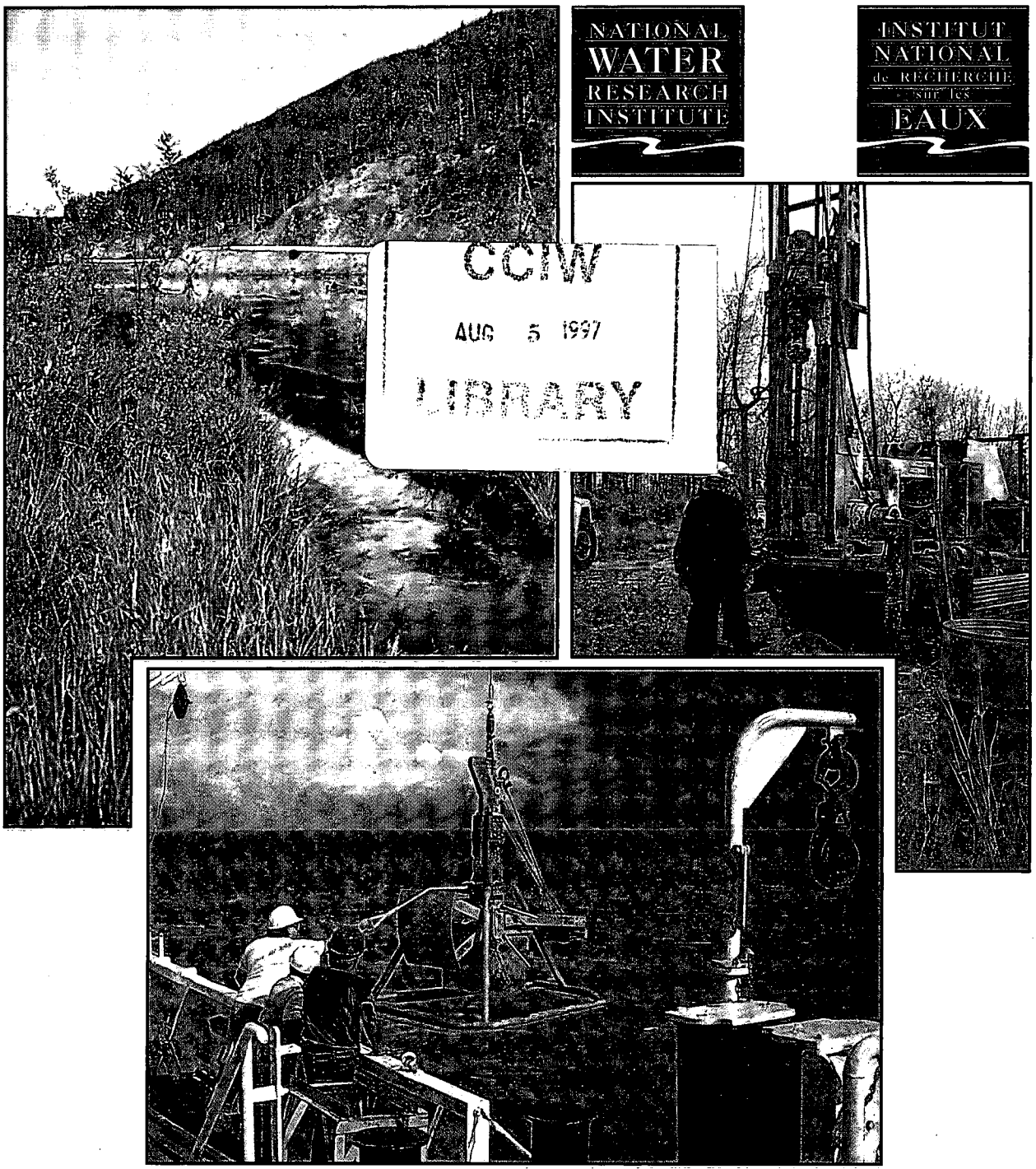

NATIONAL WATER RESEARCH INSTITUTE

INSTITUT NATIONAL de RECHERCHE sur les EAUX

AQUATIC ECOSYSTEM RESTORATION BRANCH

SCOPE OF RESEARCH

NWRI Contribution No. 94-10

MANAGEMENT PERSPECTIVE

This report presents a brief overview of the Scope of Research carried out currently by the Aquatic Ecosystem Restoration Branch (AERB) of the National Water Research Institute (NWRI), and gives an indication of anticipated future directions. A list of recent publications and collaborative linkages with other research organizations is included. The report is meant to serve primarily as a marketing document presenting available expertise for potential clients both nationally and internationally.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Le présent rapport donne un bref aperçu de l'étendue des recherches effectuées à l'heure actuelle par la Direction de la restauration de l'écosystème aquatique de l'Institut national de recherche sur les eaux. Les orientations futures prévues sont également mentionnées. On y trouve une liste des publications récentes et des formes de collaboration avec d'autres organismes de recherche. Ce rapport doit servir surtout de document de promotion des compétences à l'intention de clients potentiels, tant à l'échelle nationale qu'à l'échelle internationale.

National Water Research Institute
Canada Centre for Inland Waters
867 Lakeshore Road, P.O. Box 5050
Burlington, Ontario L7R 4A6
Canada

Compiled and edited by Jan Barica and Dianne Crabtree.
Graphic work by Mike Donnelly. Group photographs by Win Booth.

NWRI Contribution No. 94-10

AQUATIC ECOSYSTEM RESTORATION BRANCH

"Our Goal is Restoration; our Objective is Remediation."

The Role of Restoration in Sustainable Development

The Aquatic Ecosystem Restoration Branch (AERB) of the National Water Research Institute (NWRI) has a goal similar to its name, "to restore aquatic ecosystems", which means to restore degraded ecosystems to a level that can be permanently sustained through conservation and protection. More realistically, the Branch expects to mitigate effects or remediate degraded ecosystems to ones that have a higher order of ecological stability. Restoration can occur naturally, but more often involves reductions of stresses such as nutrient or contaminant levels, waste heat or management practices for example with reservoir operating procedures. Assessments of degraded aquatic ecosystems allow decisions to be made as to what to control to remediate effects or how much can be relied on nature to clean itself. To achieve ecosystem stability or sustainability requires decisions on what to do, including *in situ* options such as bioremediation or biomanipulating as well as developing ecosystem indicators of progress towards restoration.

Restoration towards a less degraded but not necessarily pristine ecosystem requires decisions as to how far to go or "how clean is clean". To arrive at such conclusions and to monitor progress towards them for surface and groundwater requires the development of indicators of ecosystem health, stability and sustainability. If these criteria are met, the ecosystem can be declared as remediated to acceptable conditions, perhaps even restored. The level of protection or control or regulation required to reach this state is dependent on the recovery or restoration of the ecosystem and the state that needs to be maintained.

Restoration then deals with degraded aquatic ecosystems which are remediated to some level of stability or sustainability involving minimization of stresses, *in situ* treatments, and probably conservation of components of the total aquatic ecosystem that have not yet been degraded.

Sustainable development assumes some economic growth of acceptable degree and rate. If a pristine ecosystem such as a national park sees no development, its ecosystem stability is conserved. However, development seldom can occur, if ever, without some degree of degradation. The question then is how much development and what type of development can occur before the aquatic ecosystem is degraded to a non-sustainable degree. This upper boundary may well be similar to that which is arrived at when degraded aquatic ecosystems are restored. In essence, the restoration of degraded ecosystems, which are those that have seen development, may result in a state of the aquatic ecosystem commensurate with a level of development that can be sustained. Of course, it may be that an acceptable recovery of an aquatic ecosystem may result in a state that is not acceptable in the case of development as opposed to conservation of pristine ecosystems.

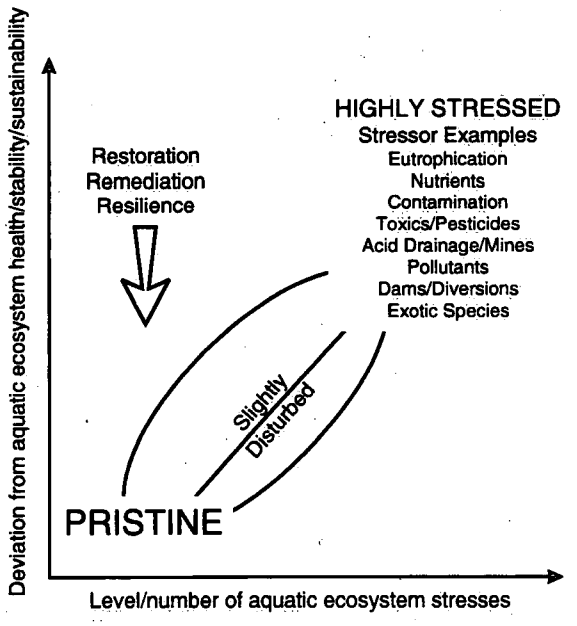

Figure 1: Branch conceptual approach towards ecosystem restoration.

Mission

The Branch conducts research to restore the chemical, physical and biological integrity of aquatic ecosystems and contributes to the Mission of the National Water Research Institute by:

- assessing aquatic ecosystem health, stability and sustainability;
- developing indicators of ecosystem health and recovery (how clean is clean);
- developing water quality, ecosystem health and sustainability guidelines and objectives;
- producing information for State-of-the-Environment reports;
- developing, proposing and implementing, if feasible, mitigation measures or remedial techniques at degraded sites.

As a Goal, the Branch focusses on the restoration of degraded and ecologically disturbed sites, for example, the Areas of Concern (AOC) which are mainly bays and harbours in the Great Lakes or similar degraded sites elsewhere in Canada; on the more stressed of the Great Lakes, i.e., Ontario and Erie; on lakes impacted by mining or used as sites of tailings disposal; and on local sites where groundwater degradation is severe and preferably has a federal component, e.g., the Niagara Frontier. However, whereas the overall Branch Goal is restoration, the realistic objective in most cases is partial restoration, mitigation or remediation. In rare cases with time, almost complete restoration may be accomplished.

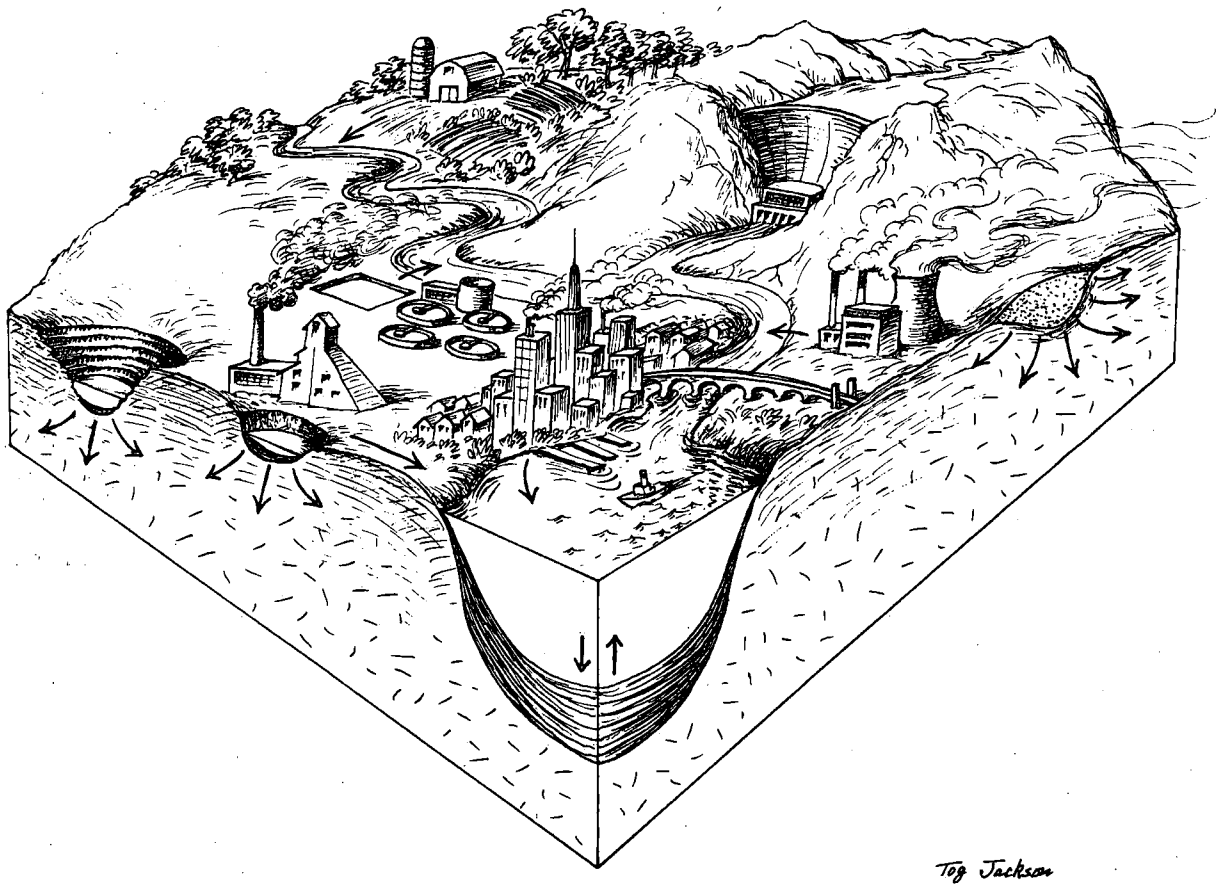

Figure 2: Schematic drawing of hypothetical landscape showing various sources of contamination and other causes of environmental degradation (open pit mine, underground mine, tailings pond, smelter, sewage treatment plant, landfill or dump site, reservoir, dam, and electric power station). Arrows indicate routes of contaminant transport and migration into surface water sediments and groundwater.

DIRECTOR'S OFFICE

The Director's office ensures efficient use of resources to support research studies in individual projects. It also performs liaison and coordination of research activities with collaborating research and operational groups in the Environment Canada (DOE) headquarters in Ottawa, five DOE Regions, other federal and provincial government departments, international agencies (particularly U.S.-Canada International Joint Commission, IJC), and numerous universities and aquatic research institutions in Canada and abroad. The Director's office staff prepare overview and synthesis publications on environmental issues such as toxic chemical pollution, eutrophication, ecosystem remedial techniques, and aquatic ecosystem health, stability and sustainability. The staff also organize, convene and chair national and international workshops, symposia and conferences. The Director's office releases over a hundred publications per year on issues of high priority to the Department both nationally and internationally.

Scope of Research

Director: R.J. Allan

- Under the Canada-Russia MOU, Co-Convened with scientists from Russia and the U.S.A., a Workshop on Hydrological, Chemical and Biological Processes of Transformation and Transport of Contaminants in Aquatic Environments, held in Rostov-on-Don, Russia. Some 60% of the fifty presentations were by Russian scientists dealing with contaminant issues in their country.
- Co-Chaired the 9th International Conference on Heavy Metals in the Environment in Toronto, Canada. Some 350 scientists from 38 countries presented 298 papers at this premier biennial meeting on the sources, fate and effects of heavy metals in the environment.
- Co-Author of a Monograph of 169 pages on Toxic Contaminants in Water and Sediments of the Great Lakes, translated into Chinese, printed and widely distributed in China by the Chinese Research Academy of Environmental Sciences.

Research Liaison and Coordination: M.A. Zarull

- Examination of ecosystem function and management, cumulative impact assessment and stress response, the bioassessment and remediation of contaminated sediments.
- Contributed presentations and chaired sessions at several international scientific meetings in the United States, Canada and Italy; facilitated and provided key-note addresses for departmental, Canada-U.S. and federal-provincial meetings on aquatic ecosystem management, contaminated sediment and Great Lakes' limnology. Served as President and Chairman of the Board of Directors, International Association for Great Lakes Research.
- Provided expertise, coordination and liaison for joint scientific activities and partnerships with other research institutes, universities and environmental regulatory agencies.

Senior Scientists:

G.K. Rodgers

- As Hamilton Harbour Remedial Action Plan (RAP) Coordinator, brought together agencies to collaborate in a cooperative effort to develop a plan to restore water quality and the aquatic ecosystem of the Harbour.
- Completion and submission of the final Plan for the Hamilton Harbour Remedial Action Plan (Stage 2 Report, 1st and 2nd editions), for consideration by all agencies for commitment.
- Research into density flows in embayments and nearshore areas of the Great Lakes; and into the thermal bar phenomenon in the Great Lakes.

J.M. Barica

- Development of a quantitive method to assess stability and sustainability of eutrophic ecosystems.
- Invited seminars and transfer of Canadian environmental expertise to Brazil, Germany, Russia, England, Poland and Slovakia.
- Editor of Water Pollution Research Journal of Canada.

Selected Examples of Collaborative Research

- University of Windsor and Ontario Ministry of Natural Resources on cooperative research programs for Lake Erie; Wayne State University, U.S. FDA Forest Service, Great Lakes Commission and International Joint Commission on implementing the ecosystem approach in resource management and regulatory programs in the Great Lakes.
- The Remedial Action Plan Program includes a technical team from National Water Research Institute, Water Resources Branch/Ontario Ministry of the Environment and Energy, West Central Region/Ontario Ministry of the Environment and

Energy, Ontario Ministry of Natural Resources, Great Lakes Laboratory for Fisheries and Aquatic Sciences, Royal Botanical Gardens, and Ontario Ministry of Agriculture and Food. Further contacts are through the Science and Education Committee of the Royal Botanical Gardens; the special committee of Hamilton-Wentworth Regional Municipality's Environmental Services Committee dealing with an aeration proposal; a Sub-Committee of the Hamilton-Wentworth Regional Task Force in Sustainable Development dealing with concrete proposals for municipal action in the area of physical services (water supply, toxic waste disposal and sewage treatment); the Halton Region Ecological and Environmental Advisory Committee (review of development proposals).

- International linkages: Bilateral agreements (MOUs) with Germany and Russia (coordination and work planning of joint projects with Universities of Berlin, Hamburg, UFZ Leipzig, GKSS Magdeburg, and Russian Academy of Sciences. Advising CAESB in Brasilia and Rio de Janeiro, Brazil and Water Research Institute, Bratislava, Slovakia on matters of algae control in drinking water reservoirs.

RECENT PUBLICATIONS

Allan, R.J. 1993. Northern Challenges: National Water Research Institute Scientists Study Contaminants in the Canadian Arctic. Editorial, NWRI Digest, Issue 16: 1-2.

Allan, R.J. 1993. Modelling the fate of persistent toxic organic chemicals in aquatic ecosystems. Proc. Int. Congress on Modelling and Simulation Vol. 3: 1157-1162.

Allan, R.J. (Chairman, Report Committee) 1993. Report of the Council of Great Lakes Research Managers to the International Joint Commission. Pub. IJC, Ottawa/Washington, 58 pp.

Allan, R.J. and A.J. Ball. 1993. An Overview of Toxic Contamination in the Water and Sediments of the Great Lakes. Pub. in Chinese by the Chinese Research Academy of Environmental Sciences, 169 pp. (Chinese translation of a 1990 Monograph.)

Allan, R.J. and J.O. Nriagu (Eds.) 1993. Heavy metals in the environment. Int. Conf. on Heavy Metals in the Environment, Toronto. Pub. CEP Consultants, Edinburgh Vol. 1: 457 pp.

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Zarull, M.A. and R.J. Allan. 1993. Remedial action plans in the Laurentian Great Lakes. Proc. 5th Int. Conf. on the Conservation and Management of Lakes, pp. 559-562.

Zarull, M.A. and A. Mudroch. 1993. Remediation of contaminated sediments in the Laurentian Great Lakes. Rev. Environ. Contam. Toxicol. 132: 93-115.

Zarull, M.A. and R.J. Allan. 1994. An overview of research conducted by the National Water Research Institute in support of the Great Lakes Action Plan 1989-1994. National Water Research Institute Contribution No. 94-01

Figure 3: Director's Office Team:

Seated (from left to right): Jan Barica, Rod Allan, Keith Rodgers.
Standing (from left to right): Lisa Le May, Elizabeth Wendel, Mike Zarull, Ethel Kerr.
Absent: Dianne Crabtree.

LAKE REMEDIATION PROJECT

The Lake Remediation Project of AERB, NWRI conducts research to assess and remediate lake ecosystems. Limnological properties of systems are investigated and assessed in terms of ecosystem health. The trajectories of water movements associated with contaminated plumes are measured as a way of delineating affected areas and the sizes of nearshore mixing zones. Physical measurements of currents and mathematical models are used to infer open lake circulation and mixing of large river plumes in the Great Lakes. Collections of sedimenting particles are used to follow the contaminant status of particles contributing to sediment deposits. Nutrient dynamics of *in situ* sediment deposits are used to determine the importance of phosphorus sources to water quality. Organic contaminants are determined in water, particulate, biological, and sediment substrates as a way of characterizing the contaminant status of lake ecosystems. Advice is provided to Remedial Action Plans under Great Lakes 2000 although studies may be conducted anywhere in Canada. Specific areas of research include:

Limnology of Large Lakes, Reservoirs, and Coastal Areas

- Studies of currents and resulting transport of plumes and patterns of flow.
- Measurement of nutrients and physical factors such as dissolved oxygen which determine the biological integrity of ecosystems.
- Problem definition and assessment of progress toward goals of restoring ecosystem function.
- Measurements and modelling of mixing in lakes and reservoirs.

Sedimentology of Contaminated Deposits in Lakes

- Identification of sediment sources and pathways in nearshore areas.
- Development of conservative sediment tracers to determine net sediment transport.

Organic Chemistry

- Development of techniques for solvent-free analyses of low level organics.
- Analyses and interpretation of PCBs, OC, PAHs, and other organics of interest in ecosystem samples.

Bioavailability of Phosphorus and Metals

- Measurement of the sources of phosphorus to sediments and the subsequent reflux rates of available phosphorus.
- Measurement and interpretation of metal-iron oxide compounds which determine the importance of heavy metals to biota.

Mixing and Flow in Riverine Systems

- Determination of effect of underwater features such as weeds on flow patterns.
- Detection and tracing of contaminated plumes using acoustic methods.

Sustainability Issues

- Implications of increasing numbers of drinking water intakes and sewage discharges in large lakes and embayments.
- Implications of nutrient loading controls and invasions of exotic species to sustainable fish yields in Lake Erie.

Research Studies

M.N. Charlton (Project Chief, Water and Sediment Quality Management in Hamilton Harbour and Lake Erie)

- Effects of Zebra Mussels on water quality on a transect in Hamilton Harbour.
- Study of contaminants in Windermere Arm area of Hamilton Harbour with members of TRICERP grant at McMaster University.
- Water quality surveys and measurement of settling rates for historic comparison to show effects of Zebra Mussels in Lake Erie.

P.G. Manning (Bioavailability of Phosphorus from Point and Non-Point Sources: Bay of Quinte, Lake Erie, Prairie Lakes)

- Changes in phosphorus sedimentation and availability as a consequence of Zebra Mussel infestation.

- Effect of Zebra Mussels on phosphorus binding capacity of offshore sediments of Lake Erie.
- Effects of anthropogenic iron on the availability of heavy metals (application for Hamilton Harbour RAP and other metallurgical sites).

Figure 4: Infestation of Zebra Mussels on sediment trap frame.

D.S. Painter (Sediment Quality - Great Lakes)

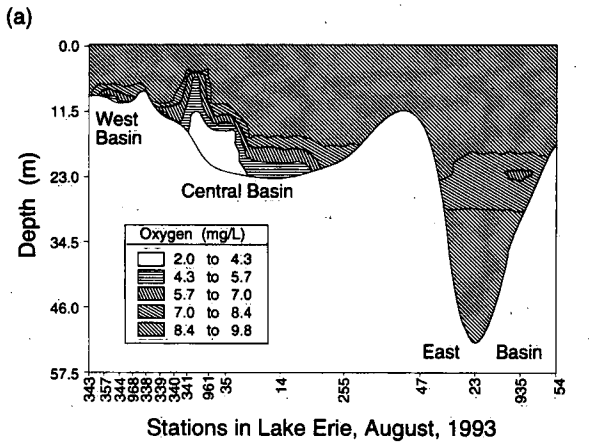
- Analyses of data showing background contaminant levels in 24,000 lakes and streams in the Great Lakes area for the purpose of determining reasonable standards and expectations of sediment quality.

M.E. Fox (Organic Contaminants in Great Lakes Areas of Concern and Other Study Locations)

- Contaminant redistribution in western Lake Erie as a result of Zebra Mussels.
- Organic contaminants in Hamilton Harbour.
- Organic chemical analyses of water, suspended solids, sediment, and biota.

C.R. Murthy (Coastal Exchange and Modelling)

- Mixing of large contaminated river plumes in large lakes.
- Water exchange in the coastal boundary layer with respect to effluents such as cooling water or contaminated sewage.
- Canada-Russia Memorandum of Agreement: Gulf of Bothnia Field Year, International Lake Lagoda Symposium, Collaborative experiments on Lakes Onega/Ladoga-Neva River, Gulf of Finland with Russian, Finnish and Estonian scientists.



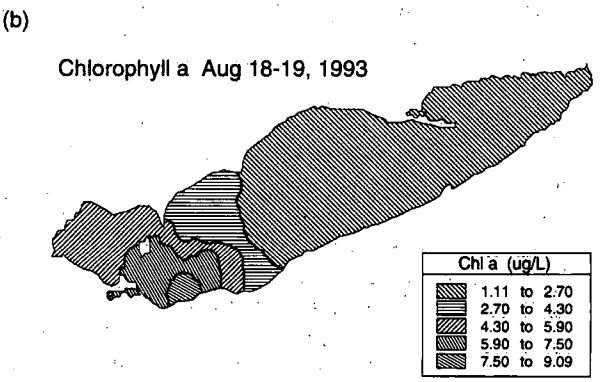


Figure 5: (a) Distribution of oxygen along an east-west transect in Lake Erie.
(b) Distribution of chlorophyll (algae) in Lake Erie.

P.F. Hamblin (Water Movements, Mixing, and Modelling)

- Three-dimensional model of Hamilton Harbour and the Burlington Ship Canal circulation.
- Vertical extent of filter feeding by Zebra Mussels in western Lake Erie.

- Flow and sediment flux in St. Lawrence River, Sorel delta and Lake St. Pierre.
- Lake remediation in abandoned water-filled mining pits in B.C. and low dissolved oxygen in ice covered lakes and reservoirs.

J.P. Coakley (Erosion and Transportation of Contaminated Nearshore Sediments)

- Development of conservative tracers for finding the movement of contaminated sediments.
- Sedimentology, sediment sources, burial rates of contaminated sediment, long-term trends, e.g., Hamilton Harbour and Humber Bay.
- Study of indicator chemicals in Moose River Estuary.

F. Chiocchio (Water Movement Climatology of West Lake Ontario)

- Analysis of historic database to summarize statistics of water movements.

K.C. Miners (Water Movements Climatology of Lake Erie's West Basin)

- Collect and analyse available data on water movement and summarize climatology of water movements.

Future Directions

The project will continue to provide scientific studies and advice to Remedial Action Plans such as Bay of Quinte, Severn Sound, and Hamilton Harbour. Collaborative studies on the St. Lawrence River system, western rivers, and Atlantic Region will be sought. Studies will be conducted leading to optimizing the sustainable use of coastal water resources for drinking water and municipal discharges.

Examples of Collaborative Research

- University of Alberta, Department of Biology, Edmonton, on nutrient processes in prairie lakes;
- McMaster University, Hamilton on contaminants in Hamilton Harbour;
- University of Western Ontario, Department of Civil Engineering, NSERC research grant on lake remediation;
- University of Toronto, Department of Mechanical Engineering, GLURF grant 1994;
- Universities of Windsor, Waterloo and Toronto as well as with Department of Fisheries and Oceans and Ontario Ministry of Natural Resources on study of Zebra Mussel effects on Lake Erie fisheries;
- McMaster University and Ontario Ministry of the Environment and Energy on development of effective sediment tracers;
- B.C. Environment on Kootenay Lake fertilization;
- U.S. EPS Mining Effluent Neutral Drainage project on mining pits;
- National Institute of Water and Atmospheric Research, New Zealand, on analysis of organic contaminants;
- GKSS, Forschungszentrum (Germany), University of Bordeaux on sediment tracers;
- Collaboration with Russian, Estonian, Swedish, Finnish and Dutch scientists on Gulf of Finland Field Year: water quality in Lakes Onega, Lagoda, Neva River and Gulf of Finland (Canada-Russia Memorandum of Agreement, Working Group 2).

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Coakley, J.P., E. Nagy and J.-B. Sérodes. 1993. Spatial and vertical trends in contaminants in the St. Lawrence River Upper Estuary. Estuaries 6(3B): 653-669.

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Murthy, C.R. and W.M. Schertzer. 1994. Physical limnology and water quality modelling of North American Great Lakes: Part I: physical processes. Wat. Poll. Res. J. Canada 29(2): 129-156.

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Schertzer, W.M. and C.R. Murthy. 1994. Physical limnology and water quality modelling of North American Great Lakes: Part II: water quality modelling. Special issue Wat. Poll. Res. J. Canada 29(2): 157-186.

Sly, P.G., M.N. Charlton and S.R. Joshi. 1993. Results of exploratory coring in Laguna Lake, Philippines. Hydrobiologia 257: 153-164.

Figure 6: Lake Remediation Project Team

Front Row (from left to right): Murray Charlton, Robin Le Sage, Scott Painter, Fausto Chiocchio, Xiaowa Wang, Phil Manning, Cheng He.
Back Row (from left to right): Mike Fox, Raj Murthy, John Coakley, Paul Hamblin, Ken Miners, Win Booth.
Absent: Lina Thiessen.

SEDIMENT REMEDIATION PROJECT

The Sediment Remediation Project of AERB, NWRI conducts a multidisciplinary research program on the pathways and effects of sediment-associated contaminants and nutrients on aquatic ecosystems in Canada. Emphasis is placed on studies relevant to the assessment of sediment quality and remediation of contaminated sediments. In support of sustainable development in the metal mining industry, multidisciplinary studies are carried out on the effects of metal mining on aquatic ecosystems and new techniques are developed and tested for subaqueous disposal of acid generating mine tailings and waste rock. Knowledge generated from this research is used to support programs such as Great Lakes Action Plan, Fraser River Management Plan, Sustainability Sectors and Environment Canada regional activities. There are presently eight study leaders with expertise in physico-chemical and geotechnical properties of sediments, sediment biogeochemistry, benthic invertebrates and sediment porewater geochemistry. Research is conducted in the following specific areas:

Assessment of Sediment Quality

- Studies of the relationship between benthic community structure and sediment biogeochemistry.
- Laboratory testing and field studies of uptake and toxicity of sediment contaminants to benthic invertebrates.
- Investigation of historical changes of concentrations of contaminants in bottom sediments.

Remediation of Contaminated Sediments

- Laboratory studies of effectiveness of different methods for in-situ treatment of contaminated sediments.
- Field demonstration and monitoring of the efficiency of in-situ treatment of contaminated sediments.

Transport of Sediment-Associated Contaminants

- Laboratory and field studies of migration of trace elements and nutrients via sediment pore water into lake water.
- Investigation of partitioning of persistent toxic substances in suspended sediments and lake water.
- Field studies of resuspension and redeposition of sediment-associated contaminants.
- Field studies of transport of pesticides from agricultural activities into coastal marshes and lakes nearshore zone.
- Evaluation of the role of waves in the transport of fine-grained sediments.

Figure 7: Sampling peeper with syringes to recover porewater samples.

Sustainable Sectors

Mining

- Multidisciplinary studies (field and laboratory) of effects of metal mining on aquatic ecosystems.
- Laboratory and field studies of feasibility of subaqueous disposal of acid generating metal mine tailings and waste rock into different lakes and man made reservoirs.

Fisheries

Determination of wave and current parameters suitable for trout spawning to assist in re-establishing sustainable fishery in the Great Lakes.

Research Studies

A. Mudroch (Project Chief, Behaviour of *In Situ* Contaminants)

- Study of transport of persistent toxic organic contaminants, particularly PCBs, by suspended particles in the nepheloid layer in Lake Ontario.
- Evaluation of processes releasing trace elements from acid generating metal mine tailings and waste rock disposed into natural lakes and man-made reservoirs.
- Study of transport and partitioning of pesticides from agricultural activities in coastal marshes and nearshore zone of Lake Erie.
- Determination of historical changes in deposition of contaminants into lakes by sediment geochemistry.

V. Cheam (Laser Spectroscopy for Analysis of Environmental Samples)

- Development and applications of laser spectroscopy to direct analysis of environmental samples.
- Sediment porewater: determination of trace elements and assessment of contamination.
- Relationship of dissolved and total lead in lake waters.
- Atomic spectrometry: fluorescence, absorption and emission.

T.A. Jackson (Effects of Heavy Metals on Microbial Communities)

- Study of effects of heavy metals on microbial communities in lake sediments under various conditions, with particular attention to the ecological impact of mine wastes such as tailings, in diverse natural and experimental systems.
- Study of the biogeochemistry of mercury, in particular methylation, demethylation, bioavailability, and bioaccumulation under different conditions, in a wide variety of freshwater ecosystems, such as mercury-polluted river-lake systems, young hydroelectric reservoirs, and experimental model systems.
- Study of the biogeochemistry, speciation, bioavailability, bioaccumulation, and toxic effects of heavy metals in a group of lakes contaminated with smelter fallout and tailings pond effluent.
- Ecological effects of humic matter, clay minerals, and oxyhydroxides in freshwater environments, in particular, their effects on microbial communities and their role in the biogeochemistry of heavy metals.

T.B. Reynoldson (Biological Assessment of Contaminated Sediments)

- Development of biologically based sediment guidelines: establishing biological indicators and objectives for Great Lakes sediments.
- Studies to establish responses in invertebrate communities to directional and non-directional change in Lake Erie.
- Development of biological prediction models: developing software for agency use for biological indicators and targets.
- Development of biological monitoring network and indicators for the Fraser River.

F. Rosa (Contaminant Cycling by Suspended Sediments in Porewater)

- Studies of the impact of mine tailings on aquatic ecosystems.
- Studies on solutes transport across the sediment-water interface.
- Theory of internal processes affecting hypolimnetic oxygen consumption.
- Development of new large-volume sampling equipment for sediment porewater.
- Theory of particles dynamics and net sedimentation in aquatic ecosystems.

M. Skafel (Sustainable Coastal Development)

- Determination of the range of wave and current parameters suitable for trout spawning.
- Investigation of the occurrence and formation of unusually large waves.
- Investigation of the transport characteristics of fine-grained sediments under a wave field.
- Study of the influence of waves on air entrainment.
- Investigation of the influence of wave groups on surface stress.

H.K.T. Wong (Dissolved Trace Contaminants; Low Level Detection)

- Development of field and laboratory methods for metal species with emphasis on mercury.
- Determination and distribution of Hg-species and their transport properties in heavily polluted environments.

- Assessment of toxic metal impact from mining activities in Atlantic Canada.

A.J. Zeman (*In Situ* Immobilization of Sediment Contaminants)

- Investigation of efficiency of *in situ* capping and armouring of contaminated sediments.
- Studies of feasibility of subaqueous disposal of mine tailings.
- Determination of offshore soil mechanics, characterization of cohesive sediment properties, mapping of contaminated sediments.
- Geotechnical and hydraulic studies related to erosion and instability of shore bluffs.

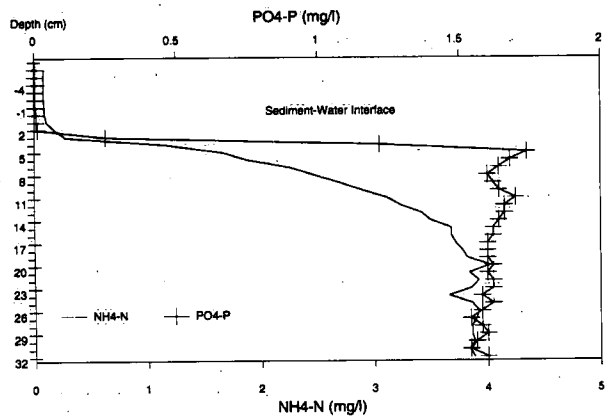

Figure 8: Sediment porewater profiles.

Future Directions

Continue research relevant to the assessment of sediment quality and remediation of contaminated sediments. New areas of research will emphasize the development of techniques for environmentally safe disposal of acid generating mine tailings and waste rock and remediation of release of contaminants from past mining activities into aquatic ecosystems.

Selected Examples of Collaborative Research

- Environmental Protection, Ontario Region, to develop biological sediment guidelines for the Great Lakes;
- Department of the Environment, Pacific and Yukon Region, to develop biological monitoring network and ecological indicators and objectives for the Fraser River;
- Agriculture Canada, on transport of pesticides from agricultural activities in Lake Erie coastal marshes;
- Ontario Ministry of the Environment and Energy, on remediation of the Great Lakes Areas of Concern and subaqueous disposal of metal mine tailings;
- Biology Departments of Universities of Windsor and McMaster on food chain responses in Lake Erie;
- University of Western Ontario on multivariate statistical methods for biological prediction;
- University of British Columbia, Rescan, Ltd., and Department of Chemistry, McMaster University, on reactivity of acid generating metal mine tailings and waste rock disposed in lakes and man-made reservoirs;
- U.S. Army Corps of Engineers, Chicago Ill, in the area of *in situ* remediation of contaminated sediments;
- U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Miss. and Louisiana State University, in the area of *in situ* capping and armouring of contaminated fine-grained sediments;
- Indiana State University, on pathways of organic contaminants and metals in bottom sediments in Lake Ontario;
- Institute of Spectroscopy, Academy of Sciences, Moscow, Russia, on applications of laser-excited atomic fluorescence spectrometry;
- Technical University Hamburg-Harburg, Germany, in the area of assessment of sediment quality and remediation and safe disposal of contaminated fine-grained sediments;
- Inland Water Research Institute, Magdeburg, Germany, on safe subaqueous disposal of mine tailings and restoration of acidified lakes and ponds;
- Aston University, U.K., on using neural networks to predict biological conditions in aquatic ecosystems;
- University of Canberra, Australia, to develop multivariate analysis techniques on benthic data;
- University del Pais Vasco, Bilbao, Spain, to work cooperatively on spiked sediment bioassays using *Tubifex tubifex* and sediment assessment methods;
- EAWAG, Switzerland and U.S. EPA Region 8, on the state-of-the-art sediment trap techniques.

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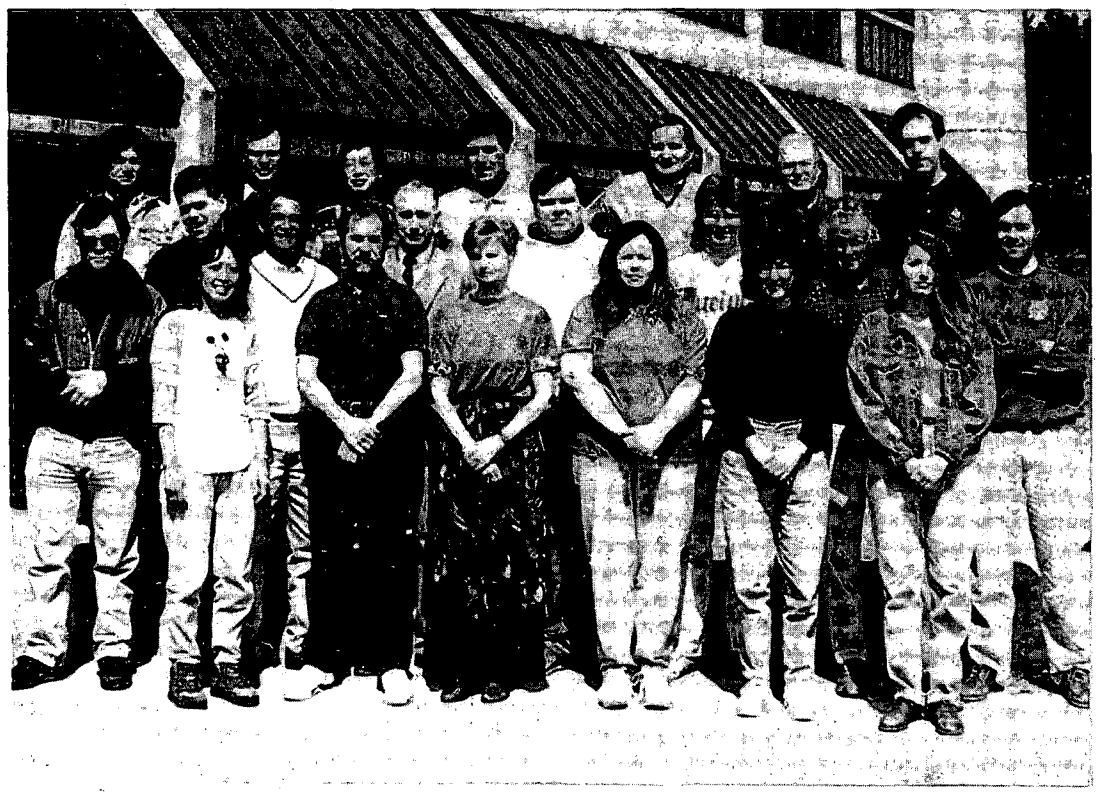

Figure 9: Sediment Remediation Project Team

Front Row (from left to right): Doug Doede, Nien Nguyen, John Dalton, Alena Mudroch, Sherri Thompson, Cheryl Clarke, Danielle Milani, José Azcue.
Centre Row (from left to right): Lloyd Hart, Ven Cheam, Togwell Jackson, Craig Logan, Scott Hughson, Trefor Reynoldson.
Back Row (from left to right): George Garbai, Mike Skafel, Henry Wong, Fernando Rosa, Alex Zeman, Bob Coker, Tim Patterson.
Absent: Jerry Rajkumar

GROUNDWATER REMEDIATION PROJECT

The Groundwater Remediation Project of AERB, NWRI conducts a multidisciplinary research program on the remediation and sustainability of groundwater resources in Canada. The research is conducted under the auspices of the Federal Water Policy, the Boundary Waters Act, the Pesticide Control Act, and the Atomic Energy Control Act. Emphasis is placed on determining the processes of contaminant transport and transformation in a variety of groundwater environments. New techniques for isolating or restoring existing groundwater contamination are being developed. Research is also conducted on the role played by groundwater in regional water budgets. Knowledge, generated from this research, is used to support regional activities within Environment Canada, and programs such as the Great Lakes and Atlantic Canada Action Plans. There are presently six study leaders with expertise in physical and chemical hydrogeology, biological systems in groundwater, and groundwater mechanics and modelling. Research is conducted in the following specific areas:

Figure 10. Groundwater sampling at the Gloucester landfill.

Contaminated Sites

- Development and field testing of geochemical and biological methods for improving the quality of migrating groundwater contamination in porous formations.
- Development of new models for simulating and predicting the installation of barrier walls which prevent the off-site migration of contaminated groundwater in fractured, unconsolidated media such as clays.
- Investigation of the processes of contaminant migration and restoration in complex fractured, groundwater environments such as are found beneath contaminated sites in southern Ontario and Atlantic Canada.

Sustainable Groundwater Resources

- Development of new groundwater modelling tools which optimize our ability to determine groundwater flow and contaminant transport within large watersheds.
- Investigation of the role of groundwater in the hydrological balance and sustainability of wetlands in the Great Lakes Basin.

Mining and Groundwater

- Research on the management and improvement of groundwater environments contaminated by high concentrations of metals from mine wastes.

Pesticides and Groundwater

- Development of pesticide transport models for improved prediction of pesticide persistence in groundwater environments.
- Field studies to assess the input of pesticides to surface waters via groundwater.

Research Studies

K. Novakowski (Project Chief, Contaminant Transport in Sedimentary Rock)

- Theory of solute transport in discrete rock fractures at the field scale.
- A study of the impact of large structural features on the presence of CH_4 and BTEX in shallow aquifers.
- Development of new hydraulic testing methods for determining the hydraulic properties of clays.

- A study of the influence of vertical fractures on groundwater flow in horizontally stratified sedimentary rocks.
- Development of methods for measuring the diffusion of chlorinated solvents in sedimentary rock samples.

A. Crowe (Pesticide Migration and Fate in Groundwater)

- Studies to quantify the role of groundwater in the hydrology and geochemistry of lakes/wetlands.
- Development and application of models for studying the fate of pesticides in the subsurface.
- Development of expert system technology for application to groundwater problems.

S. Lesage (Remediation of Organic Contaminants in Groundwater)

- A laboratory study of the dissolution and *in situ* degradation of DNAPL under anaerobic conditions using biological and biochemical methods.
- A field study of the remediation of a mixed DNAPL (PCE, TCE, TCA) using vitamin B12 and reduced titanium salts.
- A chemical study using multivariate analysis and chemical indicators to distinguish between anthropogenic and natural sources of petroleum hydrocarbons.
- The design of an indoor sand tank for the evaluation of bioremediation technologies.
- A laboratory study on the enhanced dissolution of PAHs from petroleum by humic acids.

A. Piggott (Fracture Hydraulics)

- Theory of solute transport and groundwater flow in discrete rock fractures at the laboratory scale.
- The development of inverse methods for the optimal representation of large scale groundwater flow and transport.
- The development of models for simulating hydraulic fracturing in the context of groundwater remediation.
- Formulation of laboratory protocols for the determination of solute transport.
- Development of methods of computer-assisted interpretation of hydraulic and tracer test results.

C. Ptacek (Inorganic Geochemistry)

- Application of geochemical models to the field setting.
- Field studies of the remediation of metal-contaminated groundwater.
- Evaluation of geochemical mechanisms controlling the migration of septic-system-derived effluent in aquifers.

I. Sekerka (Environmental Analytical Methodology)

- Investigation of the possibility of introducing solid samples to the laser-excited atomic fluorescence spectrometer.
- Analysis of groundwater samples for Pb, Tl and As.
- Investigation of the application of chemical and biochemical sensors and detectors for laboratory and *in situ* analysis and monitoring of groundwater.

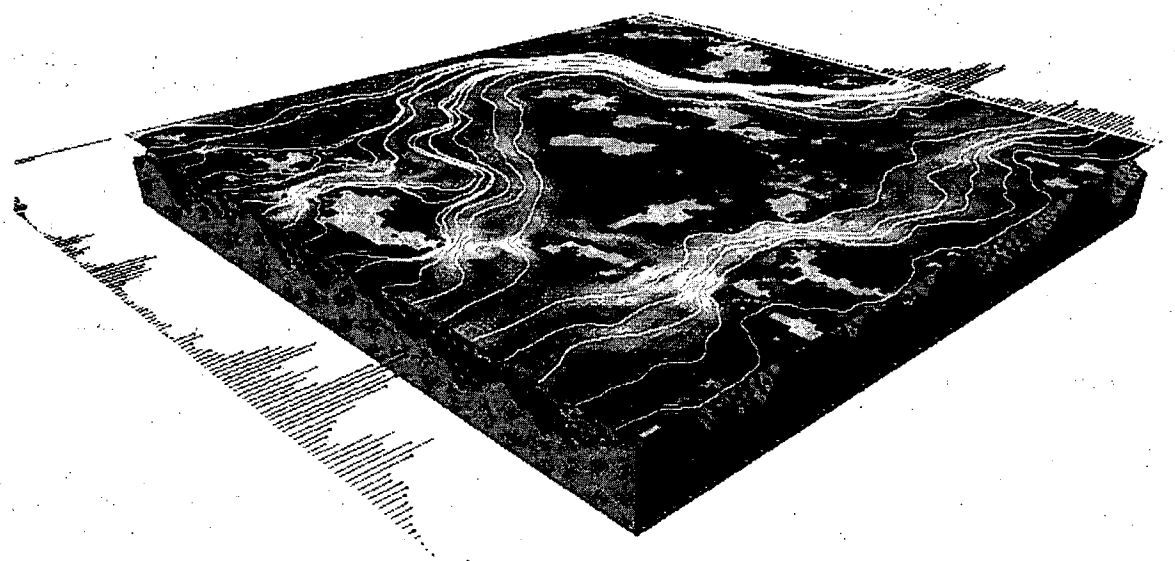

Figure 11: Visualization of groundwater flow and contaminant transport in a variable aperture fracture in rock.

Future Directions

Research activities of the Groundwater Remediation Project will continue to be multidisciplinary. Most research projects involve the use of field, laboratory, and computer modelling methods.

Research Sites

- Clarkson field site includes largest known concentration of boreholes in fractured rock in North America.
- Fletcher Creek site contains nine sub-vertical boreholes 25 to 40 m in depth, all completed in Guelph Formation.
- Wetlands study sites in the Sifton Bog in London, Ontario, the marsh at Point Pelee National Park and marsh near Copetown, Ontario.
- Field scale test of VB-12 as a remedial fluid conducted at the Borden military base.
- Septic system tile-beds at Point Pelee National Park, Ontario.
- Nickel Rim mine tailings impoundment near Sudbury, Ontario.

Selected Examples of Collaborative Research

- Universities of Waterloo, Western Ontario, and New Brunswick by formal agreement (Memorandum of Understanding);
- Brock University in the area of diffusion and transformation of BTEX in clay environments;
- Queens University on aqueous and non-aqueous phase transport in fractured rock;
- NHRI, Saskatoon, Saskatchewan, on radial diffusion and retardation, bacterial transport in fractures, and pesticide transport in the Abbotsford Aquifer in B.C.;
- University of Waterloo on the development of hydraulic testing methods for clays and the use of reductive dechlorinators for groundwater remediation;
- United States Geological Survey in the area of advective flow in boreholes and acid-mine drainage geochemistry;
- Pennsylvania State University in the area of groundwater and fracture geomechanics;
- University of Texas on inverse analysis characterization methodologies;
- The Project is a founding member of the recently formed Atlantic Groundwater Research Network which is being established to foster groundwater research in Atlantic Canada;
- Commercialization partnership with Department of the Environment Technology Development Branch on software licensing, laboratory equipment patenting, etc.

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Figure 12: Groundwater Remediation Project Team

Front Row (sitting from left to right): Allan Crowe, Carol Ptacek, Kent Novakowski, Andrew Piggott, Suzanne Lesage, Pat Lapcevic.
Centre Row (from left to right): Hao Xu, Jeff Bogan, Kelly Millar, Susan Brown, Chris Flaman.
Back Row (from left to right): John Voralek, Greg Bickerton, Shirley Schellenberg, Joe Lechner, John FitzGerald.
Absent: Ivan Sekerka, Louise Durham, Scott Bruce.

AQUATIC ECOSYSTEM RESTORATION BRANCH PROFESSIONAL AND TECHNICAL STAFF/EXPERTISE

DIRECTOR'S OFFICE

Director- Dr. R.J. Allan
BSc (Aberdeen), MSc (Wisconsin), PhD (Dartmouth), DSc (Aberdeen)
Applied geochemistry

Senior Research Scientists

Dr. J.M.Barica
MSc (Bratislava), PhD and DSc (Prague)
Limnology and algal ecology

Dr. G.K. Rodgers
BASc (Toronto), MSc (British Columbia), PhD (Toronto)
Engineering physics, oceanography and limnology

Research Liaison and Coordination

Dr. M.A. Zarull
BSc, MSc, PhD (McMaster)
Ecology, limnology and toxicology

Support Staff

Ethel Kerr
Director's Secretary

Elizabeth Wendel
Administrative Officer

Lisa Le May
Administrative Clerk

Dianne Crabtree
Word Processing Office

LAKE REMEDIATION

Chief - M.N. Charlton
BSc, MSc (Toronto)
Limnology

Study Leaders

M.E. Fox
BSc (Mount Allison)
Toxic organics chemistry

D.S. Painter
BSc, MSc (Guelph)
Aquatic plant studies

Dr. P.G. Manning
BSc, PhD (Wales)
Geochemistry of P, Fe and other metals

Dr. P.F. Hamblin
BSc (Toronto), MSc (British Columbia), PhD (Washington)
Wave dynamics and physics of lakes, rivers and estuaries

Dr. C.R. Murthy
BEng (Mysore), MEng (Indian Institute of Science), PhD (Waterloo)
Turbulent transport and diffusion processes in lakes

F. Chiocchio
BEng (Waterloo)
Physical limnology

Dr. J.P. Coakley
BSc (St. Francis Xavier), MSc (Ottawa), PhD (Waterloo)
Nearshore processes and sediment dynamics

K.C. Miners
BA (Western Ontario)
Physical limnology

Technologists

W. Booth
Senior Limnologist Technologist

P.A. Thiessen
Research Technologist

SEDIMENT REMEDIATION

Chief - A. Mudroch
Dipl Chem (State College, Prague), MSc (McMaster)
Bioavailability of sediment contamination

Study Leaders

Dr. T.B. Reynoldson
BSc (Leeds), MSc (Calgary), Ph.D. Lancaster)
Benthic invertebrates and sediment contaminant cycling

F. Rosa
BSc (McMaster)
Sediment-water processes and contaminant cycling

A.J. Zeman
BSc (Queen's), MSc (McGill)
Subaqueous erosion of lacustrine sediments

Dr. V. Cheam
BSc, PhD (Oklahoma)
Iron chromatography and atomic spectroscopy

Dr. M. G. Skafel
BA, BE, MSc (Saskatchewan), PhD (Cambridge), PEng
Coastal engineering

Dr. T.A. Jackson
BA (Columbia), MSc (Wisconsin), PhD (Missouri)
Biogeochemistry of mercury and other heavy metals

H.K. Wong
BSc (Waterloo)
Geochemistry

Dr. J.O. Nriagu
BSc (Ibadan), MSc (Wisconsin), PhD (Toronto), DSc (Ibadan)
Geochemistry, trace metals and sulphur in aquatic ecosystems

Technologists

R. Coker
Chemical Technologist

J. Dalton
Sediment Technologist

N. Nguyen
Biogeochemical Technician

S.P. Thompson
Biological Technologist

GROUNDWATER REMEDIATION

Chief - K.S. Novakowski
BSc (Brock), MSc, PhD (Waterloo)
Hydrogeology of fractured rocks

Study Leaders

Dr. A.S. Crowe
BSc (Waterloo), MSc, PhD (Alberta)
Groundwater and geochemical modelling

Dr. S. Lesage
BSc (Ottawa), PhD (McGill)
Remediation of organic groundwater contaminants

Dr. I. Sekerka
RNC, RNDr. (Prague), CSc (Ostrava)
Electroanalytical chemistry and continuous flow analysis

Dr. A.R. Piggott
BASc (Toronto), MEng (Toronto), PhD (Pennsylvania State), PEng
Groundwater geomechanics

Dr. C.J. Ptacek
BA (Wisconsin), MSc, PhD (Waterloo)
Groundwater geochemistry of mine effluents

Technologists

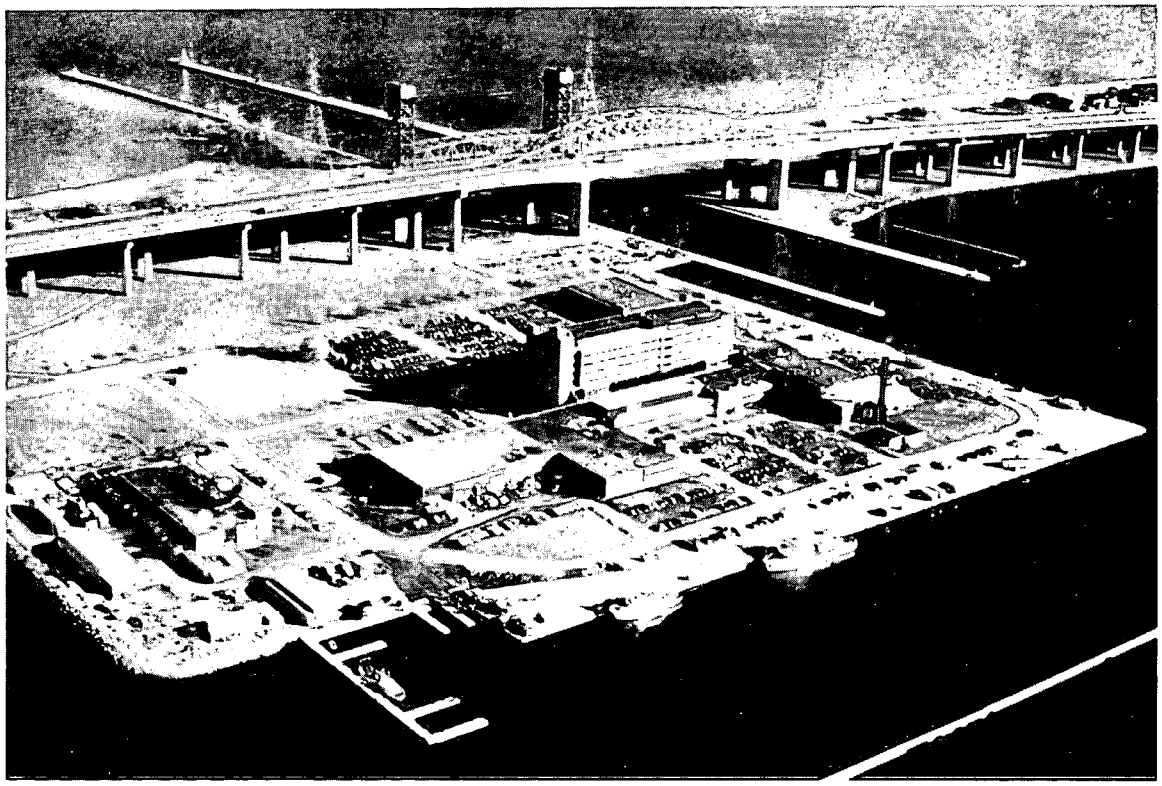
P.A. Lapcevic
BSc (Waterloo)
Hydrogeology

K.R. Millar
BSc (Toronto), MSc (Guelph)
Microbiology

S. Brown
Research Technologist

J.A. FitzGerald
Radio Chemical Technologist

J. Lechner
Analytical Methods/Instrumentation Technologist



Aquatic Ecosystem Restoration is a branch of the National Water Research Institute located at the Canada Centre for Inland Waters (CCIW).

The above photograph of CCIW was taken from the air over Hamilton Harbour looking east towards Lake Ontario.

Canada Centre for Inland Waters
867 Lakeshore Road, P.O. Box 5050,
Burlington, Ontario
L7R 4A6

Phone: (905) 336-4566
Fax: (905) 336-6430

Canada