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THE GREAT LAKES: GENERAL CHARACTERISTICS; MULTIPLE USES; UNIVERSITY INVOLVEMENT

A contribution to a discussion with members of the Great Lakes Panel of the National Council on Marine Resources and Engineering Development and university representatives, Ann Arbor, Michigan, 29-30 October 1968.

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Introduction: the basic characteristics of the region.

The Great Lakes, the largest aggregation of fresh water in the world (figure 1), lie in a watershed covering 4 per cent of the United States land area, but containing about 15 per cent of tne nation's population and producing 36 per cent (by value) of the nation's manufactured output and 23 per cent of the nation's marketed farm products. The Lakes constitute a major aquatic resource for many millions of people; and the utilization of this resource--as enormous reservoirs of potable water, convenient waste receptacles, as arteries of international transport, and as the scene of many forms of recreation--will further increase as population, industries, and the general demands for water grow.

There are sound technical and social reasons, therefore, for regarding the Lakes as part--i.e., the midwestern part--of the marine environment. Also potentialities for commercial fishing and fish processing are under-exploited, and the mineral resources are largely unexplored. From earliest times the Lakes have provided a broad highway to the continental interior. Now, through the St. Lawrence Seaway, they connect the resources of a vast hinterland to the world's oceans; they carry an even larger volume of internal traffic in support of great industries. To select an example, the combination of cheap water transport and the taconite process keeps midwestern iron mining and large sections of the steel industry in business. About half the nation's steel manufacturing capacity is located directly in Great Lakes ports, which further serve large sections of the steel industry located nearby, e.g., at Pittsburgh, Pennsylvania.

Among the resources listed above, some are particularly vulnerable because growing populations increasingly turn to the Lakes as to the ocean* for disposal of human and industrial wastes and as receptacles for drainage from agricultural as well as urban areas.

Waste treatment and the avoidance of pollution is receiving considerable attention both locally and nationally as a matter of great public concern; but municipal and agricultural drainage, however well treated, unavoidably adds large quantities of plant nutrient materials to the water, producing growths of algae often of nuisance proportions and it still remains to be seen how far these effects of intensive and varied human use of the water resource are avoidable and what the costs of such avoidance would be.

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*The sections on "Near-Shore Waste Disposal" on pp. 87-92 of "Oceanography 1966," National Acad. Sci., Nat. Res. Council, Publ. No. 1492, 1967, apply in their entirety and with great force to the Lakes.

The physical characteristics and user conflicts associated with water ~~quality~~ quantity

Some general physical and chemical characteristics of the Great Lakes are assembled in figures 1 and 2. The inter-connected basin water budget--the most fundamental physical characteristic--is presented in the form of a flow diagram in figure 3. This represents a ten year average condition , assuming steady lake levels. Lake levels, of course, vary depending on climate and topography; but engineering regulation is carried out at the outflow of Lake Superior and Lake Ontario.

The possibility of controlling a resource, as in other instances, inevitably generates conflicts of interests. For instance, navigation benefits from high water levels, but these must not be so high that they cause shore erosion and property damage. Hydropower interests* would like to use regulation to meet variations in demand, but the optimal variation for hydropower would bring increased costs to shipping, ports, shore property owners, and in the construction of water intakes and sewage outfalls.

The population increase and a rising standard of living forecast in the following section, will generate an accelerated demand for large volumes of water for domestic and industrial purposes, for air conditioning, and for power station cooling. The greatest volumetric users of water will find it more attractive to come to the Lakes, where the problems of "thermal pollution", for instance, are likely to be less severe than in rivers. As hitherto, large populations will tend, therefore, to migrate to the water; the problems of waste disposal which will then arise are discussed below. Overall planning, of which we see

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*some 80,000 megawatts are generated in the Niagara and St. Lawrence stations.

little at the moment, will be essential. For instance, the judicious siting of nuclear power plants along the St. Lawrence Seaway, could, if combined with improved lock design, use the waste heat to minimize icing and extend the shipping season.

It is evident that the hydrological/economic system, outlined above, could benefit from operational research; but the kinds of systems analyses attempted so far do not take possible future engineering works into account, for instance, regulation of the Michigan-Huron levels by control in the St. Clair river, or the construction of a Superior-Michigan canal across the upper peninsula. Diversion into and out of the Great Lakes basin (in addition to those already in operation, see figure), are also being considered, but these would require further diversion of Canadian waters, mainly for the improvement of water quality in the United States. This of course highlights the imperative need for comprehensive regional planning on an international scale.

The user conflicts associated with water quality

The conflicts of interest and the consequent need for regional analysis and planning, evident in the above considerations of water quantity appear again in greater force when water quality is considered. Excluding the City of Chicago, whose water-borne wastes are diverted to the Illinois River, twenty-eight million people occupy the Great Lakes drainage basin, concentrated mainly along the southern fringes, with over one third in the Lake Erie basin. The growth of that population since the early 1800's is illustrated in figure 4.

Demographers forecast a doubling of the population on the Great Lakes watershed within a century and the creation of a "megalopolis" linking the present centers of population from Milwaukee to Montreal. With a similar distribution of industry and with a large part of the water-borne wastes ending up in the lakes as the final "sink," growing public concern at the degradation of water quality is in no way surprising. This is the major environmental problem facing the region now, and will increasingly be so as Megalopolis grows. In the long term, therefore, the major scientific, technological and social involvement with the Great Lakes and with their resources will lie in the field of exploitation of the water resource and in the control of its quality.

The water-borne waste input to the Lakes ranges from gross pollution by toxic or offensive materials to municipal treatment plant effluents which are well treated to the "secondary" standard acceptable today. The first impact of the Water Quality Act of 1965 will be to require the universal application--by no means universal today--of secondary treatment of municipal wastes and the acceptance of comparable standards by industry.

The problem is not entirely one of pollution control, however. Fertile farms, tidy gardens,and the increased agricultural efficiency which our higher standard of living demands, produce leaks of certain plant growth-promoting substances into the waterways. Similar "nutrient enrichment" (eutrophication) is also the present end result of efficient municipal waste treatment. Entering the lake, as they eventually do, these nutrients stimulate algal growth and further biological production. This process may sometimes be beneficial in increasing the yield of a fishery, but it is usually seen by the public as a nuisance in the form of rotting algae on the beaches. Agricultural efficiency, unfortunately, also has more subtle and perhaps more disturbing effects on the water. These arise from the accumulation, in some aquatic organisms of certain pesticides which, passing through fish and fish-eating birds, can lead to infertility and death. Accumulation of DDT in eggs, for instance, now threatens the spectacularly successful coho salmon fishery.

In addition to the important distinction, made in the preceeding paragraph, between pollution and eutrophication enrichment (the former perhaps avoidable, the latter perhaps not entirely), the following points should be emphasized.

First, the land animal--man--interfaces with the Great Lakes water resource mainly near the shore, for navigation, domestic and industrial water supplies, recreation, and for waste disposal. There is a great range, therefore, in the water quality of the Lakes, depending to a large degree on the population pressure in the watershed (see figure 4). In any one basin, there are often also considerable differences in quality between inshore and offshore waters, which may persist for much of the time. The mechanisms of exchange between inshore and offshore waters require further study.

Second, biological processes in natural waters, if not overloaded, can break down and render harmless most wastes; and this is the basis of present-day water-borne disposal methods. Such methods find, of course, world-wide application and are relatively inexpensive. For a hundred years or so, the Great Lakes and their watershed rivers have provided perhaps too convenient a disposal system, the scale of which has postponed awareness of the consequences until recent years. The time-constant of remedial measures will be equally long. Problems arise because the biological system is overloaded and because many users return water to the system at a lower quality level than that at which they took it in. Water quality is affected not only by a complex interconnected (ecological) web of chemical and biological causal links, but also by another complex and interconnected (social) web of user activities.

<u>What needs to be done, and what part can universities play?</u>

To achieve understanding and control of a system as large and as complex as that presented by the Great Lakes region, progress must be made along the four main channels set out below. Effort must be applied--singly and jointly--by federal and state agencies, by industry and by universities along each of the four channels; and the application of effort must be concurrent, for progress in one channel will influence progress in another.

1. <u>Research into the functioning of natural and social systems</u>

To summarize the research needs and opportunities with any degree of completeness is an impossible task, but some outstanding themes may be mentioned. Many of these find their counterparts in "Oceanography 1966", Nat. Acad. Sci., Nat. Res. Council. Publ. No. 1492, particularly in chapter 2 ("Understanding the Ocean: New Insights") and chapter 3 ("Uses of the Ocean").

In the field of <u>physical research</u>, the Lakes have frequently been referred to as model oceans in which some universal oceanic processes and mechanisms can be studied, conveniently in the absence of major tides and without the complications of salinity gradients. While this is certainly true of many important processes, particularly air/water interactions, there is growing evidence that some conspicuous features of the circulation patterns--for instance, the internal waves and current regime described in the writer's report for the Office of Naval Research, under contract Nonr 1202 (22)*--are boundary-induced. In other words, while there are similarities or identities with oceanic events and mechanisms, there are also important differences; so that the Great Lakes--in spite of the dimensions implicit in their title--exhibit some properties of closed basins, which are also relevant to circulation patterns of shelf seas, gulfs, and estuaries.

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*see also, Mortimer, C.H. 1968. Internal waves and associated currents in Lake Michigan during the summer of 1963. Spec. Rept. 1, Center for Great Lakes Studies, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

As became publicly evident during the "Chicago Lake Diversion Case," a knowledge of the circulation patterns is essential to answer practical questions concerning such matters as the dispersal of wastes and location of water intakes and power plants. Aware of this and of the growing sense of public concern with conspicuous effects of pollution, a unit of federal government (based initially, 1961, in the Public Health Service and later transferred to the Federal Water Pollution Control Administration, Department of the Interior) embarked on a six-year study of circulation, water quality, and biological status of the Lakes--a monumental study yet to be fully reported.

In a region relatively so little investigated as the Lakes, it is not surprising that an exploratory study on this scale has suggested many lines of research of theoretical and practical importance. Prominent among these is the problem of the hydrodynamics of near-shore waters, in which several mechanisms can operate, from time to time and at different seasons, to trap water masses near the shore for several days or weeks. A better understanding of these mechanisms should be sought, as the near-shore waters are those into which nutrient materials are injected and dispersed, and from which public water supplies are extracted.

The two main themes of biological research in the Lakes have been and will continue to be related to (a) fisheries and (b) eutrophication. Future research could profitably concern itself with those factors, biological and social, which are obstructing the development of fisheries and fish processing. For instance, an objective view should be sought on whether sport fisheries and commercial fisheries are as incompatible as some state conservation departments appear to think, and on whether the relatively primitive and under-capitalized commercial fishing industry could be technically revolutionized to exploit the enrichment trends mentioned in the next paragraph or the waste heat from the increasing number of nuclear power plants being built on the Great Lakes shores. How far, for instance, can the alewife population explosion be transformed from the negative aspect of nuisance to a positive bonus in animal protein? What uses could be made of the waste heat from Lake-cooled power plants to maintain year-round fish culture or a large-scale hatchery?

Other biological studies will be based on the recognition that eutrophication is associated with increased nutrient supply from soil processes, from human activities in the drainage basin, and from other processes in the Lake. If the results are desirable, for instance as a greater fish yield, they may be looked upon as a fertilizing enrichment. If they take an undesirable form, for instance as algae fouling a beach or clogging the filters of a municipal water plant, the term eutrophication receives the connotation of pollution. It should be the aim of management to exploit the enrichment process as an asset rather than combat it as a nuisance; but, before this desirable state of affairs can be reached, much more needs to be known about the key mechanisms which are operating. Contributors to the enrichment processes are not only the major plant nutrients nitrogen and phosphorus, but also organic micronutrients, probably including some yet to be discovered.

Eutrophication-centered studies will, of course, form part of a more universal consideration of enrichment processes and effects in all natural waters, fresh and salt. However, there is evidence that results obtained in the Great Lakes, because of their scale and the character of their environments, will have direct application to marine coastal and particularly to estuarine situations. As a research strategy, there may be much to be gained by applying a large part of the effort in those Lake regions in which eutrophication and pollution trends are conspicuous, for instance, Lake Erie, the southern half of Lake Michigan, and southern Green Bay.

The research themes so far mentioned lie mainly in the field of the natural sciences--physics, chemistry, and biology. Before turning to the social sciences and to the engineering and institutional aspects considered below, a strong plea should be made for strong and continued support for basic research. There is a danger that, with increasing emphasis on applied research, directed toward resource exploitation and questions of environmental quality (for example, the Sea Grant College Program of the National Science Foundation, and the Ocean Exploration Decade), there may not be proportional support for the fundamental studies needed to maintain progress in the applied fields. The eutrophication studies, already mentioned, may be cited as an example. Considerable effort and funds have been put into this field, but the results have been largely descriptive; and little progress has been made over the years in analytical understanding of the mechanisms which might lead to control. As in cancer research, many of the key problems are the complex ones of cell biochemistry, nutrition and growth. Rapid progress should, therefore, not be expected, but progress is most likely to come from continued strong support of fundamental studies of algal nutrition, for instance in the presence and absence of bacteria.

The properties and the functioning of socio-economic systems in the Great Lakes region or sub-regions will also provide subject matter for research which universities and others will undertake. A fruitful approach, and often the only possible initial approach, will be the construction of model systems, inputs to which will come not only from the natural sciences, but also from the engineering and institutional fields mentioned below; and this will require the combined efforts of scholars, engineers, and planners from a wide spectrum of disciplines. Improved planning techniques are badly needed in the fields of water resources, transportation, and recreational aspects of the region; and it is to universities that we must largely look for the scholars and specialists, needed to deal with these problems.

The value of an operational research approach--nowadays more commonly called systems analysis--is twofold. First, it demands an estimate of the transfer function coefficients involved in socioeconomic interactions and conflicts; and where the estimates are ill-defined, it illuminates the need for future research at a critical "bottleneck". Second, it enables the effects of alternative solutions to be tested without the costs and risks attending real-life decisions. Any realistic model must, for instance, include the all-important institutional and legal constraints. Even where a model is inefficient in some respects, for instance because of lack of data or difficulty in quantifying poorly defined social or aesthetic values, it can often provide a tool for further advance. For instance, the types of model in which people participate as "players" have merit where community reactions to institutional or political decisions are the object of study.

2. Engineering and innovation

However desirable it may be to make large-scale changes in the environment or to control changes already made, we must look to the engineer and to industry for what is possible. But universities also have a role in pursuing the art of the possible. This pursuit, of course, includes not only the application of existing technologies, but also experiment and innovation. Directed to actual regional problems, such activities provide an excellent training ground for the engineers of the future. That future may expect to see notable advances, for example in: transportation and navigation, perhaps fast hydrofoil or hovercraft ferrying people and vehicles between component cities of the Great Lakes megalopolis;

large-scale environmental modifications such as level regulation, water diversions, and shoreline amenity developments; use of waste heat from power stations for improvement of navigation, hydropower generation, and fisheries; and, most important of all, techniques of waste disposal and monitoring of water quality, to prevent degradation of the aquatic resource.

With the present system of waterborne waste disposal, it seems inevitable that growing populations with rising standards of living and increasingly efficient agricultures must contribute inevitably to the eutrophication process described above. Some remedial measures will be possible--for instance, tertiary waste treatment involving removal of phosphate--but the removal of other equally important nutrient materials, including many growth-promoters, known and unknown and in extreme dilution, will be difficult and costly. Therefore it seems likely that a growing population with heightened expectations of environmental quality will demand and will be willing to pay for methods of waste disposal quite different from those in operation today. This provides a challenge for innovaters and for industry. We may see, for instance, the construction of large collector sewers to pipe much of the megalopolis wastes to treatment plants outside the drainage basin, although this will of course raise problems with river systems elsewhere. Also likely is a trend toward complete oxidation at temperatures and pressures at present beyond the capabilities of technology, followed by solute removal and production of pure water as a byproduct.

3. Training and public education

The role of the universities--in training the natural scientists, social scientists, engineers, and planners who will be engaged in the above activities--is clear and need not be elaborated in detail here. The best training, particularly but not exclusively at the graduate level, will be "on the job", i.e., students will be trained not only in the appropriate basic disciplines, but also in the application of research toward local environments or problems. For students in the natural sciences, for example, there should be opportunities for working on the Lakes; and students in the social sciences should have their attention directed to relevant regional problems.

The manpower reservoir of the midwest could provide more of the trained people needed in marine science, engineering, and resource development; and universities in the Great Lakes region should therefore be supported in the development of programs of education and research related to the Lakes and their resources and which use the Lake environment as a marine training ground. For these universities there are challenging opportunities for educational and scholarly achievements in fields of considerable intrinsic and public interest.

There is also need for rapid publication of knowledge, through university extension and other means, not only of technical information relevant to the total regional resource, but also of soundly based and well written reviews, designed to build an informed public opinion and to motivate the public will. In the final analysis, this may prove to be the best means of developing a political and legal structure capable of implementing that will.

4. <u>Organizational arrangements and planning</u>

Decisions on how the Lakes are to be used and further exploited must, in the last resort, be based on social and political choices, reached after equitable compromise and in the light of the best scientific and technical knowledge available. After the scientists, engineers, economists, sociologists, and systems analysts have identified the most pressing problems, and the techniques and costs of solving them, society still has to devise institutional structures which will ensure that the solutions are arrived at with reasonable speed. Study and experiment with such structures must receive the highest priority, even today, if an early reward is to be reaped from application of present scientific and technical knowledge, and if the effects of population increases forecast for the Great Lakes watershed are not to be disastrous.

Multiple uses of a resource and the conflicts which stem from such uses demand planning, in this case on a wide regional and indeed international scale. It is possible to list a dozen or more agencies and a similar number of commissions, federal and state, in the United States and Canada, which are concerned with planning or regulating the use of some part of the total regional resource. While many of these bodies work closely together, there is a great need for closer inter-agency cooperation, if only to set up common goals and timetables for the solution of common problems identified as urgent.

Present channels of inter-agency coordination and cooperation should, therefore, be examined to see if they can be made more effective. This may, for instance, disclose needs for:

(a) improved data storage and retrieval systems;

(b) an inter-institutional clearing house (including universities) in which the key problems can be identified and assigned priority ranking; and

(c) advisory committees of national stature--in natural science, social science, and engineering--to advise on programs and funding, as an integral part of the national oceanographic program and designed to use available funds in the most efficient manner in attempts to solve the problems identified above.

FIGURE 1

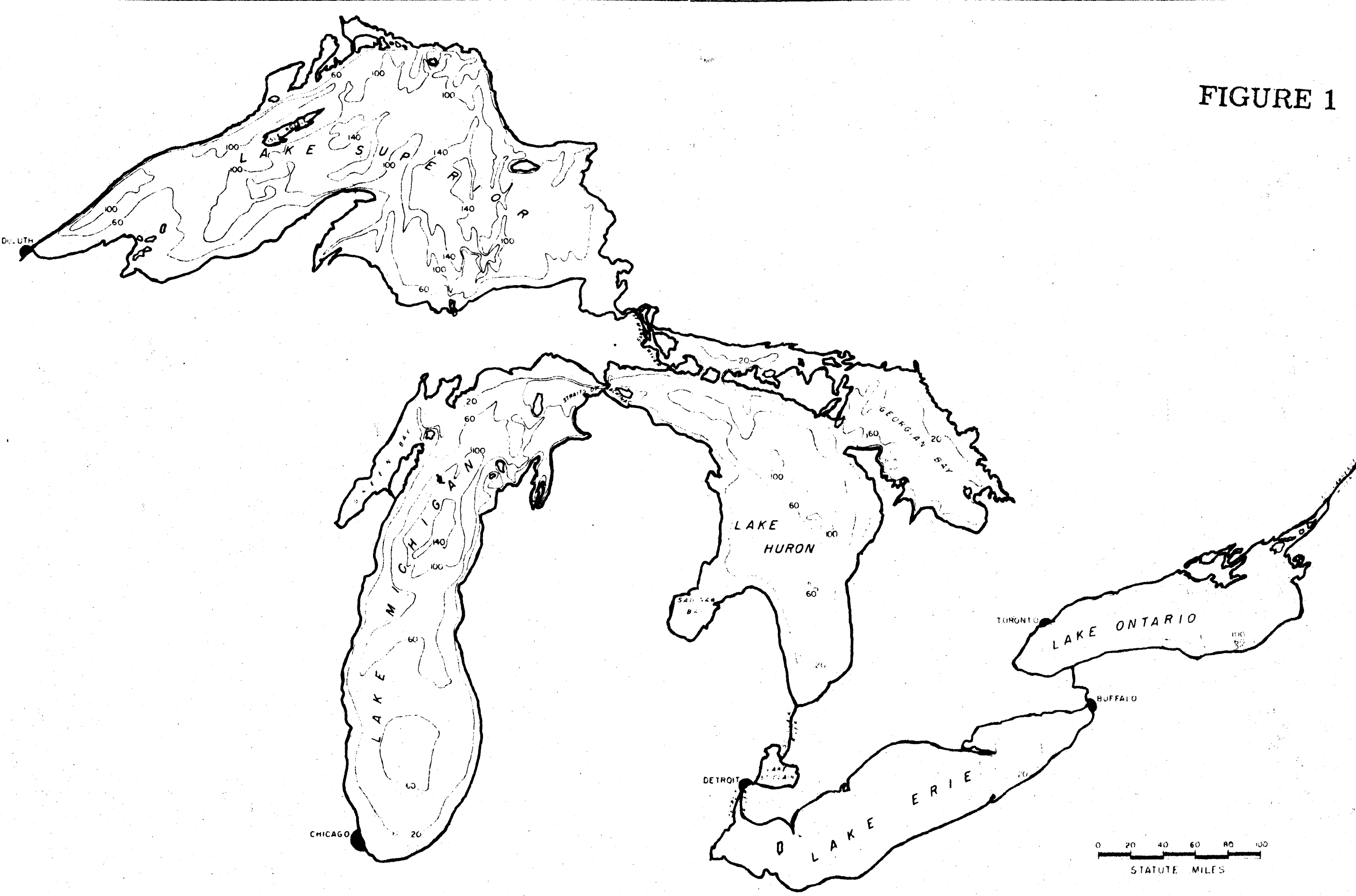


Fig. 19.1.—**Great Lakes, showing major depth contours in fathoms.**

Dimensions of the Great Lakes[a]

Lake	Length (mi)	Breadth (mi)	Area: Water surface (mi²)	Area: Drainage basin (mi²)	Average surface elevation above mean sea level since 1860 (ft)	Mean discharge (cfs)	Maximum depth (ft)	Mean depth (ft)
Superior	350	160	31,820	80,000	602.20	73,300	1,333	487
Michigan	307	118	22,400	67,860	580.54	55,000	923	276
Huron	206	183	23,010	72,620	580.54	177,900	750	195
St. Clair	26	24	490	7,430	574.88	178,000	21	10
Erie	241	57	9,930	32,490	572.34	195,800	210	58
Ontario	193	53	7,520	34,800	246.03	233,900	802	283

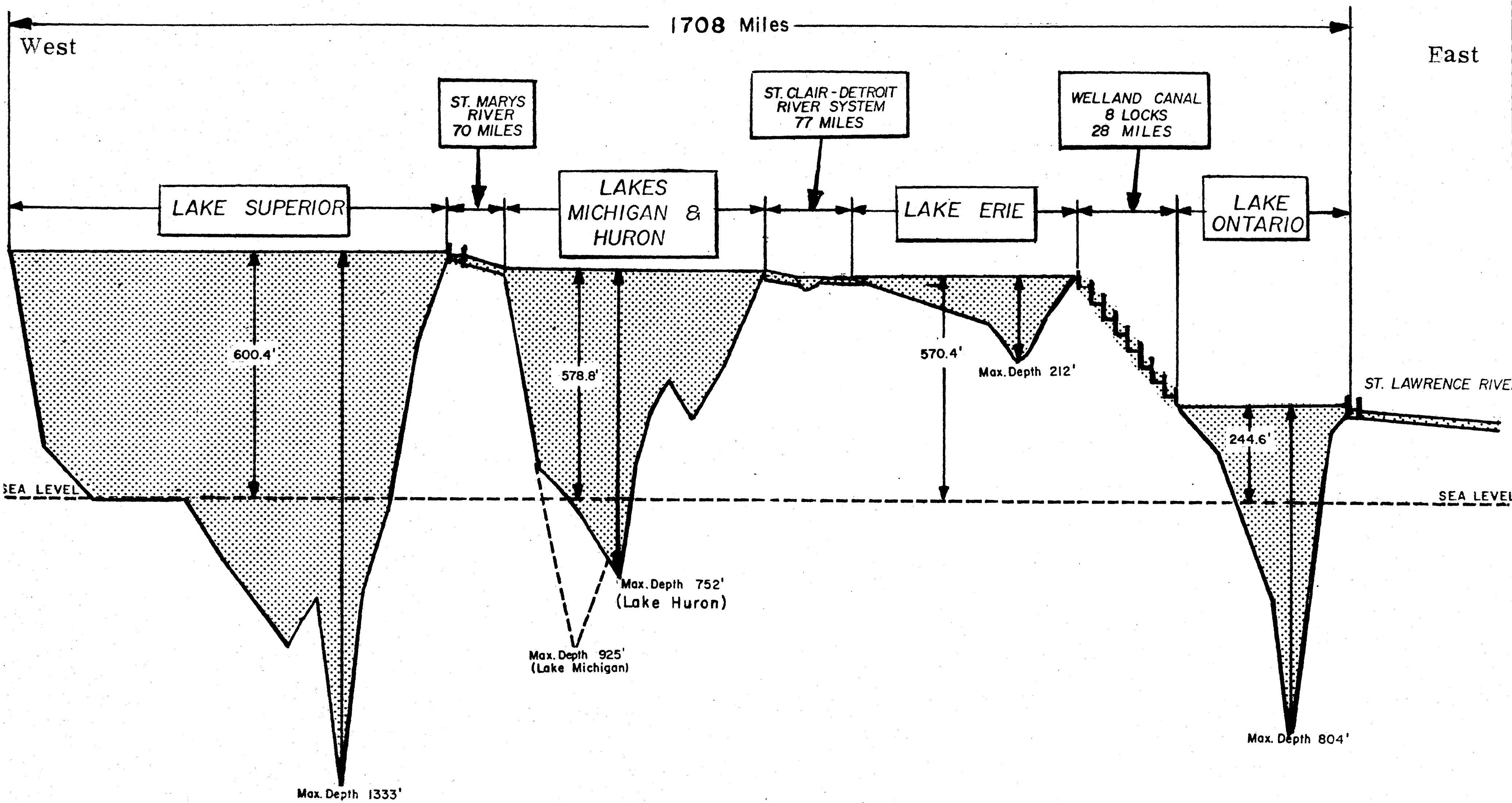
[a] Data from U.S. Army, Corps of Engineers (1960) or personal communication.

Average chemical characteristics of Great Lakes waters. U.S. Bureau of Commercial Fisheries data, unless designated otherwise. Data based on samples from various depths.

Lake	Calcium (ppm)	Magnesium (ppm)	Potassium (ppm)	Sodium (ppm)	Total alkalinity (ppm $CaCO_3$)	Chloride (ppm)	Sulfate (ppm)	Silica (ppm)	Total phosphorus (ppb)	pH	Specific conductance (micromhos at 18° C)
Superior	12.4	2.8	0.6	1.1	46	1.9	3.2	2.1	5	7.4	78.7
Huron	22.6	6.3[a]	1.0	2.3	82	7.0	9.7	2.3	10	8.1	168.3
Michigan	31.5	10.4	0.9	3.4	113	6.2	15.5	3.1	13	8.0	225.8
Erie	36.7	8.9	1.4	8.7	95	21.0	21.1	1.5	61	8.3	241.8
Ontario	39.3	9.1[b]	1.2	10.8	93[c]	23.5	32.4	0.3	—	8.5[c]	272.3

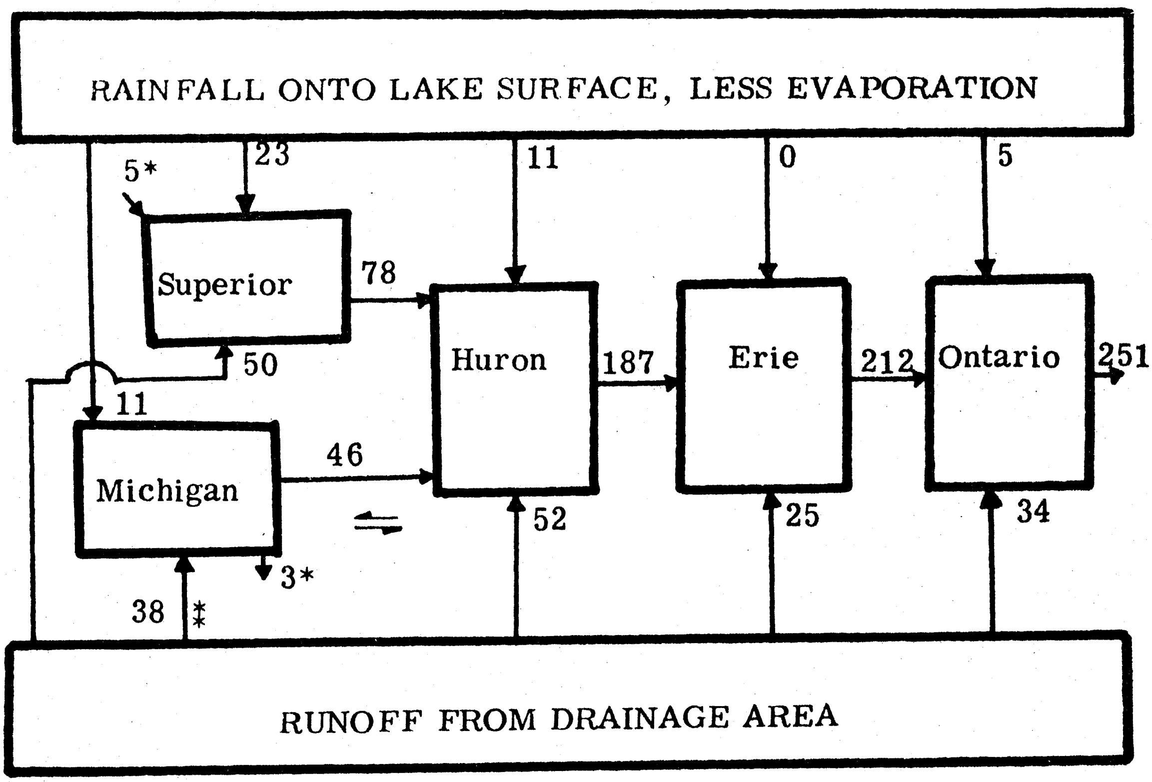
[a] Ayers *et al.*, 1956.
[b] Leverin, 1947 (average from Toronto intake).
[c] New York State Dept. Health, 1958.

Data from: Beeton, A.M. and Chandler, D.C. 1963. in "Limnology in North America," University of Wisconsin Press, p. 535.



Lake	SUPERIOR	MICHIGAN	HURON	ERIE	ONTARIO
Extreme Length, Miles	350	307	206	241	193
Extreme Width, Miles	160	118	183	57	53
Area, Square Miles	31,800	22,400	23,000	9,900	7,600
Average Depth, Feet	487	276	195	58	283
Volume, Cubic Miles	2933	1169	848	109	407

Figure 2. Profile of the Great Lakes portion of the St. Lawrence Seaway. Note: the profile passes the deepest point in each basin. A ship would follow a somewhat shorter track.



* = diversions

⇌ oscillatory flow greater than mean flow

FIGURE 3. Flow diagram (in units of thousand cubic feet per second) for the Great Lakes, assuming steady lake levels and based on U. S. Lake Survey 1950-1960 averages.

‡ Less than 4% of this passes into the lake across the most highly populated shoreline from Milwaukee, Wisconsin, south and east through Chicago, Illinois, to Michigan City, Indiana.

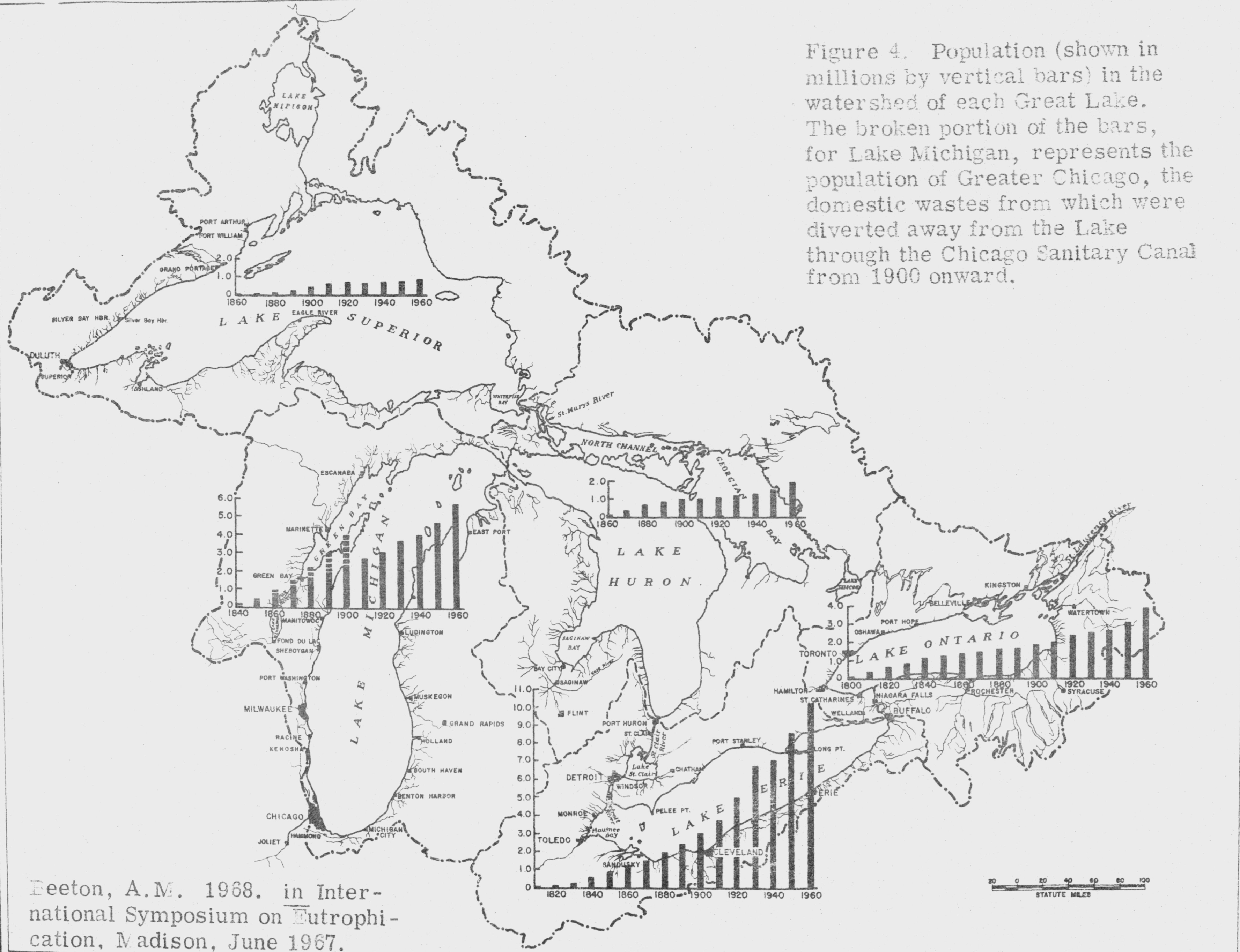


Figure 4. Population (shown in millions by vertical bars) in the watershed of each Great Lake. The broken portion of the bars, for Lake Michigan, represents the population of Greater Chicago, the domestic wastes from which were diverted away from the Lake through the Chicago Sanitary Canal from 1900 onward.

Eeeton, A.M. 1968. in International Symposium on Eutrophication, Madison, June 1967.