing, C., B. T. Lynam and D. R. Zenz. "Wastewater Disinfection: The Case Against Chlorination" in *Forum On Ozone Disinfection*, E. G. Fochtman, R. G. Rice and M. E. Browning, eds. Syracuse, New York, International Ozone Institute, Inc., 1977 pp. 1-31.

Minor, J. D. *The Avoidance Response of White Bass Morne Chrysops to Intermittent Chlorination at the R.L. Hearn Generating Station (Toronto, Ontario)*. Toronto, Ontario Hydro Research Division Report #78-203-K, 1978.

Moore, B. *Bull. of Hygiene*, Vol. 29, 1954, p. 689.

________. "Sewage Contamination of Coastal Bathing Waters in England and Wales, A Bacteriological and Epidemiological Study", *J. Hygiene*, Vol. 57, 1959, pp. 435-472.

________. *Water Pollution Control in Coastal Areas*, London, England, Institute of Water Pollution Control, 1970.

________. *Microbial Aspects of Pollution*, G. Sykes and F. A. Skinner, eds. London, England, Academic Press, 1971, pp. 11-32.

Morris, J. C. "Kinetics of Reactions Between Aqueous Chlorine and Nitrogen Compounds" in *Principles and Application of Water Chemistry*, S. D. Faust and J. V. Hunter, eds. N.Y., John Wiley and Sons, Inc., 1967, pp. 22-53.

__________. *Formation of Halogenated Organics by Chlorination of Water Supplies*, Washington, D.C., U.S. Environmental Protection Agency, 1975. (EPA-600/1-75-002).

__________. "The Chemistry of Aqueous Chlorine in Relation to Water Chlorination" in *Proc. of Conference on Environmental Impact of Water Chlorination, 1975*, Vol. 1, R. L. Jolley, ed. Oak Ridge, Tennessee, Oak Ridge National Laboratory, 1976, p. 27.

Murphy, K. L., R. Zaloum and D. Fulford. "Effect of Chlorination Practice on Soluble Organics", *Wat. Res.*, Vol. 9, 1975, pp. 389-396.

Nelson, K. E. *et al.* "An Outbreak of Leptospirosis in Washington State", *Am. J. Epidemiol.*, Vol. 98, 1973, pp. 336-347.

Oliver, B. G. and J. Lawrence. "Haloforms in Drinking Water: A Study of Precursors and Precursor Removal", *J. Am. Water Works. Assn.* Vol. 71, No. 3, March 1979.

Ontario Ministry of the Environment. *Water Management Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment*, Toronto, 1978, p. 43.

Pierce, R. C. "The Aqueous Chlorination of Organic Compounds Chemical Reactivity and Effects on Environmental Quality", Ottawa, National Research Council of Canada Report # 16450, 1978.

Pipes, W. O., ed. "Water Quality and Health Significance of Bacterial Indicators of Pollution" in Proc. of a National Science Foundation Workshop. Philadelphia, Drexel University, 1978.

Pitt, W. W., R. L. Jolley and C. D. Scott. "Determination of Trace Organics in Municipal Sewage Effluents and Natural Waters By High Resolution Ion-Exchange Chromatography", Envir. Sci. and Tech., Vol. 9, 1975, pp. 1068-1073.

Reinhard, M., V. Drevenkar and W. Giger. "Effects of Aqueous Chlorination on the Aromatic Fraction of Diesel Fuel", J. Chromatog., Vol. 116, 1976, pp. 43-51.

Rockwell, A. L. and R. A. Larson. "Aqueous Chlorination of Some Phenolic Acids", in Proc. of Conference Water Chlorination: Environmental Impact and Health Effects, 1977, R. L. Jolley et al., eds. Ann Arbor, Michigan, Ann Arbor Science, 1978, p. 67.

Rook, J. J. "Formation of Haloforms During Chlorination of Natural Waters", Wat. Treat. Exam., Vol. 23, 1974, p. 234.

________. "Haloforms in Drinking Water", J. Am. Water Works Assn., Vol. 68, 1976, p. 168.

Rosenberg, M. L. et al. "Shigellosis From Swimming", J. Am. Med. Assn., Vol. 236, 1976, pp. 1849-1852.

Schumacher, P. D. and J. W. Lingle. "Chlorine Minimization Studies at the Valley and Oak Creek Power Plants." Paper presented at the Condenser Biofouling Control Symposium, March 26-28, 1979.

Shuval, H. I et al. "The Inactivation of Enteroviruses in Sewage by Chlorination", Adv. in Wat. Poll. Res., S. H. Jenkins and L. Merdia, eds. Washington, D.C., Water Pollution Control Federation, 1967, p. 37.

Sievers, R. E. et al. "Generation of Volatile Organic Compounds from Non-Volatile Precursors in Water by Treatment with Chlorine or Ozone" in Proc. of Conference Water Chlorination: Environmental Impact and Health Effects, 1977, Vol. 2. Ann Arbor, Michigan, Ann Arbor Science, 1978, p. 615.

Smith, J. G., R. B. McCall and P. K. Chan. "Formation of Polychlorinated Aromatic Compounds During Aqueous Chlorination", Environ. Poll., Vol. 14, No. 4, 1977, pp. 289-296.

Sproul, O. "High Level Inactivation of Viruses in Wastewater by Chlorination", J. Wat. Poll. Contr. Fed., Vol. 41, 1969, p. 567.

Statistics Canada. "Sulfuric Acid, Caustic Soda and Chlorine Annual", Service Bulletin, Chemicals, Manufacturing and Primary Industries Division, Vol. 3, No. 9, 1977.

Stevens, A. A. *et al.* "Interim Treatment Guide for the Control of Chloroform and the Trichloromethanes", Appendix 2. Cincinnati, U.S. Environmental Protection Agency.

Stevenson, A. H. "Studies on Bathing Water Quality and Health", *Am. J. Pub. Health*, Vol. 43, 1953, pp. 429-538.

Tincher, W. C. "Chlorination Practices in the Textile Industry" in *Proc. of Conference Water Chlorination: Environmental Impact and Health Effects, 1977*, Vol. 2. Ann Arbor, Michigan, Ann Arbor Science, 1978, p. 775.

Tonelli, F. A. and K. W. A. Ho. *A Position Paper on Disinfection of Sewage Plant Effluents. Part II. Considerations for Optimum Disinfection.* Toronto, Pollution Control Branch, Ontario Ministry of the Environment, 1979.

Tsai, C. F. and J. A. Fava. "Chlorinated Sewage Effluents and Avoidance Reaction of Stream Fish", College Park, Maryland, University of Maryland *Technical Report No. 35*, 1975.

Usenik, P. M. and K. L. Murphy. *The Chlorination of Organic Chemicals. Wastewater Research.* Hamilton, Ontario, McMaster University Group Report #73-1211-2.

U.S. Environmental Protection Agency. *Disinfection of Wastewater Task Force Report.* U.S. Environmental Protection Agency, Office of Research and Development, July 1975.

U.S. Environmental Protection Agency. *Quality Criteria for Water.* U.S. Environmental Protection Agency, 1976, pp. 42-53.

Waller, D. H. and Z. D. Novak. "Municipal Pollutant Loadings to the Great Lakes from an Ontario Community" (In press).

Wellings, F. M. *et al.* "Isolation and Identification of Pathogenic *Naegleria* from Florida Lakes", *Appl. Environ. Microbiol.*, Vol. 34, 1977, pp. 661-667.

Youssefi, S. T., S. T. Zenchelsky and S. D. Faust. "Chlorination of Naturally Occurring Organic Compounds in Water", *J. Env. Sci. and Health*, Vol. 8, 1978, pp. 629-637.

Zaloum, R. and K. L. Murphy. "Reduction of Oxygen Demand of Treated Wastewater by Chlorination", *J. Wat. Poll. Contr. Fed.*, Vol. 46, 1974, pp. 2770-2777.

APPENDIX 1

POWER PLANTS LOCATED ON THE GREAT LAKES

TABLE 1-1

CANADIAN (ONTARIO) POWER PLANTS LOCATED ON THE GREAT LAKES

PLANT	LOCATION	RECEIVING WATER	ANTI-FOULING PRACTICE	AMOUNTS OF CHLORINE		COMMENTS
				USED (kg)	RESIDUALS (kg)	
Thermal Generating Stations						
Thunder Bay	Thunder Bay, Ontario	Lake Superior	Chlorination	49,294 (1977)	N/M	Reduction from 1977 to 1978 due to 1) reduced operation of thermal plant 2) reduced chlorination dosage
Hearn	Toronto Harbour	Lake Ontario	Chlorination	10,389 (1977) 5,200 (1978)	N/M	Reduction due primarily to reduced chlorine dosage
Lakeview	Toronto	Lake Ontario	Chlorination	13,126 (1977) 6,900 (1978)	N/M	Reduction due primarily to reduced chlorine dosage
Lambton	Windsor	St. Clair River	Chlorination	6,320 (1977) 5,788 (1978)	N/M	
Nanticoke		Lake Erie	Not needed	9,226 (1977) 2,419 (1978)	N/M	Service water only is chlorinated. Amertap mechanical cleaning system has been installed here. Not fully tested as yet, but many operational problems encountered
Lennox		Lake Ontario	Not needed	1,074 (1977) 1,900 (1978)	N/M	service water chlorinated
Nuclear Generating Stations						
Douglas Point		Lake Huron	Not needed	-	N/M	
Bruce Heavy Water Plant		Lake Huron	Not needed	2,170 (1976)	N/M	
Bruce A		Lake Huron	Not needed	-	N/M	
Pickering A	Pickering	Lake Erie	Not needed	-	N/M	

N/M = Chlorine residuals apparently not measured.

SOURCE: Ontario Hydro

TABLE 1-2

UNITED STATES POWER PLANTS LOCATED ON THE GREAT LAKES

LAKE SUPERIOR				
SOURCE	MWe FLOW $10^3 m^3/d$	TOTAL CHLORINE RESIDUAL mg/L	DOSAGE FREQUENCY	ANNUAL LOADINGS kg/year
Upper Peninsula Gen. Co. Presque Isle 1-8 Marquette, Michigan	495 MW 1,186	0.2	3/dx180	4,700
Upper Peninsula Power Co. J. H. Warden 1 L'Anse, Michigan	17.7 MW 64.1	0.2	3/dx180	250
Minnesota Power & Light Co. M. L. Hibbard Duluth, Minnesota	123 MW 1,315	0.2	3/dx180	5,200
Erie Mining Co. Taconite Harbor, Minnesota	250 MW 398.8	No Cl_2 High Water Quality	-	-
Superior Water, Light & Power Co. Winslow Station Winslow, Wisconsin	28 MW 54	0.2	3/dx180	210
Reserve Mining Corp. Silver Bay, Minnesota	128 MW 371.9	No Cl_2 High Water Quality	-	-

TABLE 1-2 cont'd.

UNITED STATES POWER PLANTS LOCATED ON THE GREAT LAKES

LAKE MICHIGAN				
SOURCE	MWe FLOW $10^3 m^3/d$	TOTAL CHLORINE RESIDUAL mg/L	DOSAGE FREQUENCY	ANNUAL LOADINGS kg/year
Commonwealth Edison Co. Waukegan Generating Station Waukegan, Illinois	932 MW 3,925	0.2	3/dx270	23,300
Commonwealth Edison Co. Stateline Generating Station Hammond, Indiana	972 MW 4,526	0.2	3/dx364	36,200
Northern Indiana Pub. Service Co. Mitchell Generating Station Gary, Indiana	529 MW 2,826	0.2	3/dx270	16,800
Northern Indiana Pub. Service Co. Michigan City 1-3, 12	679 MW 1,262	0.2 Cooling Tower	3/dx270	7,500
Northern Indiana Pub. Service Co. Bailley Generating Station West Chesterton, Indiana	616 MW 1,676	0.2	3/dx270	10,000
Indiana & Michigan Electric Co. D. C. Cook Nuclear Plant 1 & 2 Bridgeman, Michigan	2,150 MW 8,960	0.1 Diffuser	2/d - 20 min. ea. when necessary-none in 1979	<1,000
Traverse City Light & Power Bayside 1-4 Traverse City, Michigan	33 MW 92.7	0.2	3/dx270	550

TABLE 1-2 cont'd.

UNITED STATES POWER PLANTS LOCATED ON THE GREAT LAKES

LAKE MICHIGAN - (Cont'd.)

SOURCE	MWe FLOW $10^3 m^3/d$	TOTAL CHLORINE RESIDUAL mg/L	DOSAGE FREQUENCY	ANNUAL LOADINGS kg/year
Consumer Power Company Big Rock Nuclear Plant Charlevoix, Michigan	72 MW 394.4	0.2	1/year	0.16
Consumer Power Company Campbell 1-2 Burnips, Michigan	652 MW 1,634	0.2	3/dx364	1,200
Gladstone Light Utility Gladstone 1 & 2 Gladstone, Michigan	6 MW 30.3	0.2	3/dx364	160
Consumer Power Company Palisades Nuclear Plant Palisades Park, Michigan	668 MW 7.3	0.2 Cooling Tower	3/dx364	58
Consumer Power Company* B. C. Cobb Muskegan, Michigan	510 MW 2,209	0.04	3/dx270	2,620
Detroit Edison Company Consumer Power Company Ludington Hydro Ludington, Michigan	1,850 MW 52.8	0.2	3/dx364	420[1]

TABLE 1-2 cont'd.

UNITED STATES POWER PLANTS LOCATED ON THE GREAT LAKES

LAKE MICHIGAN - (Cont'd.)				
SOURCE	MWe FLOW $10^3 m^3/d$	TOTAL CHLORINE RESIDUAL mg/L	DOSAGE FREQUENCY	ANNUAL LOADINGS kg/year
Upper Peninsula Power Co. Escanaba 1 & 2 Escanaba, Michigan	29 MW 132	0.2	3/dx270	780
Grand Haven Grand Haven, Michigan	20 MW 52.84	0.2	3/dx270	310
Manitowac Public Utility Manitowac 3-6 Manitowac, Wisconsin	70 MW 124.3	0.2	3/dx270	740
Wisconsin Electric Power Co. Lakeside Generating Station Milwaukee, Wisconsin	310 MW 2,618	No Cl_2 since 1975	-	-
Wisconsin Electric Power Co. Oak Creek 1-8 Oak Creek, Wisconsin	1,692 MW 6,704	0.14	1/dx270	9,290
Wisconsin Electric Power Co. Port Washington 1-5 Port Washington, Wisconsin	400 MW 2,997	No Cl_2 since 1978	-	-
Wisconsin Electric Power Co.* Valley 1 & 2 Milwaukee, Wisconsin	200 MW 163	0.04	2/dx364	173

TABLE 1-2 cont'd.

UNITED STATES POWER PLANTS LOCATED ON THE GREAT LAKES

LAKE MICHIGAN - (Cont'd.)				
SOURCE	MWe FLOW $10^3 m^3/d$	TOTAL CHLORINE RESIDUAL mg/L	DOSAGE FREQUENCY	ANNUAL LOADINGS kg/year
Wisconsin Power & Light Co. Edgewater 1-4 Sheboygan, Wisconsin	450 MW 1,324	No Cl_2 since Dec. 1972	-	-
Wisconsin Public Service Co. J. P. Pulliam 1-8 Green Bay, Wisconsin	393 MW 2,209	0.2	3/dx364	17,700
Commonwealth Edison Company Zion Nuclear Plant 1 & 2 Zion, Illinois	2,080 MW 8,343	No Cl_2 Amertap	-	-
Wisconsin Public Service Co. Kewaunee Nuclear Station Carlton, Wisconsin	535 MW 2,253	No Cl_2	-	-
Wisconsin Electric Power Co. Point Beach Nuclear Station 1 & 2 Two Rivers, Wisconsin	994 MW 3,824	No Cl_2	-	-

TABLE 1-2 cont'd.

UNITED STATES POWER PLANTS LOCATED ON THE GREAT LAKES

LAKE HURON

SOURCE	MWe FLOW $10^3 m^3/d$	TOTAL CHLORINE RESIDUAL mg/L	DOSAGE FREQUENCY	ANNUAL LOADINGS kg/year
Detroit Edison Company Harbor Beach Station Harbor Beach, Michigan	121 MW 489	0.2 Dechlorination	160 min/dx66	780
Huron Cement Alpena, Michigan	NA 352	0.2	3/dx270	2,100
Consumer Power Company Karn 1-4 Essexville, Michigan	1,787 MW 1,657	0.04 Dechlorination	3/dx364	2,650
Consumer Power Company Weadock Generating Station Essexville, Michigan	615 MW 2,965	0.04 Dechlorination	3/dx364	4,700

TABLE 1-2 cont'd.

UNITED STATES POWER PLANTS LOCATED ON THE GREAT LAKES

ST. CLAIR RIVER				
SOURCE	MWe FLOW $10^3 m^3/d$	TOTAL CHLORINE RESIDUAL mg/L	DOSAGE FREQUENCY	ANNUAL LOADINGS kg/year
Detroit Edison Company Marysville Marysville, Michigan	200 MW 1,439	0.2 Dechlorination	160 min/dx156	1,133
Detroit Edison Company St. Clair 1-7 St. Clair, Michigan	1,620 MW 5,243	0.2	160 min/dx165	9,071

TABLE 1-2 cont'd.

UNITED STATES POWER PLANTS LOCATED ON THE GREAT LAKES

DETROIT RIVER				
SOURCE	MWe FLOW $10^3 m^3/d$	TOTAL CHLORINE RESIDUAL mg/L	DOSAGE FREQUENCY	ANNUAL LOADINGS kg/year
Detroit Edison Company Conners Creek Detroit, Michigan	500 MW 2,951	0.2	160 min/dx261	725
Detroit Edison Company Delray Detroit, Michigan	375 MW 3,267	0.2	160 min/dx248	907
Detroit Edison Company Penwalt Riverview, Michigan	37 MW 76.3	0.2	160 min/dx___	-
Detroit Public Lighting Mitersky 1-7 Detroit, Michigan	199 MW 590	0.2	3/dx364	4,720
Detroit Edison Company River Rouge 1-3 Detroit, Michigan	852 MW 2,461	0.2	160 min/dx226	19,700
Detroit Edison Company Trenton Channel Detroit, Michigan	913 MW 1,952	0.2 Dechlorination	160 min/dx310	3,130
Wyandotte Dept. Municipal Service Wyandotte 2-5 & 7 Wyandotte, Michigan	56.5 MW 257	0.2	3/dx364	2,060

TABLE 1-2 cont'd.

UNITED STATES POWER PLANTS LOCATED ON THE GREAT LAKES

DETROIT RIVER - (Cont'd.)

SOURCE	MWe FLOW $10^3 m^3/d$	TOTAL CHLORINE RESIDUAL mg/L	DOSAGE FREQUENCY	ANNUAL LOADINGS kg/year
BASF Wyandotte No. Works Wyandotte, Michigan	(105)	0.5 Dechlorination	Process Waste	19,100
BASF Wyandotte So. Works Wyandotte, Michigan	(38)	0.5 Dechlorination	Process Waste	6,920

TABLE 1-2 cont'd.

UNITED STATES POWER PLANTS LOCATED ON THE GREAT LAKES

LAKE ERIE				
SOURCE	MWe FLOW $10^3 m^3/d$	TOTAL CHLORINE RESIDUAL mg/L	DOSAGE FREQUENCY	ANNUAL LOADINGS kg/year
Detroit Edison Company Fermi Station French Town, Michigan	158 MW 928	0.2	Permit 160 min/dx___	-
Detroit Edison Company Monroe Generating Station Monroe, Michigan	3,000 MW 7,829	0.2	160 min/dx283	54,431
Consumer Power Company Whiting Generating Station Luna Pier, Michigan	325 MW 1,167	0.04 Dechlorination	3/dx270	1,390
Niagara Mohawk Power Corp. Dunkirk 1-4 Dunkirk, New York	628 MW 2,182	No Cl_2	-	-
Pennsylvania Electric Front Street 1-5 Erie, Pennsylvania	118 MW 538.8	0.5	3/dx364	10,800
Cleveland Elec. Illuminating Co. Ashtabula 1-5 Ashtabula, Ohio	456 MW 626	0.2	summer 5 d/wk winter 2 x/wk	2,617
Cleveland Elec. Illuminating Co. Avon Lake 1-9 Avon Lake, Ohio	1,275 MW 2,494	0.2	summer 2 x/wk winter 1 x/wk	5,283

TABLE 1-2 cont'd.

UNITED STATES POWER PLANTS LOCATED ON THE GREAT LAKES

LAKE ERIE - (Cont'd.)

SOURCE	MWe FLOW $10^3 m^3/d$	TOTAL CHLORINE RESIDUAL mg/L	DOSAGE FREQUENCY	ANNUAL LOADINGS kg/year
Cleveland Elec. Illuminating Co. Eastlake 1-5	1,257 MW 2,494	0.2	summer 2 x/wk winter 1 x/wk	4,596
Cleveland Elec. Illuminating Co. Lake Shore 14-18 Cleveland, Ohio	514 MW 2,143	No Cl_2 since 1977	-	-
Ohio Edison Company Edgewater 2-4	175 MW 796	0.2	1/dx260 at 30 min/dose	860
Toledo Edison Company Bay Shore 1-4	631 MW 2,811	0.8	4/dx364	101,920
Toledo Edison Company Davis Besse I	890 MW 122.3	0.2	3/dx364	200

TABLE 1-2 cont'd.

UNITED STATES POWER PLANTS LOCATED ON THE GREAT LAKES

NIAGARA RIVER				
SOURCE	MWe FLOW $10^3 m^3/d$	TOTAL CHLORINE RESIDUAL mg/L	DOSAGE FREQUENCY	ANNUAL LOADINGS kg/year
Niagara Mohawk Power Corp. C. R. Huntley 63-68 Tonawanda, New York	836 MW 2,916	No Cl_2 since Nov. 1979	-	-

TABLE 1-2 - cont'd.

UNITED STATES POWER PLANTS LOCATED ON THE GREAT LAKES

LAKE ONTARIO				
SOURCE	MWe FLOW $10^3 m^3/d$	TOTAL CHLORINE RESIDUAL mg/L	DOSAGE FREQUENCY	ANNUAL LOADINGS kg/year
Niagara Mohawk Power Corp. Nine Mile Point 1 Nuclear Station Sodus Point, New York (No. 2 under construction)	641.8 MW 1,364	No Cl_2	-	-
Niagara Mohawk Power Corp. Oswego 1-6, Oswego, New York	2,156 MW 4,482	No Cl_2	-	-
Power Authority of New York J. A. Fitzpatrick 1 Nuclear Station	821 MW 2,018	No Cl_2	-	-
Rochester Gas & Elec. Corp. R. E. Ginna 1 Nuclear Station Ontario, New York	490 MW 2,182	≤ 0.5	3/d @ 30 min. 1/wk	3,545
Rochester Gas & Elec. Corp. Russell 1-4 Rochester, New York	253 MW 655	0.3 (Avg.) 0.5 (Max.)	2/d @ 30 min. 1/wk	640

*Indirect Discharger

[1] Hydro - Misc. Cooling Systems only

APPENDIX 2

EVALUATION OF ALTERNATIVE DISINFECTION TECHNOLOGIES

APPENDIX 2

EVALUATION OF ALTERNATIVE DISINFECTION TECHNOLOGIES

Introduction

The known microbiological, ecological and chemical effects of six alternative disinfection technologies are summarized in Table 13 of Chapter 9, page 66. Included in the table is an assessment of the relative transportation and handling risks associated with use of each process as well as an estimation of costs of the alternatives to chlorine. An in-depth discussion of each technology is also given. Most of the judgemental decisions used to construct Table 13 were made on the basis of known information extracted from the literature or from research projects demonstrating recent advances.

The practicability and implementability of the alternative technologies are summarized in Table 12, Chapter 9, page 64. Considerably more work is needed in the areas of process control and process design for virtually all of the alternatives except chlorine. However, it should be recognized that, even with chlorine, poor systems have been and are still being designed which detract from the overall reliability and effectiveness of the chlorination process for microorganism control. Consequently, any conclusions reached on the basis of Tables 12 and 13 of Chapter 9 implicitly assume a well-designed system.

From Table 13, Chapter 9 it is evident that three of the six alternatives explicitly evoke some degree of acute or chronic toxicological effect on aquatic flora and fauna. Thus, some means of neutralizing this toxic effect must be devised before the process can be considered viable. The most cost-effective method of neutralizing toxic residuals, sulphur dioxide reduction, is described more fully in a later section. Implementation of sulphur dioxide neutralization is expected to involve cost increases of 10 to 30% over the disinfection system being used. The most pertinent findings and observations concerning the alternative disinfection technologies are presented below:

CHLORINE

Chlorine is the only alternative that is capable of disinfecting primary effluent with reasonable reliability. However, based on recent information presented at the Progress in Wastewater Disinfection Technology Symposium in Cincinnati (Venosa 1979), chlorination of primary effluent may result in the formation of highly mutagenic fractions or components that would otherwise not be formed (data from one treatment plant). Thus, it is recognized that there may be a low level of risk associated with such practice and this should be taken into consideration when primary effluent is involved.

The weak link in chlorination technology is the residual analyzer. The functional stability and reliability of the residual analyzer decreases considerably as effluent quality deteriorates. Consequently, either excessive chlorine or insufficient chlorine may be dosed a large part of the time, thereby exceeding the objective and endangering fish species in the receiving stream with high chlorine residuals or endangering the public health at nearby bathing beaches because of inadequate disinfection.

There is a large gap between theoretical aspects of chlorine technology and actual practice. Most recent publications profess the necessity of adequate mixing and long contact times for chlorine to be effective, yet chlorination systems are still being designed with unbaffled rectangular or circular contact tanks which suffer from severe short circuiting problems. Often poor dosage control is provided and operators are not properly trained in the routine measurement and maintenance procedures.

The fish toxicity problem is more serious with chlorine than with the alternatives. However, sufficient evidence exists to demonstrate unequivocally that sulphur dioxide dechlorination can completely eliminate chlorine toxicity. Problems of reliability and added complexity, however, do not make it a fail-safe technology.

OZONE

Technologically, ozone is farther along than any of the alternatives from the standpoint of equipment development. It has several attractive features: it is a good virucide; ozonated effluent is not toxic to fish; it has not been demonstrated to result in the formation of toxic by-products and it imparts a high dissolved oxygen level to the treated effluent.

The two major problems with ozone disinfection are the likely requirement for prior suspended solids removal and high capital and operating costs. Equipment reliability is still unproven in North America. Control instrumentation is expensive and subject to close operator attention. Dose control technology is underdeveloped because of the lack of a reliable method of residual measurement. Finally, because of the complexity of the primary and ancillary equipment, considerable operator training is required if cost-effectiveness is desired.

ULTRAVIOLET LIGHT

Ultraviolet is becoming more attractive as time progresses. Many of the design problems that have plagued ultraviolet in the past, i.e. lack of adequate means of cleaning the quartz sleeves, ineffective lamp placement and inadequate dose control appear to be near the resolution stage. The major problems still facing ultraviolet are the lack of a reliable method of measuring dose and the unreliability of ultraviolet intensity sensors.

The advantages are: (1) ultraviolet is a good virucide; (2) ultraviolet, being a physical agent, imparts no toxic residual; (3) ultraviolet has not been shown to affect significantly the non-volatile organic components of wastewater effluents and (4) equipment is very simple and easily maintained. The only major full-scale demonstration of ultraviolet disinfection was made at Northwest Bergen County, New Jersey. The effluent treated was a conventional activated sludge effluent of unusually high quality. Cost estimates made from the project indicate that the process may even be cheaper than chlorine, but work is needed on more typical effluents before that conclusion is made firm.

BROMINE CHLORIDE

Bromine chloride reacts with ammonia-nitrogen in the same way that chlorine does, but the bromamines so formed are more unstable. Consequently, the bromamines are just as effective microbiocidally as free bromine and they have a very short half-life in wastewater effluent. Thus, the induced fish toxicity is reduced because of the dissipation of the bromamine residual. Residual measurement is usually made in the contactor after a five minute time lapse from the point of injection.

Bromine chloride suffers from the same problem as chlorine, its tendency to form halogenated organics. The major problem is in the feed control system, as is stated in a later detailed description of chlorination. Unknown physiological effects of bromides have hampered its widespread acceptability. The cost of the chemical is 50 to 75% higher than chlorine. Considerably more development work is needed before bromine chloride can be considered viable.

CHLORINE DIOXIDE

Chlorine dioxide is the least developed alternative of the ones under consideration. Chlorine dioxide is attractive from the standpoint of its excellent virucidal capability as well as its reduced ability or inability to form halogenated organics. However, the relatively high cost of the sodium chlorite used in the on-site manufacture of chlorine dioxide and the handling risks of these chemicals argue against its practicability at this time.

In general, no new disinfection technology other than chlorine is readily implementable on a wide scale at the present time. However, it is anticipated that ultraviolet and ozone could be considered for new plants or planned expansion of existing plants. The only process that is readily implementable now to achieve reduction in chlorine residual is sulphur dioxide dechlorination.

DESCRIPTION OF ALTERNATIVE TECHNOLOGIES

Chlorination

DESCRIPTION OF PROCESS

Chlorine, either in the form of liquid chlorine or sodium hypochlorite, is normally applied to wastewater effluent by injecting the chemical into a small fraction of the effluent. Then, through the application of a mechanical or hydraulic mixing device, the solution is dispersed through the remainder of the wastewater flow. There are a number of ways proper mixing can be accomplished, each requiring a certain amount of energy expenditure. A detailed discussion of various mixing regimes is beyond the scope of this discussion. Proper mixing is, however, essential to achieve disinfection.

Once the chlorine is properly mixed and homogeneously dispersed through the process water, a minimum amount of contact time must be provided to allow disinfection to occur. Most wastewater effluents contain a sufficient amount of ammonium-nitrogen to convert the chlorine added to mono- and dichloramine, unless the effluent is nitrified. The chloramines are slow-acting disinfectants compared with free available chlorine, i.e. $HOCl/OCl^-$. This is why a long contact time is needed.

The design of the contact chamber is important to assure that the minimum contact time has been provided. Unbaffled rectangular or circular contact tanks are grossly inadequate, as dye tracer studies have revealed wide dispersion limits or severe short circuiting to be characteristic of such tanks. An ideal chlorine contactor design is a long outfall pipe (closed conduit) or open channel as ideal plug flow conditions are more closely approachable. However, most treatment plants are situated close enough to the receiving stream that such a contactor is impractical. The next best design, then, is a rectangular tank, baffled longitudinally to provide a length-to-width (L/W) ratio of 40:1 or more. The latter design should permit reasonably good plug flow conditions with a minimum of short circuiting.

A research project co-sponsored by the U.S. EPA and the State of California is underway to document savings in chlorine usage by improved mixing and contactor design. An optimized chlorination system has been designed, fabricated and mounted on a mobile trailer. This mobile system is being studied in parallel with existing treatment facilities located in northern California. A second mobile unit, comprised of a fish bioassay laboratory, has been incorporated into the study to investigate reductions in acute fish toxicity as a result of the improved design. A total of eight treatment plants will be included in the evaluation. So far five have been completed. Although the data have not been rigorously analyzed, evidence indicates that comparable bacteriological levels are achievable in the idealized system as in the full-scale systems with substantially less chlorine dosage applied. Acute toxicities to test fish were reduced as much as 3.5-fold, in accordance with the lower chlorine residual in the optimized system. Thus, it appears that considerable savings in the use, and therefore the costs, of chlorine and substantial reductions in the potential for chlorine-induced fish toxicity are possible by upgrading existing facilities to provide adequate flask mixing and plug flow contacting.

EFFECTS OF CHLORINE

1. Practicability
   a. New facilities - yes
   b. Old facilities - definitely. However, capital costs may rise if improved mixing is provided and baffles are installed in the contactors to increase the L/W ratio.
2. Ability to meet microbiological objectives
   a. Yes. Seasonal disinfection coupled with more effective design should enable achievement of the coliform objective more efficiently.

3. Technology limited by type of treatment plant

   a. All disinfectants are limited to some extent by the organic quality of the effluent. Chlorine is no exception. If good mixing and plug flow contacting are provided, the effect of organic demand will be minimized.

4. Worker safety

   a. This is a disadvantage with chlorine technology. Chlorine is a toxic material and proper safeguards must be undertaken to protect the working environment.

5. Commercial availability

   a. Easily available.

6. Costs

   a. Costs will vary, depending on whether liquid chlorine or hypochlorite is used. In either case, transportation costs will influence the total cost of the chemical.

   b. Costs will be directly affected by the demand of the effluent. These costs will be minimized with engineering optimization.

   c. Assuming a treatment plant size of 5,000 m^3/d (1.3 MGD), a chlorine dose of 10 mg/L, a cost of chlorine of $0.41/kg ($0.185/pound), and a minimum contact time of 30 minutes, the cost of disinfection is estimated at 1.6¢/1,000 gal. for materials, 2.2¢/1,000 gal. for operating cost and 1.3¢/1,000 gal. for capital. This gives a total cost of approximately 5.1¢/1,000 gal. (Opatken 1979). Engineering costs are included in the fixed capital investment figure. Electric power costs are assumed to be 3¢/Kwh. The total cost figure of 5.1¢/1,000 gal. is expected to be reduced by about 1/3 if seasonal disinfection is practised.

Chlorination/Dechlorination

DESCRIPTION OF PROCESS

Chlorination has already been discussed above and will not be repeated here. Information used for discussion of dechlorination was taken from Gan *et al.* (1979).

A project was funded by the U.S. EPA with the Los Angeles County Sanitation District to evaluate the cost-effectiveness of dechlorination by pilot scale testing and full-scale field survey. A questionnaire was mailed to 31 treatment plants in California practising dechlorination. Results from the survey indicated that sulphur dioxide is the most widely used dechlorinating agent in California because of its low cost and ease of application. The chemical characteristics of the gas have also added to the attraction of the process. Reaction time of sulphur dioxide and free chlorine or chloramines is very short so a contact chamber is not needed. By-products of sulphur dioxide, such as sulphite and chloride, have not been shown toxic to fish at normal levels encountered in dechlorination.

The questionnaire was divided into three categories: general information, engineering design information and operational information. A summary of the responses to the questionnaire is shown in Tables 2-1, 2-2 and 2-3. Some of the more important findings are given below:

(1) overdosing the chlorinated effluents with sulphur dioxide is essential to accomplish consistent dechlorination;

(2) excessive overdose of sulphur dioxide can be avoided by using discrete instruments and alternate methods of feed;

(3) except for the residual chlorine analyzer, the equipment in an sulphur dioxide feed control system is reliable;

(4) the analyzer is the weakest link in the sulphur dioxide feed system. Most analyzers manufactured today are incapable of maintaining calibration in the absence of chlorine and

(5) no significant physical-chemical degradation of the effluent was found after dechlorination with sulphur dioxide. Depletion of dissolved oxygen or change in pH was not observed in the pilot studies at sulphur dioxide dosage to residual chlorine ratio of 2:1.

The most common dosing method used is feed forward control. A chlorine residual signal (prior to the sulphur dioxide injection point) and a flow proportional signal are fed to the sulphonator. These two signals are combined into a product signal through an electronic multiplier before feeding to the sulphonator. This is done to avoid having to overdose the chlorinated effluent with sulphur dioxide.

Alternative methods have been devised to improve performance. In alternative No. 1, a two-stage method of dechlorination is used. Analyzer No. 1 instructs sulphonator No. 1 to dechlorinate to a 10:1 ratio of the discharge limit. The analyzer performs best within a 10:1 setting. Calibration is maintained because of the continuous presence of chlorine residual in the effluent. Sulphonator No. 2 is then used to remove the remaining residual chlorine. Because the total residual chlorine has been reduced to 1 mg/L or less in the first state, excessive overdose of the sulphur dioxide with sulphonator No. 2 is avoided.

In alternative No. 2 a biased residual chlorine signal is sent through the analyzer to keep it in calibration. A feedback residual signal from the dechlorinated effluent greater than the biased signal signifies incomplete dechlorination. The sulphur dioxide is paced to dose proportional to any signal greater than the biased signal.

TABLE 2-1

PROFILE OF DECHLORINATION FACILITIES IN SURVEY (1977)

DESCRIPTION	PERCENT OF TOTAL RESPONSES*
(a) Startup date of dechlorination facilities	
- Before January, 1976	38.7
- After January, 1976	61.3
(b) Type of treatment preceding dechlorination	
- Primary	9.7
- Secondary	83.9
- Tertiary	6.4
(c) Average daily plant flow	
- Less than $2.3 \times 10^4 m^3/d$ (6 MGD)	68.0
- 6 to 10 MGD 2.3×10^4 to $3.8 \times 10^4 m^3/d$ (6-10 MGD)	16.0
- Greater than $3.8 \times 10^4 m^3/d$ (10 MGD)	16.0
(d) Sulphur dioxide capacity	
- 0 to 45.4 kg/d (0 to 100 lbs/day)	12.9
- 45.8 to 227 kg/d (101 to 500 lbs/day)	35.5
- Greater than 227 kg/d (500 lbs/day)	51.6
(e) Total coliform discharge standard	
- Less than or equal to 2.2/100 mL	22.6
- Less than or equal to 23/100 mL	16.1
- Less than or equal to 100/100 mL	9.7
- Less than or equal to 240/100 mL	41.9
- Others	9.7
(f) Total residual chlorine discharge standard	
- 0	58.1
- Less than or equal to 0.1 mg/L	29.0
- Greater than 2 mg/L	12.9

* Based on 31 respondents.

TABLE 2-2

ENGINEERING DESIGN INFORMATION OF DECHLORINATION FACILITIES IN SURVEY (1977)

DESCRIPTION	PERCENT OF TOTAL RESPONSES*
(a) Type of feed control system	
- Feedforward	87.1
- Feedback	9.7
- Feedforward and feedback	3.2
- Flow paced	27.4
- Residual control	27.4
- Flow and residual controls	45.2
- Pneumatic flow signal	6.5
- Electronic flow signal	93.5
- Pneumatic dosage signal	9.7
- Electric dosage signal	90.3
- Gap residual controller	16.1
- Proportional and reset controller	25.8
- None	58.1
- With multiplier	35.5
- Without multiplier	64.5
- With adjustable slope factor	9.6
- Without adjustable slope factor	90.4
(b) Contacting method	
- SO_2 injected in mixing chamber	32.3
- SO_2 injected in outfall pipe	67.7
- Reaeration provided after dechlorination	3.2
- Reaeration not necessary after dechlorination	96.8
- pH adjustment provided after dechlorination	3.2
- Others	12.9

*Based on 31 respondents.

TABLE 2-3

OPERATIONAL INFORMATION OF DECHLORINATION FACILITIES IN SURVEY (1977)

DESCRIPTION	PERCENT OF TOTAL RESPONSES*
(a) Is dechlorination system operated 24-hrs. daily?	
- Yes	93.5
- No	6.5
(b) What is the desirable $SO_2:Cl_2$ ratio employed?	
- 1 or less	74.2
- greater than 1	25.8
(c) Is overdosing necessary to meet standard?	
- Yes	87.1
- No	12.9
(d) Is SO_2 feed control system reliable?	
- Yes	58.1
- No	41.9
(e) Will system handle drastic fluctuation of residual chlorine?	
- Yes	50.0
- No	50.0
(f) Is biological aftergrowth observed after dechlorination?	
- Yes	6.5
- No	93.5

*Based on 31 respondents.

The simple feed forward control system is adequate for most dechlorination installations. It requires a small capital investment and offers simplicity of controls. Its main disadvantage is that sulphur dioxide overdosing is necessary to accomplish disinfection. Overdosing cost may be a significant factor in large dechlorination installations. The alternate sulphur dioxide feed control systems would reduce the sulphur dioxide overdose requirement and hence the operating chemical cost.

Costs of dechlorination by sulphur dioxide, activated carbon and holding lagoons are summarized in Table 2-4. Sulphur dioxide dechlorination is clearly the most cost-effective method presently in use.

For small treatment plants, addition of the control instrumentation and feeding equipment, along with the safety precautions indigenous to handling of liquified gases may not justify dechlorination by sulphur dioxide. Rather, dechlorination by liquid feeding, using sodium sulphite or metabisulphite with manual feed control would probably be the more economical, albeit less efficient, method of dechlorination. In this case, over-dechlorination would probably be the rule rather than the exception, but the California experience indicates little likelihood of pH or dissolved oxygen degradation. Naturally, a savings in instrumentation, equipment and labor by not dechlorinating with sulphur dioxide would be partially offset by the added cost of the liquid reducing agent.

EFFECTS OF CHLORINATION/DECHLORINATION

1. Practicability

    a. New facilities - yes
    b. Old facilities - yes. Additional equipment needed would include a chlorinator (used as a sulphonator), a continuous chlorine residual analyzer, piping and a good mixer.

2. Ability to meet microbiological objectives

    a. Probably. Gan et al. (1979) found that within 10 minutes following application of sulphur dioxide to chlorinated effluent, an increase of 1.5 to 2.5 log units in the total coliform population occurred. This "after growth" phenomenon was traced to contamination in the form of slime on the sides of the steel chamber used to simulate a receiving stream. A slight increase in the fecal coliform and total plate count populations (about 0.5 log unit) was also observed, whereas no change in the fecal streptococci population occurred. It is believed that the microbial increase shortly after dechlorination, confined predominantly to the total coliform population, does not evoke much sanitary significance.

3. Technology limited to type of treatment plant

    a. No.

TABLE 2-4

COST ESTIMATES FOR A 38,000 m^3/d (10 MGD) ACTIVATED SLUDGE DECHLORINATION FACILITY

DECHLORINATION PROCESS	CAPITAL COST ¢/3.8m^3 (¢/1,000 gal.)	OPERATING COST ¢/3.8m^3 (¢/1,000 gal.)	TOTAL COST ¢/3.8m^3 (¢/1,000 gal.)
Sulphur Dioxide	0.4	1.3	1.7
Activated Carbon	2.3	10.5	12.8
Holding Pond	5.4	0.4	5.8

From Gan et al. (1979), p. 46.

4. Worker safety

   a. Sulphur dioxide is an irritating, pungent toxic gas requiring care in handling. The same safety precautions applying to chlorine can also apply to sulphur dioxide.

5. Commercial availability

   a. Easily available.

6. Costs

   a. Cost estimates for dechlorination by sulphur dioxide were made by Gan et al. (1979). In deriving the costs, it was assumed that the treatment plant capacity was 38,000 m^3/d (10 MGD) with 5.0 mg/L total residual chlorine to be dechlorinated. The residual chlorine concentration was based on a requirement to meet the State of California's coliform standard of 2.2 total coliforms/100 mL. Amortization was assumed to be 15 years at an annual interest rate of 8 percent. The costs were calculated to be 0.4¢/1,000 gal. for capital and 1.3¢/1,000 gal. for operating, giving a total cost of approximately 1.7¢/1,000 gal. This is likely to be an overestimate, since to meet the recommended microbiological objective for the Great Lakes, considerably less chlorine residual will be present.

Ultraviolet Light

DESCRIPTION OF PROCESS

Ultraviolet light is electromagnetic radiation of wavelength shorter than 300 nm. The microbiocidal effects in the ultraviolet region are at a maximum at a wavelength of approximately 260 nm. The lethal effect of ultraviolet radiation derives from the fact that living matter contains molecules that absorb radiant energy. Nucleic acids and proteins, the prime constituents of living matter, have structures which permit strong absorption of the ultraviolet energy. The photochemical changes produced as a result of that absorption may be reversible or irreversible, depending on the quantity of energy absorbed.

Low pressure mercury vapour lamps available on the market today emit most of their light energy at a wavelength of 254 nm, very close to the peak germicidal wavelength. Ultraviolet light does not penetrate very far through water and even less through wastewater because of the presence of ultraviolet absorbing materials. The intensity of ultraviolet light is conventionally expressed in terms of microwatts/cm^2. The actual dosage of ultraviolet would be the product of intensity and contact time (microwatt-sec/cm^2). The applied intensity may be derived from the expression:

$$I/I_0 = e^{-\alpha d}$$

where I_0 = incident intensity, i.e. the intensity of the radiation entering the medium

I = the intensity of the radiation after traversing distance d through the medium

d = distance traversed through the medium (cm)

α = absorption coefficient of the medium (1/cm)

The absorption coefficient is the fraction of radiation absorbed by the medium and is characteristic of the medium only. The higher the α, the shorter the distance the ultraviolet light can penetrate. The transmittance, I/I_0, of ultraviolet is a function of d, the distance traversed. Thus, it is important to keep this distance minimal, especially in high absorbance media such as wastewater effluent.

The main thrust in ultraviolet disinfection research until recently has been in the application to the sterilization of waters having a high ultraviolet transmission, specifically, potable waters. Its application to wastewater effluents had not been pursued to a great degree due to the physical problems associated with obtaining an efficient exposure system. Solids suspended in the liquid absorb or scatter the ultraviolet radiation, thereby attenuating it, and high absorbances encountered in wastewater effluent have established a need for higher doses.

A project has been funded by the U.S. EPA with the Northwest Bergen County Sewer Authority in Waldwick, New Jersey, to evaluate the cost effectiveness of ultraviolet disinfection under full-scale operating conditions. The ultraviolet unit being used is a prototype system housing 400 ultraviolet lamps situated perpendicular to the flow of the wastewater. The overall dimensions of the unit are 76 x 76 x 142 cm (3 x 3 x 6 ft.) with a void volume of 0.63 m^3 (22.2 $ft.^3$). Headloss is estimated at 15 cm (6 in.) at a flow rate of 21,000 m^3/d (5.5 MGD). The ultraviolet lamps are shielded from the water by quartz sleeves. The sleeves are cleaned by a mechanical wiper mechanism comprised of replaceable elastomeric glands fitted around each of the quartz tubes. The wipers are cable driven by a pneumatic cylinder at a variable stroke rate. A unique feature of the ultraviolet unit is the utilization of the "thin film" concept, which is induced by the spacing of the lamps. The nominal liquid film thickness is 0.6 cm (0.25 in.). The ultraviolet lamps are 142 cm (6 ft.), 85-watt lamps with an output of 30 watts in the germicidal range.

The Northwest Bergen County Water Pollution Control Plant is a conventional air activated sludge plant with a design capacity of 30,000 m^3/d (8 MGD) and a current average yearly flow of approximately 18,900 m^3/d (5 MGD). Influent raw wastewater is entirely domestic in origin. The treatment plant is a modern, efficient facility discharging a well-treated secondary effluent to a quality water stream.

Results to date indicate that the thin film, gravity flow disinfection unit has provided effective treatment with low maintenance over a seven to eight month period. It is flexible in its operation and mechanically simple. The wiper mechanism has had approximately 4,500 hours continuous operation with no apparent degradation in cleaning efficiency. Design nomographs were developed from regression curves of log surviving fecal coliform fraction verus log dose. The dose figure was defined by Scheible et al. (1979) as applied germicidal power (KW) divided by flow rate (m^3/s). If the expected influent fecal coliform density is 10^5/100 mL, the germicidal power requirement is estimated at 18 KW to achieve an effluent fecal coliform density of <200/100 mL. Using lamps with a germicidal output of 30 W per lamp, the implied lamp requirement would be 600. Similarly, assuming a total power consumption of 110 W per lamp, the total power application becomes 66 KW. The assumption of a linear relationship in log surviving fraction with log dose induces a sensitivity of the system design to influent coliform densities (or effluent coliform requirements). Single log increments in influent density levels (or effluent density requirements) will affect system design requirements by a factor between 3 and 3.5.

Based on the above discussion, for a 30,000 m^3/d (8 MGD) plant, the equipment purchase cost would be $240,000. Operating costs are estimated at $30,000/year, while total yearly costs (assuming 20-year amortization at 6-5/8% interest rate) amount to $50,000. Unitary cost estimates based on the design nomographs indicate the cost of ultraviolet disinfection is approximately 1 to 1.4¢/1,000 gal. (assuming an approximate 3-log coliform reduction). It should be emphasized that these are only preliminary estimates and may change as more performance data are gathered.

EFFECTS OF ULTRAVIOLET DISINFECTION

1. Practicability
   a. New facilities - yes.
   b. Old facilities - yes. The ultraviolet unit at Northwest Bergen County was simply lowered into a specially fabricated concrete support structure located at the head end of a chlorine contact chamber. Thus, retrofitting the equipment was relatively simple.

2. Ability to meet microbiological objectives
   a. Yes. However, the ultraviolet unit at Northwest Bergen County has not been challenged yet by organic or microbial degradation, so the effects of a poorer quality effluent are still unknown.

3. Technology limited by type of treatment plant
   a. It has been assumed in the past that a higher than average quality effluent is needed if ultraviolet is to be feasible. The veracity of this statement still needs to be confirmed or disproven, but evidence indicates that high level of treatment may no longer be the prerequisite for ultraviolet to be effective.

4. Worker safety

   a. Since ultraviolet is a physical agent and generated on-site, no special safety precautions are needed.

5. Commercially available

   a. Yes.

6. Costs

   a. Costs were already discussed above. Ultraviolet light appears to be competitive with chlorine at this time. However, a more complete analysis will be forthcoming within six to eight months.

Ozone Disinfection

DESCRIPTION OF PROCESS

Ozone is a potent oxidizing agent and its reaction with oxidizable materials is relatively non-selective. It is a good virucide; it is non-toxic to aquatic life; its reaction end product is dissolved oxygen and it has not been found to produce organic compounds potentially hazardous to man or other life forms. However, because it is generated on-site by electrical energy, it is a relatively expensive chemical. Ozone generating equipment is capital intensive and its operating costs are high. Any process development which offers promise in reducing the overall costs of ozonation will accelerate its acceptability as a feasible alternative to chlorine.

Because of the potent oxidizing ability of ozone, the demand exerted by organic matter in effluents can have a marked influence on its disinfection efficiency and reliability. Care must be exercised in making certain that the ozone produced is utilized in the most efficient manner, otherwise the operating costs of ozonation may be needlessly high due to excessive use of energy resources. In-depth evaluations of gas-liquid contacting devices are being conducted in an in-house research effort of the U.S. EPA, Cincinnati, Ohio (Venosa, et al. 1979 and Venosa, et al. 1978). To date, five generic-type contactors have been evaluated for ozone utilization and disinfection efficiency: packed column, jet scrubber, positive pressure injector, bubble diffuser and turbine reactor. The bubble diffuser reactor appears to be the most efficient contactor both from a mass transfer standpoint and a disinfection standpoint.

It is important to understand the fundamental relationships between ozone concentration and gas/liquid flow rates and to differentiate between applied ozone dose and absorbed ozone dose. The following relationships are given:

1. Applied Ozone Dose (D) (1)

$$D = Y_1 \ (Q_G/Q_L)$$

where Y_1 = ozone concentration in carrier gas, mg O_3/ℓ_{gas}

Q_G = carrier gas flow rate, ℓ_{gas}/min

Q_L = liquid flow rate, ℓ_{liq}/min

By inspection of equation (1), it is clear that the applied ozone dose can be varied either by changing the ozone concentration in the inlet carrier gas (Y_1) or by changing the Q_G/Q_L ratio.

2. Percent Ozone Utilization (%U) (2)

$$\%U = \frac{Y_1 - Y_2 \ (100)}{Y_1}$$

where Y_2 = concentration of ozone in the gas leaving the contactor, mg O_3/ℓ_{gas}

3. Ozone Utilization (Absorbed Dose) U (3)

$$U = \text{Applied Dose x Fraction Utilized}$$

$$= Y_1 \ (Q_G/Q_L) \quad \frac{(Y_1 - Y_2)}{Y_1}$$

$$= Q_G/Q_L \ (Y_1 - Y_2)$$

Scaccia and Rosen (1977) found that equivalent disinfection will be achieved at substantially the same utilized ozone dose, independent of contactor type studied. Venosa et al. (1979) confirmed that finding, using filtered secondary effluent. They found a highly significant correlation between log coliform reduction and log ozone utilization (equation 3), independent of contactor type. It should be emphasized that the effluent quality was good and did not vary appreciably from day to day. However, they also found that equivalent absorbed doses, i.e. utilization necessary to achieve a given bacteriological standard may not be possible in some contactors, especially if ozone is generated from air. The reason for this is that, if D is increased by increasing Q_G/Q_L (equation 1), the percentage of ozone utilization (equation 2) decreases because of the resulting higher Y_2. Consequently, ozone utilization may either increase, remain the same or actually decrease with an increase in D. The magnitude of the change in absorbed dose is determined by the contactor design. The rate of increase in U in the bubble diffuser was significantly higher than that in either the packed column or positive pressure injector. Thus, to achieve a consistent 3.3 log reduction in either total or fecal coliforms, a minimum of 4.0 mg/L ozone must be absorbed (high quality, filtered secondary effluent). Only the bubble diffuser was capable of efficiently absorbing that quantity of ozone. This points out the need for optimizing gas-liquid contacting.

Opatken (1979) conducted an extensive economic analysis of ozone disinfection, based on the results presented above. His assumptions were: a plant size of 5,000 m^3/d (1.3 MGD), 5.0 mg/L ozone utilization (1.0 mg/L more than the 4.0 mg/L reported in the above study, as a safety factor), an ozone concentration in the inlet carrier gas (Y_1) of 10 mg/L (approximately 0.8 weight percent), the cost of power at 3¢/Kwh and fixed capital investment (FCI) amortized over 20 years at 7% interest rate. Included in the fixed capital investment estimate was engineering cost (20% of the FCI). The capital cost was based on the price paid for the pilot scale ozone generator, scaled up to the 5,000 m^3/d (1.3 MGD) capacity. Six categories were included in the operating cost estimate: (1) utility cost (cost of compression and regeneration of the carrier gas, cost of ozone generation per se and the cost of cooling), (2) operating labor (1/2 man year); (3) repair labor (1% FCI); (4) supervision 15% (OL + RL); (5) repair materials (1% FCI) and (6) supplies 10% (OL + RL + supv.). Included in overhead cost were insurance (1% FCI) and amortization. The total cost of ozone disinfection was computed to be approximately 11¢/1,000 gal. (8.1¢ for ozone, 2.1¢ for operating cost and 0.9¢ for overhead). This is approximately twice the cost of the chlorine disinfection reported earlier.

EFFECTS OF OZONE

1. Practicability

   a. New facilities. Yes
   b. Old facilities. Questionable. The highest percentage of the total cost of ozone disinfection is the cost of ozone itself, i.e. capital. If an existing treatment plant switched over from chlorine to ozone, the capital expenditure would be considerable, especially in view of the fact that chlorination facilities are already existing and being paid for.

2. Ability to meet microbiological objectives

   a. Yes

3. Technology limited by type of treatment plant

   a. Possibly. Recent preliminary evidence from the U.S. EPA ozone contactor study seems to indicate that filtration may be a prerequisite for adequate disinfection by ozone. However, if the suspended solids content of the effluent is already low, ozone is quite feasible.

4. Worker safety

   a. Ozone is a toxic gas. Adequate safeguards, such as an ozone destruct system to destroy ozone in the exhaust gas and the residual coming off from the discharging effluent, must be provided to protect the immediate working environment. However, since ozone is generated on-site, there are no transportation problems.

5. Commercially available

   a. Easily available.

6. Costs

   a. Economics of ozone disinfection were presented above.

Chlorine Dioxide Disinfection

DESCRIPTION OF PROCESS

Chlorine dioxide (ClO_2) has been used successfully in Europe to disinfect water supplies and is used extensively as a bleaching agent in the pulp and paper industry. With respect to disinfection wastewater, ClO_2 has several distinguishing characteristics:

(1) it is a strong oxidant over a broad pH range;

(2) it provides a measurable residual;

(3) it does not react with ammonia to form less effective chloramines;

(4) it does not react to yield trihalomethanes and

(5) it is an excellent virucide.

The two principal methods of ClO_2 manufacture are summarized as follows (Stevens et al. 1976):

(a) Chlorine-Chlorite Process - this is the process most commonly used in waterworks practice:

$$2NaClO_2 + Cl_2 \longrightarrow ClO_2 + 2\,NaCl.$$

In practice the reaction is carried out with a molar ratio of reactants of 1:1 to achieve a yield of 85-90 percent based on the more expensive reagent, chlorite. The reaction approaches completion within one minute. The usual reactor configuration is a ring-packed, glass reaction column. The equipment requirements are simple and inexpensive, but there is substantial chlorine in the product solution. Alternative processes do exist which are claimed to produce ClO_2 substantially free of chlorine (<5% v/v) but the technologies have not been widely used.

(b) Reduction of Sodium Chlorate - equimolar amounts of sodium chlorate, sodium chlorite and sulphuric acid are mixed in a vessel where they react according to the following reaction:

$$NaClO_3 + NaCl + H_2SO_4 \longrightarrow ClO_2 + 1/2\,Cl_2 + Na_2SO_4 + H_2O.$$

The yield of the reaction is reported to be approximately 95 percent. In a subsequent absorption step, the ClO_2 is taken up by water almost quantitatively, whereas 75 percent of the chlorine passes through, so that the molar ratio of the ClO_2 to Cl_2 is approximately 8:1. This is the process most often used in pulp bleaching. A substantial cost advantage is claimed by virtue of the lower cost of chlorate compared with chlorite. However, the reaction is more complex and requires substantially more sophisticated equipment. Thus, for small treatment plants, the cost advantage of the chlorate may disappear in the form of higher amortization pay-outs.

Aieta, Chow and Roberts (1970) conducted an in-depth, statistically designed experiment comparing the bactericidal efficiencies of chlorine and ClO_2 on Palo Alto secondary effluent. Their conclusions are summarized below:

(1) both Cl_2 and ClO_2 give decreased survival ratios when dose or contact time is increased;

(2) although some variations exist, Cl_2 and ClO_2 give essentially the same survival ratios when compared on a <u>mass dose</u> basis at 30 minutes contact time;

(3) ClO_2 is a more rapid disinfecting agent than Cl_2 and

(4) comparing ClO_2 and Cl_2 on a residual basis, ClO_2 effects the same microorganism reduction as Cl_2 with a much lower residual concentration.

When the survival ratio was plotted against residual-time product on a log-log plot, a straight line relationship resulted. The regression equation was of the form:

$$N_t/N_o = [b\ (RT)]^k$$

where

N_t = the number of surviving organisms at time t

N_o = the initial number of organisms

RT = residual-time product (mg-min/1)

b = lag coefficient $(\text{mg-min}/1)^{-1}$

k = velocity coefficient.

The coefficient b is a relative measure of the lag period between dosing and the onset of bacterial destruction; the larger the value of b, the shorter the lag time. The coefficient k is a measure of the rate of kill; the larger the absolute value of k, the faster the kill. The regression equation for Cl_2 was found to be:

$$N_t/N_0 = [0.17\ (RT)]^{-3.15} \qquad (1)$$

The regression equation for ClO_2 was:

$$N_t/N_0 = [0.64\ (RT)]^{-2.90} \qquad (2)$$

Comparing equations (1) and (2) indicates that the rates of coliform kill were essentially the same for both disinfectants. The major difference between Cl_2 and ClO_2 was in the lag coefficient, b. This implies that for equal coliform reduction, a higher residual-time product is required by chlorine than by ClO_2.

The economic implications of the above discussion need to be considered. It is clear that a shorter contact time is required for disinfection when ClO_2 is used as opposed to Cl_2 at the same residual concentration. Thus, a smaller contact chamber, or possibly no contact chamber at all, would be required and a savings in capital cost would be realized. However, this saving may be offset by the higher chemical costs of ClO_2 (on a mass basis) and a higher ClO_2 dose required than that for Cl_2 to produce the same residual concentrations. The cost of sodium chlorite is $1.16/pound delivered (minimum order 220 lbs., A and S Chemical Co., New Jersey) or $0.97/lb. undelivered (minimum order 240 100-lb. drums, Olin Chemicals, Connecticut). This is approximately 5.2 to 6.3 times the cost of chlorine and the advantages afforded by ClO_2 would have to far outweigh the added cost to be considered seriously as a feasible alternative.

EFFECTS OF ClO_2

1. Practicability
   - a. Old plants - retrofitting ClO_2 equipment would be a relatively simple task, if the chlorine-chlorite generation process is used. Equipment is simple and inexpensive.
   - b. New plants - yes.
2. Ability to meet microbiological objectives
   - a. Yes, ClO_2 is an effective bactericide and an equally effective viricide.
3. Technology limited by type of treatment plant
   - a. Questionable at this time. ClO_2 does not react with ammonium-nitrogen, but because it is an effective oxidant, its demand in wastewater effluent may be equal to or greater than chlorine. More data are needed to establish its demand potential.

4. Worker safety

   a. If the ClO_2 is generated by the chlorine-chlorite process, the problems indigenous to chlorine handling still exist. Sodium chlorite itself must be handled with care to prevent skin burns and other irritations. If ClO_2 is generated in sufficient concentrations, it can be explosive so care must be exercised in controlling the generation process.

   b. If the ClO_2 is generated by the acid-chlorate process, problems indigenous to chlorine and chlorite handling are eliminated, but problems indigenous to acid handling become important.

5. Commercially available

   a. The generation equipment (chlorine-chlorite process) can be easily obtained. Although there are a limited number of manufacturers marketing sodium chlorite, the chemical should be fairly easily obtainable.

6. Aquatic toxicity

   a. A study conducted jointly by the Ontario Ministry of the Environment and Environment Canada (Conn & Cairns 1979) indicated ClO_2 was significantly less toxic to fish than chlorine. Although it was not possible to calculate an LC_{50} because of the volatility of ClO_2, the concentration of treated effluent which was toxic was $\geq 30\%$. The toxicity was removed with sodium sulphite or prolonged holding.

7. Potential for producing hazardous by-products

   a. Very low.

8. Costs

   a. At present, the economic outlook for ClO_2 disinfection of wastewater effluent is unfavorable due to the relatively high cost of sodium chlorite. More data should be available within one year as progress is made in the U.S. EPA funded project with Stanford University.

Bromine Chloride Disinfection

DESCRIPTION OF PROCESS

Bromine chloride, BrCl, is a heavy, fuming, dark red liquid with a sharp, penetrating odor. It exists in equilibrium (about 20 percent dissociated) with molecular bromine and chlorine in both the gas and liquid phase:

$$2\ BrCl \rightleftarrows Br_2 + Cl_2 \qquad (1)$$

It has a lower vapour pressure and higher solubility than chlorine. However, it is a corrosive liquid and must be handled with care.

BrCl hydrolyzes exclusively in dilute aqueous solutions to hypobromous acid according to the following equation:

$$BrCl + H_2O \longrightarrow HOBr + HCl \qquad (2)$$

The HOBr species is the active disinfectant. The chemistry of BrCl in water is similar to chlorine, in that the reactions with ammonia are identical. However, the bromamines are unstable and dissipate rapidly. For this reason bromamines have been found to be almost as effective germicidal agents as HOBr and much more effective than the chloramines. HOBr is less ionized in water than its chlorine counterpart, HOCl. Thus, it is a more active disinfectant at higher pH.

Studies in Grandville and Wyoming, Michigan (Ward, et al. 1976 and 1977) have demonstrated that chlorobrominated secondary effluents are less toxic to fish life than chlorinated effluents because the unstable bromamine residuals dissipate more rapidly. Due to the rapid decay of BrCl (or bromamine) residual, it is desirable for feed control purposes to measure the halogen residual using conventional chlorine analysis at a point which represents about five minutes of contact time after BrCl injection.

The BrCl dosing system at Grandville and Wyoming was frequently under repair. The reason was that BrCl, a liquid, must be vaporized prior to injection into the wastewater streams. The evaporator unit tended to accumulate solids with time, thereby blocking flow. Numerous attempts to resolve this problem were made, but with little success. The BrCl manufacturers presently claim that the problem has been resolved. If this is true, BrCl disinfection may have some potential as a viable alternative.

BrCl disinfection suffers from almost the same disadvantages as chlorine disinfection. Like chlorine, BrCl must be handled with care to avoid exposure. Unlike chlorine, BrCl with the higher boiling point is classified as a corrosive liquid and not a compressed gas. The halogenated organics problem elicits the same concern as with chlorine.

Regarding economics, recent price quotations obtained from Dow Chemical Company indicate that BrCl costs approximately 30¢/lb. when purchased in 1-ton cylinders. This is approximately 60 to 70 percent more than chlorine. BrCl dosing and control equipment is similar to commercial chlorine equipment. The main difference is the BrCl vaporizer unit. Retrofitting an existing plant with BrCl systems would be easily accomplished.

BrCl has several advantages over liquid bromine:

(1) BrCl is more soluble;

(2) it is less corrosive;

(3) it has a lower freezing point and

(4) it is about 5¢/lb. cheaper.

EFFECTS OF BrCl

1. Practicability

   a. Old plants - yes.
   b. New plants - yes.

2. Ability to meet microbiological objectives

   a. If equipment reliability can be shown to be much improved over past performance, BrCl should be quite able to achieve the coliform objectives.

3. Technology limited by type of treatment plant

   a. No.

4. Worker safety

   a. BrCl suffers from the same safety problems as chlorine. Care must be exercized in handling the chemical.

5. Commercial availability

   a. Only three United States companies manufacture BrCl: Dow Chemical Company, Ethyl Corporation and Great Lakes Chemical Company. However, source raw materials are in plentiful supply and commercial availability should not be a problem.

6. Aquatic toxicity

   a. Because BrCl residual dissipates rapidly with time, the acute toxicity problems of chlorobrominated effluents are much lower than chlorinated effluents.

7. Hazardous compound formation

   a. Halogenated organic compounds are formed just as readily with BrCl as with chlorine. Thus, no advantage is offered here.

8. Costs

   a. Costs should be moderately higher than chlorine, due to the higher material cost. Compared with chlorination/dechlorination the costs are more competitive.

REFERENCES

Aieta, E. M., B. Chow and P. V. Roberts. "Chlorine Dioxide: Analytical Measurement and Pilot Plant Evaluation" in "Progress in Wastewater Disinfection Technology", Proc. of the National Symposium on Wastewater Disinfection, September 18-20, 1978. A. D. Venosa, ed. Cincinnati, U.S. Environmental Protection Agency, 1979.

Conn, K. and V. Cairns. "Acute Lethality of Wastewater Disinfection Alternatives to Juvenile Rainbow Trout", Canada-Ontario Project No. 74-3-18, Environment Canada, 1979. (In press).

Gan, H. B., C. Chen and A. D. Venosa. "Dechlorination of Wastewater: State-of-the-Art Field Survey and Pilot Plant Studies" in "Progress in Wastewater Disinfection Technology", Proc. of the National Symposium on Wastewater Disinfection, September 18-20, 1978. A. D. Venosa, ed. Cincinnati, U.S. Environmental Protection Agency, 1979.

Opatken, E. J. "Economic Evaluation of Ozone Contactors" in "Progress in Wastewater Disinfection Technology", Proc. of the National Symposium on Wastewater Disinfection, September 18-20, 1978. A. D. Venosa, ed. Cincinnati, U.S. Environmental Protection Agency, 1979.

Scaccia, C. and H. M. Rosen. "Ozone Contacting: What Is the Answer?" Presented at the International Ozone Institute's Symposium on Advanced Ozone Technology, November 16-18, 1977, Toronto, 1979.

Scheible, O. K., G. Binkowski and T. J. Mulligan. "Full Scale Evaluation of Ultraviolet Disinfection of a Secondary Effluent" in "Progress in Wastewater Disinfection Technology", Proc. of the National Symposium on Wastewater Disinfection, September 18-20, 1978. A. D. Venosa, ed. Cincinnati, U.S. Environmental Protection Agency, 1979.

Stevens, A. A., D. R. Seeger and C. J. Slocum. "Products of Chlorine Dioxide Treatment or Organic Materials in Water" in Ozone/Chlorine Dioxide Workshop, November 1976, Cincinnati, 1976.

Venosa, A. D., ed. "Progress in Wastewater Disinfection Technology", in Proc. of the National Symposium on Wastewater Disinfection, September 18-20, 1978, Cincinnati, U.S. Environmental Protection Agency, 1979.

—————— et al. "Comparative Efficiencies of Ozone Utilization and Microorganism Reduction in Different Ozone Contactors" in "Progress in Wastewater Disinfection Technology", Proc. of the National Symposium on Wastewater Disinfection, September 18-20, 1978. A. D. Venosa, ed. Cincinnati, U.S. Environmental Protection Agency, 1979.

—————— et al. "Comparative Disinfection Efficiency in Two Ozone Contactors: Packed Column and Pressure Injector." Presented before the Division of Environmental Chemistry, American Chemistry Society Symposium in Disinfection, March 12-17, 1978, Anaheim, California.

Ward, R. W. et al. Disinfection Efficiency and Residual Toxicity of Several Wastewater Disinfectants, Vol. 1 - Grandville, Michigan. U.S. Environmental Protection Agency, 1976. (EPA 600/2-76-156).

Ward, R. W., R. D. Giffin and G. M. DeGraeve. Disinfection Efficiency and Residual Toxicity of Several Wastewater Disinfectants, Vol. II - Wyoming, Michigan. U.S. Environmental Protection Agency, 1977. (EPA 600/2-77-203).

APPENDIX 3

COST CURVES FOR DECHLORINATION BY SULPHUR DIOXIDE

APPENDIX 3

COST ESTIMATES FOR CHEMICAL DECHLORINATION

Construction, installation and total annual operating cost curves were developed for dechlorination with sulphur dioxide at sewage treatment plants with design capacities in the range of 4.54 x $10^3 m^3$ to 908 x $10^3 m^3$ per day. Total annual operating cost curves were estimated for both seasonal and year round operation.

Basic cost elements and assumptions are presented in Table 3-1. Cost estimates were developed for six sewage treatment plants with different design capacities. Process design assumptions are detailed in Tables 3-2 and 3-3. Estimates of construction, installation and annual operating costs are presented in Tables 3-4 and 3-5. Figures 3-1 and 3-2 were developed from Tables 3-4 and 3-5.

A few sewage treatment plants in the Great Lakes Basin have design capacities beyond the upper end of the range covered by these estimates. For these plants, the unit costs estimated for the largest plant capacity studied were extended without assuming any economies or diseconomies of scale. Results were incorporated into the global estimates for retrofitting dechlorination to all relevant plants in the Basin. At some plants with capacities near or below the lower end of the range covered, prolonged storage (16-24 hrs.) may be a more cost-effective method of eliminating chlorine residues.

TABLE 3-1

COST ELEMENTS AND ASSUMPTIONS

CONSTRUCTION COSTS

Cost Elements:

a) Sulphonation equipment including installation.
b) Sulphonation building/receiving facilities.
c) Mixing chamber including equipment installation.
d) Yard piping/yard electrical.
e) Legal, administrative, engineering.
f) Site supervision, mobilization.

Assumptions for Construction Costs in Tables 3-3 and 3-4

1) Costs are developed exclusive of standby equipment.
2) Concrete and excavation - \$150/yd.^{3} of installed concrete.
3) Sulphonation equipment - vendors prices
4) Sulphonation equipment installed
   Equipment costs x 2.5 - includes all electrical and piping.
5) Mixers - Vendors' Prices.
6) Mixers installed vendors' price x 2, including associated electrical costs.
7) Building, superstructures including heating, ventilating, lighting \$50-60 per ft.^{2} of floor area.
8) Yard piping electrical 50% of basic sulphonation equipment price.
9) Rail Spurs - \$80/per tract foot - installed, including appurtenances.
10) Total construction cost (allowing for site mobilization, supervision, legal, administrative and engineering) is 1.3 x Base Cost. Base cost includes those for direct purchase and installation of items a-e above.

OPERATING COSTS

Cost Elements:

a) Amortization
b) Power
c) Sulphur Dioxide
d) Labour
e) Maintenance Material

Assumptions for Operating Costs in Tables 3-3 to 3-5

1) Amortization 8% interest/20 year term..
2) Power costs 3¢/Kwh.
3) Sulphur Dioxide cost (including demurrage, transport)
   150 lb. cylinder - \$920/tonne
   2,000 lb. cylinder - \$520/tonne
   Railcars - \$170/tonne
4) Maintenance and operating labour \$100/per 8 hour working day. Labour allowance ranges between 36 and 180 man-days/year for smallest and largest sewage treatment plants.
5) Seasonal dechlorination implies operation over six contiguous months in each calendar year.

TABLE 3-2

PROCESS DESIGN ASSUMPTIONS - DECHLORINATION SYSTEMS - SULPHONATION EQUIPMENT

SEWAGE TREATMENT PLANT DESIGN CAPACITY 1,000 M^3/D	SO_2 DOSING RATES		SO_2 ANNUAL CONSUMPTION (TONNES)	SO_2 DOSED FROM	# OF STREAMS AND DESULFONATORS	SULPHONATOR/ EDUCTOR CAPACITY	# OF SO_2 ANALYZER CONTROLLERS[1]	CYLINDER WEIGH SCALES	HOIST	# OF SO_2 EVAPORATORS	# OF SOLUTION PUMPS	OTHER
	AVERAGE KG/D	PEAK KG/D										
4.54	4.54	11.35	1.7	150 # cyl.	1	475	1	Dual 150 #	-	-	1	-
22.70	22	55	8.0	150 # cyl.	1	475	1	Dual 150 #	-	-	1	-
45.4	45.4	113.5	16.5	1 ton cyl.	1	475	1	1 ton	1 ton	-	1	-
227	227	567.5	82.9	railcar	1	1,900	1	-	-	-	-	Railspur - 200 lineal feet of track, access platform, plus air padding facility
454	454	1,135	165.8	railcar	2	2 x 1,900	2	-	-	1	1	
908	908	2,270	331.6	railcar	2	2 x 7,000	2	-	-	2	1	

[1] One chlorine residual analyzer/controller is required for each SO_2 analyzer/controller.

TABLE 3-3

PROCESS DESIGN ASSUMPTIONS - DECHLORINATION SYSTEMS BUILDINGS AND MIXING CHAMBERS

SEWAGE TREATMENT PLANT DESIGN CAPACITY 1,000 M^3/D	MIXING VOLUME[1] (ft^3)	CHAMBER MIXER[2] (H.P.)	BUILDING SIZE
4.54	140	0.75	10'x 12'x 8' high
22.70	700	5.0	10'x 12'x 8' "
45.40	1,400	7.5	30'x 20'x 10' "
227	7,000	40	30'x 20'x 10' "
454	2 x 7,000	2 x 40	30'x 20'x 10' "
908	2 x 14,000	2 x 80	30'x 20'x 10' "

[1] 30 secs detention at peak flow.
[2] G of 300 $secs^{-1}$.
[3] Plus a covered area 30' x 18' for cylinder storage.

TABLE 3-4

SUMMARY OF OVERALL CONSTRUCTION/INSTALLATION COSTS

SEWAGE TREATMENT PLANT DESIGN CAPACITY 1,000 M^3/D	SULPHONATION EQUIPMENT INSTALLED $	SULPHONATION BUILDING/ RECEIVING FACILITIES $	MIXING CHAMBER AND EQUIPMENT $	YARD PIPING ELECTRICAL $	BASE COST $	TOTAL CONSTRUCTION/ INSTALLATION COST $
4.54	53,617	7,635	10,050	10,724	82,026	106,634
22.70	53,617	7,635	19,190	10,724	90,671	118,516
45.40	85,286	45,825	29,220	11,062	171,393	222,810
227	95,913	61,575	81,450	16,452	255,390	332,007
454	156,825	61,575	162,400	19,375	400,175	520,227
908	219,950	61,575	310,400	31,990	623,915	811,089

TABLE 3-5

SUMMARY OF ANNUAL OPERATING COSTS

SEWAGE TREATMENT PLANT DESIGN CAPACITY 1,000 M^3/D	YEAR-ROUND DECHLORINATION						SEASONAL DECHLORINATION					
	CHEMICALS $	POWER $	LABOUR $	MAINT-ENANCE MATERIALS $	AMORTIZED ANNUAL CAPITAL $	TOTAL ANNUAL OPERATING COST $	CHEMICALS[1] $	POWER[2] $	LABOUR[3] $	MAINT-ENANCE MATERIALS[4] $	AMORTIZED ANNUAL CAPITAL $	TOTAL ANNUAL OPERATING COST $
4.54	1,378	547	3,650	1,066	10,823	17,464	689	225	2,409	1,066	10,823	15,212
22.70	7,578	1,850	7,300	1,185	12,029	29,942	3,789	925	4,818	1,185	12,029	22,746
45.40	8,614	2,759	9,200	2,228	22,615	45,516	4,307	1,360	6,072	2,228	22,615	36,582
227	4,791	13,725	18,300	3,237	33,698	83,751	9,191	6,862	12,078	3,237	33,698	65,066
454	29,646	26,542	18,300	5,202	52,803	132,493	16,012	12,771	12,078	5,202	52,803	98,866
908	54,750	52,822	18,300	8,110	82,333	216,315	26,741	26,411	12,078	8,110	82,333	155,673

[1] At varying fractions of cost of year-round operation - see detailed calculation sheet.
[2] At 50% of cost for year-round operation.
[3] At 2/3 cost of year-round operation.
[4] At 100% of the cost of year-round operation.

Fig.3·1 Construction Costs of Dechlorination Facilities Using Sulphur Dioxide

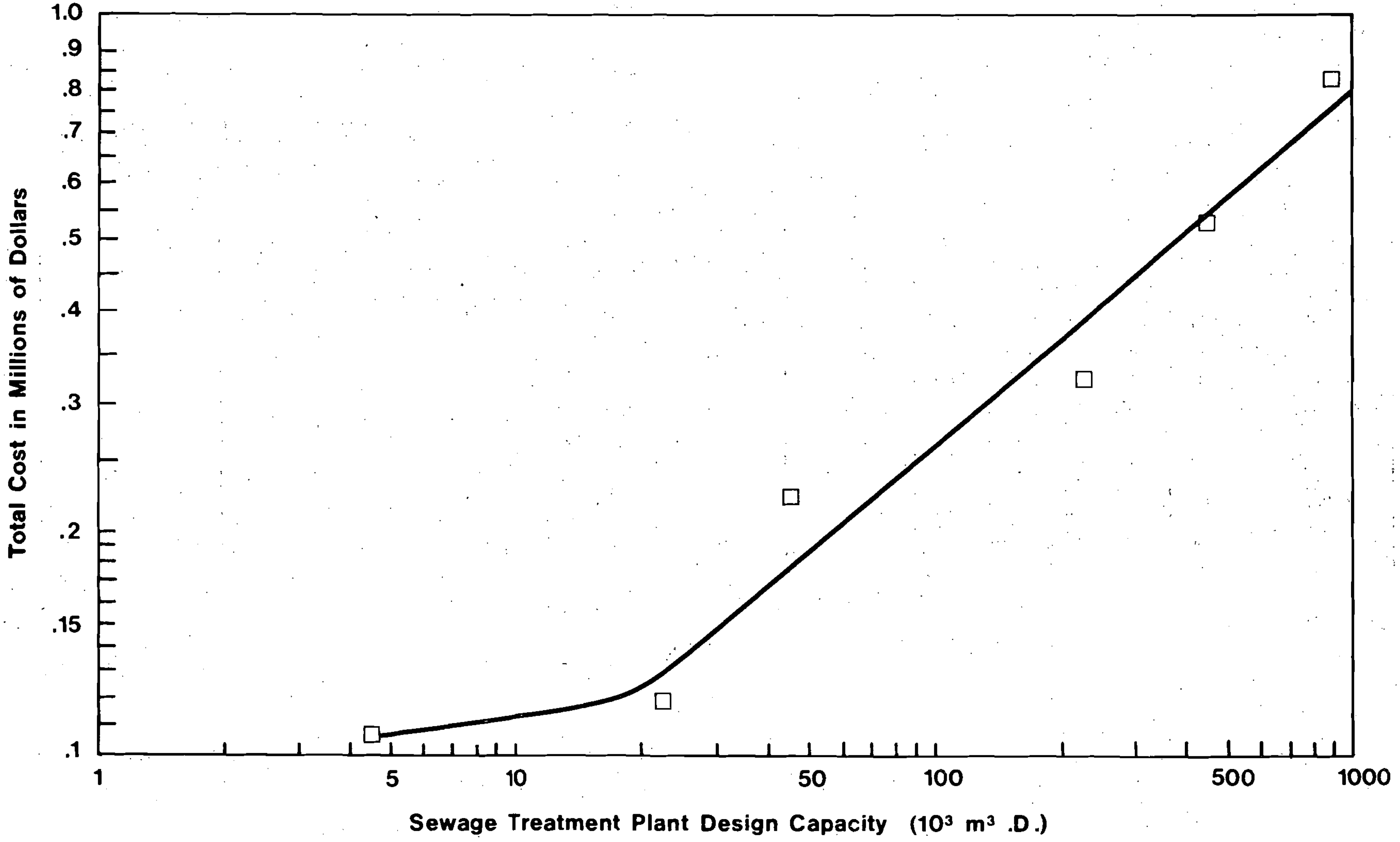
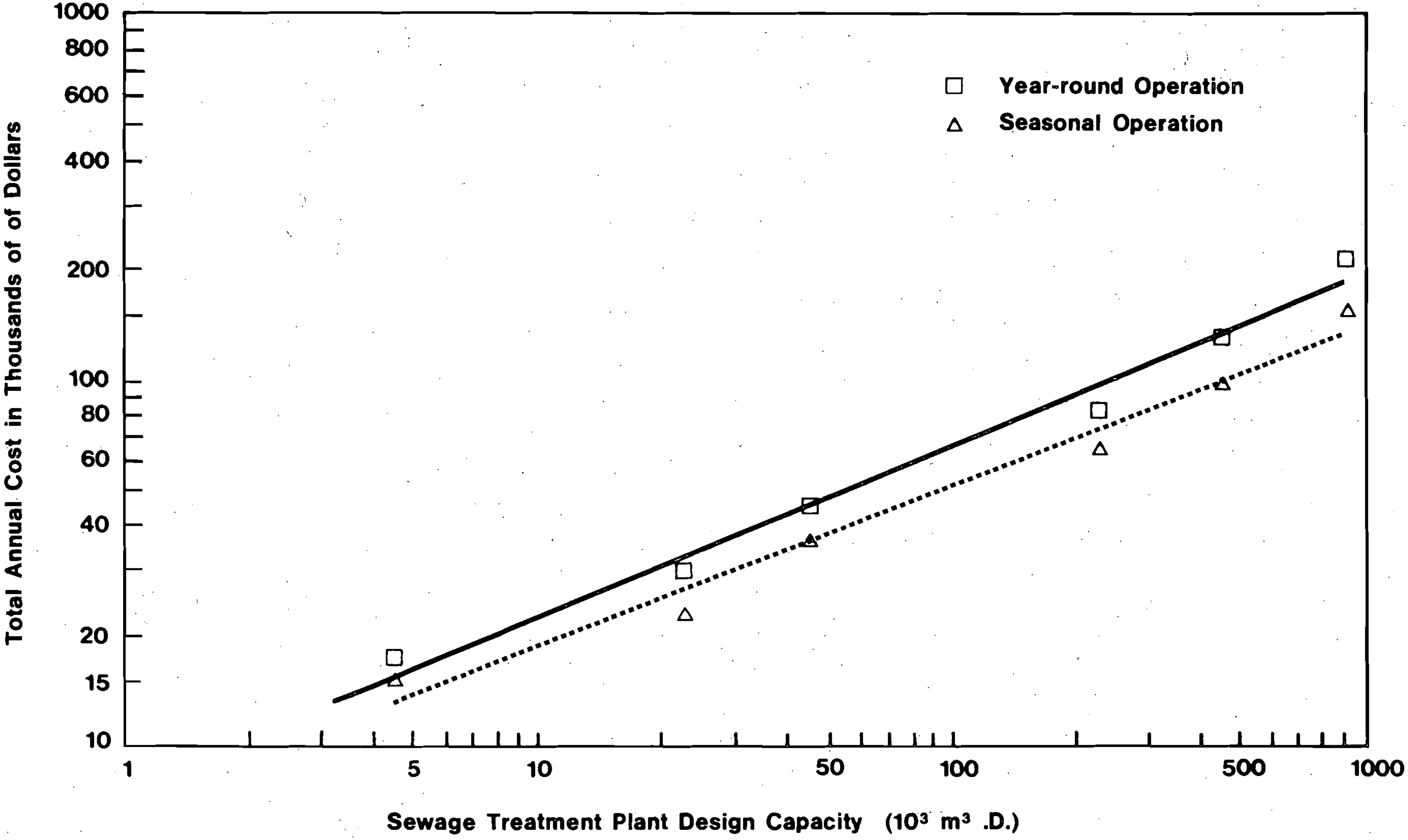


Fig. 3·2 Total Annual Costs for Dechlorination with Sulphur Dioxide



APPENDIX 4

SEWAGE TREATMENT PLANT INVENTORIES AND CHLORINE USE

TABLE 4-1

INVENTORY OF FLOWS FROM U.S. SEWAGE TREATMENT PLANTS ON THE GREAT LAKES[1]

NAME OF PLANT	1975	1976	1977	AVERAGE FLOW	RECEIVING WATER TYPE[3]
	(10^{3}m^3/day)[2]				
LAKE SUPERIOR					
Minnesota					
Grand Marais	1.0	1.04	1.3		L
Silver Bay	2.4	2.3	2.6		L
Two Harbors	4.1	7.2	5.2		L
West Lake Superior San. Dist. (Duluth - 4 plants)	73.5	72.7	70.2		T
TOTAL	81.0	83.24	79.3	81.2	
Wisconsin					
Ashland	5.6	4.6	5.1		L
Superior	17.3	16.7	13.2		L
TOTAL	22.9	21.3	18.3	20.8	
Michigan					
Marquette	10.7	11.1	10.4		L
Portage Lake	6.3	6.78	4.8		L
TOTAL	17.0	17.88	15.2	16.7	
BASIN TOTAL				118.7	
LAKE MICHIGAN					
Michigan					
Benton Harbor	39.9	36.8	36		T
Charlevoix	1.1	-	-		T
Escanaba	7.4	7.7	6.6		L
Gladstone	2.9	-	-		T
Grand Haven	14	13.7	12		T
Ludington	8.3	9.8	7.7		L
Manistique	9.1	-	-		T
Menominee	9.4	-	9.3		T
Petoskey	2.8	-	-		T
South Haven	8.3	8.36	-		T
TOTAL	103.2	76.36	62.3	80.6	

Table 4-1 - cont'd.

NAME OF PLANT	1975	1976	1977	AVERAGE FLOW	RECEIVING WATER TYPE[3]
	$(10^3m^3/day)$[2]				
LAKE MICHIGAN - cont'd.					
Wisconsin					
Green Bay	94.9	141.8	111.2		L
Kenosha	69.3	71.4	71.0		L
Manitowoc	35.1	36.0	33.8		L
Marinette	9.6	11.6	11.5		L
Milwaukee MSC					
Jones Island	519.3	561	476.6		L
South Shore	278.8	246.0	248.8		L
North Park San. Dist.	4.5	5.6	4.2		L
Oconto	5.7	4.9	3.0		L
Port Washington	6.5	6.3	4.7		L
Racine	74.2	76.8	79.6		L
Sheboygan	39.8	45.2	36		L
South Milwaukee	10.6	11.7	8.74		L
Sturgeon Bay	-	-	4.78		T
Two Rivers	11.0	10.5	7.42		L
TOTAL	1,064.4	1,087.0	990.14	1,047.2	
Illinois					
Waukegan NSSD	64.7	68.2	72.5	68.5	L
Indiana					
Chesterton	-	-	3.52		T
East Chicago	75.6	66.3	53		T
Gary	185.2	179	155		T
Hammond	144.5	167	134		L
Michigan City	33.1	31.5	31.3		T
Portage	-	-	6.30		T
TOTAL	438.4	443.8	383.12	422.7	
BASIN TOTAL				1,619.0	
LAKE HURON					
Michigan					
Alpena	11	13	12		T
Cheboygan	3.4	-	-		L

Table 4-1 - cont'd.

NAME OF PLANT	1975	1976	1977	AVERAGE FLOW	RECEIVING WATER TYPE[3]
	(10^{3}m^3/day)[2]				
LAKE HURON - cont'd.					
Michigan - cont'd.					
Harbor Beach	1.5	-	(1.5)		I
Mackinac Island	1.3	-	(1.3)		L
Rogers City	3.1	-	(3.1)		L
St. Ignace	3.4	1	1		L
Sault Ste. Marie	12.3	10.7	12.5		I
TOTAL	36.0	23.7	30.4	30.0	
LAKE ERIE					
Michigan					
Detroit	3,623	3,618	3,040		I
East China Twp.	1.6	-	-		I
Grosse Ile Twp. Wayne Co.	7.4	7.2	7.2		I
Marine City	3.2	-	(3.2)		I
Marysville	2.1	7.7	7.1		I
Port Huron	65.3	56.8	33.7		I
St. Clair	2.4	-	-		I
Trenton	18.8	18.5	18.4		I
Wayne Co. Trenton	8.8	-	6.2		I
Wayne Co. Wyandotte	269	280	272		I
TOTAL	4,001.6	3,988.2	3,387.8	3,792.5	
Ohio					
Ashtabula	14.0	14.8	16.6		L
Avon Lake	14.8	16.1	17.8		L
Cleveland Easterly	388.5	438.3	501.3		L
Cleveland Southerly	348.7	357.9	360.0		L
Cleveland Westerly	125.1	131.1	122.7		L
Clyde	5.7	4.5	-		L
Conneaut	8.0	7.3	5		L
Erie Co. - Huron and Sawmill Creek	4.6	-	(4.6)		L
Euclid	65.9	72.1	72		L
Geneva	4.2	3.2	(3.2)		L
Lake Co. Madison	7.2	9.5	8		L
Lakewood	55.4	50.7	43		L

Table 4-1 - cont'd.

NAME OF PLANT	1975	1976	1977	AVERAGE FLOW	RECEIVING WATER TYPE[3]
	(10^3 m^3/day)[2]				
LAKE ERIE - cont'd.					
Ohio - cont'd.					
Oak Harbor	3.0	3.6	-		T
Perrysburg	5.3	5.5	-		T
Port Clinton	4.9	6.4	(6.4)		L
Rocky River S.D. #6	36.0	32.2	35.8		L
Sandusky	40	42.9	38.7		L
Toledo	319.9	326.1	377		L
Vermilion	4.1	4.2	5.5		L
Willougby Eastlake	23.5	23.6	30		L
TOTAL	1,481.6	1,552.6	1,647.6	1,560.6	
Pennsylvania					
Erie	174	177	243.2	190.1	L
New York					
Cheektowaga S.D. #5	36.2	29.3	37.5		L
Dunkirk	12.5	16.7	25.7		L
Erie Co. S.D. #2S	8.7	5.7	16.5		L
Fredonia	9.9	7.0	7.9		L
Hamburg Master S.D.	9.1	9.9	12.2		L
Hamburg Mt. Vernon S.D.	1.7	1.1	1.5		L
Lackawanna	14.3	13.3	12.5		L
West Seneca	5.6	6.1	-		T
TOTAL	98.0	89.1	113.8	100.3	
LAKE ONTARIO					
New York					
Alexandria Bay	1.2	1.6	1.6		
Amherst S.D. #1	29.3	27.4	30		L
Amherst S.D. #16	28.9	33.4	35		T
Brighton					
Allen Creek Plant	21	22.7	23.4		L
Richs Dugway Plant	6.4	7.3	4.9		L
Buffalo Sewer Authority	649.8	661.2	665.0		I
Canton	4.6	7.5	4.7		L
Cape Vincent	0.4	.54	0.5		L
Irondequoit N. St. Paul S.D.	3.7	4.4	3.2		T

Table 4-1 - cont'd.

NAME OF PLANT	1975	1976	1977	AVERAGE FLOW	RECEIVING WATER TYPE[3]
	$(10^3 m^3/day)^2$				
LAKE ONTARIO - cont'd.					
New York - cont'd.					
Irondequoit Northeast S.D.	7.0	7.6	7.9		L
Lewiston	2.5	2.5	3.0		L
Monroe Co. Northwest Quadrant	29.3	38.3	33.3		L
Niagara Falls	263.3	201	247		I
North Tonawanda	26.6	28.5	22.5		I
Ogdensburg	17.3	22.9	16.1		L
Ontario	-	-	0.7		L
Oswego					
East Side	7.2	7.7	7.2		L
West Side	6.1	6.4	(6.1)		L
Potsdam	5.1	5.7	0.1		L
Rochester Frank Van Lare Plant	261.8	284.2	244		L
Sodus Pt.	2.2	-	(2.2)		L
Tonawanda	18.6	19.4	17.8		I
Tonawanda S.D. #2	48.3	50.2	57.2		I
Waddington	0.5	.4	0.5		L
Webster	7.1	6.5	6.3		L
Wheatfield	1.9	.5	5.4		L
Youngstown	1.3	2.3	0.8		L
TOTAL	1,461.8	1,460.84	1,451.9	1,458.2	
GRAND TOTAL				8,869.4	

( )Estimate discharges based on previously reported data.

[1] Includes discharges into Great Lakes, Interconnecting Channels and Tributaries up to 5 km from lake.

[2] $10^3 m^3$/day = 0.264172 U.S. MGD or 0.408727 cfs.

[3] Receiving Water Types: L = Lake, I = Interconnecting Channels and T = Tributary (up to 5 km from lake).

SOURCE: Great Lakes Water Quality Board, Great Lakes Water Quality 1977 - Appendix C - Remedial Programs Subcommittee Report. International Joint Commission, Windsor, Ontario, July 1978, pp. II-1 - II-15.

TABLE 4-2

INVENTORY OF FLOWS AND CAPACITIES OF CANADIAN (ONTARIO) SEWAGE TREATMENT PLANTS ON THE GREAT LAKES[1]

NAME OF PLANT	ONTARIO MINISTRY OF ENVIRONMENT REGION[2]	TYPE OF TREATMENT[3]	CAPACITY $(10^3 m^3/d)$	AVE. DAILY FLOW (1975-77) $(10^3 m^3/d)$	RECEIVING WATER TYPE[4]
LAKE SUPERIOR					
Marathon	N.W.	1 ry	1.4	1.27	L
Nipigon	N.W.	1 ry	1.5	1.1	T
Red Rock	N.W.	1 ry	1.0	0.8	T
Schreiber	N.W.	2 dy	0.25	0.4	T
Thunder Bay N.	N.W.	1 ry	18.1	27.9	T
Thunder Bay S.	N.W.	1 ry	27.3	25.3	L
TOTALS		6 WPCP's		56.77	
LAKE HURON					
Sault Ste. Marie	N.E.	1 ry	54.4	41.0	I
Port McNicholl	C	1 ry	1.04	0.9	T
Penetanguishene	C	2 dy	4.9	3.0	L
Midland	C	1 ry	5.7	7.7	L
Collingwood	C	1 ry	19.0	12.8	L
Meaford	S.W.	2 dy	.86	2.8	L
Owen Sound	S.W.	1 ry	24.5	16.7	L
Goderich	S.W.	2 dy	4.5	7.2	L
TOTALS		8 WPCP's		92.1	

Table 4-2 - cont'd.

NAME OF PLANT	ONTARIO MINISTRY OF ENVIRONMENT REGION[2]	TYPE OF TREATMENT[3]	CAPACITY ($10^3 m^3/d$)	AVE. DAILY FLOW (1975-77) ($10^3 m^3/d$)	RECEIVING WATER TYPE[4]
LAKE ERIE					
Sarnia	S.W.	1 ry	65.8	40.3	I
Belle River	S.W.	2 dy	6.8	1.7	I
Windsor (Little River)	S.W.	2 dy	28.3	29.5	T
Windsor Westerly	S.W.	1 ry	108.9	100.7	I
Amherstburg	S.W.	1 ry	4.5	4.6	I
Leamington	S.W.	1 ry	19.0	3.5	L
Port Dover	S.W.	1 ry	9.5	4.9	L
Fort Erie (Crystal Beach)	W.C.	2 dy	3.1	3.9	L
Nanticoke	W.C.	1 ry	9.5	3.0	L
Point Edward	W.C.	1 ry	2.6	1.6	I
Corunna	S.W.	2 dy	1.5	1.2	I
Courtwright	S.W.	2 dy	.7	0.2	I
TOTALS		12 WPCP's		195.1	
LAKE ONTARIO					
Niagara Falls	W.C.	1 ry	45.4	30.2	I
Oakville (S.E.)	C	2 dy	9.1	8.6	L
Oakville (S.W.)	C	2 dy	45.5	32.1	L
Oshawa	C	2 dy	34.0	46.4	L
Pickering	C	2 dy	15.8	10.7	L
Port Colborne E	W.C.	2 dy	3.8	3.8	L
Port Colborne W	W.C.	2 dy	6.1	11.8	I
St. Catharines (Pt. Weller)	W.C.	2 dy	55.1	35.3	I
St. Catharines (Pt. Dalhousie)	W.C.	2 dy	61.2	36.0	L
Trenton	C	2 dy	15.8	10.8	L
C.F.B. Trenton	C	2 dy	4.5	4.4	L
Whitby (Corbett)	C	2 dy	17.2	11.3	L
Whitby (Pringle)	C	2 dy	14.7	9.9	T
Port Hope	C	2 dy	9.08	7.0	L
Picton	C	2 dy	-	3.7	T
Deseronto	C	2 dy	1.36	.7	
Grimsby	W.C.	2 dy	4.0	4.0	L

Table 4-2 - cont'd.

NAME OF PLANT	ONTARIO MINISTRY OF ENVIRONMENT REGION[2]	TYPE OF TREATMENT[3]	CAPACITY $(10^3 m^3/d)$	AVE. DAILY FLOW (1975-77) $(10^3 m^3/d)$	RECEIVING WATER TYPE[4]
LAKE ONTARIO - Cont'd.					
Bath	S.E.	2 dy	1.9	0.6	T
Belleville	S.E.	2 dy	36.3	34.1	L
Burlington Skyway	C	2 dy	90.8	52.1	L
Burlington Drury Lane	C	2 dy	11.3	7.5	L
Ajax (Town)	C	2 dy	14.0	9.8	T
Ajax (Pickering)	C	2 dy	1.8	1.8	T
Cobourg	C	2 dy	15.9	13.3	T
Fort Erie (Town)	W.C.	1 ry	8.1	12.5	I
Grimsby (Baker Rd.)	W.C.	2 dy	18.1	9.3	L
Hamilton	W.C.	2 dy	272.4	249.2	T
Mississauga (Clarkson)	C (Peel)	2 dy	54.5	41.2	L
Kingston Twp.	S.E.	2 dy	24.7	9.5	L
Metro Toronto Humber	C	2 dy	283.7	342.2	L
Metro Toronto Main	C	2 dy	817.2	808.4	L
Metro Toronto Highland Cr.	C	2 dy	135.2	119.6	T
Miss. (Lakeview)	C (Peel)	2 dy	227.0	166.4	L
Newcastle	C (Durh.)	2 dy	5.8	5.8	L
Kingston	S.E.	2 dy	118.04	57.8	S
Brockville	S.E.	1 ry	17.0	17.7	S
Cornwall (City)	S.E.	1 ry	37.5	51.8	S
Cornwall (Long Sault)	S.E.	2 dy	1.36	1.1	S
Iroquois	S.E.	1 ry	.2	2.5	S
Ingleside	S.W.	1 ry	1.4	1.4	S
Prescott	S.E.	1 ry	4.5	4.4	S
TOTALS		41		2286.7	
GRAND TOTAL		67		2630.7	

[1] Includes discharges from the Province of Ontario into Great Lakes, Interconnecting Channels, Tributaries up to 5 km from the Lakes and St. Lawrence River.

[2] Ministry of Environment Regions: N.W. - Northwestern; N.E. - Northeastern; C - Central; W.C. - West Central; S.W. - Southwestern; S.E - Southeastern.

[3] Primary treatment includes chemical addition for phosphorus removal.

[4] Receiving Water Type: L - Lake; T - Tributary (up to 5 km from Lake); I - Interconnecting Channels; S - St. Lawrence River.

SOURCE: Pollution Control Branch, Ontario Ministry of the Environment.

TABLE 4-3

DAILY PROCESSED FLOWS OF TREATED MUNICIPAL SEWAGE TO THE GREAT LAKES AND INTERCONNECTING CHANNELS BY BASIN AND JURISDICTION[1]

JURISDICTION	BASIN[2] (1000 m^3/d)[3]					TOTAL	PER CENT
	SUPERIOR	MICHIGAN	HURON	ERIE	ONTARIO		
UNITED STATES CONTRIBUTIONS							
Minnesota	81.2	-	-	-	-	81.2	.7
Wisconsin	20.8	1047.2	-	-	-	1068.0	9.3
Michigan	16.7	80.6	29.0	3793.5	-	3919.8	34.1
Illinois	-	68.5	-	-		68.5	.6
Indiana	-	422.7	-	-	-	422.7	3.7
Ohio	-	-	-	1560.6	-	1560.6	13.6
Pennsylvania	-	-	-	190.1	-	190.1	1.7
New York	-	-	-	100.3	1458.2	1558.5	13.6
TOTAL	118.7	1619.0	29.0	5644.5	1458.2	8869.4	77.1
CANADIAN CONTRIBUTION[4]							
Province of Ontario	56.8	-	92.1	195.1	2286.7	2630.7	22.9
TOTAL CONTRIBUTIONS	175.5	1619.0	121.1	5839.6	3744.9	11500.1	100
PER CENT	1.5	14.1	1.0	50.8	32.6	100.0	

[1] Average Flows for 1975-1977.

[2] Includes discharges into Great Lakes, Interconnecting Channels and up to 5 km upstream in tributaries.

[3] 1000 m^3/d = 0.264172 MGD or 0.408727 cfs.

[4] Excludes flows from sewage lagoons.

SOURCE: Tables 1 and 2.

TABLE 4-4

SIZE DISTRIBUTION OF U.S. SEWAGE TREATMENT PLANTS (STPs) DISCHARGING INTO THE GREAT LAKES[1]

RANGE OF DAILY PROCESSED VOLUME ($10^3 m^3/d$)	NO. OF PLANTS IN RANGE	PERCENT OF TOTAL NO. OF ALL STPs IN RANGE	DAILY PROCESSED VOLUME IN EACH RANGE ($10^3 m^3/d$)	PERCENT OF TOTAL DAILY VOLUME FROM ALL STPs
<5	34	30.6	90	1.05
5- 50	55	49.6	917	10.35
50-500	19	17.1	3,551	40.04
>500	3	2.7	4,311	48.56
TOTALS	111	100.0	8,869	100.0

[1] Based on averaged discharges 1975-77.

SOURCE: Table 1

TABLE 4-5

SIZE DISTRIBUTION OF CANADIAN SEWAGE TREATMENT PLANTS (STPs) DISCHARGING INTO THE GREAT LAKES[1]

RANGE OF DAILY PROCESSED VOLUME ($10^3 m^3/d$)	NO. OF PLANTS IN RANGE	PERCENT OF TOTAL NO. OF ALL STPs IN RANGE	DAILY PROCESSED VOLUME IN EACH RANGE ($10^3 m^3/d$)	PERCENT OF TOTAL DAILY VOLUME FROM ALL STPs
<5	27	40.3	63.3	2.5
5- 50	31	46.2	619.2	23.5
50-500	8	12.0	1,139.8	43.3
>500	1	1.5	808.4	30.7
TOTALS	67	100.0	2,630.7	100.0

[1] Based on averaged flows 1975-77.

SOURCE: Table 2

TABLE 4-6

SIZE DISTRIBUTION OF ALL SEWAGE TREATMENT PLANTS (STPs) DISCHARGING INTO THE GREAT LAKES INTERCONNECTING CHANNELS AND RELEVANT TRIBUTARIES[1]

RANGE OF DAILY PROCESSED VOLUME $(10^3 m^3/d)$	NO. OF PLANTS IN RANGE	PERCENT OF TOTAL NO. OF ALL STPs IN RANGE	DAILY PROCESSED VOLUME IN EACH RANGE $(10^3 m^3/d)$	PERCENT OF TOTAL DAILY VOLUME FROM ALL STPs
<5	61	34.3	153.3	1.3
5- 50	86	48.3	1,536.6	13.4
50-500	27	15.2	4,690.8	40.8
>500	4	2.2	5,119.4	44.5
TOTALS	178	100.0	11,500.1	100.0

[1] Based on averaged flows 1975-77.

SOURCE: Tables 4 and 5

TABLE 4-7

INVENTORY OF LARGEST U.S. SEWAGE TREATMENT PLANTS WITHIN THE GREAT LAKES BASIN

NAME AND LOCATION OF PLANT	TYPE OF TREATMENT	DESIGN FLOW $(10^3 m^3/d)$	AVE. DAILY FLOW $(10^3 m^3/d)$	RECEIVING WATER BODY
Green Bay	Secondary	236.36	115	Lake Michigan
Kenosha	Secondary	104.54	70	Lake Michigan
Milwaukee-Jones Is.	Secondary	909.09	518	Lake Michigan
Milwaukee-South Shore	Secondary	545.45	257	Lake Michigan
Racine	Secondary	136.36	76	Lake Michigan
Gary	Secondary	227.27	173	Lake Michigan (Trib)
Hammond	Secondary	218.18	148	Lake Michigan
Detroit	Secondary	4,772.72	3,277	Lake Erie
Wyandotte	Secondary	340.90	273	Lake Erie
Port Huron	Secondary	90.90	51	Lake Erie
Cleveland-Easterly	Secondary	545.45	442	Lake Erie
Cleveland-Westerly	Tertiary	159.09	126	Lake Erie
Toledo	Secondary	463.63	341	Lake Erie
Euclid	Secondary	100.00	70	Lake Erie
Lakewood	Secondary	72.72	49	Lake Erie
Erie	Secondary	295.45	198	Lake Erie
Buffalo	Secondary	818.18	658	Lake Ontario
Niagara Falls	Secondary	227.27	237	Lake Ontario
Rochester	Secondary	454.54	263	Lake Ontario
	19 Plants	10,718.10	7,342	

N.B. These plants account for 63.8% of total processed daily volume to the Great Lakes Basin.

TABLE 4-8

INVENTORY OF LARGEST CANADIAN SEWAGE TREATMENT PLANTS WITHIN THE GREAT LAKES BASIN

NAME AND LOCATION OF PLANT	TYPE OF TREATMENT	DESIGN FLOW ($10^3m^3/d$)	AVE. DAILY FLOW ($10^3m^3/d$)	RECEIVING WATER BODY
Hamilton	Secondary	272.4	249.2	Lake Ontario (Trib)
Metro Toronto				
- Humber	Secondary	283.7	342.2	Lake Ontario
- Main	Secondary	817.2	808.4	Lake Ontario
- Highland Cr.	Secondary	135.2	119.6	Lake Ontario (Trib)
- Lakeview	Secondary	227.0	166.4	Lake Ontario
Windsor	Secondary	108.9	100.7	Lake Erie (I.C.C.)
Kingston	Secondary	118.0	57.8	St. Lawrence R.
Cornwall	Secondary	37.5	51.8	St. Lawrence R.
Sault Ste. Marie	Primary	54.4	41.0	Lake Huron (I.C.C.)
Midland	Primary	5.7	7.7	Lake Huron
Owen Sound	Primary	24.5	16.7	Lake Huron
TOTAL	11 Plants	2,084.5	1,961.5	

N.B. These plants account for 17% of total processed daily volume to the Great Lakes Basin.

TABLE 4-9

UNIT PRICES OF CHLORINE IN CANADA AND THE U.S., 1979 ($/kg)

LOCATION	TANK CARS (50-89-6 MT)	1-TON CYLINDERS (907.2 kg)	150 LB.-CYLINDERS (68.04 kg)
CANADA			
Windsor	-	$0.42	-
Hamilton	-	0.40	0.80
Toronto	0.17	0.38	-
Kingston	-	0.38	0.75
Midland	-	0.43	-
Owen Sound	-	0.40	-
Unit Price Used in Calculations	$0.17	$0.40	$0.80
UNITED STATES			
Michigan	0.13	0.26	0.44
New York	0.15	0.22	0.40
Unit Price Used in Calculations	$0.14	$0.25	$0.43

N.B. 1 kg = .4536 lb.

SOURCES: Canadian prices: Survey of Sewage Treatment.
Michigan and New York: Gerald Brezner.

TABLE 4-10

ANNUAL CHLORINE CONSUMPTION BY CANADIAN (ONTARIO) SEWAGE TREATMENT PLANTS

LAKE BASIN/ SEWAGE TREATMENT PLANT	1977 ANNUAL CHLORINE CONSUMPTION (10^3Kg)	AVERAGE DOSAGE (mg/L)	TOTAL ANNUAL FLOW ($10^3 m^3$/yr.)	EFFLUENT FLOW THAT IS DISINFECTED ($10^3 m^3$/yr.)	MONTHS OF DISINFECTION	G = GAS (CHLORINE) H = NaOCl	REMARKS
Lake Superior[a]	-	-	-	-	-	-	
Lake Huron							
Sault Ste. Marie	77.0	5.0	14,965	14,965	12	-	
Port McNicoll	0.7	2.3	328	328	12	-	
Penetanguishene	-	-	-	-	-	-	
Midland	14.7	4.9	2,810	2,810	12	-	
Collingwood	-	-	-	-	-	-	
Meaford	1.0	3.0	17,644	420	5	-	
Owen Sound	23.2	4.2	6,095	6,095	12	-	
SUB TOTAL	116.6		41,842	24,618			Average 4.73 mg/L
Lake Erie							
Sarnia	-	-	-	-	-	-	
Belle River	0.7	5.1	128	128	2.50	G	Plant put into operation Oct. 10
Windsor (Little River)	15.6	3.43	10,767	10,767	12	G	
Windsor (Westerly)	217	8.2	36,756	27,189	9	G	
Amherstburg	-	-	-	-	-	-	
Leamington	-	-	-	-	-	-	
Port Dover	-	-	-	-	-	-	
Fort Erie (Crystal B.)	-	-	-	-	-	-	
Nanticoke	4.4	6.4	1,095	540	6	-	
Point Edward	3.1	4.4	584	584	12	G	
Corunna	2.5	5.0	438	438	12	G	
Courtright	0.4	7.8	73	73	12	G	
SUB TOTAL	243.7		49,741	39,718			Average 6.13 mg/L

Table 4-10 cont'd.

LAKE BASIN/ SEWAGE TREATMENT PLANT	1977 ANNUAL CHLORINE CONSUMPTION (10^3Kg)	AVERAGE DOSAGE (mg/L)	TOTAL ANNUAL FLOW (10^3m^3/yr.)	EFFLUENT FLOW THAT IS DISINFECTED (10^3m^3/yr.)	MONTHS OF DISINFECTION	G = GAS (CHLORINE) H = NaOCl	REMARKS
<u>Lake Ontario</u>							
Deseronto	0.81	3.3	255	255	12	G	
Bath	-	-	-	-	-	-	
Belleville	24.1	2.0	12,466	12,446	12	G	
Burlington (Skyway)	25	2.9	19,016	7,923	5	G	
Burlington (Drury Lane)	2.4	2.5	2,738	1,125	5	G	
Ajax (Town)	-	-	-	-	-	-	
Ajax (Pickering)	-	-	-	-	-	-	
Cobourg	-	-	-	-	-	-	
Fort Erie (Town)							
Grimsby (Baker Rd.)							
Hamilton	100.6	4.07	90,958	24,688	5.25	G	
Mississauga (Clarkson)	48	2.9	15,038	15,038	12	G	
Kingston Twp.	7	2.0	3,467	3,467	12	G	
Metro Toronto - Humber	199.6	3.2	124,903	64,233	5.50	G	
Metro Toronto - Main	272.2	3.1	295,066	86,118	4	G	
Metro Toronto - Highland Cr.	135.6	2.8	48,240	48,240	12	G	
Mississauga (Lakeview)	226.0	4.1	60,736	60,736	12	G	
Newcastle	-	-	-	-	-	-	
Niagara Falls	-	-	-	-	-	-	
Oakville (S.E.)	-	-	-	-	-	-	
Oakville (S.W.)	-	-	-	-	-	-	
Oshawa	-	-	-	-	-	-	
Pickering	-	-	-	-	-	-	
Port Colborne E.	-	-	-	-	-	-	
Port Colborne W.	-	-	-	-	-	-	
St. Catharines (Pt. Wellar)	-	-	-	-	-	-	
St. Catharines (Pt. Dalhousie)	-	-	-	-	-	-	
Trenton	18.6	5.5	3,942	3,942	12	G	
Whitby (Corbett)	-	-	-	-	-	-	

Table 4-10 - cont'd.

LAKE BASIN/ SEWAGE TREATMENT PLANT	1977 ANNUAL CHLORINE CONSUMPTION (10^3Kg)	AVERAGE DOSAGE (mg/L)	TOTAL ANNUAL FLOW (10^3m^3/yr.)	EFFLUENT FLOW THAT IS DISINFECTED (10^3m^3/yr.)	MONTHS OF DISINFECTION	G = GAS (CHLORINE) H = NaOCl	REMARKS
Whitby (Pringle)	-	-	-	-	-	-	
Port Hope	-	-	-	-	-	-	
Picton	-	-	-	-	-	-	
Grimsby	-	-	-	-	-	-	
SUB TOTAL	1,059.5		676,825	328,211			Average 3.23 mg/L
St. Lawrence River (Lake Ontario Basin)							
Brockville	-	-	-	-	-	-	
Kingston	80.2	3.8	21,097	21,097	12		
Cornwall (City)	137.0	6.7	18,907	18,907	12	G	
Cornwall (Long Sault)	-	-	-	-	-	-	
Iroquois	-	-	-	-	-	-	
Ingleside	-	-	-	-	-	-	
Prescott	6.0	3.7	1,606	1,606	12	G	
	223.2		41,610	41,610			Average 5.36 mg/L
GRAND TOTAL (ALL BASINS) For those STPs for whom dossage is known.	1,643		810,018	434,157			

[a] No data for Lake Superior plants - Marathon, Nipigon, Red Rock, Schreiber, Thunder Bay N. and Thunder Bay S.

Average Dose is 3.78 mg/L.
% of Total Annual Flow Disinfected is 53%.

TABLE 4-11

TOTAL ESTIMATED CHLORINE CONSUMPTION AND DISCHARGES FROM CANADIAN (ONTARIO) SEWAGE TREATMENT PLANTS

1.	Total Daily Processed Volume from Canadian Plants (1975-1977) was:	2,631 x 10^3 m^3/d
2.	Daily Processed Volume for which Chlorine Dosage was known was 84.3% of the Total Daily Volume or:	2,219 x 10^3 m^3/d
3.	For those plants in which dosage was known, average Chlorine Dosage was:	3.78 mg/L
4.	Total Disinfected Flow as a Percentage of Annual Processed Volume was	54%[1]
5.	Total Annual Chlorine Consumption for those plants for which dosage was known was	1,653 tonnes
6.	Assuming that all flows are disinfected at a dosage of 3.78 mg/L, the Total Annual Chlorine Consumption is estimated as	1,960 tonnes
7.	Estimated Annual Chlorine Discharges assuming 0.5 mg/L residual	259.3 tonnes

[1] Seasonal disinfection is permitted in Ontario under defined circumstances.

TABLE 4-12

ESTIMATED ANNUAL CHLORINE USE AND EXPENDITURE AT LARGEST CANADIAN (ONTARIO) SEWAGE TREATMENT PLANTS

PLANT NAME AND LOCATION	CONTAINER TYPE	PRICE ($/kg)	ANNUAL CHLORINE USAGE USAGE	ESTIMATED EXPENDITURES ($000's)
Hamilton	Rail Car	.194	100.6	$19.5
Metro Toronto				
- Humber	Rail Car	.1815	190.6	36.2
- Main	Rail Car	.1815	272.2	49.4
- Highland Cr.	Rail Car	.1815	135.6	24.6
- Lakeview	Rail Car	.1815	226.0	41.0
Windsor	Rail Car	.2017	232.6	46.9
Kingston	Ton Cylinder	.3849	80.2	30.9
Cornwall	Ton Cylinder	.3849	137.0	52.7
Sault Ste. Marie	Ton Cylinder	.55	77.0	42.4
Midland	Ton Cylinder	.43	14.7	6.3
Owen Sound	Ton Cylinder	.368	23.2	8.5
TOTAL OF PLANTS FOR WHICH CONSUMPTION AND COSTS ARE KNOWN			1,498.7	$358.5
PLANTS FOR WHICH CONSUMPTION AND COSTS ARE ESTIMATED (ASSUMED TO BE DELIVERED IN 150-LB. CYLINDERS)		0.80	(1,653.0 - 1,498.7) 154.3	123.4
TOTALS			1,653.0	$481.9

TABLE 4-13

CHLORINE USE AND COSTS AT LARGER SEWAGE TREATMENT PLANTS IN THE U.S. - 1978

JURISDICTION	PLANT NAME	CONTAINER TYPE	UNIT PRICE ($/lb)	AVERAGE CHLORINE USE (lbs/d)	COST ($$10^3$/a)
Minnesota	Duluth	Tank Car	.078	3,600	102.5
Wisconsin	Green Bay	Tank Car	.065	1,500	35.6
Wisconsin	Kenosha	Ton	.122	200	9.0
Wisconsin	Milwaukee-Jones Is.	Tank Car	0.53	6,900	133.0
Wisconsin	Milwaukee-South Shore	Tank Car	.053	2,400	46.0
Wisconsin	Racine	Ton	.140	550	28.0
Indiana	Gary	Ton	.113	625	25.0
Indiana	Hammond	Ton	.095	250	8.0
Michigan	Detroit	Tank Car	.042	71,500	1096.0
Michigan	Wyandotte	Pipeline	.065	3,500	83.0
Michigan	Port Huron	Ton	.046	185	3.0
Ohio	Cleveland-Easterly	Ton	.100	1,500	54.0
Ohio	Cleveland-Westerly	Ton	.100	1,000	36.0
Ohio	Toledo	Ton	.090	1,930	63.0
Ohio	Euclid	Ton	.094	400	13.0
Ohio	Lakewood	Ton	.100	140	5.0
Pennsylvania	Erie	Tank Car	.040	5,000	73.0
New York	Buffalo	Ton	.125	6,700	305.0
New York	Niagara Falls	Tank Car	.060	1,700	37.0
New York	Rochester	Ton	.085	3,900	120.0
	TOTALS			113,480	2,172.0

A total of 18,788,202 kg of Chlorine were used at a total expenditure of $2,172,000.00.

TABLE 4-14

TOTAL ESTIMATED CHLORINE CONSUMPTION AND DISCHARGE FROM U.S. SEWAGE TREATMENT PLANTS

1. Total Daily Processed Volume from U.S. WPCP's (1975-1977)	8,869 x $10^3 m^3/d$
2. Daily Processed Volume for which chlorine dosage is known is 82.8% of the Total Daily Volume or:	7,342 x $10^3 m^3/d$
3. For those plants in which dosage was known, average dosage was	6.80 mg/L
4. Total Disinfected Flow as a percentage of Annual Processed Volume was	100%
5. Total Annual Chlorine Consumption for those plants for which dosage was known was	18,788 tonnes
6. Assuming that all flows are disinfected at a dosage of 6.80 mg/L, the Total Annual Chlorine Consumption is estimated as	22,012 tonnes
7. Estimated Annual Chlorine Discharge assuming .5 mg/L total residual chlorine	1,618 tonnes

TABLE 4-15

ESTIMATED ANNUAL EXPENDITURE FOR CHLORINE USED AT U. S. SEWAGE TREATMENT PLANTS

	CHLORINE CONSUMPTION (10^3 kg/yr)	UNIT PRICE ($/kg)	COST (10^3/yr)
Plants for which consumption and cost are known	18,230		2,172
Plants for which consumption and cost are estimated (chlorine use data indicates most small plants would use 150-lb. cylinder)	3,782	$.40 (150-lb. cyl.)	1,512.8
TOTALS	22,012	w/ 150-lb. cyl.	$3,684.8

TABLE 4-16

ESTIMATED TOTAL UNITED STATES AND CANADIAN SEWAGE TREATMENT PLANT CHLORINE USE, DISCHARGE AND COST

TOTAL DAILY PROCESSED VOLUME:	Can.	2,631 x $10^3 m^3$/Day	
	U.S.	8,869 x $10^3 m^3$/Day	
		11,500 x $10^3 m^3$/Day	
TOTAL YEARLY CHLORINE CONSUMPTION:	Can.[1]	1,960 x 10^3K6	
	U.S.[2]	22,012 x 10^3K6	
		23,972 x 10^3K6	
TOTAL ANNUAL ESTIMATED CHLORINE DISCHARGE ASSUMING .5 mg/L TOTAL RESIDUAL CHLORINE:	Can.[1]	259.3 x 10^3K6	
	U.S.[2]	1,618.0 x 10^3K6	
		1,877.3 x 10^3K6	
TOTAL CHLORINE COST PER YEAR:	Can.	$ 481.9 x 10^3	
	U.S.	3,684.8 x 10^3	(Using 150 lb. cylinders)
		$4,166.7 x 10^3	

[1] Seasonal Disinfection
[2] Year-Round Disinfection

APPENDIX 5

TASK FORCE MEMBERSHIP LIST

MEMBERSHIP LIST

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