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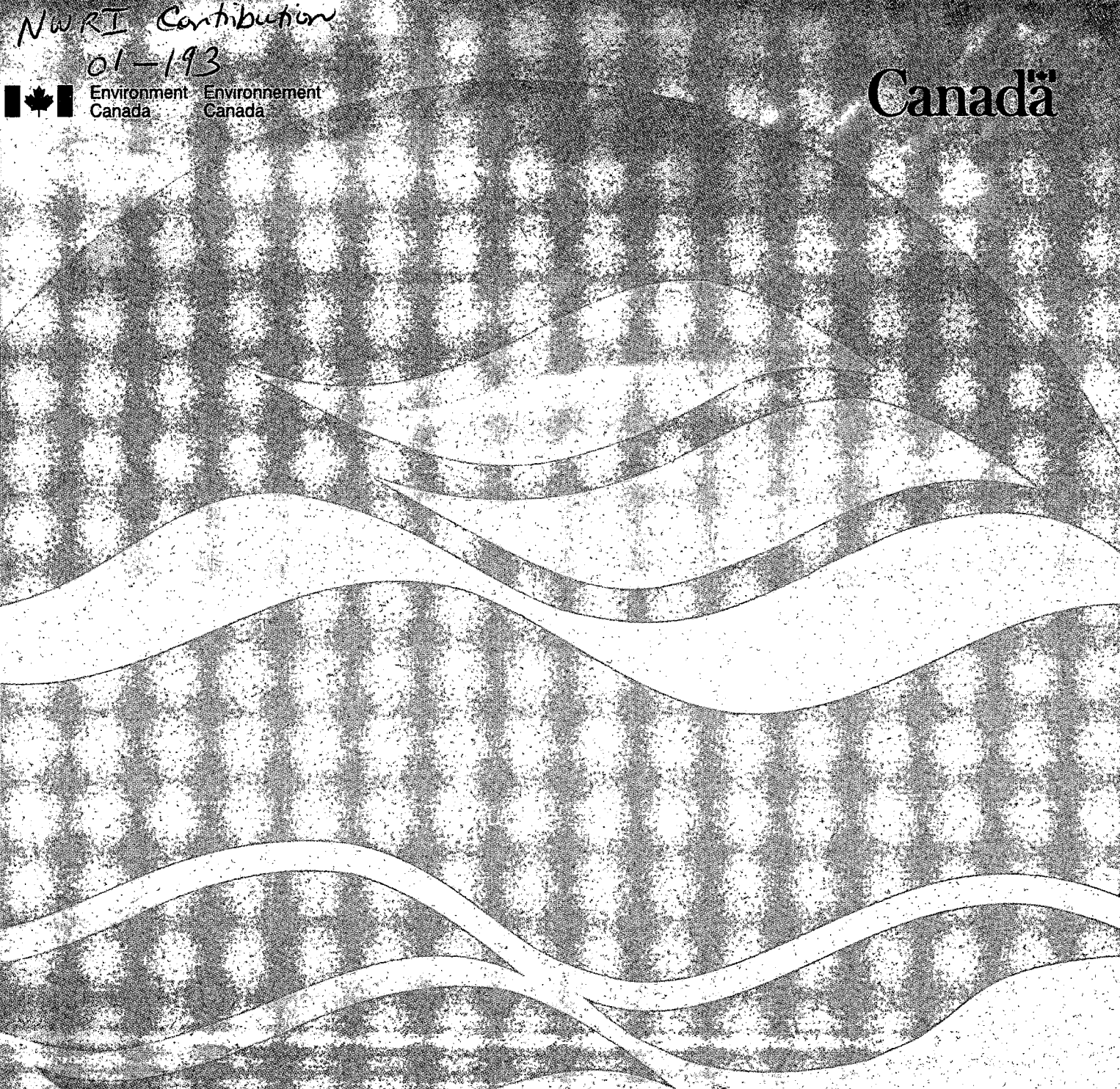

CURRENT RESEARCH - 2000/2001

AQUATIC ECOSYSTEM MANAGEMENT RESEARCH BRANCH

J. Lawrence

NWRI Contribution Number 01-193

Current Research - 2000/2001

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AEMRB Current Research 2000-2001

MANAGEMENT PERSPECTIVE

This report presents an overview of the Aquatic Ecosystem Management Research Branch activities in fiscal year 2000-2001, for our numerous domestic and international partners and collaborators, as well as interested colleagues and a knowledgeable public audience.

This work was conducted under Environment Canada's Management Framework, contributing to the Business Lines, Clean Environment and Nature. These research results contribute to our understanding and management of several Environment Canada priorities, programs and initiatives, including; Great Lakes 2020, the Toxic Substances Research Initiative, the Large Ecosystems Initiative and Petroleum Energy Research and Development.

Key research activities conducted in 2000-2001 include the assessment of aquatic ecosystem health, development of indicators of ecosystem state and recovery, impacts of urban point and non-point sources of pollution on receiving environments, control of urban pollution and, development of remediation approaches for contaminated groundwater and sediments. This report presents a synopsis of the extensive and diverse research work by the scientists of AEMRB.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Le présent rapport donne un aperçu des activités de la Direction de la recherche sur la gestion des écosystèmes aquatiques (DRGEA) pour l'exercice financier 2000-2001, à l'intention de nos nombreux partenaires et collaborateurs à l'échelle nationale et internationale, de collègues intéressés et de citoyens bien renseignés.

Les travaux de recherche, menés afin de contribuer au Cadre de gestion d'Environnement Canada, visaient à atteindre les objectifs des secteurs d'activité suivants Environnement sain et Nature. Les résultats de ces recherches nous permettent de comprendre et de gérer plusieurs priorités, programmes et initiatives d'Environnement Canada, notamment : Grands Lacs 2020, Initiative de recherche sur les substances toxiques, Initiative des grands écosystèmes et Programme de recherche et développement dans le secteur de l'industrie pétrolière.

Les principales activités de recherches menées en 2000-2001 comprennent l'évaluation de la santé des écosystèmes aquatiques, l'élaboration d'indicateurs de l'état des écosystèmes et de leur restauration, les impacts des sources de pollution urbaines ponctuelles et diffuses sur les milieux récepteurs, le contrôle de la pollution urbaine et le développement de mesures correctives pour les eaux souterraines et les sédiments contaminés. Le présent rapport constitue un résumé des divers travaux de recherche menés par les chercheurs de la DRGEA.

ABSTRACT

The Aquatic Ecosystem Management Research Branch (AEMRB), one of three research branches of the National Water Research Institute, conducts research to assess and manage surface and ground water systems degraded by anthropogenic activities. Key research activities include assessment of aquatic ecosystem health, development of indicators of ecosystem state and recovery, impacts of urban point and non-point sources of pollution on receiving environments, control of urban pollution and, development of remediation approaches for contaminated groundwater and sediments. This work is conducted within four interdisciplinary projects; Urban Water Management Research, Lake Management Research, Ecosystem Monitoring and Assessment and Aquatic Ecosystem Remediation. This report provides a synopsis of the extensive and diverse research work by our scientists for the fiscal year 2000-2001.

RÉSUMÉ

La Direction de la recherche sur la gestion des écosystèmes aquatiques (DRGEA), une des trois directions de l'Institut national de recherche sur les eaux, mène des travaux de recherche sur la gestion et l'évaluation des eaux de surface et des eaux souterraines dégradées par les activités anthropiques. Les principales activités de recherche comprennent l'évaluation de la santé des grands écosystèmes aquatiques, l'élaboration d'indicateurs de l'état des écosystèmes et de leur restauration, les impacts des sources de pollution urbaines ponctuelles et diffuses sur les environnements récepteurs, le contrôle de la pollution urbaine et le développement de mesures correctives pour les eaux souterraines et les sédiments contaminés. Ces travaux sont réalisés dans le cadre de quatre projets interdisciplinaires : Recherche sur la gestion des eaux urbaines, Recherche en gestion des lacs, Surveillance et évaluation des écosystèmes, et Restauration des écosystèmes aquatiques. Le présent rapport constitue un résumé des divers travaux de recherche menés par les chercheurs de la DRGEA au cours de l'exercice financier 2000-2001.

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DIRECTOR'S INTRODUCTION

The National Water Research Institute (NWRI) is Canada's largest freshwater establishment. It conducts a comprehensive program of research and development in the aquatic sciences, in partnership with the Canadian and international science communities. Through ecosystem-based research, NWRI creates and disseminates new knowledge and understanding of aquatic ecosystems required for the resolution of environmental issues of regional, national or international significance to Canada.

The Aquatic Ecosystem Management Research Branch (AEMRB), one of three research branches of the National Water Research Institute, conducts research to assess and manage surface and ground water systems degraded by anthropogenic activities. AEMRB delivers research results within Environment Canada's Management Framework, contributing to the Business Lines, Clean Environment and Nature. Key research activities include assessment of aquatic ecosystem health, development of indicators of ecosystem state and recovery, impacts of urban point and non-point sources of pollution on receiving environments, control of urban pollution and, development of remediation approaches for contaminated groundwater and sediments. Branch scientists assess contaminant fate and effects, develop models and, apply knowledge and expertise to generate and evaluate mitigative and rehabilitative techniques and technologies. This work is conducted within four interdisciplinary projects.

The Urban Water Management Research Project, led by Dr. J. Marsalek, conducts research on the characterization, effects and controls of urban wet weather pollution; urban sediment contamination; fine sediment transport and flocculation; floc-contaminant associations and; best management practices for the control of agricultural pollution.

The Lake Management Research Project, led by Mr. M. Charlton, performs research on nutrient and sediment management in the Great Lakes; contaminants in Great Lakes Areas of Concern; PAHs and metabolites in sediment and biota, taste and odour compounds in drinking water sources; nearshore erosion and sediment transport; coastal engineering; coastal water movement; sediment-water contaminant exchange and; sustainable aquaculture.

The Ecosystem Monitoring and Assessment Project, led by Dr. T. Reynoldson, provides research on the bioassessment of aquatic ecosystem quality; metal mining; the impacts of long-range transport of acid precipitation; the hydrogeochemical responses to acid rain; remote monitoring of aquatic, wetland and terrestrial ecosystems; ultra violet radiation fluxes in aquatic ecosystems and; the statistical analysis of water quality.

The Aquatic Ecosystem Remediation Project, led by Dr. S. Lesage, conducts research on groundwater flow and contaminant transport in fractured rock; remediation on chlorinated solvents in groundwater; biobarriers in fractured bedrock; sediment remediation; geochemistry of metals and nutrients in groundwater; subsurface water remediation with humic substances; physical sedimentology of contaminated sediments and *in situ* capping of contaminated sediments.

This report presents an overview of the branch activities in fiscal year 2000-2001 for our numerous domestic and international partners and collaborators, as well as interested colleagues and a knowledgeable public audience. This report should provide a synopsis of the extensive and diverse research work by our scientists and the reader is encouraged to contact the Study Leaders directly for more detailed information.

John Lawrence
July 2001

INTRODUCTION DU DIRECTEUR

L'Institut national de recherche sur les eaux (INRE) est le plus grand établissement de recherche sur les eaux douces du Canada. On y exécute un programme complet de recherche et développement dans le domaine des sciences aquatiques en partenariat avec les communautés scientifiques du Canada et de l'étranger. Grâce aux recherches écosystémiques, l'INRE a fait reculer les limites de la connaissance et de la compréhension des écosystèmes aquatiques et a diffusé ces connaissances pour régler les problèmes environnementaux ayant une importance régionale, nationale ou internationale pour le Canada.

La Direction de la recherche sur la gestion des écosystèmes aquatiques (DRGEA), une des trois directions de l'Institut national de recherche sur les eaux, mène des travaux de recherche sur la gestion et l'évaluation des eaux de surface et des eaux souterraines dégradées par les activités anthropiques. Les travaux de recherche, menés afin de contribuer au Cadre de gestion d'Environnement Canada, visaient à atteindre les objectifs des secteurs d'activité suivants Environnement sain et Nature. Les principales activités de recherche comprennent l'évaluation de la santé des écosystèmes aquatiques, l'élaboration d'indicateurs de l'état des écosystèmes et de leur restauration, les impacts des sources de pollution urbaines ponctuelles et diffuses sur les milieux récepteurs, le contrôle de la pollution urbaine et le développement de mesures correctives pour les eaux souterraines et les sédiments contaminés. Les chercheurs de la Direction évaluent le devenir et les effets des contaminants, élaborent des modèles et utilisent leurs connaissances et leur expertise pour mettre au point et évaluer des techniques et des technologies d'atténuation des impacts et de remise en état. Les travaux de la Direction sont effectués dans le cadre de quatre projets interdisciplinaires.

Le Projet de recherche sur la gestion des eaux urbaines, dirigé par le D[r] J. Marsalek, porte sur la caractérisation et les effets de la pollution liée aux épisodes de précipitation, ainsi que les moyens d'intervention; la contamination des sédiments urbains; le transport et la flocculation des sédiments fins; les associations flocs-contaminants; enfin, les pratiques de gestion optimales pour le contrôle de la pollution agricole.

Le Projet de recherche en gestion des lacs, dirigé par M. M. Charlton, porte sur la gestion des éléments nutritifs et des sédiments dans les Grands Lacs; les contaminants dans les secteurs préoccupants des Grands Lacs; les HAP et leurs métabolites dans les sédiments et le biote; les composés sapides et odorants dans les réseaux d'eau potable; l'érosion côtière et le transport des sédiments; les travaux maritimes; le mouvement des eaux côtières; l'échange de contaminants dans les sédiments et l'eau; enfin, l'aquaculture durable.

Le Projet de surveillance et d'évaluation des écosystèmes, dirigé par le D[r] T. Reynoldson, porte sur l'évaluation biologique de la qualité des écosystèmes aquatiques; l'exploitation des mines de métaux; les effets du transport à distance des précipitations acides; les réactions hydrogéochimiques aux précipitations acides; la surveillance spatiale des milieux aquatiques et terrestres ainsi que des milieux humides; les flux de rayonnement ultraviolet dans les écosystèmes aquatiques; enfin, l'analyse statistique de la qualité de l'eau.

Le Projet de restauration des écosystèmes aquatiques, dirigé par le D[r] S. Lesage, porte sur l'écoulement des eaux souterraines et le transport des contaminants dans la roche mère fracturée; l'assainissement des eaux souterraines contaminées par des solvants chlorés; les barrières biologiques dans la roche mère fracturée; l'assainissement des sédiments; la géochimie des métaux et des éléments nutritifs dans les eaux souterraines; la dépollution des eaux subsuperficielles à l'aide de substances humiques; enfin, la sédimentologie physique des sédiments contaminés et le recouvrement *in situ* des sédiments contaminés.

Le présent rapport présente un aperçu des activités des différentes directions au cours de l'exercice financier 2000-2001 à l'intention de nos nombreux partenaires et collaborateurs à l'échelle nationale et internationale, de collègues intéressés et de citoyens bien renseignés. Le présent rapport constitue un résumé des divers travaux de recherche menés par les chercheurs de l'INRE, et le lecteur est invité à communiquer avec les chefs de projet pour de plus amples renseignements.

John Lawrence
Juillet 2001

URBAN WATER MANAGEMENT PROJECT

The UWM Project provides essential scientific information on management of urban water resources, including water supply issues; sources, transport, effects, control and treatment of urban wastewaters; and sustainable management of urban receiving waters and their ecosystems. Environment Canada uses this knowledge to make decisions with respect to various acts and environmental initiatives, including the Canada Water Act (1970), the Canadian Environmental Protection Act, the Great Lakes Water Quality Agreement as amended by the 1987 protocol, and Priority Ecosystem Initiatives, including Great Lakes Basin 2020. Current activities include assessment of urban wastewater impacts on sediment and benthic communities, characterization of floc/contaminant associations in relation to contaminant transport and transformations, combined sewer overflow characterization and treatment, control of agrochemical pollution by best management practices, development of best management practices for urban stormwater control, fine sediment transport processes and dynamics, and support of international activities on urban water management.

STUDY TITLE: **Management of Urban Wet-Weather Pollution in the Great Lakes Region**

STUDY LEADER: J. Marsalek
STUDY TEAM: B.G. Krishnappan, Q. Rochfort (contractor)
PARTNERS: Queen's University, Kingston; Wastewater Technology Centre, Burlington
CLIENTS: Great Lakes Sustainability Fund (GLSF), City of Toronto, Toronto Region Conservation Authority
FUNDING: GL 2020, GLSF

Introduction

Urban wet-weather pollution is one of the major impediments to delisting a number of Areas of Concern with significant discharges of urban stormwater and combined sewer overflows (CSOs). To develop the knowledge required by remedial action planning teams to control wet-weather pollution, novel methods for mitigation of stormwater and combined sewer overflow pollution are being developed. This work is done in collaboration with colleagues at NWRI, research partners at Queen's University (Kingston, Ontario) and Wastewater Technology Centre (Burlington, Ontario), and several supporting partners - the Great Lakes Sustainability Fund (GLSF), the City of Toronto, and the Toronto Region Conservation Authority.

Study Areas: Toronto

Results

Two classes of stormwater quality controls were addressed - source controls and filters. Urban stormwater Source Control Measures (SCMs) are non-structural as well as structural measures designed to reduce urban runoff flows and pollutant entry into stormwater. SCMs offer numerous advantages, because they serve to prevent rather than just abate drainage problems. An overview of source control measures starts with measures reducing runoff by infiltration, urban development resource planning and on-site rainwater/stormwater detention and infiltration. Other SCMs enhance urban runoff quality. The measures addressed included public education and participation, land use planning and management, management of potentially harmful materials, preventative maintenance, and progressive sewer ordinances and their enforcement. Source controls should be selected with respect to the pollutants of concern, regulatory requirements, public acceptance, ease of implementation, costs and institutional constraints, and evaluated for local conditions. Source controls for urban stormwater and agricultural runoff were discussed at a NATO Advanced Research Workshop, which was held at St. Marienthal, Germany, Nov. 8-12, 2000. Workshop preprints were published and formal proceedings will be published in the fall, 2001.

Laboratory studies of stormwater sand filters were completed in the form of an in-house study and a graduate student project, for which co-supervision was provided by J. Marsalek. A M.Sc. thesis was successfully defended in April, 2000. Sand filters were found effective in removing suspended solids (up to 99% removal), and dissolved metals (83%). Even higher removals were obtained with biofilters tested at NWRI (>90%). Field testing of a biofilter indicated that the ultimate performance of stormwater filters is controlled by their maintenance - the frequency of backwashing. Research findings indicate that pretreated stormwater can be polished to high quality, as may be required in the case of sensitive receiving waters.

This information will be used in further development of stormwater treatment technologies and also by the designers and operators of stormwater management facilities.

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STUDY TITLE: Measurement of Urban Wet-Weather Pollution Impacts on Receiving Waters in the Great Lakes Region

STUDY LEADER:	J. Marsalek
STUDY TEAM:	L. Grapentine, B.G. Krishnappan, B. Brownlee, G. Leppard, Q. Rochfort (contractor)
PARTNERS:	Wastewater Technology Centre, Burlington
CLIENTS:	Great Lakes Sustainability Fund (GLSF), City of Toronto, Toronto Region Conservation Authority
FUNDING:	GL2020, GLSF

Introduction
Urban wet-weather pollution is recognized as one of the major impediments to delisting a number of Areas of Concern with significant discharges of urban stormwater and combined sewer overflows (CSOs). To develop the knowledge required by remedial action planning teams to control wet-weather pollution, novel methods for the evaluation of impacts of wet-weather pollution on urban streams were investigated. These activities were undertaken in collaboration with colleagues at NWRI, research partners at Queen's University (Kingston, Ontario) and Wastewater Technology Centre (Burlington, Ontario), and several supporting partners - the Great Lakes Sustainability Fund (GLSF), the City of Toronto, and the Toronto Region Conservation Authority.

Study areas: Hamilton, Kingston, Ottawa and Toronto (Ontario)

Results
Studies of urban wastewater impacts on sediment toxicity and benthic communities were conducted at nine field sites in Hamilton, Kingston, Ottawa and Toronto. Investigations of sediment chemistry, sediment toxicity and benthic community structure (BCS) upstream and downstream of sewer outfalls were completed and results published in a journal paper. These results indicate that in spite of chemical contamination, the stream sediments show relatively low toxicity (as measured by laboratory bioassays) or nutrient enrichment at some sites, and benthic invertebrate communities are not significantly different between locations upstream and downstream of outfalls. This effect was also observed in a subsequent study of a CSO outfall into the Don River. In later experiments, research focused on two stormwater outfalls in Greater Toronto. Effects on BCS were examined using colonized artificial substrates transplanted into locations upstream and downstream of the outfalls. In the same locations, *in situ* toxicity tests were performed with caged amphipods. Bioavailability of contaminants (metals and PAHs) were measured in both caged and field collected organisms. In addition, laboratory flume experiments using the substrates were conducted to study effects of shear stress, sediment smothering, and stormwater contaminants. Preliminary results for the caged amphipods indicate no outfall-associated toxicity and only low bioaccumulation of metals. Analyses of other experimental results are in progress. Investigations of chemical speciation of trace metals in stormwater pond and wetland sediments indicated that significant fractions of metal burdens were in potentially mobile forms and could be released into the

overlaying water column. Such environmental risks can be reduced by proper maintenance, including contaminated sediment removal. Another impact of urban runoff is the thermal pollution caused by runoff heating, by solar energy, on impervious surfaces and in storage facilities. Results of the earlier completed studies were now published in two journal papers. The new information on low effects of urban sediment on benthos, mobility of metals in urban sediments, and thermal effects of urban runoff will be used in mitigation of impacts of urban stormwater and CSOs on receiving waters.

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STUDY TITLE: Flocs and Colloids: Structure and Behaviour within Natural and Engineered Systems

STUDY LEADER:	Gary G. Leppard and Ian G. Droppo
STUDY TEAM:	C. Jaskot, B. Trapp
PARTNERS:	Ryerson Polytechnic University, McMaster University, University of Toronto, multiple industrial partners, University of Ottawa, Northwestern University in greater Chicago, Universities of Geneva, Lausanne and Neuchatel in Switzerland
CLIENTS:	EC and industrial supporters, and international funding agencies
FUNDING:	NSERC, GLAP, GLB 2020, TSRI, STAGE, EC, international

Introduction

Investigations into the source, fate and effect of sediments and associated contaminants have typically relied on traditional methods of sediment sampling and analysis which do not take into account the structure of the sediment. Awareness is increasing that the structure of sediment particles (flocs) controls the physical, chemical and biological behaviour of the sediment. Flocs constitute a complex matrix of microbial communities, organic matter (detritus, cellular debris and extracellular polymers) and inorganic cohesive materials. Most of these intrafloc components are colloidal in nature. Research is currently focusing on 1) how the microbial population mediates the growth, strength, and contaminant uptake/transformation of flocs in both natural and engineered wastewater facilities, 2) compartmentalization of metals to intrafloc colloidal components, 3) characterization of the different colloidal components of flocs, to relate specific colloids to specific activities, and 4) ascertaining how the gross floc structure (size, shape, porosity) influences the transport characteristics of flocs in various environments.

Study Areas: Hamilton Harbour, Toronto Harbour, numerous Canadian rivers, numerous industrial wastewater treatment systems in Canada and USA.

Results

Research has been carried out in two areas; natural aquatic systems and engineered wastewater systems. A comprehensive conceptual model has been developed to enhance our understanding of what constitutes flocculated material and how it influences our aquatic and engineered environments. It has been determined that it is the surface properties of flocs (hydrophobicity, surface charge and extracellular polymeric substances (EPS) composition), rather than the quantity of EPS, that govern bioflocculation. The EPS content was found to be more important in controlling the settleability of flocs. Work with industrial activated sludge floc has revealed a propensity for metals to bind to specific colloidal

components of the floc. Results suggest that biomanipulation of the above floc parameters may allow for an improved operation efficiency of treatment systems, in terms of sediment and contaminant removal.

The following results were achieved using multi-method combinations of transmission electron microscopy, energy-dispersive spectrometry, electron energy loss spectrometry, laser scanning confocal microscopy and synchrotron-based X-ray absorption spectrometry in combination with standard methods of analytical chemistry, microbiology, biochemistry and engineering.

- For contaminant transport in Hamilton Harbour, it was shown that carriers of PAHs in one portion of the Harbour have markedly different physico-chemical properties (density, size, activity) than carriers in another portion (flocs vs colloidal humic substances), a result of importance for improved contaminant modeling.
- Nanoscale observations on floc architecture revealed how specific characteristics of flocs in bench-scale versions of wastewater treatment tanks can be manipulated.
- For small contaminated lakes (copper in Larder Lake, zinc in Lake DePue), the major sinks for the heavy metal pollutants were described in terms of specific sediment materials having specific physico-chemical properties.

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STUDY TITLE: Transport/Erosional Characteristics of Contaminated Bed Sediment

STUDY LEADER: Ian G. Droppo
STUDY TEAM: C. Jaskot, B. Trapp
PARTNERS: Southampton Oceanographic Centre (SOC)
CLIENTS: EC, SOC
FUNDING: EC, SOC

Introduction

Hamilton Harbour, Ontario, is one of the 42 Areas of Concern (AOC) around the Great Lakes designated by the International Joint Commission (IJC) due to environmental impairments. As with the majority of AOCs, Hamilton Harbour has been identified as having impaired bed sediments due primarily to anthropogenic inputs of heavy metals and PAHs. Because there is busy ship traffic within Hamilton Harbour, concern has been raised over the possibility of the resuspension of this contaminated sediment by propeller wash, with its eventual transport to, and contamination of, cleaner areas of the Harbour. Experiments on the erosion characteristics of contaminated bed sediments from Hamilton Harbour as well as controlled flume experiments with kaolin clay were conducted in an annular flume.

Study Areas: Hamilton Harbour

Results

It was discovered that the way in which the bed deposited (e.g., deposited under quiescent conditions, or under shear) had a strong influence on the stability of the bed. The amount of stress required to erode beds deposited under shear was up to eight times larger than for beds deposited under quiescent conditions. In addition, it was discovered that the presence of biofilm had very significant impacts on the erosion resistance of the bed as well as on the behaviour of the sediment flocs brought into suspension.

The results of this study are relevant to any aquatic environment where sediment remobilization is of concern and should be considered when the transport of sediments and associated contaminants are being modelled.

CONTACT
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STUDY TITLE: Combined Sewer Overflows and Stormwater Runoff

STUDY LEADER:	Ian G. Droppo
STUDY TEAM:	C. Jaskot, B. Trapp
PARTNERS:	State University of New York, College at Buffalo, Ryerson Polytechnic University
CLIENTS:	EC, biotechnology and industrial supporters
FUNDING:	EC, STAGE

Introduction
Surface washoff generated during rain storms in urban and industrial areas can collect and deliver significant quantities of pollutants to natural aquatic environments. Contaminants can be transported through urban systems and to receiving water bodies via a number of different, but linked pathways. These linked pathways are referred to as the urban continuum and include the sequential transport of surface washoff from depositional and erosional surfaces to sewer systems and finally to receiving water bodies (via combined sewer or storm sewer outfalls) or to sewage treatment plants. Management of surface washoff through various best management practices (BMPs) helps to minimize the impact of stormwater washoff from urban and industrial surfaces on receiving water bodies. Research is currently focusing on 1) evaluating the changes in sediment structure and contaminants as they progress through the urban continuum to a receiving water body via a CSO, 2) evaluating the washoff characteristics of industrial coal pile towards the development and implementation of BMPs and 3) evaluating how the microbial community structure of bed sediments are impacted by the effluent from combined sewer and stormwater overflows.

Study Areas: Toronto Harbour

Results
Research into the physical characteristics of flocculated particles as they progress through the urban environment (surface deposition>washoff>sewer transport>CSO>receiving water body) has demonstrated substantial changes in floc size, density, porosity and settling velocity as they move through the linked pathways of the urban environment. From our floc research, we know that changes in floc structure will influence their propensity to uptake and modify contaminants collected/adsorbed within the urban continuum. Results indicate the importance of measuring floc characteristics and how they change through the urban continuum to improve future modelling of sediment and contaminant transport and for the evaluation, modification and/or development of BMPs aimed at minimizing the impact of the urban continuum on our aquatic ecosystems.

Runoff from industrial stockpiled coal can represent a significant source of contaminants to receiving water bodies. Laboratory simulations of stormwater runoff from industrial coal piles revealed that the hydrophobicity and structural characteristics of the sediment controlled the runoff dynamics of coal piles.

Temporal changes in the packing and surface seal development resulted in substantial changes in runoff characteristics. Coal particles within runoff were found to resist flocculation which, combined with the low density of coal, suggest a propensity for a longer range of transport than if the particles flocculated. Results show the need to determine the optimal slope which minimizes water contact time, but at the same time, minimizes the potential for mass wasting and rill erosion. Promotion of a 'sealed' surface is beneficial for the minimization of solids removal while a stormwater detention pond with potential flocculant additive was suggested as a viable remedial measure for the containment and treatment of coal pile runoff.

Through various microbial analytical techniques, it was observed that bed sediments impacted by urban environments will possess different microbial communities than those which are not impacted by urban environments. Using Toronto Harbour as a study site, factor analysis illustrated a significant difference between control, CSO and storm sewer effluent impacted bed sediment microbial communities. Work is ongoing to investigate the contaminant/sediment/microbial relationships which are responsible for these differences.

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STUDY TITLE: **Fine Sediment Transport Processes and Sediment/Contaminant/Biota Interactions**

STUDY LEADER:	B.G. Krishnappan
STUDY TEAM:	Dr. J. Marsalek and Mr. Robert Stephens
PARTNERS:	Department of Indian Affairs and Northern Developments
CLIENTS:	Environment Canada, RAPs.
FUNDING:	DIAND, GL2020

Introduction
Fine sediments play a major role in the transport of contaminants through aquatic ecosystems and hence the knowledge of their transport processes, such as erosion, deposition, settling and flocculation, is vital for preserving the health of the ecosystem. At the present time, our knowledge of the fine sediment transport processes is far from complete and there is a definite need for further research in this area. To address this need, we have initiated a comprehensive research program on fine sediment transport processes. In our research, we study the transport processes of fine sediment both in the field and in the laboratory. For field research, we have developed some sophisticated field instruments that allow us to measure the fine sediment transport properties under the field conditions. For laboratory research, we have a specially designed rotating circular flume in which we can generate realistic turbulent flow conditions and study the fine sediment transport processes under controlled conditions. Some of the significant results of our studies that we carried out during the study year 2000-2001 are outlined below:

Study Areas: St. Lawrence River, Cornwall

Results
Field testing of the in-situ erosion flume in the St. Lawrence River near Cornwall, Ontario:
Field testing of our new in-situ erosion flume was carried out in the St. Lawrence River near Cornwall, Ontario. The flume was deployed from a boat and was positioned on the sediment deposit with the help

of two underwater video cameras mounted on the frame of the flume. When resting on the sediment bed, the flume has a configuration of a rectangular duct measuring 2.5 m in length, 0.30 m in width and 0.08 m in height. The bottom part of the flume is open over a length of 1.0 m and a width of 0.30 m, and the opening begins at a distance of 0.75 m from the flume entrance. The entrance section of the flume consists of two segments. The first segment is a smoothly contracting section that accelerates the flow as it enters the flume. The second section is a flow straightening section and contains a set of straight acrylic tubes over the whole cross section to damp out any secondary circulation. The exit section of the flume contracts gradually into a circular cross section and connects to a pump that draws water through the flume and discharges to the ambient. When the flume is resting on the sediment bed properly, the surface of the bed will be in line with the bottom plate of the flume at both end-sections of the flume. The average shear stress acting on the exposed sediment bed is related to the flow rate through the flume and the flow rate in turn was measured using a pitot tube mounted at a fixed height over the exposed sediment bed. The relationship between the pitot tube reading and the flow rate was established by calibration. The amount of sediment eroded was obtained by measuring the concentration of the sediment in the water column using two optical sensors. An underwater video camera was installed in the flume to facilitate the visual observation of the erosion of the sediment bed.

Three sites were chosen for testing the erodibility of sediment in the study area. After ensuring that the flume is resting on the sediment bed properly, the flow through the flume was increased gradually in steps. Each step was maintained for about 30 minutes. During each step, the output signals from the optical sensors and the pitot tube were monitored and the data were stored on a hard drive in an onboard computer. The video signal from the underwater camera was recorded on a VCR for further viewing. The number of flow steps tested varied from five to eight covering a bed shear stress range from 0.1 to 1.0 N/m^2.

Results of the tests indicated that the sediment bed consists of a top layer of loose sediment that can be eroded easily (at bed shear stresses in the order of 0.1 N/m^2) and a resistive stiff layer below (low transport rate even at the maximum flow). The results from these tests will be useful for the Remedial Action Plan for the Cornwall region for developing clean up strategies for the contaminated sediment at this site.

Measurement of sediment transport parameters for the Hay River sediment in collaboration with the Department of Indian Affairs and Northern Developments.

Erosion and deposition characteristics of sediments from the Hay River near Hay River, Northwest Territories were studied in the rotating circular flume. The study was funded by the Department of Indian Affairs and Northern Development. For this study, samples of sediment and water were brought from the river and were placed in the rotating flume. For collecting the sediment samples, a newly designed and built fine sediment sampler was used. This sampler collected the fine sediment deposited on a coarse gravel bed. It had an inverted cone with a propeller to dislodge the fine sediment. The resuspended sediment was then pumped from the sampler into a container placed in the boat. The inverted cone sampler was also fitted with an underwater video camera to observe the stream bed topography and the sample collection process.

The deposition experiments in the rotating flume showed that the Hay River sediment behaved in a manner similar to that of the cohesive sediment and the experiments yielded quantitative data on the critical shear stress for deposition and the rates of deposition as a function of bed shear stress and the initial concentration of the suspended sediment. The erosion experiments indicated that the growth of the biofilm on the sediment deposit is a significant factor for determining the erosion resistance of the Hay River sediment. Further research is needed to quantify this effect.

Initiation of a study to examine the effect of flow and sediment transport rate on benthic invertebrates using the rotating circular flume in collaboration with Drs. Marsalek and Grapentine.

The assessment of benthic communities in terms of species richness and organism abundance is often used as a means of assessing the impact of pollution on aquatic ecosystem. However, recent studies have suggested that the physical factors such as flow velocity and sediment deposition (siltation) can also affect the benthic communities' richness and abundance. To understand this process further, a new study was initiated in collaboration with Drs. Marsalek and Grapentine of NWRI. In this study, the flow field was generated using the rotating circular flume and the benthic communities were brought to the flume by colonizing them onto concrete tiles placed in an urban stream impacted by sewer outfalls. As a preliminary investigation, the concrete tiles were tested under three different flow conditions. The roughness of the flume bed was adjusted to match the stream bed by placing a 10 cm thick layer of about 2 cm stones in the flume. The assessments of the benthic communities subjected to the flow fields are currently underway.

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STUDY TITLE: Development of High Technology for the Analysis of Aquatic Colloids and Flocs

STUDY LEADER:	Gary G. Leppard
STUDY TEAM:	Ian G. Droppo, Togwell A. Jackson, Chris H. Marvin
PARTNERS:	McMaster University, Ryerson Polytechnic University, University of Ottawa, University of Toronto, Northwestern University in greater Chicago, Texas A&M University in Galveston, the Universities of Geneva, Lausanne and Neuchatel in Switzerland, and the CLS Synchrotron in Saskatoon
CLIENTS:	EC, TSRI, NSERC and international funding agencies
FUNDING:	EC, GL 2020, TSRI, NSERC and international funding agencies

Introduction

For contaminated suspended sediments in natural aquatic ecosystems, the mechanisms of transport, sedimentation, bioavailability changes and burial have to be better understood. To model properly the important roles of flocs in these ecosystems, and to apply newly improved models towards achieving best management practices, science must properly define "floc" and its many characteristics. For engineered systems of water decontamination, there is a parallel need to understand flocs as water decontamination "machines", rather than as the "black boxes" of the past. Awareness is increasing that the structure (physical, chemical, microbiological) of flocs controls their various important roles, be they in the water column, in bottom sediments or in treatment tanks. Flocs constitute a complex matrix of microbial communities, organic matter (detritus, cellular debris and extracellular polymers) and inorganic cohesive materials. Most of these intrafloc components are colloidal (submicrometre size in least dimension) and determine (for floc populations in a given ecosystem) such floc parameters as size, shape, porosity, density, internal gradients and permeabilities, and contaminant binding activities. The key to understanding the roles of flocs is to understand their intrafloc components. To this end, novel analytical technologies from several disciplines must be developed for correlative application to fresh samples, with an essential contribution required from novel electron-optical methods and apparatus (for visualizing, characterizing and speciating individual colloids and their 3-D associations). Our research focuses on the

development of technology to analyze colloids and flocs on the nanoscale, while accomplishing it in such a manner as to relate directly to overall gross structure and to contamination-related phenomena.

Study Areas: Hamilton Harbour, Toronto Harbour, industrial wastewater treatment systems in Canada and the USA., heavily contaminated small lakes in northern Ontario and Illinois, and a complex natural drainage system in the Jura mountains of Switzerland

Results

New technology was successfully developed by the team and its partners for characterizing the principal aquatic colloids and floc-contaminant associations at many sites in two diverse environmental contexts, natural freshwater ecosystems and engineered wastewater ecosystems. Our regional collection of apparatus and expertise, coupled to our international research network, has allowed us to become an informal centre of excellence which is second to none in the world, as witnessed by a sample (below) of some of our works of the past year. Increasingly, we focus much of our research on specific colloids suspected of dominating contaminant-particle interactions. Some of these dominant colloids are: fibrillar species of EPS (extracellular polymeric substances) which constitute the matrix material of most flocs; specific natural coatings on bacterial surfaces (e.g. porous iron oxide minerals which sorb toxic heavy metals); bacteria and specific subcomponents of bacteria known to be involved in contaminant immobilization and transformation; humic substance components of flocs. To illustrate the importance of a better understanding of aquatic colloidal phenomena, for environmental management purposes, consider the following: (1) improperly-addressed floc dysfunction in treatment tanks costs taxpayers one billion dollars each year in North America; (2) colloidal phenomena occurring at submerged metal surfaces throughout North America cost taxpayers several billion dollars per year to address biofilm-induced corrosion damage; (3) 12 years ago, a mucilage phenomenon in coastal waters, attributed to colloidal processes, cost several billions of dollars in a single summer to the tourist industry of Italy.

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STUDY TITLE: Control of Agrochemical Pollution by Best Management Practices

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PARTNERS:	[1] Agriculture Agri-Food Canada, [2] University of Guelph
CONTRACTORS:	Michele Bullock and Dagmara Tyszler
CLIENTS:	Ontario Region EC
FUNDING:	GLWQP

Introduction

Under the Great Lakes Water Quality Agreement, the governments of Canada and the United States are committed to protect the water quality in the Great Lakes basin. One of the issues addressed under this agreement is the need to increase our understanding of agricultural nutrients and pesticides released into the environment, their interactions, and means of improving the water quality in the Great Lakes basin by best management practices. Such practices should help farmers conserve the soil and water quality in both the short and long terms.

The current activities include evaluation of integrated controlled drainage, subsurface irrigation, tillage practices, application rates and crop rotation for nutrient management, mitigation of persistent organic pollutants movement to the aquatic systems, assessment of municipal compost for on-farm application, and the investigation of nitrate baseline levels for fertilisation efficiency. In co-operation with Agriculture and Agri-Food Canada, the technology for controlled drainage, subsurface irrigation, tillage practices, crop rotation for nutrient management and the mitigation of pesticides to the aquatic ecosystems in the Great Lakes Basin, and the assessment of municipal compost for on-farm application were investigated. The baseline levels of nitrogen were studied in collaboration with the Faculty of Engineering, University of Guelph. Locations of experimental sites are listed below.

Study Area: Bicrel farm (42° 18' 08" N, 82° 29' 56" W), Chevalier farm (42° 12' 15" N, 82° 44' 50") 2000, Shanahan farm (42° 12' 15" N, 82° 45' 58" W) and Elora Research Station (43° 38' 02" N, 80° 24' 50" W) 2001

Results

The controlled drainage/subsurface irrigation (CDS) treatment associated with conventional tillage was assessed using the field data collected on Bicrel farm. The CDS reduced the nitrate loss by up to 37%, from 60 kg of N/ha for free drainage (FD) treatment to 38 kg of N/ha for CDS treatment. CDS treatment reduced the mean nitrate concentration by up to 44%, from 19.1 mg/L for the FD plot to 10.8 mg/L for the CDS plot. CDS treatment increased crop yields by up to 64%.

Investigations of municipal compost applications were conducted on Chevalier and Shanahan farms. The municipal compost was applied at 75 tonnes/ha (dry weight) to one of the two plots at each study site, after harvests in the falls of 1998 and 1999. The 1999 tile drainage samples collected at Chevalier farm under conservation tillage with compost application, from January to August of 1999, contained on average 43.7 mg/L of nitrate N, which was more than double compared to the average nitrate concentration for a plot without compost application, 19.71 mg/L. Similarly, at the Shanahan farm, the average nitrate concentration (24.3 mg/L) for plot with compost application and no-till practices was about double of that (13.7 mg/L) observed at a plot without compost application. These results further suggest that conservation tillage on Chevalier farm contributed to greater nitrate leaching (43.7 mg/L) compared to the no-till plot (24.3 mg/L) on Shanahan farm.

Baseline levels of nitrate were investigated on two field plots located at the Elora Research Station. Both plots were kept under grass with zero input of nitrogen (i.e., no fertilizer or manure) for five consecutive years. The results of the nitrate loading monitored from 1997 to 2000 showed that the N loading in precipitation was 4 to 7 times higher than that in the tile drainage from these plots. The cumulative nitrate loadings in precipitation, plot 1 and plot 2, respectively, were 13.9, 3.45 and 1.98 kg/ha.

The effect of fertilization was investigated in terms of physiological developments of corn, with and without nitrogen input. The nitrogen input rate at one of the plots was 12.5-100-80 (N:P:K) kg/ha, with a side dressing of 28% of urea ammonia nitrate band-applied at 165L/ha to the corn rows. Compared to the non-fertilized plot, the physiological development of the leaf length, stem size and height, was 30% larger in the fertilized plot. The wet weight of the plant mass, including cobs, was 0.43 kg/plant for the fertilized plot, compared to 0.21 kg/plant for the non-fertilized plot. These data, together with nitrogen baseline levels in precipitation and in tile drainage, provide basic information for determining the fertilizer application rates.

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LAKE MANAGEMENT RESEARCH PROJECT

The LMR Project generates knowledge for sustainable management of Canadian lakes, reservoirs, and wetlands, assessment and restoration of the most polluted areas of concern in the Great Lakes, the impacts of aquaculture and to understand the development of Taste and odour aquaculture. This knowledge, primarily in the area of eutrophication management and organic contaminants, is used to develop and implement Lakewide Management Plans (LaMPs) and Remedial Action Plans (RAPs) in collaboration with other Environment Canada partners (Priority Ecosystem Initiatives: Great Lakes Basin 2020), provincial governments and municipalities, and the public and private sectors. The Project accomplishes its goals by measuring nutrients and other measures of water quality as well as algae and tracking outcomes of various eutrophication management efforts. Measurements of water movements and modelling are used to help understand the fate of materials introduced into water, while organic contaminants are measured to understand the sources and fate of these materials in lakes and areas of concern. Results and implications are communicated to LaMP and RAP groups and concerned citizens.

STUDY TITLE: Great Lakes Water Quality Management

STUDY LEADER:	M.N. Charlton
STUDY TEAM:	M.N. Charlton and J.E. Milne
	Partners, University of Waterloo, The Ohio State University, City of Hamilton
CLIENTS:	Ontario Region EC, OMEE, RAPS, City of Hamilton, Region of Halton
FUNDING:	Great Lakes 2020

Introduction:
Over the last 20 years efforts have concentrated on Lake Erie and Hamilton Harbour. The expenditure of about $20B to clean up the Great Lakes is the stimulus to assess and understand the factors leading to changes in the lake that were demanded in the Great Lakes Water Quality Agreement (GLWQA). Those changes were initially to be year round oxic conditions in the central basin and lower algal population generally. Later in the late 80s and 1990s the GLWQA incorporated Lakewide Management Plans and Remedial Action Plans and these became the focus of the work.

Study Areas: Lake Erie, Hamilton Harbour

Results
Lake Erie
Assessment and understanding of Lake Erie has been hampered by the addition of about one new exotic species per year for the last 12 years. For example, the predacious zooplankton Bythotrephes is a new consumer that introduces further inefficiency in the food chain leading to fish. The most spectacular invaders have been the zebra and quagga mussels. Early on the potential for the mussels to affect, water quality by filtration was recognized. The mussel's effect on water quality is in the same direction as that caused by the nutrient controls in the GLWQA. In the 1980s and 1990s a series of research cruises were conducted on Lake Erie to find out how the lake was responding to the combination of exotic species and nutrient reductions.

One common assumption has been that the mussels have cleaned up the whole lake. Our data show that there have been some improvements since the mussels invaded in the late 1980s in the west basin but little change attributable to the mussels over most of the lake. Improvements in clarity measured by Secchi disk did occur during the period of nutrient reductions up to the mid-1980s. The mussels have had more effect in nearshore areas where the mean depth allows them to filter more of the available water. These data are used to show the public that the lake is more complicated than supposed so when real data are gathered some surprises occur.

Phosphorus in the lake was a main target of the GLWQA. The overall load to the lake was reduced by 50% largely in municipal effluents. A downward drift in phosphorus occurred in the central and east basins representative of most of the lake. This effect was only a few ugP/L; the main effect was in the west basin where the loads were highest. In the mid 1990s phosphorus decreased again perhaps coincident with the advent of the mussels. Since 1995, particularly in the central basin phosphorus has increased as much as it decreased due to the GLWQA. There is no explanation for the recent perturbations in phosphorus. One hypothesis is that it is due to varying success of the planktonic larvae of the mussels. These represent a new and variable sedimentation vector in the lake. Essentially there are not enough scientists studying the lake to learn the fundamental processes responsible for the changes. Indeed, even basic information such as whole lake phosphorus loads has been missing in the last several years.

Recently, questions have been raised as to whether nutrient controls went too far given the effects of the invading mussel species. These concerns were raised by sport fishing groups. The data show that massive re-pollution of the lake would be needed to increase the phosphorus in the central and east basins based on the decreases that occurred formerly. Apparently, increases have occurred naturally since 1995 although the reasons are not clear. The data from Lake Erie were recently used in discussions of the Parlimentary Standing Committee on Fisheries and Oceans.

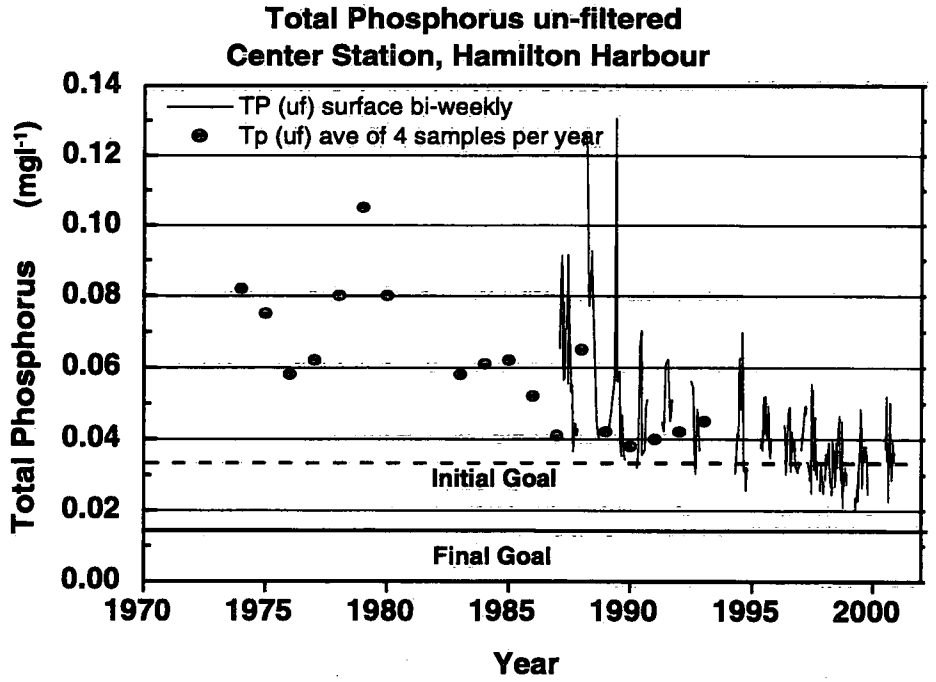
Partners in Lake Erie Research include University of Waterloo, The Ohio State University, Bowling Green University, and Ryerson University.

The whole lake research is now in a consolidation phase. A new initiative to study the east end of the lake with collaborators in University of Waterloo is beginning in 2001. These experiments seek to determine changes in processing of organic matter, inshore offshore transport, and effects on lake export caused by retention in shallow water due to mussels.

Hamilton Harbour

As one of the 43 original Areas of Concern identified in the 1987 GLWQA Hamilton Harbour is the worst Canadian example. Although metals loading from the steel industry have been brought down to achieve Provincial guidelines, eutrophication in the harbour is still a problem. Due to the large expenditures needed to reduce municipal phosphorus loads from four sewage plants a long term integration of science and advice through the Remedial Action Plan has been needed. The phosphorus loading issue is followed by annual measurements during the season of eutrophication parameters such as phosphorus, ammonia, and chlorophyll, and Secchi depth. These measurements are then related to the RAP process through technical reports and public fora.

The understanding of the harbour situation was part of Halton Region's recent decision to optimize the Skyway sewage plant prior to expansion. Positive results are shown in the figure containing long term phosphorus measurements. The decrease in phosphorus in the last four years coincides with better performance at the Skyway plant. This is crucial information because it proves that the harbour will respond well to lower phosphorus loads that may occur at the Hamilton facility which is four times larger.



Recently, initiatives have begun to measure bacteria throughout the harbour as a way of helping determine why the recently re-opened beaches are sometimes closed. Generally bacteria levels are low except in the spring before treated sewage effluents are disinfected. Higher numbers also occur near combined sewer outlets. Most of the numbers in the summer are below guidelines for swimming. This leads to the hypothesis that the bacteria responsible for closing beaches are related to use of the beaches themselves. Nevertheless, the higher numbers that occasionally occur in open waters need to be investigated.

In 2000 and 2001 work has begun to examine the morphology of the zooplankton population in the harbour and to measure the overall population numbers. This information will be used to determine if the population is degraded or not. Work has begun to quantify the number of zebra mussel veliger larvae present in the water. These larvae may have an effect on water quality. Work was finished to compare availabilty of phosphorus of various sources in Cootes Paradise. Algal samples are now being enumerated and sampling is scheduled for taste and odour compounds.

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STUDY TITLE: Origins of Taste and Odour Compounds in Lake Ontario

STUDY LEADERS:	B. Brownlee, M. Charlton and S. Watson
STUDY TEAM:	G. MacInnis and J. Milne
PARTNERS:	Research Consortium – Taste and Odour 2000; St. Lawrence River Institute of Environmental Sciences; University of Calgary
CLIENTS:	Western Lake Ontario Municipalities
FUNDING:	Research Consortium – Taste and Odour 2000; GL2020

Introduction

In late summer of 1998 and 1999, severe episodes of musty/earthy taste and odour (T/O) afflicted the water supplies of municipalities using western Lake Ontario as their source of drinking water. In early 2000, a research consortium was formed to study the origins of the compound(s) responsible for the off-flavours. This consortium consists of seven municipalities which provide the majority of the funding; NWRI and MOEE, which carry out the research; private sector laboratories which carry out various analyses; and the Ontario Clean Water Agency which provides coordination and project management. The objective of the Consortium is to elucidate the spatial and biological origins of the causative compounds and the limnological mechanisms of their production, as a basis for predicting episodes and selection of remedial measures. While the research effort is concentrated on western Lake Ontario, the entire lake and the upper St. Lawrence River are being studied, since taste and odour episodes affect eastern Lake Ontario and upper St. Lawrence River municipalities with even greater frequency than the western portion of the lake. Previous studies had shown that western lake problems were due primarily to geosmin, and that a combination of geosmin and 2-methylisoborneol (MIB) occur in the eastern lake and upper St. Lawrence River. These two volatile organic compounds (VOCs) are known to be secondary metabolites of select species of Cyanobacteria (blue-green algae) and filamentous bacteria (Actinomycetes).

Study Areas: St. Lawrence River, Lake Ontario, Niagara River

Results

In-Lake Study Near Water Intakes

As part of studies partially funded by western Lake Ontario municipalities, Lake Management Research staff sampled inshore and offshore waters near Peel Region intakes for the second year. The stations range from very close to shore, to offshore at the two intakes of Lorne Park and Lakeview water treatment plants, to a site 10 km offshore at a depth of 70 m. Although there were few complaints due to geosmin concentrations which were much lower than in 1999 (maximum concentrations of ca. 7 vs. 220 ng· L^{-1}, respectively), we found that the same temporal pattern occurred as in 1999. This suggests that similar processes may have occurred in both years, but at less intensity in 2000. Planktonic Cyanobacteria showed little overall correlation with VOC levels at these stations. These taxa had similar temporal dynamics to geosmin in 1999 and 2000, but the predominant species differed between years. Furthermore their biomass was consistently too low to account for the observed geosmin levels, particularly in 1999. In late summer 2000, geosmin built to a small peak over a few weeks and subsided as rapidly. This was slightly preceded by a very small increase in Cyanobacteria in the surface layer (ca. top 16m), with a maximum biomass of approximately half of that attained in 1999 (150 vs. 300 µg· L^{-1}). The reasons for the differences in VOC levels between the years are not clear. Following this situation should eventually provide clues that point the way to the causes of the problem. As in 1999, water from the greatest depths had the least geosmin in 2000; this means that communities near deep water potentially could avoid or minimize T/O problems by drawing water from this zone.

It is unknown whether actinomycetes, which are widespread in terrestrial environments, are also indigenous T/O producers in aquatic environments. This was the subject of the second component of this work, which measured the abundance of actinomycetes at these sites and further upstream in the Credit River, and their aquatic VOC production potential. The majority of the actinomycetes found in the water samples were associated with silt, indicating a benthic or terrestrial origin. Over half of the actinomycetes isolated from these sites generated one or both of geosmin and MIB in unenriched river water, with very potent and very poor producers amongst these isolates. These results require verification during a more severe odour event, but implicate both watershed and source waters as origins of surface water T/O; however their importance relative to in-lake processes needs to be determined.

Niagara River

Water samples were collected biweekly at the Ontario Region permanent sampling facilities at Fort Erie (upstream) and Niagara-on-the-Lake (downstream) from July 5 to October 11, 2000, and analyzed for MIB and geosmin to determine if the Niagara River (and indirectly Lake Erie) can be a significant source of these odour compounds to (western) Lake Ontario. Upstream levels showed a strong seasonal pattern for MIB (13-55 ng· L^{-1} peaking on August 30) and geosmin (3-16 ng· L^{-1} peaking on August 2). Downstream levels were consistently lower and less variable for both MIB (6-21 ng· L^{-1} peaking on September 13) and geosmin (3-5 ng· L^{-1} peaking on September 13). Planktonic blue-green biomass was minimal at both sites in the river (20 µg· L^{-1}), and again lower at the downstream site. From these low concentrations we conclude that during the 2000 season, the Niagara River was not a strong source of MIB and geosmin to the lake, and the upstream/downstream differences in concentration suggest that there are removal processes such as volatilization and/or biodegradation occurring in the river.

Lake Wide Survey

A lake wide survey for geosmin and MIB was conducted Sept 11 to 15, 2000. The purpose of the survey was to determine spatial patterns in odour compounds and phytoplankton that might correlate with major nutrient sources and river inputs. Levels of the two VOCs were generally minimal (Fig. 1), and measures of very low geosmin concentrations in bottom waters were verified by repeated analyses. Geosmin and MIB showed similar differences in spatial patterns as in previous years. MIB was found mainly in the Niagara River and the far east end of the lake. Low concentrations of geosmin were found at all stations

with a tendency for higher concentrations to coincide with higher nutrient levels. In almost all areas, the phytoplankton was dominated by flagellates (cryptophytes) and diatoms, which do not produce either geosmin or MIB. Both planktonic and picoplanktonic Cyanobacteria were generally very low in abundance (50 $\mu g \cdot L^{-1}$) and their spatial distribution showed no correlation with that of either VOC except in the Bay of Quinte region, where both geosmin and blue-green biomass were elevated. This distribution needs to be tested with more surveys, because the results are consistent with the idea that further nutrient controls may be beneficial.

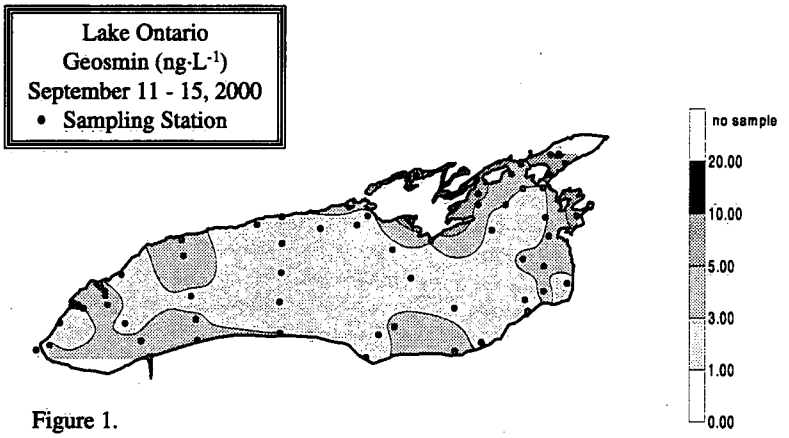

Figure 1.

Eastern Lake Ontario/Upper St. Lawrence River

The objective of this portion of the study was to evaluate lotic littoral and benthic areas vs. eastern Lake Ontario as potential sources of T/O in the St. Lawrence River. Replicate samples were taken in late summer at selected sites along the river from periphyton beds, macrophytes and zebra mussels. These were analyzed for VOCs, algae, associated actinomycete abundance, and VOC production. It was found that macrophyte epiphytes were mainly diatoms which generated no significant odour. In contrast, periphyton on rocks and mussels included a significant flora of Cyanobacteria, and represented a patchy but very high potential source of geosmin which was associated with the biomass and released upon cell lysis. Such cell death could occur during periodic slough off during storm events or changes in water levels, which provides one plausible explanation for the prolonged nature of T/O events along the river relative to those in Lake Ontario. Similarly, actinomycete abundance was high in some of these zones, and included some very potent geosmin and MIB producers. At the time of sampling, mussel material had no detectable levels of geosmin or MIB, but yielded high numbers of viable actinomycetes, many of which were subsequently shown to generate very high levels of geosmin and/or MIB in culture. In comparison, inflowing Lake Ontario VOC levels were low. These preliminary results indicate that the odour in the river is generated from internal sources, an hypothesis that is being tested by more focussed future research.

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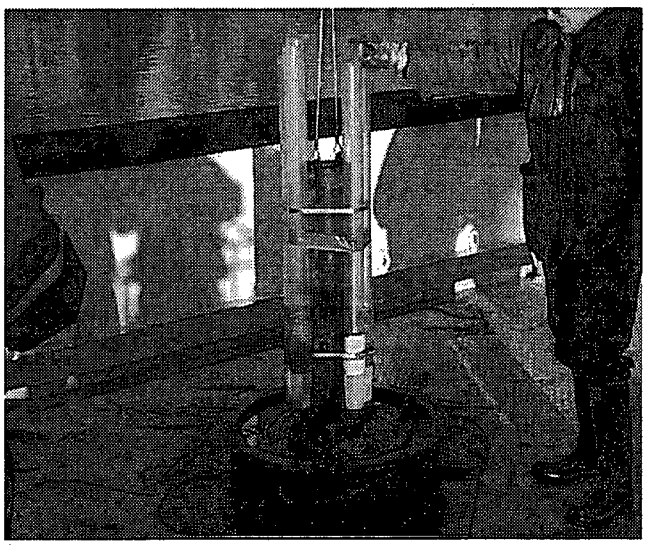
STUDY TITLE: **Persistent Organic Pollutants in the Great Lakes and Associated Areas of Concern**

STUDY LEADER:	C. H. Marvin
STUDY TEAM:	C.H. Marvin, P.A. Thiessen
PARTNERS:	Ontario Region, Ontario Ministry of the Environment, Department of Fisheries and Oceans
CLIENTS:	Ontario Region, Detroit River RAP, Lake Erie Lakewide Management Plan
FUNDING:	GL 2020

Introduction

The presence of persistent organic pollutants can adversely impact Great Lakes wildlife, biodiversity and aquatic ecosystems. Annual surveys are carried out to measure the occurrence and spatial distribution of toxic substances. Results of these investigations further our understanding of the role human activities play in discharging chemicals to the environment and provide important information for developing effective strategies to mitigate deleterious effects. Studies are being carried out in Lake Erie and the western corridor extending from the Detroit River through Lake St. Clair and the St. Clair River. Locations of sampling sites reflect shore based activities and inflows from tributaries. Sampling strategies are employed for collection of a variety of matrices including water, suspended sediments, bottom sediments and some forms of aquatic biota. Samples are returned to the laboratory for analysis of a variety of toxic substances including heavy metals, polycyclic aromatic hydrocarbons, organochlorine pesticides and PCBs. Our suite of chemical analyses has been expanded to include contaminants of emerging interest including brominated flame retardants and chlorinated paraffins.

Study Areas: Detroit River, Lake St. Clair, St. Clair River, Lake Erie



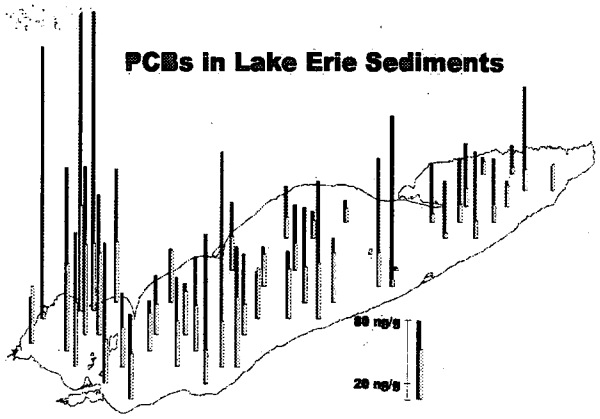
Results

Sediment trap moorings for collection of suspended sediment were deployed during 2000 in the Detroit River – Lake St. Clair – St. Clair River corridor. Collection and analysis of monthly samples has provided the Lake Erie LaMP and the Detroit River and St. Clair River Remedial Action Plans with current information on levels and distributions of contaminants in the river; this information will also serve as a benchmark in assessing ongoing remediation of severely contaminated sites that can be significant sources of toxics to the rivers and Lake Erie.

Sediment trap mooring in the Detroit River

Surveys of the Great Lakes enable characterization of the spatial extent of contamination by pollutants such as PCBs. Comparison of current levels with historical information allows determination of temporal trends and the degree of improvement in environmental quality since the advent of measures to reduce discharges of toxic contaminants. This information also assists in the identification possible sources of these compounds and regions where contamination exceeds sediment quality guidelines for the protection of aquatic biota. Analysis of sediment core samples is used to detect recent inputs that exceed the historical norm.

The spatial trend in PCBs showed an increase from the eastern basin to the western basin where levels are historically higher. These data also showed a marked improvement in sediment quality over the past 25 years. These spatial and temporal trends are also evident for a variety of other persistent chlorinated organic pollutants including DDT. These monitoring and research activities will continue in the future to ensure that wildlife and ecosystems within the Great Lakes basins are adequately protected.



Map of Lake Erie showing sediment levels of PCBs in 1971 (solid) compared with levels in 1995 (clear).

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STUDY TITLE: Georgian Bay Caged Aquaculture Studies

STUDY LEADER: M.Charlton
STUDY TEAM: P.Hamblin, J. Milne, C.He , summer student
PARTNERS: OMEE, Canadian Hydrographic Service
FUNDING: Aquaculture Fund

Introduction

Water quality degradation in the neighbourhood of caged aquaculture sites has been identified in northern Lake Huron. Our approach has been to collect new and past observations and to employ them to construct three-dimensional transport models of water quality constituents in the areas of caged aquaculture operations. Other lower dimensional water quality models are used when appropriate. At this point the basic models are being adapted to various environmental settings and we hope to soon start to validate them with field observations.

Study Areas: (1)Fraser Bay, Manitouwanning Bay and McGregor Bay in Georgian Bay
(2) Northern Lake Huron (Lake Wolsey)

Results

A model of the phosphorus budget of Lake Wolsey was reported on at an international conference, the annual conference of Great Lakes Research. A manuscript on the phosphorous budget of Lake Wolsey and co-authored by P. Gale of OMEE was submitted for publication to the Journal of Great Lakes Research. As a first step to three-dimensional modelling, a very detailed mesh consisting of 5000 elements was prepared for the above area (2) of Georgian Bay which contains three caged aquaculture sites. Assistance in obtaining the original bathymetric soundings in the study area was kindly provided by the Canadian Hydrographic Service.

A study of the importance of benthic deposits of fish farm waste was expanded. A deposit at a recently discontinued site was re-sampled for the second year. A deep water site with seasonal fallowing was also sampled for the first time. An experiment was begun at a third shallow site on fallowing (moving fish cages). Sediments were sampled at an area about to receive the cages and some samples were collected at the present cage area. It is hoped that these studies will help find out the duration of fish waste deposits and the effect of deeper water and whether fallowing would be an effective way to prevent buildup of the waste on the bottom.

In partnership with University of Guelph and OME a study is beginning at a carefully monitored fish farm. All of the feed inputs will be measured and a model based on optimal laboratory conditions will be used to estimate waste production. Camera systems are used to minimize overfeeding. A student will conduct four intensive monitoring periods. Staff from NWRI are supplying expertise and equipment such as water quality monitors and current meters. It is intended that a full appreciation of water quality impacts at a deep water fish farm can be derived from the work.

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STUDY TITLE: Ecological Modelling in the Great Lakes of the World

STUDY LEADER: P.F. Hamblin
STUDY TEAM: C. He.
CLIENTS: Hamilton Harbour RAP, UNU, Aquaculture
FUNDING: GL2020

Introduction
Water quality concerns have been identified at almost all the Great Lakes "Areas of Concern" (AOC), in northern Lake Huron and in other Great Lakes of the world. Our approach has been to construct three-dimensional transport models of water quality constituents although older lower dimensional models are used when appropriate. At this point the basic models are being developed and adapted to various environmental settings and validated by field observations.

Study Areas: Hamilton Harbour and western end of Lake Ontario, Northern Lake Huron (Lake Wolsey) and Georgian Bay, Lake Erie, Lake Malawi/Nyasa (East Africa)

Results
In general, the models were used to test various hypotheses on how the ecosystem responds to external stressors.

A model of the phosphorus budget for a restricted water body containing a fish farm, Lake Wolsey was developed from the application of an exchange flow model. This study was presented at an international conference and a manuscript submitted for publication. The model showed that there is little storage of phosphorus from the fish farm in the bottom sediment. A detailed mesh consisting of 5000 elements was prepared for an area of Georgian Bay containing three caged aquaculture sites (Figure 1).

A manuscript on a model on the hydrodynamics of Lake Erie was accepted for publication and progress made on its application to dissolved oxygen, algae and the sensitivity to zebra mussel filtration. A

manuscript of the water quality modelling phase of the study is in preparation. The model permitted interbasin transports of various water quality constituents to be estimated for the purposes of further modelling.

Progress on three-dimensional modelling of the exchange between Hamilton Harbour was presetned at two international meetings. Attention is now focused on the validation of total dissolved solids in this study as it is a good indicator of ammonia and phosphorus and the flow conditions in the vicinity of the proposed outfall of the Skyway Sewage Treatment Plant in the western end of Lake Ontario. The modelling results showed progress towards three-dimensional water quality modelling of lakes and harbours.

Testing of another three-dimensional model of the flow and temperature structure of Lake Malawi/Nyasa showed that the major source of model uncertainties in this Rift Valley lake is the meteorological forcing field. Two manuscripts were prepared for publication, a presentation made at an international meeting and a course on mesoscale meteorological modelling on this topic attended. The results showed that mesoscale meteorological models are useful in specifying the forcing of water quality models in large Rift Valley lakes.

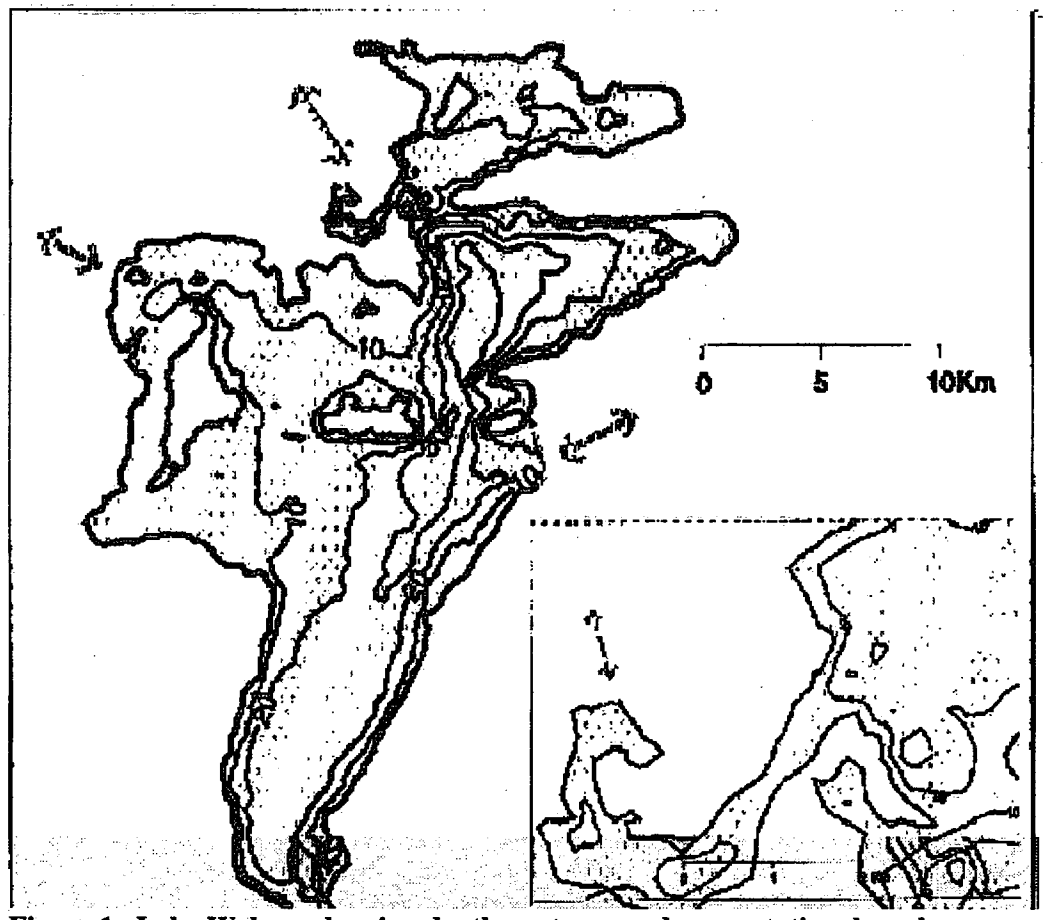

Figure 1. Lake Wolsey, showing depth contours and computational mesh.

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STUDY TITLE: Coastal Transport and Modelling in the Great Lakes

STUDY LEADER:	Raj Murthy
STUDY TEAM:	Raj Murthy, Fausto Chiocchio, Ken Miners
CLIENTS:	Hamilton Harbour RAP, Taste and Odour Consortium, Aquaculture, NOAA/GLERL CoOP
FUNDING:	GL2020

Introduction

In the Great Lakes the gradients of many biogeochemically important materials (BIMs) are considerably higher in the coastal areas. In the presence of these large gradients, coastal circulation is a primary mechanism for the exchange of material between nearshore and offshore waters. In the coastal regions of the Great Lakes it has been observed that the mean alongshore transport is much larger than the cross-shore transport. However, both the alongshore and cross-shore current components exhibit strong episodic behavior due to wind forcing. Circulation in the lakes is driven by wind, but the effects of earth's rotation, basin topography, and vertical density structure are also important. During the unstratified season, the higher wind speeds and the absence of the thermocline allow the effects of wind action to penetrate deeper into the water column. In shallow water the entire water mass moves in the direction of the wind, while return flow occurs in the deeper parts of the lake.

Study Areas: Lake Michigan, Lake Ontario

Results

Episodic Events In Great Lakes Experiment : EGLE

In order to understand the cross-shore transport of BIMs and quantify the physical processes that are responsible for the nearshore-offshore mass exchange, a multidisciplinary research program, EGLE (Episodic Events Great Lakes Experiment) was recently initiated by NOAA (National Oceanic and Atmospheric Administration) and NSF (National Science Foundation) in Lake Michigan. National Water Research Institute (NWRI) was invited by the Great Lakes Environmental Laboratory (GLERL/ Ann Arbor) to participate in this unique experiment.

Moored instrument arrays and Lagrangian experiments provide a detailed description of the flow field (currents, vorticity, patterns of convergence, plume dynamics, and the net offshore transport of the water) and an understanding of physics during the winter/spring transitions in the coastal zones of Great Lakes. In the moored instrumentation time series of currents, winds, and temperature data were obtained for the field years of 1997 to 2000. A maximum of 17 fixed point moorings of ADCPs and VACMs are deployed from the 20 m to 60 m depth contours by GLERL. As a part of the program NWRI deployed additional instrumentation consisting of seven SACMs, and two ADCPs in the shallow waters at a depth of 12 m along with two coastal meteorological stations. The drifter program is designed to make use of quasi-Lagrangian measurements with satellite tracked drifters. EGLE experiments were conducted during a period of three years from 1997 to 2000. These experiments provide insights into the nearshore/offshore exchanges of BIMs in the coastal zones of Great Lakes. Simultaneous analysis of experimental data to elucidate the coastal physical processes and coastal modelling are underway to understand the coastal sediment plume formation and transport in southern Lake Michigan.

Western Lake Ontario coastal experiment

A comprehensive study on coastal physical processes in western Lake Ontario was undertaken from 1996 to 2000 in support of the proposals to divert municipal sewage into the lake. Based on detailed experimental data and results, coastal transport models were developed to asses the impact of the sewage diversions into the nearshore waters, particularly the strategic locations of the drinking water intakes in relation to the locations of the STP's. A detailed report summarizing the experimental data and results on coastal physical processes and the coastal outfall models has been completed in addition to several publications in journals and conference proceedings.

These experiments have provided a wealth of data and results to synthesize the relevant coastal physical transport processes relevant for developing coastal transport models. A hierarchy of coastal transport models have been developed starting the empirical/semi-empirical (analytical, correlation, objective analysis and impulse response models) to full hydrodynamic models. These models have been tested and validated using the experimental data and results on coastal physical processes. Models have been applied to practical problems such as coastal outfall STP discharge of municipal sewage and sediment plume dynamics(formation, transport and dispersal) in nearshore waters of the Great Lakes. The experimental data, process oriented analysis, parameterization of the physical processes and models can be used in specific cases to understand the alongshore transports and cross-shore transport of BIM.

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STUDY TITLE: **Hamilton Harbour Sand Capping Project: Sediment Pore Water Assessment**

STUDY LEADER: F. Rosa
CLIENTS: Ontario Region EC, OME, RAPs
FUNDING: GL 2020, RAP

Introduction
The Canadian Government, launched a $125-million Great Lakes action Plan in 1989. As a result, $55 million was allocated to Environment Canada's Great Lakes 2000 Cleanup Fund which created the Remediation Technologies Program in 1990. This program is designed to demonstrate and assist in the commercialization of innovative technologies for remediation of contaminated sediment.

One alternative procedure to the remediation of contaminated sediment is underwater in-situ capping. Sediment capping has been performed in Japan, Europe and the United states, but not in the Great Lakes. Advantages to this procedure are numerous under certain conditions. Compared to dredging, capping eliminates the need for treatment or disposal, making it less expensive.

Study area: Hamilton Harbour (2001-2002)

Results
From July to September 1995, Environment Canada carried out a sediment capping demonstration in Hamilton Harbour. The objective of this was to determine the appropriateness of this procedure to remediate other Canadian Areas of Concern. The demonstration site measured 100 m x 100 m, with water depths varying from 12 to 17 m. The sediment that was capped consisted mainly of a mixture of very soft black silty clay, considered highly contaminated when compared with Ontario Ministry of

Environment and Energy Guidelines. The procedure applied a layer of sand averaging 35cm thick over the experimental area.

Dialysis chambers (peepers) were deployed on the cap site to monitor pore water movement from the contaminated sediments through the sand cap to the overlying water. Yearly, sediment pore water profiles, for nutrients and trace elements over a period of five years have been measured. Preliminary results of pore water profiles at the capping site indicate upward migration, of pore water contaminants by molecular diffusion and/or sediment compaction. This upward migration seems to be occurring through the first 10 to 15cm of the 35cm sand cap, after a period of five years. The amount of diffusion that has occurred will determine the efficiency of sand as a capping material to deter contaminant migration to the overlying lake water. Sediment capping is intended to be a long-term solution, evaluation of the demonstration should be performed over many years. Pore water will be monitored until the fall of 2002, making this a seven year study. Evaluation of the data will then lead to a judgement on the efficacy of the sand cap.

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STUDY TITLE: Sustainable Coastal Development

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STUDY TEAM: D. Doede
PARTNERS: OME; DFO
CLIENTS: Ontario Region; RAPs, Taste and Odour Consortium
FUNDING: GL2020

Introduction
Various techniques and methodologies from the field of coastal engineering are applied to problems in Areas of Concern in the Great Lakes. These techniques include site specific measurements of waves and currents, analysis of wind data and other pertinent physical data. Process specific physical variables such as waves are isolated and investigated under controlled conditions in laboratory flumes.

Study Area: Hamilton Harbour, Lake Ontario, Lake Ontario, Lake Erie

Results
The dispersal of effluents from STPs in Hamilton Harbour and off Toronto in Lake Ontario has been investigated using coprostanol as a tracer. The dispersal patterns could not be reconciled with currents from two-dimensional models. Measurements of currents with acoustic Doppler current meters, analysis of meteorological records and of relative effluent buoyancy helped explain the dispersal patterns (see Figure 1). Current measurements in the winter period 1999-2000 off Toronto provided valuable insight into the numerical modelled currents which showed gyres around Toronto Island, in the vicinity of STP outfalls in Humber Bay and Ashbridges Bay.

As part of the team effort to understand the taste and odour problems in municipal drinking water in the late summer months, current profiles were measured with acoustic Doppler current profilers (ADCPs) at the Cobourg and Hamilton WTP intakes. In addition, data from OME current meters deployed off Toronto, Lakeview, Oakville, Port Dalhousie, and Ontario Power Generation ADCPs at Darlington and Pickering were analyzed. Preliminary analysis of these current and temperature data sets indicates that

the taste and odour event occurred during a period of easterly winds producing a westward directed coastal jet of warm surface waters along the north shore of Lake Ontario. Continuing efforts in 2001 will focus on monitoring temperature profiles off Mississauga and Grimsby.

Concurrent measurements of current profiles in Hamilton Harbour (1999 and 2000) and other indicators (conductivity, temperature, and turbidity) are being evaluated as a methodology to resolve trends in water quality in areas of spatial and temporal variability. The one survey in 1999 and three in 2000 clearly showed the harbour to be in different states during each survey, and also clearly showed that the Windermere Arm was an area that always showed elevated levels of tracers.

The occurrence of unusually large waves on the Great Lakes and on the oceans is a major factor in safety and pollution prevention (The sinking of Edmund Fitzgerald on Lake Superior and the sinking of the Ocean Ranger off Newfoundland are two examples where safety was compromised by unusually large waves). The internal water velocities (and hence the estimated forces on ships and offshore structures) were not adequately described with existing models. Based on laboratory flume tests at NWRI, a more complete description of the kinematics has been made. A new model has also been developed which better predicts the internal velocities under the crests of these unusually large waves.

Mortality of Lake Ontario lake trout eggs appears to have a higher sensitivity to physical shock than other stocks based laboratory tests. How these differences relate to survival in the wild is unclear. Bottom currents are one factor that may induce shock causing egg mortality. These currents were monitored at a lake trout spawning reef off Stoney Creek in Lake Ontario from October to December, in 1998 and 1999, to determine the duration and magnitude of high currents that could lead to physical shock. The site is exposed to the full force of north-easterly storms, common in the fall and winter months, when eggs are incubating. Mean currents and storm induced oscillatory flow are documented, and wave conditions inferred from the current data.

It has been hypothesized that biofilm growth can have a significant effect on the development of flocs in the water column. The latter have an effect on the dispersion of contaminants. In the nearshore zone, biofilms and their development are influenced by the systematic variation in wave induced shear stress, due to the variation in bathymetry. Preliminary investigations of biofilm development under wave action are being undertaken in a laboratory wave flume to gain insight into these processes and responses.

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ECOSYSTEM MONITORING AND ASSESSMENT PROJECT

The EMA Project develops and provides methods and guidance for biological and chemical assessment of aquatic ecosystems, using field and laboratory approaches. The knowledge generated by the Project is used by management agencies in support of Environment Canada's programs and regional activities; for example, Great Lakes Basin 2020, Fraser River Management Plan, Environmental Effects Monitoring and the Canadian Environmental Protection Act. Multidisciplinary studies are conducted on the assessment of cumulative biological effects of anthropogenic stress at large spatial scales; long-term effects of acidification at the catchment scale; and application of remote sensing techniques for monitoring and assessment of large ecosystems. In addition, interpretative and statistical methods are being developed and applied for use with environmental data at different spatial and temporal scales.

STUDY TITLE: Application of Biological Sediment Guidelines (BEAST) in the Great Lakes

STUDY LEADER: T.B. Reynoldson and L. Grapentine
STUDY TEAM: D. Milani, C. Logan and S. Thompson
PARTNERS: Lambton Industrial Society, Fisheries & Oceans Canada
CLIENTS: Ontario Region EC, OMEE, RAPs
FUNDING: GL2020

Introduction

Contaminated sediment has been identified by the IJC at almost all the Great Lakes Areas of Concern (AOC). There has been an ongoing debate in the scientific community on the most appropriate method for determining the effect of these contaminants on ecosystem health; making a decision on the need for remedial action and; assessing the success of any remediation undertaken. The institute has, over the past 10 years, developed a set of numerical biological guidelines for assessing sediment contamination based on invertebrate community structure and invertebrate toxicity tests. As a consequence of this development work the Institute has received funding from GL2020 to implement these guidelines at all Canadian AOCs over the 5 year period 2000 – 2004.

In each of the study years 3 AOCs will be assessed using the benthic assessment of sediment BEAST biological guidelines. Through consultation with both Ontario Ministry of Environment and Ontario region Environment Canada the following work schedule was agreed for years 1 and 2, future schedules will be based on discussion among the parties, In addition a steering committee representing NWRI, OME and Ontario Region was formed:

Study area: Peninsula Harbour, Bay of Quinte, Hamilton Harbour (2000), St Lawrence River, Detroit River, St Clair River (2001)

Results

Sampling was conducted at the three sites scheduled for 2000, the sites sampled were: Penninsula Harbour (33 sites); Bay of Quinte (42 sites), and ; Hamilton Harbour (43 sites). In addition 35 reference sites were also sampled.

While the BEAST methodology does provide criteria for health of the invertebrate community and invertebrate toxicity and these are generally the most sensitive endpoint for most contaminats in sediments, the possibility exists that these organisms may not be responsive to contaminants that can bioaccumulate and biomagnify up the food chain, thus attaining concentrations in top predators that may be toxic to those organisms but not in invertebrates. Therefore, an approcah was sought to establish both protocols and criteria for assessing the risk associated with biomagnification. A workshop was held at CCIW of university and government scientists to discuss the various approaches for developing sediment biogmanification criteria. As a result NWRI has developed a proposed approach that is under review by federal and provincial agencies.

In order to make the criteria more useable by managers an expert system is being developed, based on the RAISON software, that will be bundled with the current BEAST software. This expert system provides a decision making framework that integrates information from sediment chemistry, community and toxicity data and biomagnification risk and will provide the user with management options specific to the site. The rule base for this software was developed and is being reviewed by OME and regional staff and will be modified and finalized through an expert workshop.

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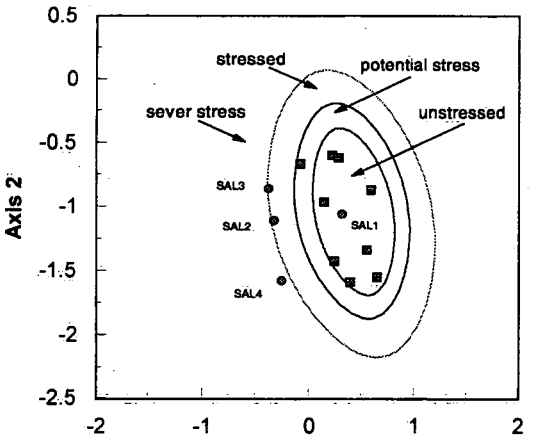
STUDY TITLE: Canadian Aquatic Biomonitoring Network (CABIN)

STUDY LEADER:	T.B. Reynoldson
STUDY TEAM:	L. Grapentine, T. PACs, C. Logan
PARTNERS:	P&Y Region, EMAN, Fisheries & Oceans Canada
CLIENTS:	All Regions, EC, OMEE, RAPs
FUNDING:	None

Introduction

Bioassessment based on macroinvertebrates is so effective, that national river health programs are based on them in the United Kingdom and Australia. State-of-the-art methods for working with benthic invertebrates were pioneered in the United Kingdom and are now in routine use there in 8000 river sites under the aegis of the National River Authority. Although a program, similar to those in the U.K. and Australia, is not in place in Canada, the National Water Research Institute in partnership with the Ontario Region and Pacific and Yukon Region has completed two major projects that use state-of-the-art techniques in benthic bioassessment; the Laurentian Great Lakes and the Fraser River catchment in B.C. (Reynoldson et al. 2000, Rosenberg et al. 2000). These projects have established permanent reference conditions, against which potentially impacted sites can be compared now and in the future. These studies are the basis for the proposed Canadian Aquatic Biomonitroing Network (CABIN) which would be used for assessing the health of Canadian river and lake systems, using benthic species as indicators of aquatic health. This coordinated approach to freshwater management would be of use to industry, consultants, federal, provincial, and local levels of government, conservation authorities, and environmental groups interested in maintaining healthy, functioning freshwater systems. Furthermore, it could be directly applied to such national initiatives as EEM reporting, SOE reporting and addressing biodiversity issues in aquatic ecosystems.

The proposed network is based on the Reference Condition Approach. In this method a database of reference sites define a "reference condition" (219 for the Fraser River Basin, 233 for the Great Lakes nearshore). The sites represent as many different geographic regions and stream sizes as possible. Multivariate statistics are used to create groupings of organisms, and to identify a few physical/chemical variables capable of predicting group membership. Once the reference condition has been established, sites suspected of being impaired are sampled; group membership of the benthic organisms is predicted based on the physical/chemical variables. Differentiation between the reference group and test-site organisms indicates the degree of impairment of the site.



Reference condition assessment plots for Salmon R., using ***BEAST*** stress bands

Study Areas: Fraser River, Laurentian Great Lakes

Results

The major effort in 2000 has been to investigate the feasibility of developing elements of CABIN by collaborating with ongoing programmes. An attempt is being made to integrate several small-scale invertebrate biomonitoring programmes conducted in Southern Ontario by Conservation Authorities, Universities and Ontario Ministry of Environment into a regional programme. An attempt is being made to standardise field collection methods, habitat descriptors and develop a common web accessed database to allow the development of predictive models.

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STUDY TITLE: The Aquatic Effects of "Acid Rain" in Southeastern Canada

STUDY LEADERS:	D.S. Jeffries and R.G. Semkin
STUDY TEAM:	J. Franklyn, G. LaHaie, R. Neureuther, F. Norouzian, M. Seymour
PARTNERS:	NRCan-CFS, DFO-GLLFAS, DFO-FWI, OMNR, EC-MSC, EC-CWS-OR, EC-QR, EC-AR, OMOE, Trent U., Laurentian U., Waterloo U., U. of Western Ontario, York U.
CLIENTS:	EC-EPS(Air Pollution Prevention -Transboundary Air Issues), National Air Issues Coordinating Committee, Canada/US AQA Science Committee, UN ECE International Cooperative Programs (Acidification of Lakes and Rivers and Integrated Monitoring), Conference of New England Governors and Eastern Canadian Premiers
FUNDING:	EC, Clean Environment Table (Acid Rain Science Plan)

Introduction

Acidification is a mature environmental issue and Canadian studies have been at the vanguard of defining the aquatic effects of 'acid rain' (correctly 'acidic deposition'). Research and monitoring projects

conducted during the 1980s and 1990s (including those from NWRI) documented and/or predicted the extent and magnitude of the chemical and biological effects of acidic deposition on Canadian surface waters. The knowledge gained permitted preparation of a sequence of state-of-knowledge reviews, with the last comprehensive assessment occurring in 1997.

The scientific consensus reached on aquatic effects helped to justify reducing emissions of acidifying pollutants. Several national and international agreements have subsequently reduced or capped SO_2 and NO_x emission levels, i.e. the domestic 'Acid Rain Control Program', the United Nations Economic Commission for Europe (UNECE) SO_2 and NO_x Protocols, and the Canada-U.S. Air Quality Agreement (AQA). In response, overall North American SO_2 emissions are now ~40% less than in 1980, and NO_x emissions have not increased even though the number of NO_x sources has increased. Despite this improvement, existing levels of acidic deposition are still unlikely to promote widespread recovery of aquatic ecosystems, and hence, a 'Canada-Wide Acid Rain Strategy for Post-2000' was signed in 1998 by the federal-provincial-territorial governments which intends to further reduce acidifying emissions to meet critical loads. The Strategy also calls for periodic assessments, the next being in 2004.

Current NWRI research focuses both on verifying the effectiveness of existing emission controls in reducing chemical effects in Canadian lakes and on addressing important knowledge gaps identified in the Environment Canada Acid Rain Science Plan. The former involves assessing the direction and magnitude of de-acidification or 'recovery' trends, and the latter quantifying the ecosystem factors that control or modify recovery responses. Work occurs both at a site-specific level through the intensive research and monitoring conducted at the Turkey Lakes Watershed (TLW) north of Sault Ste Marie, Ontario, and at a regional level by assessing the chemical responses of lakes monitored across southeastern Canada. Work at both levels can only be accomplished through partnership with researchers from: (a) the Atlantic, Quebec and Ontario Regions of Environment Canada, (b) other federal and provincial departments or ministries, and (c) several universities (see Partners list above). Canadian results are also considered in a broader (international) context through participation in UN ECE cooperative programs and inclusion in AQA Progress Reports.

Study Areas: Turkey Lakes

Results

Eighteen-year monitoring records for bulk deposition, shallow and deep ground water, two headwater streams and two lake outflows from the TLW have been tested to identify statistically significant monotonic trends. The TLW appears to be responding to declining acidifying emissions because the most prevalent chemical trend across sample types/stations was decreasing sulphate. Increasing pH was detected in four of the seven data sets, but only the hydrogen ion decrease in bulk deposition was of a magnitude to be an important ionic compensation for the sulphate decline. There is little evidence of acidification recovery in TLW waters however. Increasing alkalinity was found only in the outflow of the penultimate lake of the basin, and in fact, deep ground water and the other lake outflow had decreasing alkalinity trends (i.e., continuing acidification). Across surface water stations the greater part of the ionic compensation for declining sulphate was decreasing base cations. Increasing nitrate was important in ground waters. Drought has strongly influenced trends and delayed recovery by mobilizing S stored in catchment wetlands and/or soils. Many of the ecosystem responses observed at the TLW were also seen at other locations in Ontario and Quebec.

The composition of stream water during spring snowmelt reflects a complex interaction of biogeochemical and physical processes. The processes and interactions were evaluated for a small headwater catchment in the TLW by comparing the chemistry of above ground waters (bulk deposition, throughfall, and snowmelt) with that of forest floor and mineral soil waters during the spring melt periods of 1992-1996. Hydrogen ion input in bulk deposition was consumed (7-8 meq m^{-2}) in both throughfall-

snowmelt and in the subsurface soils. The chemical change (increase) in calcium plus magnesium was similar (9 meq m^{-2}) above and below the ground. Dissolved organic carbon and potassium loadings increased significantly in snowmelt and in the forest floor but were reduced via biological uptake and/or adsorption in the mineral soil. Ammonium and nitrate were consumed during the melt process but the loss in inorganic N, particularly ammonium, was greater in the mineral soil. The rapid infiltration of melt waters and the existence of a relatively impermeable layer in the mineral soil resulted in the formation of a perched water table in the subsurface such that snowmelt moved through and above the forest floor at peak flow conditions. Over the period of snow accumulation and snowmelt, pre-melt stream water and water routed through the forest floor and upper mineral soil accounted for 12%, 29% and 59%, respectively, of the stream flow at the outlet of the catchment.

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STUDY TITLE: Satellite Monitoring of Optically-Complex Inland Waters

STUDY LEADER:	R.P. Bukata
STUDY TEAM:	J.H. Jerome
PARTNERS:	Canadian Space Agency, York University, Nansen International Environmental and Remote Sensing Centre (Russia), NOAA/GLERL, others as they develop
CLIENTS:	Environment Canada, International Ocean Colour Coordinating Group
FUNDING:	EC

Introduction
Environment Canada has been involved in environmental remote sensing since the launch of ERTS-1/Landsat-1 in 1972. Apart from atmospheric physics and climatology foci, however, EC environmental remote sensing monitoring activities have been both minimal and fragmented, particularly with respect to inland and coastal water quality issues. Imminent launchings of hyperspectral satellite packages suggests that it is appropriate for EC to co-ordinate its environmental remote sensing efforts. To address the inland and coastal water quality concerns of Environment Canada that would best be served by first, inclusion within the Canadian Space Agency's Long-Term Space Plan (CSA's LTSP) and, second, developing models, algorithms, and research activities that would enable use of time-series satellite data to monitor ecosystem change.

To ensure that EC's water quality responsibilities are incorporated into the CSA's LTSP, a collaborative relationship with the Canadian Space Agency was established several years ago. Furthermore, to ensure that EC is directed towards implementing a coordinated ecosystem space monitoring plan that is consistent with the mandates of EC and the CSA's LTSP, a team of colleagues was assembled from government, academe, and private sector workers with expertise in remote environmental monitoring.

Study Areas: Lake Erie

Results
Incorporating inputs from discussions with numerous colleagues a "strawman" document ("Remote Sensing - A Tool for Ecological Monitoring") was prepared to serve as the basis of an intended presentation to the EC Nature Table. The document outlines remote sensing applications that could

reasonably accommodate the ten priority issues identified within the Environmental Scan for the Nature Science/ Research Agenda, contributions that could be directed towards assessing environmental change on the basis of ecosystem behaviour. The document was requested by and sent to the Secretariat of Canadian Information System for the Environment (CISE).

As an invited member of the international expert panel assembled by the International Ocean Colour Coordinating Group (IOCCG), a comprehensive report has emerged co-written by the assembled expert panel. The 140 page book summarizes state-of-the-art remote sensing of inland and coastal waters as requested by the American and European Space Agencies. The report is also directed towards scientists, students, and aquatic resource managers concerned with monitoring water quality from space vehicles. The bio-optical modeling and *in situ* optical research performed at NWRI over the past two decades by Bukata et al. are prominently featured in the two scientific and technical chapters of the IOCCG publication, viz. "Chapter 2: Colour of Case 2 Waters" and "Chapter 3: Algorithms for Case 2 Waters".

As a member of the committee that established the CSA's "Earth Observation Applications Development Program" (EOADP) the "Water Resources" Section of the "EOAPD Hyperspectral Work Package" was written. This outlined the science/products to be expected from proposals to the CSA focusing on the use of hyperspectral satellite data to monitor and assess inland and coastal water quality. As a consequence NWRI has become an invited participant by a private sector colleague on a CSA-sanctioned proposal entitled "Water Quality Products for Inland and Coastal Canada". The NWRI contribution will focus on water clarity changes in Lake Erie, direct determinations of the inherent optical properties of organic and inorganic matter in Great Lakes waters, remote measurements of water colour, GIS/expert system analyses of raster and vector data sets, geo-chemical and bio-optical modeling, and assessment of change in aquatic and terrestrial bioproductivity.

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Study Title: Quantitative Risk Assessment

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CLIENTS:	Atlantic and Ontario Regions EC, Dept. of Indian Affairs & Northern Development

Introduction

Quantitative methods play a central role in the study of environmental issues. Over the past two decades, research at the Institute has focused on the development and application of these methods for studying these issues with the main objective being to communicate the findings to decision makers. Current research is concerned with the study of the sources and effects of contaminants on the function and structure of aquatic ecosystems. Specific areas of applications include but not limited to: contaminants in the Great Lakes; chemicals in Turkey Lakes; habitat and breeding bird populations in Labrador; oil contamination of the Atlantic Coast; the setting and implement action of water quality standards and regulations. An important feature of the study is the strong collaboration among the partners involved so the subject matter knowledge is fully integrated in the development of statistical methods. Two scientists

from the Atlantic region visited the institute to work with the study leader last year and two students (Doctoral and Master) completed their theses under the study leader supervision.

Study Areas: Turkey Lakes, Lake Superior, Lake Ontario

Results

A model for accumulation of polychlorinated biphenyl (PCBs) concentration in lake trout from Lakes Superior and Ontario using age as a surrogate variable was developed. The model contains only two parameters one is fish specific while the other is lake specific and is related to the PCB concentration in the lake. The model can be used as a risk assessment tool since it provides a reliable estimate for probability that the concentration exceeds a specific limit and or estimate the fish age range that corresponds to a specific concentration limit.

In 1992 Environment Canada conducted a helicopter survey of breeding bird populations in 25 plots in southern Labrador. The analysis of spatial changes in the American Black Duck population was the focus of the study. The number of times the ducks were detected and the total number of ducks were modeled using habitat and location (longitude and latitude) as explanatory variables. The negative binomial distribution was used to model the data since the variability was above that expected under the Poisson model. The 22 Habitat variables were found to be adequately divided into two groups of 19 and 3 variables each. Only two variables (sparse spruce (lichen cover) non-commercial and lichen scrub/open bog) were found to be important habitat explanatory variables. In addition the location variables were found to have significant influence on the variability of the counts. The model is then used to predict the duck count distributions for various scenarios of the habitat variables.

Time series models have been developed to measure the temporal and spatial changes in Turkey Lakes water chemistry data (1981- 1997). Trend cycles were identified in many of the chemicals and this casts doubts on the suitability of Kendall's Tau test, which is widely used in the analysis of data of this type.

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STUDY TITLE: Quantifying the Ultraviolet Light Field in Natural Waters

STUDY LEADER:	J. H. Jerome
STUDY TEAM:	R. P. Bukata, R. Bourbonniere
PARTNERS:	DFO, Borstad Associates
CLIENTS:	MSC
FUNDING:	EC

Introduction

Solar ultraviolet irradiance at depth in a natural water body is dominated by the character and concentration of dissolved organic matter (DOM) present in the water column. This study attempts, through laboratory and field measurements, to quantify the effects of the atmospheric and aquatic parameters that control the subsurface levels of UV radiation. The results are relevant to the estimation of the impacts of stratospheric ozone depletion on aquatic ecosystems. This year's work included the deployment of the submersible ultraviolet and visible spectrometer (UV-VIS spectrometer) on the Lake Erie 'UV and Microbial Community' research cruise, the analyses of the resultant data set, the

conversion of the Water to Air Transfer of Electromagnetic Radiation System into a remotely-controlled instrument, and a return to the application of remote sensing in aquatic research.

Study Areas: Lake Erie

Results

The submersible spectrometers (UV-VIS) were deployed in Lake Erie during the UV and Microbial Community study. One UV-VIS system collected incident UV and visible radiation data during the entire cruise, and the other system monitored the subsurface irradiance profile periodically to determine the spectral irradiance attenuation coefficients. This data will be used in conjunction with results from surface and *in situ* rate studies, and screening studies to evaluate aspects of carbon cycling, and DOM and H2O2 photochemistry. The novel design of the UV-VIS spectrometer enabled it to measure the UV irradiance attenuation coefficient under adverse ambient conditions consisting of 0.75m waveheights. Such conditions would have prevented any existing commercial instruments from performing the measurements.

Times series measurements of subsurface UV irradiances provided data to verify our subsurface UV spectral irradiance model. By employing the diffuse nature of incident ultraviolet radiation, the model can reliably estimate the diurnal UV light field in natural waters from incident levels and the spectral irradiance attenuation coefficients. The UV irradiance model differs from a PAR (photosynthetically active radiation) irradiance model by reducing the importance of solar angle in the model calculations. A final report is being prepared.

Broadband UV-B and UV-A sensors (Vital Technologies) were shown to be highly inaccurate when using their factory calibrations. However they can be calibrated using coincident measurements with the UV-VIS spectrometer.

The WATERS (Water to Air Transfer of Electromagnetic Radiation System) instrumentation, used to measured a suite of aquatic optical properties including water colour, was modified to enable its deployment from a large ship such as the LIMNOS. It can now be remotely-controlled from the ship, via a laptop, to eliminate the impact of the ship on the underwater light field. However its refurbishment was not completed in time for it to be used on the Lake Erie research cruise. As a result, activities scheduled for its use in this field season had to be delayed until the 2001/02 field season. The refurbishment was undertaken at an opportune time as its field deployment in 2001/02 and the resultant data analyses will be a major component of NWRI's contribution to a proposal submitted to the Canadian Space Agency under the Earth Observation Applications Development Program (EOADP) .

UV-B spectral attenuation in central Lake Erie was determined to be 20% higher during July 2000 compared to July 1999, reducing the depth of impact zones a corresponding 20% (neglecting mixing effects). NLET results are still outstanding so the cause of the change is still not determined.

In preparation for a return to remote sensing of aquatic resources after working for over 5 years in UV related research, a bibliography of optics and remote sensing of aquatic resources was updated (includes over 600 references). The bibliography was supplied to IOCCG (International Ocean Colour Co-ordinating Group).

A proposal was submitted to the Canadian Space Agency in the Earth Observation Applications Development Program (EOADP) by G Borstad (Borstad Associates), J Gower and A Pena (DFO), and R Bukata, M Charlton, and J Jerome (NWRI) entitled "Water Quality Products for Inland and Coastal Canada". The program will take an optical model, developed at NWRI, to estimate water quality

parameters from water colour, and apply it to satellite imagery of the Great Lakes and BC coastal waters. Funding has been received for the first year of the project.

An initial investigation was undertaken into the application of classified satellite data, available from DND, to areas of interest at NWRI. DND, in Ottawa, was visited to obtain information on, and view satellite imagery that is currently available. Many possible research applications were evident, but the cost of data and its analyses are prohibitive at this time.

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AQUATIC ECOSYSTEM REMEDIATION PROJECT

The AER Project's multidisciplinary research team develops methods and tools for the biological, chemical and ecotoxicological assessment and remediation of contaminated groundwater and sediments. The knowledge generated by the Project supports Environment Canada's national and regional programs and the Canadian Environmental Protection Act. New techniques to treat contaminated sediments and groundwater *in situ* are developed and tested using bench and pilot scale operations. The research is conducted in collaboration with other government agencies, industry and universities.

STUDY TITLE: Groundwater Remediation using Vitamin B12

STUDY LEADER: Suzanne Lesage
STUDY TEAM: Kelly Millar and Susan Brown
PARTNERS: URS-Dames and Moore
CLIENTS: U.S. Army Garrison at Aberdeen Proving Grounds, Maryland
FUNDING: U.S. Department of Defense

Introduction

The vitamin B12/titanium citrate technology for the remediation of chlorinated organic compounds was developed at NWRI and a U.S. patent was obtained in 1997. URS-Dames and Moore, a major environmental consultant to the U.S. Army, contracted us to do a feasibility study in the laboratory in 1998. This was followed by a pilot-scale evaluation conducted in two phases in the fall of 1999 and 2000 at Aberdeen Proving Grounds, a large military research facility located on the Bay of Chesapeake in Maryland. The major contaminants of concern are carbon tetrachloride and 1,1,2,2-tetrachloroethane. This latter compound, although not common, was examined under CEPA and found in large concentrations at the Ville-Mercier site in Quebec. Therefore, the result of this research is applicable to Canadian sites.

Study areas: Aberdeen Proving Grounds, Maryland (2000)

Results

One of the advantages of the vitamin B12/titanium citrate mixture is its ability to degrade mixtures of chlorinated methanes, ethanes and ethenes. The major contaminants of concern at the study site are carbon tetrachloride, 1,1,2,2-tetrachloroethane (TeCA) and trichloroethene. The total concentration of chlorinated aliphatic hydrocarbons in the source area groundwater monitoring wells ranges from 4,000 to 6,000 µg/L.

One of the major difficulties in the implementation of chemical treatment in groundwater is to ensure proper mixing. For this reason, instead of using the traditional injection well, it was decided to use a recirculation well to do in-ground mixing of the water and the treatment mixture. The project was conducted in two three-month phases. In the initial phase (Fall 1999), the emphasis was placed on maximizing the amount of reaction occurring in the well itself while minimizing chemical addition. With a residence time of approximately 30 minutes and average concentration of 2.1 mM Ti and 3 mg/L vitamin B12, complete degradation of carbon tetrachloride was achieved, but the degradation of TeCA varied between 50-80% because of fluctuations in the stability of the delivery system. The transformation of TeCA into cis- and trans-DCE continued to occur in-situ and was essentially complete by the first row of monitoring wells, ten feet away from the recirculation well. In this first phase, the mixture was supplemented with a glucose-fructose syrup as a preferential carbon source to citrate and as a source of organic acids known to be a source of H_2 to support dechlorinating bacteria. Changes in the ratio of cis- to trans-DCE in groundwater samples over time were indicative of some bacterial dechlorination activity. While this strategy was successful in allowing titanium citrate to be transported at least 20 feet from the well, it caused excessive bacterial growth and clogging in the vicinity of the well.

After using various methods to clean the well screens, it was decided to change the rate of delivery of the chemical treatment and to add Tolcide™ as a bacteriostatic agent (see report on Microbial Processes in Groundwater). The purpose of the second phase (Fall 2000) was to deliver a concentrated treatment as directly as possible to areas of higher contaminant concentrations, indicative of a dense non-aqueous phase residual. The treatment mixture was added in weekly concentrated pulses of 20 hours. The pH and

Eh, as surrogate parameters for the movement of the active ingredients, were monitored daily for the first two weeks and weekly thereafter, in the 24 monitoring points installed radially up to 80ft away from the recirculation well. After three months of uninterrupted pulsed treatment the contaminant concentrations decreased to below guidelines in a 20 ft radius around the recirculation well.

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STUDY TITLE: Contaminant Transport in Fractured Rock

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STUDY TEAM:	J. Voralek, C. Talbot
PARTNERS:	Smithville Phase IV Bedrock Remediation Program (MOE), Queen's University, CLIENTS: MOE, Regions
FUNDING:	GL2020, Smithville VNR

Introduction
Contaminant transport in groundwater within complex fractured rock deposits is controlled by the three dimensional arrangement of the fractures and the properties of the rock matrix. Proper hydrogeological characterization of these deposits is key to understanding contaminant transport, designing effective remediation schemes and predicting transport behaviour in order that our valuable groundwater resources can be protected. Large portions of the industrialized areas of the Great Lakes' watersheds are underlain by flat-lying sedimentary rock. In many regions, the bedrock is overlain by thin sequences of overburden leading to rock aquifers, which are highly susceptible to contamination from surface sources. Some of the major sites of groundwater contamination in Canada are underlain by fractured rock (i.e. Ville Mercier, Smithville, and Sydney). The presence of fractures perpendicular to the earth's surface (ie. vertical) allows for widespread contamination at depth. Generally, common practise in the industry is to treat fractured rock deposits in a manner analogous to unconsolidated material. While appropriate in some instances, adopting this conceptual model will lead to serious error in areas where the rock is sparsely fractured.

Our current studies on contaminant transport in fractured rock are focussed primarily on the following areas: (1) Methods of measuring groundwater velocity in discrete fractures, (2) Geostatistical interpretation of hydraulic and core measurements and (3) Characterization of heterogeneous rock aquifers.

Study Areas: Smithville

Results
Recent studies at the Smithville site have shown that determining groundwater velocities, using hydraulic head measurements at different scales in fractured rock deposits is difficult. At the regional scale the connectivity of the flow paths may not be easy to discern or necessarily follow the geological unit boundaries. In addition to determining connectivity of fractures zones both in the horizontal and vertical dimensions at the site scale, differences in hydraulic head in the order of centimetres leads to hydraulic gradients and groundwater velocity measurements which are prone to measurement error. Consequently, if complex groundwater systems are to be understood, other direct methods of measuring groundwater

velocity need to be used to corroborate both the inferred hydraulic connections and the groundwater velocities. These may include point-dilution and multi-well tracer experiments and inter-borehole hydraulic tests.

During the previous four years, as part of site characterization activities at a contaminated site in Smithville Ontario, hydraulic head has been measured in the Lockport dolostone at over 75 monitoring locations on a weekly basis. The boreholes used for monitoring are located within an area of several square kilometres. Monitoring zones range in length from 1-20 m and access various horizons over the depth of the Lockport Formation. This formation, which ranges from 30-50 m in thickness in the study area, is typical of the shallow bedrock in Southern Ontario and Western New York. Results suggest that well-connected horizontal fracture zones dominate the flow system at the regional scale. At the field scale (hundreds of square metres), hydraulic gradients between 10^{-4} and 10^{-3} were measured. Temporally, hydraulic head varies at all levels due to climatic variations with differences of up to 2 m observed. Current groundwater levels are lower than average and consistent with trends observed elsewhere in southern Ontario. Additionally, groundwater velocities in discrete fractures ranging from a few metres a day to several hundred metres a day were measured using point-dilution techniques. These measurements compare favourably with velocities and hydraulic gradients determined from hydraulic head measurements.

Using geostatistics to interpret the field transmissivity measurements at various scales suggests that correlation is evident at various scales. The most well-correlated structure occurs in the intact rock at the scale of cms. At scales greater than this the interplay of fracturing and diagenitic processes impart complexity into relatively simple flow systems. Further work is planned to investigate the relationships between permeability of the rock mass and the three-dimensional fracture framework.

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STUDT TITLE: Microbial Processes

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PARTNERS:	URS Corp., Lockheed Martin Energy Systems,
CLIENTS:	U.S. Army Garrison, APG, Maryland
FUNDING:	VNR

Introduction

The vitamin B_{12}/titanium citrate technology for the remediation of chlorinated organic compounds was developed at NWRI and a U.S. patent was obtained in 1997. A successful laboratory study in 1998 conducted for URS, a major environmental consultant to the U.S. Army, was followed by a field pilot in 1999, at Graces Quarters, Aberdeen Proving Ground, in Maryland. Groundwater at this site is contaminated with 1,1,2,2-tetrachloroethane, carbon tetrachloride, trichloroethene, tetrachloroethene, and chloroform. Although the pilot test showed favourable results, biological fouling of the chemical injection/recirculation well and the near-by formation halted pilot test operations after 14 weeks of treatment. To assess the extent of the biofouling, geoprobe samples of the aquifer matrix were collected and submitted for laboratory testing of permeability, and analysis of microbial phospholipid fatty acids (PLFAs), and 16S rDNA. After successful redevelopment of the injection/recirculation well using the

Aqua Freed® process, and several modifications to the chemical treatment mix and injection strategy, aimed at preventing future biofouling, the pilot test was resumed. Modifications included the use of a biocide and a pulsed, rather than continuous, approach to the injection of the vitamin B_{12}/titanium citrate treatment.

Study Areas: Aberdeen Proving Ground, Maryland

Results

Microbial analyses revealed that biomass was most concentrated in the vicinity of the injection/recirculation well. PLFA profiles were indicative of a diverse microbial community, consisting primarily of gram-negative bacteria. Biomarkers for decreased membrane permeability, indicating an adaptation to environmental stress, were present in the gram-negative communities. DNA sequencing of prominent bands isolated during denaturing gradient gel electrophoresis (DGGE), revealed strains of delta and beta proteobacteria and some gram-positive bacteria. The Aqua Freed® well redevelopment process, which disrupts biomass through the injection of pressurized carbon dioxide, was successful in restoring full permeability to the system. Treatment was resumed in the fall of 2000. System modifications included a pulsed application of the vitamin B_{12}/titanium citrate treatment and the use of a non-oxidizing biocide, Tolcide®, containing tetrakis(hydroxymethyl)phosphonium sulfate (THPS) as the active ingredient. The data show that daily application of Tolcide® at a 150-mg/L active concentration, in combination with pulsed injection of the vitamin B_{12}/titanium citrate mix was effective for the prevention of biological fouling over a 12-week remediation treatment. The inhibitory effects of Tolcide® were limited to the anaerobic treatment zone and did not interfere with ongoing biological degradation of organic contaminants outside this region. Tolcide® was effective in preventing premature citrate utilization, thereby extending the area of the abiotic vitamin B_{12}/titanium citrate treatment. Chlorinated contaminants were degraded to meet drinking water guidelines in a 7-m radius around the well.

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STUDY TITLE: Algal Toxins as Initiators of Avian Botulism

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PARTNERS:	Ducks Unlimited, Horizons' program
CLIENTS:	Manitoba Environment, CWS
FUNDING:	Ducks Unlimited, US Army Corps

Introduction

As many waterfowl die each year from avian botulism as are reared in all North American habitat projects or are harvested by hunters. The disease is natural but it appears to be becoming more common. Some of the outbreaks are associated with the presence of algal toxins. Algal toxins, especially microcystins are becoming common in many eutrophic waterbodies. Many Canadian Prairie lakes are highly eutrophic. The eutrophication process may be accelerated by runoff in agricultural areas, but the problem can be compounded by the natural geochemistry of the area that enhances phosphorus availability. Bacteria metabolism converts high levels of sulphate to high levels of sulphide and this process inactivates iron, thereby enhancing the mobility of phosphorus. High levels of nitrogen in

phosphorus-rich lakes also can enhance the growth of microcystin-producing microcystis algae. However, nutrient sources and cycling are not fully understood within the Whitewater Lake watershed and selection of appropriate management practices depends on a better understanding of system dynamics.

Study areas: Whitewater Lake, Manitoba (2000)

Results

Available data include macronutrient levels (N and P), metals levels, algal enumeration, and algal toxin levels in the water column at six master sites. In addition to the data collected at the six master sites, sampling for water pH, conductivity, temperature, salinity, and dissolved oxygen was done using a Hydrolab datasonde at 18 other sites around the lake. Samples for chlorophyll a, fluorescence, and bed sediment texture and loss-on-ignition also were collected at all sites. A floating sampling platform and meteorologic tower was installed in the lake during the summer months to collect data on wind speed, direction, air temperature, water temperature, relative humidity, solar radiation, and water turbidity. An ISCO automated pump sampler was connected to the meteorologic datalogger and the system was programmed to collect water samples once every day and when wind velocity exceeds 8 m s^{-1}.

All sediment and water quality data have been organized using ArcView GIS. Data on fertilizer application rates and crop yield/soil type (as an indicator of nutrient source) were obtained for the watershed from the Manitoba Crop Insurance Corporation. High winds (at least 8 m s^{-1}) are capable of resuspending sediment from the lake bottom, thereby releasing nutrients and potentially enhancing algal growth (but in some cases lysing algae cells containing toxins). Winds of this velocity occurred 4% of the time during the summer of 1998 and the mean suspended solids concentration for these wind resuspension events (68.9 mg l^{-1}) was significantly greater (α=0.05) than the mean for non-event samples (32.4 mg l^{-1}). Dissolved calcium levels were highly correlated (r=0.835) with the suspended sediment concentrations, indicating a release of calcium from the bed during storm perturbations. Chlorophyll a levels (an indicator of algal biomass) generally increase as the summer progresses and GIS visualizations show that the levels frequently are highest in the northern and northeastern part of the lake. These spatial trends of chlorophyll a are consistent with those observed in a study conducted on the lake in the early 1950's that attempted to explain conditions that initiated avian mortality. It appears that wind affects the distribution of chlorophyll a, as this north-northeast pattern is consistent with the prevailing wind direction. However, there are times that the highest chlorophyll a levels are found elsewhere in the lake and are not consistent with wind direction. This spatial pattern may reflect nutrient source location (e.g. standing herds of cattle, individual septic tank/municipal sewage discharges).

As a first step to exploring nutrient sources, fertilizer use in the watershed was investigated. Nitrogen fertilizers are applied within the watershed at a spatially-averaged rate of 60-65 pounds per acre, while phosphorus fertilizers are applied at a spatially-averaged rate of 30 pounds per acre. These application rates within the watershed are similar to average rates for the province, indicating that the lake is not at a higher nutrient load risk due to higher fertilizer use.

However, the GIS visualizations showed that much of the productive land in the southern part of the watershed has a relatively dense stream drainage network and the shorter flow paths to the streams can facilitate movement of nutrients to the lake.

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STUDY TITLE: Sediment Restoration

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PARTNERS:	Golder Associates
CLIENTS:	Hong Kong City, DLZ Company, Massachusetts Electric Company, Boston Gas Company
FUNDING:	clients

Introduction

Environment Canada has developed a new technology involving the injection of remedial amendments into sediments to enhance contaminant degradation by indigenous microorganisms. Typically bench-scale treatability of sediments is assessed prior to pilot and full-scale remediation. The primary goal is to inexpensively determine the limitations of sediment bioremediation prior to committing major funding to clean-up. The scientific goal is to improve upon the treatment process so that more sediments can be treated. This year we conducted bench-scale treatability studies in CCIW with sediments from a Detroit oil refinery pond and from Hong Kong. Application of this technology was initiated by our licensee Golder Associates in 1998 as part of a potential five-year program demonstrating the effectiveness of remedial amendments to intertidal zone marine sediments at a former manufactured gas plant in Salem, MA. Full-scale sediment remediation by our licensee is also beginning in Hong Kong and Detroit.

Study areas: Salem, Mass., Lake Biwa, Japan, Hong Kong, Detriot, Mi. (2000)

Results

Salem:

The full-scale treatment at Salem by Golder Associates (as licensing agent) has been highly effective. Analyses of sediment samples collected from one of the treatment areas reflected an average reduction of 90 percent for total concentration of polyaromatic hydrocarbons (PAHs). Pre- and post-treatment data acquired during 1998-1999 showed that the concentration of primary PAHs (naphthalene, 1-methylnaphthalene, 2-methylnaphthalene, and phenanthrene) reduced from an average of 115 mg/Kg to 10 mg/Kg. Significant concentration reductions also were shown for other contaminant types: 85 percent for diesel range organics (an average of 400 mg/Kg reduced to 50 mg/Kg), 77 percent for gasoline range organics (168 mg/Kg reduced to 38 mg/Kg), and 50 percent for total petroleum hydrocarbons (400 mg/Kg reduced to 200 mg/Kg). Indirect indicators that biodegradation occurred at increased levels within the treatment area included the observation of green alga and gaseous emissions that were previously absent, field measurement of oxidizing conditions that contrasted to reducing conditions outside the treatment area, and decreased organic constituent concentrations.

Additional sampling and laboratory testing will be conducted in 2001 to better understand the mechanisms for biodegradation and to observe contaminant reductions at this site. Several years may be required, however, to determine whether migration of separate phase coal tar to surface water can be abated and to what levels the coal tar constituents can be degraded when compared to background conditions.

Japan:

Ongoing collaboration has confirmed that vivianite [$Fe_3(PO_4)_2 \cdot 8H_2O$] dissolution in the sediments of Lake Biwa is contributing to the eutrophication of this lake. Sediment treatments can only be effective if vivianite stability is increased and this can be achieved by *in situ* oxidation and pH buffering. Control of external loading must consider both nutrient control and organic carbon and sulphur loading. The continued loading of organic matter and sulphur results in increased sulphide concentration in lake

sediments and in turn vivianite dissolution. The situation is unusual in that it appears that some of this eutrophication process is set up by atmospheric loading of sulphur.

Hong Kong and Detroit:
The bench-scale treatments of sediments from the Shing Mun River (Hong Kong) and an oil refinery pond in Detroit oxidized more than 99% of the sulphides. The results lead to our licensee initiating full-scale remediation projects at these sites by our licensee.

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STUDY TITLE: Long-Term Fate of Metals at Abandoned Mine Sites

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STUDY TEAM:	J. Rajkumar, co-op students and graduate students
PARTNERS:	University of Waterloo
CLIENTS:	Province of Manitoba, Placer Dome, Falconbridge
FUNDING:	TSRI, NSERC

Introduction
Active and abandoned mines are the largest point source of metal release to the environment. Old mine sites around the world continue to release elevated concentrations of metals to surface waters, decades to centuries after mining activities have ceased. Initial oxidation of sulfide minerals in mine wastes results in the formation of acidic waters and release of metals to pore waters. These metals can accumulate further downgradient along groundwater flow paths. Over time, and under changing geochemical conditions, the accumulated metals can be released into flowing groundwater and discharge to surface water bodies. At certain sites, even under neutral conditions, the release of undesirable constituents such as arsenic can also occur. A combination of laboratory and field studies is being conducted to evaluate the mechanisms controlling the attenuation of metals and arsenic at four mine sites in Ontario and Manitoba. Chemical and mineralogical analysis of tailings and aquifer material will be performed to evaluate the mass and form of metals and arsenic accumulated along the ground-water flow path. Column studies will be conducted to evaluate the potential for release of metals into flowing water of differing compositions. Field studies will include measurements of hydrogeological and geochemical processes controlling transport of metals and arsenic in the tailings impoundments, in the impacted aquifers and at the groundwater surface water interface, to assess the potential for long-term release of metals into the aquatic environment. The results will be modelled using a fully coupled reactive solute transport model developed at the University of Waterloo.

Study areas: Sudbury, Timmins and Red Lake, Ontario, and Northern Manitoba (2000), Northern Manitoba (2001)

Results
The mine sites were selected to cover a range in age of the waste piles and a range in mineralogical composition of the tailings. The sites include three base-metal and one gold mine site. Two sites are active, and two were abandoned fifty years ago. Piezometers were installed and cores collected for pore-water squeezing and solid-phase analysis. Cores were collected within the tailings, and in the impacted aquifers. Pore-water dialysis samplers were installed in the lake sediments adjacent to the tailings areas.

Samples of tailings pore water and groundwater were collected to determine the concentrations of metals, arsenic and other geochemical parameters. Cores were sectioned in the laboratory and analysed during 2000. Laboratory column experiments were initiated to assess the potential for release of metals and arsenic from the tailings and aquifer materials. Geochemical speciation model calculations were performed to determine mineral saturation indices. The results of the laboratory and field studies will be used to predict the long-term release of metals and arsenic from the mine sites.

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STUDY TITLE: Biological Barriers in Fractured Bedrock

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PARTNERS:	Petro-Canada, Ecole Polytechnique, Queen's University
FUNDING:	PERD

Introduction
Fractured rock aquifers remain a scientific, as well as an economic challenge in groundwater remediation. The concept of biological barriers, consisting of a biofilm formed by exopolysaccharides-producers (EPS-producers) bacteria, has been studied mainly for the remediation of porous media. In most studies, the formation of the biobarrier has been promoted by the injection of bacteria (bioaugmentation) and nutrients. However, the persistence of some injected micro-organisms and the introduction of new environmental regulations created a need to investigate aquifer bioclogging via stimulation of the indigenous microflora (biostimulation).

The project includes laboratory and field experiments (Petro-Canada, Mississauga). The objectives are to: 1- monitor the changes in permeability due to bioclogging, 2- assess the changes in the microbial community, 3- measure the potential ecotoxicity of the biostimulation, 4- model the changes in groundwater flow, and 5- monitor the long term stability over time. This study includes a collaboration with École Polytechnique de Montréal and Queen's University.

Study Areas: Mississauga

Results
Year 2000-2001 was used to develop a laboratory apparatus, conduct a preliminary experimental design at lab scale, and prepare the field site. An existing laboratory apparatus, simulating a 2.0 m x 0.6 m fracture plane (fracture = 1.5 mm), has been modified to increase the intensity of monitoring by the addition of 15 sampling ports and in-situ Eh electrodes. The formation of a biofilm in the apparatus is being performed in a coldroom at 10 °C, a temperature typical of Canadian groundwater. The experimental design includes 18 analytical parameters (hydrogeological, microbiological, and ecotoxicological).

The field preparation activities consisted of testing the instrumentation of 27 existing boreholes, deciding on instrumentation design suitable for non-intrusive monitoring of the bioclogging, drilling 3 new boreholes, constructing new packers and probes, and conducting hydraulic testing.

A research agreement has been prepared with École Polytechnique de Montréal. We have collaborated specifically on the definition of the laboratory scale experiments conducted both at NWRI and École Polytechnique (Françoise Castegnier, M.Sc. student). Dr. Louise Deschênes has funded a Co-op student (Diane Filion) from University of Waterloo for the 2001 winter term. The collaboration with Kent Novakowski (Queen's University) focused on the development of a computer model which integrate the groundwater flow equations with biofilm formation.

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STUDY TITLE: Physical Sedimentology and Acoustics of Freshwater Sediments

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PARTNERS:	Canadian Hydrographic Service, Fresh Water Institute
CLIENTS:	Ontario Region EC, Environment Protection Branch, RAPs, DFO, State of Michigan
FUNDING:	GL2020 Sustainability Fund, Great Lakes Fishery Trust

Introduction
This project develops and uses innovative techniques for mapping and monitoring the physical properties of riverbed and lake sediments in general and contaminated sediments in Areas of Concern (AOCs) in particular. We use RoxAnn, a seabed-classification system to map fine-grained, potentially-contaminated sediments, bottom-mounted acoustic and video dataloggers to monitor contaminated-sediment stability, and acoustic/video and free-fall penetrometers to record sediment surface properties and thickness. These techniques have been applied successfully to six AOCs, to capping and dredging projects in Hamilton Harbour and at Massena, NY, and to nearshore surveys in Lake Ontario in support of shoreline development, harbour maintenance, coastal zone management, and zebra-mussel mapping.

Study areas: Hamilton Harbour, Cornwall, Detroit River, Bay of Quinte, Lake Ontario

Results
Geometry of the contaminated Randle Reef deposit in Hamilton Harbour:
Detailed measurements of soft-sediment thickness with the STING free-fall penetrometer were used to map the geometry of contaminated sediments and estimate their volume. Data on sediment properties collected over the past 5 years have been compiled in a report to be used for remediation planning by the harbour RAP.

Sediment stability at Cornwall:
An underwater videologger and seabed flume were used to collect data on sediment stability at the most contaminated Cornwall site. Results from both confirmed earlier acoustic data suggesting that sediment erosion and resuspension was unlikely. Detailed data on sediment thickness were collected with an underwater-video system to refine the estimate of contaminated-sediment volume. The results of both

studies were presented to a sediment-strategy workshop at Cornwall held to determine the need for remediation and the approaches which might be used.

Mapping and stability of Detroit River contaminated sites:
A followup of last year's RoxAnn survey of bottom sediments of the entire reach was run with the focus on areas of fine-grained sediment accumulation. General data coverage was increased with the cooperation of NOAA who incorporated acoustic mapping of bottom sediments into their detailed hydrographic survey of the river. Acoustic monitoring of riverbed erosion and deposition at two sites was continued and a full year of data is now available for use in modeling of sediment transport. A new underwater videologger was successfully used at one of the sites to provide visual data confirming the acoustic results. Trial measurements of sediment thickness with the STING free-fall penetrometer were conducted in one of the largest deposits of fine-grained sediments to demonstrate its usefulness for volumetric estimates.

Substrate mapping in the Bay of Quinte for sediment quality and macrophyte studies:
Two RoxAnn and underwater-television surveys were run in the Trenton, Belleville and Picton areas of the Bay of Quinte, one to locate and determine the thickness of contaminated sediments in support of a coring program by the EP Branch, and the second for substrate classification in support of a macrophyte survey by DFO.

Trials of RoxAnn acoustic mapping in Lake Ontario:
A RoxAnn survey of Lake Ontario was run on the Limnos to demonstrate the feasibility of collecting data on substrate type by piggybacking on ship or launch surveys designed for other purposes. Good data were obtained at normal ship speeds and to depths of about 80 m by using a new echosounder and a specially-designed transducer "bra". The new data will contribute to a revised substrate map of Lake Ontario basin sediments for use in the LaMPs program. Results of last year's collaboration with Chris Marvin and OME in trials of acoustic and video mapping of zebra mussels at Port Dalhousie were used by OME to develop a video system for a study on the effects of zebra mussels on both substrate and water quality.

Comparison of RoxAnn and other acoustic approaches for bottom-sediment classification:
A study of different approaches to acoustic bottom-sediment classification was undertaken in collaboration with the local hydrographic service and the Fresh Water Institute. RoxAnn, QTC View (a Canadian RoxAnn-system) and the CHS multi-beam sonar system were used to classify a small test area of western Lake Ontario. Results will contribute to the selection of the best system to be used locally for contaminated-sediment mapping and also to a binational program of detailed mapping of the substrate of the Great Lakes.

Videologger system:
An underwater videologger system has been designed and constructed to complement the acoustic logger and to provide independent visual records of sediment erosion and transport in areas of contaminated sediments. Preliminary trials at Cornwall were successful in documenting two perturbations that were affecting the quality of the acoustic data. Records from the Detroit River were able to confirm almost continuous sediment transport.

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STUDY TITLE: Use of Commercial Humic Products in Subsurface Remediation

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FUNDING: Luscar Ltd., A-base

Introduction

In this research, commercial humic products are under investigation as potential flushing agents for subsurface remediation. These products bind hydrophobic organic contaminants which results in enhanced contaminant solubilization and mobilization in soils and aquifer materials. The anticipated result is the development of a novel groundwater remediation technology, of interest to the groundwater remediation service industry in Canada, and a contribution toward Environment Canada's Clean Environment theme. The intended result is that the environmental and human health threats posed by toxic substances and other substances of concern are prevented or reduced.

Compared to some other proposed flushing agents (e.g., synthetic surfactants), humic products offer several advantages: they are relatively inexpensive, non-toxic, and resistant to biodegradation, which means that they do not compete with the contaminants (e.g., hydrocarbons) for the oxygen needed to support biodegradation.

Plans are underway to characterize and select various commercial humic products in 2001-02, in preparation for subsequent pilot scale field applications.

Study Areas: Burlington (Lab Study)

Results

We have investigated the commercial humic acid-assisted flushing of PAHs from an artificial diesel source in groundwater at the laboratory pilot scale (6 m x 2 m x 1 m). The results indicate that the presence of the humic acid at 1 g/L enhanced the solubilization of various PAHs from the diesel source by 2 to 10 fold and reduced the time of clean-up approximately five-fold. The pilot scale test was closely simulated using a comprehensive 3D numerical model that accounted for carrier-assisted transport, sorption and biodegradation. Another simulation suggests that in the presence of 10 g/L humic acid , the length of time required to flush PAHs from the diesel source would be decreased by 20-fold, compared to flushing with water (i.e., conventional pump and treat). These results and supporting bench-scale studies indicate that the use of concentrated humic acid solutions may be a useful technique for enhancing the subsurface remediation of organic contaminants. Our next goal is to test this technology at contaminated sites under various field conditions (i.e., different soil textures, aquifer materials, and contaminants). The computer model is available to test different scenarios and whether this novel approach is likely to work at a given site.

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STUDY TITLE: Immobilization of Contaminated Sediments by In-Situ Capping

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Introduction

Contaminated aquatic sediments pose globally some of the most difficult environmental problems. Miscellaneous organic and inorganic contaminants are typically bound to fine-grained sediments with very high water content. In many industrial harbours, rivers and estuaries, volumes of contaminated sediments are large, and the economic and ecological costs of ex-situ methods (dredging, treatment and disposal) are frequently unacceptable or impractical. A relatively new and cost-effective remediation method for contaminated sediments is the technique of in-situ capping. In-situ capping requires the placing of a layer of clean material over contaminated sediments to prevent contaminants from entering the water column and to provide a clean substrate for benthic invertebrates. The capping material most often used is sand or silt. Little field experience exists so far with the use of finer-grained material.

Study Areas: Hamilton Harbour, Lake Superior, St. Lawrence River

Results

In 1994, a demonstration capping project planned for a Hamilton Harbour site has been endorsed by the technical team of Hamilton Harbour RAP and by the Bay Area Restoration Council (BARC). The actual placement of the sand cap took place in the summer of 1995. Post-capping physical, chemical and biological monitoring has taken place at the site in 1995, 1996 and 1997. In-situ capping remediation has been evaluated for Peninsula Harbour AOC in Lake Superior in 1999. It has been further proposed to use capping in combination with dredging at the Randle Reef remediation site in Hamilton Harbour and at several locations in the St. Lawrence River.

The thickness of contaminated sediments at the Randle Reef remediation site in Hamilton Harbour has been investigated by several coring and in-situ testing methods. The information on highly variable sediment properties and distribution of PAH contamination is required for estimates of site remediation costs. Several approaches have been used to map the contaminated sediments at the site including Benthos coring, measurements of depth to refusal with acoustic and Sting™ penetrometers and limited geotechnical measurements and borehole sampling from a spudded barge. A compilation of core, tripod and Sting™ data yielded estimates of the total volume of severely contaminated sediments at the site. The results and data interpretation are compiled in a NWRI report.

A two-week visit to the Environmental Research Centre (UFZ), Leipzig, Germany, in September-October 2000 was used to carry out initial laboratory capping experiments with a new column apparatus installed at the UFZ. The purpose of the experiments is to determine the effectiveness of capping PAH-contaminated sediments under controlled temperature, pH and redox conditions.

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Presentations

Brownlee, B., M. Alaee, **M. Charlton,** J. Ridal, **S. Watson,** S. Hamilton-Browne, C. Cannon, **G. MacInnis** and **J. Milne.** Analytical methods suitable for shipboard extraction of the odour compounds 2-methylisoborneol and geosmin. 36th Central Canadian Symposium on Water Pollution Research, Burlington, ON, February 5-6 2001.

Charlton, M. and **B. Brownlee.** Sampling and analysis of geosmin during a taste and odour event in Lake Ontario 1999. 43rd IAGLR Conference, Cornwall, ON. May 21-26, 2000.

Charlton, M.N., J. Milne, S. Watson, B. Brownlee and S. Hamilton-Browne. Do physical factors contribute to taste and odour events in Lake Ontario? 36th Central Canadian Symposium on Water Pollution Research, Burlington, ON. February 5-6, 2001.

Charlton, M.N. Aquaculture Research in Ontario. Aquaculture 2000, Moncton, NB. May 28-31, 2000.

Charlton, M.N. Water quality in Hamilton Harbour, western Lake Ontario environmental Coalition, Hamilton, ON. April 27, 2000.

Charlton, M.N. Why do we have weed in Hamilton Harbour? Royal Hamilton Yacht Club, May 11, 2000.

Charlton, M.N. How does the Harbour respond to water quality enhancements? At State of the Lakes Environment conference (SOLEC 2000), Hamilton, ON. October 16, 2000.

Charlton, M.N. Cleaning up Hamilton Harbour, Hamilton Rotary club, Hamilton, ON. June 23, 2000.

Charlton, M.N. Great Lakes Research, Ugandan delegation, Burlington, ON. June 16, 2000.

Charlton,M.N. Great Lakes eutrophication experience. Workshop Eutrophication and its countermeasures in China, Dali City, China. October 25-28, 2000.

Charlton, M.N. Progress in Great Lakes Research. State University of New York. November 16, 2000.

Charlton, M.N. Sustainable Water Uses for the Great Lakes. University of Toronto at Mississauga, ON. December 8, 2000.

Charlton, M.N. Water quality in Hamilton Harbour. Workshop on Research and monitoring in Hamilton Harbour. Burlington, ON. January 17, 2001.

Cheng He and **P.F. Hamblin.** Validation Of A 3-D Harbour Flushing Model With Field Observations From Hamilton Harbour And The Western End Of Lake Ontatio, Annual Conference of 43rd IAGLR Conference, Cornwall, ON. May 23, 2000.

Coakley, J P, M.G. Skafel and R.V. Elliott. Natural Sediment Tracers vs. Hydrodynamic Transport Models As Predictors Of Contaminant Dispersal, Toronto Waterfront, Lake Ontario. II Latin American Sedimentological Congress.

Coakley, J P, M.G. Skafel, C.H. Marvin and T. Bachtiar. Transport of sewage-contaminated sediment in Northeastern Hamilton Harbour. 43rd IAGLR Conference, Cornwall, ON., May 23, 2000.

Coakley, J.P. and **M.G. Skafel.** Transport patterns and fate of sewage-contaminated sediment in Hamilton Harbour. Hamilton Harbour Research/Monitoring Workshop, Burlington, ON. January 2001.

Droppo, I.G. Redefining what constitutes suspended sediment in the urban continuum. Open lecture for Coventry University, Coventry, UK. November 22, 2000

Droppo, I.G. Suspended sediment: Not necessarily what the eye beholds. Open lecture for the University of Leeds, Leeds, UK. November 20, 2000.

Droppo, I.G. Sedimentological characteristics and floc research in Hamilton Harbour. Invited presentation at the Bedford Institute of Oceanography, Dartmouth, NS. February 9, 2001.

El-Shaarawi, A.H. On the Estimation of Probability or the Level of Exceedance with Environmental Applications. Invited paper for the Biometric Section at the Joint Statistical Meetings of the American Statistical Association in Indianapolis. August 13-17.

El-Shaarawi, A.H. Detecting and Modelling Environmental Changes. Keynote address for the Fourth International Conference on Environmetrics and Chemometrics; Las Vegas; September 18-20.

El-Shaarawi, A.H. Quantitative Methods in Environmental Studies. Keynote Address for the Saudi Mathematics Conference "Mathematics 2000" at King Saud University. April 11-13, 2000.

El-Shaarawi, A.H. and Jari Walden. Modelling changes in water and air chemistry: A case study for Canadian lakes and Finnish Air. Keynote Address for the 30th Annual International Symposium on Environmental Analytical Chemistry, Helsinki, Finland. June 13-16, 2000.

Hamblin, P.F. On the validation of a 3-D model of unsteady stratified exchange flow between a harbour and a lake in David Wilkinson Memorial Session of the 5th International Symposium on Stratified Flow, Volume 1, pp. 549-554 Univeristy of British Columbia, Vancouver, BC. July 10-15, 2000.

Hamblin, P.F. Evaluation of mesoscale meteorological models for large lakes. Joint Plenary Session with the 3rd International Vereshchagin Baikal Conference, Irkusk, Russia. August 24.

Hamblin, P.F. Physical limnology and three-dimensional mathematical of Hamilton Harbour. Workshop on Research and Monitoring of Hamilton Harbour, Burlington, ON. January 17, 2001.

Hamblin P.F. Analytical models for the development of three-dimensional models of lakes and coastal zones, Colloquium Department of Applied Mathematics, University of Waterloo. March 1, 2001.

Hamblin, P.F. Water Quality Modelling of Caged Aquaculture Impacts in the North Channel of Lake Huron, 43rd IAGLR Cornwall, ON. May 23, 2000.

Hamilton-Browne, S., Y. Macabuag, A. Chaput, **B. Brownlee, M. Charlton** and T. Howell. Taste and odour research in western Lake Ontario. 16th Eastern Canadian Symposium of the CAWQ on Water Pollution Research, Ottawa, ON. November 17.

Hickey, M.B.C., J.J. Ridal and **B. Brownlee**. Do zebra mussels play a role in the production of taste and odour compounds in St. Lawrence River drinking water? 36th Central Canadian Symposium on Water Pollution Research, Burlington, ON. February 5-6.

Irvine, K.N., **T.P. Murphy**, T. Tang, L.M. Romano and D. Walters. Spatial and Temporal Trends in Chlorophyll *a*, Nutrient Characteristics, and Sediment in Relation to Large Scale Avian Mortality, Whitewater Lake, Manitoba. SQA4, Conference in Otsu, Japan. October 24, 2000.

Jeffries D.S. Responses of Canadian watersheds to changing levels of acidic deposition. Conference on Sustainable Forestry, Lakehead University, Thunder Bay, ON. May, 2000.

Jeffries D.S. Aquatic acidification: issue status and outlook. Environment Canada Workshop on Threats to Water Quality, Toronto, ON. January, 2001.

Jordan, I., **I.G. Droppo, G.G. Leppard,** D.F. Schmid and S.N. Liss. 2000. Microbial Ecology of Flocculated Sediments. Presented at Environment Canada's Strategic Technologies Application of Genomics in the Environment Workshop, Hull, Quebec. April 27-28, 2000.

Jurjovec, J., **C.J. Ptacek,** K.U. Mayer and D.W. Blowes. Reactive transport modeling of reactions controlling metal release in mine tailings. 11th Annual V.M. Goldschmidt Conference, Hotsprings, VA. May 20-24, 2001.

Krishnappan, B.G. Modelling cohesive sediment transport in the Athabasca River in Alberta, Canada. Presentation to the Swiss Federal Institute of Technology at Lausanne, Switzerland. August, 15, 2000.

Lapcevic P.A. and K.S. Novakowski. The Variability of the Hydrogeological Properties of the Carbonate Bedrock in Southern Ontario. 43rd IAGLR Conference, Cornwall, ON. May 22-26, 2000.

Lapcevic P.A. The Characterization of Fractured Dolostone Underlying Smithville, ON, Dept. of Earth Sciences, University of Waterloo, January 23, 2001.

Lapcevic P.A., J. Voralek and C. Talbot. Hydraulic Head and Groundwater Velocity Variations in Fractured Sedimentary Rock. 36th Central Canadian Symposium on Water Pollution Research, Burlington, ON. Feb 5-6, 2001.

Lapcevic P.A. and K.S. Novakowski. Multiple-Scale Measurement Of Groundwater Flow And Transport Parameters In The Lockport Dolostone Underlying Smithville, Ontario. Fractured Rock 2001, Toronto, ON. March 25-28, 2001.

Lapcevic P.A. and K.S. Novakowski The Hydrogeological Characterization of The Carbonate Bedrock Underlying a Contaminated Site in Smithville, Ontario, Americana 2001, Montreal Quebec. March 26-30, 2001

Leppard, G.G. 2001. Floc/colloid processes in fresh water. Invited presentation at the Bedford Institute of Oceanography, Dartmouth, NS, February 9, 2001.

Leppard, G.G. The electron-optical speciation of native colloids in aquatic ecosystems: Relevance to the transport, bioavailability and fate of contaminants. Invited lecture at American Society of Limnology and Oceanography (ASLO) 2000 - Research Across Boundaries. Special Session on Role of Aquatic Colloids, Copenhagen, Denmark. June 5-9 , 2000.

Lesage, S. Groundwater Remediation using Vitamin B12. Guest lecturer of the Center for Environmental Biotechnology of the Lawrence Berkeley National Laboratory. University of California at Berkeley Bioremediation Education Science and Technology (BEST) network.

Lesage, S., S. Brown and **K. Millar.** Field demonstration of vitamin B12 for the *in-situ* degradation of chlorinated solvents in groundwater. CAWQ, Burlington, ON. February 5-6, 2001.

Lesage, S., S. Brown, K. Millar, C.S. Mowder, T. Llewellyn, S. Forman, D. Green, K. Gates and G. DeLong. Remediation of chlorinated solvents in groundwater using vitamin B12. Presented at the Innovative Site Assessment and Remediation Technology Workshop for Federal Contaminated Sites. November 6-7, 2000.

Malley, D.F., P. Badioul, **T. Murphy** and M. Kumagai. Potential for sediment quality monitoring in Lake Biwa, Japan, using near-infrared spectroscopy. SQA4, Otsu, Japan. Oct. 27, 2000.

Marvin, C.H., N.A. Rukavina, T. Howell and **B. Trapp.** 2000. Characterization Of Bottom Sediments And Dreissena Colonization Using The RoxAnn Acoustic Seabed Classification System And Potential Associations with Water Quality. 43rd IAGLR Conference, Cornwall, ON. May 2000.

Marvin C.H., M.G. Skafel and E.T. Howell. Investigation of Optical and Physical Profiling for Tracer Applications in Hamilton Harbour. 35th Central Canadian Symposium on Water Pollution Research, Burlington, ON. February 7-8, 2000.

Marvin, C.H., S. Painter, **M. Charlton, L. Thiessen,** M. Fox, **F. Rosa** and **T.B. Reynoldson.** Environment Canada Research on Organic Pollutants in the Lower Great Lakes. 4th Biennial State of the Lakes Ecosystem Conference, Hamilton, ON. October 17th-19th.

Marvin, C.H. and **M. Charlton.** Contaminants associated with suspended sediments in the Detroit River. Meeting of the Detroit River Data Management and Modelling Project and Associated Activities on the Detroit River, Great Lakes Institute for Environmental Research, Windsor, ON. March 22nd, 2000.

Marvin, C.H., M. Charlton, S. Painter, **T.B. Reynoldson, F. Rosa** and **P.A. Thiessen.** Temporal and spatial contamination in Lake Erie sediments. Lake Erie Millenium Plan Conference, Contamination Processes in Lake Erie. Presque Isle PA. September 11-12, 2000.

Marvin, C.H., S. Painter, **M. Charlton** and S. Backus. Spatial Distribution of toxaphene in Lake Erie sediments. Organohalogen Compounds, 20th International Symposium on Halogenated Environmental Organic Pollutants and POPs, Monterey, CA.

Marvin, C., L. Thiessen, M. Fox, **M. Charlton, J. Milne** and B. McCarry. Persistent organic pollutants in Hamilton Harbour: Current status and temporal trends. 43rd IAGLR Conference, Cornwall, ON. May 23, 2000.

Marvin, C.H., S. Painter, **M. Charlton, L. Thiessen,** M. Fox, **F. Rosa** and **T.B. Reynoldson.** Environment Canada Research on Organic Pollutants in the Lower Great Lakes. Canadian Coast Guard Ship Limnos Open House, Port Colborne ON. August 5-7.

Mowder, C.S., **S. Lesage, K. Millar, S. Brown**, K. Gates and D. Green. Field demonstration of *in situ* vitamin B12-catalyzed reductive dechlorination. Pacific Environmental Restoration Conference, Honolulu, Hawaii. April 1-5, 2000.

Murphy, T.P. A review of sediment treatment Invited presentation to Japanese Ministry of Transportation and Industry, Hiroshima, Japan. June 27, 2000.

Murphy, T.P. Progress on sediment management of Lake Biwa. Invited presentation to the Japanese *In-Situ* Sediment Treatment Association, Otsu, Japan. June 30, 2000.

Murphy, T.P. Potential treatment of Hong Kong Sediments. Invited presentation to Hong Kong government. July 6, 2000.

Murphy, T.P. A review of lake management. Invited opening presentation to workshop attended by local government officials, consultants and a delegation of 14 water managers from People's Republic of China, Calgary, AB. August 30, 2000.

Murphy, T.P. and M. Kumagai. Eutrophication Control by Sediment Treatment Common Assumptions and Misconceptions. Invited presentation to SQA4, Conference in Otsu, Japan. October 24-27, 2000.

Murphy, T.P. and M. Kumagai. Spatial and temperal variation in redox in Lake Biwa sediments. Presentation to SQA4, Conference in Otsu, Japan. October 27, 2000.

Murphy, T.P. and M. Kumagai. Spatial and temporal variation in redox in Lake Biwa sediments. Society of International Limnology, Melbourne, Australia, February 5, 2001.

Murphy, T.P. Review of lake restoration. Invited presentation to Vietnam National University, HCM City. February 16, 2001.

Murphy, T.P. and K. Irvine. Avian botulism in the Canadian prairies. Invited presentation to a workshop organized by the New York and Ohio Sea Grants, Erie, PA. January 24, 2001.

Murphy, T.P. Algal toxins and reactive capping in Hamilton Harbour, Great Lakes Sustainability Fund. Burlington, ON. Jan. 29, 2001.

Ng, H.Y.F., C.S. Tan, C.F. Drury and J.D. Gaynor. Perspective of controlled drainage and subsurface irrigation technologies for agricultural water management: A Case Study. Agri-Food 2000 Conference, Winnipeg, Manitoba. July 15-19, 2001.

Novakowski, K.S., **P. Lapcevic, J. Voralek** and G. Bickerton. Measuring Radial Solute Transport in a Discrete Fracture at the Macroscopic Scale. American Geophysical Union's Fall Conference in San Francisco, CA. December 2000.

Ptacek, C.J., M. Moncur, R. McGregor and D.W. Blowes. Geochemical controls on metal concentrations in mine tailings that have undergone 50 years of oxidation. 11th Annual V.M. Goldschmidt Conference, Hotsprings, VA. May 20-24, 2001.

Reynoldson, T.B., S.P. Thompson and D. Milani. Setting toxicity criteria using multiple test endpoints, a comparison of multivariate and ranking methods. World SETAC Congress, Brighton, U.K.

Reynoldson, T.B. The need for regional and national scale biomonitoring in Canada. Seminar presented at Acadia University, February 2001.

Reynoldson, T.B. The importance of biological scale in designing environmental assessment networks for Canada: a worms eye view. Seminar presented to Atlantic Region, Environment Canada, Halifax. February 2001.

Reynoldson, T.B. Through a glass more clearly: unmuddying the waters. Presentation to the Cornwall RAP, Cornwall, ON. February 2001.

Ridal, J., **B. Brownlee** and M.B. Hickey. Identification of sources of geosmin (GM) and 2-methylisoborneol (MIB) in the St. Lawrence River. 43rd IAGLR Conference, Cornwall, ON. May 21-26.

Ridal, J.J., M.B.C. Hickey and **B. Brownlee**. Sediment sources of taste and odour compounds in the St. Lawrence River. 36th Central Canadian Symposium on Water Pollution Research, Burlington, ON. February 5-6.

Rukavina, N.A. New methods for mapping and monitoring contaminated sediments. Invited presentation, Great Lakes Research Consortium Annual Meeting, Environmental applications of remote sensing, Spatial and Spectral, Syracuse, NY. June 2000.

Rukavina, N.A. Research on sediment geometry and stability in the St. Lawrence River, Canada. Eighth International Symposium On Regulated Streams, Toulouse, France. July 2000.

Rukavina, N.A. and H. Biberhofer. The anatomy and stability of a contaminated deposit in the St. Lawrence River at Cornwall, Ontario. 43rd IAGLR Conference, Cornwall, ON. May 2000.

Rukavina, N.A. and **B. Trapp.** Mapping sediment properties with NWRI's underwater video-acoustic tripod. 43rd IAGLR Conference, Cornwall, ON. May 2000.

Rukavina, N.A. A.J. Zeman and T.S. Patterson. Research on the properties of contaminated sediments at the Randle Reef remediation site, Hamilton Harbour. Presentation to the Hamilton Harbour RAP, Burlington, ON. February 17, 2001.

Satchwill, T., **S.B. Watson**, E. Dixon and E. McCauley. The impact of Chrysophyte algae on drinking water taste and odour. 36th Central Canadian Symposium on Water Pollution Research, Burlington, ON. February 5-6.

Skafel, M.G. Currents in Hamilton Harbour: Applications of the ADCP. Hamilton Harbour Research/Monitoring Workshop, CCIW Burlington, ON. January 17.

Sylvestre S., **T.B. Reynoldson** and T. Tuominen. Expanding the use of the Reference Condition Approach developed for the Fraser River basin to assess slow moving soft bottom streams. N. American Benthological Society meeting, Keystone, CO.

Van Stempvoort, D.R., J.W. Molson and **S. Lesage.** Aqueous Humic Products for Subsurface Remediation. Innovative Site Assessment and Remediation Technology Workshop for Federal Contaminated Sites, Ottawa, ON. November 6-7, 2000.

Watson, S., T. Satchwill and E. McCauley. Chrysophyte taste and odour: Under ice blooms in Glenmore Reservoir. 35th Central Canadian Symposium on Water Pollution Research. Burlington, ON. February 7-8.

Watson, S. and E. McCauley. Outbreaks of mixotrophic algae: multiple resource exploitation or coupled processes? ASLO Annual Symposium, Research across Boundaries. Copenhagen, June 5-9.

Watson, S.B., B. Brownlee, M. Charlton and S. Hamilton-Browne. Aquatic odour origins: Multiple within-system sources? 36th Central Canadian Symposium on Water Pollution Research, Burlington, ON. February 5-6, 2001.

Watson, S.B. and E. McCauley. Within- And Among Lakes Patterns In Odour-Causing Algal Taxa: Ecological and Applied Implications. Annual meeting of the Society of Canadian Limnologists (SCL) Toronto, ON. January 4-6, 2001.

Zaitlin, B., **S. Watson** and D. Parkinson. Actinomycetes in aquatic systems: Origins and activities. Central Canadian Symposium on Water Pollution Research, Burlington, ON. February 5-6.

Zeman, A.J., N.A. Rukavina and T.S. Patterson. 2000. Research on the properties of contaminated sediments at the Randle Reef remediation site, Hamilton Harbour, 43rd IAGLR Conference, Cornwall, ON. May 22-26, 2000.

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