REVIEW OF PLANNING FOR THE GRAND RIVER WATERSHED

MANAGEMENT SERVICES DIVISION

TREASURY
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REVIEW OF PLANNING FOR THE GRAND RIVER WATERSHED

MANAGEMENT SERVICES DIVISION,
PROJECT # 229,
OCTOBER 20, 1971.

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SUMMARY AND CONCLUSIONS

We have now completed a general investigation of those issues related to water management in the Grand River Basin which have been amenable to analysis with existing information. Our terms of reference for this study were:

> "To review the future likely growth and development of the communities in the Grand River Basin and the various demands for water which this will entail. Further, to study the water available from different sources and the proposals suggested to date for satisfying the requirements from these sources. This will include an examination of the consequences of the alternative proposals in terms of water supply, quality, flood control, recreation and in general, the management of the river system as a resource. Costs and financial implications of each alternative will be identified and analysed. Based upon this review, the broad policy options will be discussed as to their desirability and short term priorities will be recommended. The requirements in terms of future studies to allow the formulation of a detailed long-term development plan and a process to evaluate the consequences of changing conditions on this plan will be summarized."

On February 26, 1971 our interim report, listing five short-term priority recommendations was presented to the Annual Meeting of the Grand River Conservation Authority, in Galt, by the Honourable George A. Kerr. This present report and its recommendations are the product of further studies carried out since that date by an inter-departmental government team directed by the Management Science Branch of the Treasury Board Secretariat.

We have approached these studies with the aim of addressing the major contentious issues and priority needs. We are of the opinion that our recommendations will provide solutions to pressing water management problems of the next decade and will further provide the wherewithal to complete the comprehensive planning necessary to handle the next thirty years. Certain rather substantial shifts in priorities from those suggested in the past by other reports and supported by various agencies, will be found in our recommendations. In addition, certain issues which were claimed to be resolved by past reports have been held over for future study in this report. We make no apologies for this, as it is, based upon our belief that past studies have not addressed all of the complexities and alternatives inherent in the system. Despite the multitude of studies carried out concerning various aspects of water management in the basin over past years, we are left with the inescapable conclusion that there is presently insufficient relevant data to clearly resolve all of the main issues. The terms of reference for past studies have tended to be narrow due to budgetary restrictions and divided jurisdictions concerning water management. In addition, public awareness and concern for environmental issues have greatly increased recently and the technology for dealing with many of the complex problems is still in its infancy. When several hundred million dollars of possible expenditures are at stake for water management, as they are for the Grand River watershed, it is obvious that a detailed understanding of the system is essential. We have, therefore, suggested a list of rather costly future studies required over the next three to four years, in addition to our recommendations on specific capital works and more general matters. Although these studies would likely cost in the neighbourhood of $2 million, they have been justified in our report based upon the risk of mis-spending vastly larger sums without them.

In terms of water quality and pollution considerations, we have made only limited recommendations for specific works, principally the reservoirs above Guelph on the Speed River and above Elmira on the Canagagigue Creek to deal with critical quality problems. In addition, we have reviewed plans for waste treatment at various points in the watershed and those situations which we felt were seriously lacking. Our main efforts have been devoted to identifying gaps in required information and in developing methods of analysis to allow knowledgeable and determined steps to improve water quality. In addition, we have made recommendations which should improve facility operations and coordination among the various agencies involved.

Our analyses concerning water supply have been principally for the municipalities of Guelph, Hespeler, Preston, Galt, Waterloo, Kitchener, Brantford and those in the lower end of the watershed, although water supply sources for all communities have been reviewed. We have concluded that all communities other than those specifically mentioned, should continue indefinitely on their present sources of supply, or in a few cases might tie into one of the supply options designed for the population centres mentioned. We feel that there is adequate developable groundwater in the Guelph vicinity to make unnecessary any other source of supply for the next thirty years at least. We have, for this report, assumed that such additional supply would likely be developed north of Guelph along the Eramosa River, and that the Everton Reservoir would then be utilized partly to restore baseflows if severe stream interference takes place. If further studies on groundwater in the Guelph area indicate that our assumptions in this report are invalidated, then other alternative reservoirs could be re-examined before finally committing to the Everton site. Detailed evaluations of a large number of feasible water supply options for the five municipalities of Hespeler, Preston, Galt, Waterloo and Kitchener (referred to as the "Megalopolis" in the report) indicate to us that a shared and inter-connected system would be most efficient. On an economic basis, our deliberations show that utilizing internal sources based upon groundwater with the Ayr Reservoir used to recharge groundwater aquifers could be much less costly than systems based upon a Great Lakes pipeline. However, all aspects of the analysis could not be completed in the time allotted to produce this report, and certain key information is not available, so that we have not made a firm recommendation concerning the Ayr Reservoir. The main information required relates to the cost and feasibility of groundwater recharge schemes and further study has been recommended to resolve these questions. We are of the opinion that with better management of existing wells and the development of known aquifers, there will be sufficient supply for the Megalopolis for about the next ten years. We have made recommendations on the additional studies which would be required to resolve the issue in sufficient time to avoid future water supply problems.

The best long term source of supply for Brantford depends very much upon what system eventually becomes adopted for the Megalopolis. If the system outlined above is proven out by future studies, then from an economic point of view, Brantford would be best to continue indefinitely obtaining supply from the river. There is a question of possible risk of utilizing the river for a source of supply at Brantford, but the extent to which this exists and can be balanced against cost savings has not been resolved in this report. If the Nanticoke-Lake Erie system should for any reason be extended to the Megalopolis, it would make economic sense for Brantford to join the scheme whenever it is built.

Flood control dams have been recommended in this report to the extent that they are justified on a benefit-cost basis and as part of the overall water management system. The Guelph Dam will provide very large benefits to all downstream communities in the basin. There are good indications that dams at Hespeler and Everton or Arkel could be justified on flood control grounds, but we feel that further study should be carried out before confirming such decisions. Although present information indicates that the Ayr Dam is not justified on flood control grounds alone, substantial flood control benefits to Paris, Brantford and downstream communities would be realized if it is built as part of a water supply system for the Megalopolis.

Works which we have concluded should be deferred for the next few years, until additional studies are complete, include the proposed water supply pipelines from the Great Lakes to Brantford and upstream communities; and the West Montrose, Everton, Hespeler and Ayr Dams, although we have recommended the purchase of land for the latter three reservoirs. The reasoning behind the conclusions reached can be found discussed in detail in the text of the report. It is essential to look behind the factor of location of the recommended Guelph Reservoir in order to see its impact on the basin and why we have assigned to it first priority. Thus, the flood control benefits of the Guelph Reservoir exceed those of any other reservoirs, even though some of the latter have much greater storage capacity. The key to this seemingly anomalous result is that location of a flood control structure can be more important than capacity, and the sites of Everton and Guelph turn out to be very strategic in terms of flood hydrology. Our calculations indicate that Guelph, Hespeler, Preston, Galt, Paris and Brantford will all obtain greater flood control benefits for the capital expended under our recommendations than would be the case if the previous priorities of the Five Dam Proposal were followed. A major reason for the omission of the West Montrose Reservoir from our recommendations is that the low flow augmentation benefits which we have been able to assess are much less than previously assigned by Clough (1966). This is largely since Clough traded off secondary waste treatment against low flow augmentation resulting in substantial assumed benefits. This, in our view, is not a reasonable approach to follow. It is perhaps acceptable to consider a tradeoff of flow augmentation against advanced treatment, but when so doing, we have not found substantial flow augmentation benefits using currently available information.

It is important to stress again that the importance of reservoirs to the various communities in the watershed should not be looked at in terms of their actual physical location, but rather in terms of their influence on the basin as a whole and the improvements in flexibility of planning and operations which they provide. Further, we repeat that a number of important issues remain to be resolved, and that a coordinated follow up to the present report, including the future studies described, is an essential next step.

As a first priority we recommend the construction of a dam on the Speed River upstream of Guelph and that engineering and construction should proceed as soon as possible. The reservoir should be designed and operated for the primary purpose of low flow augmentation and operational systems should be developed to provide satisfactory stream quality in the Speed River below the Guelph waste treatment plant. The other main purposes of the reservoir should be for flood control and recreation.

..........RECOMMENDATION NO. 1

We recommend that the OWRC investigate further steps that might be taken to reduce the loading on the Speed River from the Guelph waste treatment plant.

.... RECOMMENDATION NO. 2

We recommend that programs now being undertaken by staff of the OWRC should proceed as fast as possible to allow the input of industrial waste into the Elmira waste treatment plant without adversely affecting the treatment process. At the same time, we feel that the industry is responsible for the consequences of its wastes and should concurrently search out ways of improving them.

*.......... RECOMMENDATION NO. 3**

We recommend that the Woolwich Dam on the Canagagigue Creek above Elmira should be proceeded with immediately and its primary purpose should be for low flow augmentation.

*.......... RECOMMENDATION NO. 4**

We recommend that a study be undertaken immediately to develop an optimal operating system for the storage facilities at Conestogo and Belwood Lakes with respect to low flow augmentation. Furthermore, as new dams are constructed, they should be included in a revised operating procedure for low flow augmentation designed with the whole downstream river system in mind.

*.......... RECOMMENDATION NO. 5**

We recommend that water quality standards and further planning evaluations related to river quality and effluent loading guidelines should employ a computer simulation; to take account of the probabilistic nature of the processes and to incorporate mathematical stream flow models to describe the significant water quality characteristics, such as dissolved oxygen, in the stream. In addition, we recommend that further field work on river quality characteristics adequate to allow for the evaluation of planning alternatives and the calibration of stream models be carried out. Such studies would include, among other things, a quantitative study of biomass and its major determining factors, rates of photosynthesis and respiration, benthal deposits, re-aeration rates, the sources and rates of assimilation of B.O.D. and the hydraulic characteristics of the river. Furthermore, such data should be collected so as to represent the probabilistic behavior of pollution sources and stream response.

.... RECOMMENDATION NO. 6

We recommend that the OWRC should identify those potential sources of pollution not under its control at present. Following this, it should search out new opportunities to set standards and approve designs for municipalities and commercial enterprises on the design, installation and operation of equipment, storage facilities or piping which carry polluting materials that could enter surface or groundwater. Furthermore, provision should be made for regular inspection of such facilities by the OWRC and for remedial actions to be enforced even if stream pollution has not yet occurred.

.... RECOMMENDATION NO. 7

We recommend that communities on the Speed and Eramosa Rivers above Guelph, above Waterloo on the Grand River, above Ayr on the Nith River, and on other tributaries, should restrict their growth to the greatest possible degree, and in general, that the communities in the Grand River Basin should exercise moderation in planned growth and should accept the responsibility for ensuring that environmental problems do not develop from future increases in population or industry.

.... RECOMMENDATION NO. 8

We recommend a coordinated program by provincial government departments to stimulate a renewed emphasis on grass roots conservation practices through improved regulations, conservation education, fiscal incentives and research, so as to minimize the adverse effects of land and livestock management on the water quality and quantity in the Grand River Basin.

.... RECOMMENDATION NO. 9

We recommend that a three-man technical operations coordinating committee be set up with representation from the OWRC, the GRCA and the Conservation Authorities Branch. This committee should be responsible for ensuring a closer exchange of plans and information among the three agencies through regular meetings.

.... RECOMMENDATION NO. 10

We recommend that all impoundments on the Grand River and its tributaries having the facility for controlling stream flows and which are considered by the OWRC or the Conservation Authorities Branch to be of consequence in terms of stream quality or quantity considerations, should be required to file a plan of operations with the Grand River Conservation Authority. Any planned deviations should be subject to prior approval of the technical operations coordinating committee (see recommendation 10).

.... *RECOMMENDATION NO. 11*

We recommend that the OWRC and the GRCA jointly investigate the potential improvement to the quality of the Speed River, of modified operations for small dams located between the site of the new Guelph Dam and the confluence with the Grand River during low flow periods in the summer. Further, if the improvements are significant, the GRCA should determine what measures could be taken to operate these reservoirs consistent with the results indicated.

.... *RECOMMENDATION NO. 12*

We recommend that the OWRC initiate an investigation of the sanitary, storm and combined sewers of municipalities in the Grand River Basin with a view to establishing the extent and consequences of storm runoff on stream quality and aquatic life; and further to suggest the alternatives and their costs to alleviate the problems found. The information should be collected so as to be useable in the computer simulation (see recommendation 6).

.... *RECOMMENDATION NO. 13*

We recommend that a field pilot program into land disposal of treated sewage effluents should be carried out in the Grand River Basin by the OWRC to establish feasibility with respect to the effects on stream quality, groundwater, stream flows and the quantities which could be disposed of and the related costs as compared to at-plant advanced treatment.

.... *RECOMMENDATION NO. 14*

We recommend that the Conservation Authorities Branch develop a hydrologic simulation to allow the prediction of the consequences of real or assumed flood events under different flood routing policies. We further recommend the development of a mathematical optimizing model to select flood routing policies so as to ensure maximum benefits from existing reservoirs considering their multi-purpose nature.

.... *RECOMMENDATION NO. 15*

We recommend that land for the proposed Hespeler Reservoir on the Speed River should be purchased as it becomes available, but that the dam should not be constructed nor detailed design carried out, until its validity as part of the overall water management plan is confirmed.

.... *RECOMMENDATION NO. 16*

We recommend that all new water supply developed for the municipalities of Kitchener, Waterloo, Hespeler, Preston and Galt (hereafter called the Megalopolis) should be based upon an integrated plan for potable water for the whole area rather than for any one municipality.

.... *RECOMMENDATION NO. 17*

We recommend that Brantford should temporarily continue its water supply from the Grand River, pending an ultimate decision on the long-term supply source for the Megalopolis. If the Megalopolis obtains its long-term supply from the Nanticoke-Lake Erie system, then Brantford should also obtain their water from this source. If the Megalopolis does not obtain their supply from the Nanticoke-Lake Erie system, the least costly alternative for Brantford would be to continue obtaining supply from the Grand River.

.... *RECOMMENDATION NO. 18*

We recommend that Guelph should obtain its long-term water supply from groundwater sources, with careful planning of well development so as to prevent reduction in base flows of streams.

.... RECOMMENDATION NO. 19

We recommend that land for the proposed Everton Reservoir, on the Eramosa River, should be purchased as it becomes available, but that the dam should not be constructed until further evaluations related to flood control and groundwater are completed. We further recommend that if the Everton Dam is constructed, an ecological study should be carried out to minimize any possible adverse effects on the Eramosa River.

.... RECOMMENDATION NO. 20

We recommend that a detailed field study be carried out, starting within the next year, to establish groundwater availability and quality, artificial recharge rates, stream flow interference effects and development costs for recharge schemes and new well fields in the Megalopolis and Guelph areas. As a first step, analysis should be undertaken to determine the optimal groundwater management program and yield for existing well fields. Concurrently, sufficient field work should be done to establish reconnaissance estimates for recharge schemes and subsequently for drilling schemes. The program should be set up with sufficient flexibility that it may be terminated without major expenditure of funds if results are not promising.

..........RECOMMENDATION NO. 21

We recommend that the municipalities of the Megalopolis should continue to utilize groundwater for their supply at least until the period when a review of the results of the groundwater study (recommendation 21) is completed. Subsequently, a further evaluation of long-term water supply options for the Megalopolis should be carried out with particular emphasis on systems based on the Ayr Reservoir and a Lake Erie pipeline as alternatives. This further evaluation should incorporate the economic, social and water management implications of the various schemes.

.... RECOMMENDATION NO. 22

We recommend that land for the proposed Ayr Reservoir, on the Nith River, should be purchased as it becomes available, but that the dam should not be constructed nor detailed design carried out, until the results of further studies and evaluations (see recommendations 21 and 22) confirm it as part of the long-term water supply system for the Megalopolis.

.... RECOMMENDATION NO. 23

We recommend that a multi-disciplinary planning team, within government, should coordinate the continuing development of a comprehensive water management plan for the Grand River Basin and in particular, should carry out or coordinate the carrying out of the various studies outlined in the recommendations. Staff assigned to the planning team should be relieved of sufficient other duties to make their contribution reflect the importance of the assignment.

.... RECOMMENDATION NO. 24

*
Recommendations 1 to 5 are, with slight changes of wording, the same as presented in our interim report of February 19, 1971, presented to the Annual Meeting of the GRCA at Galt on February 26, 1971.

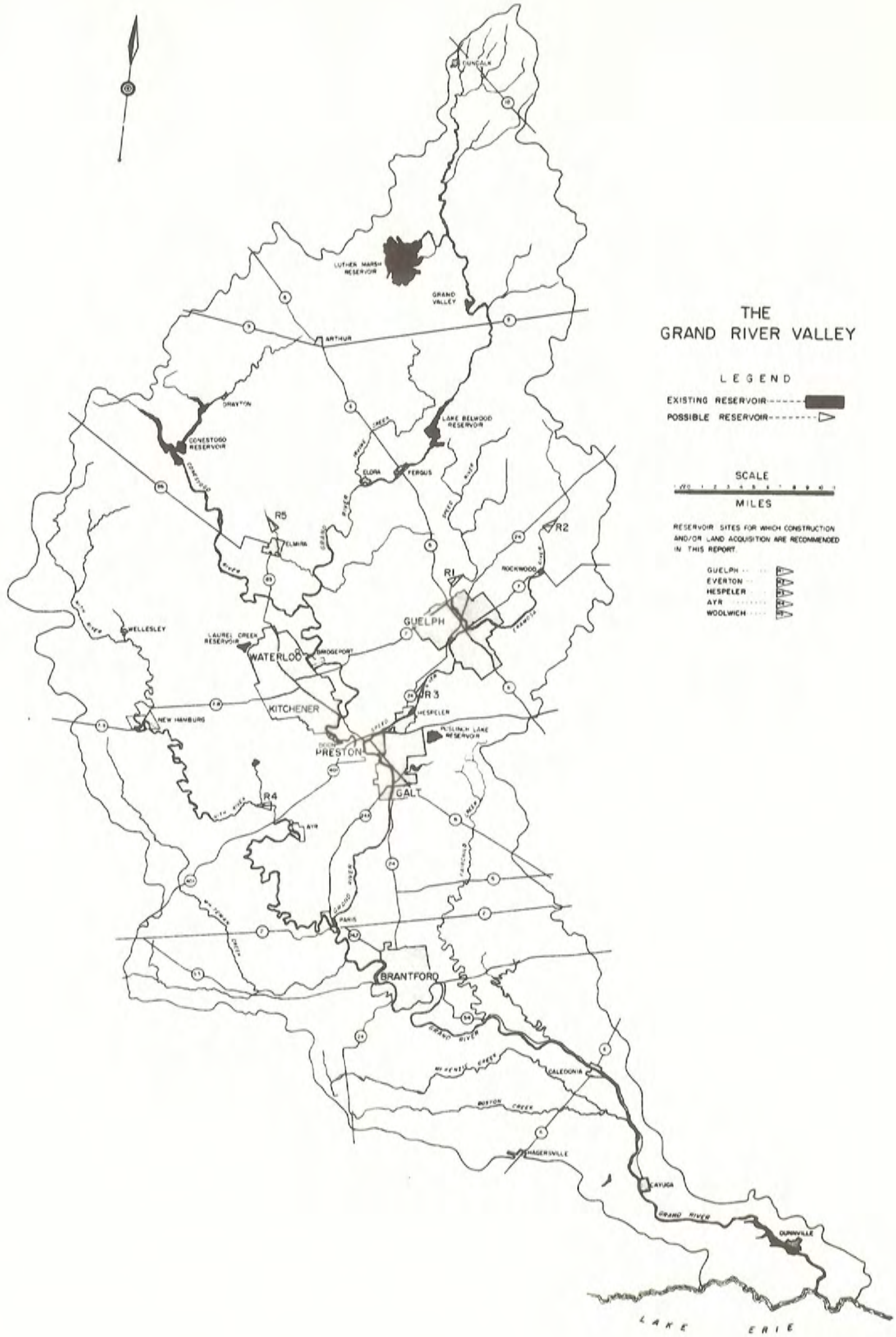

THE
GRAND RIVER VALLEY
LEGEND
EXISTING RESERVOIR
POSSIBLE RESERVOIR
SCALE
MILES
RESERVOIR SITES FOR WHICH CONSTRUCTION AND/OR LAND ACQUISITION ARE RECOMMENDED IN THIS REPORT.
GUELPH
EVERTON
HESPELER
AYR
WOOLWICH
DUNDALK
LUTHER MARSH RESERVOIR
GRAND VALLEY
ARTHUR
DRAYTON
CONESTOGO RESERVOIR
LAKE BELWOOD RESERVOIR
ELORA
FERGUS
R5
ELMIRA
R2
R1
ROCKWOOD
GUELPH
WELLESLEY
LAUREL CREEK RESERVOIR
WATERLOO
BRIDGEPORT
R3
KITCHENER
HESPELER
NEW HAMBURG
PRESTON
PUSLINCH LAKE RESERVOIR
GALT
R4
AYR
PARIS
BRANTFORD
GRAND RIVER
CALEDONIA
BOSTON CREEK
HAGERSVILLE
CAYUGA
DUNNVILLE
LAKE ERIE

FIG. I

THE GRAND RIVER BASIN

The Grand River Basin (see figure 1) is defined by an area of 2,600 square miles stretching from Port Maitland on Lake Erie, to the head waters close to Georgian Bay. The Grand, and its major tributary rivers the Nith, Speed and Conestogo, flow through one of the most important socio-economic regions in Ontario, containing the major population centres of Kitchener, Waterloo, Guelph, Galt and Brantford as well as many other towns and villages and important agricultural areas. The population of the watershed is approximately 500,000 with a growth rate over the past 10 years of 2-3% annually. The river system is very important to the people of the basin, providing water for municipal, industrial and agricultural uses, recreation and a vehicle for the conveyance of wastes. It also poses a serious hazard to significant portions of the population from time to time due to severe flooding.

Water management planning for the Grand River Basin involves a large number of conflicting factors. The major considerations of water supply, water quality, flood control, recreation and preservation of the environment all conflict, in the sense that the achievement of one effectively influences the degree to which the others can be achieved. Other conflicts of a spatial nature arise due to actions at one location in the basin causing consequences at other locations. For example, downstream communities are directly affected by the amount of pollution released to the river by their upstream neighbours and the degree to which they treat it. This conflict is further highlighted by the observation that the quantity of groundwater taken by the upstream communities, resulting in stream flow interference, and their rate of growth will make the pollution problem even more acute for the downstream neighbours.

Many more examples of this type of "system interaction" could be discussed, however, this has probably been adequate to communicate the complexity of the system. There are, of course, also conflicts due to divided jurisdiction among various agencies, and a gigantic number of possible planning components to achieve the ends desired. Such planning components include dams, diversions, pipelines, tertiary treatment, land disposal and so on and on.

In this study, we have taken only the required first steps so as to resolve the most pressing problems and also those for which clear choices could be made based upon available information. A discussion of further planning which will be required may be found later in the report under "Comprehensive Basin Planning".

WATER QUALITY IN THE GRAND RIVER SYSTEM

The problem of improving the quality of the Grand River and its tributaries has been recognized for some time. The Grand River Conservation Report (1962) ranked stream flow augmentation as equal in importance to flood control, and this has been repeated and stressed in subsequent reports by consultants. The Ontario Water Resources Commission carried out biological surveys in 1966 on the Grand River and its tributaries and in 1965 and 1970 on the Speed River. These showed that the Canagagigue Creek was "extremely polluted by toxic industrial wastes and organic matter" while the Speed River showed "gross organic contamination below Guelph and Hespeler". More moderate impairment of water quality was found in the Alder Creek, local points on the Grand River below Dundalk and Fergus and in the entire river between Bridgeport and Brantford. From Brantford to Caledonia and below Dunnville there was also found to be considerable evidence of pollution.

In addition to heavy organic pollution, high enrichment of the water by nutrients such as phosphorus and nitrogen was observed, starting at Bridgeport on the Grand River and at Guelph on the Speed River. These were accompanied by "a luxuriant growth of filamentous green algae" except for the stretches of deep water below Brantford where physical characteristics of the stream were unsuitable for this type of algae to attach. High coliform counts have been observed from time to time below the sewage treatment plants, causing some concern about the safety of these areas for water contact sports.

Since the 1965 and 1966 reports, there have been only moderate changes in the status of the waste treatment facilities in the watershed at the major centres. Guelph, whose secondary treatment plant was close to capacity, has now enlarged this and has included into the treatment some of the sources of industrial wastes previously separate. A major industrial source of pollution has moved from Brantford and the industrial input to the Elmira sewage treatment plant is now better controlled to produce less frequent upsets of the municipal treatment process. Hespeler, which had negligible treatment, still has not completed its planned activated sludge plant. Dunnville, which previously released untreated wastes into Sunfish Creek now has completed its waste treatment facilities. Results from the routine monitoring program carried out by the OWRC at various points on the river system show the coliform counts (sampled during 1970) as being high on occasion at a number of points, in particular Hespeler, Elmira, Port Maitland and Dunnville. The 1970 Biological Survey of the Speed River has shown very little in the way of improvement for that river over the 1965 report. In January 1971, the OWRC issued an interim report on Wastewater Loading Guidelines for the Grand River Basin. This again confirmed the problems discussed, plus other localized actual and potential polluted areas in the Conestogo and Nith systems. Improved treatment at some of these points is underway or proposed and along with changes in the seasonal discharges to the stream, should eliminate most of the problems on the Conestogo and Nith Rivers. Some local problems are likely to continue on tributary streams such as the Baden, Alder and Wellesley Creeks even with these proposed actions. These problems would take on increased importance with the presence of the Ayr Reservoir as a water supply source.

In terms of low flow augmentation, the capacity has been constant since 1959 when the Conestogo reservoir was completed and is only significant on the Grand and Conestogo Rivers. Lack of flow augmentation is considered to be a serious problem on the Speed River and Canagagigue Creek, due to the high waste loading imposed on these watercourses and the very low base flows during drought conditions.

To summarize the state of quality: serious problems have existed and continue to exist in several areas of the Grand River basin and will become aggravated as population increases. It seems clear that if the river is to be markedly improved in quality, the causes leading to the present situation must be carefully diagnosed and solutions beyond those presently in effect considered.

Pollution and Uses of the River:

When considering pollution in the Grand River system, we have used the term in this report in the sense of: "those substances which either are deleterious to desirable uses of the river or which are present in significantly higher amounts than for the natural or pristine state of the river". It is a somewhat academic exercise to concern ourselves with attempting to return the river to its pristine quality. It is a fact that over the past century large population concentrations have come into being, as well as extensive agriculture and a significantly changed physiography. We will certainly have to accept that some price will be paid in terms of the purity of the river because of these changes. The significant question is: how much degradation in quality is too much? One way to interpret this is in terms of the uses of the river, defined in the broadest sense. In the Guidelines and Criteria for Water Quality Management in Ontario (OWRC 1970) the uses have been broken down into five categories for convenience:

1) Agriculture
2) Aquatic Life and Wildlife
3) Industrial Water Supplies
4) Public Water Supplies
5) Aesthetics and Recreation

to this can be added a very common sixth use, namely

6) Assimilation of Wastes.

The OWRC have listed criteria necessary to protect the first five years in the above mentioned report in considerable detail. We have not attempted to deal with all of the measures of possible pollution mentioned since we considered it to be beyond the scope of the present report. We have instead selected those measures which relate most particularly to the difficulties mentioned in the review of the present state of the river.

The major problems which we see in terms of achieving these uses are due to the high organic and nutrient enrichment entering the rivers from the rapidly growing population centres. The major consequences are on the satisfactory use of the streams for recreational pursuits and as an aesthetic source of relaxation and visual enjoyment. Although the major municipalities all have secondary treatment plants installed, visual obersvation of the river below these points indicates turbidity and excessive algae growths of an unappealing nature. The extensive algae has a further undesirable attribute in that night time respiration causes dissolved oxygen levels to drop to very low values, giving conditions where desirable fish species are unable to survive. As an example of this, night time D.O. levels were tabulated in the Speed River (OWRC 1970) down to 1 mg/l. Desirable warm water species are not able to survive under such conditions, and this is indicated by the biological samples carried out during the same investigation. Suspended solids are not a particular problem under optimal operations of the treatment plants, but under upset conditions, deposition of solids may take place in quiescent reaches of the river. This is augmented by the deposition of slit from storm runoff and by the end products of decaying algae. The result is again an unappealing appearance and a further oxygen demand due to the benthal deposits. Toxics and pathogenic bacteria are of concern on a more occasional basis. Examination of routine monitoring results shows high coliform values occuring from time to time at various points in the watershed, and toxic spills have been documented. Both of these effects should be handled by tight quality control measures.

We have prepared as part of this study, a water use inventory for the entire basin. Agricultural uses include irrigation on several tributary streams which under drought conditions, can cause serious depletion of stream flows in Horner, McKenzie, Mount Pleasant, and Fairchild Creeks and the Nith River above Ayr. There is also summertime watering of cattle resulting in stream bank erosion and pollution. Most industrial water supply is via private wells or the municipal systems with only a few exceptions. Domestic supplies are at present all from groundwater except for Brantford and Cayuga which take directly from the Grand River, and Dunnville which is on a pipeline from Lake Erie. Aquatic life and wildlife are intimately tied up with the whole area of aesthetics and recreation, which will now be discussed in some detail.

A review of present use and future potential of the river system for recreational purposes has been carried out. This has been aided by information obtained from the GRCA, the OWRC, the Departments of Lands and Forests, Energy and Resources Management, Tourism and Information, and other available studies.

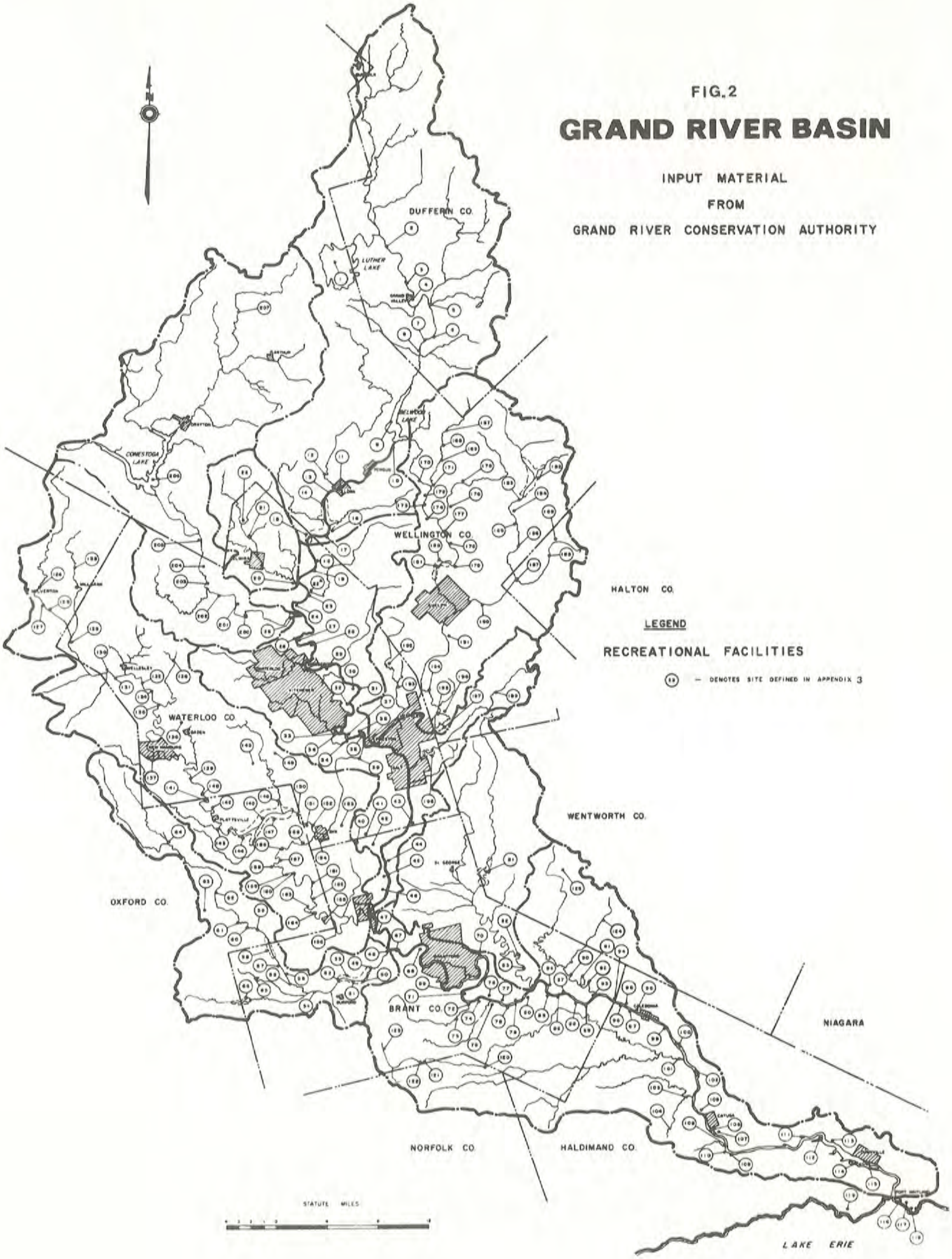
Extensive development of river bank recreation facilities has taken place and is planned for the future. The Grand River Conservation Authority has produced a list of 214 present or proposed sites oriented towards and dependent upon an aesthetically pleasant aquatic environment (see figure 2). In addition to the organized recreational facilities listed, the GRCA is working to create corridors of green belts beside the rivers and their tributaries to provide open space for unorganized recreational endeavours. We feel that this is a very important part of the development of the river system, and should be given a high priority in the allocation of funds. In addition to the direct recreational benefits, a properly planned green belt can contribute to improving water quality in the river.

Swimming is common throughout the watershed and boating is popular, particularly in the lower reaches of the river and within the reservoir lakes, with an estimate of 700 boats being used each summer. A recent study (Department of Tourism & Information, 1968) suggests that with construction of five small dams and locks, the Grand River between Port Maitland and Brantford could potentially attract 5,000 boats each summer, contributing an estimated increase in economic activity to the area of $4 million annually. We would caution, however, that before serious consideration is given to such a scheme, the water quality and ecological implications should be studied thoroughly. Dams can hinder the movement of fish species throughout the river system. This may perhaps be the reason why Walleye are common below the dam in Brantford but not above it. Also, there have been spring and fall runs of Coho salmon and Rainbow trout up the lower Grand and these could be adversely affected by a series of dams. In terms of fishing, it has been estimated that activity is currently at a rate of 200,000 angler days per year throughout the basin, and could be much higher as population increases and if river quality improved, bringing with it improved species of fish. The encroachment of man's developments has tended to reduce the availability of good quality sports fish as poor land use practices have changed the quality of the streams. This has been due to decreased cover, increased temperatures and turbidity and reduced flows and oxygen concentrations. The result has been that the number of streams capable of supporting trout is now drastically reduced. It is possible that many of these streams can be rehabilitated to again produce an environment suitable for the production of trout. However, this can only occur after a long and intensive program based on comprehensive long-range land use planning, which employs an ecological approach as its basis. For this to be achievable, municipalities, industry, developers and the farming community must plan their activities with reference to their consequences upon the river system (see recommendations 8 and 9).

FIG. 2

GRAND RIVER BASIN

INPUT MATERIAL
FROM
GRAND RIVER CONSERVATION AUTHORITY



LEGEND

RECREATIONAL FACILITIES

— DENOTES SITE DEFINED IN APPENDIX 3

At the present time, impoundments on the river system provide good fishing potential. Generally speaking, stocking is done annually since a self-maintaining fishery has not been successfully achieved at the major reservoirs. However, good results have been achieved with the stocking program, and for example at Belwood and Conestogo Reservoirs, one thousand 8 inch Rainbow trout entered into the reservoir in the past year "showed good growth at Conestogo and tremendous growth at Belwood" (GRCA 1970).

We have taken into account the possibility of quality fisheries at the proposed reservoirs in this report and feel that some reservoirs should, with proper management, be capable of supporting self-maintaining fish populations.

The river system also provides for other important wildlife and recreational opportunities besides those related to fish. Waterfowl are maintained in large numbers, particularly at Luther Marsh and there are small but significant trapping and commercial bait activities carried on.

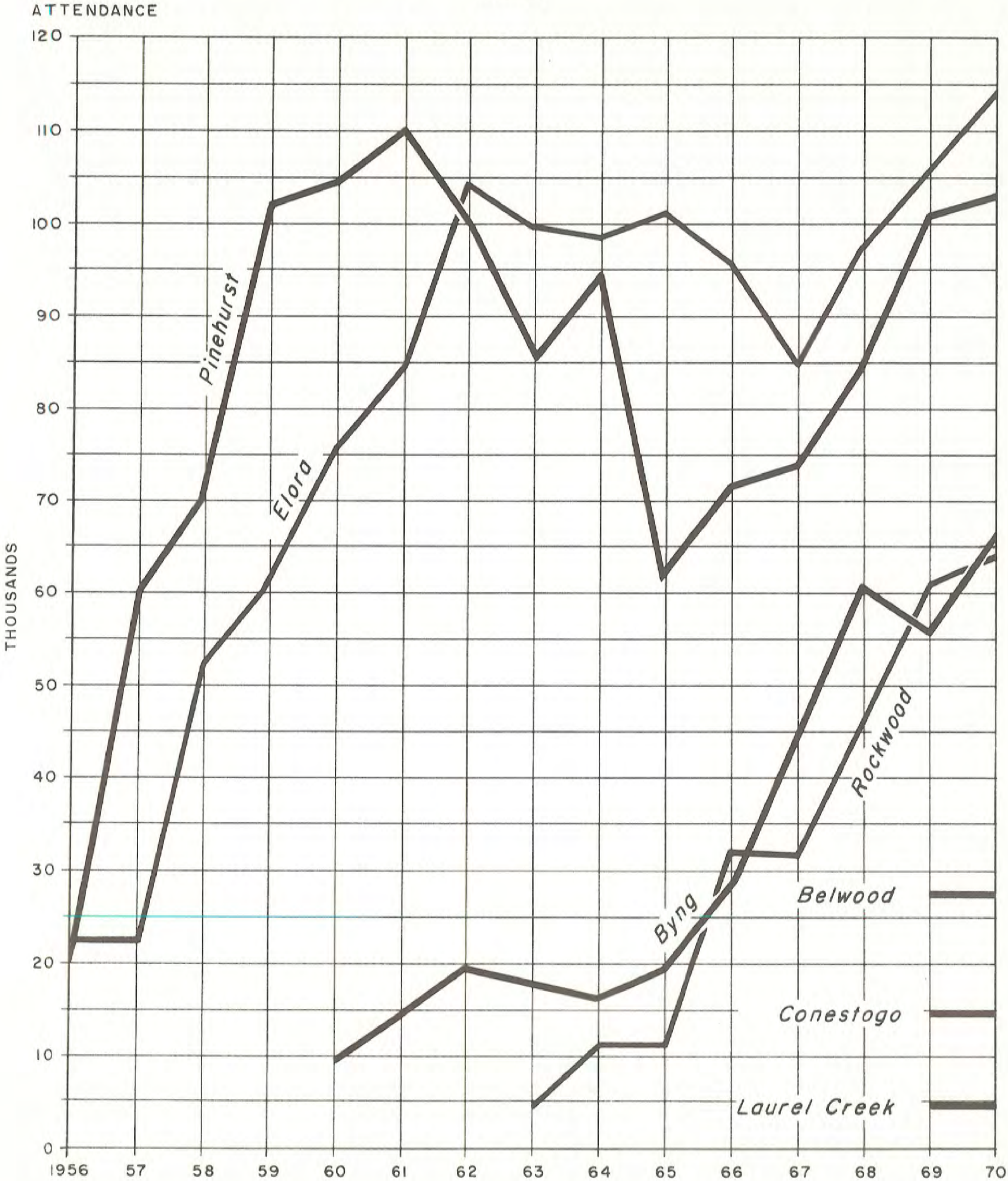
In terms of actual day use at possible and proposed reservoir sites, we feel that no adequate analysis has been carried out to date to permit dollar benefits to be assessed. One cursory appraisal was carried out by Clough (1966) which indicated day use and benefits as in the following table:

Reservoir	Present Worth of Benefits
Guelph	$575,000
Hespeler	300,000
Everton	300,000
West Montrose	300,000
Ayr	300,000

The present usage of major conservation areas in the basin are shown in figure 3, taken from the 1970 annual report of the GRCA. Given the fact that some of these existing areas are not yet completely developed, that Lake Erie will become more attractive for recreation if anti-pollution measures begin to bear results and that there has been no real supply-demand study done for the area, we feel that Clough's figures are of doubtful validity for a benefit-cost analysis. However, since his estimates of recreation benefits are fairly small, they will not have a major impact on justifying or rejecting any particular dam.

We would add, however, that our study confirms that the Guelph Reservoir would be the most valuable for recreational purposes of those being

FIG. 3



ATTENDANCE
AT
MAJOR CONSERVATION AREAS

suggested. In particular, considering the five dams proposed by the GRCA (1966), our conclusions regarding net recreation benefits can be summarized as follows:

West Montrose - We have not recommended construction based on our analysis in this report, but if constructed, the lake created would be in direct competition for use with those at Belwood and Conestogo because of their proximity. Also, some of the "river-gorge" orientation of the site would be lost to hikers and nature lovers and on balance, we are not sure that there would be any net recreational benefits generated because of the dam. Of course, the very fact that extra land would be purchased would increase the capacity of the site; this suggests the possibility that further land might be purchased by the GRCA along the river below Elora even if the West Montrose Dam is not constructed.

Hespeler - We have not recommended construction of the Hespeler Dam in this report. We are opposed to assigning recreation benefits to a Hespeler Reservoir mainly because of its likely un-aesthetic ultimate condition. All reservoirs in the basin are subject to possible singificant enrichment, however, the Hespeler Reservoir would be particularly prone to problems because it is located downstream of Guelph. We feel that a severe algae problem would rapidly manifest itself and the site would be unappealing for recreational purposes. A flood retardation dam is a possibility in this location. Although no water would be stored for long periods behind the dam, recreation benefits would be gained from the large undeveloped area of land reserved for the floodwaters.

Ayr - Generally speaking, the Ayr Reservoir would be of some value as a recreational site, although the actual usage would depend on demand for recreation of the ultimate population, which has not been established. Due to draw-downs for water supply and requirements that the water be kept pure, boating and especially motor boating would not likely be an important use. The major likely use would be for a sports fishery since use of the reservoir for domestic supply would imply a large winter carry over of water, giving a suitable environment for a self-maintaining fish population.

Everton - Everton Reservoir would be in a position of competing to some extent with both Guelph and Belwood Reservoirs for visitors. Also, it should be noted that a reservoir would adversely affect a valuable forested and wildlife area, and one of the few significant deer habitats in the watershed. Its operation would imply flow augmentation in the Eramosa River and thus maintenance of a fixed reservoir recreational level would be a secondary consideration. We thus feel that direct recreational benefits of Everton would, on balance, be small.

Guelph - We have recommended a reservoir on the Speed River above Guelph for the principal purpose of low flow augmentation, flood control and recreation (see recommendation 1). In terms of recreation, the reservoir will be particularly desirable because of its proximity to the rapidly growing city of Guelph. Also, our calculations indicate that even with large releases for flow augmentation, the characteristics of the reservoir site are such that a fairly constant lake level could be maintained during the summer recreation period. This aspect would be even easier to maintain if the Everton Reservoir is also completed. A successful cold water fishery should be possible at the site further adding to the benefits. Based upon these considerations, we feel that there is some basis for assigning quantitative benefits and would accept Clough's figures of $575,000 benefits as a working estimate.

In summary, we feel that water-based recreation should be an important component of any comprehensive basin planning. Also, as we said in our interim report, it is our view that quality recreation will follow quality water, and the standards for water quality throughout the entire Grand River Basin should reflect aesthetics and recreation as an important use.

Water Quality Standards:

It is necessary to implement specific standards for water quality in the river system, in order that a consistent and reasonable approach to planning and quality control may be taken. The simplest approach is to document the uses of the river and then to accept the criteria for preservation of these uses as enforcement standards. This approach is deficient to some degree in that economics and feasibility are ignored.

Direct quantification of the benefits of preserving certain river uses is probably not meaningful since economic proxies are not available for such factors as aesthetics, preservation of species, etc. It should be pointed out that some analysts suggest a benefit-cost approach to justifying purposes and standards, (e.g. Nemerow 1970) however, we have not attempted it. A more satisfactory approach is to develop tradeoff curves relating quality measures to the costs of achieving them. As an example, it might be accepted that a long term objective for dissolved oxygen in the river should relate to the requirements of warm and cold water biota such as are suggested in "Criteria for Water Quality Management in Ontario" (OWRC 1970). It is important to study the implications inherent in adopting such criteria as standards. Dissolved oxygen in the stream is highly dependent upon the B.O.D. load, and waste treatment plants do not release to the stream a constant quantity and quality of effluent day by day. In reality, there is considerable variability in these quantities, as may be seen in table 1 where data for 72 days at the Kitchener waste treatment plant were analysed. It may be seen that for this sample, effluent B.O.D. ranged from daily averages of 4 mg/l to 55 mg/l. Expressed in other terms, the total daily B.O.D. entering the stream ranged from 380 pounds to 7450 pounds. It is customary to perform calculations on acceptable loadings at various points in the river based upon fixed effluent quantity and quality. Thus, for instance, if we assume that an activated sludge plant gives an average B.O.D. effluent of 15 mg/l and we assume the present population of Kitchener, then a B.O.D. loading of approximately 2100 pounds would be achieved. Reference to table 1 indicates that the average loading was exceeded 24% of the time based on the 72 point sample. It should thus be clear that basing loading guidelines, or the ability to achieve quality standards, on average conditions is very misleading. Compounding the problem is the fact that B.O.D. in the stream may vary randomly due to several other effects, viz:

- variations in streamflow,
- loading from storm sewers during rainstorms,
- overflows from combined sewers,
- changes in background B.O.D. levels due to rural runoff, decaying vegetation or scouring of benthal deposits during high flows,
- illegal or accidental spills of pollutants.

In taking a further step to translate the B.O.D. into its effects on D.O. in the stream, we find that other influences may be equally important on oxygen levels. Thus, for example, at the present time, the presence of large amounts of algae and aquatic plants raises and lowers D.O. through photosynthesis and respiration. Even after the proposed phosphorus removal program is underway, this may be a significant influence. As a further example, criteria for protecting fish are based upon "minimum 7-day average low flows equalled or exceeded 95% of the time" (OWRC 1971). As pointed out above, a number of factors influence the B.O.D.

TABLE 1

Summary of Daily Effluent B.O.D. For 72 Days From Kitchener Waste Treatment Plant During 1965 To 1971

FLOW (MGD)	MG/L	POUNDS/DAY	FLOW(MGD)	MG/L	POUNDS/DAY
11.8	6	710	9.1	21	1900
11.8	7	770	10.1	20	2020
12.3	8	990	10.1	14	1410
12.7	9	1140	10.2	8	780
11.4	55	6270	15.0	8	1170
12.1	40	4840	10.6	10	1060
9.9	4	400	10.1	10	1010
11.6	24	2780	11.0	33	3630
11.5	12	1380	8.7	17	1470
11.6	12	1390	11.1	11	1220
10.8	20	2160	11.3	15	1700
10.0	13	1300	9.8	11	1070
10.7	7	750	9.9	20	1980
11.9	10	1130	9.9	20	1970
10.1	50	5050	8.9	20	1780
10.3	26	2680	11.5	10	1150
9.8	19	1860	8.0	7	590
11.0	21	2310	9.9	9	870
9.4	47	4420	11.1	12	1330
9.5	5	430	8.9	28	2480
11.6	6	700	10.1	9	890
12.1	24	2910	10.1	5	530
10.5	32	3360	13.0	12	1560
13.3	14	1860	11.8	10	1180
9.7	4	390	9.7	23	2230
8.8	21	1850	9.9	21	2080
9.9	17	1680	8.1	23	1860
10.0	9	880	10.1	32	3220
10.8	12	1300	14.1	53	7450
11.7	24	2810	9.1	22	2010
9.1	6	580	9.0	11	990
12.3	10	1180	8.4	9	740
11.5	15	1720	8.3	15	1250
12.4	11	1360	9.9	13	1290
10.2	8	860	10.7	20	2150
9.6	4	380	12.5	52	6480

and consequently the D.O. on a continuous basis, and of course the fish are responsive to short-term oxygen supplies, not the average for a 7 day period. It would appear that a standard for D.O. should be based upon some fraction of a day rather than for a 7 day period if it is to be of use to the fish.

All of these effects on loading must be taken into account concurrently when estimating guidelines for discharges to the watercourses otherwise we shall think that the standards are being met when they are not. This type of argument has long been recognized by biologists who employ monitoring of biota rather than chemical parameters as indicators of intermittent extreme pollution. This is not meant to imply that measurement of chemical parameters is not essential, but only that insufficiently frequent sampling can result in variations in quality levels being undetected. If it were found to be important to provide continuous monitoring of chemical parameters, it could be done although at greatly increased costs over the present.

All of the factors discussed above exhibit a random behavior in that their timing and magnitude cannot be predicted. Furthermore, the various factors all interact in a way which is difficult to predict. Thus, for example, a high effluent concentration of B.O.D. from a sewage plant may occur at the same time as a high stream flow and low sewage flow and this may be of little consequence. However, if the stream flow were low and the sewage flow high, the same concentration of effluent B.O.D. could depress oxygen levels in the stream seriously.

In order to analyse stream quality so as to take account of this complex of interacting, variable elements, we have designed a computer simulation. A simulation is a representation, on an electronic computer, of the real world. If all of the important factors influencing events in the real world can be built into the structure of the simulation, the representation will be very accurate. If important factors are left out, or represented badly, the results of the simulation will not be valid. Due to limitations of time and data availability, we have only developed a preliminary simulation to analyse stream quality in the Grand River Basin. It includes variability of stream flows, treatment plant qualities and quantities. It also is structured to include dissolved oxygen models, incorporating the effects of benthal demand in the stream, photosynthesis and respiration from algae. However, for these latter we presently cannot directly estimate the effects due to a lack of information about the biomass at various points in the river, its composition and seasonal growth patterns and the photosynthesis and respiration rates involved. We feel that base data on these factors should be obtained so as to allow, as an example, the evaluation of the effects of phosphorus removal programs and also to allow their inclusion in the simulation analysis. We have not had time to include effects of storm flows in our simulation to meet the deadlines of this report but feel that it should be included. To do this would involve assessing the degree of bypass from the sanitary sewers under different rainstorms plus the amount and quality of storm run-offs. Actual field work would be preferable but in the interim, comparisons to other cities could perhaps suffice.

A more detailed discussion of the simulation model may be found in the appendix. As discussed later in the report, considerable improvements are required in the simulation and a good deal of data must be collected before it can be used as a planning tool.

> *We recommend that water quality standards and further planning evaluations related to river quality and effluent loading guidelines should employ a computer simulation to take account of the probabilistic nature of the processes and to incorporate mathematical stream flow models to describe the significant water quality characteristics, such as dissolved oxygen, in the stream. In addition, we recommend that further field work on river quality characteristics adequate to allow for the evaluation of planning alternatives and the calibration of stream models, be carried out. Such studies would include, among other things, a quantitative examination of biomass and its major determining factors, rates of photosynthesis and respiration, benthal demand, re-aeration rates, the sources and rates of assimilation of B.O.D. and the hydraulic characteristics of the river. Furthermore, such data should be collected so as to represent the probabilistic behaviour of pollution sources and stream response.*
>
> .... *RECOMMENDATION NO. 6*

Computer simulations and mathematical models are currently being developed in various parts of the world to analyse river quality problems. An example is described for the River Trent in the United Kingdom (New Scientist 1971) where a computer model has been developed to examine the river in terms of a series of installations (sewage works, water treatment plants, power stations, industrial effluent plants, abstractions, weirs, stream confluences) linked together spatially by 16 water quality parameters. The model shows the costs and effects of various planning alternatives and changes in pollution sources on river quality. Another example of a simulation approach rather similar to that we have suggested, is that prepared for the Saint John River Basin in New Brunswick. It should be noted at this point that a simulation will not be a panacea since the understanding of water quality response is still far from complete. The costs of developing a computer simulation of the type mentioned are high, mainly because of the extensive data collection required. Preliminary rough estimates of the effort and cost to be expected may be found in the appendices. It should be stressed, however, that a good deal of the investigations and data collection required to complete the simulation would be needed in any case for a detailed water quality investigation. Furthermore, it is almost certain that techniques such as we have recommended will be the standard approaches in the future, rather than having a large research flavour as is the case at present. Since the Grand River is a complex system, the experience gained by Government staff would be beneficial in establishing a technical competence which could be applied to other situations.

DISCUSSION OF PLANNING OPTIONS FOR WATER QUALITY

We have, for ease of discussion, broken the alternative approaches to achieving water quality objectives into three classes: (1) Elimination of Pollution Sources, (2) Improved Stream Management, (3) Improved Waste Treatment. Long-term planning options would be formed from approaches selected from these three classes.

(1) Elimination of Pollution Sources

Domestic, agricultural and industrial wastes cannot, of course, be eliminated; however, steps can be taken to minimize or eliminate some of the harmful components. Examples illustrating this principle are the current reductions in allowable phosphates in detergents and the actions being taken to prevent mercury from entering the lakes and rivers. Improvements can come about either by persuasion or coercion and each appears to have its place. Current legislation allows for "after the fact" action to be taken against polluters; however, this is of little comfort to the users of a city's water supply system or to fish in the stream if they have already been adversely affected by the pollutant. One spill of a toxic substance into the stream could have very serious effects upon aquatic life for a number of years. It should be possible to design virtually fail-safe systems for storage tanks or pipes carrying polluting materials so as to make small the chances of their entering ground or surface waters. Another serious problem which could be alleviated by tighter controls is that due to agricultural runoff. This is discussed further at the end of this section of the report.

Although it might be possible to consider various ways in which legislation could be changed to stress enforcement of preventive measures, it is probably a better policy in the short term to utilize existing legislation to its limit and to employ inter-agency cooperation and precedents to facilitate the same ends.

> *We recommend that the OWRC should identify those potential sources of pollution not under its control at present. Following this, it should search out new opportunities to set standards and approve designs for municipalities and commercial enterprises on the design, installation and operation of equipment, storage facilities or piping which carry polluting materials that could enter surface-water or groundwater. Furthermore, provision should be made for regular inspection of such facilities by the OWRC and for remedial actions to be enforced even if stream pollution has not yet occurred.*
>
> .... *RECOMMENDATION NO. 7*

It must be recognized, however, that there is no way to eliminate all pollutants or prevent them from ever entering the watercourse. There will always be accidents beyond any reasonable control. As examples, trucks may go off the road, emptying their cargo into the river, equipment may fail, people may make mistakes and we must expect that occasionally quality criteria will not be met. However, we should strive to see that those sources under our control are handled in such a way as to make such occurrences rare.

One method for preventing the entry of waste treatment plant effluents into the river is to introduce all wastes into a collector system which would convey them to some other point. Thus it would be possible to have either an open-channel or sewer collecting the treated wastes from Guelph, Waterloo, Kitchener, etc. and carrying these to Lake Erie. The reconnaissance estimate of an open-channel system stretching from Dunnville to Waterloo and Guelph indicates a cost of approximately $70 million to service the population forecasts used in this report for the year 2001. Problems could occur such as winter freezing of the channel, clogging with algae during the summer and possible objections due to odours and aesthetic considerations. Some objections could be overcome by using a completely enclosed sewage system, but at an estimated cost of $200 million. Also, an enclosed system could result in deterioration of the effluent over the long distances travelled. Some objections may be overly pessimistic, as open channel schemes of the type considered have been used successfully for many years in Germany. It is reasonable to assume, however, that simply transferring the problem to Lake Erie would not be acceptable. Further treatment would be essential before the collector system could be emptied into the lake and this would increase costs.

We have reviewed the collector system concept to Lake Erie and have concluded that it is not justifiable at least at this time. It would appear to be more costly than other alternatives designed to improve river quality and there is no guarantee that the algae problem in the river would be eliminated. Furthermore, stream flows would be reduced by the municipal waste flows which would no longer enter the river and which are a significant component of the flow. In fact, low flow at Brantford would be reduced in the year 2001 by about 200 cfs. In any event, we feel that the problem should be tackled at its source rather than being transferred elsewhere and thus, no further consideration has been given to a waste collector system to Lake Erie in this report. There could, however, be possible economies of scale in using local collector systems in conjunction with area tertiary treatment plants or land disposal methods utilizing effluents from several municipalities. We feel that this should be considered as part of a detailed investigation of alternatives to achieve stream quality objectives and will not be analysed in this report.

A good many future river quality problems are going to be caused simply because more and more people will be living in the watershed. An obvious way to alleviate this problem would be to slow or stop the rate of growth and thus the quantity of wastes being produced. We are faced here with a fundamental question of goals, the tradeoff between economic growth and environmental preservation. The former has historically been given a higher priority by government, industry and the population for various reasons: the difficulty of measuring the consequences of environmental destruction in economic terms, a lack of understanding of interactions between economic and environmental factors and a lack of public awareness of the issue. There has been a shifting of values in recent years and many people no longer look on economic growth as a panacea but are willing to tradeoff some economic growth for an improved quality of life. That such a shift is taking place within the Grand River Basin has been confirmed by our discussions with municipal officials, and the premises underlying the work of the Waterloo County Area Planning Board. The rate of innovation in technology for dealing with environmental problems has not kept pace with the rate of growth of the problem areas, and this presents a dilemma. One way out is to stress economic growth, and hope that solutions to the problems spawned will be found. This does not seem reasonable to us, as without a shift in priorities the necessary funds will not be allocated to the problems. In the Grand River Basin there are reaches of the river system where quality problems are serious, but others where conditions are still quite acceptable. The former will require time and a considerable expenditure of funds in order to achieve desired stream quality, however, there is for the latter, only the problem of keeping additional pollution from entering the stream in the future. The oft quoted "ounce of prevention is worth a pound of cure" seems to be appropriate to this situation. Due to both our present inadequate understanding of cause-effect relationships governing stream quality and the still inadequate waste treatment methods available, we feel that it is reasonable to regard lower population growth as an important and valid tool for preserving river quality. We recognize that slowing population growth is difficult and that local political and economic pressures, lack of coordination among government agencies and a host of other reasons will work against it. Also, whether the concept will be valid if re-examined twenty years hence will depend upon the efforts put into developing new concepts in waste treatment and industrial processes. Nevertheless, for the present we think that the conservative course of minimizing future undesirable conditions requiring remedial action is warranted. It is particularly important that waste sources upstream of reservoir sites be carefully controlled since organic loadings, toxics and nutrients can very rapidly turn a reservoir from a valuable asset to a problem and a liability.

We recommend that communities on the Speed and Eramosa Rivers above Guelph, above Waterloo on the Grand River, above Ayr on the Nith River and on other tributaries should restrict their growth to the greatest possible degree, and in general that communities in the Grand River Basin should exercise moderation in planned growth and should accept the responsibility for ensuring that *environmental problems do not develop from future increases in population or industry.*

..........*RECOMMENDATION NO. 8*

In addition to arguments relating to pollution control and preservation of the environment, there are also large water management costs associated with sizeable growth of communities in the basin beyond their present populations. This is due to increased demands for sewers, expansion of water supply systems, advanced waste treatment and so on. A further discussion of this point will be found in the chaper "Analysis of Water Management Options".

There is evidence that a significant amount of stream water quality deterioration is due to pollution from land and livestock management. In terms of agriculture, these sources are as follows:

(a) Siltation resulting from erosion of farm fields, stream banks and drainage ditches, which results in damage to sensitive fish and benthal organisms and transports a heavy load of nutrients to the stream.

(b) Pollution from livestock sources such as barnyard runoff, manure storage and manure spreading on farm fields especially during the winter. To put this situation in perspective, it is perhaps worth observing that a feedlot with 1,000 beef cattle has been reported (Steggles 1967) to produce a waste disposal problem equivalent to that produced by a city of 10,000 persons.

(c) Runoff and leaching of commercial fertilizers from farm fields.

Another serious source of soil erosion and stream pollution is due to non-agricultural construction, including sub-divisions and road building. In some areas of rapid urban growth, erosion due to construction activities is probably the greatest single source of silt in stream courses, and has probably contributed greatly to the elimination of trout in such areas.

Reduction of pollution resulting from land and livestock management practices can take place based upon regulation, education, fiscal incentives and research. Regulation is probably necessary to control pollution from construction projects and intensive farming units. However, education is the most useful tool, albeit the one which will take the longest to show beneficial results. Education should involve a "grass roots" approach to the farming community to demonstrate the benefits to individuals and the community of agricultural practices to reduce runoff and erosion. Results cannot be achieved by preaching at the farmers, but tangible demonstrations, such as are provided by the GRCA Whiteman Creek Project, can be a good selling point. Agencies such as the Ontario Department of Agriculture and Food, the University of Guelph, the Colleges of Agricultural Technology and the Conservation Authorities Branch of the Department of the Environment must join the GRCA in planning the program. Ultimately, leadership could be passed along to local rural organizations within the watershed to ensure implementation.

In some cases, fiscal incentives are the only effective and equitable means of ensuring proper erosion control practices. This could apply to stream bank erosion control which is costly to the individual farmer, to ditch construction under the Municipal Drainage Act and to county and municipal road and sewer construction.

Finally, very little hard information is available on the contribution of agriculture to pollution in the Grand River Basin. It would be helpful if the Provincial Government could fund some research in this area.

> *We recommend a coordinated program by Provincial Government departments to stimulate a renewed emphasis on grass roots conservation practices through improved regulations, conservation education, fiscal incentives and research, so as to minimize the adverse effects of land and livestock management on water quality and quantity in the Grand River Basin.*
>
> .... *RECOMMENDATION NO. 9*

(2) Improved Stream Management

Low flow augmentation is generally recognized as a means to enhance stream quality. Increasing flows lowers the concentrations of pollutants and, in general, increases the assimilative capacity of the stream. Thus the same level of dissolved oxygen may in principle be achieved in the stream either by decreasing the B.O.D. load entering the stream or by increasing stream flow. Unfortunately, the improvements in stream quality are usually short lived, as increased population or industry rapidly utilizes the additional assimilative capacity in lieu of a higher degree of waste treatment with its attendant costs. It is important to consider the actual conditions at hand when examining the benefits of low flow augmentation. It may be generally stated that for a given waste discharge, flow augmentation benefits will be highly dependent upon the ratio of stream flow to waste flow entering the stream. This may be readily seen by referring to figure 4, where percent reduction in average B.O.D. concentration in the stream is plotted against the ratio of stream flow to waste flow. In the limiting case, if stream flow becomes nil during drought conditions, pure effluent flows down the channel. Although very effective treatment processes are available, all are subject to some variability of their effluent quality and a base flow in the stream is desirable. Also, waste treatment plants occasionally malfunction or even cease to operate entirely. Under such circumstances the presence of an upstream reservoir allows the stream flow to be increased so as to mitigate the consequences. For example, if in 1976 the Guelph sewage treatment plant were to temporarily go out of operation, it would be possible to disinfect the sewage and increase the flow in the river at the treatment plant by means of the upstream reservoir until the wastes were adequately diluted. This would, of course, result in a reduction of reservoir storage available for other purposes. It was on the basis of arguments such as these that we foresaw the requirement for the new Guelph Reservoir and recommended it in our interim report of February 1971 (recommendation no. 1).

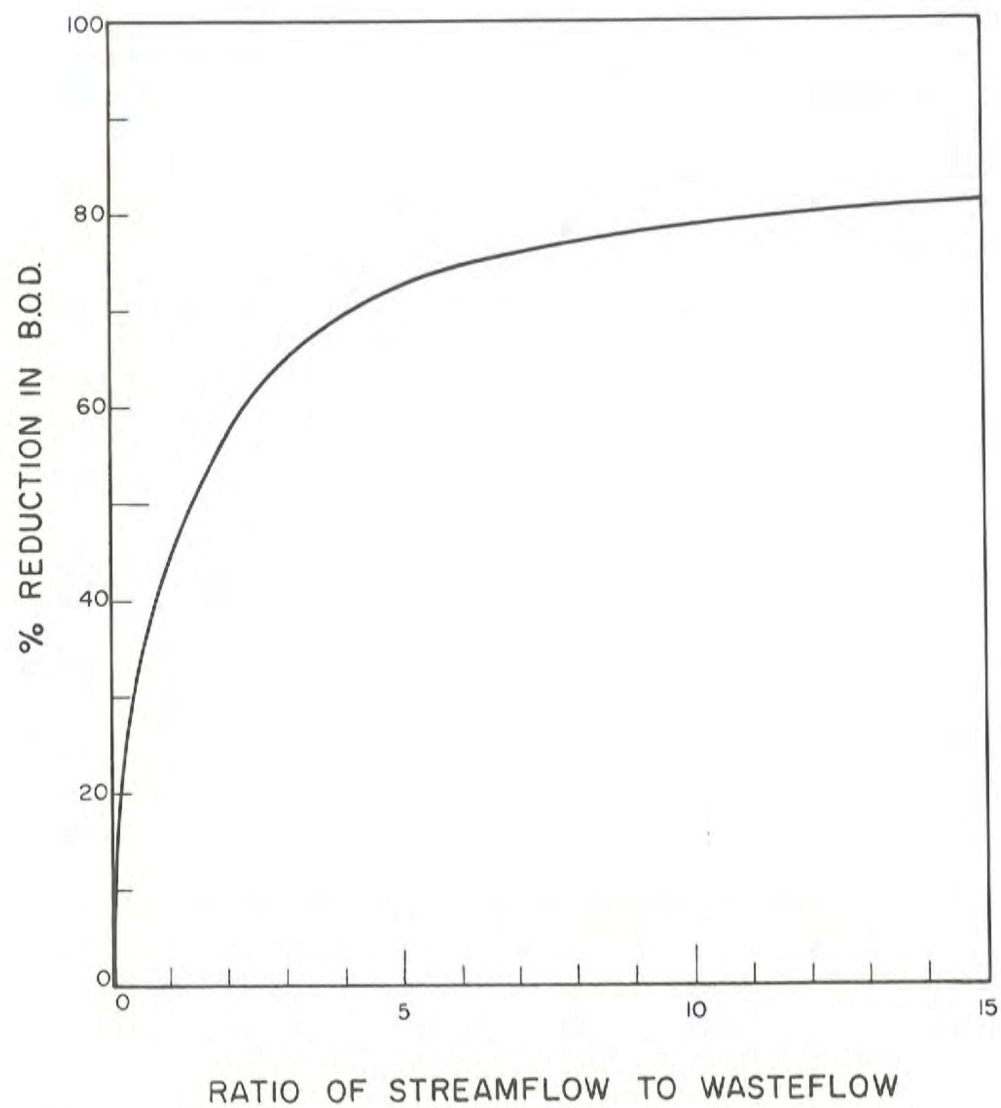
The same sort of arguments also led us to recommend the early construction of the Woolwich Reservoir at Elmira (recommendation no. 4). Even if the Elmira municipal effluent could be improved to be a sufficiently high average quality to be acceptable at near zero flow conditions, (and this would require advanced treatment if it could be done at all), the disruptions at the plant due to the variable quality of the industrial influent would cause frequent plant problems and poor quality effluents. When this is coupled with the fact that the sewage treatment plant is located in the flood plain and that a serious flood could knock out the process for several days, the flood control aspects of the Woolwich Dam are a further point in its favour.

A preliminary appraisal of the controlled flows which could be expected below Guelph when the new Guelph Reservoir is completed is shown in figure 5 in terms of the probability of being realized. Because of its proximity to the Guelph sewage treatment plant, this reservoir should be more flexible in its capacity for low flow augmentation than the other major reservoirs in the basin. We may reasonably expect the Guelph waste treatment plant to be able to call for flow augmentation based upon actual conditions at the treatment plant, but this would not be practical at Kitchener, for example, where the damage would likely have taken place before the extra dilution water could arrive.

Proximity gives a great benefit in terms of controlling the flow with reference to the operations of the sewage treatment plant instead of controlling the outflows in terms of a more average dilution requirement. Additional monitoring equipment would presumably be necessary at the

FIG. 4

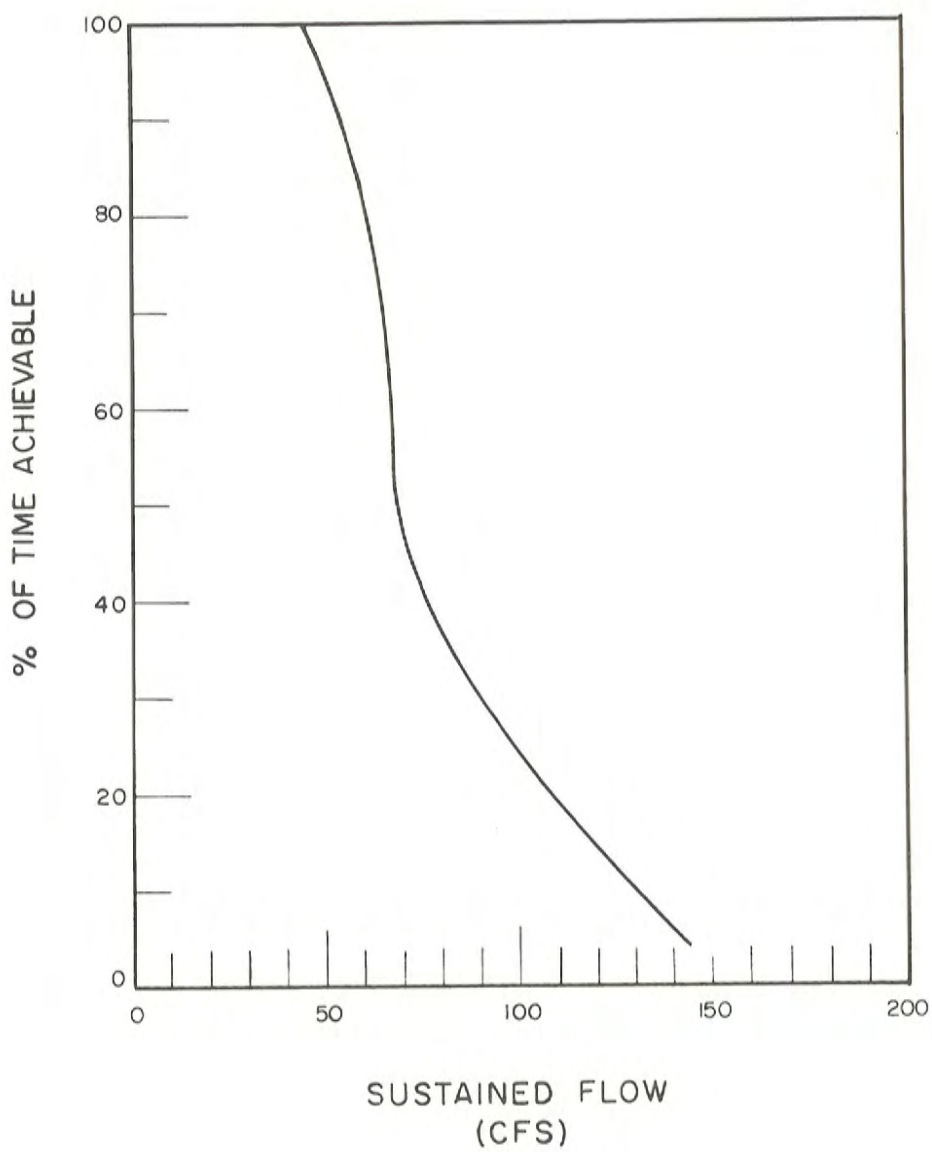
PERCENT REDUCTION IN B.O.D. IN A STREAM VERSUS THE RATIO OF STREAMFLOW TO WASTEFLOW.



NOTE: ASSUMING WASTEFLOW B.O.D. OF 15 MG/L AND STREAM BACKGROUND OF 2 MG/L

FIG.5

SUSTAINED FLOW ACHIEVABLE AT GUELPH W.P.C.P. WITH NEW GUELPH DAM IN OPERATION.



Guelph treatment plant and an ability to coordinate with the GRCA to provide the required flows. At the Guelph Reservoir, equipment suitable for flexible within-day release of water should be installed. The coordination of this system, the conditions under which various flows should be released and the communications necessary would all have to be further defined to make this operational. Also, the interactions with flood control and recreation requirements would have to be included. There is a similar problem for all existing and new reservoirs in the system in terms of optimizing low flow augmentation while at the same time providing for flood control, recreation and other uses. We have covered this area in recommendation number five.

Some streams, such as the Canagagigue Creek, have historical low flows of zero, while others such as the Speed River, have always some small natural base flow. However, excessive demands for irrigation or interference from wells may severely lower stream flows. Also, the flows may be purposely cut off, such as on the Speed River in August 1962 below Guelph when construction was underway in the river channel. It is obvious that rivers cannot be purposely shut off or reduced to negligible flows if aquatic life is to be protected. Minimum flow levels and their allowable durations should be established with reference to the aquatic life to be maintained and reductions below these levels should be avoided. It seems rather ludicrous to construct multi-million dollar reservoirs for flow augmentation and to expend funds for advanced treatment plants to ensure a satisfactory environment for aquatic life; and then to dry up the stream based upon a local construction or the fact that a mill dam has closed its gates. Although in some cases there might be problems of riparian rights, it is worth considering whether deliberate impediment or serious reduction of stream flows should be included, along with the addition of pollutants to a watercourse, as possible offenses subject to fines or other penalties. We have been informed by the GRCA that there are at least 49 small dams on the river system not under their control. It is reasonable to assume that the chances of maintaining minimum stream flows at a satisfactory level would be highest if all controlled impoundments were under the jurisdiction of the same agency. Also, in talking to GRCA staff, it was apparent that some uncertainty has arisen in the past as to required reservoir releases to meet OWRC water quality objectives. The situation will hopefully clarify as actual water quality standards are established for the basin in the future, nevertheless improved cooperation between the agencies involved is desirable.

We recommend that a three-man technical operations coordinating committee be set up with representation from the OWRC, the GRCA, and the Conservation Authorities Branch. This committee should be responsible for ensuring a closer exchange of plans and information among the three agencies through regular meetings.

.... RECOMMENDATION NO. 10

We recommend that all impoundments on the Grand River and its tributaries having the facility for controlling stream flows and which are considered by the OWRC or the Conservation Authorities Branch to be of consequence in terms of stream quality or quantity considerations, should be required to file a plan of operations with the Grand River Conservation Authority. Any planned deviations from the plan should be subject to prior approval of the technical operations coordinating committee (see recommendation 10).

.... *RECOMMENDATION NO. 11*

In some reaches of the river system, there are indications that existing small dams may be impairing river quality. Small reservoirs such as that in Hespeler and that impounded by the Wellington Dam in Guelph, create conditions suitable for the accumulation of silt and decaying solids due to their quiescent nature. Benthal deposits can build up leading to depletion of oxygen and if anaerobic conditions develop at the benthal layer, nutrients may be recycled leading to excessive algae growth. Also contributing to the problems is the fact that the dammed up water is deep and has little current, resulting in low reaeration rates and depressed oxygen levels. Compensating re-aeration due to wave action does not occur to any large degree as would be the case with a lake or large reservoir. It is also likely that water temperatures are elevated in the small impoundments, reducing the solubility of oxygen in the water, and its availability to aquatic life. Due to the fact that the Speed River is one of the major quality problem areas in the basin, we feel that it would be worthwhile to examine the effects of operating existing small reservoirs with the aim of improving river quality.

We recommend that the OWRC and the GRCA jointly investigate the potential improvement to the quality of the Speed River, of modified operations for the small dams situated between the site of the new Guelph Dam and the confluence with the Grand River, during low flow periods in the summer. Further, if the improvements are significant, the GRCA should determine what measures could be taken to operate these reservoirs consistent with the results indicated.

..........*RECOMMENDATION NO. 12*

In order to obtain dilution water at various points in the Grand River system, we have looked at the possibilities of diversions. An obvious possibility here would be to divert water from the Belwood Reservoir into the Speed River. This could be done using an overflow channel at spring freshet or by pumping during other times of the year. The cost of the latter has been estimated at over one-half million dollars. However, unless it were possible to rob the Grand River of flow during low periods, this system would be feasible only for diverting spring flows. Should it ever become necessary in the future to comtemplate constructing the Barrie

Hill Reservoir or other reservoirs on the Speed River above Guelph, this possibility could be considered, to guarantee that in a dry year both it and the new Guelph Reservoir could be filled.

Another possible diversion would be of wastes from the Kitchener water pollution control plant to below the Ayr Reservoir if the latter were constructed. This would, of course, lower the loading on the Grand River. A preliminary analysis indicates that this is not likely to be a worthwhile course of action, especially since in the long term there would be very little stream augmentation available from the Ayr Reservoir. It will be seen later in the report that we only recommend construction of the Ayr Reservoir if it is to be used for water supply to the Megalopolis. In that event, as pointed out, there will be little storage remaining in a dry year for flow augmentation.

(3) Improved Waste Treatment

Most waste treatment processes used by municipalities in the Grand River Basin are of the so called secondary type; a listing of present and proposed treatment facilities is included in table 2. These treatment processes are biological in nature and are essentially designed to reduce the B.O.D. and suspended solids in the entering wastes and to disinfect the effluent for public health reasons. Since the pervasive effects on river quality are largely from the major municipalities, we shall discuss possible treatment alternatives at such points only. As can be seen from table 2, the major municipalities all have, or shortly plan to have, activated sludge plants. The OWRC have stated an objective of 15 mg/l of B.O.D. (average) for the performance of such plants. We have evaluated the resultant B.O.D. in the stream based upon this assumption for low flow conditions likely to recur once in twenty years. We have assumed that the reservoirs would be optimally operated for low flow augmentation. It may be seen from the graph in figure 6 for example, that Kitchener would be able to meet the proposed guidelines for dissolved oxygen (OWRC 1971) until 1986 with their existing degree of waste treatment. Similar curves were obtained for the other major municipalities on the Grand River and it was determined that Kitchener would be the first to require advanced treatment. However, this simple analysis does not take into account variability in treatment plant effluent quality and quantity, effects of storm runoff, photosynthesis and respiration from algae, etc. Inclusion of this multitude of factors into the analysis would certainly show that conditions are worse than appears from these curves. We thus feel that the simple analysis of average conditions is of little use if we are interested in preserving high quality aquatic life; and it is basically for this purpose that the oxygen guidelines were presumably suggested. It also follows that we consider the loading guidelines

(cont'd.)

Municipality	Treatment	Status
Guelph	10.0 m.g.d. activated sludge plant	-
Hespeler	septic tanks and sand filters	activated sludge plant to be constructed shortly
Kitchener	13.5 m.g.d. activated sludge plant	-
New Hamburg	27.5 acre lagoon	-
Paris	0.5 m.g.d. activated sludge plant	-
Preston	1.8 m.g.d. activated sludge plant	enlargement under study
Rockwood	septic tanks	facilities under study
St. George	septic tanks	facilities under study
Waterloo	4.0 m.g.d. activated sludge plant	enlargement under study
Wellesley	septic tanks	facilities under study

*
Note:

- in addition to the comments under "STATUS", phosphorus removal facilities are planned for most of the above municipalities;

- the above list is meant to summarize the present status of waste treatment and should not be construed as being based upon our comprehensive water management study.

FIG. 6

GRAPHS SHOWING AVERAGE B.O.D. ESTIMATED BELOW KITCHENER SEWAGE TREATMENT PLANT UNDER SUMMER LOW FLOW CONDITIONS.

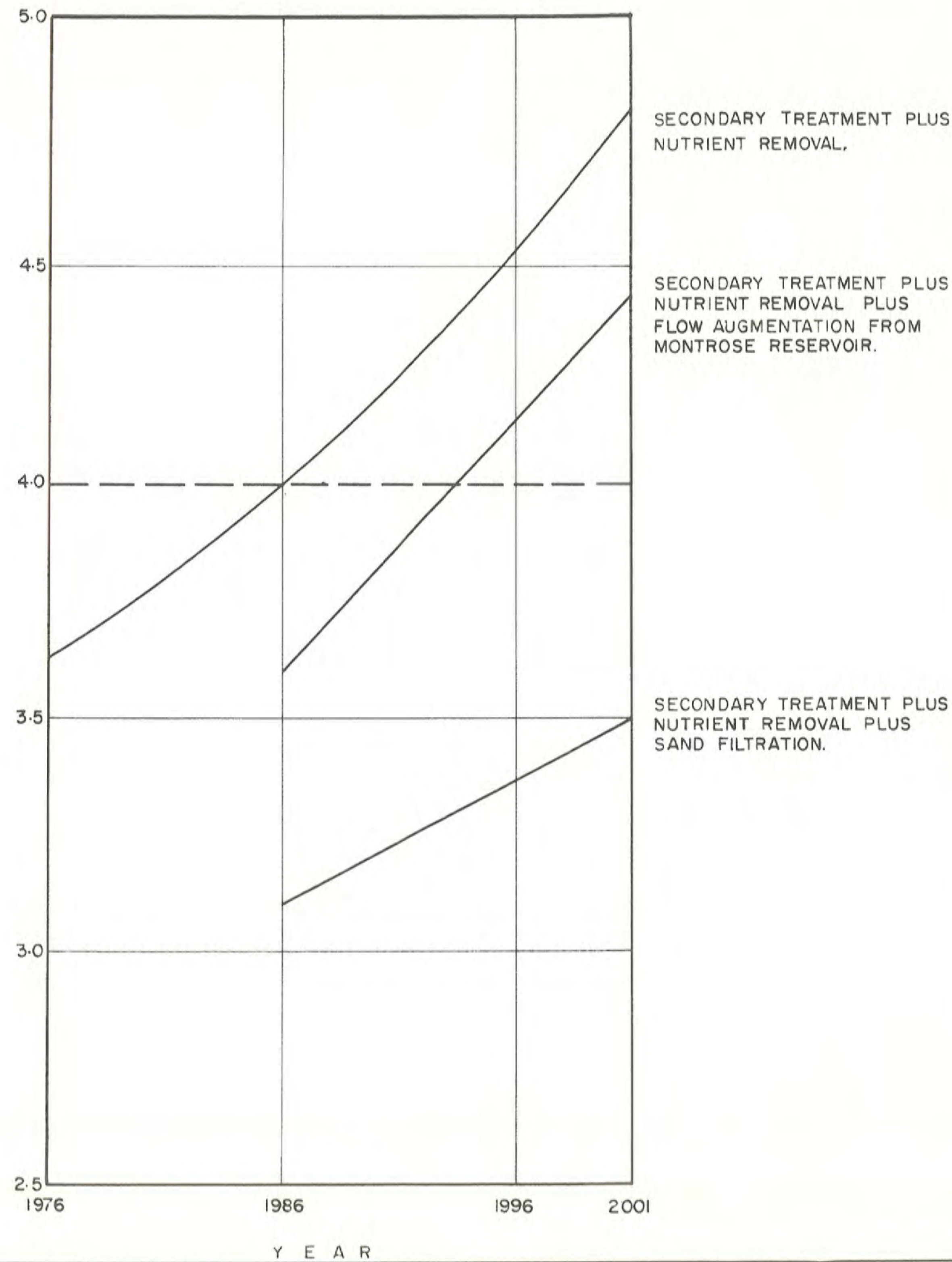
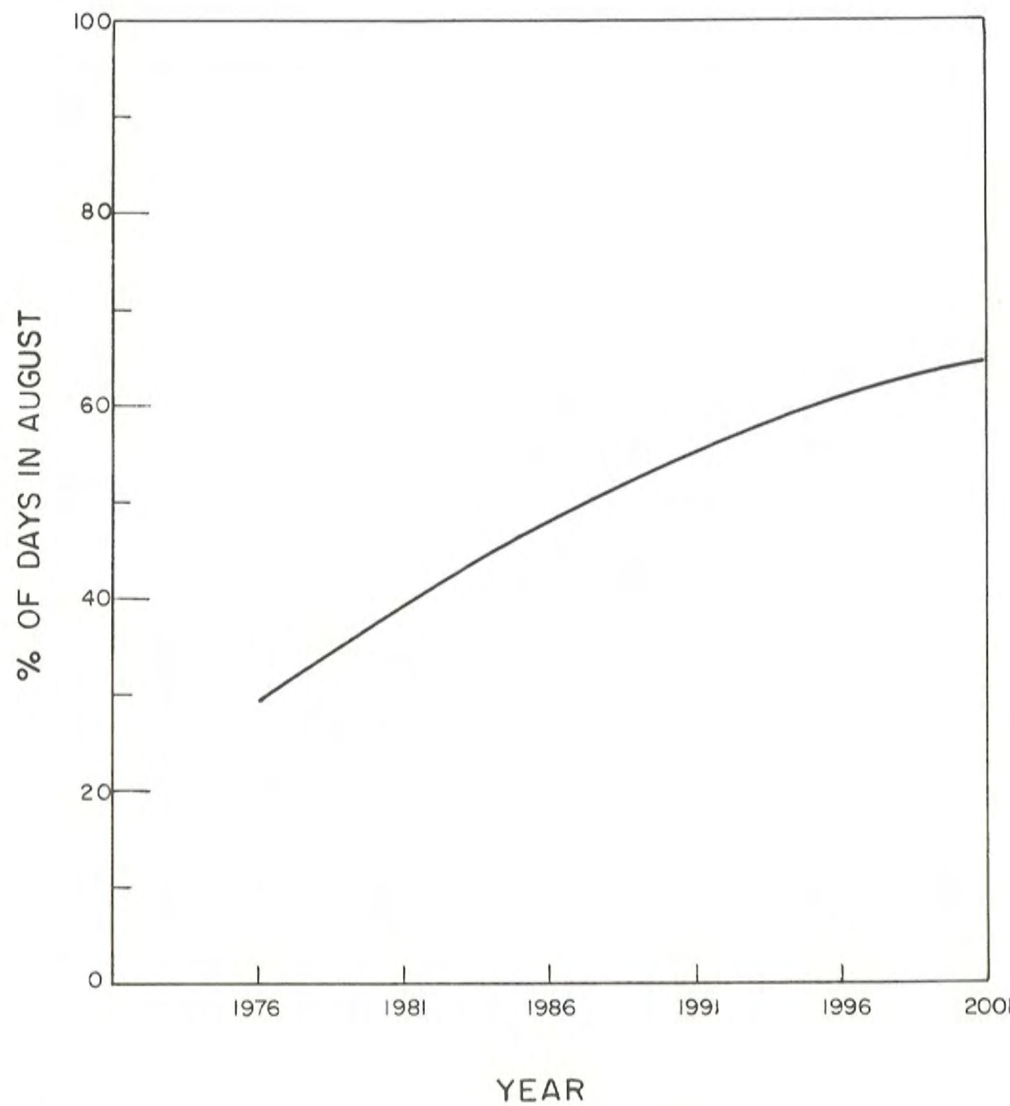


FIG. 7

PERCENTAGE OF DAYS IN AUGUST
WHEN B.O.D. IS GREATER THAN 6 MG/L
AT GUELPH.



NOTE: WITH SECONDARY TREATMENT AT GUELPH
(INCLUDING NUTRIENT REMOVAL)

developed in the same report (OWRC 1971) to be inadequate. We have discussed earlier that meaningful quality objectives cannot be set for the Grand River and its tributaries until further data and analysis methods are developed (see recommendations 6 and 13). As a corollary, we feel that specific assessments of the degree of possible advanced treatment and when it may be required at the various municipalities cannot be clearly made in this report. The exceptions are for Guelph and Elmira, which based upon average stream B.O.D. above, require immediate action (see recommendations 2 and 3) to reduce the loading on the receiving streams from their waste treatment plants. In an attempt to overcome some of these problems we have done some preliminary design on a computer simulation to represent the various stream processes and random behavior earlier outlined (see also the section "Water Quality Standards"). Unfortunately data collected in the past has not been specifically for the purposes of planning, but has been more oriented to monitoring quality on an average basis. We have thus been unable to develop the simulation to a sufficient degree that an accurate representation of dissolved oxygen in the stream can be produced. We have, however, been able to generate a meaningful stream B.O.D. description for the Speed River just below Guelph and the results of this may be seen in figure 7. We feel that this is a confirmation of our conclusions that stream quality analysis must be based on much more sophisticated approaches than have been taken for the Grand River Basin in the past. We have included a detailed discussion of the simulation approach which has been developed in prototype form in the appendices. We have also recommended that further development work on the simulation be carried out under recommendation six.

It would appear that some improvement in the algae problem should become apparent in the near future. There are plans to incorporate phosphorus removal at all major municipalities in the Basin by 1973. It should be pointed out that the purpose of the phosphorus removal program is to improve conditions in Lake Erie, and the degree to which it reduces the algae problem in rivers such as the Grand is not clear at present. Taking the Speed River as an example, and assuming 80% phosphorus removal at Guelph, then at low flow conditions with the new Guelph Reservoir in operation, we have forecast the total phosphorus concentration in the stream below Guelph at approximately 0.3 mg/l in 1976. The same levels would be present below Kitchener and would at all points of course increase steadily with passing years. It has been stated in the literature that nuisance algae conditions can probably occur in a stream with total phosphorus concentration of 0.1 mg/l or lower. It can, therefore, be seen that there may be a significant algae problem and associated night time drops in D.O. due to respiration even after phosphorus removal is carried out.

In the following two sub-sections of the report, we describe a review of currently available advanced treatment methods and those which are in the pilot plant stage, in order to see which methods might be applied in the Grand River Basin. Conventional treatment does not remove all organic and inorganic materials from wastes and certain "refactory substances" remain which require advanced treatment for their removal. We may divide advanced treatment into two categories: (i) treatment plants, and (ii) land disposal.

(1) A basic advanced waste treatment system could include the following processes into a secondary biological treatment system:

- Coagulation and sedimentation; removal of phosphates essentially (this stage is planned for treatment plants in the Grand River Basin).

- Filtration; removal of residual suspended solids (including some B.O.D. and phosphates).

- Ammonia stripping; removal of nitrogen compounds, which are an important algae nutrient. Problems are currently being found in making ammonia stripping work satisfactorily and in particular, there is a loss of efficiency at low temperatures.

- Activated carbon adsorption; removal of refactory organics.

- Electrodialysis, distillation, ion exchange, reverse osmosis, or freeze desalination; methods which could possibly be used to remove or reduce levels of dissolved solids. These processes have, to date, been largely concerned with desalination of water, although they offer promise in water and waste treatment. Efficiencies and costs are still somewhat uncertain and in general, they could not be realistically applied at this time for advanced waste treatment.

Although the methods listed for reducing dissolved solids are still somewhat exploratory, all of the other processes are presently feasible, with the proviso that ammonia stripping could be inefficient in our climate. The best example of a complete advanced process is probably the plant at Lake Tahoe, California, which includes facilities for phosphorus and ammonia removal, filtration and carbon adsorption after a conventional secondary plant. The effluent has a reported B.O.D. of less than 4 mg/l and phosphorus of less than 0.27 mg/l. The effluent is used for irrigation of hay and pasture and also for stocking trout; in addition, it is approved for all water contract sports. The costs of the complete treatment facilities including phosphorus removal are about double those for a secondary plant alone. Estimated 1971 costs for the advanced processes alone, including operating costs and amortization of capital, is about 26.5¢ per 1,000 gallons of which 11.9¢ refers to phosphorus removal and 3.2¢ to ammonia stripping. Upon reviewing the current status of the various projects employing these methods, there appears to be no reason why filtration, (probably rapid sand filtration with backwashing) and carbon adsorption could not be included in treatment of wastes for the Grand River, if further treatment beyond secondary plus phosphorus reduction is shown to be necessary.

In addition to these advanced treatment processes, our earlier discussion of variability in the effluent quality indicates that important gains in stream quality could be realized by reducing this variability. In particular, flow equalization tanks prior to the treatment plant and quality equalization tanks following the plant are logical methods to consider. Flow equalization tanks smooth the influent flow to the plant, thus tending to smooth the total pounds of B.O.D. entering the stream. Quality equalization tanks following the plant do not improve the process efficiency but would allow mixing before release to the stream thus attaining a more uniform quality of effluent. When completed, the computer simulation would be of great assistance in establishing the worth and optimal sizing of these tanks.

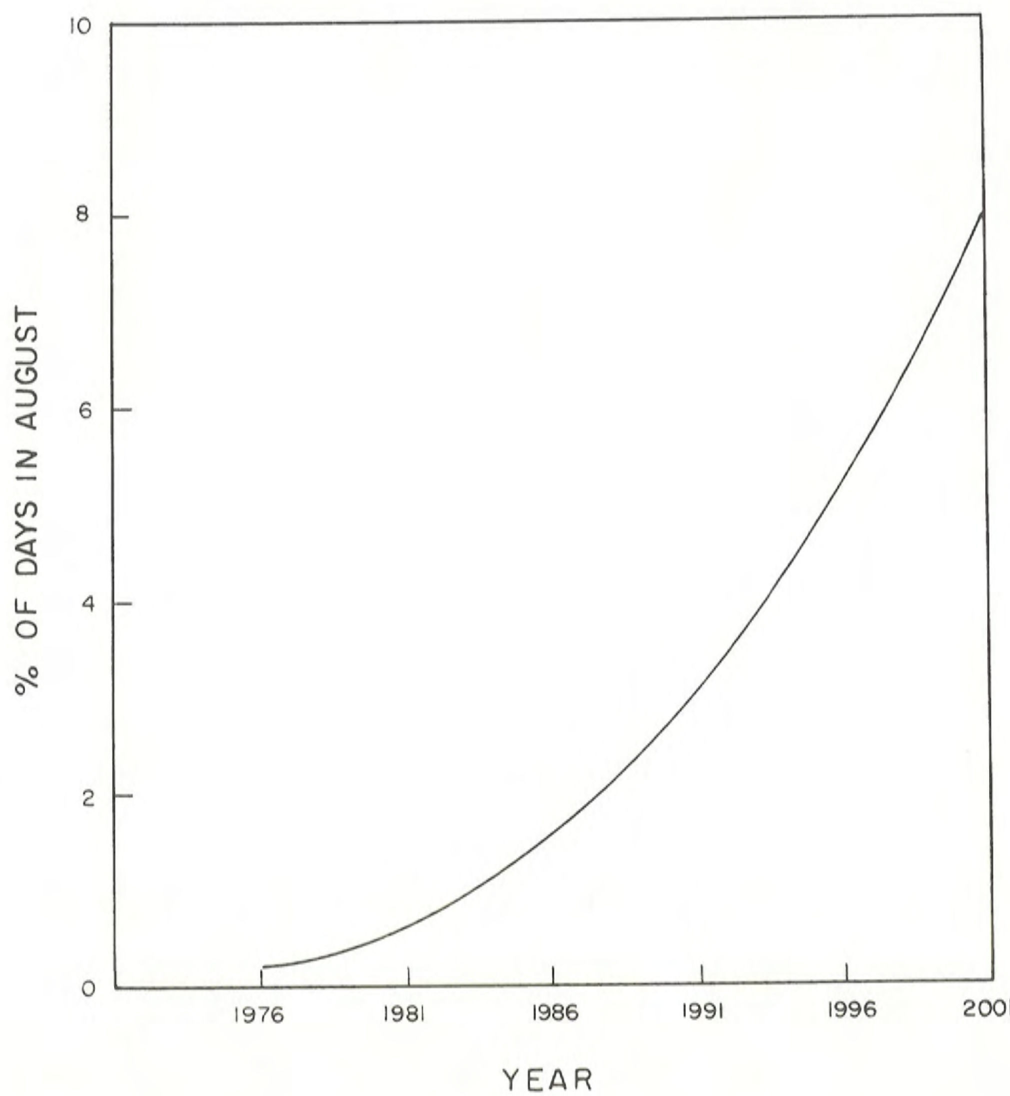
We have utilized the computer simulation to do a preliminary evaluation of the effects on stream B.O.D. of the inclusion of rapid sand filtration at the Guelph plant as a further treatment stage. The results are shown in figure 8. It should be stressed that these results are based upon only a superficial analysis and a much more detailed investigation would have to be carried out before conclusions could be validly drawn from the graphs.

Another method, which can be employed to improve effluent quality and to lower its variability, is through tighter quality control procedures in the plant. This would imply more frequent monitoring of such parameters as suspended solids and consequent adjustments in the level of biological activity in the plant, perhaps utilizing automatic control equipment. The level of suspended solids would appear to be a good, although not infallible, indicator of the B.O.D. as can be seen from reference to figure 9, based upon 72 sample points from the Kitchener waste treatment plant.

As already discussed earlier in the report, the effects of storm runoff are potentially very important on stream quality. Infiltration to sanitary or combined sewers can result in the hydraulic capacity of the sewers becoming exceeded, with consequent bypassing of untreated sewage

FIG. 8

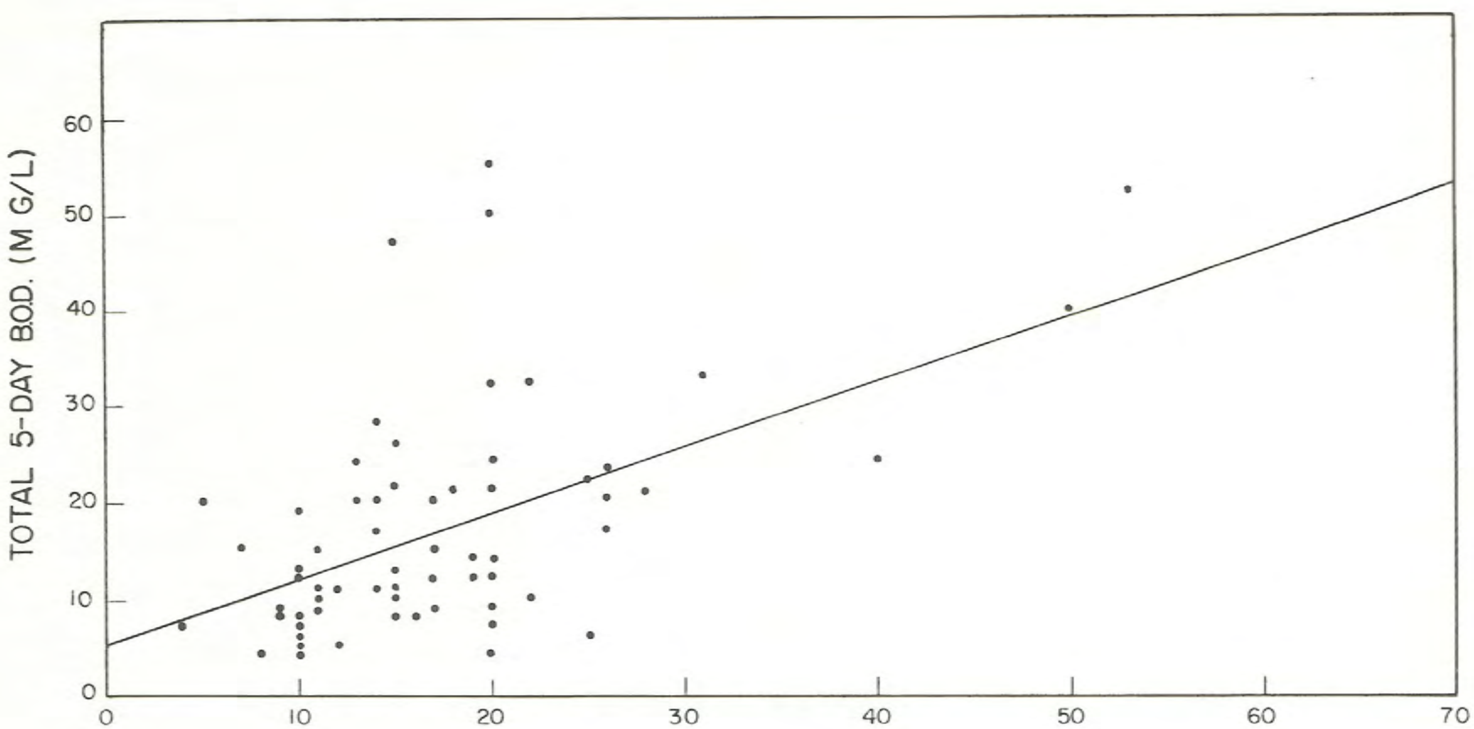
PERCENTAGE OF DAYS IN AUGUST WHEN B.O.D. IS GREATER THAN 6 MG/L AT GUELPH.



NOTE:
WITH SAND FILTRATION IN ADDITION TO SECONDARY TREATMENT AT GUELPH (INCLUDING NUTRIENT REMOVAL)

FIG.9

LINEAR RELATIONSHIP BETWEEN B.O.D. AND SUSPENDED SOLIDS AT KITCHENER. (BASED ON 72 SAMPLE POINTS FROM 1965 TO 1971)



NOTE:
RELATIONSHIP IS STATISTICALLY
SIGNIFICANT AT 99% LEVEL
CORRELATION COEFFICIENT IS 0.63

to the water course. Even separate storm sewers are not a complete answer since it has been found that after a prolonged dry period, the first half-hour or so of storm runoff may have B.O.D. and other characteristics equivalent to that of untreated domestic sewage. A review of the literature indicates that the shock loading may be great enough to cause large fish kills. On this point (Barrett 1971) has reported several large fish kills in the St. James River in Missouri, which have been traced to storm water runoff. An example of storm runoff data for various cities may be seen in table 3. The poor quality of urban runoff is due to street refuse such as dirt, litter, oil, disintegrated asphalt; animal droppings; stale and septic water from storm sewer catch basins, ditches and other depressions; and chemicals from many sources (APWA 1968). A possible solution to this problem could be through catching and retaining in holding tanks the first concentrated surge of storm sewage and releasing it gradually for treatment into the sanitary sewers. There is no fundamental reason why this type of approach could not be used for municipalities in the Grand River Watershed although there could be a number of detailed engineering problems and the cost would be substantial. To obtain a rough idea of the latter, we have estimated the cost of building holding tanks to retain the first half-hour flows in storm sewers for 90% of rainstorms likely to occur over municipalities in the basin. Based on our population estimates for the year 2001, this would be very approximately \$5 to \$6 million. This is obviously a very significant sum of money and any justification of expending it should be based on a careful analysis. We have not made any estimates of costs involved in any required changes to sanitary or combined sewers.

We recommend that the OWRC initiate an investigation of the sanitary, storm and combined sewers of municipalities in the Grand River Basin, with a view to establishing the extent and consequences of storm runoff on stream quality and aquatic life; and further to suggest the alternatives and their costs to alleviate the problems found. This information should be collected so as to be useable by the computer simulation (see recommendation 6).

.... *RECOMMENDATION NO. 13*

(ii) Land disposal in this report refers to the application of secondary treated sewage effluent onto the land. The treatment resulting from this is approximately equivalent to coagulation and sedimentation, filtration and passage through activated carbon. Both coliforms and B.O.D. are reduced to negligible levels after the liquid applied percolates through several feet of soil. Phosphate compounds are fixed in the top layers of the soil and only reach the groundwater table in minute amounts (Wall and Weber 1970), usually less than 0.01 mg/l. Thus, removal of phosphorus and B.O.D. are higher with a properly run

TABLE 3 CHARACTERISTICS OF STORM WATER

(Taken from "Water Pollution Aspects of Urban Runoff")
Federal Water Pollution Admin. (U.S.)

	BOD mg/l	Total Solids mg/l	Suspended Solids mg/l	Coliform /l	Chlorides mg/l	COD mg/l
1. East Bay Sanitary District						
Minimum	3	726	16	4	300	
Maximum	7,700		4,400	70,000	10,260	
Average	87	1,401	613	11,800	5,100	
2. Cincinnati, Ohio						
Maximum Seasonal Means	12	260				110
Average	17		227			111
3. Los Angeles County						
Average 1962-63	161	2,909			199	
4. Washington, D.C.						
Catch-basin samples during storm						
Minimum	6		26		11	
Maximum	625		36,250		160	
Average	126		2,100		42	
5. Seattle Washington	10			16,100		
6. Oxney, England	100**	2,045				
7. Moscow, U.S.S.R.	186-285	1,000-3,500**				
8. Leningrad, U.S.S.R.	36	14,541				
9. Stockholm, Sweden	17-80	30-8,000		40-200,000		18-3,100
10. Pretoria, South Africa						
Residential	30			240,000		29
Business	34			230,000		28
11. Detroit, Michigan	96-234	310-914	102-213***	930,000**		
Criteria for:						
A. Potable water						
(to be filtered)				5,000	600**	10
(not to be filtered)				50		10
B. Water Contact Water				2,400	NA	

*New York State
**Max.
***Mean

land disposal scheme than for the most advanced treatment methods presently in operation. However, a build-up of nitrates and dissolved solids can occur resulting in higher concentrations of these substances ultimately entering the stream and possible impairment of groundwater sources.

Land disposal methods can be of two types: irrigation or infiltration. Irrigation, using treated sewage effluent, has been utilized for a number of years in many parts of the world. Examples are mainly found in arid or semi-arid areas and this method is very common in Israel and has been employed at Lubbock, Texas since the 1930's. Since 1962 an experimental program has been under way utilizing sewage effluent at the Pennsylvania State University for fertilizing crops and forests. The beneficial aspects of irrigation would be to prevent the effluent from entering the water course, to raise the groundwater table and to provide nutrients for crops. There would be increased crop yields in dry years, however, the benefits would likely be marginal or negligible in the wet years in our area. Based upon what appear to be reasonable figures for possible spraying rates, we would require the following number of acres to be irrigated to utilize the available flows:

	1976	2001
Kitchener only	1,500	3,200
Megalopolis plus Guelph	4,000	10,000

Preliminary calculations indicate that if the system were capable of year round operation, costs might be the order of 15¢ to 20¢ per 1,000 gallons of effluent. This assumes that complete development of a new irrigation system would be required. This cost compares favourably with that likely from implementing phosphorus removal and sand filtration. In addition, there would be the added benefits of virtually complete elimination of B.O.D. and phosphates entering the stream from municipal wastes. Disadvantages of the system would be that only certain crops could be acceptably sprayed, there would be a build-up of salts in the soil and nitrates in the percolate and possible crop damage could occur depending upon the constituents of the effluent. Winter time operation could cause problems although research at Pennsylvania State University indicates that these can perhaps be overcome.

Infiltration methods have also been used for land disposal purposes. In this case, the treated effluent is applied at a high rate to the ground and allowed to percolate into the soil. The rates of application are,in general, too high to allow any useful crops to be grown, but on the other hand, the land requirements are reduced compared to irrigation. Bouwer (1970) has reported infiltration rates of 300 acre-feet of effluent per acre per year based on work carried out since 1967 at Phoenix, Arizona. Other reports indicate that this is not unreasonable, although perhaps somewhat high for our area. Actual estimates of infiltration rates would require a thorough study of soil and subsoil conditions. Based upon infiltration rates of 250 feet per acre per year, reasonable assumptions give cost estimates for an infiltration system of about 10¢ to 15¢ per 1,000 gallons. The uncertainty inherent in these estimates and the fact that they may be conservative can be seen from published costs, which range from 1.85¢ to 10.4¢ per 1,000 gallons. The lower value is based on 1971 data from the Flushing Meadows Project at Phoenix, report by Bouwer, and includes pumping the reclaimed water to the surface. It must be stressed that any estimates of infiltration rates or costs are purely speculative at this point for the Grand River Basin.

In addition to waste disposal benefits, groundwater supplies could be greatly augmented by infiltration of treated wastes. However, there could be objections to use of the reclaimed water on aesthetic or health grounds. As pointed out earlier, coliform bacteria and virus do not seem to be transmitted through significant distances in the ground, but build-ups of nitrates and dissolved solids could be a problem. The degree to which groundwater impairment would actually occur could only be determined by a careful review of results from on-site research in the basin. Should recharge of domestic groundwater supplies be unacceptable, the reclaimed water could be pumped up into the streams rather than allowing it to infiltrate to the groundwater aquifers reserved for supply purposes.

In summary, it would appear that land disposal could be less costly by 10¢ to 20¢ per 1,000 gallons of treated sewage than advanced at-plant treatment for large municipalities. Considering for a hypothetical example, Guelph and Kitchener being (1) on advanced treatment from 1980 to 2000, and (2) an alternative of land disposal for the same cities with a saving of 10¢ per 1,000 gallons of (2) over (1); then the total dollar difference over the twenty year period would be $34 million. This is, of course, only a hypothetical example, since no firm justification for advanced treatment by 1980 for these two cities has been given, and further the 10¢ per 1,000 gallons taken as savings might be very inaccurate for that period of time. However, phosphorus removal will be in operation by 1980 at Guelph and Kitchener and we can see a requirement for at least the degree of treatment offered by sand filtration at Kitchener and Guelph. The figures are obviously large enough to indicate that a good deal of money is at stake when discussing tertiary treatment alternatives. To evaluate the feasibility of large-scale land disposal in the Grand River Basin, careful studies of infiltration rates and groundwater movement would be necessary. A test site should be established and field work carried out over an extended period to more accurately forecast likely results and costs. Such a study would probably require two years and could cost about $600,000 to carry out. This expenditure seems very worthwhile to us in terms of the possible effectiveness and potential savings inherent in a successful outcome of the research.

We recommend that a field pilot program into land disposal of treated sewage effluents should be carried out in the Grand River Basin by the OWRC to establish feasibility with respect to the effects on stream quality, groundwater, stream flows and the quantities which could be disposed of and the related costs as compared to at-plant advanced treatment.

.... RECOMMENDATION NO. 14

FLOOD CONTROL

Introduction

Any inundation from the river may be regarded as flooding, but it becomes of real significance only when the water causes, or has the potential to cause property damage or loss of life because of residential, commercial, or other development in the area. Flooding occurs when the channel does not have sufficient capacity to pass the volume of water generated by rainfall and/or snowmelt conditions. "Flood losses may be defined as the destruction or impairment, partial or complete, of the value of goods or services, or of health, resulting from the action of flood waters and the silt and debris they carry" (Hoyt 1954).The primary reason for flood losses is development on the flood plain and the degree of loss is dependent on the type and location of development. The methods used for estimating flood damages in this report are described in "Guidelines for Analysis, Volume 2, Flood Damages", prepared for the Governments of Canada and Ontario by Acres Limited. The basic data were collected by the Grand River Conservation Authority.

Flood Damage Reduction

The most common methods presently used for reducing flood losses are:

(i) Engineering Works

This is the method usually considered first, especially in extensively developed areas. Dikes to confine the flow,reservoirs to impound flood waters, channel enlargement and straightening to reduce stages, by-passes to carry water around the town, or a combination of several of these methods may be used.

Each type has its advantages and disadvantages. Dikes usually require a minimum of flood-plain land but often produce catastrophic results when they are breached or over-topped. Reservoirs are a more positive means of control, require less expensive land, and a flood exceeding the design capacity of the reservoir system is usually not catastrophic. Channel improvements and diversions, although effective, often require expensive urban land for their development.

(ii) Regulation of Development

Future potential losses may be minimized in an area by prohibiting and/or restricting new development on flood-prone lands. The Grand River Conservation Authority is presently preparing regulations which will utilize this technique along the rivers and streams of the Grand River Basin. Regulation of this kind does not necessarily prohibit development, but defines the type of development permissible within the framework of comprehensive urban planning, to insure the most judicious use of the land compatible with the aim of minimizing potential flood damage.

(iii) Flood-Proofing

Many types of changes can be made in existing developments in flood plains, or incorporated into the planning and design of future development to reduce flood losses, such as: land filling, design and layout of buildings, raising vulnerable parts of equipment such as motors, and provisions for emergency installation of water-tight doors.

(iv) Flood Warning

Temporary evacuation of people and damageable goods can be an effective measure in reducing flood losses. The success of this technique is dependent on an efficient flood warning system. Such a system is presently being utilized in the Grand River Basin. Further improvements could be made in this system if the likely hydrologic consequences of an approaching storm could be predicted more accurately. Further comments are made on this in our discussion of recommendation 15.

The people of the Grand River Basin have faced various types of water management problems ever since man first inhabited the area. As with most regions of Ontario, the earliest recorded problems were those of flooding. The Grand River Conservation Report (1962) gives a very complete history of flooding on the Grand River watershed from about 1790 A.D. to 1954 A.D., based chiefly on diaries and newspaper accounts. As outlined in that report, flooding on the Grand River and its tributaries has always been a severe problem. Major flood damages have occurred at the Cities of Brantford, Galt, and Guelph, the Towns of Caledonia, Dunnville, Fergus, Hespeler, New Hamburg, Paris and Preston, and the Villages of Ayr, Bridgeport and Elora.

Over the years, dikes have been constructed at some of the major flood-vulnerable points along the river. Brantford, for example, constructed dikes in 1894 and extended and raised them in subsequent years. According to the Grand River Conservation Report, "In 1949 the dikes at Brantford were raised and extended ... This money was well spent; for in the spring flood of 1950 the water again rose close to the top of the dikes. A small additional rise would have overtopped the dikes and the loss would have been extremely heavy".

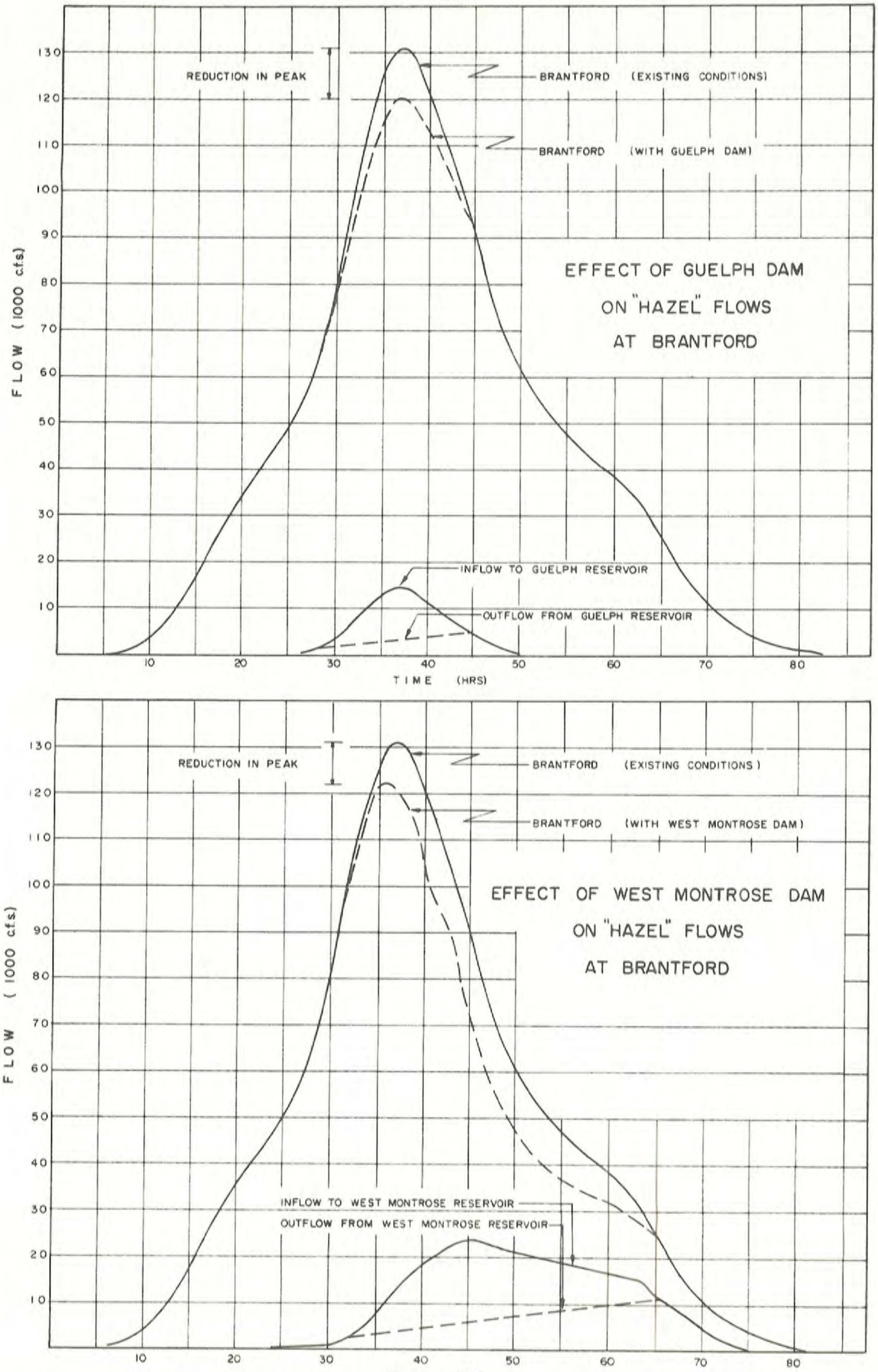
Since 1940, three major flood control dams have been constructed: Shand Dam (1942), Luther Dam (1954), and Conestogo Dam (1958). These dams have changed the flow regime of the river considerably and have provided a large flood control benefit. However, the potential for flood damage is still very high because several major tributaries remain uncontrolled and because a great deal of urban development has taken place in the past two decades. In more recent times, as population and industry have increased, problems of water supply and pollution have become very evident as have demands for more recreation and streamlife management. Through the Grand River Conservation Commission, the Grand Valley Conservation Authority, and presently the Grand River Conservation Authority, action has been taken over the years to plan and construct facilities which will help to resolve these water problems.

The main emphasis in the planning of water control facilities to date has been on flood protection. However, the final design and operation has usually incorporated and developed the multiple purposes of flood control, pollution abatement, recreation and wildlife management. The emphasis in this study is towards the complete integration of all water management activities, including water supply, within the watershed to reflect the optimum system and operating policies at the planning stage. With this concept in mind, various possible water control structures were evaluated as to their beneficial and/or detrimental effects on the socio-economic and environmental systems rather than focusing on flood control as an isolated problem.

The objective of flood control activity is to minimize the average annual flood damage with the least cost. The primary constraint on this evaluation is that the average annual flood damage reduction must exceed the average annual cost of achieving that reduction. The cost in this respect must reflect the actual cost of constructing a flood control facility and the conflict cost which may be allocated to any interference the flood control facility may have with any other part of the system.

The flood damage reduction or benefits which may be assigned to any system consist of both tangible benefits, those to which a dollar value can be assigned, and intangible benefits, or those which are not fully measurable in monetary terms. The benefits which are used for this analysis are tangible benefits. Tangible benefits may be further sub-divided into benefits achieved by reduction of direct damages, i.e. damage to structures and contents; and indirect damage, i.e. business disruptions, temporary unemployment, traffic disruptions and general relief of flood victims.

The optimum benefits from flood control due to reservoirs depends on



EFFECT OF SUB-HYDROGRAPHS ACCORDING TO RESERVOIR LOCATION

FIG. 10

both the flood storage capacity of the reservoir and its location with respect to the area susceptible to flooding. A particular flood hydrograph at an area subject to flooding (e.g. Brantford) can be developed by analysing the sub-hydrographs from all the various sub-watersheds such as, for example, Speed, Nith or Conestogo. In this study, sub-hydrographs were generated at all points of interest such as the key areas of flooding and the existing and proposed reservoir sites. By studying the effect that a sub-hydrograph from a proposed reservoir has on the key flood locations, one can thus choose and analyze various combinations of flood control facilities. It can be readily seen that a sub-hydrograph from one particular reservoir location may have a much more significant effect on the flood peak than a sub-hydrograph from another reservoir in a less strategic location even thought both reservoirs have the same storage capacity (see figure 10).

With this concept in mind, the major reservoirs proposed for the Grand system were analyzed for five different storms (10-year, 25-year, 50-year, and 100-year storms and Hurricane Hazel centred storm). From the basic damage data provided in the report on "Flood Damages on Grand River Watershed", (GRCA 1970), it was then possible to carry out an analysis of the expected annual benefits to be derived from each of the reservoir alternatives. This information was then used as part of the basis by evaluating different water management options for the basin. However, in this report, no reservoirs have been recommended purely on flood control grounds even when calculated benefits have exceeded their costs. This is because in certain instances, it was necessary to extrapolate beyond the damage flow curves prepared by the GRCA. More accurate data will have to be collected before firm benefits can be assigned to flood control facilities.

Consideration was given to seven major reservoirs, viz. Guelph, Everton, Arkell, West Montrose, Ayr, Barrie Hill and Hespeler, each with various different storage capacities. In all, approximately 70 combinations of reservoirs and storage capacities were analyzed as to their flood control benefits. As most of these reservoirs would be used for multiple purposes, two conditions for flood control were considered: (i) the reservoir empty in the spring and (ii) the reservoir at half the conservation pool storage during the remainder of the year. Sixty percent of the floods were considered to occur in the spring and forty percent during the remainder of the year.

The synthetic hydrograph approach developed by the U.S. Soil Conservation Service was the basis of hydrologic analyses carried out in this study.

For the purpose of this study, a synthetic hydrograph was used to represent surface runoff resulting from a design rainstorm over a watershed.

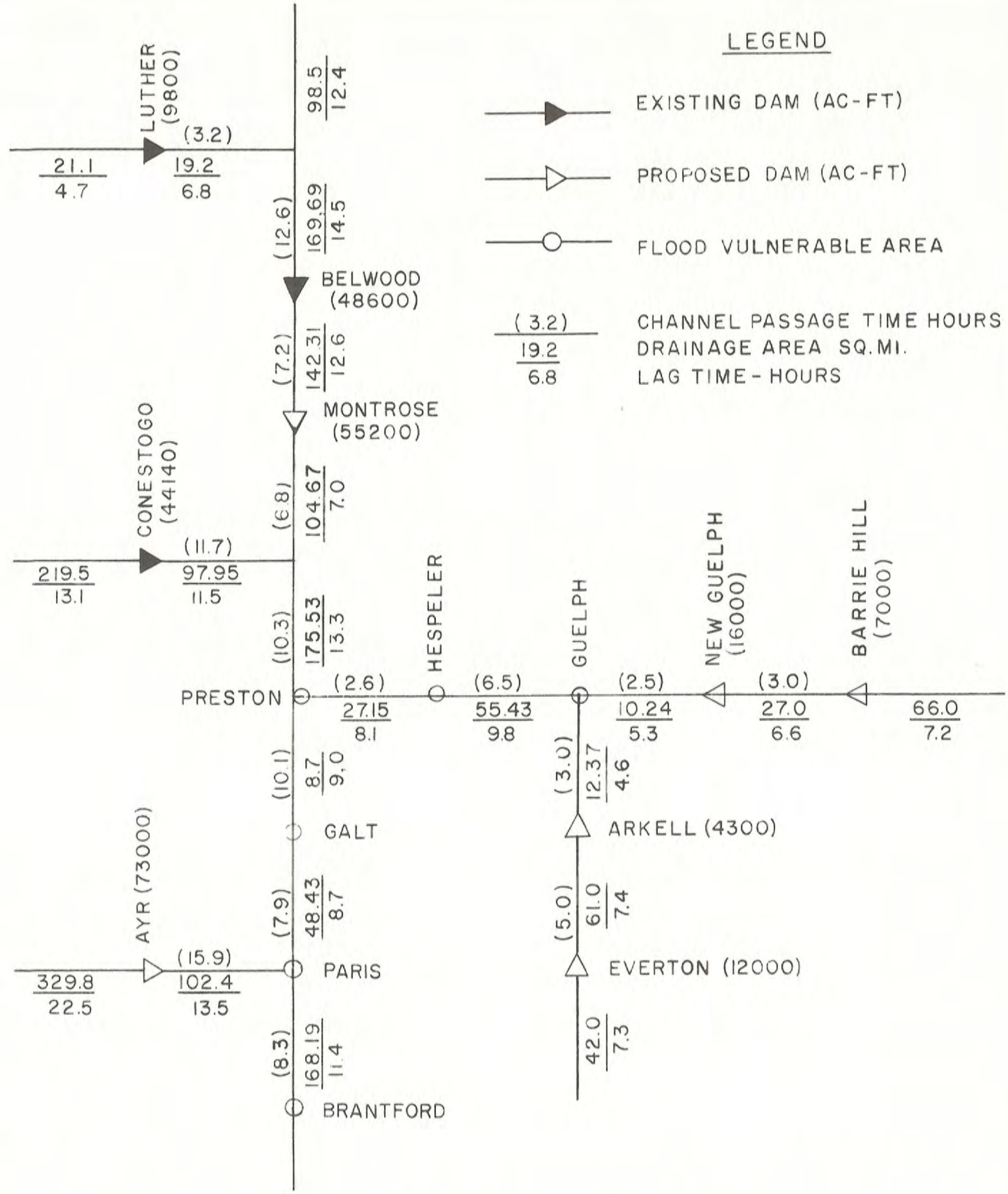


FIGURE 11 - SCHEMATIC DIAGRAM OF GRAND RIVER WATERSHED

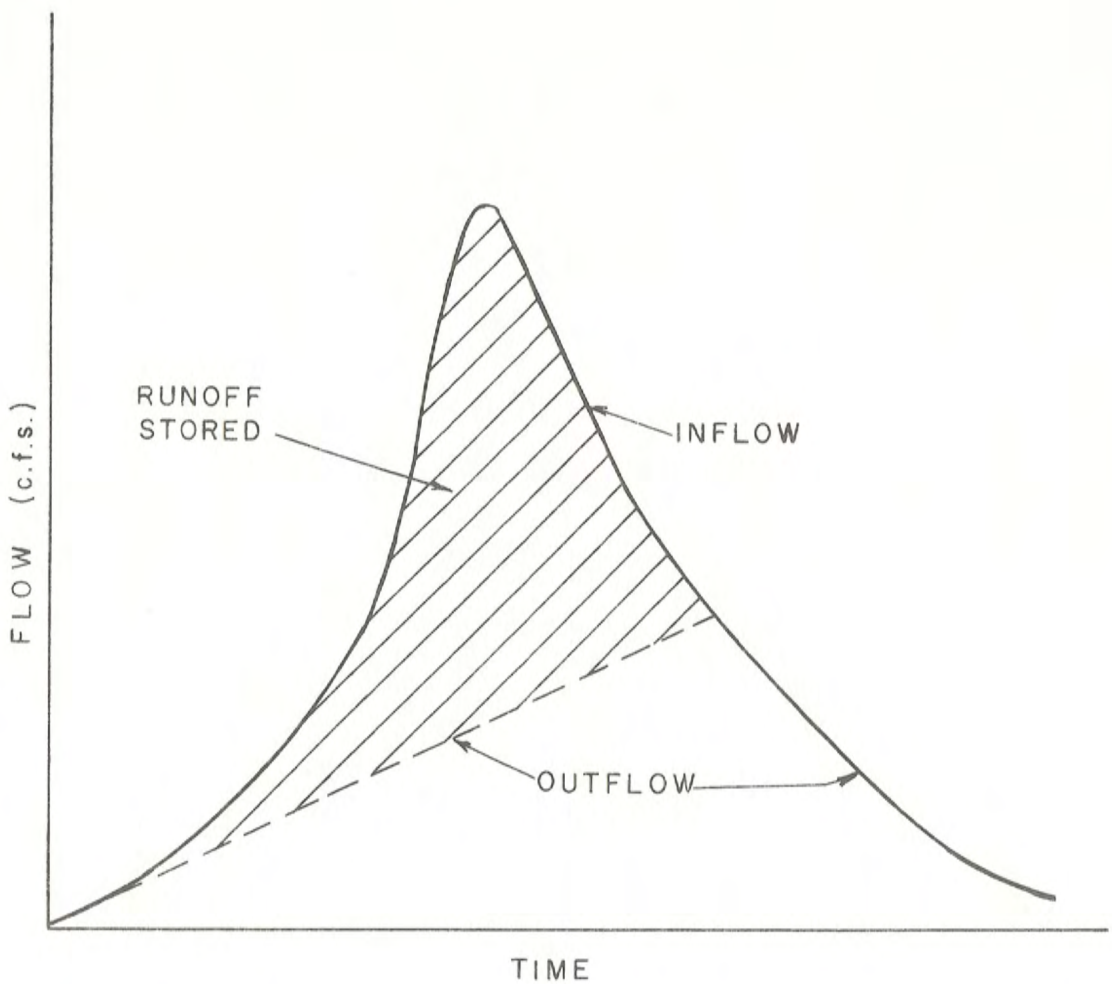


FIGURE 12 — RESERVOIR ROUTING

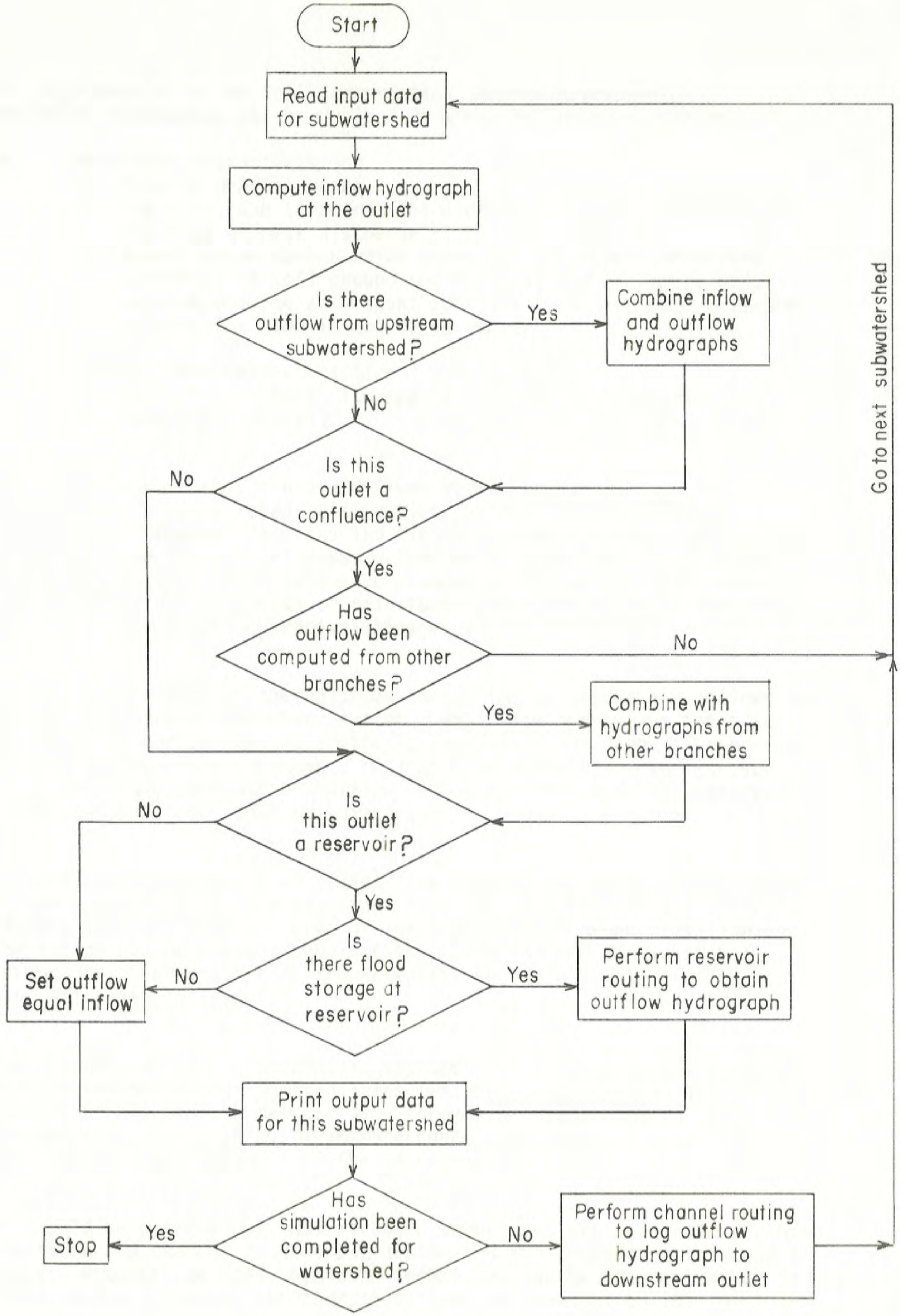


FIGURE 13- FLOW DIAGRAM FOR SIMPLIFIED HYDROLOGIC SIMULATION

To aid with this study, a simplified hydrologic simulation program was developed to allow analyses to be carried out for various combinations of dams and allocated flood storage. Figure 13 is a simplified flow chart which shows the sequence in which various major functions are performed by the computer.

The data supplied to the hydrologic simulation for each sub-watershed consists of the drainage area, lag time, runoff curve number, amount of rainfall, type of storm, flood storage allocated in the reservoir, channel passage time, confluence identification and operation mode. The program prints out the peak discharge, its time of occurrence and the amount of runoff at the outlet of each sub-watershed. In addition it will print out a complete hydrograph if requested.

The program provides for the continuous analysis of different storms over a watershed under present conditions and with various reservoir combinations.

Examination of the results of the analysis indicate that considerable insight into the hydrologic processes and the sensitivity of flood peaks to changes in type of storms and operating rules can be had by the use of hydrologic simulation methods. We feel that further refinement of this approach would yield benefits in terms of improved operations of systems of reservoirs under severe flooding conditions. The large damages from flooding occur during infrequent storms, for which the planning and operating staff do not have an opportunity to perfect their procedures through actual operating experience. The hydrologic simulation would allow any configuration of reservoirs, and any operating rules to be tested out against hypothetical flood events, so as to build up the valuable experience necessary to cope efficiently with the real thing when it ultimately occurs. The large number of possible combinations inherent in a complex system such as the Grand, indicates that some type of mathematical optimizing model should be developed concurrently with the simulation. As was indicated earlier, the hydrologic simulation actually developed for this study was very simplified in form and requires considerable refinement.

> *We recommend that the Conservation Authorities Branch develop a hydrologic simulation to allow the prediction of the consequences of real or assumed flood events under different flood routing policies. We further recommend the development of a mathematical optimizing model to select flood routing policies so as to ensure maximum benefits from existing reservoirs considering their multi-purpose nature.*

.... *RECOMMENDATION NO. 15*

If completed, the simulation would provide benefits additional to those discussed; such as improved flood warning, training of staff and applicability with modest adjustments, to other Ontario watersheds.

The total cost would probably be the order of $50 thousand for the Grand basin. As will be noted in our discussion of flood control benefits, we feel that the accuracy of the data and analysis used would not justify recommending any reservoirs on purely flood control grounds alone. The hydrologic simulator and mathematical model recommended would be of immense help in further reviewing the West Montrose, Hespeler and any other reservoirs suggested for flood control in the future.

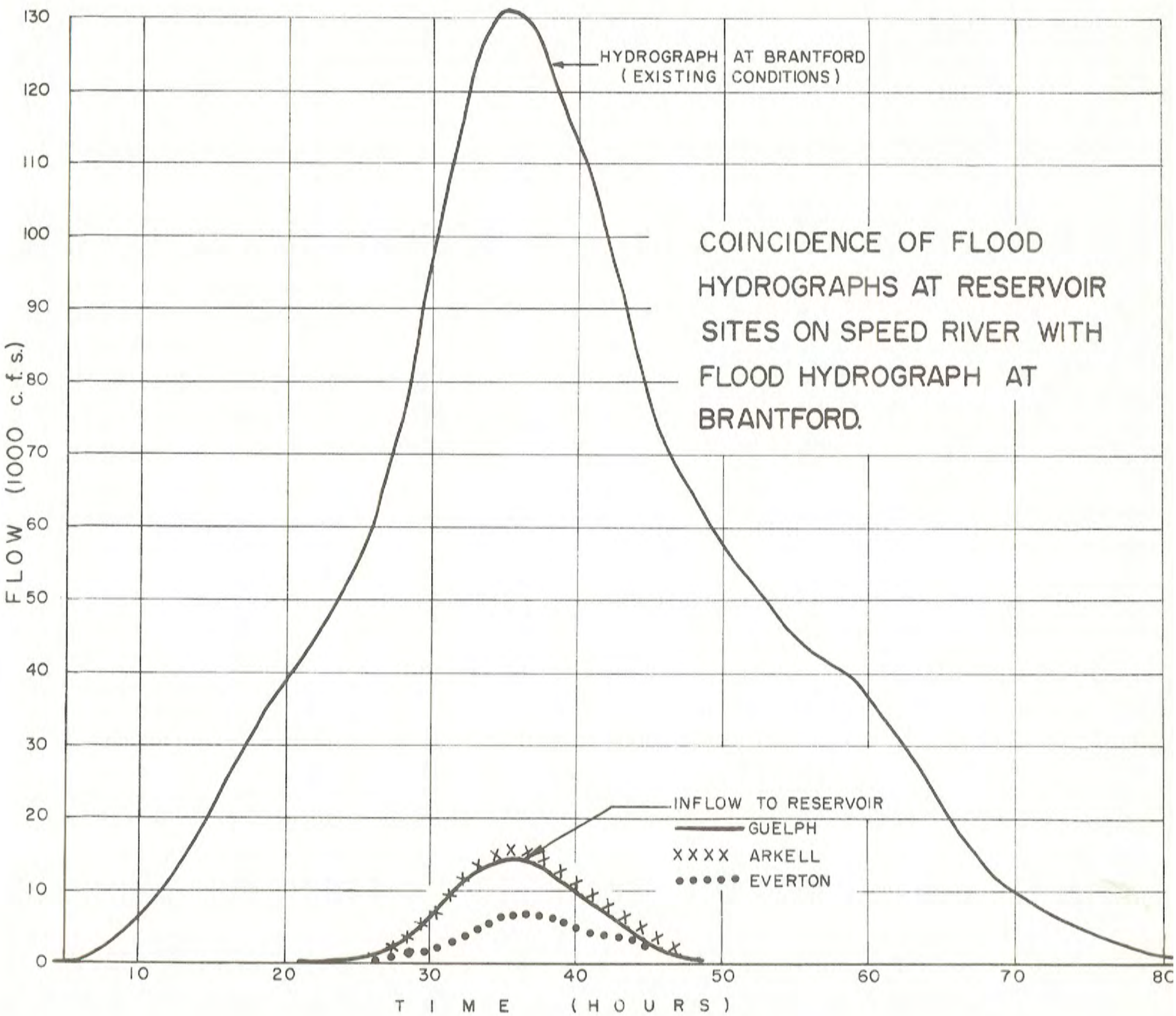
Summary of Analysis

From the analysis of flooding, it is apparent that the reservoirs on the Speed and Eramosa Rivers have a greater influence on flood damage reduction than do the Ayr or West Montrose Reservoirs. The reasons for this are obvious when one considers:

(1) that the sub-hydrographs from the various reservoir locations on the Speed and Eramosa when translated to the areas of flood damage are, in general, coincident with the peaks at the flood damage locations (see figure 14); and

(2) that there are a greater number of major flood damage locations downstream of the reservoirs on the Speed and Eramosa Rivers than there are downstream of the proposed Ayr and West Montrose Reservoirs.

FIG. 14



HYDROGRAPH AT BRANTFORD
(EXISTING CONDITIONS)
COINCIDENCE OF FLOOD HYDROGRAPHS AT RESERVOIR SITES ON SPEED RIVER WITH FLOOD HYDROGRAPH AT BRANTFORD.
INFLOW TO RESERVOIR
GUELPH
XXXX ARKELL
EVERTON
FLOW (1000 c.f.s.)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
10
20
30
40
50
60
70
80
TIME (HOURS)

TABLE 4

Flood Control Benefit Evaluation (in $,000)*

System of Reservoirs Considered	Average Annual Flood Control Benefits
(all include Belwood, Conestogo and Luther)	(over and above those due to existing dams)
(A) New Guelph	1176
(B) New Guelph + Everton	1628
(C) New Guelph + Arkell	1964
(D) New Guelph + Ayr + Everton	2042
(E) New Guelph + West Montrose + Everton	1913
(F) New Guelph + Ayr + Everton + Hespeler	2805

Individual Reservoirs	Average Annual Flood Control Benefit	Net Present Worth for 50 Years @4%	@5%	Cost of Reservoir	Benefit/Cost @4%	@5%
New Guelph (A)	1176	25,800	21,900	7,200	3.6	3.0
Everton (B) - (A)	452	9,900	8,440	6,600	1.5	1.3
Arkell (C) - (A)	788	17,300	14,700	8,400	2.0	1.8
Ayr (D) - (B)	414	9,050	7,720	18,800	0.5	0.4
West Montrose (E) -(B)	285	6,250	5,300	15,000	0.4	0.35
Hespeler (F) - (D)	763	16,700	14,200	8,700	1.9	1.6

*The six combinations presented are only selected examples to illustrate generally the flood control benefits associated with various reservoirs. In Appendix 4 will be found a listing of a large number of other combinations evaluated. Actual benefits have not been quoted in this report for all combinations since we feel that further refinement of the numbers is warranted. Extreme caution must be used in interpreting benefits from any reservoir since benefits depend upon the mode of operation and which other reservoirs are also present in the system. As an example, for Everton and Arkell above, assuming Hespeler also in the system would considerably reduce the benefits obtained from the Everton and Arkell Reservoirs and reduce the apparent relative superiority of Arkell.

would be seriously affected by the heavy nutrient load from up stream, only a dry or retardation dam was considered. With the existing information it is apparent that this facility could have a substantial flood control benefit and that therefore the land should be protected until such time as more precise data and sophisticated methods of analysis are available.

> *We recommend that land for the proposed Hespeler Reservoir should be purchased as it becomes available, but that the dam should not be constructed, nor detailed design carried out until its validity as part of the overall water management plan is confirmed.*
>
> ....*RECOMMENDATION NO. 16*

The Everton, Arkell, Ayr, West Montrose and Barrie Hill Reservoirs were also considered as parts of various water supply alternatives and further discussions regarding them will be deferred until after the discussion on water supply which follows.

MUNICIPAL WATER SUPPLY

Demand Forecasts

Future water demands of the municipalities are essentially dependent upon two forecasts: a projection of population distributed among the communities in the basin, and a forecast of expected per capita water usage. The population projections have been based upon a number of related studies and reports including:

- The Waterloo South-Wellington Area Economic Base Study, presented in July 1969 by Canadian Urban Economics Ltd.
- The Six Goals Plans, formulated by the Waterloo Area Planning Board.
- Demographic forecasts of communities in the Grand River Watershed, supplied by staff of the Economic Analysis Branch of the provincial Department of Treasury and Economics.
- County Population Estimates for Waterloo, Wellington and Brant Counties from D. B. S. 1969 figures.

In addition, there have been discussions with staff of the Haldimand Norfolk Study, the Regional Development Branch of the Department of Treasury and Economics, the Community Planning Branch of the Department of Municipal Affairs, the Waterloo County Area Planning Board, and the Regional Services Planning Branch of the OWRC.

The per capita water usage forecasts were based upon three assumptions:

1) With increasing affluence and leisure time, domestic demand will grow rapidly. This assumption seems reasonable if one reflects on the rapid growth in ownership of automatic dish-washers and clothes washers, childrens wading pools, family swimming pools, etc.

2) Industrial usage will decrease with a growing acceptance by industry of responsibility for preservation of the environment.

3) In the long term, the industrial trend of decreasing usage will be more significant than the domestic trend of increasing usage.

The population projections used in this report and the associated water demands are presented in table 5 for the municipalities most affected by our present analysis. To allow necessary staging considerations to be incorporated into the reconnaissance estimates for the major water supply alternatives looked at, the projections have been broken down into five year intervals as shown. Examination of the contents of table 5 shows that the populations forecast for the year 2001 are somewhat lower than those presented in the Waterloo-South Wellington Study, which was based upon 1966 census figures. The 1969 D.B.S. County Population Estimates would seem to support the more conservative estimates that have been used in this study. On the other hand, tentative population estimates for this area worked out by the Toronto Centred Region Study are lower than those used in this report. As the Toronto Centred Region figures are still under review at the time of writing this report, it has not been possible to use them for population forecasts. It should be noted that the Toronto Centred Region figures are target populations, i.e. an assessment of what the results of "economic management" might be in future years. We have re-examined our recommendations in light of possible lower population estimates and found that they remain valid. The per capita usage forecast of 120 gallons per day by the year 2001, for all centres of more than 50,000 population, is lower than that generally forecast by others (usually in the range 130 to 150 g.p.d.*). Whether this conservatism is justified is a matter of opinion, but it is a working assumption which we have accepted as valid for this report. Demand projections up until the year 2001 were carried out for all population centres in the basin, however, except for those municipalities quoted in table 5, only a very cursory analysis of supply and demand was carried out. Geography and size force one to the conclusion that the smaller municipalities should continue to depend upon local water resources to meet their present and future needs. These resources appear adequate except for Caledonia and Cayuga, which would have to be considered for any regional supply system. Should rapid growth occur at any of the other small municipalities in the future, it would be necessary to re-evaluate the adequacy of local supplies.

The growth rates which have been used for forecasts of total basin population are shown in table 6. For the purposes of analysis, a planning period of 30 years, up to 2001 was considered. There are two ways of interpreting a fixed horizon such as this. Firstly, it can be assumed that population will level off by the year 2001 and remain approximately constant thereafter. This is unlikely to happen for both economic and demographic reasons. A second way of considering the 30-year planning horizon is that facilities would be designed to service the population forecast for the year 2001, and additional facilities would have to be planned for later to take account of any additional population growth beyond the year 2001.

We feel that our approach is reasonable, particularly since planning facilities for a longer period ahead than thirty years is probably of little value, given the rapid pace of change in technology and social needs. However, to test the sensitivity of alternate plans to the length

* gallons per day

TABLE 5

Population and Water Demand Projections for Selected Municipalities in the Grand River Basin*

Centre	1971	1976	1981	1986	1991	1996	2001
Kitchener Waterloo (Pop.)	145.0	174.0	203.0	240.0	271.0	313.0	352.0
Galt Preston Hespeler (Pop.)	60.0	69.0	86.0	124.0	167.0	195.0	223.0
Total for Megalopolis (Pop.)	205.0	243.0	289.0	364.0	438.0	508.0	575.0
" (Demand)	22.71	27.13	32.92	42.10	51.44	60.32	69.00
Guelph (Pop.)	58.0	70.0	82.0	93.0	107.0	121.0	134.0
" (Demand)	6.09	7.52	9.02	10.46	12.31	14.22	16.08
Brantford (Pop.)	62.0	65.0	68.0	75.0	82.0	90.0	99.0
" (Demand)	6.82	7.28	7.75	8.70	9.68	10.80	11.88
Caledonia (Pop.)	3.1	4.8	7.3	8.0	9.5	11.0	13.0
" (Demand)	0.23	0.40	0.66	0.76	0.95	1.10	1.30
Cayuga (Pop.)	1.1	1.6	3.1	6.0	8.0	10.0	17.0
" (Demand)	0.12	0.20	0.36	0.71	0.96	1.20	2.04

* Population in thousands of persons and demands quoted as average M.G.D.

TABLE 6

ANNUAL POPULATION GROWTH RATES

Period	Middle Grand Area	Brantford
1971-1976	3.1%	1.0%
1976-1981	3.5%	1.0%
1981-1986	4.0%	2.0%
1986-1991	3.5%	1.8%
1991-1996	3.1%	1.8%
1996-2001	2.5%	1.8%

of the planning period, we have made evaluations for 50 years, i.e. to the year 2021, assuming a static population between 2001 and 2021. The prime purpose of this sensitivity analysis was to identify any plans wherein operating costs could shift investment decisions given a sufficiently long planning period.

It should be noted that because of limitations of time and resources, it has been necessary to base this study on a single population forecast with a fixed distribution. For a reconnaissance type survey this must suffice but the tradeoff between service costs and population should not be ignored. Water supply and sewage treatment are a significant part of total service costs, but one must also bear in mind that the social and environmental impact must be included. This more sophisticated approach to analysis would treat growth as a decision variable rather than an external input. It has been assumed that with more time and resources, such a methodology would be applied to future studies of the basin. This would imply close coordination between agencies responsible for planning and the water management study team.

Present Water Supply

Present sources of potable water in the basin in order of importance are groundwater, riverwater, Lake Erie water and, to a minor extent, rainwater stored in individual cisterns.

The Middle Grand communities rely entirely on groundwater. Well takings are largely from the Guelph-Amabel bedrock aquifer in the east-central area and the overburden aquifer overlying the Salina formation in the west-central area of the basin.

Guelph has developed a number of wells in the bedrock aquifer and also uses an extensive collection system at Arkell Springs which picks up water from a local overburden aquifer.

The total rated capacity of present Guelph sources is in excess of 25 m.g.d. It should be pointed out however that this figure includes private industrial wells and ratings have been arrived at on an individual well basis. If all wells were pumped simultaneously on continuous operation, it is felt that a true perennial yield for these sources would be closer to an average of 13 m.g.d. Of this amount the potential industrial well yield is about 4 m.g.d. Therefore a perennial yield of about 9 m.g.d. would be available for municipal use if industries in the area were to fully utilize their developed well capacity. Present usage is approximately 6 m.g.d. which is 106 g.p.d. per capita with a peak factor of

TABLE 7

ADEQUACY OF PRESENT WATER SUPPLY SOURSES

Municipality	Estimated Perennial Yield (M.G.D.) (1)	Approx.Present Usage (M.G.D.)	Per Capita Usage (G.P.D.)	Peak Ratio
Waterloo	2.3	4.0	104	1.8
Kitchener	10.5 - 15.2	11.6	105	1.5
Galt		4.7	134	2.2
Preston	12.0	1.3	110	1.8
Hespeler		0.6	92	1.6
Total for Megalopolis	24.8 - 29.5	22.2	-	-
Guelph	9.0 - 13.0	6.0	106	1.5
Brantford	15.0 (2)	7.0	109	1.7

(1) OWRC Estimates

(2) Rated capacity of the treatment plant.

1.5. The Guelph water supply is relatively hard, at 316 p.p.m. hardness, and in places contains iron slightly in excess of OWRC criteria for public supply.

As with other communities in the area, treatment requirements are minimal.

Kitchener and Waterloo, whose distribution systems are inter-connected, take all of their water from wells in the thick glacial overburden underlying and to the west of these centres. The total combined estimated perennial yield of their present well fields is somewhere between 12.8 m.g.d. and 17.5 m.g.d. (see table 7), compared with a 1970 average daily pumpage of 15.6 m.g.d. Some of the existing well fields are being mined to the extent that with existing withdrawals, pumping water levels in the aquifers will reach the well screens by 1978 and cutback will be required. The groundwater being used in this area averages 300 p.p.m. hardness. It should be noted that large quantities of water are available in the area from the underlying bedrock, but high sulphate content makes it unusable and to date, economic treatment methods have not been developed. Treatment processes utilizing reverse osmosis could possibly provide a solution to this problem in the future.

Galt, Preston and Hespeler take most of their groundwater from bedrock aquifers. The combined estimated perennial yield for all three municipalities is 12 m.g.d. compared with a 1970 average daily usage of about 6.6 m.g.d. (see table 7). The Galt and Preston distribution systems are inter-connected for emergencies. Most of the developed well capacity belongs to Galt and there have been small shortages experienced in Preston in the past.

If we examine the estimated perennial yield for the entire Megalopolis and also project the future water demand, it would appear that there are adequate supplies to last until somewhere in the period 1973 to 1978 without mining the aquifers appreciably. This implies a judicious usage of the present well fields developed by the Megalopolis. Study of present groundwater utilization in the Megalopolis area indicates a lack of integrated planning. Non-optimal well spacing results in interference among the wells of Galt, Preston and Hespeler. The same situation exists as regards some Waterloo and Kitchener wells, but also there is severe streamflow interference caused by groundwater takings of these two communities. In addition, the water table is lowered in some areas excessively by uncoordinated pumping of the aquifers and this can dry up wet lands and change the types of ground cover. In addition to the above, we feel that minimal costs for all of the people of the Megalopolis will be achieved through integrated planning for future supplies.

We recommend that all new water supply developed for the municipalities of Kitchener, Waterloo, Hespeler, Preston and Galt (called the Megalopolis) should be based upon an integrated plan for potable water for the whole area rather than for any one municipality.

.... RECOMMENDATION NO. 17

The encroachment of urban development on well field recharge areas may also turn out to be a serious problem. Urbanization results in large areas exhibiting quick runoff characteristics due to extensive paving, roofing and various forms of drainage. If recharge areas are urbanized, the consequence will be reduced perennial yield for the affected well fields. As an example, sub-divisions are now approaching the Mannheim field which is a present source of supply and may be a key element in future recharge schemes. It would be unfortunate if a major supply source were to be lost to the Megalopolis due to urban encroachment on recharge areas.

Aside from the Megalopolis, all other communities in the middle and upper Grand watershed depend upon local well water supplies which generally appear to be adequate in terms of both quality and quantity.

In the lower Grand, the largest community is Brantford which treats water from the Grand River. The hardness of the water varies, depending on the season and river flows, but seems to average about 270 p.p.m. An adequate quantity of water is available from the river for any foreseeable growth of Brantford and the treatment plant capacity is rated at more than twice Brantford's present average usage. There have been taste and odour problems in the past, but in the last four years these seem to have been well under control. We feel that there is some risk to quality inherent in a water supply source from the river since there is a large concentration of population and industry upstream. Whether this risk is significant and whether it can be traded off against cost considerations is a question we have not been able to come to grips with in this report. With forecast growth of Brantford as shown in table 5, the capacity of the present water treatment plant would be exceeded on peak days by 1991.

Of the remaining lower Grand population centres, Caledonia and Cayuga would have to be considered as potential participants in any watershed supply systems. Caledonia is presently obtaining groundwater of poor quality from local wells, augmented by individual cistern storage. Cayuga has a small treatment plant utilizing water taken from the Grand River. As in Caledonia, individual home owners also store rainwater in cisterns. For both Caledonia and Cayuga, present supplies are barely adequate in terms of both quantity and quality to meet present demands.

Supplies will be completely inadequate if, as expected, growth in the area is stimulated by economic expansion at Nanticoke.

Dunnville presently uses Lake Erie water and we have assumed that this would continue to be the case, regardless of what systems might be proposed for the rest of the basin. Paris presently has a satisfactory source of groundwater. Any major growth in the future could presumably be satisfied from further groundwater development in the glacial overburden several miles to the north of the town.

GENERAL DISCUSSION OF ANALYSIS METHODS

Evaluation Criteria

In the analyses carried out for this report, we have used as a primary evaluation criterion the "total system cost". In the Grand River Basin, there are potential conflicts among the objectives of different communities, different levels of government, and different departments within government. The total system cost includes all costs without reference to how they might be apportioned among participant agencies. Thus capital and operating costs plus householder costs (water softening equivalent) are included, as are benefits, as from flood control, which can be considered as negative costs. Planning options have been ranked according to the magnitude of their total system cost taken in present worth terms. As was discussed in the chapter on Flood Control, present worth takes account of when benefits and costs actually occur, weighting near-term dollars more heavily than those off in the future. The weighting factor used is a discount rate made up of components to reflect both inflation and the cost of capital. In the detailed comparisons of system costs which are given in the next chapter, a planning period of thirty years has been used with cost of capital of 7%, and inflation of 4% for land and construction and 3% for water softening costs and flood damages.*

Because of grant structures and methods of financing, a planning option not having the lowest total system cost could be the cheapest in the eyes of a particular agency or community. However, if this were to be the case, it would necessarily follow that some other participant in the system would have to pay more than if the optimal option were chosen. It has not been possible to delve into the details of the rating structures that might result from the choice of each option. We have taken as obvious that the selection of the plan giving the least cost to the greatest number of participants should be made. It would then be (in principle) possible to resolve any individual inequities through follow-up analysis and negotiation.

In actually evaluating the various planning options (see appendices 4 and 5), various considerations other than total system cost have been incorporated. These include: financial burdens on the municipalities; risk to the population; environmental consequences; reasonable water management technology; aesthetics and public acceptability. Any further development of the water management plans following this report must continue to stress all of these evaluation criteria plus the relationship of the different planning options to economic growth.

Costing

Cost elements that have gone into the evaluation of alternative plans include both capital and operating. Flood control benefits, softening costs, conflict costs, recreational benefits and pollution abatement requirements

*In our sensitivity analyses of total system costs, we varied these percentages to study the effect.

have all been included either in the quantitative analysis or in subsequent subjective evaluations.

All costs are approximate reconnaissance estimates, and are not based on detailed engineering studies.

Capital Costs

All capital costs have been assessed at 1971 prices (Engineering News Record Index of 1300) based on reconnaissance engineering design. In no case have previous design and costs from other studies been accepted. All projects have been costed on a comparative basis in line with the assumptions laid out in this report.

Because of the lack of reliability of long term forecasts, no plan component has been considered that would entail completion of large scale construction after 1991. It has further been assumed that no large project could be completed before 1976 (other than the development of new groundwater supplies) and that costing would be based on each plan component becoming operational in one of the bench years (1976, 1981, 1986, 1991).

Pipelines and treatment plants have been designed to meet expected peak day demands in 2001. For the larger communities maximum day has been taken as 1.6 times average day demand. It has also been assumed that because of large differences in the physical quality (hardness) between groundwater and lake water the two would not be mixed and pipelines and related facilities are designed to meet the total demands of any community on the system; i.e. pipeline water would completely replace groundwater sources, as has happened with the London, Ontario system. In designing all supply systems it has been assumed that delivery would be to a terminal point on the outskirts of each community. No allowance has been made for any necessary modification or extension to existing distribution systems.

Groundwater well-field systems have been designed with auxiliary wells to meet maximum-day demands. Perennial yield has been used as the upper limit on well-field capacity with allowance for exceeding perennial yield on maximum days. No new systems have been designed where groundwater takings could cause undue streamflow interference.

Operating Costs

For pipeline systems, operating costs have been derived by assessing the labour, production and maintenance, pumping, treatment and general costs. Labour and general costs have been estimated from evaluation of the manning requirements at significant points through the planning period. To assess production and maintenance costs, a percentage of capital has been taken depending on the type of equipment being costed. Pumping costs have been arrived at by applying Ontario Hydro rates to average and maximum flows. To obtain treatment costs, the treatment cost incurred in similar plants has been projected to the average day flows each system was designed for.

Derivation of operating costs for internal sources has been on the same basis except that treatment costs on internal reservoir plants have been augmented by 10% of plant production costs to account for possible taste and odour problems.

Costs of existing groundwater supplies have been taken as an average of \$50 per million gallons for all communities. Brantford treatment plant costs have been set at \$90 per million gallons (exclusive of transmission, distribution and debt repayment).

Flood Control Benefits

For all dams and combinations of dams, flood benefits have been estimated as described in Chapter 5.

Recreation Benefits

Recreational benefits have not been included in the quantitative analysis but have been considered subjectively on a post-optimality basis. The justification for this approach is that these benefits are relatively inconsequential in tangible, economic terms when compared to water supply flood control and pollution abatement. Recreation benefits have been more thoroughly discussed in Chapter 3.

We have not included pollution abatement benefits due to flow augmentation from reservoirs in our systems costs since our studies have not yet clarified the best long-term advanced treatment methods for the basin. For example, if land disposal should ultimately prove to be most effective and economical, then additional low flow augmentation would have negligible benefits on the streams presently having large impoundments. On the other hand, if at-plant advanced treatment is ultimately installed at municipalities, additional flow augmentation could defer some waste treatment expenditures. We have carried out preliminary evaluations on flow augmentation benefits in the latter case for the West Montrose Reservoir, trading off against installation of sand filtration facilities and the result was less than \$1 million in present worth terms. Benefits from the Ayr Reservoir would be even harder to define and presumably smaller. Furthermore, until the computer simulation of water quality is completed, no realistic estimates of pollution abatement benefits of flow augmentation can be obtained. Based on all this, we have not included pollution abatement costs (and benefits) in the system costs. It will also be noted from our recommendations and conclusions, that we have made no specific suggestions regarding construction of pollution abatement structures or equipment. This matter will be deferred for later study.

Though there is an intimate relationship between pollution abatement and water supply requirements, it has not been possible to include explicitly the costs of pollution or the benefits of non-pollution in the quantitative analysis. Rather, a satisficing procedure has been followed. In the case of designing reservoirs, this has meant that a minimal base flow equal to the "lowest year of record" flows has been provided downstream of the dam before any plans have been made for use of the remaining impounded water. In practical terms, this implies that in the dry year the previously recorded lowest flow will be guaranteed, while in most years, the summer and fall low flows will be augmented.

As already pointed out, no groundwater takings have been planned that could conceivably contribute to excessive streamflow interference. The only well development without streamflow replenishment that has been considered has been in the Grand Valley itself. The effects of this potential interference would be minimal in relation to total flows in the Grand River and can be ignored for all practical purposes.

The satisficing procedure has necessitated a non-standard approach to evaluation of the West Montrose Reservoir. Rather than requiring baseflow releases to meet dry year flows at Kitchener (185 c.f.s.), a more stringent requirement of 250 c.f.s. has been applied, since we feel that this can be guaranteed with existing reservoirs.

Softening Costs

Traditionally, the individual homeowner in the basin has accepted responsibility for the cost of softening his water if he chooses to do so. This individual cost is excessively high (anywhere from \$.50 to \$2.00 per 1000 gallons as compared to \$.09 to \$.11 per 1000 gallons for municipally softened water). Because of the large difference in hardness of approximately 200 p.p.m. between lake water and internal water, account must be taken of either the cost of softening internal water to the lower level of hardness, or the intrinsic value of the softer water. This study team has opted for the latter alternative since it avoids extensive work in assessing complex municipal softening schemes. The value used has been \$3.10/person/year which reflects the cost of extra soap etc. required with the harder water based on a study carried out by Howson (1961). The 1961 figure has been adjusted to account for inflation and the resulting benefits have been applied as costs to each groundwater or reservoir scheme. It is recognized that some people would not consider that a cost penality should be assessed against hard water, but instead that because of its superior drinking water qualities, a benefit should be assigned to it. We have for now treated this consideration as an intangible. Those who take that view can regard the net cost before the softening correction as valid rather than the "total system cost". In that event, internal sources of supply are further enhanced when compared to Great Lakes water supply systems.

Conflict Costs

Probably the best example of potential conflict cost is the possible adverse effect on the Elora Gorge if West Montrose Dam is built. It is extremely difficult to put a value on a natural scenic attraction such as the gorge. If an optimal plan (from an economic point of view) includes construction of West Montrose, one can obtain an imputed value on the Elora Gorge by finding the second best solution and determining the difference in cost between best and second best plans. If the decision-maker decides to exercise the second best plan, he is in effect, saying that the imputed value of the gorge is greater than the cost difference.

No conflict costs have been built into the quantitative analysis, with the understanding that should such conflicts arise they would be treated in subsequent considerations in the manner stated above.

Notation

For brevity of presentation, all planning options in the next chapter have been presented in a compact notation. Thus, for example, planning option (2) is denoted:

L.E.: B76
L.O.: M76, G76

where L.E., L.O. refer to Lakes Erie and Ontario. The first line says that Brantford is to be part of a Lake Erie system in 1976, the second line says that the Megalopolis and Guelph would become part of a Lake Ontario system in 1976. The other abbreviations used are as follows:

GR: expansion of Brantford water treatment plant and continuation on river supply.

EV: construction of Everton Reservoir to maintain flow on Eramosa in conjunction with well development.

AYR: Ayr Reservoir with a treatment plant at the site.

LH: Lake Huron pipeline.

In all cases, the entries following the colon will refer to the cities which are on the particular system and the year when this would be operational.

ANALYSIS OF WATER MANAGEMENT OPTIONS

As already discussed, suggestions have been made in the past to utilize the Great Lakes as a water supply source for various municipalities in the basin. In particular, Lakes Erie, Ontario and Huron and Georgian Bay are geographically located so as to be possible supply sources. We have not done any detailed analyses of a Georgian Bay source, as a preliminary evaluation of pumping costs indicated that it would be far too costly. A comparison of options involving the three Great Lakes is shown below, assuming importation of water in 1976. For these three options it was assumed that Brantford would always be part of the Nanticoke-Lake Erie system since this was obviously less costly than a source of supply from the other two lakes.

	Net Present Worth of Capital plus Operating Costs
(1) L.E.: B76, M76, G76*	$105,600,000
(2) L.E.: B76 L.O.: M76, G76	$117,200,000
(3) L.E.: B76 L.H.: M76, G76	$133,300,000

As can be seen, the system based partly on Lake Ontario would cost almost $12 million more in present worth terms than one based entirely on Lake Erie, while a system based partly on Lake Huron would cost almost $28 million more. We are of the opinion that treated Lake Erie water would be of good quality and that similarly treated water from the other Great Lakes would offer no advantages over it. However, we do recognize that for Lake Erie to be a suitable long-term source, public acceptance is necessary and a commitment to pollution abatement action by industry, municipalities and water control agencies in Canada and the United States is required. Recent announcements by both countries offer hope in this regard, and we have chosen to adopt an optimistic point of view concerning the long-term quality of Lake Erie water. There has been a suggestion made in the past that a cheaper Lake Huron system could be developed for the Megalopolis by constructing a pipeline to London and utilizing water available at London. We feel that this suggestion is unworkable since the existing Lake Huron scheme was designed to meet only forecast London requirements. An attempt to force greater quantities of water through the system than provided for in its design would result in unmanageable water-hammer problems. We have thus been led to the costs of a Lake Huron supply as shown in option 3.

*For a description of the notation and terminology used here, please refer to Chapter 7.

It is our opinion that on economic grounds Georgian Bay and Lake Huron should be completely eliminated as water supply sources for the basin. The case is not quite as clear cut for Lake Ontario. In the Middle Grand Report (OWRC 1966), it was stated that a Lake Ontario system would be less costly in terms of capital required than a Lake Erie system to the Megalopolis and Guelph. This judgement was made before the Nanticoke complex was planned, the fact that a substantial intake and pipeline system would be constructed from Lake Erie to supply Nanticoke, Hagersville, Jarvis, Lynn, Port Dover and presumably Caledonia and Cayuga, would reduce considerably the capital required to provide Lake Erie water to the Megalopolis. In fact, our analysis confirms that with present population forecasts, a Lake Ontario based system would be more costly than a Lake Erie system both in terms of capital and operating costs. If a major shift in population or water demand should occur due to presently unknown factors, such as the location of the new international airport, then Lake Ontario could conceivably be a viable alternative. As a conclusion, the obvious Great Lakes source would be Lake Erie, but under some circumstances Lake Ontario might be competitive.

The largest component of cost of a lake-based water supply would be for the Megalopolis. If a pipeline were to be built from Lake Erie to service the Megalopolis,it is important to determine when it should come into service. As we have earlier discussed, there appears to be adequate groundwater already developed or exploitable to supply the Megalopolis until about 1981. We have determined that it would be less expensive to develop this groundwater than to construct a Lake Erie pipeline to be ready by 1976 (the earliest date likely). If the pipeline were deferred beyond 1981, other supplementary supply sources would have to be developed. Some of these which we have examined include utilizing the West Montrose, Ayr and Barrie Hill reservoirs to delay the pipeline construction date. In all cases we have found that <u>if the pipeline is to be constructed</u>, the optimal time for completion would be about 1981 based upon population forecasts used in this report.

If, for the moment, we assume that a Lake Erie pipeline is constructed to service the Megalopolis in 1981, and further that groundwater (and the Everton Reservoir to maintain baseflow in the Eramosa River) provides the Guelph supply, then the following three options can be compared:

Net Present Worths

	Capital Plus Operating Costs	Flood Control Benefits	Net	Softening Correction	Net (Total System Cost)
(15) L.E.: B91,M81 EV: G81	$106,600,000	$4,300,000	$102,300,000	$9,000,000	$111,300,000
(23) L.E.: M81 EV: G81 G.R.: B91	$112,900,000	$4,300,000	$108,600,000	10,100,000	$118,700,000

(16) L.E.: B81, M81 EV: G81	$104,200,00	$4,300,000	$99,900,000	$7,800,000	$107,700,000

(15) and (23) differ only to the extent that in the former Brantford is assumed to join the pipeline scheme (already assumed constructed to the Megalopolis in 1981) in 1991, while for the latter Brantford would remain on the river supply and expand its treatment plant in 1991. This comparison shows that for Brantford to also be part of the pipeline system in 1991 would have a cost (present worth) of about $6 million less than if not part; and considering flood control and softening, the difference would widen to over $7 million. Comparing (15) versus (16) shows that Brantford should become part of the pipeline system to the Megalopolis, at the same time as the segment to the Megalopolis is built. A further cost saving over option (15) of $2 million would be realized by not delaying until 1991; and including flood control and softening, this would widen to about $4 million. On the other hand, if a pipeline is not constructed to service the Megalopolis in 1981, our calculations (not displayed) indicate that the cost (present worth) to Brantford would be $5 million less to expand its treatment plant in 1991 and retain a river supply, and $4 million if a correction for softening is included.

We recommend that Brantford should temporarily continue its water supply from the Grand River, pending an ultimate decision on the long-term supply for the Megalopolis. If the Megalopolis obtains its long-term supply from the Nanticoke-Lake Erie system, then Brantford should also obtain their supply from this source. If the Megalopolis does not obtain their supply from the Nanticoke-Lake Erie system, the least costly alternative for Brantford would be to continue obtaining supply from the Grand River.

.... *RECOMMENDATION NO. 18*

If we now turn for a moment to Guelph, the following two options are relevant:

	Net Present Worths				
	Capital Plus Operating Costs	Flood Control Benefits	Net	Softening Correction	Net (Total System Cost)
(15) L.E.: B91, M81 EV: G81	$106,600,000	$4,300,000	$102,300,000	$9,000,000	$111,300,000
(21) L.E.: B91, M81 G81	$120,600,000	$ 0	$120,600,000	$6,000,000	$126,600,000

As can be seen, the only difference here is that: for (15) Guelph would obtain supply from groundwater along with use of Everton Reservoir to maintain baseflows in the Eramosa River; for (21) Guelph would obtain water from Lake Erie in 1981. Option (15) is about $14 million (present worth) less costly than option (21) and the difference becomes even greater with the inclusion of flood control benefits from the Everton Dam and softening corrections. We feel that there are no adequate reasons to change the existing water supply sources for Guelph over at least the next 30 years, except that further groundwater development will be necessary.

We recommend that Guelph should obtain its long-term water supply from groundwater sources, with careful planning of well development so as to prevent reduction in base flows of streams.

.... RECOMMENDATION NO. 19

Our studies indicate that future supplementary water supply for Guelph beyond 1981 could be developed along the Eramosa River. This would, however, reduce groundwater discharge to the river and drastically reduce summer baseflows. The Everton Reservoir, if built, could be used to maintain satisfactory streamflows. In addition, in Chapter 5 on Flood Control, it was seen that our present information indicates that the benefit-cost ratio of the Everton Reservoir due to flood control benefits alone exceeds one. We thus feel that the Everton Reservoir is supportable on the grounds of both flood control and also of maintenance of streamflows in the Eramosa River.

We recommend that land for the proposed Everton Reservoir, on the Eramosa River, should be purchased as it becomes available, but that the dam should not be constructed until further evaluations related to flood control and groundwater are completed. We further recommend that if the Everton Dam is constructed, an ecological study should be carried out to minimize any possible adverse effects on the Eramosa River.

.... RECOMMENDATION NO. 20

We feel that ecological considerations should be incorporated in formulating the reservoir operating system to reflect the fact that summer baseflows will be in large measure made up of reservoir releases while the river in its natural state during low flows is almost completely composed of groundwater. The effects on aquatic life of this difference should be studied and steps taken to minimize any adverse consequences.

In the chapter on Flood Control, it was seen that the Arkell Reservoir would have greater flood control benefits than those for the Everton; however, for an overall water management option, the Everton Reservoir results in lower costs. The difference is essentially because with an Arkell system water would be taken directly from the reservoir into the distribution system. The treatment plant and costs would be large and would more than overshadow the large flood control benefits of Arkell versus Everton. In the event that future groundwater development can be shown to present no stream reduction problems for the Eramosa River, the question of whether the Arkell or Everton site would be superior could be reviewed. For the present, we feel that the arguments favour the Everton site and land should be acquired as it becomes available to prevent development and subsequent added expenses.

For the Megalopolis, we have narrowed down the water supply alternatives to three: one based upon a Lake Erie pipeline by 1981 and the other two based upon the Ayr Reservoir being built by 1981. The water management options for the basin relating to the first two situations are summarized below under (16) and (R5).

Net Present Worths

	Capital Plus Operating Costs	Flood Control Benefits	Net	Softening Correction	Net (Total System Cost)
(16) L.E.: B81, M81 EV: G81	$104,200,000	$4,300,000	$99,900,000	$ 7,800,000	$107,700,000
(R5) G.R.: B91 AYR: M81 EV: G81	$ 86,300,000	$8,300,000	$78,000,000	$22,100,000	$100,100,000

Option (16) would provide water via a Lake Erie pipeline to the communities of the Megalopolis in 1981. Option (R5) would provide water supply by utilizing the impounded water directly from the Ayr Reservoir after suitable treatment. We have assumed that water treatment would be provided for all of the Megalopolis from a treatment plant located at the reservoir site. It will be seen that both options include the optimal supply alternatives for Brantford depending upon the course of action followed by the Megalopolis. It may be seen that the system based on internal sources, viz (R5) is approximately $18 million (present worth) less costly than that based on Lake Erie. Including flood control benefits and a softening correction, this difference narrows to about $7 million. If we extend the period of operation of the system from the year 2001 to 2021 (but hold the population and demand constant at the 2001 level), the cost difference remains at about $18 million (present worth), but including flood control and softening corrections the difference between the two options becomes negligible. We can, therefore, see that ignoring softening costs, which has been the procedure used in all previous studies on water supply for the basin, would lead to a clear economic advantage of an internal supply source based on taking water directly from the Ayr Reservoir over any Great Lakes pipeline. Our economic criterion includes the softening correction and results in a clear choice not being apparent between the two systems. Further, as the planning period is made longer, the economics of the reservoir system compared to the pipeline become less favourable. A number of considerations of an intangible or (presently) non-quantifiable nature assume importance due to the narrow economic advantage of the reservoir-based system over the pipeline:

(1) More detailed engineering cost estimates could either narrow or widen the difference.

(2) Softening corrections are subject to a very large error and a good case could be made for them being higher than estimated, thus lending support to the pipeline.

(3) A large segment of the population would prefer hard water for drinking purposes, and this is perhaps a plus for the reservoir supply.

(4) Quality problems due to algae growth could be significant in the reservoir. Satisfactory treatment can be installed to eliminate these problems, but our cost estimates may be considerably too low (or high) since the extent of the problem will not be known until the reservoir has been in existence for several years.

(5) Public acceptance of a direct reservoir source is not known and could be mixed or negative.

(6) The Lake Erie pipeline would import about 130 c.f.s. of water into the basin which would presumably produce benefits to streamflows.

(7) Population changes from those forecast in the report are quite possible.

(8) A pipeline system would probably produce greater stimulus for economic growth than a direct reservoir system, although this can be used as an argument against either scheme according to the point of view adopted.

(9) There would be considerably different financing problems and a smaller amount of capital to be raised, especially in the next ten years, for the reservoir system.

Based upon these considerations, and probably others, it is clear that simple economic calculations are an inadequate base for a recommendation.

We think that should the final choice come down to either a Lake Erie pipeline or direct water supply from the Ayr Reservoir, a further review of these various factors including particularly public attitudes, should be the basis of the decision.

Another very crucial aspect of the problem must now be discussed. The Megalopolis alternative presented in option (R5) is based upon utilizing water from the Ayr Reservoir directly, after passing through a treatment plant, as a supplementary source for the Megalopolis. For the third option, we have investigated the concept of using the Ayr Reservoir to recharge groundwater aquifers used for water supply by the cities and towns of the Megalopolis. Such a scheme would offer three principal advantages over direct supply from the reservoir:

(1) all water supply for the Megalopolis would continue to be groundwater, of approximately the same characteristics as the present supply;

(2) the groundwater recharge scheme could conceivably be considerably less expensive, since the large and costly treatment plant at the reservoir would not be needed; and

(3) fewer objections on possible quality or aesthetic grounds could be anticipated, and in particular, the water would be considerably cooler than directly from the reservoir.

We feel that with the economic advantages of (R5) over (16), and the further possible improvements in cost and acceptability which might be incorporated into (R5) by modifying it to a recharge scheme, the likely best future water supply for the Megalopolis would be based upon the Ayr Reservoir being constructed, and used as part of a groundwater recharge scheme. However, at this point we have not completely rejected the Lake Erie alternative since sufficient information is not available to prove the cost and feasibility of the suggested recharge scheme. In particular, we do not have any good estimates for such parameters as the recharge rate which could be expected, the capture efficiency of the recharged groundwater and even the suitability of various areas. The actual location of the recharge areas would determine the cost of transporting the recharge water from Ayr. Furthermore, a number of other cost elements could only be estimated after detailed field investigations.

We recommend that a detailed field study be carried out, starting within the next year, to establish groundwater availability and quality, artificial recharge rates, streamflow interference effects and development costs for recharge schemes and new well fields in the Megalopolis and Guelph areas. As a first step, analysis should be undertaken to determine the optimal groundwater management program *and yield for existing well fields. Concurrently, sufficient field work should be done to establish reconnaissance estimates for recharge schemes and subsequently for drilling schemes. The program should be set up with sufficient flexibility that it may be terminated without major expenditure of funds if results are not promising.*

..........*RECOMMENDATION NO. 21*

This program could take three to four years to carry out and costs over that period have been estimated at about $600,000. If properly set up, the work could be terminated at various points along the way if results were not favourable. On the other hand detailed pilot work would generate considerable costs in excess of those estimated, but these would only be expended if a decision to proceed with the recharge scheme was made. The savings which might accrue from the groundwater-recharge scheme versus a Lake Erie pipeline cannot be estimated until the study outlined in recommendation number twenty-one is carried out. However, to illustrate the possible worth of the study, reasonable assumptions about some of the unknown factors produced an estimated cost (present worth) of $29 million less than for the Lake Erie system or $18 million including softening and flood control corrections. It must be stressed that at this point these numbers are purely speculative.

In the recommendation, the first step is the determination of an optimal groundwater management program for the existing wells. This would be accomplished by constructing a mathematical model to analyse the hydraulic response of the aquifer system. Test drillings might be required to provide hydraulic data for the model in some areas. Among other things, we feel that one of the benefits of this model would be to develop more efficient procedures for mining the presently utilized aquifers and thus determine more accurately, the life of present supply sources.

Based upon the lack of present information to confirm the best long-term course of action for the Megalopolis (and therefore Brantford), the fact that large amounts of money are at stake, and our determination that sufficient existing and developable groundwater is available to provide supply for the Megalopolis until about 1981, then:

We recommend that the municipalities of the Megalopolis should continue to utilize groundwater for their supply at least until the period when a review of the results of the groundwater study (recommendation 21) is completed. Subsequently, a further evaluation of long-term water supply options for the Megalopolis should be carried out with particular emphasis on systems based on the Ayr

Reservoir and a Lake Erie pipeline as alternatives. This further evaluation should incorporate the economic, social and water management implications of the various schemes.

.... *RECOMMENDATION NO. 22*

Assuming a 5 year lag between decision and facility completion for pipeline, Ayr treatment plant, or groundwater recharge schemes, a 1981 date implies that a final decision need not be made before 1976. Our evaluations have shown that in terms of present worth, it is more economic to build a final system in 1981 than in 1976, and in addition, more reliable population projections should be available five years hence. All of these factors offer further support to the above recommendation.

Since the Ayr Reservoir is an essential component of one of the two main water management options, and since we further feel that additional studies are likely to confirm its superiority, it would be wise to ensure that land will be available for the dam and impoundment if and when required.

We recommend that land for the proposed Ayr Reservoir on the Nith River, should be purchased as it becomes available, but that the dam should not be constructed nor detailed design carried out until the results of further studies and evaluations (see recommendations 21 and 22) confirm it as part of the long-term water supply system for the Megalopolis.

..........*RECOMMENDATION NO. 23*

COMPREHENSIVE BASIN PLANNING

We have, based upon our work over the past nine months or so, reached a number of conclusions and made specific recommendations concerning water management planning for the Grand River Basin. However, as already noted, large amounts of essential information are not available and extremely complex analysis problems remain. In our "Summary and Recommendations" at the beginning of the report, we made 9 recommendations concerning future studies required for a comprehensive basin plan to be soundly established. This covers only the major identifiable deficiencies in our data and analysis tools and is by no means completed; not covering in sufficient degree, information regarding land use, social and attitudinal questions, industrial development, recreational planning and so on. We feel that it would be undesirable to terminate the thrust which we have started and to allow future efforts to again become fragmented with the inherent inefficiencies and misunderstandings. We suggest that the issues at stake are of great importance and should be followed through under the auspices of a continuing study.

It is worth perhaps noting that comprehensive basin management studies are by no means rare. Many such efforts are under way in the United States (Delaware, Potomac), in the United Kingdom (Trent), and in Canada (Okanagan, Saint John, Saskatchewan-Nelson, Qu'Appelle), among others. To put the problem of river basin planning in proper perspective, we have reviewed the studies being carried out for the four Canadian situations mentioned. The Saint John study has, to date, involved about one year, during which a number of technical investigations, including the development of mathematical models and simulations to analyse pollution abatement alternatives, were carried out. It is expected that another three years will be required to complete the study. The Saskatchewan-Nelson study is a four year, $5 million effort mainly involved with evaluating the surface water resource of the river system. Clause 6 of the agreement between Canada, Alberta, Saskatchewan and Manitoba provides that:

> "In carrying out the study, the Board will consider the engineering feasibility and cost of the many combinations of storage and/or diversion works needed to provide a firm supply of varying amounts and with varying seasonal distributions, at various selected points along the river system." (Durant 1970)

This study, although involving a much larger river system than the Grand, does not have some of the complexity of the latter where large populations, waste disposal and groundwater are all considerations of greater importance. In addition, the Saskatchewan-Nelson study will not actually produce water management plans, but instead a very sophisticated water inventory upon which planning can later be based.

A related study also underway on a tributary of the Saskatchewan-Nelson system is the Qu'Appelle River Basin Study, a three-year effort to cost an estimated $460,000. In this case, the study emphasis appears to be on identifying sources of pollution, requirements for water supply to the year 2000 and the preparation of a land use plan.

Finally, the Okanagan Study will cost $2 million and take four years to produce "a comprehensive framework plan for the development and management of water resources for the social betterment and economic growth in the Okanagan Basin". (Hodges 1970)

We have quoted from these four studies to show the scope of the efforts required to resolve water management problems for major river basins. All of these studies have adopted an approach rather similar to ours,including the extensive use of mathematical models and computer analysis. Of course, they have been set up in a much more formal manner and have been able to plan out their activities over the long term. To indicate the effort put into the preparation of our present report, over five man years have been spent by members of our study team and others from the OWRC and the Department of the Environment over the past nine months.

This present report has attempted to address the most critical or contentious problem areas and to make specific recommendations to overcome them. It has also made recommendation to carry out the further investigations necessary to resolve water management problems for which there are presently insufficient data or understanding. In particular, we have deferred final judgement on the major expenses, such as a Great Lakes pipeline and a good part of the GRCA reservoir program. It is essential that the momentum produced by our efforts to date not be dissipated through a cessation of the study or a return to the fragmented approaches of many past studies. The coordination of the study program among the various government departments should continue and be expanded to further involve local groups and agencies concerned with water management planning.

This coordination would ensure that the specific point of view of any one government department or agency would not prevail independent of other valid opinions. With the divided water management jurisdiction throughout the government plus the large financial and regional development implications, we feel that the future coordination of this study would best remain with a central agency of government, such as the Treasury Board. We do not feel that a specific river basin study team independent of other departmental responsibilities and with its own budget is necessary to carry out this study.

Completion of the studies recommended in our Summary and Recommendations as well as other necessary data collection and analysis would probably take three to four years. The costs would depend very much upon whether the bulk of the work was done by external consultants or internally (which we would recommend). Our preliminary estimates of the cost of these investigations, including costs of the staff assigned, would be about $2 million. These estimates would have to be firmed up for actual budgeting purposes.

We recommend that a multi-disciplinary planning team, within government, should coordinate the continuing development of a comprehensive water management plan for the Grand River Basin and in particular, should carry out or coordinate the carrying out of the various studies outlined in the recommendations. Staff assigned to the planning team should be relieved of sufficient other duties to make their contribution reflect the importance of the assignment.

.... *RECOMMENDATION NO. 24*

A P P E N D I C E S

APPENDIX I

SIMULATION OF THE GRAND RIVER BASIN TO STUDY WATER QUALITY PARAMETERS

1. Introduction

Recommendation 6 of this report stated that water quality standards and further planning evaluations related to river quality and effluent loading guidelines in the Grand River Basin should be based upon a computer simulation. The reasons for a computer simulation and the type of simulation model envisaged are summarized in section 2 of this appendix. A prototype simulation of the Grand River Basin has already been carried out. This is described in section 3. A discussion of possible ways of extending and improving this prototype is given in section 4.

We have included this detailed discussion of the proposed water quality simulation here because the approach and techniques used are probably not very familiar to many persons who will read this report.

2. Simulation of the Grand River Basin

A simulation of the Grand River Basin is envisaged as an important tool for the comparison of planning alternatives in terms of their effect upon river quality. There are many factors determining river quality, most of which have an inherent element of variability. These factors interact in a complex way to cause a variation in river quality which affects the survival of desirable life-forms. A computer simulation is able to take account of this variability in providing increased information about the possible effects of given planning decisions in the river basin.

Some of these factors are:

(i) the populations of cities on the river basin, the quantities and types of municipal and industrial sewage, and their variation within the day and through the year,

(ii) rainfall and its effect upon storm sewer flows, infiltration into sanitary sewers, and urban surface runoff,

(iii) variability in performance of sewage treatment plants,

(iv) streamflows and their dependence upon rainfall and operation of dams,

(v) environmental conditions and their effect on waste assimilation, dissolved oxygen concentrations, and algal photosynthesis and respiration,

(vi) nutrients and their effect on algal populations and growth rates,

(vii) the hydraulic characteristics of the river under varying streamflows,

(viii) land use and surface runoff.

With suitable field study, it is, in general, possible to develop mathematical models of the above factors. These models can be incorporated into a computer simulation program so as to be able to better estimate the response of river quality under the influence of these factors. With this framework, it is possible to evaluate the consequences on river quality of planning alternatives such as:

(a) construction of dams for flood control, recreation, or low-flow augmentation,

(b) alternative treatment plant processes such as sand filtration or nutrient removal,

(c) construction of storage tanks at treatment plants for flow-equalization or quality-equalization,

(d) diversion of wastes from one part of the river basin to another,

(e) use of stream reaeration equipment,

(f) alternative sanitary and storm sewer systems, including treatment of storm sewer wastes.

A characteristic of a computer simulation is that a long period of actual time can be "simulated" in the computer in a matter of seconds. For this reason it is possible to consider the day-to-day effect on a planning decision on river quality throughout a future year of interest. By building the structure of the Grand River Basin into the computer program, the movement of water through the basin can be represented. This enables river quality to be calculated at different times and different points in the basin, so that the variation in quality is determined.

The computer simulation can be designed to provide the type of information considered most useful by biologists, sanitary engineers, and others involved in river basin planning. Typically this might consist of probability distributions of the dissolved oxygen and biochemical oxygen demand concentrations at specified points in the Grand River Basin and at specified times of year. Other water quality parameters could also be evaluated. The interpretation of the output in terms of effects on biological diversity within the river would still have to be carried out by biologists and others. However, they would have greatly increased information on which to make these interpretations over what is available at present. We also recognize that the response of biota to chemical and environmental factors is by no means well understood, and the simulation proposed is not meant to resolve this question.

This section has summarized the type of computer simulation that has been recommended. The following section describes the prototype already developed and discusses in more detail the way in which some of the factors are modelled.

3. The Prototype Simulation

The prototype computer simulation described in this section represents an initial first attempt to demonstrate the feasibility and effort required to carry out development of such a planning tool. We have not attempted to incorporate all essential factors in the simulation at this stage, nor to optimize the computer programming and running time. Many parts of the simulation will have to be made more sophisticated and we have attempted to indicate where this is necessary in the following discussion. It should be stressed that although we see no severe technical constraints in terms of the model building and computer analysis steps, the data collection stage is of crucial importance to make an undertaking of this sort worthwhile.

The prototype computer simulation represents the Grand River Basin by the system shown in figure 15. The system is divided into uniform reaches in order to approximate the complex changes in physical characteristics that occur along the actual river. Each reach is assumed to be an open channel of rectangular section, constant width, constant slope, and constant coefficient of roughness. Reaches are chosen so that sewage treatment plants pass their effluents into the stream at the head of a reach. The incremental streamflow from the drainage area between the head and the end of a reach is assumed to be injected into the stream at the end of the reach. Streamflows passing into the system at Guelph (Speed River), Waterloo (Grand River), and Paris (Nith River) are accumulated streamflows from upstream drainage areas, taking into account any dams present in the planning alternative under consideration.

The simulation considers the effect of the following factors upon water quality in this system:

(i) sewage flow-rates at Guelph, Hespeler, Waterloo, Kitchener, Preston, Galt, Paris, and Brantford, as determined by the forecast populations of these cities,

(ii) sewage effluent quality at each treatment plant as determined by the types of treatment process under consideration,

(iii) partially controlled streamflows, as determined by the operation of existing and proposed dams upstream of Guelph, Waterloo, and Paris (on the Nith River),

(iv) the interaction of the variability of each of the above factors.

The water quality parameters considered are total five-day biochemical oxygen demand (B.O.D.) concentration and dissolved oxygen (D.O.) concentration. The total B.O.D. is determined as the sum of its filterable and non-filterable components, since these have significantly different assimilation rates in the river because of the sedimentation

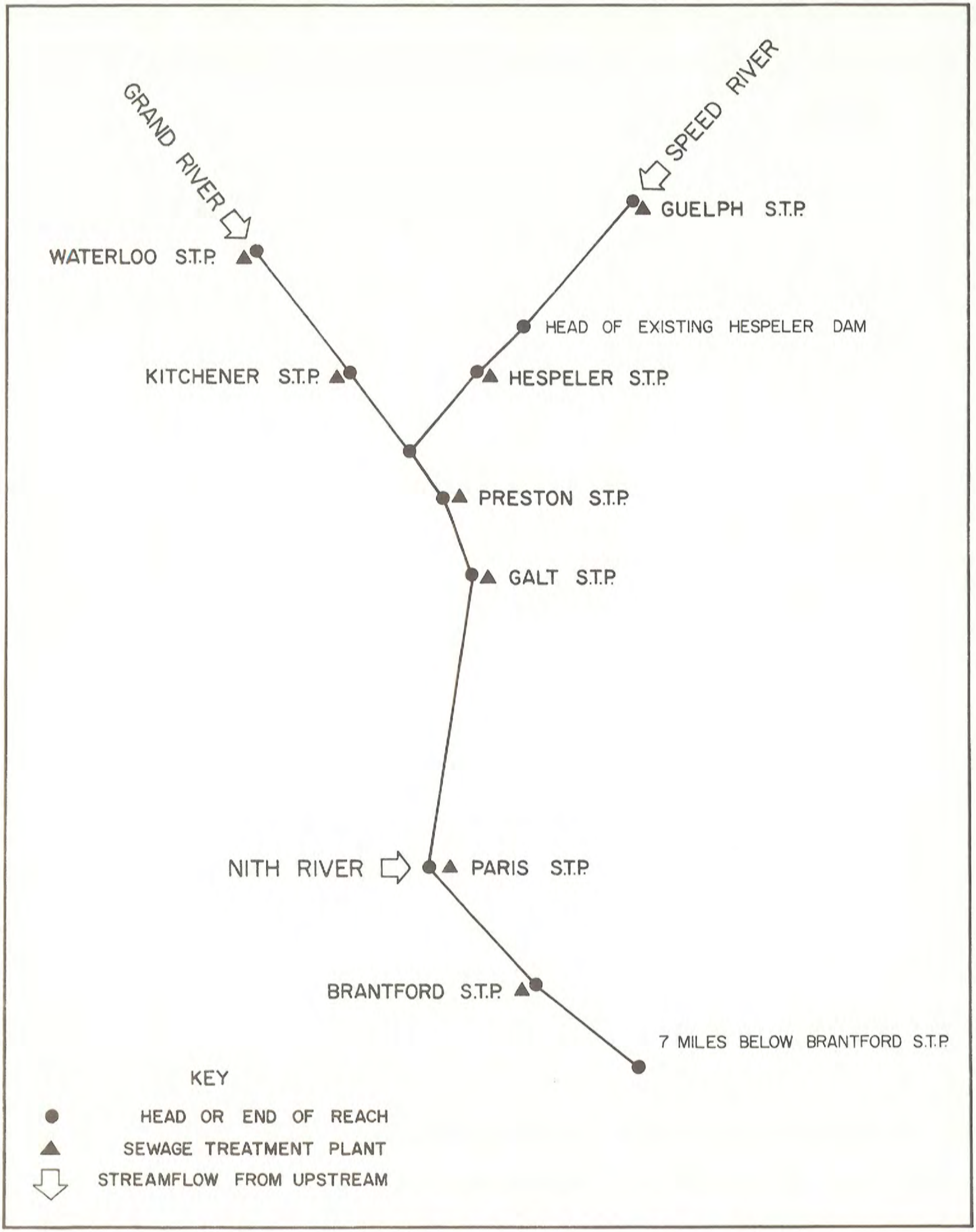


Figure 15 : GRAND RIVER SYSTEM

of the filterable component. The mathematical models used to calculate these concentrations take account of the decay of B.O.D. by micro-organisms, the consequent removal of D.O., the addition of D.O. by reaeration through the water surface, and the addition or removal of D.O. by photosynthesis or respiration of attached plants, such as algae.

The simulation is presently designed to consider the period from May through November or any subset of this period. The remainder of the year should be designed into the simulation if further development work is carried out. This allows for representation of the seasonal trends in sewage flow-rates, streamflows, and river temperature. In order to evaluate the effect of variations occurring on a shorter time scale, such as within-day variation in the net rate of oxygen production by attached plants, the characteristic time unit used has been eight-hours. The state of the system is therefore examined during each eight-hour period separately. The actual time increment used in a refined simulation would be determined by a tradeoff between desired accuracy of predicted results and costs (due to data collection and computer processing).

In order to simulate the effect of a given planning decision on river quality in a given future year, certain input data must be specified. These data include:

(i) the months of the year to be simulated,

(ii) for each sewage treatment plant, the coefficients of a multiple regression model used to calculate sewage flow-rate on each day of the season. These coefficients implicitly define the populations served by the sewage treatment plants. The regression model takes into account the variation in flow-rate with the particular day of the week,

(iii) for each sewage treatment plant, the parameters defining probability distributions for total and non-filterable B.O.D. concentrations in the plant effluent, and a constant specifying the percent of filterable B.O.D. removed by tertiary treatment, if present,

(iv) for each sewage treatment plant, parameters defining a within day pattern of sewage flow-rate variation, and parameters defining a within-day pattern of B.O.D. concentration variation,

(v) for each sewage treatment plant, the effluent dissolved oxygen concentration,

(vi) for each upstream streamflow source (Guelph, Waterloo and Paris) and each month of the season, a probability distribution of stream flow-rates. These distributions are assumed to take into account the operation of existing or proposed dams. A flow-rate selected from the distribution is assumed fixed for the month ,

(vii) for each month of the season, a probability distribution of uncontrolled incremental flow rates arising from drainage area above a suitably chosen river gauging station. This distribution is used to determine the incremental streamflows to be injected at the head of each reach,

(viii) the average river temperature for each month in the season. These temperatures are used to correct B.O.D. decay rates, D.O. removal rates, reaeration rates, and D.O. saturation concentrations for temperature,

(ix) for each reach in the system, the length of the reach, the coefficient of roughness, the average width, and the average slope. These are used to calibrate a hydraulic model ("Manning's formula") with which velocities of the stream are calculated from flow-rates. This particular portion of the prototype simulation is presently very inaccurate and would have to be improved before useful results could be generated,

(x) for each reach in the system, the filterable B.O.D. decay rate constant, the non-filterable B.O.D. decay rate constant, the D.O. removal rate constant due to filterable B.O.D. decay, and the D.O. removal rate constant due to non-filterable B.O.D. decay,

(xi) for each reach in the system, the net rate of oxygen production per unit area by attached plants during each of the three periods 1 a.m. - 9 a.m.; 9 a.m. - 5 p.m.; 5 p.m. - 1 a.m.,

(xii) for each reach in the system, a pro-rating factor for the amount of stream-flow injected at the head of the reach, constants specifying the filterable and non-filterable B.O.D. concentrations in this flow, and constants specifying the percent saturation by D.O. These constants can be chosen in such a way as to define within-day patterns of concentration variation.

The above input data implicitly specifies the conditions to be simulated, as determined by the planning alternatives under consideration. The prototype simulation allows a certain flexibility in the type of information which can be requested for output when the simulation run is completed. In general, the output makes statements about the frequency with which certain quality standards are violated at different points in the system and at different times of the year. Examples are given later. Also see figures 7 and 8 in the main body of the report as typical output examples. Requests for output are made by specifying in the input data points of interest in each reach, quality standards, material of interest (only B.O.D. or D.O. may be specified at present), months of interest, and whether violations of standards are to be counted on a daily or an eight-hour basis.

A simulation "run" proceeds in the following general way. For each day of the season and for each sewage treatment plant, a filterable and non-filterable B.O.D. concentration are selected at random using the specified probability distribution and taking into account advanced treatment if present at the plant.* In addition, the effluent flow-rate at each plant is calculated taking into account the day of the season, day of the week, and a random component. The within-day patterns are imposed on these B.O.D.'s and flowrates, and then the effluents are mixed with the stream assuming instantaneous and perfect latitudinal mixing. The qualities of the streamflows into which the effluents are mixed are determined by the effluents of any upstream treatment plants and the background quality of streamflows. At present the background quality is treated deterministically, although it should more ideally be treated as a probabilistic process. The times taken for water in the stream to pass from one plant to the next are determined by the velocities of the stream in the appropriate reaches. These velocities depend upon the flow-rates, which in turn depend upon run-off and sewage flowrates accumulated upstream. These times also determine the change in quality of water passing down the system, using the mathematical models mentioned earlier. The state of the system during each eight-hour period of this day is therefore known. The program checks for violation of specified quality standards at each specified point in the sytem. Any violations are noted. The simulation then moves on to the next day of the season.

The above procedure is repeated for each day of the season. In order to allow full interaction of the different elements of variability, the program repeats the simulation of the season a number of times (specified in the input data). Each simulated season differs from the next mainly according to the streamflows selected each month from the distributions of streamflows specified for Guelph (the Speed River), Waterloo (the Grand River), and Paris (the Nith River). For a given simulated season the streamflows selected reflect the wetness of that season. This enables the random variability in climatic conditions to be taken into account.

A more detailed description of the causal structure of the simulation outlined above is given in figure 16.

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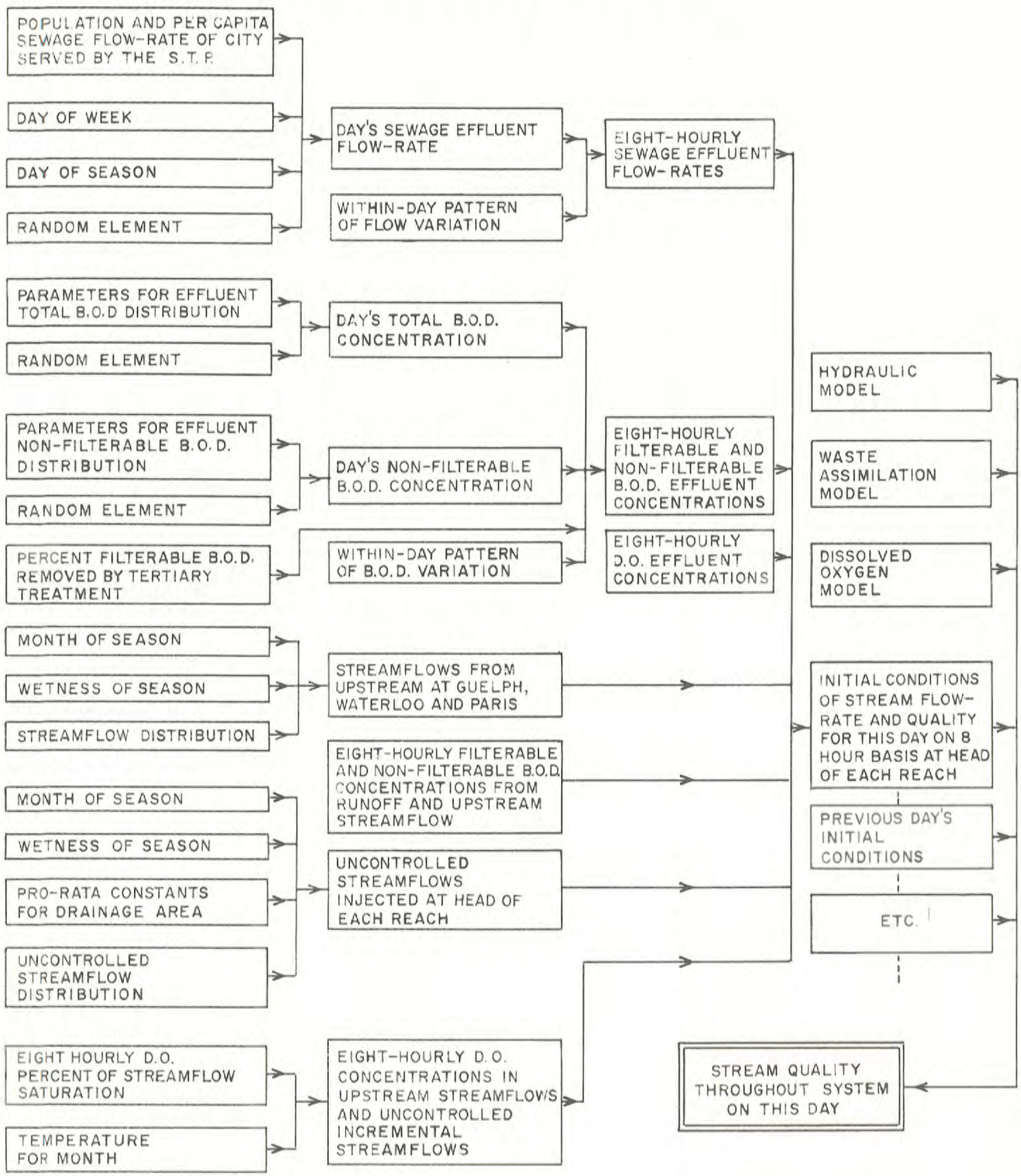
* for types of advanced treatment where actual operating data is not available, informed estimates of the range of performance would have to be made subjectively.

FIG. 16

CAUSAL STRUCTURE OF SIMULATION



Output produced by the prototype simulation is basically one of two types. An example of the first type is (with artificially chosen numbers):

Percentage of days in August when the total 5-day B.O.D. concentration violates the standards specified in the reach from Point A to Point B at a distance of X miles below A (where A, B, X would be specified)

4 mg/l	=	72%
5 mg/l	=	48%
6 mg/l	=	30%
10 mg/l	=	1%
20 mg/l	=	0%

A violation of a standard on a day is considered to have occurred if the average concentration during any of the three eight-hour periods of the day violates the specified standard. Alternatively this output can be expressed in terms of the percentage of eight hour periods in which a violation has occurred. These kinds of output can also be produced for D.O., for different months of the season, for different points in each reach, and for different quality standards.

An example of the second type of output is (with artificially chosen numbers):

Probability that the total 5-day B.O.D. standard of 6 mg/l is violated on at least N days during August in the reach from Point A to Point B at a distance of X miles below Point A

N = 0,1,2,......,10	: probability = 1
N = 11	: probability = 0.9
N = 12	: probability = 0.8
N = 13	: probability = 0.6
N = 14	: probability = 0.3
N = 15	: probability = 0.1
N = 16,17,......,31	: probability = 0.0

The first type of output may be interpreted as an estimate of the chances of the various standards being violated on any day in August, and may be of interest when short term effects are being considered. The second type of output indicates the severity of the water quality problem when longer term effects, such as survival of a fish population in that stretch of river, are of interest. Both types of output are prototypes and can easily be modified in any future development of the computer simulation. The actual form and content of the output would be carefully chosen so as to provide the information most useful to the various disciplines involved in the planning process.

4. Conclusion

Based on experience gained during development and use of the prototype several aspects of the simulation have been identified as needing further study and field data collection in order to improve their realism. Other factors not at present included in the prototype require study for possible inclusion in a more advanced simulation of the kind described in section 2. Some of these are as follows:

(i) Field study is required in order to better calibrate hydraulic models of the river reaches. This would improve the accuracy of the stream velocity, depth, and reaeration rate calculations.

(ii) Field study is required to develop a more realistic model for background quality of streamflows and run-off.

(iii) Day to day variations in streamflows from up-stream at Guelph, Waterloo, and Paris (the River Nith) should be modelled. Related to this would be development of hydraulic models relating streamflows and run-off to rainfall. This is likely to be a very difficult aspect of the undertaking.

(iv) Models of sanitary, storm, and combined sewer systems should be included in the simulation. This would enable the effect of rainfall upon urban run-off, sanitary sewer infiltration, and therefore river quality to be evaluated.

(v) The possibility of relating sewage treatment plant effluent quality to influent quality should be studied further.

(vi) Models for predicting algae populations based on nutrient availability, environmental conditions, etc. should be developed. This would essentially involve fundamental research, and would not be carried out by the actual simulation project team.

(vii) Field study is required to improve models for photosynthesis and respiration of algae.

Appendix 2 of this report discusses the required field study in more detail and gives an estimate of the cost of a pilot field study programme on the Speed River from Guelph to the confluence with the Grand River.

APPENDIX 2

RECOMMENDED FIELD STUDIES ON RIVER CHARACTERISTICS

Recommendation number 6 of this report stated that water quality studies and further planning evaluations, related to river quality and effluent loading guidelines, should be based upon a computer simulation and that further field work on river quality characteristics, adequate to allow for the evaluation of planning alternatives and the calibration of stream models, should be carried out. This appendix describes these recommended field studies in more detail and gives a reconnaissance estimate of their cost.

For the purposes of field study the Grand River system can be considered in terms of six sections:

(1) from the city of Guelph to the confluence of the Speed and Grand Rivers,

(2) from the city of Waterloo to the confluence of the Speed and Grand Rivers,

(3) from the confluence of the Speed and Grand Rivers to Glen Morris,

(4) from Glen Morris to the city of Brantford,

(5) from the city of Brantford to Onondaga, and,

(6) from Onondaga to Lake Erie.

These sections are of suitable size for a field team to carry out on each section the studies described later in the appendix. The precise definition of the beginning and end of each section would, of course, have to be determined prior to the field study, taking into account local conditions having significant effect upon river quality. For example, the beginning of section 1 should be sufficiently far upstream to enable the effect of Guelph city surface run-off and storm sewer loads to be examined.

The following have been identified as components of the field studies to be carried out on each section of the Grand River system:

- study of the physical and hydraulic characteristics of the river,
- study of water quality parameters in the river,
- study of the growth characteristics of algae in the river,

- study of the performance characteristics of sewage treatment plants situated on the section of river, and

- study of the sewer systems of municipalities situated on the section of river.

The sewer system study is referred to in recommendation number 13 of this report, and is not discussed further in this appendix. Cost estimates for the sewer system study have not been included in the estimates following for data collection related to the Speed River. The other components of the field study are described below. All the components are designed with a view to representing the probabilistic behaviour of pollution sources and stream response.

A study of the physical and hydraulic characteristics of each section of the river system should be carried out under at least three different streamflow conditions. This is in order to develop the hydraulic models necessary for representing the effect of variation in streamflow rate upon, for example, the velocity and depth of the stream, which are required for the mathematical water quality models in the simulation program.

Each study should include the measurement of cross sectional profiles, longitudinal profiles (for the determination of the slope of the river bed), flow-rates, times of travel and, if possible, direct measurement of the dissolved oxygen reaeration rate. In addition a qualitative description of the physical features of the section of river should be obtained by visual inspection, noting the presence of algae, stream obstructions, nature of the river bed, types of water use, and so on.

In order to determine the parameters for mathematical water quality models used in the simulation, several studies of water quality should be carried out in each section of the river. These studies should be carried out, if possible, under different environmental conditions, such as time of year, temperature, rainfall, sunlight intensity, and stream flow rate. This is because the simulation program is intended to provide information about water quality on an all year round basis, taking into account these and other elements of variability.

Each study should consist of measure of the chemical, biological and bacteriological aspects of water quality. Chemical aspects include concentrations of B.O.D., dissolved oxygen, nutrient materials, and others to be determined during detailed planning of the simulation and field study work. Biological aspects include biomass of algae, type of growth, and others to be determined in consultation with biologists. We feel that one question of fundamental importance to be resolved is the actual causal nature of algae growth. Thus the effects of different nutrient and micronutrient concentrations, water temperature, sunlight, physical streambed conditions etc., all certainly affect the growth and behaviour of algae and aquatic plants. It will probably be necessary, in addition to the sampling program discussed, to carefully set up experimental designs to try and break out the main causal factors affecting algae growth and behaviour and to quantify the responses. This work could perhaps be partially carried out in the laboratory, but in large measure it would have to take place at the specific river sites of interest. Bacteriological aspects include coliform concentrations. In addition, the particular environmental conditions under which each study is carried out should be noted. As mentioned earlier, these include water temperature, sunlight intensity, rainfall, seasons, stream flow-rate and times of travel. For this reason it may be convenient to carry out the physical studies described above concurrently with water quality studies.

We have assumed that perhaps 10 separate field studies should be carried out, each over a 24 hour period, obtaining direct measurements (such as for dissolved oxygen concentration) or samples (such as for B.O.D. concentration) every two hours at each of about 15 points along the section of river. The positions of these points will depend upon the characteristics of the particular section of river being studied, but should be chosen so as to be able to establish the model parameters sufficiently accurately and to evaluate the quality of water arriving from upstream of the river section. The 24 hour period of study at each point should begin at a time later than the point above it roughly equal to the time of travel between the points.

A study of the performance of each sewage treatment plant situated on the section of river should be carried out. This should at least include measurement of the quality and flow rate of the plant effluent, but may also be designed to evaluate the relationship between influent and effluent, and possibly the performance of the separate stages of the plant.

The measured quantities should include flow rate, concentration of B.O.D., dissolved oxygen, nutrient materials, solids, and other parameters to be determined in detailed planning of the studies. These measurements should be carried out on a number of separate samples, obtained at equal intervals during the day, for a number of consecutive days, and at several times during the year. In particular, measurement of effluents should be carried out consecutively with each of the 24 hour water quality studies described above. It would also be worthwhile to measure rainfall at each treatment plant during each day of the year, for use in conjunction with the sewer system study referred to in recommendation 13.

Pilot Programme

It is proposed that a pilot field study programme of the nature described above be carried out during 1972 on the section of river from Guelph to

APPENDIX 3

(Input Material From the
Grand River Conservation Authority)

RECREATIONAL FACILITIES IN THE GRAND RIVER BASIN

Site	Description	Water Body	Activity *			
			Swimming	Fishing	Boating	Shoreline Development
1	Luther Marsh Conservation Area	Luther Lake	P	P	D	P
2 & 3	Proposed picnic sites (GRCA)	Grand River	P	P		P
4	Grand Valley Conservation Area	Grand River	D			D
5	Waldimar Park	Grand River	P	P		P
6 to 8	Proposed picnic sites (GRCA)	Grand River	P	P		P
9	Belwood Lake Conservation Area	Grand River	D	D	D	D
10	Belwood Lake Conservation Area	Grand River	D			D
11	Elora Bissel Conservation Area	Grand River	P	P	P	D
12	Proposed picnic site (GRCA)	Irvine Creek		P		P
13	Elora Gorge Conservation Area	Grand River	P	D	D	D
14	Montrose Reservoir (proposed)	Grand River	P	P	P	P
15 to 17	Proposed picnic site (GRCA)	Grand River				P
18	Private park	Grand River	D	D	D	D
19	West Montrose covered bridge	Grand River	P	D		D
20	Proposed picnic site (GRCA)	Grand River				P

* P - Potential
D - Developed

Appendix 3 - continued...

21	Woolwich Conservation Area (reservoir proposed)	Canagagigue Creek	P	P		P
22	Floradale pond	Canagagigue Creek		P		P
22a	Private park	Grand River		D		D
23	Proposed picnic site (GRCA)	Grand River				P
24	Conestoga Golf and Country Club	Grand River				D
25	Proposed picnic site (GRCA)	Grand River	P	P		P
26	Kaufman's Flats	Grand River	D	P	D	D
27	Proposed conservation area (GRCA)	Grand River	P	P	P	P
28	Kiwanis Park	Grand River		P	P	D
29	Bingeman Park	Grand River	P	D		D
30	Proposed conservation area (GRCA)	Grand River	P	P		P
31	Proposed picnic site (GRCA)	Grand River				P
32	Chicopee conservation area	Unnamed tributary				D
33	Doon Pioneer Village	Schneider Creek				D
34	Willow Lake (dam collapsed)	Schneider Creek	P			P
35	Doon Valley Golf Club	Grand River				D
36	Proposed Conservation area (GRCA)	Grand River	P	P		D
37	Pioneer Tower (Historic site)	Grand River				D

Appendix 3 - continued...

38	Waterloo County Fish & Hunt Club	Grand River				D
39	Proposed Conservation area (GRCA)	Blair Creek	P	P	P	P
40	Dickson Wilderness Area	Ponds				D
41	Bannister Lake Wildlife Area	Bannister L.				D
42	Pinehurst Lake Conservation Area	Pinehurst Lake				D
43	Everglades Park	Grand River	P	D	D	D
44 to 47	Proposed picnic sites (GRCA)	Grand River				P
48	Five Oaks Camp	Whiteman Cr. & Grand River	D	D		D
49	Rest Acres Park	Whiteman Cr.				D
50	Proposed picnic site (GRCA)	Whiteman Cr.				P
51	Private park	Whiteman Cr.				D
52	Lion's Centennial Park	Whiteman Cr.				D
53	Proposed Whiteman Creek Reservoir	Whiteman Cr.	P	P	P	P
54 to 57	Proposed picnic sites (GRCA)	Whiteman Cr.		P		P
58	Proposed Princeton Reservoir	Whiteman Cr.				P
59 to 62	Proposed picnic sites (GRCA)	Whiteman Cr.		P		P
63	Park Haven Lake Park	Park Haven Lake	D	D	D	D

Appendix 3 - continued...

64	Proposed picnic site (GRCA)	Whiteman Cr.		P		P
65	Crestwood Lake (private park)	Crestwood Lake	D	D	D	D
66	Proposed Vandecar Reservoir	Whiteman Cr.				P
67	Proposed picnic site (GRCA)	Grand River	P	P		P
68	Brant Conservation Area	Grand River		P	P	D
69	Proposed picnic site (GRCA)	Grand River				P
70	Mohawk Lake Park	Mohawk Lake			D	D
71 to 78	Proposed picnic site (GRCA)	Grand River		P		P
79	Street Boat Ramp and Park	Grand River		P	D	D
80	Proposed picnic site (GRCA)	Grand River				P
81	Proposed Harrisburg Reservoir	Fairchild Cr.	P	P	P	P
82 to 83	Proposed picnic sites (GRCA)	Fairchild Cr.		P		P
84 to 86	Proposed picnic sites (GRCA)	Grand River		P	P	P
87	Chiefwood Park	Grand River		D	D	D
88	Proposed picnic site (GRCA)	Grand River		P	P	P
89	Iroquois Village	Grand River	P	P	P	P
90 to 92	Proposed picnic sites (GRCA)	Big Creek				P
93	Caledonia Hunters & Anglers Club	Grand River		D	D	D

Appendix 3 - continued...

94	Boat Ramp	Grand River		D	D	
95	Proposed Conservation Park (GRCA)	Grand River	P	P	P	P
96	Ross Deagle's Boat Ramp	Grand River	D	D	D	D
97	McAlpine's Boat Ramp	Grand River		D	D	D
98	Proposed Conservation area (GRCA)	Grand River	P	P	P	D
99 to 100	Proposed picnic sites (GRCA)	Grand River		P	P	P
101	Proposed picnic site (GRCA)	McKenzie Creek	P	P	P	P
102	Proposed picnic site (GRCA)	Grand River		P	P	P
103	Proposed picnic site (GRCA)	Rogers Creek				P
104	Taquanyah Conservation Area	Rogers Creek	D	D	D	D
105	Grand Oaks Park	Grand River	D	D	D	D
106	Conway Park	Grand River	D	D	D	D
107	Riverview Motel and Boat Ramp	Grand River	D	D	D	
108	Potential park site	Grand River				P
109	Potential park site	Sulphur Creek & Grand River	P	P		P
110	Laundry Boat Ramp	Grand River		D	D	
111	Sunnibank Park	Grand River	D	D	D	D
112	Potential park site	Grand River	P	P	P	P
113	Roger's Fishing Haven	Grand River	P	D	D	D
114	Byng Island Conservation Area	Grand River	P	D	D	D

Appendix 3 - continued...

115	L.S.P. Marina	Grand River		D	D	
116 to 119	Recreational Beaches	Lake Erie	D	D	D	D
120	Victoria Hill Conservation Area	McKenzie Cr.	D	D	D	D
121	South Brant Lions Park	McKenzie Cr.	D	D		D
122	Proposed picnic site (GRCA)	McKenzie Cr.	P	P	P	P
123	Willow Lake Park*	McKenzie Cr.				
124	Dunmark Park	Big Creek	D	D	D	D
125	Arrowhead Park	Tributary to Big Creek	D	D		D
126 to 128	Proposed picnic sites (GRCA)	Smith Creek				P
129 to 131	Proposed picnic sites (GRCA)	Nith River				P
132	Crehwing Scout Camp (Perth Dist.)	Nith River	D	D		D
133	Morrington Centennial Project	Nith River		D		D
134 to 135	Proposed picnic sites (GRCA)	Nith River				P
136	Yorkstown Lodge	Tributary to the Nith River				D
137	W.J. Scott Conservation area	Nith River	D	D	D	D
138	Sun Valley Beach	Tributary to Baden Creek	D			D
139	Holiday Beach	Nith River	D	D	D	D
140 to 146	Proposed picnic sites (GRCA)	Nith River		P		P
147	Ayr Reservoir (Porposed)	Nith River	P	P	P	P

Appendix 3 - continued...

148	Spring Valley Trout Farm	Tributary to Alder Creek		D		D
149	Country Gardens	Tributary to Alder Creek	D	D		D
150 to 151	Proposed picnic sites (GRCA)	Nith River	P	P		P
152	Nith River Park	Nith River	D	D		D
153	Proposed Development of an isolated lake near Ayr		P			P
154	Ayr Conservation area	Nith River	D	D	D	D
155 to 159	Proposed picnic sites (GRCA)	Nith River				P
160	Peacehaven Scout Camp (South Waterloo District)	Nith River	D	D	D	D
161 to 163	Proposed picnic sites	Nith River				P
164	Blenheim Bend Conservation Area (under development)	Nith River	P	P		P
165 to 166	Proposed picnic sites (GRCA)	Nith River		P		P
167 to 177	Proposed picnic sites (GRCA)	Speed River		D		P
178	Guelph Township Centennial Park	Speed River	D	D		D
179	Proposed picnic site (GRCA)	Speed River		P		P
180	Guelph Reservoir (proposed)	Speed River	P	P	P	P
181	Picnic site (not fully developed)	Speed River	D	D		D
182	Everton Reservoir (Proposed)	Eramosa River	P	D	P	P

Appendix 3 - continued...

183	Everton Mill Conservation Area	Eramosa River	P	D	D	D
184	Everton Scout and Cub Camp	Eramosa River	D	D		D
185	Camp Bre Beuf	Eramosa River	D	D		D
186	Rockwood Conservation Area	Eramosa River	D	D	D	D
187	Edgewood Park Lutheran Camp	Eramosa River	D	D		D
188	Halton Presperty United Church Camp	Blue Springs Creek	D	D		D
189	Blue Springs Scout Camp	Blue Springs Creek	D	D		D
190	Guelph District Scout Camp	Eramosa River	D	D		D
191	Kortright Waterfowl Park	Speed River		D		D
192	Golf Course	Tributary to the Speed R.				D
193	Fishermill Pond	Tributary to the Speed R.	D	D		D
194	Private Mill Pond	Creek from Puslinch Lake to Speed R.	D	D		D
195	Barbars Beach	Puslinch Lake	D	D		D
196	Butlers Beach	Puslinch Lake	D	D	D	D
197	Puslinch Lake Conservation area (no development proposed)	Puslinch Lake				
198	Shade's Mills Conservation Area	Galt Creek	D	D	D	D

Appendix 3 - continued...

199	Aberfoyle Mill Park	Galt Creek	D	D	D	D
200	Proposed picnic site (GRCA)	Conestogo R.				P
201	Riverside Maples	Conestogo R.				D
202 to 205	Proposed picnic sites (GRCA)	Conestogo R.	D	D		D
206	Conestogo Reservoir	Conestogo R.	D	D	D	D
207	12th Field Regiment Park	Conestogo R.	D	D		D
208	Grand York Sportsman's Club	Grand River		P		D
209	Ruthven Park (private)	Grand River		P	P	P
210	Hamilton Yacht Club	Grand River		D		
211	Conestogo Yacht Club	Conestogo R.			D	
212	Waterloo City Park	Laurel Creek				D
213	Silverbirch Lodge	Galt Creek		D		D

Note: * - uses of the area could not be established.

APPENDIX 4

GRAND RIVER FLOOD CONTROL ALTERNATIVES (1,2,3)

FLOOD CONTROL STORAGE - (AC-FT.)

West Montrose	Barrie Hill	Everton	Arkell	Ayr
27,600	0	0	0	73,000
"	7,000	0	4,300	"
"	"	0	0	"
"	"	12,000	0	"
"	"	5,800	0	"
"	0	0	4,300	"
"	0	0	0	"
"	0	12,000	0	"
"	0	5,800	0	"
"	0	0	0	24,000
"	0	5,800	0	24,000
"	0	5,800	0	33,000
"	0	0	0	33,000
"	0	5,800	0	51,000
"	0	0	0	51,000
"	0	5,800	0	60,000
"	0	0	0	60,000
0	0	12,000	0	59,000
0	7,000	12,000	0	59,000
0	7,000	0	0	59,000
25,000	0	0	0	0
46,000	0	0	0	0
25,000	0	5,800	0	0
46,000	0	12,000	0	0
52,000	0	5,800	0	0
52,000	0	12,000	0	0
46,000	0	0	4,300	0
52,000	0	0	4,300	0
52,000	0	0	0	0
0	0	0	0	0
0	7,000	0	4,300	73,000
0	0	0	4,300	73,000
0	0	12,000	0	73,000
0	0	5,800	0	73,000
0	0	0	0	73,000

APPENDIX 4 (Contd.)

West Montrose	Barrie Hill	Everton	Arkell	Ayr	Hespeler
0	0	0	0	33,000	
0	7,000	0	0	73,000	
0	7,000	12,000	0	73,000	
0	7,000	5,800	0	73,000	
0	0	0	0	24,000	
0	0	5,800	0	24,000	
0	0	5,800	0	33,000	
0	0	5,800	0	51,000	
0	0	0	0	51,000	
0	0	5,800	0	60,000	
0	0	0	0	60,000	
0	0	12,000	0	0	
0	0	5,800	0	0	
0	0	0	4,300	0	
0	7,000	0	0	0	
0	0	0	7,700	0	
0	7,000	0	7,700	0	
0	7,000	0	7,700	60,000	
0	0	0	7,700	60,000	
0	0	0	7,700	73,000	
46,000	0	0	7.700	0	
52,000	0	0	7,700	0	
0	0	0	4,300	51,000	
0	0	0	4,300	24,000	
0	0	0	4,300	33,000	
25,000	0	0	4,300	0	
0	0	12,000	0	59,000	0
					4,000
					7,000
					10,000
0	0	5,800	0	24,000	0
					4,000
					7,000
					10,000
0	0	5,800	0	33,000	0
					4,000
					7,000
					10,000

(1) All combinations include the Luther, Belwood, Conestogo and New Guelph reservoirs.

(2) One additional combination (not listed) was evaluated to determine the benefits of the New Guelph Reservoir over the three existing reservoirs.

(3) Results for the last 12 combinations are based on a finer sub-division of the watershed than the first 61 to allow the inclusion of the Hespeler Reservoir.

APPENDIX 5

SUMMARY OF WATER SUPPLY OPTIONS EVALUATED

In terms of allocating resources to communities, it has been assumed that interconnection between the Megalopolis Communities (Waterloo, Kitchener, Galt, Preston, Hespeler) would exist by 1981. This simplifies the allocation problem in that Middle Grand resources would then have to be divided between only two population centres; Megalopolis and Guelph. On the basis of geography and timing of need, most resource assignments become readily evident on this basis.

A full list of the alternate internal source plans which have been evaluated appears in this appendix along with a listing of the various pipeline solutions that were considered.

Though the list of pipeline designs might appear large at first glance, it should be pointed out that a number of problems appear when considering pipeline design. A specific design is predicated upon a knowledge of the source, the communities to be served, design populations (in this case populations projected to the year 2001), the staging of various segments of the system and the approach taken to staging (oversizing of some parts of system for later add-ons or twinning of the pipeline back to the source). As with internal source facilities, pipelines have been designed so that all completions of construction would occur at one of four bench mark years through the planning period (1976, 1981, 1986, 1991). Lakes Huron, Ontario and Erie were all considered as supply sources. However, because of large differences in capital and operating costs between the first two and Lake Erie, only two planning options were included in later analysis for each of Lake Huron and Lake Ontario. For Lake Erie as a source, forty-six different designs were considered.

Internal Sources

Service to Guelph:

- Build Everton Reservoir to maintain stream flow in Eramosa, develop a recharge facility at Arkell Springs (first phase), lay pipeline up valley and develop groundwater (second phase). Operational by 1976 or 1981.

- Repeat above option, but re-dedicate dam to other purposes by 1986 or 1991. This implies a pipeline by 1986 or 1991 to replace groundwater.

- Build Arkell Reservoir and treatment plant. Operational by 1981.

- Build West Montrose Dam and water treatment plant. Operational by 1981, service to continue throughout planning period to Guelph only.

- Build West Montrose Dam and water treatment plant initially for Megalopolis (1976). Convert to Guelph service by 1986.

- Build connecting pipeline between Guelph and Megalopolis, Guelph groundwater to augment Megalopolis supply to 1976. Build Ayr reservoir and treatment plant to be operational in 1976 and service both Guelph and Megalopolis to end of period.

- Build Birge's Mill Reservoir to maintain flow in Lutteral Creek. Develop wells along Lutteral Creek.

Service to Megalopolis:

- Build West Montrose Reservoir and treatment plant to be operational by 1976. Re-dedicate reservoir in 1986 or 1991 (implies Lake Erie pipeline or Ayr Reservoir to be operational in 1986 or 1991).

- Build Ayr Reservoir and water treatment plant to be operational by 1976 or 1981 or 1986. Other supply sources would be required for augmentation depending on year that Ayr becomes operational.

- Build Ayr Reservoir and treatment plant to be operational by 1976. Re-dedicate in 1991 and replace supply with Lake Erie system.

- Build Ayr Reservoir and use water impounded for groundwater recharge. (Full cost evaluation not possible at present.)

- Build Barrie Hill Reservoir on Speed River with either (a) a freshot diversion system from Belwood or (b) a pumping diversion from Belwood. With both systems build diversion from Barrie Hill Reservoir into Cox Creek and develop wells along Cox Creek. With system (b) develop wells along Speed River from Barrie Hill to Belwood.

- Develop groundwater along Grand River from Bridgeport to Belwood.

- Develop groundwater on O.H.C. lands.

- Build Lake Erie pipeline to Ayr Reservoir and treatment plant. Mix waters before treatment.

- Build effluent spreading system from Kitchener water pollution control plant. Use renovated water as recharge for Cedar Creek or similar stream and develop wells in stream valley. (Full evaluation not possible at present.)

- Build water treatment plant on Grand River.

Service to Brantford:

- Expand treatment plant on Grand River when need arises.

External Sources

All of the following pipeline systems have been described in the same way, i.e. the source is given, followed by each area on the system, and the year in which they come on. For any city which does not come on the system immediately, an indication is given as to whether the system is twinned or oversized. The abbreviations being used are as follows:

Sources:	L.E.	=	Lake Erie
	L.O.	=	Lake Ontario
	L.H.	=	Lake Huron
Customers:	N	=	Nanticoke area including industrial customers, Lynn, Jarvis, Hagersville, Caledonia, Cayuga
	B	=	Brantford
	M	=	Megalopolis including Kitchener, Waterloo, Galt, Preston, Hespeler
	G	=	Guelph

SOURCE	CUSTOMERS
L. H.	M (1976) G (1976)
L.H.	M (1976)
L.O.	M (1976) G (1976)
L.O.	M (1976)
L.E.	N (1976)
L.E.	N (1976) B (1976)
L.E.	N (1976) B (1991) - Oversize
L.E.	N (1976) B (1991) - Twin
L.E.	N (1976) B (1976) M (1976)
L.E.	N (1976) M (1976) B (1991) - Oversize
L.E.	N (1976) M (1976) B (1991) - Twin
L.E.	N (1976) M (1986) - Oversize B (1991) - Twin
L.E.	N (1976) M (1981) - Oversize B (1991) - Twin
L.E.	N (1976) M (1981) - Oversize
L.E.	N (1976) M (1986) - Oversize

SOURCE	CUSTOMERS
L.E.	N (1976) B (1976) M (1981) - Oversize
L.E.	N (1976) B (1976) M (1986) - Twin
L.E.	N (1976) B (1976) M (1991) - Twin
L.E.	N (1976) B (1991) - Twin M (1991) - Twin
L.E.	N (1976) M (1986) - Twin B (1991) - Oversize 1986 stage
L.E.	N (1976) M (1981) - Oversize B (1991) - Oversize both stages
L.E.	N (1976) M (1986) - Oversize B (1991) - Oversize both stages
L.E.	N (1976) M (1981) - Oversize B (1981) - Oversize
L.E.	N (1976) M (1986) - Oversize B (1986) - Oversize
L.E.	N (1976) M (1986) - Twin
L.E.	N (1976) M (1991) - Twin
L.E.	N (1976) M (1976)
L.E.	N (1976) M (1976) B (1976) G (1976)

SOURCE	CUSTOMERS
L.E.	N (1976) M (1976) B (1976) G (1981) - Oversize
L.E.	N (1976) M (1976) B (1976) G (1986) - Oversize
L.E.	N (1976) M (1976) B (1991) - Oversize G (1981) - Oversize
L.E.	N (1976) M (1976) B (1991) - Oversize G (1986) - Oversize
L.E.	N (1976) M (1976) B (1991) - Oversize G (1991) - Oversize
L.E.	N (1976) M (1981) - Oversize G (1981) - Oversize B (1991) - Oversize both stages
L.E.	N (1976) M (1981) - Oversize G (1986) - Oversize B (1991) - Oversize both stages
L.E.	N (1976) M (1981) - Oversize G (1991) - Oversize both stages B (1991) - Oversize both stages
L.E.	N (1976) M (1981) - Oversize G (1981) - Oversize B (1981) - Oversize
L.E.	N (1976) M (1981) - Oversize B (1981) - Oversize G (1986) - Oversize both stages

SOURCE	CUSTOMERS
L.E.	N (1976) M (1981) - Oversize B (1981) - Oversize G (1991) - Oversize both stages
L.E.	N (1976) M (1986) - Twin B (1986) - Twin G (1986) - Twin
L.E.	N (1976) M (1986) - Twin G (1986) - Twin B (1991) - Oversize twin
L.E.	N (1976) M (1986) - Twin G (1991) - Oversize twin B (1991) - Oversize twin
L.E.	N (1976) M (1991) - Twin G (1991) - Twin B (1991) - Twin
L.E.	N (1976) B (1976) M (1981) - Oversize G (1981) - Oversize
L.E.	N (1976) B (1976) M (1981) - Oversize G (1986) - Oversize both stages
L.E.	N (1976) B (1976) M (1981) - Oversize G (1991) - Oversize both stages
L.E.	N (1976) B (1976) M (1986) - Twin G (1986) - Twin
L.E.	N (1976) B (1976) M (1986) - Twin G (1991) - Oversize twin

SOURCE	CUSTOMERS
L.E.	N (1976) B (1976) M (1991) - Twin G (1991) - Twin
L.E.	N (1976) B (1976) M (1976) G (1991) - Oversize

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NOTE: In addition to the above references referred to in the text, a very large number of reports by consultants and government departments and agencies, local governments as well as technical papers in the literature, have been reviewed during this study.