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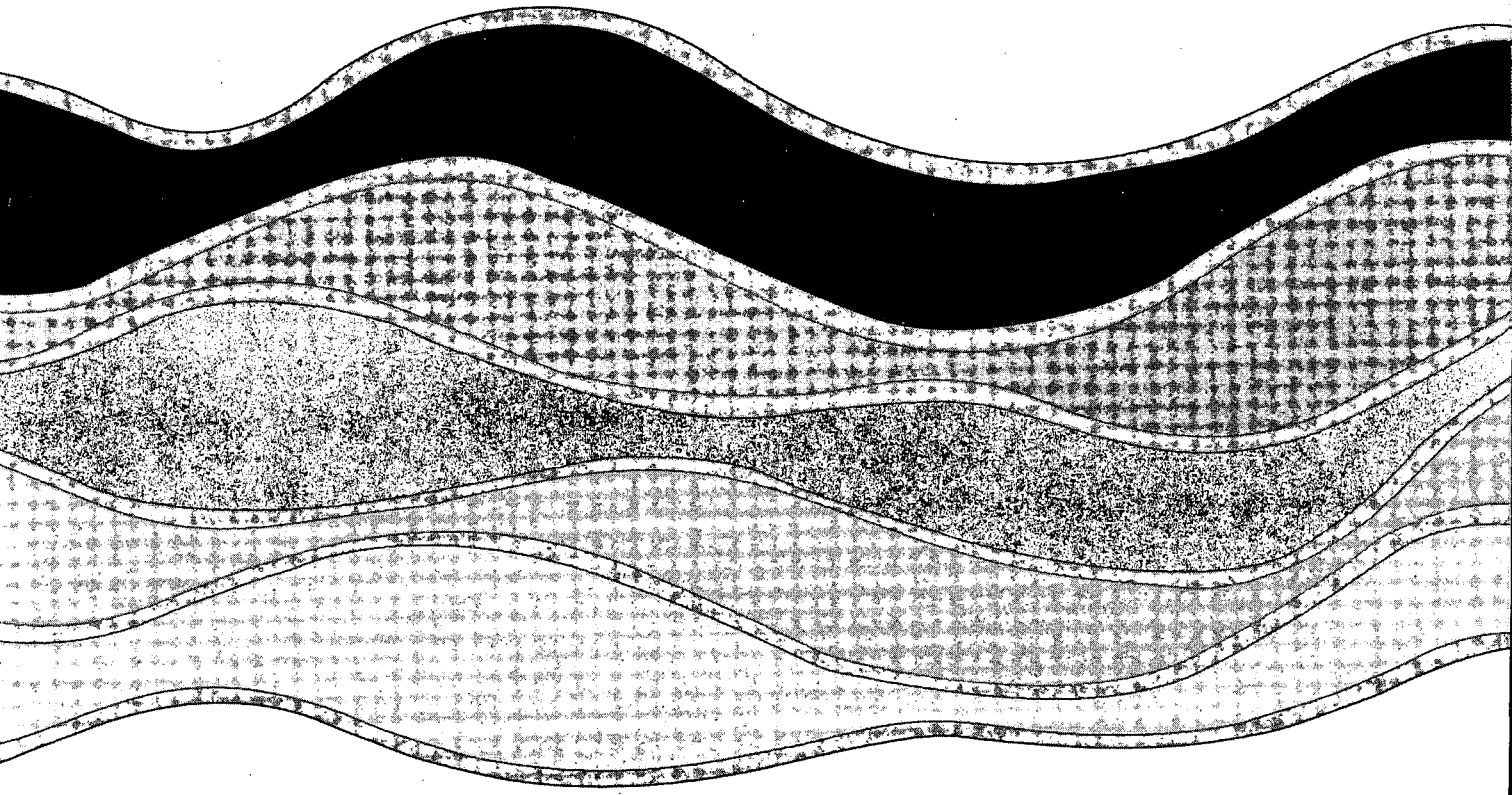

PROGRESS ON RESEARCH ACTIVITIES UNDER THE GREAT LAKES ACTION PLAN 1988-1990

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NWRI Contribution No. 90-48

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MANAGEMENT PERSPECTIVE

With the provision of funding under the Great Lakes Action Plan (GLAP), critical resources have been provided to procure the necessary knowledge to effectively manage the Great Lakes. The Great Lakes Preservation Fund has provided a significant increase in the base funding which was previously available for Great Lakes work at the institute. Although several of the scientists at NWRI are participating in Clean-up Fund activities and receiving resources under that fund, the majority of research activity is supported via the Preservation Fund.

Since one of the goals of the institute is to develop knowledge and authoritative expertise in the aquatic sciences which can be used in the decision-making process and management of Canada's water resources, much of our Great Lakes research is directed to the two major water quality management initiatives in the Great Lakes - Remedial Action Plans and Lakewide Management Plans.

Scientists at the institute are participating directly in RAP writing teams, Lakewide Management Plan workshops and planning exercises, as well as several federal-provincial and bi-national committees related to Canada's responsibilities under the Great Lakes Water Quality Agreement.

The following report provides some detailed information on the results of research activities conducted under the GLAP. The report is organized to provide specific reference to the relevant areas of the Great Lakes Water Quality Agreement which represents a bi-national commitment on the part of Canada to the restoration, protection and management of the Great Lakes.

PERSPECTIVES DE LA DIRECTION

Grâce aux subventions allouées dans le cadre du Plan d'action pour les Grands Lacs, d'importantes ressources ont été fournies afin d'assurer l'acquisition des connaissances nécessaires à la gestion efficace des Grands Lacs. Le Fonds de préservation des Grands Lacs a fourni une augmentation importante du financement initial qui était disponible antérieurement pour les travaux sur les Grands Lacs menés par l'Institut. Même si plusieurs scientifiques de l'Institut national de recherches sur les eaux (INRE) participent aux activités du Fonds pour la dépollution des Grands Lacs et reçoivent des subventions dans le cadre de ce fonds, la majorité des recherches sont subventionnées par le Fonds pour la protection.

Puisque l'un des buts de l'Institut est d'acquérir des connaissances et une expertise éclairée dans le domaine des sciences aquatiques qui peuvent être utilisées dans le processus de prise de décision et au niveau de la gestion des resssources en eau du Canada, la plus grande partie de nos recherches sur les Grands Lacs sont axées sur les deux principales initiatives en matière de gestion de la qualité de l'eau dans les Grands Lacs, soit le plan de mesures correctives et le plan d'aménagement panlacustre.

Des scientifiques de l'Institut font partie d'équipes de rédaction du plan des mesures correctives, participent à des ateliers sur le plan d'aménagement panlacustre et à des exercices de planification, et font aussi partie de plusieurs comités fédéraux-provinciaux et bilatéraux liés aux responsabilités du Canada en vertu de l'Accord relatif à la qualité de l'eau dans les Grands Lacs.

Le présent rapport fournit quelques informations détaillées sur les résultats de recherches menées dans le cadre du Plan d'action pour les Grands Lacs. Le rapport est présenté de manière à fournir une référence particulière aux domaines pertinents de l'Accord relatif à la qualité de l'eau dans les Grands Lacs, qui est un engagement bilatéral à l'égard du rétablissement, de la protection et de l'aménagement des Grands Lacs.

INTRODUCTION

Water quality management initiatives for the Great Lakes include the development of Remedial action Plans for the near-shore Areas of Concern and Lakewide Management Plans for each of the lakes. The keys to developing successful Remedial Action Plans (RAPs) to restore impaired uses are a clear understanding of the environmental problems, their causes and a critical evaluation of the options available to correct these problems. Considerable resources and efforts are being devoted to these objectives by the National Water Research Institute. In addition, the institute continues its whole-lake work on impacts, inputs and processes. The fundamental information gained through these programs should be used in the development and implementation of federal, provincial, and binational aquatic resource management plans (e.g., lakewide management plans).

Scientists at the institute are participating directly in RAP writing teams, lakewide management plan workshops and planning exercises, as well as several federal-provincial and binational committees related to Canada's responsibilities under the Great Lakes Water Quality Agreement. In addition to the needs and demands of these activities, considerable research has been advanced in response to the Fourth and Fifth Biennial Report of the International Joint Commission.

Since the release of Canada's first report under the 1987 Protocol to the 1978 Great Lakes Water Quality Agreement, funding from the Great Lakes Action Plan has been made available to the institute. Several of the programs described in that report and called for in the Protocol have been initiated. The following report provides some detailed information on the results of research activities conducted under the Great Lakes Action Plan.

ANNEX 1: SPECIFIC OBJECTIVES

Since 1988, five ecosystem objectives have been drafted for Lake Ontario.

1. Aquatic Communities

The waters of Lake Ontario shall support diverse healthy, reproducing and self-sustaining communities in dynamic equilibrium, with an emphasis on native species. This objective will be measured by the selection of attributes for a population of a large predator fish species or community assemblage and components of a benthic community. Separate targets for the nearshore and offshore will be established.

2. Wildlife

The perpetuation of a healthy, diverse and self-sustaining wildlife community that utilizes the lake for habitat and/or food shall be ensured by attaining and sustaining the waters, coastal wetlands and upland habitats of the Lake Ontario basin in sufficient quality and quantity. Candidate indicators for this objective are bald eagle, osprey, cormorant, gull, and mink populations.

3. Human Health

The waters, plants and animals of Lake Ontario shall be free from contaminants and organisms resulting from human activities at levels that affect human health or aesthetic factors such as tainting, odour and turbidity.

4. Habitat

Lake Ontario offshore and nearshore zones and surrounding tributary, wetland and upland habitats shall be of sufficient quality and quantity to support ecosystem objectives for health, productivity and distribution of plants and animals in and

adjacent to Lake Ontario. Development of indicators will be to specific a minimum number of acres of suitable habitat such as wetlands. This will require an initial and continuing inventory.

5. Stewardship

Human activities and decisions shall embrace environmental ethics and a commitment to responsible stewardship. This, perhaps, is the most difficult, tenuous, and novel of the proposed objectives. Quantifiable indicators such as the proportion of profit/budget of a company spent on effluent control, the number of courses offered on the environment in schools, or the enrollment in environmental studies could be employed.

This work has involved NWRI scientific personnel in the Bi-national Ecosystems Objectives Work Group which has used a public workshop, as well as other international gatherings and evaluation methods, to produce the objectives. The proposed 'indicators' from these objectives are still under development.

A paper, proposing the use of the burrowing mayfly (Hexagenia limbata) as an ecosystem objective for nutrient rich (Mesotrophic J. Great Lakes Waters, e.g., parts of Lake Erie). Further work on mesotrophic objectives is underway using paleolimnological studies and laboratory assessments on the environmental requirements of the mayfly.

PUBLICATION

Reynoldson, T.B., Schloesser, D.W. and Manny, B.A. 1989. Development of a benthic invertebrate objective for mesotrophic Great Lakes Waters. J. Great Lakes Res. 15(4): 669-686.

ANNEX 2: REMEDIAL ACTION PLANS AND LAKEWIDE MANAGEMENT PLANS

Scientists at NWRI are participating directly in the writing and review of Remedial Action Plans, as well as performing the essential research required for adequate problem definition. Past and continuing work in Thunder Bay (Lake Superior), Spanish River, Severn Sound (Lake Huron), St. Clair River and Lake St. Clair (upper connecting channels), Niagara River, Hamilton Harbour, Toronto waterfront, Bay of Quinte (Lake Ontario), and the St. Lawrence River is not only fundamental to the definition of environmental problems, but also necessary for the development and selection of remedial options. These programs examine the physical, chemical and biological conditions and processes which affect the past and present environmental state of the area. In addition, through the development of conceptual and mathematical models, future conditions can be predicted to assist resource managers, industry and the public.

The following information highlights some of the results of work conducted since 1988.

REMEDIAL ACTION PLANS

Hamilton Harbour

Recent detailed assessments of sources and the biological effects of contaminated sediment have resulted in the discovery of a 'hotspot' comprised of 70,000 m^3 of coal tar contaminated sediment. Polynuclear aromatic hydrocarbon (PAH) concentrations have been found to exceed 200 µg/g. The study has shown that, while the 'hotspot' is acutely toxic to aquatic organisms, low levels of toxicity occur throughout most of the remainder of the harbour. Therefore it is the coal tar area which urgently requires removal and treatment. A suitable procedure of *in situ* treatment for coal tar has not been found. Contaminant concentrations in sedimenting/resuspended solids, collected with sediment traps, varies regionally and depends on the depth and proximity to industrial areas. PAH concentrations sometimes exceed 5,000 ng/g, which is 2-3 times higher than in the bottom sediments. Metals in these traps routinely exceed the open water disposal levels specified in the Ontario sediment dredging guidelines. Four years of data are now available and will provide a background or benchmark with which to measure further improvements and the effects of dredging.

Intensive monitoring has shown that phosphorus and ammonia have changed little in response to improvements at Hamilton sewage treatment plant; however, chlorophyll and water transparency seem to have shown some improvements. Concentrations of PCBs in tributaries, STP effluents, outfall areas, Hamilton Harbour water and Lake Ontario intakes were 7-18 ng/L, 12-23 ng/L, 13-75 ng/L, 6-35 ng/L, and 4 ng/L, respectively. The types of PCBs found indicate weathered material, rather than new sources. These ongoing PCB loads explain much of the concentration found in bottom sediments and sediment traps.

Analysis of water exchange between the harbour and Lake Ontario has confirmed the importance of the exchange in maintaining oxygen levels in the bottom water. It is thought that this exchange will produce acceptable oxygen levels if ammonia control is achieved.

Bay of Quinte

Eutrophication of the Bay of Quinte was thought to depend heavily on release of phosphorus stored in the historically enriched sediments. Evaluation of the importance of phosphorus sources, including *in situ* sediment, has shown that phosphorus introduced to the upper Bay of Quinte is quickly recycled. Little phosphorus is stored in sediments; thus the sediments are not an impediment to clean-up, as previously believed. Preliminary information from an investigation of the Trent River shows that upstream phosphorus sources can be as important as STPs to the Bay of Quinte. Sediment samples are currently being analyzed for organic contaminants.

Spanish River

An examination of Spanish River sediments found elevated levels of contaminants (particularly metals) and depressed benthic fauna populations at the mouth of the river. Results indicate an impoverished benthic fauna, both in number of species and in abundance. The distribution of the benthic fauna was inversely related to concentrations of Ni, Cu, and Zn in sediments.

LAKEWIDE MANAGEMENT PLANS

Although still at a very rudimentary stage, a lakewide management plan for Lake Ontario is being developed. All such plans will require information in the relative significance of the sources and fate of each contaminant of concern. A mathematical model, TOXFATE, was developed at NWRI for these kinds of applications.

The predictive capacity of the contaminant fate model, TOXFATE, was verified using new field data on PCB concentrations in the Lake Ontario system. This model accurately relates loadings to concentrations of PCB in water, sediment and fish and predicts the responsiveness of the lake to various loading scenarios. In subsequent research, the TOXFATE model was coupled with the hydrodynamic model, RAND, to describe the fate of contaminants entering Lake Ontario from sources at the Toronto waterfront. Based on data for the late 1980's, inputs of organic contaminants from the Toronto area represent approximately 0.5% to 25% of the loading from the Niagara River to the lake. As controls and abatement programs are implemented on the Niagara River, its loadings will decrease, which in turn will increase the relative significance of other sources including the Toronto area. Due to currents and upwellings, the water mass along the Toronto waterfront area is being replaced with lake water on average once every ten to fifteen days.

NWRI has initiated planning for a potential, integrated ecosystem study of Lake Ontario to begin in 1992, in support of a lakewide management plan.

PUBLICATIONS

Barica, J. 1988. Limnological anomalies of Hamilton Harbour, Lake Ontario. National Water Research Institute Contribution No. 88-30.

Barica, J. 1990. Ammonia and nitrate contamination of Hamilton Harbour. Water Poll. Res. J. Can. (submitted).

Barica, J., Poulton, D.J., Kohli, B. and M.N. Charlton. 1988. Water exchange between Lake Ontario and Hamilton Harbour; water quality implications. Water Poll. Res. J. Can. 23(2): 213-225.

Boyce, F.M., Schertzer, W.M., Hamilton, P.F. and C.R. Murthy. 1989. An assessment of current understanding of the physical behavior of Lake Ontario with reference to contaminant pathways and climate change. National Water Research Institute Contribution No. 89-23, 40 p.

Boyce, F.M., Hamblin, P.F., Robertson, D.G. and F. Chiocchio. 1990. Evaluation of sediment traps in Lake St. Clair, Lake Ontario, and in Hamilton Harbour. National Water Research Institute Contribution No. 89-09.

Brouwer, H., Murphy, T.P. and L. McArdle. 1990. A sediment-contact bioassay with Photobacterium phosphoreum. National Water Research Institute Contribution No. 90-11.

Chiocchio, F. and F.M. Boyce, 1989. Sediment mobility in Hamilton Harbour. National Water Research Institute Technical Note LRB-89-67, 68 p.

Chiocchio, F., Boyce, F.M. and L. Royler. 1990. Vertical automatic profiling system (VAPS) Hamilton Harbour 1981 data report. National Water Research Institute Technical Note LRB-90-TN-1, 189 p.

Chiocchio, F., Boyce, F.M., Painter, D.S., Hampson, L. and K.J. McCabe. 1990. Grindstone Creek water clarity - source and effects. National Water Research Institute Contribution No. 90-15.

Halfon, E. 1990. Simulation of the fate of toxic contaminants in the Toronto waterfront, May-October 1987. National Water Research Institute Contribution No. 90-04.

Halfon, E. 1990. Pollution ranking analysis and distribution of chlorobenzenes, pesticides and PCB isomers in Lake Ontario near the Toronto waterfront, May-October 1987. National Water Research Institute Contribution.

Halfon, E., Simons, T.J. and Schertzer, W.M. 1990. Modelling the spatial distribution of seven halocarbons in Lake St. Clair in June 1984 using the TOXFATE model. J. Great Lakes Res. 16: 90-112.

Manning, P.G. 1990. Forms of iron, phosphorus and sulfur in the sediments of eutrophic Bay of Quinte, Ontario. National Water Research Institute Contribution No. 90-06.

Mayer, T. and P.G. Manning. 1990. Environmental impact of Hamilton Harbour on the nearshore area of western Lake Ontario. National Water Research Institute Contribution.

Mayer, T. and P.G. Manning. 1990. Inorganic contaminants in suspended solids from Hamilton Harbour. J. Great Lakes Res. 16(2): 299-318.

Mudroch, A., Onuska, F.I. and L. Kalas. 1989. Distribution of polychlorinated biphenyls in water, sediment and biota of two harbours. Chemosphere 18: 2141-2154.

Murphy, T.P. 1990. Oxygen treatment of Hamilton Harbour: a pilot scale test. National Water Research Institute Contribution No. 90-08.

Murphy, T.P., Brouwer, H., Fox, M.E., Nagy, E., McArdle, L. and A. Moller. 1990. Assessment of the coal tar contamination near Randle Reef, Hamilton Harbour. National Water Research Institute Contribution No. 90-10.

Painter, D.S., McCabe, K.J. and W.L. Simser. 1988. Past and present limnological conditions in Cootes Paradise affecting aquatic vegetation. National Water Research Institute Contribution No. 88-47.

Painter, D.S. and P. Harvey. 1989. Contaminant status of Cootes Paradise sediments in the vicinity of the marsh restoration project. National Water Research Institute Contribution No. 89-06

Painter, D.S., Murphy, T. and D. Boyd. 1989. The contaminated sediments of Hamilton Harbour. National Water Research Institute Contribution No. 89-15.

Painter, D.S. and K.J. McCabe. 1989. Water clarity in Hamilton Harbour. National Water Research Institute Contribution No. 89-31.

Painter, D.S., Hampson, L. and K.J. McCabe. 1990. Hamilton Harbour water clarity response to nutrient abatement. National Water Research Institute Contribution No. 90-14.

Painter, D.S., Hampson, L. and K.J. McCabe. 1990. Grindstone Creek water clarity - source and effects. National Water Research Institute Contribution No. 90-15.

Painter, D.S. 1990. Establishing habitat goals and response in an Area of Concern using a geographic information system. National Water Research Institute Contribution No. 90-20.

Rosa, F. and A. Mudroch. 1990. Sediment loading in Port Hope Harbour. National Water Research Institute Contribution No.

Rukavina, N.A. 1989. Geotechnical properties of Hamilton Harbour cores at acoustic test sites, (May) 1989). National Water Research Institute Technical Note LRB-89-33.

Simons, T.J. and W.M. Schertzer. 1989. Hydrodynamic models of Lake St. Clair. In Modeling Marine Systems - Volume II, CRC. Press (in press).

Simons, T.J. and W.M. Schertzer. 1989. Modeling wind-induced water setup in Lake St. Clair. J. Great Lakes Res. 15(3): 452-464.

Spigel, R.H. 1989. Some aspects of the physical limnology of Hamilton Harbour. National Water Research Institute Contribution No. 89-08.

Turner, L.J. and L.D. Delorme. 1989. ^{210}Pb dating of lacustrine sediments from Hamilton Harbour (Cores 152, 153 and 154), Ontario. National Water Research Institute Technical Note LRB-89-30.

ANNEX 11: SURVEILLANCE AND MONITORING

NWRI support for surveillance and monitoring activities, under Annex 11, have included the development, procurement and testing of state-of-the-art water quality profiling systems. These activities are designed to increase the efficiency of the surveillance program, while at the same time improve the precision and accuracy of the data gathered. GLAP funding has provided some of the necessary resources to begin modernization of the basic field monitoring capability of the various agencies undertaking GLWQA surveillance, monitoring and research. In particular, there were two initiatives: (i) an Acoustic Doppler Profiling System was to be acquired and made operationally available to researchers and, (ii) the major research vessels are being equipped with state-of-the-art Water Quality Profiling Systems over a 3 year period. The former involved the purchase of commercial equipment and implementation for our particular research needs while the latter involves system definition, component specification, procurement, acceptance testing and implementation.

The prototype of the Water Quality Monitoring system is presently undergoing testing against specification. This will be completed by mid-September 1990. Field tests are planned for the FY 90/91 late fall period in Hamilton Harbour, with the prototype unit in service aboard the MV Limnos for the 91/92 field season. A second system will be procured upon completion of the present acceptance tests.

The Acoustic Doppler Profiler (ADP) and controller was delivered in March 1990 and operation and maintenance crews were sent on training courses. An initial successful deployment was undertaken in Hamilton Harbour, with data taken to support the RAP program. The system was subsequently deployed in the Burlington Ship Canal where it is presently acquiring a time-series data set. Further, the MV Gander is presently being modified in the NWRI Machine Shop to enable mounting of the ADP for a real-time data gathering along the north shore of Lake Ontario. By the start of the 91/92 field season, this devise will be completely operational.

In addition, the Institute, through the Quality Assurance Group, Research and Applications Branch, has designed, developed and implemented external quality assurance studies. These studies are evaluated through the IJC Great Lakes Regional

Office by the Data Quality Work Group and address the performance of laboratories in the US and Canada. Comparison studies have involved over 100 laboratories. Studies over the last two years have included phosphorus in waters (low level), phosphorus in sewage effluents, toxic metals in sediments, and toxic organics (e.g., PCBs, OCs, and PAHs) in sediments in ampule standards.

These studies provide a measure of laboratory performance and, in part, evaluate the comparability and compatibility of the many data sets used in assessing the state-of-the-lakes under the Great Lakes International Surveillance Plan.

Improvements were made on the statistical analysis of river monitoring data, specifically better precision and separation of the effects of analytical method changes and station variability as well as trend analysis. The methodology is superior to previous ones. It uses several factors, the most important of which is the consideration of seasonal components. Additional work on the statistical analysis of Niagara River contaminant data is ongoing. The previously common procedure of replacing non-detectable values with those between zero and the detection limit, was shown to produce biased means and standard deviations. Our research now allows the calculation of such biases, and hence improves the accuracy of data interpretation.

ANNEX 12: PERSISTENT TOXIC SUBSTANCES

A prerequisite for assessing the fate and effects of persistent toxic substances, as required in Annex 12, is the development of standard laboratory analytical techniques. Reference methods for dioxins and furans, polychlorinated biphenyls (PCBs), a variety of chlorinated organics, phenols and metals in sediment, water, effluent and biological material, have been developed at the institute over the past two years.

Research on the effects and the structure-activity relationships of a variety of hazardous compounds, which are known to be present in the Great Lakes, has also continued. The results of these studies have provided an understanding which will be useful, both for the prediction of the effects of new chemicals (which might be released into the environment in the future) and for the development of standards and guidelines for known contaminants.

Data have been compiled on the effects of over 500 toxic chemicals on the microorganism Photobacterium phosphoreum, commonly known as the Microtox test. This exhaustive compilation of literature and in-house data is useful for the interpretation and prediction of the effects of known and potential environmental contaminants. Research into inter-species and inter-endpoint correlations of the toxicity of single chemicals to a variety of aquatic and non-aquatic species, including the Photobacterium phosphoreum bacteria, algae, zooplankton, two freshwater fish species (fathead minnow and goldfish) and a terrestrial mammal (Norway rat), indicate significant co-linearity of such data over a molar toxicity range of up to eight orders of magnitude.

In collaboration with university researchers, earlier research at the institute into quantitative structure-activity relationships of hazardous chemicals, quantitative correlations of molecular parameters with the Photobacterium toxicities were developed. While there are still certain shortfalls in predicting the effects of multiple substituted compounds, significant advances were obtained for several series. The toxic effects of a variety of nitrobenzene, aniline, phenol, chlorobenzene and related derivatives can be estimated for ab initio computed molecular electron density shifts in electron distributions at the oxygen atoms of the nitro group. This works particularly well for para-substituted nitrobenzene derivatives where large variations in toxicity are observed with relatively minor changes in chemical structure. These results confirm and extend our ability to predict toxic biological effects from chemical structure.

PUBLICATIONS

Afghan, B.K. 1989. Proposed reference methods for PCDDs and PCDFs. National Water Research Institute Contribution No. 89-128.

Carron, J.M. and B.K. Afghan. 1989. Environmental aspects and analysis of phenols in the aquatic environment. In: Analysis of Trace Organics in the Aquatic Environment, B.K. Afghan and A.S.Y. Chau (Eds.), CRC Press Inc., Boca Ratan, Fl., pp 119-149.

Cheam, V., Aspila, K.I. and W. Horn. 1988. National Interlaboratory Quality Control of Study No. 35 - Trace metals in sediments. Environment Canada, Inland Waters Directorate, Report Series No. 76.

Cheam, V. and Li. E. Xue. 1988. Ion chromatographic determination of low level Cd(II), Co(III), and Mn (III) in water. J. Chromatogr. 450: 361-371.

Cheam, V. and Li. E. Xue. 1988. Ion exchange-spectrophotometric determination of PPB and sub-PPB Cd. Amer. Chem. Soc., Div. Environ. Chem. 28: 416-420.

Cheam, V., Aspila, K.I. and A.S.Y. Chau. 1989. Analytical reference materials. VIII. Development and certification of a new Great Lakes sediment reference material for eight trace metals. Sci. Total Environ. 87/88: 517-524.

Gough, K.M. and K.L.E. Kaiser. 1988. QSAR of the acute toxicity of para-substituted nitrobenzene and aniline derivatives to Photobacterium phosphoreum. In: QSAR-88, Proc. 3rd Intl. Workshop in Environmental Toxicology, May 22-26, 1988, Knoxville, Tennessee, J.E. Turner, M.W. England. T.W. Schultz and N.J. Kwaak (Eds.), National Technical Information Service, US Dept. Commerce, Springfield, Virginia, CONF-880520, pp. 111-121.

Kaiser, K.L.E. and K.M. Gough. 1988. Predictability of unusually high acute toxicity to Photobacterium phosphoreum of 1,4-disubstituted benzene derivatives. In: Proc. 11th Symp. Aquatic Toxicology and Hazard Assessment, G.W. Suter II and M.A. Lewis (Eds.), Amer. Soc. for Testing and Materials, Philadelphia, STP 1007, pp. 424-441.

Kaiser, K.L.E. and J.M. Ribo. 1988. Photobacterium phosphoreum toxicity bioassay, II. Toxicity data compilation. Toxicity Assessment 3: 195-237.

Kohli, J., Ryna, J.F. and B.K. Afghan. 1989. Phthalate esters in the aquatic environment. In: Analysis of race Organics in the Aquatic Environment, B.K. Afghan and A.S.Y. Chau (Eds.), CRC Press Inc., Boca Raton, Fl., pp. 243-281.

Lee, H.B. 1988. Perfluoro and chloro amide derivatives of aniline and chloroanilines. J. Chromatogr. 457: 267-278.

Lee, H.B., Hong-Zou, R. and P.J.A. Fowlie. 1988. Chemical derivatization analysis of phenols. VI. Determination of chlorinated phenolics in pulp and paper effluents. National Water Research Institute Contribution No. 88-110.

Lee, B.H., Kokotich, E.A. and J.A. Abbott. 1988. Determination and confirmation of some synthetic pyrethroids and their metabolites in water samples. National Water Research Institute Contribution No. 88-70.

Lee, B.H. and G.D. Kissoon. 1989. Determination and confirmation of chloronitrobenzenes in water and fish samples. National Water Research Institute Contribution No. 89-81.

Lee, H.B., Peart, T.E. and J.M. Carron. 1989. Gaschromatographic and mass spectrometric determination of some resin and fatty acids in pulpmill effluents as their pentafluorobenzyl ester derivatives. National Water Research Institute Contribution No. 89-125; J. Chromatogr. 498(1990): 367-379.

Niimi, A.J., Lee, H.B. and G.D. Kissoon. 1989. Octanol-water partition coefficients and bioconcentration factors of chloronitrobenzenes in rainbow trout (Salmo gairdneri). Environ. Toxicol. Chem. (in press).

Onuska, F.I. 1989. Analysis of polycyclic aromatic hydrocarbons in environmental samples. In: Analysis of Trace Organics in the Aquatic Environment, B.K. Afghan and A.S.Y. Chau (Eds.), CRC Press Inc., Boca Raton, Fl, pp. 205-241.

Onuska, F.I. and K.A. Terry. 1988. Supercritical fluid extraction of 2,3,7,8-tetrachloro dibenzo-p-dioxin from sediment samples. J. High Resolut. Chromatogr., Chroamtogr. Commun. 12: 357-361.

Onuska, F.I. and K.A. Terry. 1989. Identification and quantitative analysis of N-containing polycyclic aromatic hydrocarbons in sediments. J. High Resol. Chromatogr. 12: 362-367.

Onuska, F.I. and K.A. Terry. 1989. Supercritical fluid extraction of PCBs in tandem with HRGC in environmental analysis. J. High. Resolut. Chromatogr. 12: 527-531.

Onuska, F.I. and K.A. Terry. 1989. Quantitative HRGC and mass spectrometry of toxaphene residues in fish samples. J. Chromatogr. 471: 161-171.

Scott, B.F. and M. Masons. 1988. Enhanced gas chromatographic quantitation of organochlorines. National Water Research Institute Contribution No. 88-11.

Scott, B.F. and F.I. Onuska. 1989. Analysis for polychlorinated biphenyls by dual capillary column chromatography. J. Microcolumn Separations 1: 119.

Scott, B.F. and R. Szaviola. 1989. Comparison of results between PCB congener method and standard method obtained during validation study. National Water Research Institute Contribution No. 89-9.

Sherry, J.P., Afghan, B.K., ApSimon, J., Collier, L., Bishai, F., and P.W. Albro. 1989. Radioimmunoassay for the detection of polychlorinated dibenzo-p-dioxins in environmental samples: introduction, preliminary evaluation, and development of a working assay. National Water Research Institute Contribution No. 89-80.

Sherry, J.P., ApSimon, J., Collier, L., Wilkinson, R., Albro, P.W., and B.K. Afghan. 1988. The use of radioimmunoassay for the detection of polychlorinated dibenzo-p-dioxins in fish samples. National Water Research Institute Contribution No. 89-76.

Sherry, J.P. and H. Tse. 1989. A procedure for the determination of PCDDs in fish. National Water Research Institute Contribution No. 89-133.

Sherry J.P., ApSimon, J., Collier R., and P.W. Albro. 1989. Dimethyl sulfoxide as solubilization agent in a radioimmunoassay for the detection of PCDDs. Water Poll. Res. J. Can. 24(4).

Tse, H., Carron, J., Forbes, M. and H.B. Lee. 1989. A multi-residue method for the determination of chlorobenzenes, PCB, organochlorinated insecticides, PAH, and chlorophenols in suspended sediments. National Water Research Institute Contribution No. 89-82.

ANNEX 13: POLLUTION FROM NON-POINT SOURCES

Research activities on non-point source pollution, in support of the Great Lakes Water Quality Agreement, included identification and characterization of non-point pollution from urban and agriculture sources. For urban runoff, a new methodology for evaluation of loadings was developed and used to produce screening estimates of loadings of toxic substances in urban runoff from the Canadian Great Lakes Basin. Detailed studies focused on several Areas of Concern, including the St. Mary's River in Sault Ste. Marie, the St. Clair River in Sarnia, the Detroit River in Windsor, and Hamilton Harbour. For the first three locations, planning-level estimates of urban non-point pollution loadings were established and used in the development of pollution control strategies. These studies will be complemented by the ongoing investigations of urban sources of bacteriological pollution. For Hamilton Harbour, distributions of hydraulic loadings from urban non-point sources were determined. Significant loadings of polynuclear aromatic hydrocarbons (PAHs) in urban runoff from Sault Ste. Marie led to further investigations of sources and pathways of PAHs in this area. The feasibility of control of such sources will be addressed next. Another land use activity generating non-point source pollution is automobile traffic. Studies of highway runoff pollution in two locations indicated significant loadings of heavy metals and PAHs. The data obtained will be used to develop predictive models for the evaluation of highway runoff pollution. The last non-point source addressed is agricultural runoff. Transport of sediment and chemicals from agricultural land has been studied in a research catchment and the modeling of such transport by two models of different complexities is underway. A recently initiated program on tributary loadings and non-point source pollution will address loading calculations, monitoring procedures, ecosystem health indicators, characterization and control of pollution.

PUBLICATIONS

Boon, A. and J. Marsalek. 1988. Accumulation of polycyclic aromatic hydrocarbons (PAHs) in an urban snowpack. Sci. Total Environ. 74: 133-148.

Kovacz, G., Zuidema, F.C. and J. Marsalek. 1988. Human interventions in the terrestrial water cycle. In: Comparative Hydrology, T. Chapman and M. Falkemark (Eds.), UNESCO Press, Paris, Chapter 5, pp. 105-130.

Marsalek, J. 1988. Evaluation of pollution loads from urban non-point sources. Proc. of the International Joint Commission Miniworkshop on Non-Point Sources of Urban Pollution, IJC, Windsor, Ontario, October, pp. 1-22 (available from IJC).

Marsalek, J. 1989.Characterization of urban runoff in Sault Ste. Marie. National Water Research Institute Contribution.

Marsalek, J. and H.O. Schroeter. 1989. Annual loadings of toxic contaminants in urban runoff from the Canadian Great Lakes Basin. Water Poll. Res. J. Can. 23(3): 360-378.

Marsalek, J. 1989. Modelling agricultural runoff: overview. Sediment and the Environment, Proc. of the May 1989 Baltimore IAHS Symp., pp. 201-209. National Water Research Institute Contribution No. 89-109.

Marsalek, J. 1989. Evaluation of pollutant loads from urban non-point sources. National Water Research Institute Contribution No. 89-118.

Marsalek, J. 1989. PAH transport by urban runoff from an industrial city. Proc. of the 5th International Conference on Urban Storm Drainage 1: 481-486. National Water Research Institute Contribution No. 89-169.

Marsalek, J. and H.Y.F. Ng. 1989. Evaluation of pollution loadings from urban non-point sources. J. Great Lakes Res. 15: 444-451.

Marsalek, J. 1990. Stormwater management: recent developments and experience. In: Proc of the NATO Workshop, Urban Water Resources, K.E. Schilling and E. Porter (Eds.), Kluwer Academic Publishers, pp. 217-239. Ng., 89-105.

Ng, H.Y.F. and J. Marsalek. 1989. Stormwater discharges to Hamilton Harbour. National Water Research Institute Contribution No. 89-67.

ANNEX 14: CONTAMINATED SEDIMENT

Research at NWRI on contaminated sediments in the Great Lakes continued to provide a guide to the development of remedial action plans, to evaluate the impact of polluted sediments on the Great Lakes system, and to contribute to the development of Lake-wide Management Plans.

Methods for the biological assessment of contaminated sediments have been developed and tested in cooperation with US government agencies and universities as well as the Ontario Ministry of the Environment through the COA Polluted Sediment Committee. Test species included oligochaetes, a widely distributed and important component of the Great Lakes benthic community, and Photobacterium sp..

NWRI staff members took part in the preparation of the IJC documents, "Procedures for the Assessment of Contaminated Sediment Problems in the Great Lakes", and "Options for the the Remediation of Contaminated Sediments in the Great Lakes". These documents were prepared as guidelines for RAP teams for the remediation of contaminated sediments. An overview of sediment treatment technologies was summarized and presented at the World Dredging Congress. In addition, NWRI actively participated in the organization and program presentations of the "Technology Transfer Symposium for the Remediation of Contaminated Sediments in the Great Lakes Basin" sponsored by the IJC in October 1988. Proceedings of the symposium were published in 1990.

Development of a model for the evaluation of contaminated sediment/water interactions has started. Data gathering for verification of the model included the identification of sediment pollution, transport studies of sediment-associated contaminants by resuspension and redeposition in Lakes Erie and Ontario, transport of contaminants in the nepheloid layer in Lake Ontario, migration of contaminants through sediment pore water, as well as the biological assessment of contaminated sediments at selected areas in the Great Lakes.

A comprehensive review of the methodologies used for quantifying and evaluating the transfer of contaminants and nutrients to and from bottom sediments was completed in 1989. As a result, several recommendations were made for the development of a standard set of methods for assessing chemical and biological exchange between sediments and water which would have application in the Great Lakes.

In response to the information requirements related to the management of dredge spoil disposal, scientists at the institute have completed a series of studies on contaminant loss and bioaccumulation associated with confined disposal facilities (CDFs). Ten sites were examined; one in Lake Superior, two in the St. Clair River and Lake St. Clair, two in Lake Erie and five in Lake Ontario. The studies showed that some metals and organic contaminants are being transferred to the vegetative cover and resident invertebrates, birds and mammals. The results further indicate that the amounts and rates of transfer of contaminants are affected by the depth of "clean soil" cap and vegetative cover. It is evident that careful management of these facilities will be required to reduce or eliminate any long-term environmental effects.

PUBLICATIONS

Coakley, J.P. 1990. Contamination hazard from waste disposal sites near receding Great Lakes shorelines. Water Poll. Res. J. Can. 24(1): 81-100.

Coakley, J.P. and R.A. Rukavina. 1989. Nearshore bedload and suspended sediment transport in the vicinity of Pickering Nuclear Generating Station, Lake Ontario. National Water Research Institute Contribution No. 89-17.

Coakley, J.P. and D.J. Poulton. 1990. Tracing long-term fine sediment transport in Humber Bay, Lake Ontario. National Water Research Institute Contribution No. 90-92.

Daniels, S.A., Munawar, M. and C.I. Mayfield. 1989. An improved elutriation technique for the bioassessment of sediment contaminants. Hydrobiologia 188/189: 619-631.

Diamond, M. and A. Mudroch. 1990. Review of techniques for quantifying the transfer of contaminants and nutrients from bottom sediments. National Water Research Institute Contribution.

Dobos, R.Z., Painter, D.S. and A. Mudroch. 1990. Environmental health of confined disposal sites on the Canadian Great Lakes. National Water Research Institute Contribution.

Dobos, R.Z., Painter, D.S. and A. Mudroch. 1990. Contaminants in wildlife utilizing confined disposal facilities. National Water Research Institute Contribution.

Joshi, S.R. and A.G. Bobba. 1988. Finite-element modelling of transport Ra-226 and U-235 from a radioactive waste management site to Lake Ontario. In: Reliability of Radioactive Transfer Models, G. Desmet (Ed.), pp. 193-200, Elsevier Science Publishers.

Mudroch, A. and K. Hill. 1990. Distribution of mercury of Lake St. Clair and the St. Clair River sediments. Water Poll. Res. J. Can. (in press).

Nagy, E., Carey, J.H. and J.H. Hart. 1989. Hydrocarbons in Great Lakes sediments. National Water Research Institute Contribution No. No. 89-01.

Nalewajko, C., Ewing, C. and A. Mudroch. 1989. A comparison of the effects of sediments and standard elutriates on phosphorus kinetics in lakewater. Water Air Soil Pollut. (in press).

Orchard, I. and A. Mudroch. 1989. An overview of treatment technologies for contaminated sediments in the Great Lakes. Proc. XII World Dredging Congress, Orlando, Florida, pp. 603-610.

Painter, S., Murphy, T.P. and D. Boyd. 1990. The contaminated sediments of Hamilton Harbour. Proc. Technology Transfer Symposium for the Remediation of Contaminated Sediments in the Great Lakes Basin. International Joint Commission, Windsor, Ontario, pp. 121-145.

Platford, R.F. and S.R. Joshi. 1989. Radionuclide partitioning across Great Lakes natural interfaces. Environ. Geol. Water Sci. 14: 183-186.

Prepas, E.E., Murphy, T.P. and H.R. Hamilton. 1990. Application of lime to eutrophic surface waters and contaminated sediments. In: Proc. Technology Transfer Symposium for the Remediation of Contaminated Sediments in the Great Lakes Basin. International Joint Commission, Windsor, Ontario, p. 106.

Reynoldson, T.B. and M.A. Zarull. 1989. The biological assessment of contaminated sediments - the Detroit River example. Hydrobiol. 188-189: 463-476.

Reynoldson, T.B. and Stervoski, L. 1989. The effects of various sediment treatments on bioaccumulation of three organic contaminants by the tubificid oligochaete Tubifex tubifex. National Water Research Institute Draft Report, 13 p.

Stone, M. and A. Mudroch. 1989. The effect of particle size, chemistry and mineralogy of river sediments on phosphate adsorption. Environ. Technol. Letters 10: 501-510.

ANNEX 15: AIRBORNE TOXIC SUBSTANCES

The establishment of an integrated atmospheric deposition network is specified under Annex 15 of the GLWQA. A three phase programme (2 years each) designed to accomplish this has been approved by the US and Canada and is on schedule. A "master" or research station is operational at Port Petrie (Lake Ontario), a second site (operational in 1991) has been selected, and several "Satellite" or routine stations have been tentatively identified (operational in 1992). Preliminary rainfall data from 1989 have been analyzed and a report is in preparation. In addition, an all-weather sampler has been tested and a report on its feasibility is in preparation.

Determination of the mass transfer coefficients for vapour phase contaminant movement at the air-water interface is also identified under Annex 15. A gas transfer flume has been constructed, consisting of a 31 m recirculating flume interfaced with an enclosed wind tunnel (see Figure 1). Conditions simulating 0-80 km/h winds over water can be achieved; instrumentation for characterizing wave motion and turbulence has been installed. Some delay has been experienced due to the loss of key personnel. Current results using chlorobenzene in the flume demonstrated good reproducibility for mass transfer coefficients in accord with theoretical values.

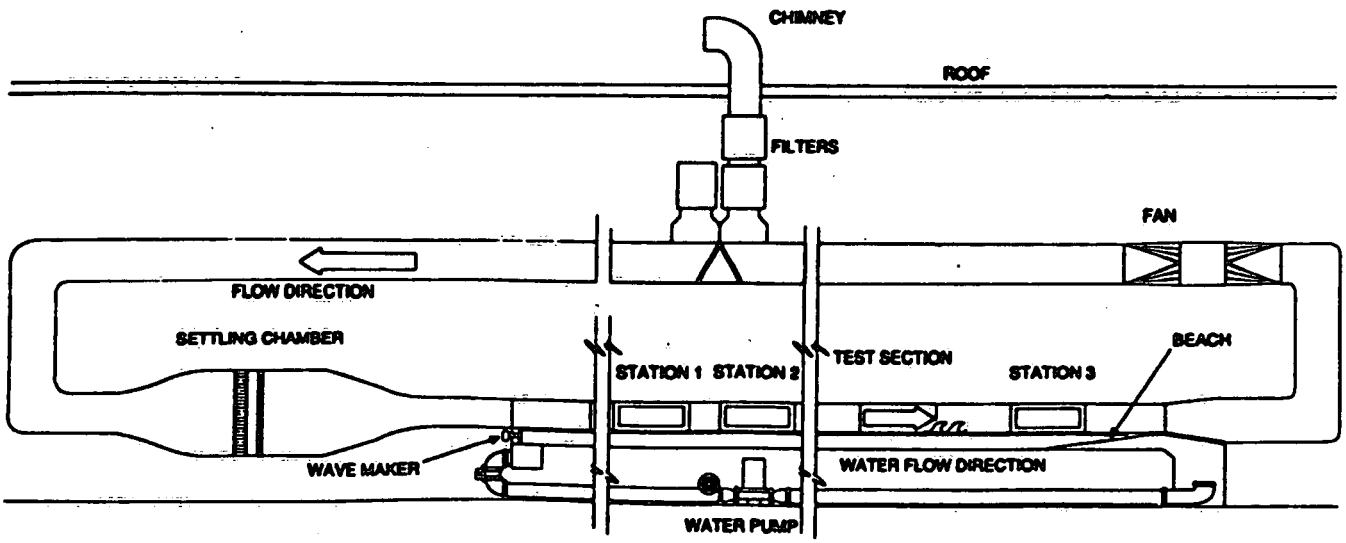

Figure 1. Gas transfer flume used in experimental studies of the transfer of toxic chemicals across the air-water interface.

Trace metals are among the identified atmospheric pollutants entering the Great Lakes. A major failing in current analytical methodology for metals has been contamination at trace levels. A new facility has been constructed to provide "clean" conditions for processing such samples. Complimentary collection and preservation methodology is to be completed in FY 1990/91. This technology is to be applied to surface water samples, rain and airborne dryfall, and other atmospheric related samples to respond to various requirements in Annex 15 as well as to confirm results from the deposition monitoring network.

As part of surveillance and monitoring activities, selected vegetation is being investigated for use in monitoring trends of established contaminants. Shoreline-inland transects with moss, lichens, forest litter and other atmospheric-related sample types have been completed in the Lake Superior area. Related studies have established pine needles as suitable monitors for atmospheric contamination in the vapour state.

Annex 15 specifically requires development of models for determining the significance of atmospheric loadings relative to other pathways. Determinations of tributary and outlet ("dissolved" and suspended), in situ ("dissolved", suspended and surficial sediments), as well as atmospheric (vapour, particulate and rainfall) burdens/loadings to lake systems have been done. These provide a basis for validating a model for persistent organic chemicals in lakes on a seasonal basis. Sampling and analyses are complete for a small lake in the Lake Superior watershed (Turkey Lake) and sampling will be complete for Lake Ontario during FY 1990/91. Physical models for both systems are available and are being integrated with fugacity-type distribution models. Model development is nearly complete for Little Turkey Lake; similar activity for Lake Ontario awaits refinement and testing of the former.

One project at the Institute on the dynamics of atmospheric contaminants entering lakes is studying the linkage(s) between the trophic status of lakes and contaminant dynamics. A set of 33 oligotrophic-mesotrophic lakes in south-central Ontario are being investigated; all of them receive persistent organic chemicals only via the atmosphere. Present investigations have shown that the major factor determining concentrations in zooplankton is an inverse relationship with spring total phosphorous concentrations (see Figure 2).

Concentrations higher in the food chain appear to be related to the length of the particular food chain and the presence of planktivores in the chain.

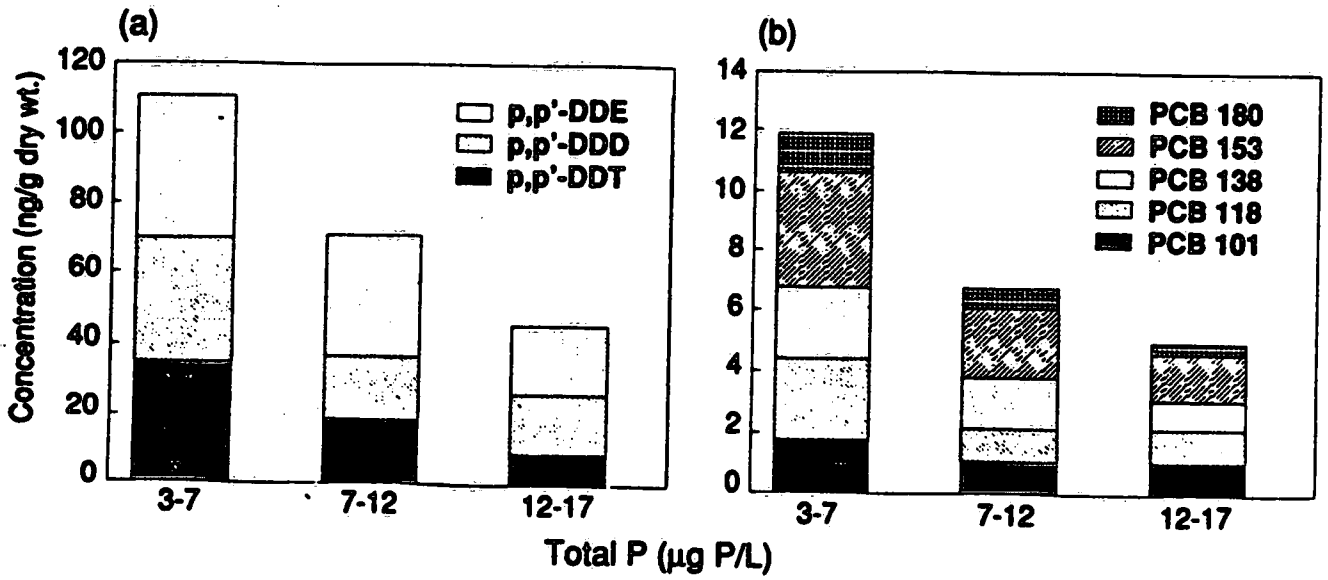

Figure 2. Average concentrations of (a) DDE, DDD and DDT, and (b) five PCB congeners in zooplankton for lakes grouped according to their total phosphorus concentrations in spring.

PUBLICATIONS

Baxter, R.M., Carey, J.H., Lean, D.R.S. and B.K. Burnison. Influence of trophic status on the behaviour of contaminants in aquatic systems. J. Contam. Hydrology (in press).

Carey, J.H., Lean, D.R.S., Taylor, W.D. and D.J. McQueen. 1989. The influence of lake trophic status on concentrations of atmospherically transported organochlorine contaminants in lake zooplankton. National Water Research Institute Contribution No. 89-28.

Erickkson, G., Jensen, S., Kylin, H. and W.M.J. Strachan. 1989. The pine needle as a monitor of atmospheric pollution. Nature 341: 42-44.

Eisenreich, S.J., Willford, W.A. and W.M.J. Strachan. 1989. The role of atmospheric deposition in organic contaminant cycling in the Great Lakes. In: Intermedia Pollutant Transport: Modeling and Field Measurements. D. Allen (Ed.), Plenum Publ., New York.

Flegal, A.R., Nriagu, J.O., Niemeyer, S. and K.S. Coale. 1989. Isotopic tracers of contaminant lead contamination in the Great Lakes. Nature (London) 339: 445-458.

Johnson, N.D., Lane, D.A., Schroeder, W.H. and W.M.J. Strachan. 1989. Measurement of selected organochlorine compounds in air near Ontario lakes: Gas-particle relationships. Presented at 32nd IAGLR Conference, U. of Wisconsin, Madison, May 30-June 2, 1989.

Nriagu, J.O. 1989. A global assessment of natural sources of atmospheric trace metals. Nature (London) 338: 47-49.

Nriagu, J.O. 1989. Natural versus anthropogenic emissions and trace metals to the atmosphere. In: Control and Fate of Atmospheric race Metals. J.M. Pacyna and B. Ottar (Eds.), Kluwer Academic Publishers, Dordrecht, pp. 3-13.

Sawchuk, A.M. and W.M. Schertzer, 1989. Overview of evaporation formulations for application to large lakes: Part I. National Water Research Institute Contribution No. 90- , 32 p.

Simons, T.J., and W.M. Schertzer. 1989. The circulation of Lake Ontario during the summer of 1982 and the winter of 1982/83. IWD Scientific Series No. 171, 91 p.

Strachan, W.M.J. Atmospheric deposition of selected organochlorine compounds in Canada. Chapter 16. In: Long Range Transport of Pesticides. D.A. Kurtz (Ed.), Lewis Publ., Chelsea, 1990 (in press).

Strachan, W.M.J. and S.J. Eisenreich. Mass balance accounting of chemicals in the Great Lakes. Chapter 19. In: Long Range Transport of Pesticides. D.A. Kurtz (Ed.), Lewis Publ., Chelsea, 1990 (in press).

ANNEX 16: POLLUTION FROM CONTAMINATED GROUNDWATER

During the period 1988 to 1990, research into the factors influencing the migration of groundwater contamination at Niagara Falls continued. During this time, a regional study of groundwater flow in the Niagara Falls area was completed. The results of the study show that there are primarily two groundwater flow regimes in Niagara Falls, one at shallow depth confined to the Lockport and Guelph Dolostones, and a second at great depth in the Cataract Group of shales and sandstones. The upper flow regime is characterized by active groundwater flow in regionally extensive sheeting fractures. Conversely, groundwater flow in the low flow regime is virtually non-existent with little groundwater movement in recent geological history. The water quality in both regimes is highly variable although the water in the upper regime generally has less dissolved constituents than that in the lower regime. Recent work is focused on developing new methods to investigate the hydraulic and contaminant transport properties of large scale sheeting fractures. This work has been conducted with the cooperation of the US Geological Survey using several boreholes drilled by the USGS in Niagara Falls, NY. The results of the study show that standard methods of testing usually employed to determine the permeability of fractured rock will lead to an incorrect interpretation of the distribution of fractures in the type of bedrock common in Niagara Falls. In addition, the use of the standard method failed to give an accurate determination of the permeability of the bulk rock matrix. Knowledge of the matrix permeability is crucial in formulating accurate predications of contaminant migration.

During the same period, groundwater investigations continued in the Sarnia, Ontario, region. The objective of the study is to assess the possible impact of the deep well disposal of industrial wastes on a local aquifer. A monitoring well network of 29 piezometers was installed in the Sarnia area adjacent to the St. Clair River. Numerous samples of groundwater were obtained from this network and from a nearby deep monitoring well for geochemical analysis. Many of the volatile organics observed to be present in the deep well are not detected in the shallow network. It is concluded that the migration of contaminants from depth towards the shallow aquifer is not widespread. Furthermore, the localized presence of chloride contamination observed in the shallow aquifer is likely due to the upwelling of deeper chloride rich formation water. One of the difficulties encountered in this study is related to the differentiation between

chemicals of natural and anthropogenic origin. A new multi-variate plotting technique was developed to address this issue. The method was employed with some success to fingerprint fluid from the disposal well and natural formation waters in the Sarnia area.

PUBLICATIONS

Bobba, A.G. and S.R. Joshi. 1988. Groundwater transport of radium-226 and uranium from Port Granby waste management site to Lake Ontario. Nucl. Chem. Waste Manage. 8: 199-209.

Lapcevic, P.A. and K.S. Novakowski. 1989. The use of short packer spacings to characterize hydraulically open fractures in the Lockport Formation, Niagara Falls, New York. National Water Research Institute Contribution No. 89-144.

Lesage, S., Jackson, R.E., Priddle, M.W., Beck, P., and K.G. Raven. 1989. Monitoring shallow groundwater for injected liquid industrial wastes, Sarnia. Canada. National Water Research Institute Contribution No. 89-171.

Lesage, S. and P.A. Lapcevic. 1990. Differentiation of the origin of BTX in groundwater using multi-variate plots. Ground Water Monitoring Review, Spring Issue. pp. 102-105.

Novakowski, K.S. and P.A. Lapcevic. 1988. Regional hydrogeology of the Silurian and Ordivician sedimentary rock underlying Niagara Falls, Ontario, Canada. J. Hydrol. 104: 211-236.

ANNEX 17: RESEARCH AND DEVELOPMENT

The federal government maintains research programs to further the understanding of fundamental processes operating in the Great Lakes Basin Ecosystem and to ensure that this scientific information can be driven to clean-up, protect and preserve the aquatic resources. Recent emphasis has been focused on the sources, pathways, fate and effects of pollutants directly released to the system or indirectly introduced via the atmosphere. These research activities have been driven to a large extent by the needs of the agencies fulfilling the objectives of the Annexes of the Revised GLWQA. Since the last report, much fundamental research has been carried out during site-specific studies in the Areas of Concern, under both Annex 2 and 14. Research fostered by the needs of Annexes 13, 15, and 16 are being further developed and enhanced since the new funding under Great Lakes Action Plan (GLAP) became available in 1990. Research progress in these areas are described in each Annex chapter.

A major contribution to the development of the science and technology needs to manage and conserve the Great Lakes is the recently announced Great Lakes University Research Funds (GLURF). This program will put $4 million dollars at the disposal of Canadian Universities over the next four years to conduct fundamental research and to develop a research infrastructure able to effectively address Great Lakes environmental issues in the future. The fund will support multi-disciplinary projects on three main issues:

1. Research on the sources, pathways, fate and effects of pollutants in the Great Lakes ecosystem;

2. Research on the responsiveness of the Great Lakes ecosystem to stress other than pollution such as climate change, habitat alteration, exotic species invasion;

3. Research on restoration and remediation technologies to reverse or mitigate environmental degradation.

The fund will enhance collaborative research projects between federal government laboratories and the universities, thus combining their intellectual resources in ways that will make optimum use of each community's strengths.

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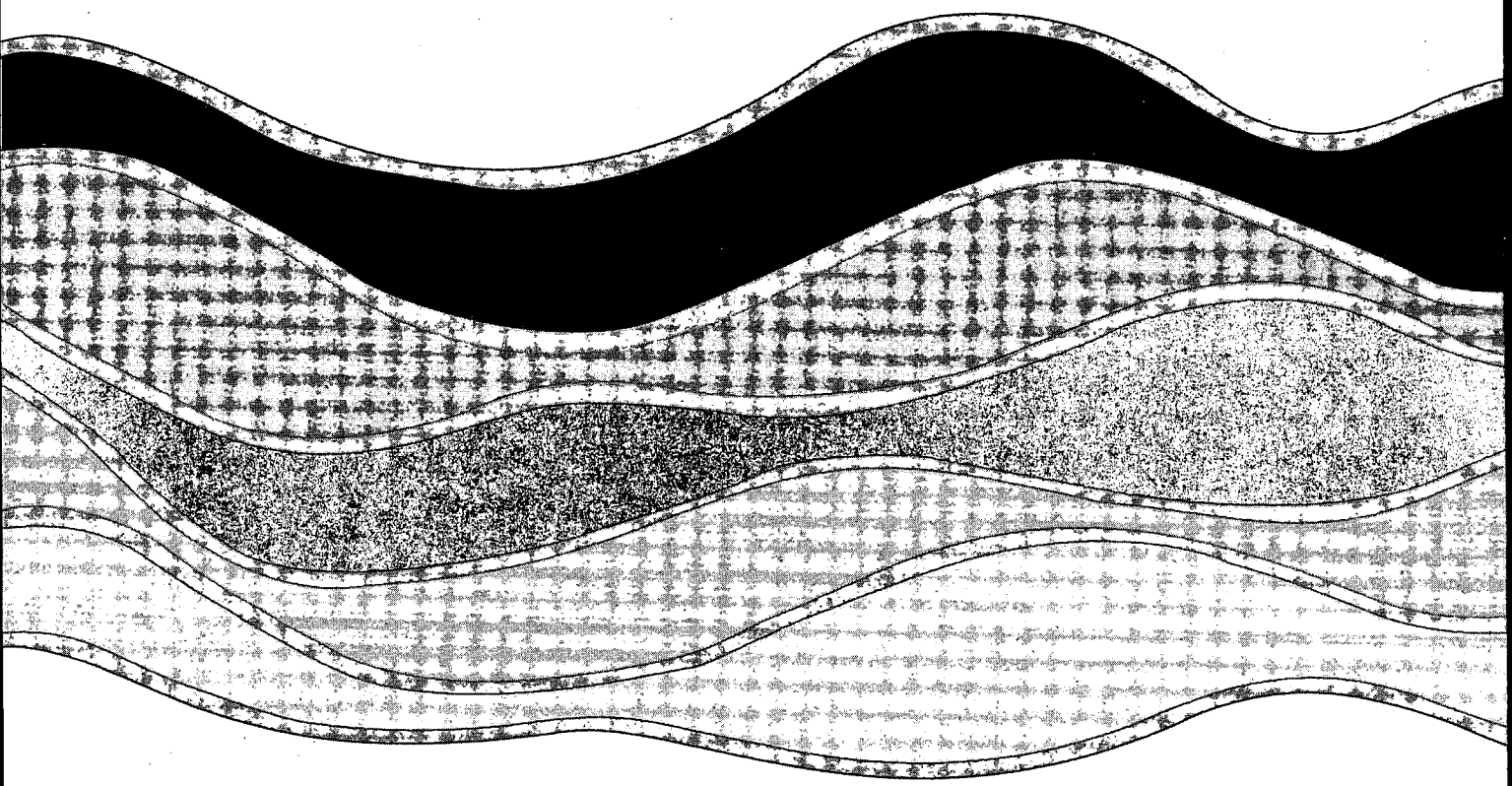

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