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FEATURE ARTICLE

PERSPECTIVES ON U.S. GREAT LAKES CHEMICAL TOXIC SUBSTANCES RESEARCH

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ABSTRACT. Because of their magnitude, their geographic and demographic characteristics, and their unique limnological properties, the Great Lakes appear to be especially susceptible to chemical contamination. The scientific basis for dealing with this contamination is very limited compared with the magnitude of the problem. This is particularly evident when the vast array of toxic xenobiotic substances of anthropogenic origin are considered. Major knowledge gaps exist on the critical transport pathways, ultimate fate, and ecological effects of toxic substances (of urgent importance are health effects on humans residing in the basin), as well as on the economic and social aspects of toxics management.

The economic climate of the 1980s, however, is likely to severely limit the resources available for the conduct of research which is so badly needed. Consequently, it appears that the Great Lakes research community will have imposed upon it a markedly increased demand for information and a concomitant reduction in the resources available to accomplish the task. Finally, despite a pessimistic outlook for research support, there is optimism that the Great Lakes will respond positively, and in a relatively short time span (years as opposed to centuries), to the abatement of toxic inputs. Nevertheless, additional information on the processes affecting the distribution and fate of toxic substances is still critical to the understanding required to ensure effective remedial actions.

INTRODUCTION

It is very apparent that contamination by toxic substances of anthropogenic origin currently represents the major environmental problem facing both the scientific community and the management structure associated with the Great Lakes. More than 30,000 chemical compounds of commercial and/or industrial significance are now used in the United States, and approximately 1,000 new compounds are developed each year (Maugh 1978, Ames 1979). Even if only a small percentage of these chemicals enters the Great Lakes environment, the magnitude of the problem should be obvious. Therefore, studying the effects of these chemicals will likely be a critical research area for years to come. However, if the research is to be effective, it should be carefully conceived and well executed. Failure to achieve the necessary design and implementation steps may, given the urgency for information, force Great Lakes research into an entirely reactive role based on fear, instead of a thoughtfully considered approach, firmly established in scientific fact.

In an effort to foster the initiation of a carefully conceived approach, the Standing Committee on Research and Development of the Great Lakes Basin Commission, along with the Michigan Sea Grant Program, the Wisconsin Sea Grant Program, the Great Lakes Environmental Research Laboratory of the National Oceanic and Atmospheric Administration, and the Large Lakes Research Station of the U. S. Environmental Protection Agency established an invitational workshop on the "Scientific Basis for Dealing with Chemical Toxic Substances in the Great Lakes." The specific purpose was to assess current scientific knowledge, the adequacy of current research, and future research needs with regard to toxic contamination of the Great Lakes. It would appear that effect has been salutary, since the results have already been helpful in securing the focus of attention on the severity of the problem in the Great Lakes.

The purpose of this communication is to share the results of the workshop with the community of Great Lakes research scientists, as well as to provide a perspective upon toxic substances research which has been developed since the work-

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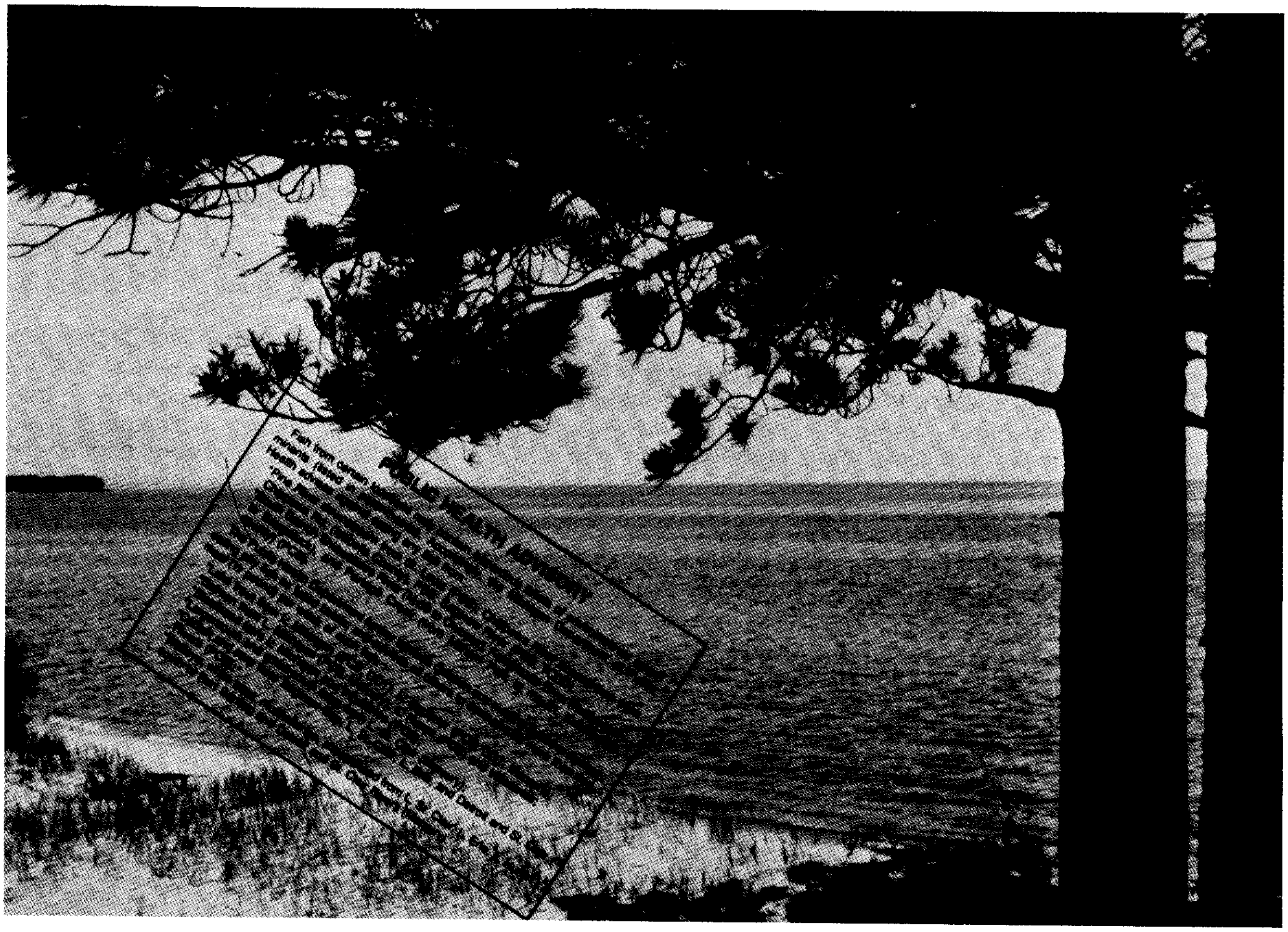

shop took place. The authors are indebted to the more than 60 scientists from the United States and Canada who contributed their ideas and thoughts so freely and openly during the workshop.

SCOPE OF THE PROBLEM OF TOXIC SUBSTANCES IN THE GREAT LAKES ECOSYSTEM

While an exhaustive discussion of the extent of the problem of toxic substances of anthropogenic origin in the Great Lakes is beyond the scope of this report, even a general review of the question demonstrates problems of massive proportions. These difficulties result from the combined natures of both the compounds in question and of the Great Lakes themselves.

A review of the several hundred residue-forming xenobiotic contaminants that have been identified in Great Lakes water, sediment, and biota (International Joint Commission 1977, 1978) suggests a number of characteristics shared in common by many of these compounds. These characteristics, listed below, suggest that a solution to the problem will be difficult.

1. A ubiquitous nature and widespread geographic distribution enabling inputs from a variety of widely disseminated sources.
2. A sizable reservoir of the contaminant outside of the aquatic ecosystem, which continues to provide materials to the point and diffuse sources noted above.
3. Although the reservoirs of these materials may be external to the water mass, a variety of transport mechanisms ensures that the materials reach the aquatic ecosystem.
4. Many of the compounds are poorly metabolized and biodegraded.
5. A number of these compounds have a demon-

strated lipophilicity, and hence, bioaccumulate and bioconcentrate within the ecosystem, and
6. All have the potential for deleterious environmental effects. These impacts usually fall into one of four classes of toxicity:
   a. Carcinogenicity
   b. Mutagenicity
   c. Teratogenicity
   d. All other toxic effects

Many years of research experience with the question of nutrient additions have demonstrated that there is normally a direct relationship between population demography and the extent of eutrophication. In general, the greater the urban pressure, the larger the magnitude of the problem. It can reasonably be expected that, except for these compounds for which atmospheric dissemination is the primary route of transport, a similar relationship will exist for toxic substances. It is of more than passing interest, then, that nearly 20 percent of the total U. S. population and 50 percent of the population of Canada live in the Great Lakes basin (McGrath 1980).

Perhaps the scope of the problem is most geographically demonstrated if one considers the extent of the resources required to determine the safety of an individual compound. If it can be assumed that 2,000 to 3,000 compounds each year represents a fair estimate of the new contributions of industrial research and development, and further assuming a laboratory of 50 staff scientists in the Great Lakes basin engaged in toxicological testing of these new compounds, then, based on an average work year, it can be reasonably expected that the time available for the complete analysis of each new compound for environmental safety is in the range of 30 to 50 hours. This level of effort is insufficient even to perform routine 96 hour LC_{50} testing on these new parent products, not to mention metabolites, daughter compounds, degradation products, and the like.

Required then is some form of expeditious short-cut methodology which will enable the use of quick screening methodologies to separate the relatively small percentage of compounds with the potential for serious environmental consequences from the vast array of materials currently in use. Figure 1 shows a theoretical framework for the screening of toxic substances in the Great Lakes. Ideally, a screening mechanism of this sort could rapidly separate compounds into two convenient categories providing a "safe-unsafe" decision matrix. This would then allow detailed investigation of those substances falling into the latter category and eliminate needless efforts related to the first category. Unfortunately, for most of the compounds presently used in the Great Lakes basin, the existing screening program (Figure 2) is less than adequate. It is clear that increased emphasis will be required in the areas of analytical methodology, predictive numerical simulation, and structure-activity correlations.

SUSCEPTIBILITY OF THE GREAT LAKES TO CHEMICAL TOXIC SUBSTANCES

One of the two specific focuses of the workshop on the Scientific Basis for Dealing with Chemical Toxic Substances in the Great Lakes was to address the question of why the Great Lakes seem especially sensitive to chemical contamination problems. Some of the worst contamination problems in North America have occurred within the Great Lakes basin. Indicative of the problem is the present international concern over the levels of a number of potentially toxic compounds in Great Lakes fish.

A workgroup, led by Dr. Clifford Mortimer of the Center for Great Lakes Research at the University of Wisconsin-Milwaukee, enumerated a number of factors which may contribute to the apparent sensitivity of the Great Lakes. These factors may be grouped according to the sources and kinds of contaminants, and the physical, chemical, and biological characteristics of the lakes' ecosystems.

An obvious factor contributing to the lakes' contamination problems is that they are close to, and often downwind from, major population centers and, hence, pollution sources. Contaminants from these sources, although often contributed at low levels, have been accumulating over a long period of time. Atmospheric pollution is quantitatively significant to the Great Lakes as a result of their vast surface areas. Atmospheric inputs of chemical contaminants are particularly important since they are not filtered through soils and sediments as is often the case for tributary-derived pollutants.

The low suspended sediment load per unit volume (low volumetric inputs) to each of the Great Lakes, except Lake Erie, may also contribute to their sensitivity. Low volumetric sediment loads decrease the opportunity for sorption and

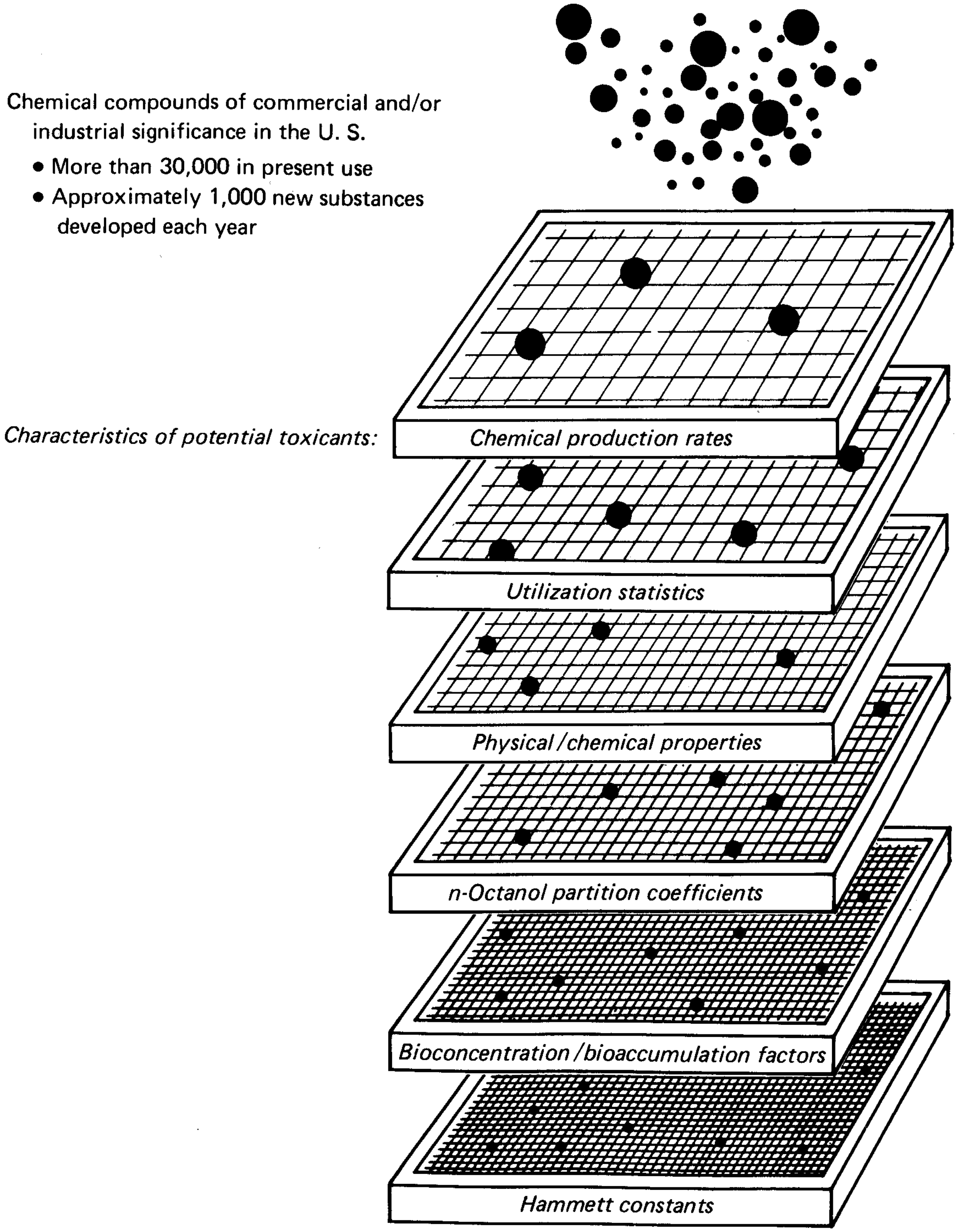

FIG. 1. Theoretical screening program for Great Lakes toxicants.

subsequent removal by scavenging of soluble contaminants, especially compared with lakes which have higher external loadings of particulates. Low solids loads may also prevent dilution of toxic concentrations in bottom sediments which would occur at a faster rate in less oligotrophic lakes. These factors may also explain, at least in part, the lower levels of some contaminants in Lake Erie

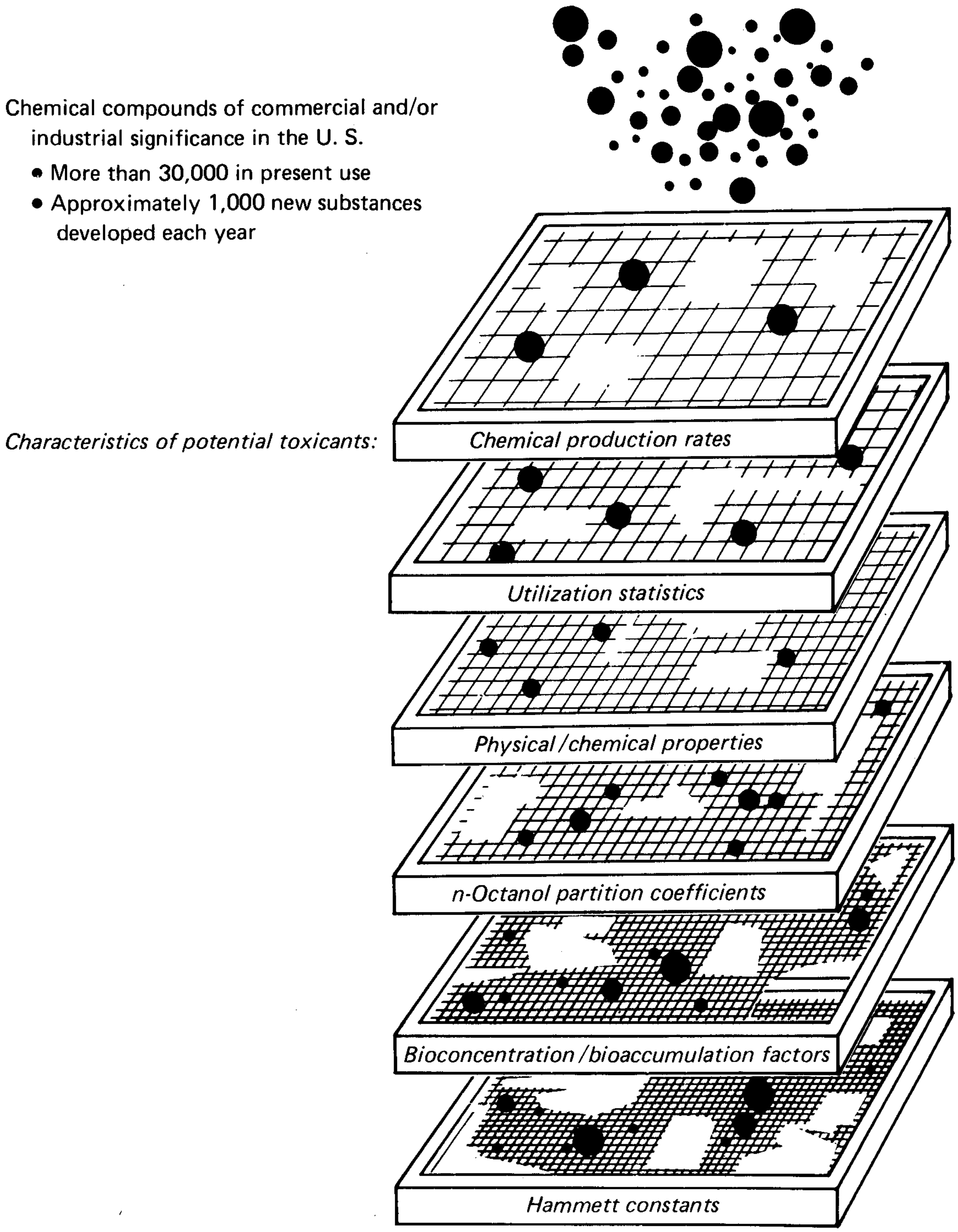

FIG. 2. Existing screening program for Great Lakes toxicants.

compared to the other Great Lakes (Konasewich, Traversy, and Zar 1978). For example, Lake Erie receives over 100 times more tributary sediment input than Lake Superior per unit of volume (Thomas, Robertson, and Sonzogni 1980).

Unique physical characteristics of the Great Lakes also contribute to their sensitivity to toxics. Because of the depth of most of the Great Lakes, the time it takes for particulate material to settle out of the water column is relatively long. The long retention of toxics in the water column thus affords good opportunity (compared to shallower lakes) for exposure of fish and other organisms to the toxic material. As a result of the large volume of the lakes, contaminants are also subject to comparatively long hydraulic detention times, allowing, in some cases, the build-up of low-level inputs. The active circulation and mixing which are characteristic of the Great Lakes also help to rapidly distribute contaminants throughout the lakes.

Some distinctive biological characteristics are also likely factors in the apparent sensitivity of the lakes to toxic pollution. A large portion of Great Lakes waters are oligotrophic, and such waters generally contain highly sensitive biota. The relatively unproductive nature of the Great Lakes (low autochthonous production of particulates which can scavenge contaminants and carry them to the sediments), with the exception of Lake Erie, may also contribute to low rates of removal of toxic substances from the water column.

Finally, the susceptibility of the Great Lakes to toxic substances pollution may be more apparent than real. What appears to be susceptibility may be, at least partially, a manifestation of public and scientific attention placed on the Great Lakes as a function of the size and value of the resource, and the limitations put on its use by toxic substances contamination.

POTENTIAL FOR RECOVERY OF USES OF THE LAKES FOLLOWING TOXIC SUBSTANCES POLLUTION ABATEMENT

Another major focus of the workshop addressed whether the lakes can recover from chemical pollution and, if so, how rapidly. For example, since the use of DDT was curtailed in the early 1970s, accumulations of DDT and its metabolites in fish have dramatically decreased. Can a similar response be expected for PCBs and other toxic chemical contaminants? This question, of course, is of paramount practical importance in the development of a management strategy for the lakes.

Dr. John Robbins of the NOAA Great Lakes Environmental Research Laboratory led a workgroup to consider this topic. This subgroup concluded that uses of the lakes depend on the levels of contaminants. Further, they decided to focus on PCBs, since this group of substances may be used as a behavioral surrogate for many other contaminants.

The overall conclusion that evolved from this discussion is one that might have been anticipated—enough information does not exist to predict the potential for recovery. There is some optimism that a reduction of contaminant levels will proceed more rapidly than original estimates suggested, if PCB inputs can, indeed, be reduced. Despite a ban on production of several years' duration, PCB inputs to the lakes are still large as a result of large reservoirs in the environment (Eisenreich, Hollod, and Johnson 1979). But without better information, this optimism is little more than speculation.

The workgroup did specify several major areas where research was especially needed. First, reliable mean annual concentrations of PCBs in water and suspended matter must be determined for each of the lakes. More data on PCBs in fish, particularly apex predators, are also necessary. To achieve this end, sampling strategies must be refined and coordination of inter-laboratory sampling and analysis must be improved. New rapid techniques with increased sensitivity are required. More refined estimates of inputs to the lakes, especially atmospheric inputs, will also be needed.

Secondly, more information on in-lake physical processes associated with PCB transport and accumulation must be acquired. For example, the scavenging of PCBs by descending particles, the distribution of PCBs among particle size fractions, and the kinetics of sorption/desorption processes must be better understood. The role of seasonal stratification and cycles of productivity on the distribution of PCBs also needs better elucidation. While the sediments appear to be the major sink for PCBs in the Great Lakes, the rate at which PCBs are deposited and the potential for recycling back into the water column still await further efforts. Furthermore, the areal deposition patterns of distribution in the surficial sediments and the influence of circulation effects on these patterns should be carefully assessed.

Finally, the biological processes of PCB bioaccumulation, bioconcentration, biodegradation, and the biological mechanisms of PCB removal from the lakes, also need further study. Specifically, additional laboratory and field studies of the nature and magnitude of PCB transfer between members of the food chain, especially benthos-plankton linkages, need to be addressed.

Thus, a better awareness of the overall system response to PCB contamination is required. It was suggested that this could be accomplished through in-lake macroscale studies, or perhaps through a demonstration study on a lake area with a relatively short response time (e.g., a harbor or embayment). Further, it was noted that mathematical models, which would enable conceptual and quantitative descriptions of the behavior of PCBs in the lakes, will have to be developed if a system as complex as the Great Lakes is to be comprehended.

HUMAN HEALTH PERSPECTIVES

The final portion of the workshop was devoted to a panel discussion by several leading researchers involved in assessing the effects of chemical toxic substances on the health of humans residing in the Great Lakes basin. Human health studies are a vital component of any comprehensive program examining toxic pollution in the Great Lakes, but their implementation and interpretation are often extremely difficult.

The discussion highlighted the need for specification of vectors (e.g., a particular species of fish) through which toxic chemicals are transferred to man, and subsequent determinations of the chemical forms present in the vector. It was established that not all forms of even a given pollutant (e.g., different PCB isomers) are proven health hazards. Further, the panel concluded that research should continue into chemical structure/toxicity relationships.

The potential seriousness of human health effects is also illustrated by considering the exposure to PCBs received by eating Great Lakes fish. As a group, sport fishermen and their families in the 18 counties of the State of Michigan that border on Lake Michigan consume more than three times the national average of fish per year. Preliminary studies (Humphrey, undated) have demonstrated what appears to be a direct, nearly linear relationship between the total amount of Great Lakes fish consumed and the circulating titer of PCBs in the blood of these individuals.

Sources of nonoccupational PCB exposure other than fish include potable drinking water and respired ambient air. Assuming raw drinking water PCB levels of about 4 ng/L (finished drinking water levels are generally an order of magnitude less), the average annual exposure from orally ingested drinking water is very small. Further, assuming complete and instantaneous sorption and selective uptake of PCBs at the alveolar surface of the lung, based on an average tidal volume of approximately half a liter, the annual uptake of PCBs through the respiratory route is only on the order of 5 to 10 mg annually for residents of non-metropolitan areas. Thus, in terms of exposure potential, it is possible to breathe the air in the Lake Michigan basin and drink its water for a period of more than five years before achieving the same effective exposure as from eating a single pound of Lake Michigan lake trout or coho salmon.

Of particular critical concern is the potential for serious impacts on infant populations. A mother, belonging to the group of consumers who eat large quantities of Lake Michigan sports species of fish, selectively increases her own circulating blood titer of PCBs as a result of additional exposure to fish. Since there is evidently transplacental passage of the molecule, her unborn child is also exposed to the substance as a result of maternal circulation. For the nine month gestation period, the unborn infant is exposed to a substantial proportion of his mother's blood burden. This exposure comes at a time of unprecedented growth and development, and critical maturation of tissues.

At birth, the child may be exposed to an additional source of PCB as a result of nursing. A recent nationwide survey of 1,038 nursing mothers in the U. S. (cited in Ames 1979) demonstrated that approximately a third of the women had PCB in measurable amounts in their breast milk. Among the women exposed to PCBs as a result of consumption of large amounts of Lake Michigan fish, between 4 and 15 parts per million (fat basis) in breast milk samples are routinely found.

Dose, as opposed to exposure, is normally calculated on the basis of mass per unit of body weight. The U. S. Food and Drug Administration (FDA) allows 1.0 μg/kg of body weight for full grown adults. If one makes the reasonable assumption that a 2.7 to 4.5 kg (6 to 10 pound) infant consumes one kilogram of breast milk per day, then that child receives a daily dose which greatly exceeds FDA standards for adult intake.

The above examples illustrate the importance of research on human health effects from exposure to Great Lakes xenobiotics. It will be especially important to develop a perspective on the relative risks of these contaminants, not only among the contaminants themselves, but also relative to other risks to which individuals are exposed each day.

FUTURE RESEARCH— WILL IT MEET THE NEED?

Many of the questions and research needs mentioned so far are obviously being addressed in one form or another. However, is the current research effort adequate? Is it consistent with the enormity and severity of the problem? Can we avoid a crisis response based on fear?

In order to help address these questions, an inventory of ongoing or planned U. S. research on toxic substances in the Great Lakes was conducted (Great Lakes Information 1980). While some important research was omitted from this survey (for example, some non-Great Lakes research not included may be applicable to the Great Lakes), it does provide a useful perspective.

Table 1 presents a categorization of research projects derived from Great Lakes Information (1980). The research areas into which the projects were organized generally follow a Great Lake toxics pollution research strategy first developed at the Green Bay research workshop (Harris and Garsow 1978). The research areas are also consistent with the PCB research needs discussed previously.

Note (Table 1) that much of the ongoing research is concentrated on processes (including modeling) and effects of exposure on aquatic biota. The one research project on physical/chemical properties is exclusively focused on activity-structure correlations. No research was found which specifically addressed analytical methods.

Most of the work under sources and inputs appears to be related to atmospheric contributions. Only two projects were found which deal with the effects of exposure to man from toxicants specifically found in the Great Lakes. However, there are obviously many projects underway dealing with human health effects of toxicants which are not specific to the Great Lakes, and thus not included in the survey.

Of the ongoing research projects given in Great Lakes Information (1980), 13 deal specifically with PCBs, 12 with metals, 8 with pesticides, one with industrial organics (excluding PCBs), and one with radionuclides. Most of the projects are actually concerned with a combination of parameters rather than concentrating on a single contaminant. This suggests that much Great Lakes research is still in the problem definition phase. Interestingly, heavy metals continue to be actively studied although there is little definitive evidence that ambient metal levels in the lakes are causing substantive problems.

TABLE 1. Categorization of ongoing U.S. research on toxic substances in the Great Lakes.

Research Areas	Number of Projects	Funding Level (>$1,000,000[1])
Physical/Chemical Properties	1	X
Sources and Inputs (Does not include monitoring)	8	
In-Lake Distribution (Does not include monitoring)	6	
In-Lake Transport Mechanisms	6	
Biogeochemical Processes	15	X
Toxic Substances Modeling	9	X
Effects of Exposure on Biota (Excluding Man)	15	X
Effects of Exposure to Man	2	
Socio-economic Implications	2	

[1]Since funding levels for all projects were not available, the total dollars could not be determined accurately; the information presented here is an estimate designed to indicate the relative level of effort.

Only two projects were identified in Table 1 that were concerned with the socio-economic implications of toxic substances problems. Moreover, no projects were found which considered remedial measures, a further indication of the state-of-the-art in toxic substances research. Despite the apparent lack of attention to these areas, they are likely to be important research areas of the future, particularly as problem definition proceeds and research begins to focus on critical issues, parameters, and pathways.

ECONOMICS A MAJOR FACTOR IN THE 1980s

While most residents of North America would probably agree that clean Great Lakes are desirable, framed against the economic realities of today (high taxes, energy shortages, unemployment, spiraling inflation, etc.) environmental research is not likely to enjoy the same priority of a few years ago. While the value of the research dollar may appear to be increasing, in actuality, it has decreased about 60 percent compared with its relative purchasing power of 10-12 years ago (Swain and Mount 1979). In fact, with the value of the dollar declining so rapidly domestically and abroad, it appears that we may be entering a period of economic concern virtually unprecedented in our history. It would appear that despite the enormity of toxic contamination problems in the Great Lakes, financial support needed to cope with the problem is likely to be increasingly difficult to acquire.

In order to offset the declines in available resources, it is necessary to make better use of the resources available. Basic, fundamental research is essential to an adequate understanding of the problem, but it is also necessary to be pragmatic in our efforts. It is crucial that first order problem substances be separated from those of lesser priority, and research efforts be concentrated upon the near-term solutions to these problem substances. Simultaneously, it is necessary to make deliberate efforts to increase our analytical capabilities. Coordination and cooperation, more than ever before, will be essential. It will also be necessary to pay increased attention to the social and economic implications of toxic substances problems. Of critical urgency is the need to place perspectives on the human health risks associated with contaminants found in the Great Lakes compared to other common risks, and to determine more cost-effective means of correcting contamination problems. Finally, as was called for in the International Joint Commission's Pollution From Land Use Activities Reference Group (PLUARG) report (1978), "Socially meaningful yardsticks need to be developed against which the cost of remedial measures should be weighed."

CONCLUSIONS

Responsible and cost-effective decisions for dealing with chemical toxic contamination problems in the Great Lakes are severely constrained by the lack of adequate information. Therefore, very high priority should be given to research on the environmental consequences of toxic substances in the Great Lakes, and to efforts to determine the *relative* risk associated with the contamination.

Listed below are specific research needs which were identified by workshop participants:

1. While there are some indications that the Great Lakes could recover from toxic pollution in a relatively short time if pollutant inputs were abated (years compared to centuries), additional information on the processes affecting the distribution and rate of toxic substances is needed.
2. Better use and more in-depth analysis of data already available is encouraged.
3. Better coordination is necessary between on-going laboratory and field work (analytic measurement of toxics should continue to be improved and a storage bank for Great Lakes water, sediment, and air should be created).
4. Developmental research to devise new or improved equipment and methods for monitoring physical inputs and outputs of chemical toxics is needed. A reliable method to quantitatively determine the magnitude of airborne deposition of toxics on the lakes' surfaces as well as the watershed is crucial.
5. Additional diagnostic and prognostic model research should be undertaken to complement the conceptual and quantitative models whose importance to the analysis of toxics problems is now generally recognized.
6. Studies of human populations directly affected by potentially toxic pollution is further encouraged. Only with results from such studies can recommendations confidently be made concerning toxicity and the effects of different levels of contamination on humans.
7. More information on the socioeconomic factors of managing toxic substances pollution must be obtained.

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