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CURRENT RESEARCH 2002/2003

AQUATIC ECOSYSTEM MANAGEMENT RESEARCH BRANCH

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NWRI Contribution Number 03-221

CURRENT RESEARCH - 2002/2003

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NWRI Contribution No. 03-221

AEMRB CURRENT RESEARCH - 2002/2003

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, lake ecosystem function and recovery, modeling and decision support, 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, Integrated Watershed Modelling and Management and Aquatic Ecosystem Remediation. This report provides a synopsis of the extensive and diverse research work by our scientists for the fiscal year 2002/2003.

RECHERCHE ACTUELLE 2002/2003 - DRGEA

RÉSUMÉ

La Direction de la recherche sur la gestion des écosystèmes aquatiques (DRGEA), une des trois directions de recherche de l'Institut national de recherche sur les eaux, étudie 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 écosystèmes aquatiques, fonctions et rétablissement d'écosystèmes de lac, l'aide à la décision et à la modélisation, 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. Ces activités sont réalisées dans le cadre de quatre projets interdisciplinaires : Recherche sur la gestion des eaux urbaines, Recherche en gestion des lacs, Modélisation et gestion intégrées des bassins hydrographiques et Restauration des écosystèmes aquatiques. Le présent rapport résume les travaux divers et abondants menés par les chercheurs de la Direction au cours de l'exercice financier 2002-2003.

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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. The AEMR Branch 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, decision and modeling support, 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, sustainable aquaculture and; the application of remote sensing techniques for monitoring and assessment of large ecosystems.

The Integrated modeling and Management Project, led by Dr. D. Lam, provides research to develop knowledge and models for better-integrated watershed management and performs research on contaminant mass balance and water quality modeling, decision support systems, integrated assessment modeling, and 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 of 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 2002-2003 for our numerous domestic and international partners and collaborators, as well as interested colleagues

and a knowledgeable public audience. It provides 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 2003

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. Par ses recherches écosystémiques, l'INRE fait reculer les limites de la connaissance et de la compréhension des écosystèmes aquatiques qui sont nécessaires afin de régler les problèmes environnementaux d'importance régionale, nationale ou internationale pour le Canada, et il diffuse ses résultats.

La Direction de la recherche sur la gestion des écosystèmes aquatiques (DRGEA), une des trois directions de recherche de l'Institut national de recherche sur les eaux, étudie la gestion et l'évaluation des eaux de surface et des eaux souterraines dégradées par les activités anthropiques. Les travaux contribuent à atteindre les objectifs des secteurs d'activité Environnement sain et Nature définis dans le Cadre de gestion d'Environnement Canada. Les principales activités de recherche comprennent l'évaluation de la santé des écosystèmes aquatiques, l'aide à la décision et à la modélisation, 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 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. 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; l'aquaculture durable; enfin, l'application des techniques de télédétection à la surveillance et à l'évaluation des grands écosystèmes.

Le Projet de modélisation et de gestion intégrées des bassins hydrographiques, dirigé par D. Lam, porte sur l'acquisition de connaissances et la mise au point de modèles dans le but d'améliorer la gestion intégrée des bassins hydrographiques; le bilan massique des contaminants; la modélisation de la qualité de l'eau; les systèmes d'aide à la décision; la modélisation d'un processus intégré d'évaluation; enfin, l'analyse statistique de la qualité de l'eau.

Le Projet de restauration des écosystèmes aquatiques, dirigé par 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 de la Direction au cours de l'exercice financier 2002-2003 à l'intention de nos nombreux partenaires et collaborateurs à l'échelle nationale et internationale, des collègues intéressés et des citoyens bien renseignés. Il résume les travaux divers et abondants menés par nos chercheurs, et le lecteur est invité à communiquer avec les chefs de projet pour de plus amples renseignements.

John Lawrence
Juillet 2003

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:	K. Exall, L. Grapentine, B.G. Krishnappan, Q. Rochfort, P. Seto
PARTNERS:	Queen's University, Kingston; Wastewater Technology Centre, ETAD, Burlington; City of Toronto
CLIENTS:	Great Lakes Sustainability Fund (GLSF), City of Toronto, Toronto Region Conservation Authority
FUNDING:	GL2020, GLSF

Introduction

Urban wet-weather pollution represents a major impediment to delisting Areas of Concern with large discharges of combined sewer overflows (CSOs) and urban stormwater. To develop the knowledge required for controlling wet-weather pollution, novel methods for mitigation of stormwater and CSO 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, ETAD (Burlington, Ontario), and several partners providing financial or in-kind support - the Great Lakes Sustainability Fund (GLSF), the City of Toronto, and the Toronto Region Conservation Authority.

Study Areas: Etobicoke, Kingston, North Toronto

Results

Studies of urban stormwater management practices have been continued and documented in a number of publications. At the international level, an international report on stormwater management has been prepared and published by the International Water Association (IWA). The report summarized findings on stormwater practices in 18 countries on four continents. It confirmed high interest in stormwater management, and a movement towards a holistic approach to stormwater management. Specific implications include emphasis on source controls, transition from "hard" to "green" infrastructures, needs for maintenance and rehabilitation, formation of stormwater agencies, and sustainable funding through drainage service fees. Also at the international level, at the invitation of IWA, a chapter on stormwater management ponds was prepared for the forthcoming IWA book on wastewater ponds and their use in wastewater management. This chapter summarizes the latest information on stormwater pond design and sizing, performance in pollutant removal, maintenance, and pond processes, including hydraulic transport, water quality processes and ecology.

Experience with stormwater pond processes from ten years of research at the Kingston pond was summarized in a journal paper. It comprises the essential considerations in pond design, starting with physical layout, and its improvement by retrofit of internal flow baffles; improvement of pond performance by polishing the effluent by biofiltration or constructed wetlands; assessment of pond operation in various seasons; the assessment of ecological conditions in the pond caused by sediment contamination and its toxicity; and, the effects of exposure to contaminated sediment on pond biota. Seasonal performance studies focused on winter operation of the pond, and general effects of road salts on stormwater management in cold climate. It was noted that stormwater management affects chloride transport and fate in urban areas. Road salts caused

densimetric stratification of the Kingston pond, with chloride concentrations reaching toxic levels (as high as 1000 mg/L).

Further advances have been achieved in characterizing physical properties of fine-grain sediment from the Kingston pond with respect to transport characteristics. Deposition tests conducted in the NWRI rotating flume served to establish the critical shear stress for deposition (τ_{cd} = 0.050 N/m^2) and the amount of sediment staying permanently in suspension. From experiments for two consolidation periods, 41 and 138 h, the critical shear stress for erosion of the surface sediment layer was estimated as 0.12 N/m^2. Finally, empirical relationships were developed to estimate sediment deposition and erosion as a function of bed-shear stress and recommended for future modeling of fine sediment transport in the pond studied. The earlier published Krishnappan's model for settling in still water and the knowledge obtained through these studies were used to formulate a new model for flocculated settling of fine sediment in stormwater ponds. The model predicted well measured suspended sediment concentrations and size distribution of flocculating sediment.

Other research involving contractors and partners focused on treatment of stormwater and CSOs by chemically aided settling. Stormwater treatment was studied during the 2001 and 2002 field seasons at a site in Etobicoke, Ontario. In total, 51 clarification tests were completed with and without lamellar plates. Total vessel surface loads varied from 9.9 to 15.1 m/h and polymeric flocculant dosages ranged from 0 to 8 mg/L. The dosage of 4 mg/L was the most effective in total suspended solids (TSS) and other pollutants removal, followed by 8 mg/L, 2 mg/L, and unaided settling. The corresponding average TSS removals were 84, 62, 61 and 26%, respectively. Average removals of other constituents were lower, e.g., just 25% for $cBOD_5$, 48% for COD, and 46-60% for the metals studied. In the later part of the experimental program, the clarifier lamellar plates were removed to test conventional clarification for various polymer dosages. The dosage of 4 mg/L again produced the best removal of TSS (52%), but such a removal was not significantly different from that obtained for the dosage of 2 mg/L (47%). To address concerns about possible toxicity of polymer treated stormwater, both the influent and treated effluent were tested for acute toxicity by two tests - Microtox™ and the 96-h acute toxicity rainbow trout bioassay. In 20 tests of fish toxicity, polymer flocculant addition did not increase the risk of fish toxicity.

The treatability of CSOs has been studied with respect to two aspects – settleability, and treatment by coagulation and flocculation. Working with Dr. Krishnappan of the AEIRB (HIAEP Project) on testing CSO settleability, a novel elutriation method has been proposed and tested with a limited number of samples. Compared to the traditional column settling tests, the novel method allows testing dynamic settling of CSOs and testing changes in CSO settleability as a result of chemical additions.

Combined sewer overflows tend to be highly variable in composition, presenting a challenge to effective treatment. The robustness of various coagulants and coagulant combinations was studied under Dr. Exall's leadership with respect to their ability to bring about efficient contaminant removal under variable physico-chemical conditions. To accomplish this, the effects of suspended solids (SS) and dissolved organic carbon (DOC) concentrations on chemically enhanced settling of simulated CSO wastewater using various inorganic salt and organic polyelectrolyte products were evaluated. The coagulants and flocculants studied varied in their responses to changes in SS and DOC concentrations, particularly in terms of DOC removal and sensitivity to DOC concentration. The required dosages of the coagulants (inorganic and

organic) were quite sensitive to DOC concentration, but good to excellent SS and DOC removals were obtained. By comparison, the organic flocculants displayed good SS removal, but poor removal of DOC under all conditions, in spite of sensitivity to initial DOC concentration. The coagulants and flocculants studied also varied in effects on sample pH and in tendency to restabilize suspended material at high dosages. While no coagulant or flocculant is universally applicable, understanding the trends in treatment efficiency can help in choosing the type of product that is most suitable for treatment under given wastewater quality conditions.

In preparation for the 2003 field season, the North Toronto CSO Storage Facility was redesigned for more effective operation. Specific measures include a changeover from flow proportional to solids-flux proportional flocculant dosing, more accurate flow measurement, and improved understanding of flow distribution in the facility and its implications for flocculant mixing and solids settling.

Other activities included providing support and leadership with respect to four events: (a) The Canadian Council of Ministers of the Environment (CCME) workshop on wastewater reuse and recycling, (b) The Environment Canada workshop on Threats to Water Availability, (c) The UNESCO urban water management project, and (d) The NATO Urban Water Management Workshop. The CCME workshop on water reuse was held in Calgary in May, 2002. About 60 invited participants, representing various sectors and regions of Canada, were in attendance. The workshop proceedings indicated that even in a relatively water-rich country like Canada, there are regions where significant economic and environmental benefits can be achieved by water reuse and recycling. There is a need for developing regulations for such activities, using the existing experience from several Canadian provinces and abroad. For the workshop on Threats to Water Availability, the leadership was provided for a chapter dealing with Municipal Water Supply and Development. The whole document will be published in the NWRI Scientific Assessment Report Series. Support was provided to two international agencies dealing with water science – UNESCO and NATO. For UNESCO, a working group on urban water management has been established and charged with responsibility of preparing a manual on the management of urban water cycle. This effort is now under way. In support of the NATO science program, an advanced research workshop was held on Urban Water Management: Science, Technology and Service Delivery. The workshop was held in Bulgaria, in October 2002.

CONTACT

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STUDY TITLE: Pharmaceuticals and Personal Care Products in Municipal Wastewater

STUDY LEADER:	P. Seto, M. Servos, M. Béland
STUDY TEAM:	H-B. Lee, D. Bennie, K. Burnison, P. Falletta, K. Kwong, R. McInnis, D. Nuttley, G. Pacepavicius, V. Palabrica, T. Peart, L. Svoboda, K. Terry, M. Baker, T. Neheli, K. Sarafin, S.A. Smyth, J. Toito, V. Voora
PARTNERS:	Ontario Ministry of the Environment, Wastewater Technology Centre
FUNDING:	WTC, OMOE

Introduction

Pharmaceuticals and personal care products (PPCPs) in the environment is an emerging area of concern in Canada. Municipal sewage has been identified as an important source of PPCPs. Analytical methods were developed and validated for acidic drugs, musks, and antibiotics in liquid sewage. Methods for neutral drugs are under development. A survey of municipal wastewater treatment plant influent and effluent, and concurrent upstream and downstream surface water, was completed for 12 plants which discharge their effluents to the Thames River. These activities were undertaken in collaboration with colleagues at NWRI and WTC. Both the WTC and the MOE provided financial support.

Study Areas: Thames River Watershed

Results

Preliminary results indicate that a higher residential component in the wastewater is associated with higher concentrations of PPCPs in the influent, and that treatment plants which achieve nitrification also appear to achieve higher removal of PPCPs from the liquid stream.

Future Plans

Analytical methods for PPCPs in biosolids are in progress. When validated, we will be able to determine what proportion of PPCPs are partitioned to the solid phase and what proportion are degraded by the wastewater treatment and/or sludge digestion processes. Optimization of wastewater treatment for PPCP removal will be investigated through the use of bench-scale activated sludge reactors. A long-term intensive study at two Ontario treatment plants will be carried out to study the removal of PPCPs at each stage of the treatment train (eg. Primary, secondary, tertiary, sludge digestion, etc.). A survey of treatment plants along the Grand River is also planned, in conjunction with surface water sampling by Ontario Region. WTC will provide the analytical support for these studies. Environmental impacts of PPCPs discharged to the receiving stream are being investigated by other study teams.

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STUDY TITLE: Role of Groundwater in the Hydrology and Quality of Wetlands

STUDY LEADER:	A.S. Crowe
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CLIENTS:	Parks Canada, Wainfleet Bog Conservation Authority, New Brunswick Department of Environment
FUNDING:	GL2020, NRCan, Parks Canada

Introduction

Groundwater is an important component of a variety of aquatic and terrestrial ecosystems. Groundwater is an especially vital component of the hydrology of wetlands, and in many cases groundwater is the principal source of water for these fragile ecosystems. Thus, wetlands rely on a consistent supply of clean groundwater. In order to ensure that these vital ecosystems are conserved and protected, it is important to understand the role of groundwater in the hydrology of wetlands, and the role of groundwater in the transport of contaminants to and from these wetlands. To develop the knowledge required to conserve and restore wetlands, a variety of field and numerical modeling activities are underway.

Study Areas: Point Pelee National Park (Ontario), Wainfleet Bog (Ontario), Shediac (New Brunswick)

Results

Point Pelee Marsh

Several of the open water ponds adjacent to recreational areas of Point Pelee National Park are experiencing sever eutrophication. It is suspected that the park's septic systems are contribution excess nutrients via groundwater discharge to the marsh. Field studies undertaken during the past few years showed that the direction of groundwater flow within the barrier bar adjacent to the marsh is highly complex and influenced by infiltration, width of the barrier bar, and fluctuating lake and marsh levels. During the past year a numerical model to simulate the movement of the plumes of septic-system derived nutrients at Point Pelee National Park was completed. The results of the field and model studies indicate that because groundwater flow velocities and directions are highly variable, septic system derived contaminants may or may not discharge to the marsh. In fact throughout much of the barrier bar, groundwater flow and accompanying contaminant transport is towards Lake Erie. The model simulations were presented as animations, which show the transport and spatial distribution of the contaminants during a 5 to 10- year period. Results of this work will be used by Point Pelee National Park to assist in the place of new septic systems within the park.

Wainfleet Bog

Research is being undertaken to assist the Niagara Peninsula Conservation Authority with their efforts to restore of this unique ecosystem. Because the Bog was mined since the 1900's, the water table is severely depressed and must be restored to ground surface in order for the

sphagnum peat moss to grow. The primary goal of the hydrological component of this restoration program focuses on raising the elevation of the water table to surface, or about 1-2 m. This may not be possible because dewatering at a large quarry (1.2 km x 0.8 km x 24 m deep) situated ~300 m to the south may induce drainage from the bog. The base of the bog is separated from bedrock by ~25 m of clay, preventing significant leakage through its base. However, the southern end of the bog either abuts bedrock (Onondaga Escarpment) or is separated by a few metres of clay. Our studies indicate that these few metres of clay form an effective barrier to drainage. Even if the clay was absent, upon restoration, a lower water table caused by drainage along the escarpment-bog contact would extend <50 m into the bog. The large surface area of the bog, relative to the area of the contact means more water enters the bog as infiltration than as drainage along the contact. Hence, current quarry and future expansion will have minimal impact on the bog.

Shediac Bogs

Increasing development in southeastern New Brunswick has resulted in conflicts for groundwater resources among residential well owners, peat producers and conservationists. The residents are concerned that dewatering of local peat bogs during peat mining will lower groundwater levels throughout the region and hence limit groundwater for domestic consumption. Conservationists are concerned that increased pumpage of groundwater from all residential development will dewater the natural bogs, hence destroying this fragile ecosystem. Peat producers feel that their dewatering is not affecting regional groundwater conditions, and that water levels (and hence the ecosystem) can be re-established once mining ceases. A research study was initiated to investigate the relationship between the peat bogs within the Shediac area and the regional groundwater flow regime in the underlying regional carboniferous aquifers. During the past two years, field studies have characterized the local setting of the peat bogs, and differentiated the groundwater flow regimes within the peat bogs and the underlying bedrock. Peat bogs are separated from the carboniferous bedrock by a thin (1-5 m thick) layer of till. Because this forms an effective barrier to rapid movement of groundwater between the peat and bedrock, the groundwater flow regimes within each are distinct. Numerical model of region is being undertaken to investigate the impact of future groundwater withdraws on the sustainability of the bogs.

Numerical Modeling of Groundwater-Wetland Interaction

A computer model which simulates groundwater-wetland interactions and contaminant transport within the groundwater flow system adjacent to wetlands has been developed during the past few years. The model is designed to provide insight into hydrological processes in a groundwater-wetland environment and undertake long-term predictions. Improvements were made to the code during the past year to enhance the flexibility of analyses and simulate a wider range of groundwater-wetland settings. The model has been applied to provide insight into groundwater – wetland interaction in the Great Lakes, Point Pelee, Wainfleet Bog, and southeastern New Brunswick.

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STUDY TITLE: Assessing the Fate and Persistence of Pesticides in the Subsurface

STUDY LEADER: A.S. Crowe
STUDY TEAM:
PARTNERS: McMaster University, Parks Canada
CLIENTS: Parks Canada
FUNDING: GL2020, CRESTech, Parks Canada

Introduction

Although pesticide are a vital component of agriculture; without pesticides we could produce the quantity nor the quality of agricultural products. However, because pesticides are specifically designed to kill living organisms, there use in the environment is not without risk. Pesticides are often retained in the surficial soil or bioactive portion of the soil, and thus present a health risk to human and animals that live or come into contact with the contaminated soil. This pesticide will ultimately leach to the water table, and then flow with groundwater. Thus, downstream users (wells, dugouts) or endpoints (rivers, lakes, wetlands) of this groundwater is potentially a risk to contamination. Thus it is important that we understand the fate of pesticides in the subsurface, and specifically what controls their persistence, retention and transport in the subsurface.

Study Areas: Point Pelee National Park (Ontario)

Results

Assessing the Distribution of DDT and Dieldrin at Point Pelee National Park

Large areas of Point Pelee National Park (PPNP) are contaminated with DDT and Dieldrin because it was widely used for pest control in the former orchards, vegetable fields, and recreational areas. This has lead to the current presence of high levels of DDT and Dieldrin in the soil. This represents the principle pathway by which wildlife and humans may come into contact with the pesticides, and in fact several species have been severely affected by DDT and Dieldrin. Before the Park can undertake programs to protect and restore the ecological integrity of the wildlife habitat, an assessment of both the distribution of these pesticides within the Park, and the environmental factors responsible for its persistence is required. The shallow soils within different areas of PPNP (based on soil and sediment types, organic carbon content, depth to water table, susceptibility to flooding by the marsh, former land-use activities) have been identified as having significant statistical differences in pesticide concentrations and rates of degradation. Contaminated groundwater may represent a pathway to exposure to humans through the Park's water supply wells, and to the aquatic ecosystem via groundwater discharge to the marsh. Recent studies have assessed the distribution and concentrations of DDT and Dieldrin in the

groundwater beneath soil exhibiting high concentrations of these pesticides, and determining processes controlling its leaching. Groundwater analyses indicate that concentrations of Total DDT and Dieldrin are extremely low. The thickness of soil/sediment through which DDT and Dieldrin much leach, and the concentrations of these pesticides in soil at ground surface, are not a significant factor controlling concentrations in groundwater. Concentrations of DDT and Dieldrin in groundwater are not controlled by concentrations at surface but by the desorption properties of the pesticides.

Remediation of Soil Contaminated with Organochlorine Based Pesticides

Existing methods of remediation soil contaminated by OC-based pesticides involve excavating the contaminated soil and disposing of it in a landfill or aggressively and continually mixing (bioreactors, plowing, tilling) the soil with chemical/nutrient additives. These approaches are not acceptable in many areas because they would essentially destroy the local ecosystem and wildlife habitat though the removal of vegetation, soil and wildlife. A research project is underway to develop a technique for remediating groundwater and soil contaminated with OC-based pesticides while causing minimal disruption of the ecosystem. The remediation technology employs the application of a surfactant at ground surface that is flushed through the contaminated soil. As the surfactant moves downward through the soil, it enhances biodegradation by both increasing soil moisture conditions and changing the redox state of the soil to an anaerobic condition. The surfactant also mobilizes the OC-based pesticides through desorption from the soil's organic matter, flushing the contaminants downward in soil and away from the shallow soil or bioavailable zone. The technology was applied a site at Point Pelee contaminated by DDT and Dieldrin. Preliminary results show that concentrations of the DDT and Dieldrin residues in shallow soil at sites that are undergoing treatments are decreasing quickly relative to the non-treated control sites. These results indicate that under some conditions OC-based pesticides in soil are largely accessible for rapid dechlorination and flushing.

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STUDY TITLE: Flocs and Colloids: Structure, Activity and Behaviour in Natural and Engineered Systems

STUDY LEADER:	Gary G. Leppard and Ian G. Droppo
STUDY TEAM:	T. A. Jackson, C. H. Marvin, C. Jaskot, Q. Rochfort, B. Trapp
PARTNERS:	Ryerson University, McMaster University, University of Toronto, multiple industrial partners, University of Ottawa, York University, Northwestern University in greater Chicago, Texas A&M University in Galveston, Berkeley and Brookhaven Synchrotrons in U.S.A., Universities of Zurich and Lausanne in Switzerland, University of Vienna in Austria
CLIENTS:	EC and industrial supporters, and international funding agencies
FUNDING:	NSERC, GLAP, GLB 2020, TSRI, 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 and chemical behaviour and biological activity 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, Larder Lake, North Toronto CSO Treatment Facility, Dorset lakes, Sudbury lakes, several Canadian and U.K. rivers, several industrial wastewater treatment systems in Canada and U.S.A., contaminated soils near U.S.A. nuclear energy plant, Danube River in Austria.

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 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. Solids retention time and phosphate levels have been chosen as variables to study, for achieving desired biomanipulation.

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.
- A fractal analysis technique has been developed for differentiating flocs from water-stable soil aggregates. This is important as aggregates and flocs behave differently in terms of their physical, chemical and biological behaviour.

- For small contaminated lakes (e.g., copper, zinc and nickel in Larder Lake, northeast of Sudbury), the major sinks for heavy metal pollutants are being described in terms of specific colloidal sediment materials having specific physico-chemical properties.
- Clients for our novel technology have been emerging in Canada, Austria, the U.K. and the U.S.A., allowing us great external support to extend our research.

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STUDY TITLE: Development of High Technology for the Analysis of the Structury, Activity and Behaviour of Biofilms and Flocs

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STUDY TEAM:	John R. Lawrence, Togwell A. Jackson, Ian G. Droppo, Chris H. Marvin
PARTNERS:	McMaster University, the CLS Synchrotron in Saskatoon, the Berkeley ALS Synchrotron in California, the Brockhouse Institute for Materials Research in Hamilton, Ryerson University in Toronto, University of Ottawa, University of Toronto, University of Vienna in Austria, the Universities of Zurich and Lausanne in Switzerland, the DFO-Freshwater Institute in Winnipeg, Texas A&M University in Galveston, and Northwestern University in greater Chicago,
CLIENTS:	EC, GL 2020, TSRI, NSERC, CLS national synchrotron program, international
FUNDING:	EC, GL 2020, TSRI, NSERC and international funding agencies

Introduction

To better understand biofilms and flocs, we seek to develop novel applications of (1) correlated high-resolution analytical electron microscopies, (2) synchrotron radiation, (3) confocal laser scanning microscopy, (4) genomics, and (5) metabolomics. 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. Where biofilms are considered in place of flocs, a similar argument can be made. 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 and biofilms constitute a complex matrix of microbial communities, organic matter (detritus, cellular debris and extracellular polymers) and inorganic cohesive materials. Most of these embedded components are colloidal (submicrometre size in least dimension) and determine (for

communities or populations in a given ecosystem) such floc/biofilm parameters as size, shape, porosity, density, internal gradients and permeabilities, contaminant binding activities, and contaminant transformations. The key to understanding the activities of flocs and biofilms is to understand their diverse internal components. To this end, correlative analytical technologies from several disciplines are being developed and refined for application to fresh samples, with an essential contribution required from novel electron-optical and spectroscopical 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, flocs and biofilms at the nanoscale, while accomplishing it in such a manner as to relate directly to overall gross structure and properties, and to contamination-related phenomena. The genomics and metabolomics aspects are currently at an early stage.

Study Areas: Hamilton Harbour, the South Saskatchewan River at Saskatoon, the North Toronto CSO Treatment Facility, industrial wastewater treatment systems in Canada and the U.S.A., heavily contaminated small lakes in northern/central Ontario, the Danube River in Austria, and a nuclear energy site in the U.S.A.

Results

New protocols and novel combinations of techniques were successfully developed by the team and its international partners for characterizing the principal aquatic colloids and floc-contaminant associations at many sites in two diverse environmental contexts, (1) natural freshwater ecosystems and (2) engineered wastewater ecosystems. Additionally, synchrotron-based technology is being successfully explored, in a correlative multi-method context (with Transmission Electron Microscopy and Confocal Laser Scanning Microscopy), to achieve similar progress with industrially-relevant biofilms. Our regional and national 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 our recently published works. 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 and biofilms; 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; and humic substances, as suspended colloids and as 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) colloid-based phenomena occurring in biofilms on submerged metal surfaces throughout North America currently cost taxpayers several billion dollars per year to address biofilm-induced corrosion damage; (3) 14 years ago, a mucilage phenomenon in coastal waters, attributed to colloidal processes, cost several billions of dollars in lost revenues in a single summer to the tourism industry of Italy, and led to a multi-national Adriatic Sea mucilage research grant of $24,000,000 in which I participated.

The influence of the high technology developed by my collaborators and myself is revealed by the following events. Within the brief lifetime of this study, I have: (1) been appointed a Consulting Fellow of the World Innovation Foundation (U.K. and U.S.A.); (2) been appointed a

Faculty Member of the Brockhouse Institute for Materials Research; (3) co-received an NSERC-MFA (Major Facilities Access) grant for synchrotron research outside Canada; (4) been invited into a competition for the establishment of a national Network of Centres of Excellence, where my group has advanced to the final stage of the competition; and (5) been invited into a national CFI competition for the establishment of a "Centre for Genomics and Environmental Health" on the McMaster University campus.

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STUDY TITLE: Nutrient Control and Best Management Practices (BMP)

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PARTNERS:	NWRI, Agriculture and Agri-Food Canada,
CLIENTS:	Ontario Region EC, AAFC, GLWQP
FUNDING:	EC, GL2020, Canada/Ontario Green Plan

Introduction

(a) Nutrient Control and BMP

Farming practices promoted erosion and leaching, which carry potential pollutants from farmland into surface and subsurface water. The major pollutants carried by water coming from farmland are sediment, nutrients (especially nitrogen, phosphorus and potassium), pesticides (including fungicides, insecticides, and herbicides), bacteria and salts.

Assessing and controlling these effects, particularly related to water quality, is complicated by the difficulty in tracing chemicals back to sources such as diversity of farms, soil types, and farming practices. The time lag between substances is applied to the farmland and when its effects to the environment may become evident. Control and reduction of the inputs of agricultural chemicals are essential options. Water table control and tillage practices have been reported to have a pronounced effect of on-farm water quantity and quality. To evaluate such effect, a study on water table control combined with tillage practices and compost was conducted. The study divided into two phases. The Phase 1 study (May 1995 to September 1998) was to investigate water table control versus free drainage. Both schemes associated with same tillage practices. The Phase 2 study (October 1998 to October 2001) was to investigate compost versus free drainage and both schemes associated with same tillage practices. The studied water quality parameters included nutrients, major ions and trace metals for a total of 23 parameters.

(b) Wetland Study

Constructed wetlands have been recognized to improve water quality or removing contaminants. Wetlands are also important for wildlife breeding, feeding and resting areas. The overall goal of

this study is to develop an integrated agricultural land-water-crop management system. The system combined with controlled drainage, surface and subsurface irrigation device, a constructed wetland reservoir for easy access of irrigation water and retention off-site agricultural pollutants.

Study Areas: Chevalier and Shanahan farms, southwestern Ontario; Holiday Beach, north shore of Lake Eire

Results:

(a) Nutrient Control and BMP

The influence of controlled drainage (CD) and compost (CP) treatments associated with conventional tillage (CT) and no-tillage (NT) were assessed for agricultural tile drainage water quality by comparing with free drainage treatment (FD).

The results from the Phase 1 study (Figure 1)showed that the CD associated with CT (CD-CT) treatment had reduced geometric mean concentration (GMC) for studied nutrients (NH_3-N, NO_3-N, TN and TP), major ions (Cl, Na, Ca, and Mg) and trace elements (Fe, Mo and Sr). The CD associated with NT (CD-NT) treatment had also reduced GMC for the studied nutrients. Conversely, the CD-NT treatment had increased GMC for the studied major ions (Cl, K, Na, Ca and Mg), Mo and Sr.

The results from the Phase 2 study (Figure 2) revealed that the CP-CT had increased GMC for all nutrient, major ions, Ba, Cu, Mo, Ni and Sr. The CP-CT treatment had reduced GMC of Al, Be, Cr, Fe, Li, Mn, Pb, V and Zn. The CP-NT treatment had similar results as CP-CT, but it had decreased GMC of Al, Be, Cr, Fe, Li, Mn, Pb, V and Zn.

(b) Wetland Study

Samples collected from the free drainage (FD) and controlled drainage with subsurface irrigation (CDS) plots after harvesting (September to December 2001) and prior to planting (January to April 2002) were tested for K, TN, TP, NO_3NO_2, NH_3 -N, pH, conductivity, colifom and *E.coli.* Wetland samples (January to December 2001 and March to April 2002) were tested for NO_3NO_2, NH_3 -N, pH, conductivity, coliform and E.coli. The results showed that wetland system could reduce the average concentration of NO_3NO_2 by up to120% and NH_3 -N by greater than two folds compared to controlled drainage systems. Wetland system increased pH slightly by about 4% and conductivity by about 6% compared to controlled drainage systems. The bacteria count for drainage controlled system ranges from 135 -181 MPN/100mL for coliform and 10 -13 MPN/100mL for *E.coli.* The bacteria counts for wetland system were < 3 MPN/100mL. for both coliform and *E.coli.* There were no water samples to conduct analysis of constituent and test for coliform and *E.coli.*, during the cropping season of 2002.

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STUDY TITLE: Coliform and *E. coli* in Surface and Subsurface Tile Effluent

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PARTNERS: NWRI, University of Guelph,
CLIENTS: Ontario Region, EC, GL2020, OMAF
FUNDING: GL2020, OMAF

Introduction

Manure contains essential nutrients and organic matter to increase crop yields and improve soil's ability to retain valuable nutrients. Animal manure contains pathogenic bacteria. Pathogenic bacteria such as fecal coliform, fecal streptococcus, and *Escherichia coli* (*E.coli*), a subpopulation of fecal coliform, may originate from several sources such as deer, horses, dogs and birds. It is difficult to ascertain the specific sources of the contamination in surface waters. Waterborne pathogenic bacteria pose a threat to sources of drinking water. Specifically, *E. coli* O157: H7 has been identified as a human pathogen and produces potent toxins that can cause severe illness in humans. *E. coli* O157:H7 may survive and grow in ovine or bovine feces under favourable environmental conditions. Canadian drinking water guidelines specified the maximum acceptable concentration (MAC) for coliforms in drinking water as no sample should contain more than 10 total coliform organism per 100 mL, and none of which should be *Escherichia coli* or thermo tolerant coliforms. Spreading of liquid manure on agricultural lands or the use of treated wastewater for irrigation are potential sources of these pathogens including enteric virus. This study was to compare coliform and *E.coli* density in surface runoff and in tile drainage water between two field plots. One of the field plots was manure treated (10,000L/ha) while the other plot with granular fertilizer treatment (500 kg/ha of N-P-K (0-20-20)).

Study Areas: Elora Research Station, Ontario

Results

The results showed that manure treated plot had increased the cumulative counts of coliform (Figure 3) in surface runoff by 61% for the manure treated plot compared to the fertilizer treated plot. Conversely, the cumulative counts of *E.coli*s in the surface runoff had107% less for the manure treated plot compared to the fertilizer treated plot, suggesting that other sources such as fecal deposits from births and wildlife also can contribute significantly. Cropped land appeared to be attractive to wildlife and birds because of food sources. The cumulative counts of total coliform in the tile effluent had 23% lower with the manure treated plot compared to the fertilizer treated plot where the cumulative counts of *E.coli* in tile effluent with the manure treated plot had 20% higher compared with the fertilizer treated plot (Figure 4). The lower number of coliform counts in the tile effluent from the manure treated plot appeared to be due to low rate application of manure. Thus, the magnitude of coliform and *E.coli* density in the tile effluent depended primarily on the manure application rate.

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STUDY TITLE: Modeling Nutrient Transport and Algae Blooms

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STUDY TEAM:	Min Ye, Guoxing Hou
PARTNERS:	NWRI, Yangtze Valley Water Resources Protection Bureau (YVRPB), Huazhong University of Science & Technology (HUST), Wuhan, China.
CLIENTS:	EC, MWR/China, YVRPB, HUST
FUNDING:	EC, MWR, YVRPB, HUST

Introduction

The flux of nutrients from land to rivers, lake and reservoir has been recognized as the major sources to cause eutrophication. The principal cause is the input of nutrients to agricultural land and by human activities on urban land. This has caused ecological changes in fresh and marine waters. Recently, algae bloom has subsequently occurred in the downstream of Hanjiang River (a major tributary of Yangtze River), respectively in the summer of 1992, 1998 and 2000. This has prompted a study on nutrient input to Hanjiang River. A study program funded by the Ministry of Water Resources, China has been developed. The study focuses on the causes, mechanisms and control measures of pollution at the downstream of Hangjiang River. This has prompted Madam Ye and Professor Hou for a visit to National Water Research Institute to acquire advanced knowledge, collaboration, information and practice on watershed modeling to deal with non-point pollution.

Study Areas: Hanjing River Watershed, Yangtze Basin, China

Results:

A multi-tasks model, BASINS3, developed by the U.S. Environmental Protection Agency has been setup for study of different scenarios based on environmental conditions and information.

The BASINS3 was assessed for possible application to Hanjiang watershed for prediction of nutrient input and algae bloom scenarios. Direct application of BASINS3 to Hanjiang River was unable to achieve at this time due to incompatible format of the digital map, land use data and soil property of Hanjiang watershed. A NWRI Technical Note has been completed. The Note outlined the advantage of applying the BASINS3 to Hanjiang watershed and the shortcoming of the digital map of the Hanjiang watershed.

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Figure 1. Comparison of chemical concentration under the influence of CD and CP treatments to FD treatment at Chevalier farm

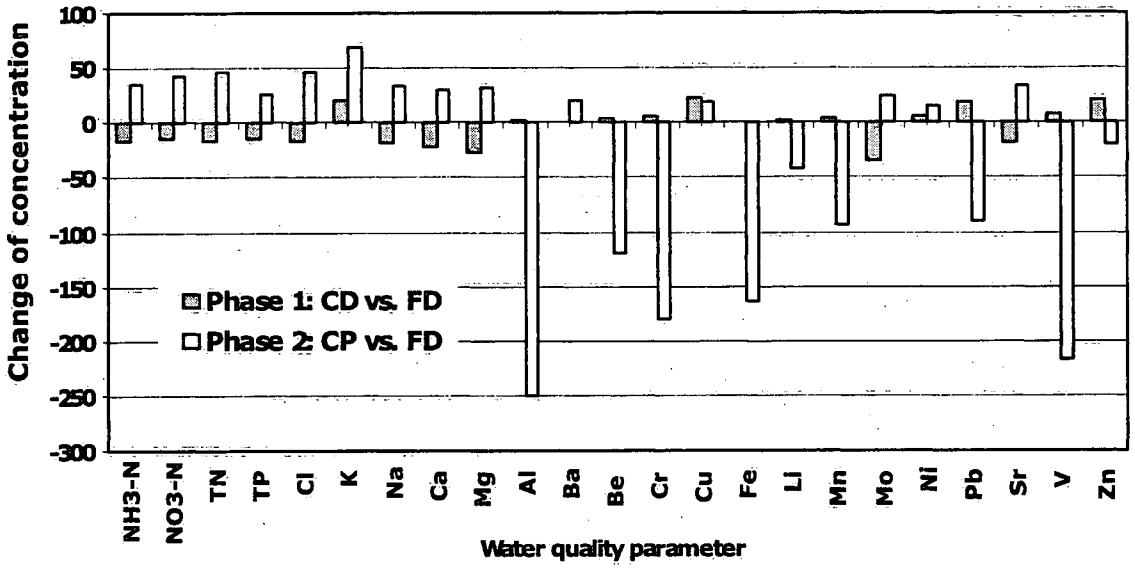
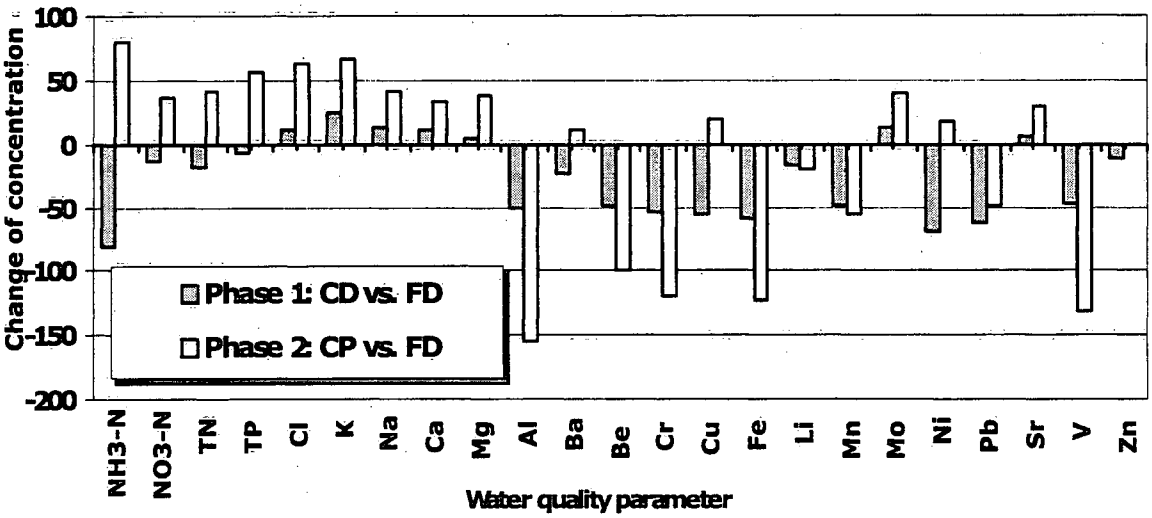


Figure 2. Comparison of chemical concentration under the influence of CD and CP treatments to FD treatment at Shanahan farm



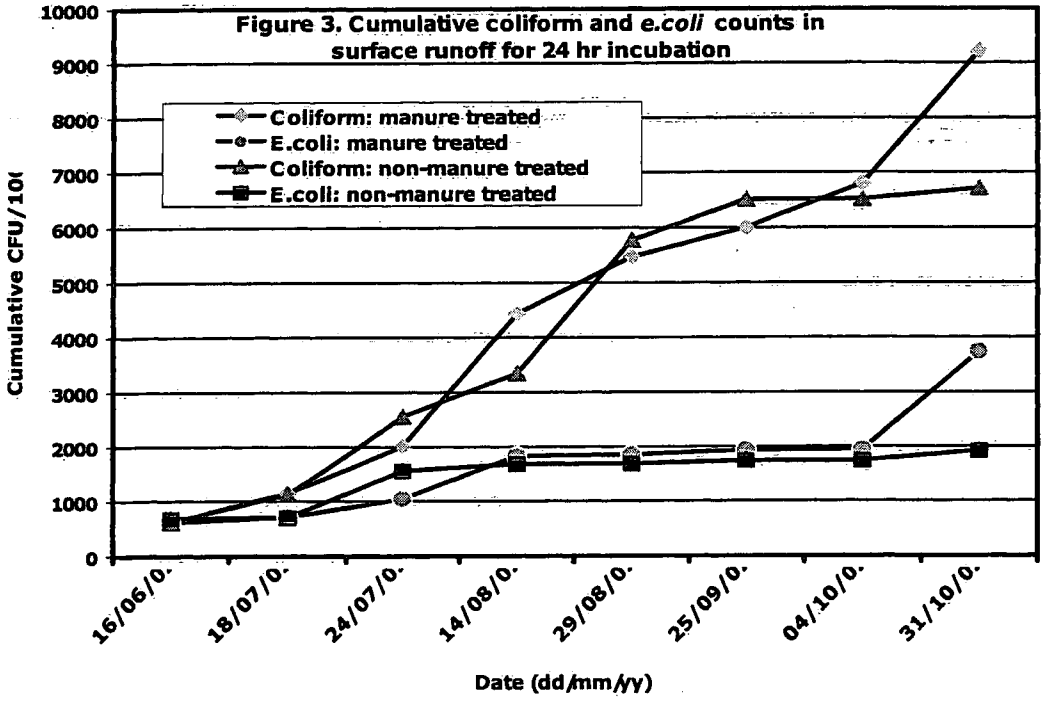
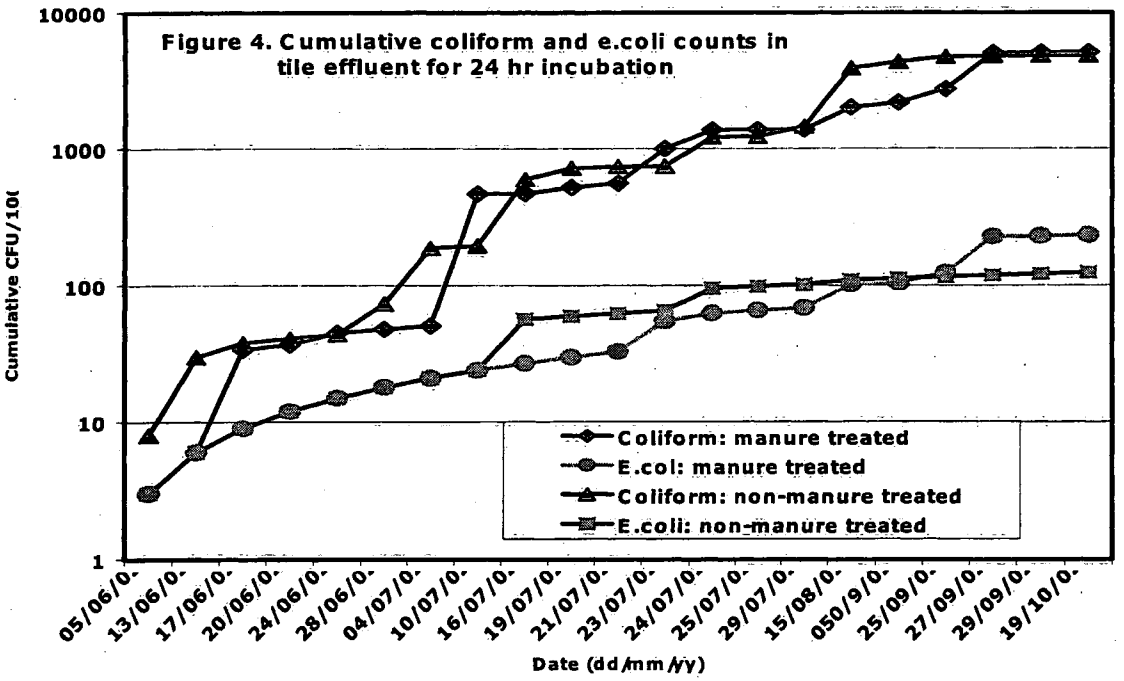


Figure 3. Cumulative coliform and e.coli counts in surface runoff for 24 hr incubation
Coliform: manure treated
E.coli: manure treated
Coliform: non-manure treated
E.coli: non-manure treated
Cumulative CFU/10
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
16/06/0.
18/07/0.
24/07/0.
14/08/0.
29/08/0.
25/09/0.
04/10/0.
31/10/0.
Date (dd/mm/yy)



STUDY TITLE: Refinement of Hydraulic Operation of a Complex CSO Storage Facility by Numerical and Physical Modeling

STUDY LEADER:	Cheng He
STUDY TEAM:	Dr. J. Marselek, Dr. B.G. Krishnappan, Mr. Robert Stephens
PARTNERS:	City of Toronto
CLIENTS:	Environment Canada, RAPs
FUNDING:	DIAND, GL2020

Introduction

Past studies have identified urban combined sewer overflow (CSO) and storm water runoff as major contributors to the degradation of many urban lakes, streams, and rivers.

To improve the treatment and efficiency of the original undersized CSO and storm settling tanks constructed in 1924 the City of Toronto expanded the North Toronto (NT) CSO settling tanks in 1991. However, for larger volume events ($V > 6000\ m^3$), not all CSO can be handled by the treatment plant and surplus is spilled to the surface water without having any minimum treatment. Reducing overflows escaping from CSO Storage facility by modify structure of the facility has been a long time goal of City of Toronto. Unfortunately, there is no easy answer to this problem due to the complexity of the hydrodynamic characteristics in the North Toronto

CSO treatment facility. Obviously, full scale experimentation would be very expensive, and not feasible because of too many additional uncontrollable variables.

Compared to field investigations, the numerical modeling approach has numerous advantages. It allows good control and reproducibility of experiments and opportunities to investigate the effects of structural modifications of the facility at low cost. So, a 3-D hydrodynamic numerical model is a natural candidate for this study on performance of a combined sewer overflow (CSO) storage facility in North Toronto. Towards this end, a computational fluid dynamic (CFD) multiphase 3-D numerical model, PHOENICS, was set up for, and used in, these investigations. A hydraulic scale model (1:11.6) was also built at National Water Research Institute for verification of numerical model. The main study objectives were to (a) assess the feasibility of increasing the hydraulic loading of the CSO facility without bypass, and (b) establish numerical and physical models of the facility for future work.

Study Areas: CSO in North Toronto

Results:

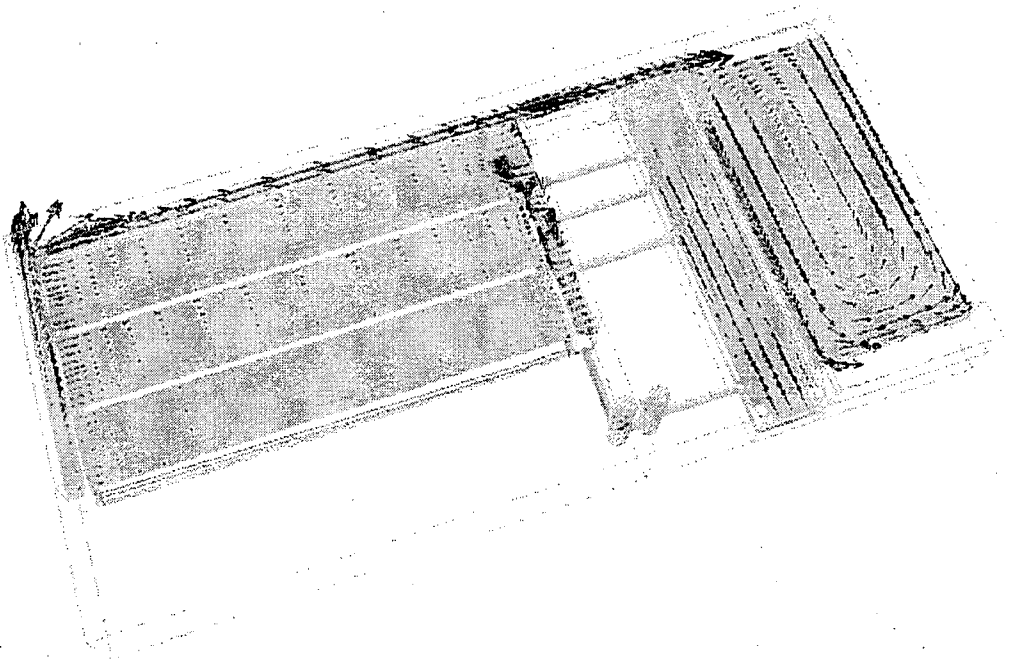
The assessment of flow behaviour in the North Toronto CSO Facility by numerical and physical modelling provided a good insight into facility operation and performance improvements by structural changes. The potential improvements of the maximum flow capacity were addressed in this study phase. The results obtained show that the CFD model can simulate hydraulic conditions in the facility reasonably well, as it accurately reproduced the filling rate, water levels at various locations and flow velocities in feed pipes. The figure shows the general flow condition in whole CFD storage facility without having the obvious numerical noise. The numerical model was also capable of accurately simulating overflows from the inflow channel, which reduces the performance of this facility in controlling wet-weather pollution. Most of the numerical model results were verified by measurements in a 1:11.6 physical scale model, and the differences between the numerical model output and measured results were less than 5%, in most cases.

When examining the feasibility of increasing the facility flow capacity, several problems were identified. Water profiles through the facility were affected by the 90° bends in effluent channel and by flow control weirs. Modeling results showed that:

(a) reducing the height of the final effluent weir only may be a simplistic solution for this complex system. A more comprehensive plan may be needed and should address the effluent channel bend problems;

(b) the rates of flow change in the system also depend on the height of the final effluent weir itself. For lower weirs, increases in flow rate become smaller when reducing the final effluent weir by a constant step, because the water level in the stormwater tank is also affected by the hydraulic conditions upstream. Thus, even if further reductions of the final effluent weir height may appear feasible, considering the decreasing efficiency of this measure and the environmental consequences of sacrificing the stormwater tank storage, a more balanced approach combining effluent channel improvements and lowering the final effluent weir should be taken.

The analysis of the facility showed that with respect to passage of flows, the facility is a complex, highly non-linear hydraulic system. With a few structural changes examined by numerical simulation, the maximum inflow rate of the CSO storage facility would be increased by up to 31%. A manuscript of this study has been submitted for journal publication.



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STUDY TITLE: Grand River Plume Study with 2D Numerical Modeling

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PARTNERS:	Ontario Ministry of the Environment
CLIENTS:	Environment Canada, RAPs.
FUNDING:	GL2020

Introduction

The Grand River discharge (average daily 705 m^3) has been known as one of principal contributors for water quality problem along north shoreline in the eastern Basin of Lake Erie, especially during the spring time when the road salt was brought into stream by melted snow.

Various field data in wide region of eastern Basin of Lake Erie has been and will continue to be collected to improve our understanding of processes that influence the occurrence, distribution, transport, fate, and effects of many of the contaminants of concern in eastern Basin. Although much progress has been made in the Lake Erie Basin to control and mitigate contamination and improve water quality since the early 1970's, water-quality managers must often implement best-management practices and regulate certain contaminants on the basis of incomplete or conflicting information because the sparse and discontinuous measured data does not always be able to tell the whole story of complex hydrodynamic and transport phenomena. Our approach in this study has been to utilize numerical model as an alternative tool to investigate the Grand River plume transport under the influent of the wind stress and river discharge in continuous manner.

Study Areas: Grand River and Eastern Basin of Lake Erie

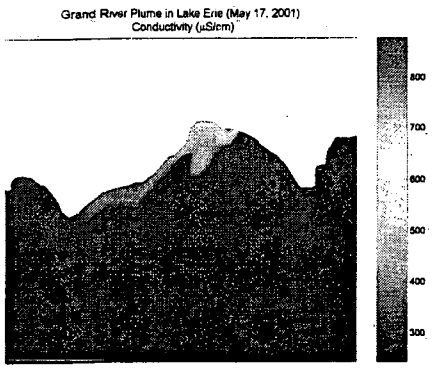
Results:

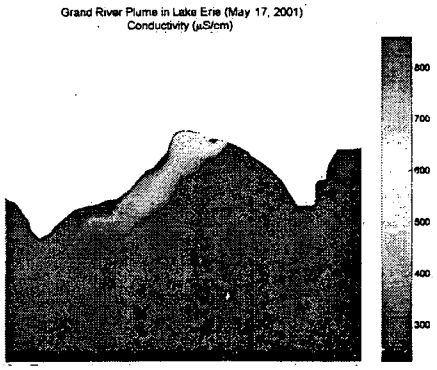
The numerical simulation, in this study phase, focused on the Grand River plume transport in the spring of 2001 with 2D hydrodynamic and transport model based on three reasons: (1) During this time period there were the best available measured data sets, (2) Because the lack of observations needed for specifying boundary condition of numerical model, the using of 3D model is unfeasible and (3) As mentioned above the Grand River plume might have the most impact on water quality of Lake Erie during the spring time.

The numerical model was able to reproduce many observed features of the current and plume transport, including an episode that the river plume was extended beyond 5 km from shoreline. For most of time the river plume was carried away by along shoreline current as expected for plume transport in large lake, and the bandwidth of plume is less than 1 km from shore. With strong and persistent wind, the plume could be traced in the region of down wind direction as far as 10 km. The agreement between simulated and observed lake current for both along and off shore component at two available measuring stations was reasonably well.

Figure shows that the Grand River plume traveled westward along shoreline driven by wind on May 17, 2001. The left panel is measured water conductivity collected with an instrument mounted on a boat and right panel is numerically simulated conductivity in the same region. It can be seen that there is a good agreement between two panels with the similar plume pattern and concentration level, even though the recognizable over diffusion was shown in model result, which is associated with numerical diffusion as the case with most of numerical simulations.

Comparing with measurement, the model output could offer much more detail information in whole simulated region about how the Grand River plume transport with time under various external forces, which will assistant to broadcast the movement of plume and to assess the plume impact on around water quality at much lower cost. A manuscript on result of this study is in preparation for journal publication.





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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 events. 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 modeling 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. Remote sensing techniques are applied for the monitoring and assessment of large ecosystems. 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, C. Mamone, P. Hamblin, S. Watson, M. Skafel, J. Jerome, R. Bukata, R. Yerubandi, M. Evans, G. Mackie
PARTNERS:	University of Waterloo, The Ohio State University, City of Hamilton, University of Guelph
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.

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, by filtration, water quality 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 in the mussels in the west basin but little change attributable to the mussels over most of the lake since the mussels invaded in the late 1980s. 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.

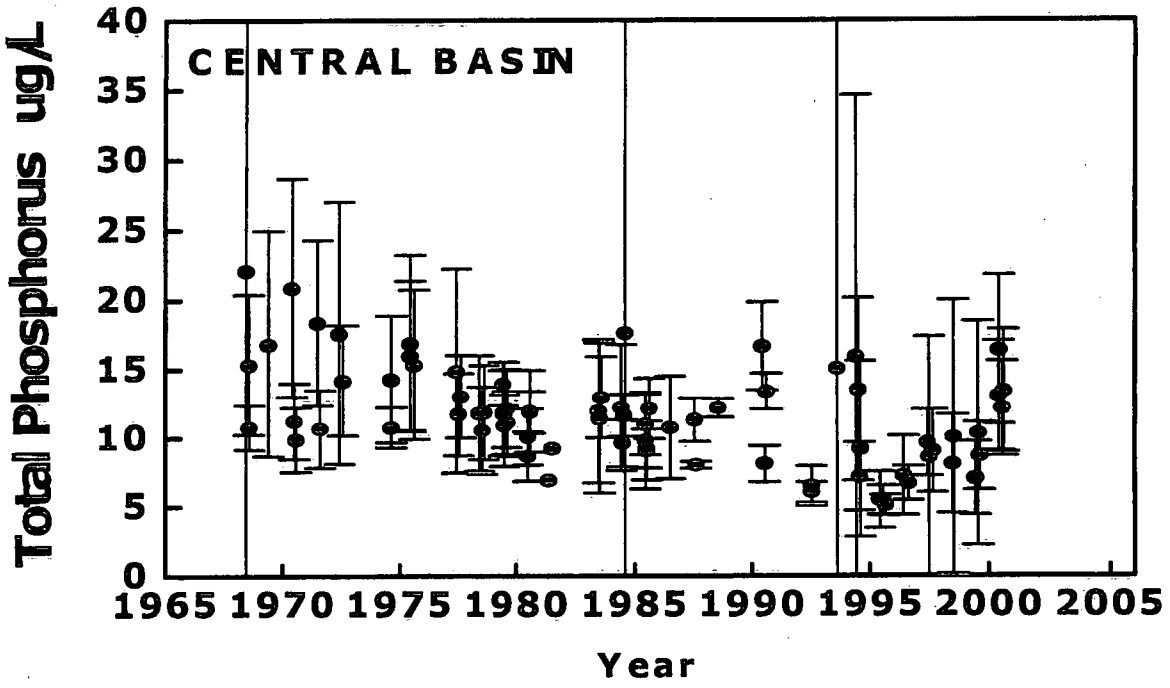
Phosphorus in the lake was a main target of the GLWQA. The overall load to the lake was reduced by 50% largely in municipal effluents. A downward drift in phosphorus occurred in the central and east basins representative of most of the lake. This effect was only a few ugP/L; the main effect was in the 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. (FIG. 1) 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. Although phosphorus concentrations are generally low in much of Lake Erie the year-round oxic conditions in the Central Basin hypolimnion that were called for in the GLWQA have not materialized (Fig. 2.). Due to

recent media attention, a presentation was prepared showing four reasons not to be alarmed at the persistent low oxygen situation in the central basin of Lake Erie.

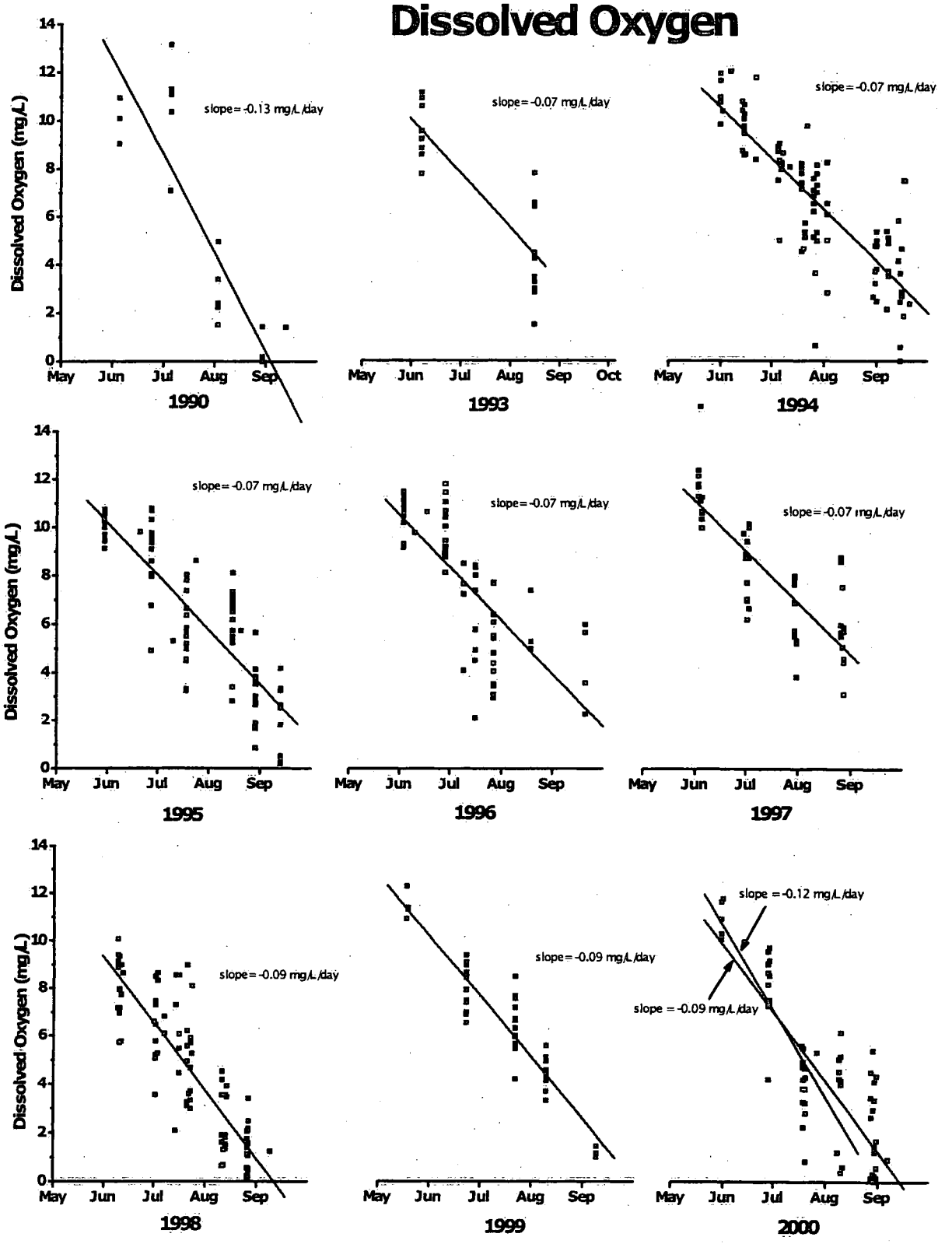
Recently, questions have been raised as to whether nutrient controls went too far given the effects of the invading mussel species. These concerns were raised by sport fishing groups. The data show that massive re-pollution of the lake would be needed to increase the phosphorus in the central and east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

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 at University of Waterloo began in 2001 and will continue through 2003. 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.



Lake Erie
Central Basin
Dissolved Oxygen



Hamilton Harbour

Of the 43 original Areas of Concern identified in the 1987 GLWQA Hamilton Harbour is the most polluted Canadian site. 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 data of 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.

Recent initiatives have included to measurements of bacteria throughout the harbour as a way of helping determining why the recently re-opened beaches still sometimes have to be 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. In 2001 and 2002 we sampled a series of stations from open water towards the Bayfront Park beach. The numbers of E.Coli usually increased in water closer to the beach. Highest numbers of E.Coli occurred in a few centimetres of water right at the water's edge. This seems to imply that the bacteria do, somehow, come from the beach. Indeed the test for E.Coli is not specific for which warm blooded animals may be the source. Work in 2003 will seek to identify the animal source by genetic means. Nevertheless, the higher numbers that occasionally occur in open waters also need to be investigated.

In 2000 and 2001 and 2002 work was begun to examine the morphology of the zooplankton population in the harbour and to measure the overall population numbers. This work continued in 2002 and 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.. Algal samples are now being enumerated and sampling is scheduled for taste and odour compounds. An important algal bloom was revealed by our sampling. These algae mainly represented a species of Microcycstis which is noted for toxin production. A noticeable bloom of this algae first appeared in 1999 but was less apparent in 2000. In 2001 an intense bloom covered the harbour and accumulated as scums around the shoreline and at structures such as docks. The algae released a toxin and public areas were consequently posted with danger signs. These algal blooms highlight the need to further reduce nutrient loads to the harbour.

Aquaculture

A study of environmental effects of caged fish aquaculture was continued in the North Channel area of Georgian Bay. The bottom waste deposit at a discontinued site was sampled for the third year. A new penetrometer was used to measure deposit thickness. Overall the deposit seems to be decomposing rapidly. A study of fallowing (moving parts of the fish farm around the water lot) was begun at another site. Bottom sediment characterization was done before cages were moved and the deposit at the former location is being studied to see if periodic fallowing is a way to avoid heavy buildup of waste on the bottom. Water quality is being studied in collaboration with a professor and graduate student from

University of Guelph. Experiments were conducted on depth and timing of fish excretion as a way of determining the optimum strategy for sampling water quality effects at fish farms. Visual observations at the three sites did not reveal algal accumulation on nearshore rock which would otherwise be a symptom of excessive nutrient concentrations.

Shoreline Algae

In the last four years shoreline algae have returned to Lake Ontario in quantities sufficient to cause complaints. The algae were initially under control due to reduced nutrient loads from 1970 till 2000. Now, though the lakeshore seems more sensitive to nutrient inputs. We sampled nutrients, observed underwater accumulations and experimented with artificial substrates to investigate the growths. Occasionally, soluble phosphorus which could stimulate the algae was found nearshore and we are working with Halton to determine its source. Artificial substrates grew little algae offshore but copius growth occurred nearshore; this experiment is being repeated to ensure all substrates are held nearshore and have an equal chance of colonization before they are spread out along a depth gradient.

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STUDY TITLE: Caged Aquaculture Studies

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PARTNERS:	OMEE, Canadian Hydrographic Service, Aquaculturists
FUNDING:	Aquaculture Fund

Introduction

Potential environmental effects of cage aquaculture at the present scale of the industry and following future expansion is an interest of user groups in the North Channel area of Lake Huron. Possible impacts may be due to nutrient load from fish farms and due to deposits of waste on the lake bottom below the cages. One of our approaches 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. Another approach is to study the longevity of the bottom deposit at a discontinued site as a way of adding information on the importance of deposits. Water quality and currents at another site are studied in conjunction with partners at University of Guelph. Water quality and the effects of fallowing areas of a farm are studied in Wolsey Lake. The quality of sediment and benthos is studied at one of the oldest and deepest farms with partners at DFO.

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 published in the Journal of Great Lakes Research. As a first step to three-dimensional modeling, 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. Dr. P. Hamblin, who recently retired, is completing a report.

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 third year and a penetrometer with attached camera was used to map the remaining thickness of the deposit. A deep water site with seasonal fallowing was also sampled for the first time in the winter and spring of 2003. 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 continuing 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 and that improvements to monitoring design may be forthcoming. At the same time this site uses a waste collection system under the cages. NWRI current information will provide background on the stresses these collectors withstand which will be important if they are used elsewhere.

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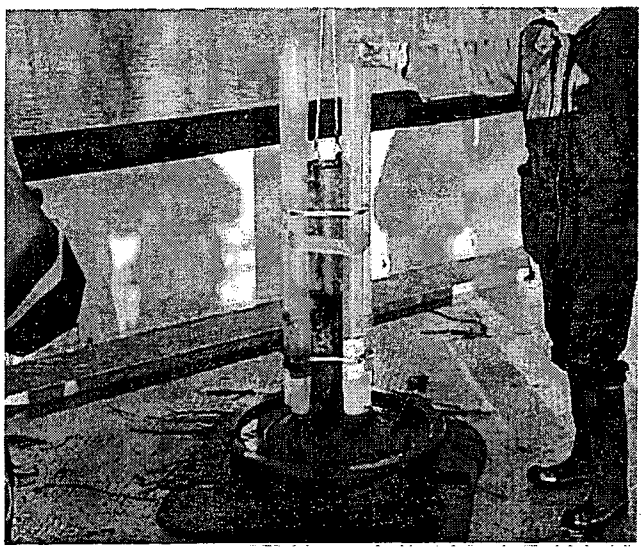
STUDY TITLE: Persistent Organic Pollutants in the Great Lakes and Associated Areas of Concern

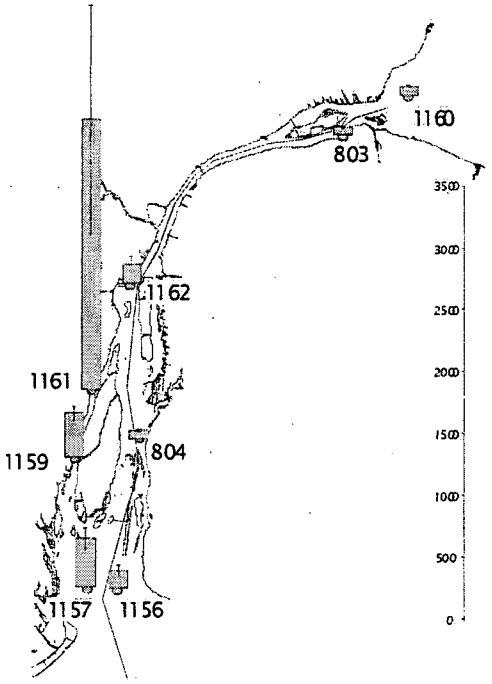
STUDY LEADER:	Dr. C.H. Marvin
STUDY TEAM:	C.H. Marvin, P.A. Thiessen, J. Schachtschneider
PARTNERS:	Ontario Region, Ontario Ministry of the Environment, Department of Fisheries and Oceans
CLIENTS:	Ontario Region, Detroit River RAP, Lake Erie and Lake Ontario LaMPs
FUNDING:	Great Lakes 2020

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.



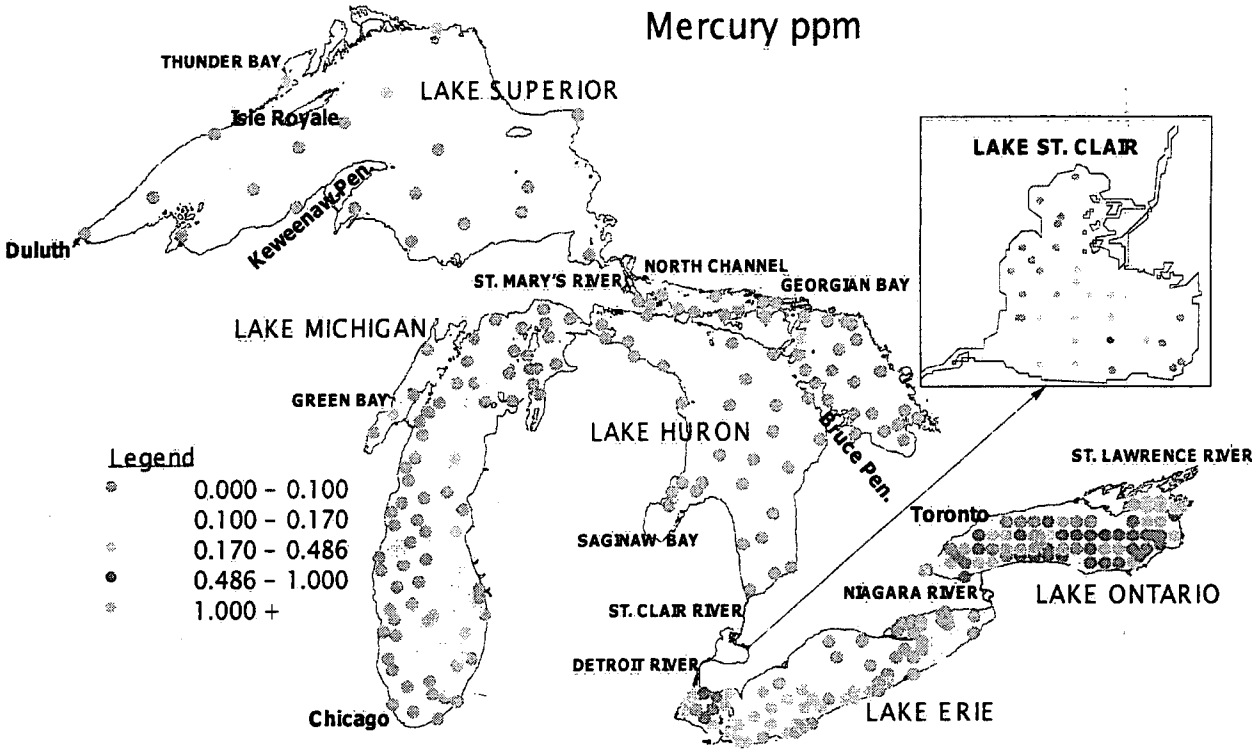


Sediment trap mooring and distribution of PCBs (ng/g) in suspended sediments of the Detroit River

Results

Sediment trap moorings for collection of suspended sediment were deployed during 2001 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.

Surveys of the Great Lakes enable characterization of the spatial extent of contamination by persistent pollutants including PCBs and mercury. 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 of potential 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 determination of spatial trends in contamination resulting from lake-wide surveys showed that sediment in Lake Ontario is of poorer quality, compared to Lake Erie. However, these surveys also showed a marked improvement in sediment quality over the past 25 years. These monitoring and research activities will continue in the future to ensure that wildlife and ecosystems within the Great Lakes basins are adequately protected.



Comparison of surface sediment contamination by mercury (μg/g or parts per million) in the Lauretian Great Lakes. The Canadian Sediment Quality Guidelines threshold effect level (TEL) is 0.486 μg/g.

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STUDY TITLE: Coastal Transport and Modeling in the Great Lakes

STUDY LEADER:	Raj Murthy
STUDY TEAM:	Raj Murthy, Ram Yerubandi, Fausto Chiocchio,
CLIENTS:	Hamilton Harbour RAP, Taste and Odour Consortium, Aquaculture, Regional Municipalities
FUNDING:	NOAA/GLERL CoOP 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

Episodic Events in Great Lakes

In order to understand the cross-shore transport of materials and quantify the physical processes that are responsible for the near shore-offshore mass exchange, a multidisciplinary research program, Eagle (Episodic Events Great Lakes Experiment) was undertaken by the National Water Research Institute (NWRI) and the Great Lakes Environmenta.0l Laboratory (GLERL/ Ann Arbor) to participate in this unique experiment.

Moored instrument arrays and Lagrangian experiments have provided detailed description of the flow field (currents, vorticity, and 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 current meters were 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 current meter moorings 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. Eagle experiments were conducted during a period of three years from 1997 to 2000. These experiments will provide insights into the nearshore/offshore exchanges of materials in the coastal zones of Great Lakes. Simultaneous analysis of experimental data to elucidate the coastal physical processes and coastal modeling are underway to understand the coastal sediment plume formation and transport in southern Lake Michigan and western Lake Ontario.

Monograph on Coastal Zone Research

The monograph will be a synthesis of generic coastal processes in Large Lakes and marine and estuarine environment. The monograph will highlight the research conducted over the past 30 years at NWRI with emphasis on the science and technology in the monitoring and modeling of the coastal environment.

Results

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 was developed to predict nearshore/offshore transport and concentrations of materials. These models were 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: Physical Processes in the Great Lakes and Coastal Regions

STUDY LEADER:	Ram R. Yerubandi
STUDY TEAM:	Ram Yerubandi, Raj Murthy, F. Chiocchio, M. Skafel, M. Charlton, P.Guliani (Contractor).
PARTNERS: MOEE,	Great Lakes Environmental Research Laboratory
CLIENTS:	Hamilton Harbour RAP, Aquaculture, Taste and Odour Consortium, Western Lake Ontario Municipalities.
FUNDING:	GL2020, Aquaculture Fund.

Introduction

Knowledge of physical processes (water movements and mixing) is a prerequisite for the study of a multitude of water quality problems of large lakes and coastal oceans. Our approach to provide this information is by collecting observations of currents, temperature, winds, and employs numerical models wherever they are necessary. Studies are being carried out in Lake Ontario, Lake Michigan and a small embayment of Lake Huron.

Western Lake Ontario

The alternate strategies of lake discharge may alleviate the need for unusually stringent treatment needed to meet water quality goals of the Hamilton Harbour Remedial Action Plan (RAP). The latest update of the RAP recommended a study of the possibility of offshore discharges. This study uses long-term observations of temperature and current profiles, and different types of numerical models for near-field and far-field mixing scenarios. Another objective of this study is to use the numerical models to examine the near-and far-field dilutions for combined Hamilton and Burlington sewage discharged into the lake. The modeling studies showed that the recommended site for open-lake outfall provides acceptable near-field dilutions for treated effluents under typical lake currents and density structure. The extension of outfall to a location farther offshore is only marginally beneficial. With the proposed Burlington outfall location and discharge conditions no far-field contamination is observed near the beaches or water intakes for typical summer and winter conditions. Thus, this study indicates that by discharging the treated sewage from an outfall in Lake Ontario it is possible to achieve the Hamilton Harbour RAP goals.

Taste and Odour

Circulation and thermal structure of the coastal waters were studied as a part of an interdisciplinary program to investigate the taste and odour problem in drinking water along the north and western shores

of Lake Ontario. The currents and temperature variations were found to be strongly linked to winds, with winds from the west causing upwelling and eastward flowing currents; and winds from the east inducing downwelling and warm westward flowing currents. The downwelling along the north shore during late August and early September of 2000 was associated with a pulse in concentration of the taste and odour causing compound geosmin. Our study indicates that during this episode the onshore directed mean currents and cross-shore fluxes in the surface layer transported geosmin to the coastal waters of the north shore. In 2002 another intensive investigation was carried out to investigate nearshore currents and temperature structure of western Lake Ontario by installing several moorings of current meters and thermistor chains. Again we found a downwelling event in August correlated with Taste and Odour event.

Aquaculture

Lake Wolsey is a restricted embayment along the northwestern shoreline of Manitoulin Island. A caged aquaculture operation exists in lake Wolsey and Rainbow trout are reared in netted enclosures. Nutrient release from fish farming could have an impact on water quality in the lake, which ultimately drains into the North Channel of Lake Huron. In a previous study the water quality monitoring activity and potential phosphorus loading from caged aquaculture operations in the North Channel and Georgian Bay areas of Lake Huron reported the preliminary findings on the environmental consequences of one operation on Lake Wolsey (Hamblin and Gale 2002). In 2002, we took up an ambitious modeling exercise to describe the three-dimensional structure of hydrodynamics of the lake. Several experiments were carried out with different types of environmental settings. The results are very encouraging and model validation experiments will be conducted in 2003-04.

Episodic Events in the Great Lakes

In order to understand the cross-shore transport during episodic events, a large multi-disciplinary program EEGLE (Episodic Events Great Lakes Experiment) was conducted by National Water Research Institute and the Great Lakes Environmental Research Laboratory. Moored observations of winds, currents and temperature made off the south-eastern Lake Michigan shore during 1998 to 2000 winter periods are studied to describe the mean winter circulation and circulation during episodic late winter-spring plumes coinciding with northerly storms in southern Lake Michigan. The currents during the winter season are mainly barotropic with predominant cyclonic circulation. The interannual variability of mean and fluctuating currents are due to the variability of prevailing wind forcing. The measurements of currents show the signature of forced two-gyre circulation in the southern basin. During northerly storm episodes it is observed that the combination of directly wind forced currents and northward propagating vorticity wave generates significant offshore transport in this region.

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STUDY TITLE: Sustainable Coastal Development

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STUDY TEAM:	D. Doede, R. Yerubandi, I. Droppo, N. Ross, C. Jaskot
PARTNERS:	OME
CLIENTS:	Ontario Region, RAPs, Ontario Water Works Research Consortium
FUNDING:	GLAP

Introduction

Various techniques and methodologies from the field of coastal engineering and physical limnology 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: 2002, Lake Ontario, Lake Erie, Hamilton Harbour

Results

Taste and Odour, Western Lake Ontario

Over five million people rely on western Lake Ontario for potable water. Each summer there is an episode of earthy taste and odour in the drinking water that forces local utilities to spend millions of dollars on systems to ameliorate the problem. The earthy taste and odour is caused by geosmin, a secondary metabolite (terpenoid) of *some* Cyanobacteria and Actinomycete bacteria. Extensive field studies were undertaken in 2000 and 2002 to document the lake physics before and during the taste and odour event to understand better the processes controlling the delivery of geosmin to the water treatment plant intakes. In two study years, using current meters and fixed temperature profilers at several sites, a downwelling event was documented along the northwestern shore of the lake during the period of elevated geosmin concentration in the intake waters from Cobourg to Grimsby. The events were characterized by elevated water temperatures nearshore coincident with onshore and cyclonic alongshore circulation. In 2002, the downwelling was relatively poorly developed off Cobourg where the geosmin concentration was the least elevated. The downwelling event was stronger off Mississauga and Grimsby, where the geosmin concentrations were higher. The flow regime supports the hypothesis that the elevated geosmin concentrations originated in the warm offshore waters driven inshore and alongshore during a downwelling event.

Effects of Biofilm Age on Sediment Biostabilization in a Wave-Dominated Environment

Biostabilization can reduce erosion and mass transfer in sediment beds, and little information is available on its implications in a wave-dominated environment. This concept was studied comparing different stages of biofilm growth in a wave flume using kaolinite clay and water from Hamilton Harbour. Bed stability, where the biofilm grew, its structural character and the microbial diversity were assessed. Although the biofilm thickness increased with time, the stabilization of the bed was more efficient with the 9-day biofilm compare to the 21-day biofilm. Visually, this could be explained by the generation of gas bubbles that lifted the biofilm up to 2-3 cm above the bed after 15 days of growth. This study showed the capacity of biostabilization to increase the cohesion of a sediment bed, which suggest a potential application of this concept to decrease the contaminant transport in a wave-dominated environment.

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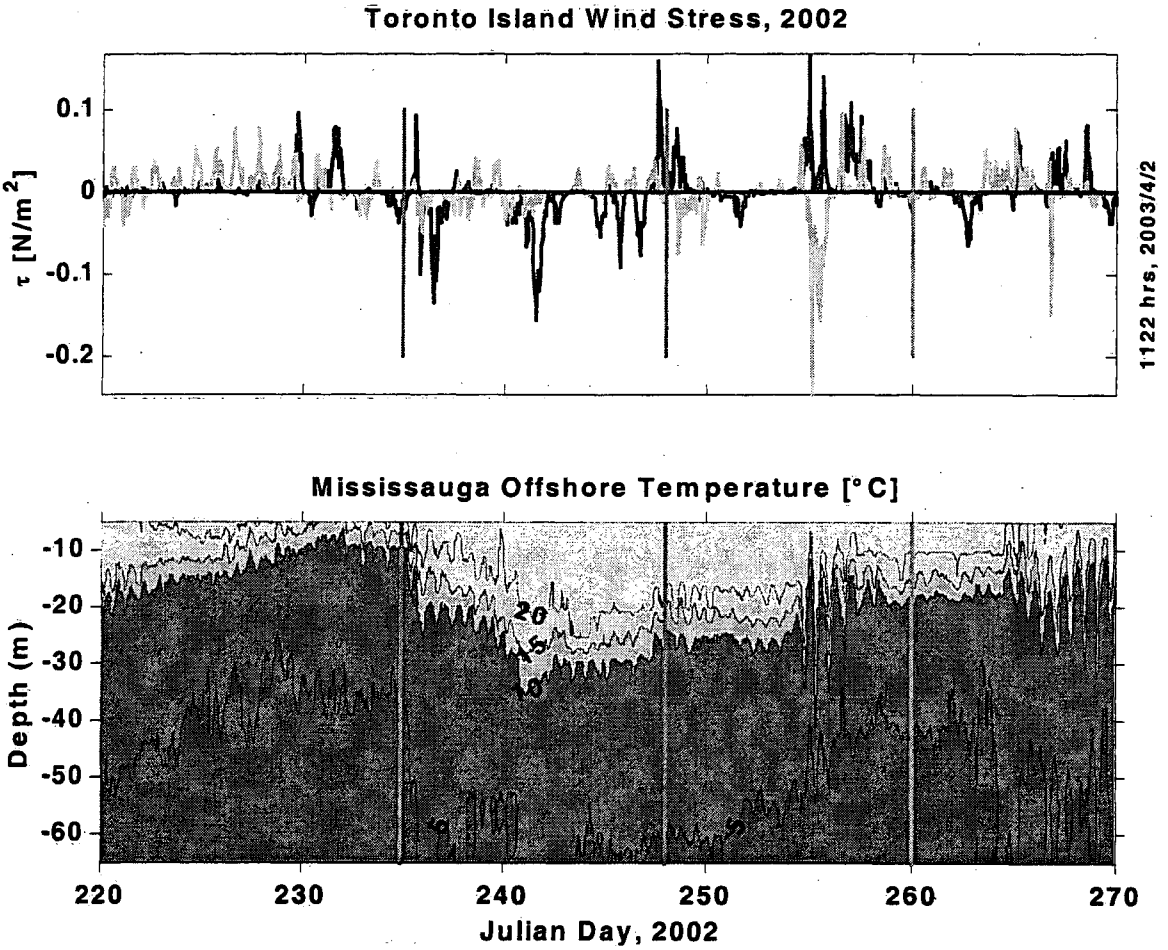

Top Panel: Wind stress at Toronto Island Airport indicating strong winds from the east (negative blue line between days 235 and 248) at the start of a taste and odour event (from day 235 to day 260).

Bottom Panel: Lake temperature variation with depth indicating a downwelling event (depressed isotherms) starting at the same time as the east winds (day 235) and persisting beyond the end of the taste and odour event to day 265.

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 (2002-2003)

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 seven 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 5 to 10cm of the 35cm sand cap, after a period of seven 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 2003, making this an eight year study. Evaluation of the data will hopefully lead to a judgment on the efficacy of the sand cap as am appropriate capping material.

Other Current Research Studies:

A. The Role of Sediments in Nutrient Loadings in Cootes Paradise

The Cootes Paradise Nature Sanctuary continues to be a hypereutrophic environment with high nutrient (TP, NH_3) concentrations both in the water column and the bottom sediments. Nutrient release, by diffusion, is being estimated, from pore water profiles which were measured in the summer of 2002, at

three additional areas in the marsh. . Three main sites selected for the investigation were located at the West Pond (WP), which receives the effluent from the Dundas Sewage Treatment Plant (STP), near the mouth of the Chedoke Creek (CC), and in the vicinity of the RBG boathouse (BH). The results derived from the Fickian diffusion model indicate that there are substantial (nearly 20 fold) differences in diffusive P fluxes from sediments, resulting from large spatial variation in sediment porewater chemistry. Sites receiving outfalls of STP and Combined Sewer Overflows (CSOs) had the highest nutrient fluxes, with the estimates of phosphorus (P) fluxes highest (5.3 $mg/m^2.d$) at the West Pond site, followed by the site adjacent to the Chedoke Creek (4.4 $mg/m^2.d$). The lowest flux was estimated at the Boathouse site (0.3 $mg/m^2.d$) which is located in the main body of Cootes Paradise. The differences in nutrient fluxes appear to be attributable to spatial heterogeneity of bottom sediments. The West Pond site, which has the greatest phosphorus fluxes has the largest sediment phosphorus pool (Fig. 1) and exhibits the highest porewater P gradients, followed by the Chedoke Creek site. These two sites have also the highest NH_3-N fluxes. The RBG Boathouse site, which has the lowest nutrient fluxes has the lowest sediment nutrient pool and the smallest nutrient gradients. The results suggest that sediment P geochemistry is important in regulating the P concentrations in porewater, which in turn is an important factor controlling the fluxes of P from sediments. The data also suggest that sediment may be an important source of nutrients in areas containing nutrient contaminated sediments and release of nutrients from these sediments may delay the recovery of the marsh even fter the reduction of the external phosphorus loading.
Joint study with AEPRB.

B. Diagenetic Metal Remobilization Versus Chronological Metal Loading in Lake Sediments

Results from previous reconnaissance surveys of sediments from ~100 lakes in the vicinity of the Horne smelter in Rouyn-Noranda (Quebec, Canada) indicate that metal concentrations are elevated in modern-day sediments in comparison with pre-industrial layers. This increase has been attributed to increased anthropogenic metal loading and/or to diagenetic metal remobilization. This study aims to combine traditional and advanced analytical techniques to identify the diagenetic processes that distribute or redistribute metals in lake sediments. **Joint study with the Geological Survey of Canada (GSC)**

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STUDY TITLE: Research, Applications, and Policies for Satellite Monitoring of Inland Waters

STUDY LEADER:	R.P. Bukata
STUDY TEAM:	J.H. Jerome, W.G. Booty, M.N. Charlton, and J. Lawrence
PARTNERS:	Canadian Space Agency, Borstad Associates Ltd., Institute of Ocean Science (DFO), Commonwealth Scientific and Industrial Research Organization (CSIRO, Australia), Nansen International Environmental and Remote Sensing Centre (Russia), York University, NOAA/GLERL, others as they develop
CLIENTS:	Environment Canada, Canadian Space Agency, Taste and Odour Working 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. Very recent and imminent launchings of hyperspectral satellite packages suggests that EC co-ordinate its environmental remote sensing efforts. This on-going study focuses on the interplay amongst remote sensing technology, the water quality concerns and policies of Environment Canada, the Canadian Space Agency's Long-Term Space Plan, and the models, algorithms, and research activities of NWRI that would enable use of time-series satellite data to monitor ecosystem change.

To address such goals, a collaborative relationship with the Canadian Space Agency was established several years ago. Further, to ensure that an ecological space monitoring plan is implemented that is consistent with both Environment Canada's mandates and those of the Canadian Space Agency, a team of colleagues (government, academe, private sector) expert in remote sensing has been/is working with NWRI.

Study Areas: Lake Erie, the Laurentian Great Lakes, Pacific Coast of Vancouver Island

Results

Incorporating inputs from discussions with numerous colleagues a "strawman" document ("Remote Sensing - A Tool for Ecological Monitoring") was prepared. The document outlines remote sensing applications that could accommodate the ten priority issues identified within the Environmental Scan for Environment Canada's 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) and has recently been presented and discussed at an EC Nature Table meeting.

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 (along with the Institute of Ocean Sciences) by a private sector colleague (G.A. Borstad Associates Ltd.) on a CSA-sanctioned proposal entitled "Water Quality Products for Inland and Coastal Canada". Preliminary results have been published in the open literature (and applauded by the CSA). The NWRI bio-optical water quality model, along with direct data acquired from the NWRI suite of above- and below-surface spectrometers (acronymed WATERS) were used to derive Lake Erie chlorophyll concentrations from water colour as recorded by the Terra (EOS AM-1)/MODIS satellite/sensor system. Direct determinations of the inherent optical properties of organic and inorganic matter in Lake Erie were made. The chlorophyll derived by the NWRI model (both full-colour spectra and restricted red wavelength region) were in excellent agreement with the solar-stimulated chlorophyll fluorescence models of IOS and Borstad Associates. This EOADP collaboration is continuing.

Being appointed a member of the Board of Directors of the Alliance for Marine Remote Sensing extends the forum for stressing the need for and the ability to enable remotely-acquired water quality products to gain acceptance by environmental monitors, water resource managers and political policy-makers - as does being one of two international scientists selected by the Union Radio-Scientifique Internationale (URSI) to author a solicited review paper on the science behind the remote sensing of inland water quality. The review appeared as Chapter 23 in *"URSI Review of Radio Science 1999-2002"* which was

published in concert with and distributed to the delegates of the URSI General Assembly in The Netherlands in the fall of 2002.

The NWRI aquatic optics and remote sensing research contributions to the monitoring of inland and coastal waters has been incorporated into the World Meteorological Organization Progress Report.

In addition, written contributions and/or verbal representations were made to Environment Canada and Canadian Space Agency initiatives, documents, and activities. These included two long-term proposals to the CSA regarding current and archival space data and their application to the time-series analyses of changes in inland water quality and Canadian ecozones/ecotones, a "big picture" document *"Using Space for the Environment and Sustainable Development"* as a component of the *Government of Canada Space Strategy,* submissions to the CSA's Government Research Initiatives Program (GRIP), assessing water quality using remote sensing at the Canadian Council of Ministers of the Environment (CCME) "Experts Workshop on Water Quality Monitoring - The Current State of the Science and Practice", working with Borstad Associates and Institute of Ocean Sciences to compile an inventory for the CSA of government department ongoing activities that are not utilizing Earth Observations, but could benefit from doing so, as well as ongoing committee work with the Canadian Space Agency (hyperspectral satellite missions, water quality algorithm calibration/validation, user-oriented environmental space products, etc.) as part of the CSA's *"Space for Canadians"* Initiative.

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STUDY TITLE: *In situ* and Remote Optical Monitoring of Aquatic Ecosystems

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PARTNERS:	DFO, Borstad Associates, MOEE
CLIENTS:	EC/Ontario Region, Canadian Space Agency
FUNDING:	EC

Introduction

The use of satellite data to monitor algal (chlorophyll) concentrations in oceanic waters has been operational for over two decades. The application of this oceanographic methodology to coastal and inland waters (optically-defined as Case 2 waters) has been impeded by the presence of the additional colour producing agents (CPAs), dissolved organic matter and suspended sediments. With the recent launches of satellites carrying multiband optical sensors dedicated to water colour monitoring, the possibility of developing a methodology for Case 2 waters has appeared. The research performed within this study is concerned with understanding and determining the optical properties of the components of an aquatic ecosystem that provide the linkage between the optical signals received by satellite instrumentation and the status of these aquatic components. Knowledge of the optical properties can then be applied through the development of bio-optical models that enable the determination of the concentrations of all CPAs within inland waters via satellite monitoring.

Study Areas: Lake Erie, Lake Huron

Results

The optical data collected on Lake Erie during the 2001 field season (spectral irradiance attenuation, spectral remote sensing reflectance, and beam attenuation) along with the concentrations of the main colour producing agents, CPAs, (chlorophyll, dissolved organic carbon, and suspended sediments) were analyzed using multivariate optimization techniques to determine the inherent optical properties of the CPAs. These optical properties are necessary input parameters for the NWRI bio-optical model used to predict CPA concentrations from the water colour. Incorporating these values into the model it was possible to estimate the concentrations of chlorophyll a (mean error = -4% and RME = 34%) and suspended sediments (mean error = 1% and RME = 43%) from the spectral reflectance of Lake Erie waters when a constant concentration of DOC (equal to the lake average) was assumed.

The in-situ optical measurements were also used to quantify the accuracy of some of the optical parameters that are predicted by NOAA from the data collected by the MODerate-resolution Imaging Spectroradiometer (MODIS) systems aboard the TERRA and AQUA satellites. NOAA firstly attempts to remove the impact of the atmosphere on the MODIS data by applying an atmospheric correction algorithm that uses typical atmospheres (maritime, continental etc). Next aquatic algorithms developed by optical oceanographers are used to predict various optical and water quality parameters of the observed water body. Analyzes showed that the applications of the aquatic algorithms are severely limited by the inaccuracies inherent in using typical atmospheres to provide an atmospheric correction for the Great Lakes. It was demonstrated that an atmospheric correction based on local conditions is required for the accurate application of aquatic algorithms.

The final report "Water Quality Products for Inland and Coastal Canada" was submitted to the Canadian Space Agency in the Earth Observation Applications Development Program (EOADP) by G Borstad (Borstad Associates), J Gower, (DFO), and R Bukata and J Jerome (NWRI) on the research programme carried out in 2001/2002. This study's contributions to the report focused on the development of optical techniques to monitor chlorophyll and suspended sediments from the in-situ measurement of spectral reflectance. Two distinct methodologies were developed: 1/ the NWRI bio-optical model with the inherent optical properties pertinent to Lake Erie. This model uses the entire spectrum from 400-700nm to predict the concentrations of chlorophyll a and suspended sediments; 2/ a red reflectance model that uses only the spectral region from 668-748nm to predict the water quality parameters. This second methodology was developed in response to the limited success of the NOAA atmospheric correction algorithm. Reducing the region of the spectrum used in the analyses helps to mitigate the impact of an imprecise atmospheric correction. If future remote sensing programmes applying water colour analysis can employ data collected by the Europeans Space Agency's MERIS spectrometer, the spectral region is reduced by a further 50%, which will further reduce the impact of an imprecise atmospheric correction.

An archive of MODIS images of the Great Lakes has been developed. Quicklook real colour images of the entire Great Lakes region are available on one CD for almost every day from April 2001 to present. This archive will aid in the selection of appropriate satellite data for future remote sensing studies of the Great Lakes.

The southeast shore of Lake Huron has undergone significant changes over the last decade. Growth of cladophora beds in the area as well as beach fouling by dead vegetation has become a regular occurrence. Increased inputs of non-point source nutrients into the nearshore zone are likely the cause. Mixing between the nearshore zone and the offshore waters is an important factor in determining the level of nearshore nutrients. Satellite imagery was purchased in preparation for this continuing study as part of the Lake Huron Southeast Shore Working Group, which involves NWRI, EC-Ontario Region, and MOEE. The Landsat Thematic mapper images will be employed in the definition of the nearshore zone along the SE shore of Lake Huron. Preliminary analyses indicated that the nearshore zone, with its high

turbidity, is easily discernible in the imagery. The small plumes emanating from the Saugeen and Bayfield Rivers are also visible and can be delineated by the imagery.

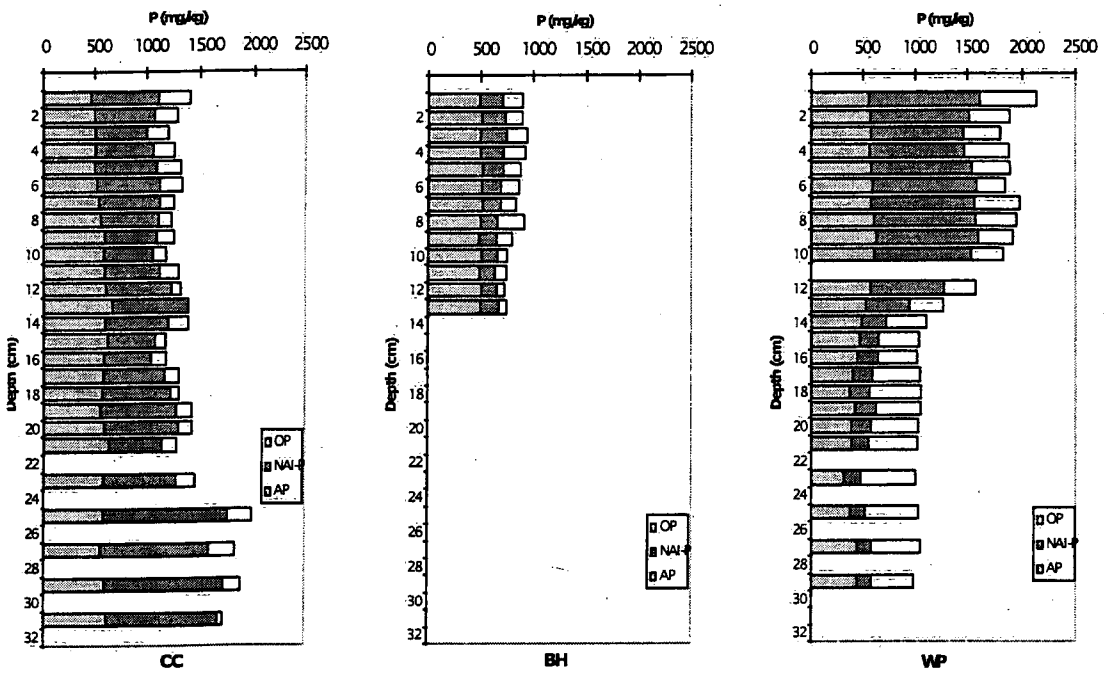

Figure 1. Phosphorus forms in sediment cores from CC, BH, and WP sites

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

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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 the past decade, there has been an increase in the occurrence of late-summer muddy/musty taste and odour (T/O) in drinking water drawn from W. Lake Ontario and the St Lawrence River.. Initial work showed that these events are caused by high levels of one or both of the two terpenoids, geosmin and 2-methylisoborneol (MIB). The biological origins of these compounds are as yet unclear, although some strong candidates have been identified recently. These outbreaks are significant for two major reasons. First, T/O costs the water industry millions annually to update and improve treatment processes. While T/O has no known adverse effects on human health, it undermines consumer confidence in the safety of water, and often provokes increased use of alternatives such as bottled sources. Second, the onset of T/O may signal fundamental changes in the source water. Although no major changes in nutrient levels have been detected, there is some indication of subtle differences in the levels and nature of inshore loading. Furthermore, widespread introduction of exotic species has modified nutrient cycling, along with food web structure and function, and resulted in significant increases in water transparency and may be linked with the reappearance of prolific shoreline growth of the attached alga *Cladophora* in the past five years.

In 1998 and 1999, particularly severe episodes of musty/earthy taste and odour (T/O) afflicted the water supplies of municipalities in the NW basin of Lake Ontario, which resulted in the formation of the Ontario Waterworks Research Consortium (OWWC; http://www.owwrc.com) in early 2000 to address these issues. 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 analyses; and the Ontario Clean Water Agency which provides coordination, funding and project management. The overall goals of the OWWRC are

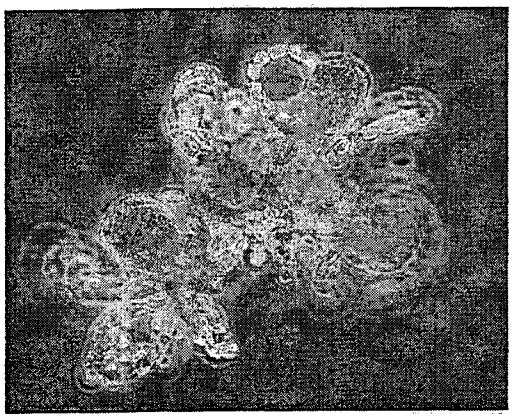

Plate 1. Mature colony of the N_2-fixing cyanobacteria *Anabaena lemmermanii*, found in offshore regions of Lake Ontario and other areas of the great Lakes. The large brown-coloured ciliates are commonly found attached to these colonial cyanobacteria.

i) to identify the sources, triggers and modifiers of the T/O outbreaks as a basis for predicting episodes, reducing costs and allowing a proactive response from the water treatment plants (WTPs); ii) to provide a long-term management strategy (e.g. via nutrient abatement or relocation of WTP intakes) and iii) investigate the links between T/O and recent shifts in ecosystem structure and processes. While the research effort is concentrated on western Lake Ontario, the entire lake and the upper St. Lawrence River are being studied, since T/O episodes affect eastern Lake Ontario and upper St. Lawrence River municipalities with even greater frequency than the western portion of the lake.

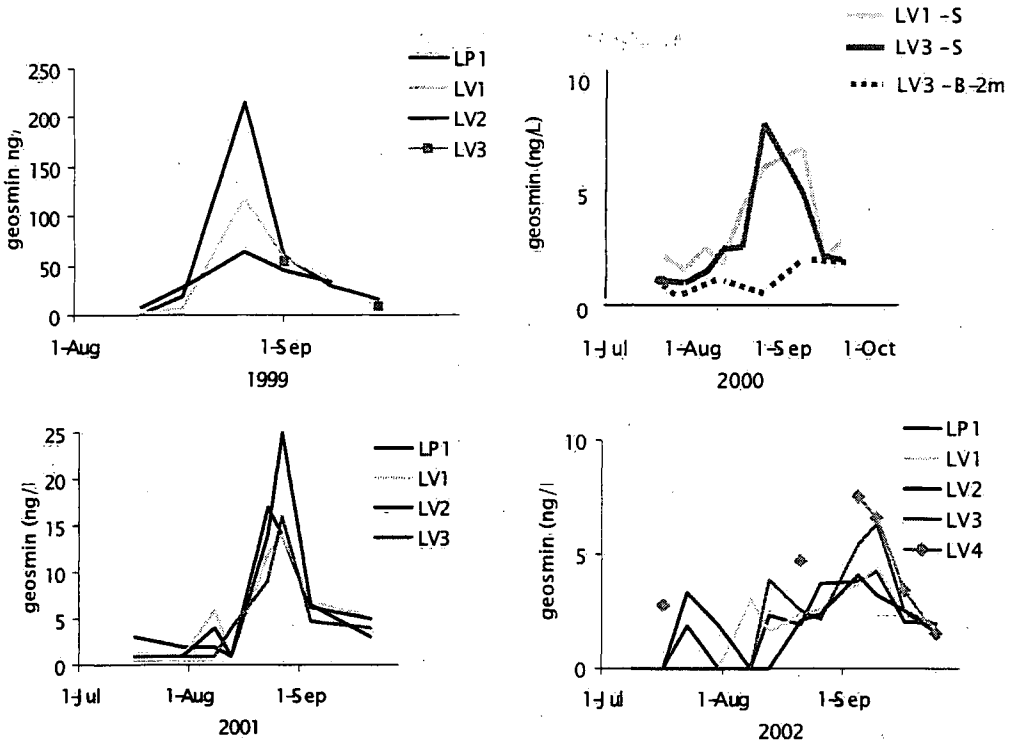

Fig. 1A-D. Geosmin levels recorded at Lakeview (LV) and Lorne Park (LP) stations over the mid-late summer, 1999-2002. All values from surface samples (S; taken at 0.5m), with one series (Fig. 1B) shown from samples taken 2m above the bottom (B-2m; approximately 70m) in 2000 at LV3. Stations numbered in order of proximity to shore, with LV3 the most distant.

Several key observations arose from the initial 1999-2001 research. First, a late summer geosmin peak occurs annually in W. Lake Ontario (late August-early September), but is intense enough to cause complaints only in some years, contributing to the sporadic nature of the drinking water T/O experienced by consumers (Fig. 1). The factors underlying the variability in the peak, however, are multi-faceted. Second, an analysis of historical data suggests a relationship between the rate of early spring warming and the intensity of the T/O event. Third, the geosmin peak is restricted to the upper layers (e.g. Fig. 1B), which has significance for the water utilities, since it can be largely avoided by drawing deep water from offshore (see below). These observations generated the working hypotheses that i) geosmin is produced offshore by planktonic cyanobacteria, ii) peak levels are increased if early warming extends the period of warm surface temperatures and algal growth/geosmin production, and iii) the geosmin is delivered in the dissolved form and/or as cells to the WTPs during a downwelling event. Elevated offshore growth/geosmin production by the source organisms and physical transport inshore to WTP intakes in the deeper layers are *both* necessary to generate severe T/O at these utilities. In 2001, the large buoyant nitrogen-fixing cyanobacteria *Anabaena lemmermanii* (Plate 1) was identified as a likely cause of the T/O, based on its pattern of abundance in the lake relative to geosmin levels, its prevalence in the surface layers, (Fig. 2) and the high *in vitro* geosmin production demonstrated by a strain of this species from the USA (below).

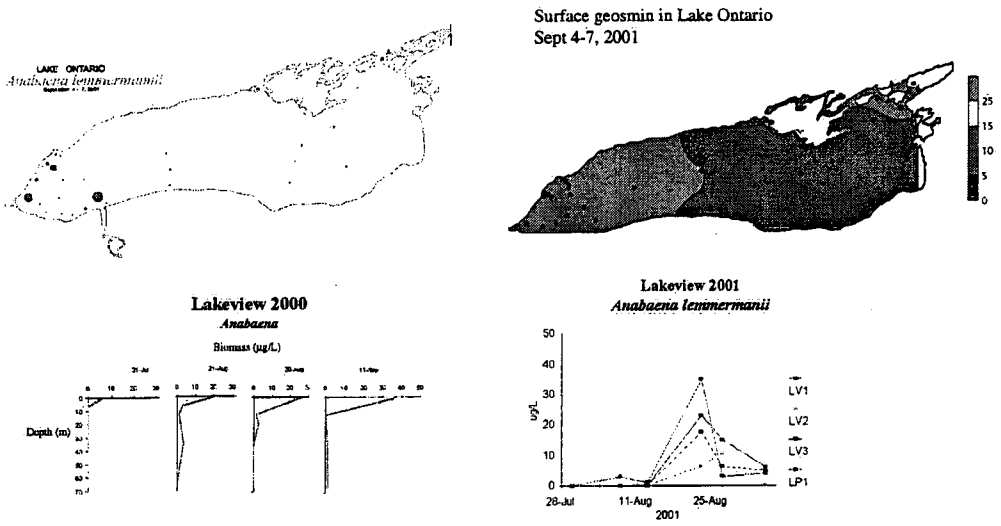

Fig. 2. **A:** Distribution of *Anabaena lemmermanii* in L. Ontario surface waters from live samples taken during 2001 CGS Limnos survey, qualitative estimates indicated by size of circles; **B.** Corresponding geosmin levels in surface waters from samples taken during the survey; **C.** Depth distibution (2000) of *A. lemmermanii* at Lakeview; **D.** Temporal dynamics of *A. lemmermanii* at Lakeview inshore and offshore stations, 2001

2002-2003 Research Programme

These hypotheses were the basis of the research carried out in 2002-3, which intensified field and lab work from the previous years. Water quality (WQ), nutrients, T/O and phytoplankton were sampled over an extended period at Lakeview inshore-offshore stations. Three new offshore stations in the west basin also were monitored to distinguish spatial and temporal patterns in T/O which may coincide with East-West water movement identified by deployed current meters and ADPs; the latter were also used to identify inshore-offshore movement associated with upwelling and downwelling events. Samples were monitored for the presence of *A. lemmermanii*, and where present, fresh material was isolated into culture to test for geosmin production. The annual late-summer CGS Limnos survey of the lake and upper Saint Lawrence River included experiments modifying light and *Anabaena lemmermanii* abundance using shipboard incubations of lakewater. Laboratory work with the USA isolate of *A. lemmermanii* investigated variability in morphology, growth and geosmin production under different light, temperature and nutrient levels. Once isolated successfully, the L. Ontario strains were also characterized for geosmin production.

Results

As in 2000 and 2001, there was no severe odour event in 2002. Geosmin levels were even lower than the two preceding years, peaking below the odour detection level (OTC) of 10ng/L at Lakeview (Fig. 1), and showing similar low values at all WTPs that monitored this compound in raw water drawn from the Western Basin. These levels were also comparable to the very low values recorded in 2000 (Fig. 1). Overall, spatial and temporal odour patterns observed in the

Geosmin concentrations in the western lake were slightly elevated above those in the eastern lake during our lakewide survey during the last week in August.

preceding study years were repeated in 2002, showing the late-summer peak in surface waters, and a predominance of geosmin in the western basin (Fig. 3). eastern lake during our lakewide survey during the last week in August. Bottom concentrations of geosmin were lower than those at the surface at Lakeview and across the Lake, except in areas of the Saint Lawrence River (below). MIB concentrations were extremely low in both surface and bottom water throughout the western and eastern lake, with most samples below detection for the method (about 1-2 ng/L) except in the St. Lawrence River.

One of the objectives of the spatial surveys is to identify correlations between geosmin (and MIB) concentrations and nutrient sources in the nearshore areas and test the hypothesis that the producers may be responsive to a higher nutrient load in this basin and thus potentially controllable. Overall, this hypothesis is borne out by the data (Figs. 3,4). The cumulative data show elevated geosmin levels in the W. Basin each year, and higher average TP levels particularly in the NW. The higher average geosmin values in 2001 corresponded with marginally higher TP levels that year, although there was considerable variability among sites (e.g. Fig. 4).

Overall, combined 1999-2002 phytoplankton samples show Lake Ontario has a mixed phytoplankton community consisting of a diversity of taxa, predominated by flagellates and diatoms for much of the year. With the exception of some inshore areas and embayments (e.g. Hamilton Harbour), Cyanobacteria have remained at low biomass, even during the severe odour events in 1999. Relatively few planktonic Cyanobacteria taxa have been identified from the lake itself, which narrows down the number of potential odour producers.

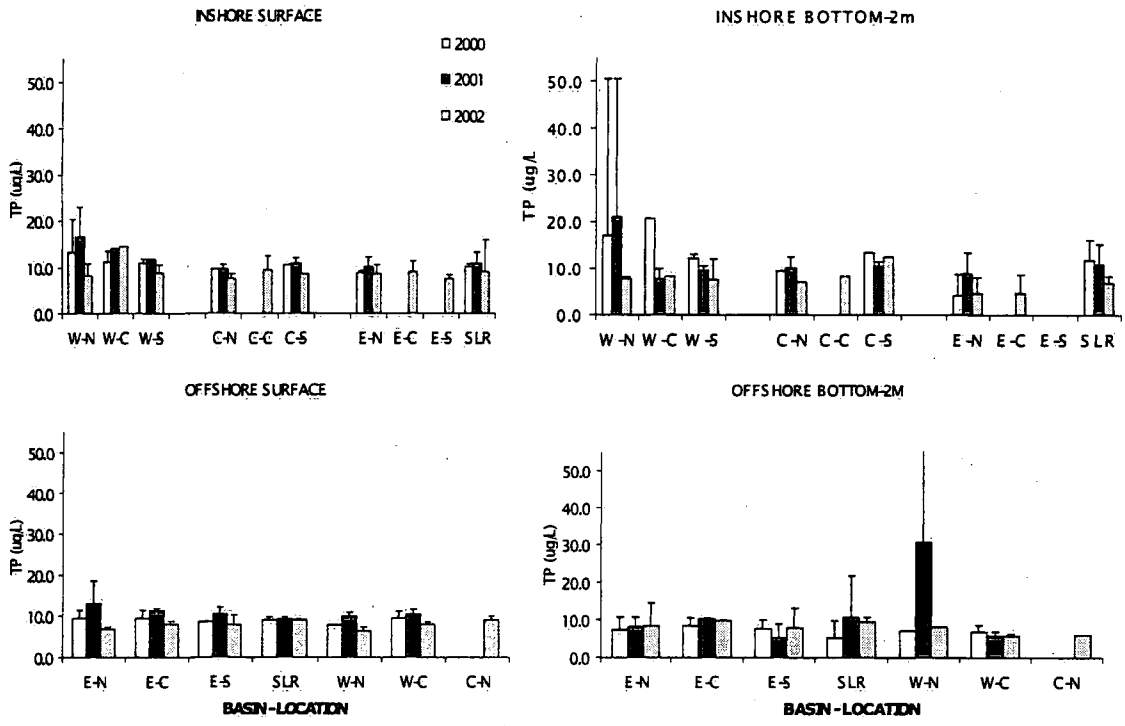

Fig. 4. Mean TP (unfiltered) from samples taken from surface and bottom-2m depths the Lake Ontario surveys, late Aug-Sept 2000-2002. Means calculated from samples grouped according to basin (W,C,E) and location relative to North shore (N), Centre (C) or South (S) shore.

As noted above, the major cyanobacteria species identified as a prime suspect in these events is *Anabaena lemmermanii,* which shows sporadic appearances in samples preceding and during the seasonal geosmin peaks. It also was present at low – moderate abundance (~5% total biomass) in the plankton during the odour event of 1998 (Barbiero et al. 2000. *J. Gt. Lakes Res.* 27:134-154; plate 2), but reported as *A. flos-aquae*, with which it can be confused. This taxon has a very cosmopolitan distribution, and is reported from across the Great Lakes in low abundance, as well as a diversity of other surface waters that range in size and nutrient status from oligotrophic to eutrophic. There is some work indicating that the species also shows several morphologies (i.e. cell length and width). This suggests that that the species has a number of ecotypes, or is highly adaptable to a range of environmental conditions, the basis of some of the laboratory experiments this year (below).

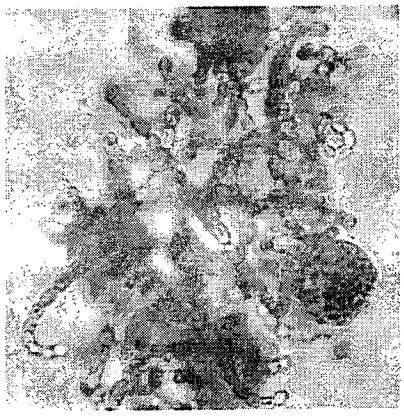

Plate 2. *A. lemmermanii*, from samples obtained from R. Barbiero, collected from W. Lake Ontario offshore sites in late summer 1998

Laboratory Experiments

Work with the US isolate of *Anabaena lemmermanii* showed it as a prolific geosmin producer, with a cellular production rate measured at ~10x that reported for many other less odourous Cyanobacteria. Preliminary experiments with light and temperature regimes showed that growth, akinete formation and geosmin production per cell are strongly temperature-dependent. Results from a second, controlled series of experiments which grew this isolate under different levels of light and N and/or P raised important questions about inter and intra-specific differences in geosmin production. These experiments showed major variation in: i) key morphological traits traditionally used to identify this species (cell length and width, akinete size and shape, filament configuration (straight vs. coiled)), and ii) cell geosmin at different nutrient levels and growth stages. Significantly, it was estimated that if the Lake Ontario populations of this species produced similar levels of geosmin to those shown under optimum conditions by the USA isolate, these cyanobacteria potentially could produce geosmin levels in the range of those measured at Lakeview during the severe T/O event in 1999, even at the moderate abundance of this species measured during this time.

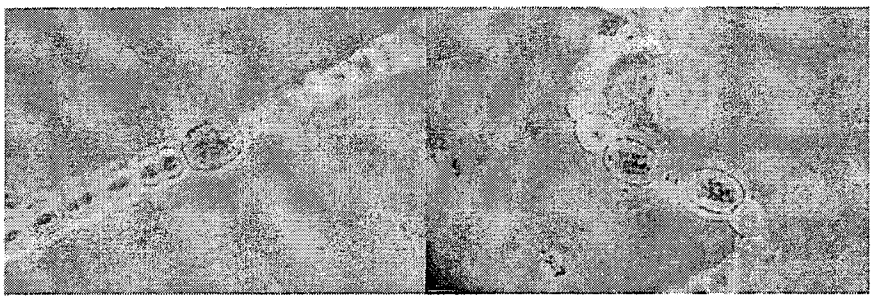

Plate 3. *Anabaena lemmermanii:* US isolate, showing variability in morphology

A total of seven strains of *A .lemmermanii* were isolated from Lake Ontario during 2002 and established in culture were successful. These all produce geosmin, but at low levels. To date, under nutrients and light levels optimal to most cyanobacteria none of these isolates have shown the same levels of geosmin synthesis as the USA isolate, producing some ~100x less. Work in 2003 will attempt to measure geosmin production under a variety of conditions and also attempt to work with strains germinated from akinetes in sediment collected from inshore and offshore sites in Lake Ontario, to elucidate whether geosmin production is a function of environment or if it is strain-specific – i.e. genetically based.

Are there other suspects in this case of unsolved odour in the western basin? Some correlation between geosmin and the abundance of taxa identified collectively in early analyses as "*Oscillatoria*" species has been noted. Some of these taxa (*Pseudanabaena spp., Limnothrix*) are reported in other studies as geosmin/MIB producers. They were observed at the Lakeview sites (1999 – 2002), where they reached higher abundance than *A. lemmermanii*, but tend to be most abundant at deeper strata. Unlike *A. lemmermanii*, these taxa do not fix N_2, and remain as individual trichomes, and some may also be found associated with benthic communities.

The highest concentrations of T/O compounds were found in the St. Lawrence River in all three years where T/O is an annual problem. In contrast to the odour pattern seen in N.W. Lake Ontario, this is

caused by both geosmin and MIB. We now have very strong evidence that odour in the St. Lawrence River is generated by attached biota associated with the periphyton communities along the shore of the river, both on rocks and macrophytes. These may be either or both of Cyanobacteria or Actinomycetes; both are important components of these communities. Clear spatial differences are seen amongst sites, suggesting strong local inshore effects. This was also indicated by the results from cross-river transects taken in the Kingston basin during the 2001 and 2002 cruises, which showed maximum values of both geosmin and MIB at each shoreline, with minimal concentrations midstream. It is hypothesized that odour in some areas of the S.W. basin of Lake Ontario (e.g. Grimsby) also is generated by similar communities, associated with rocks, mussels or other substrates.

INTEGRATED WATERSHED MODELING AND MANAGEMENT PROJECT

The IWM Project develops and provides research to develop knowledge and models for better-integrated watershed management and performs research on contaminant mass balance and water quality modeling, decision support systems, integrated assessment modeling, and statistical analysis of water quality. National assessment on environmental issues such as acid rain, industrial and agricultural effluent requires basin-wide water quality and quantity modeling tools that simulate physical, chemical and ecological processes in soil, rivers and lakes. Better use of monitoring and research data requires advanced statistical methods for interpretation of results and improvement of experimental sampling design. Practical and integrated decision support tools and information systems are developed to help make better choices for protecting ecosystems and conserving biodiversity

STUDY TITLE: Phosphorus and Oxygen Model for Lake Erie Pre- and Post-Zebra Mussel Arrival

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STUDY TEAM: W. Schertzer, C. McCrimmon, M. Charlton
PARTNERS: U. of Waterloo, U. of Guelph, McMaster U.
CLIENTS: Lake Erie Lakewide Management Plan, Great Lakes 2020
FUNDING: Lake Erie LaMP, Great Lakes 2020

Introduction

In 1987, NWRI published the results of a nine-box water quality model that simulated phosphorus and oxygen dynamics in the three Lake Basins (West, Central and East) and in the associated three vertically stratified water layers in each basin. The model was calibrated and verified with 16 years of data, all in the pre-zebra mussel period. In the present modeling study, we explore and ascertain the relationships further, if any, between the phosphorus and oxygen dynamics and zebra mussels, in the post-zebra mussel years. To do so, instead of adding a new zebra mussel sub-model, the NWRI nine-box model was run as is, without changing any of its coefficients, for selected post-zebra mussel years. The strategy is to detect any deviations in model predictions from observations and attribute them to new processes due to zebra mussels. A sensitivity analysis of the physical, chemical and biological processes before and after the zebra mussel arrival then identifies knowledge gaps for the most sensitive processes and key inputs required for model improvement

Study Areas: Lake Erie

Results

It was found that the total phosphorus concentration has decreased in the east basin after the zebra mussel arrival using data from 1994 and 1997, while soluble reactive phosphorus has increased in the west basin. Based on the modeling and sensitivity analysis results, these findings are attributable to possible effects of zebra mussel. On the other hand, there have been changes in dissolved oxygen concentration in the lake pre- and post-zebra mussel arrival. However, modeling and sensitivity analysis results indicate that these changes in dissolved oxygen are due to weather influences and not due to zebra mussels. This is a significant consideration for the reoccurrence of anoxia, i.e. the so-called Lake Erie "dead zone" problem because the oxygen depletion in Central Basin hypolimnion was shown largely explainable by the physical influence of weather on the hypolimnetic thickness and sediment oxygen demand. The results will be considered by the Lake Erie Lakewide Management Plan for future strategic planning and implementation of phosphorus abatement. The result on the weather influence on dissolved oxygen, in spite of zebra mussel arrival, is an important consideration for future climate change adaptation strategies. A joint research study on further lake thermal regime modeling for climate change investigation has been conducted with University of Guelph and McMaster University under a research grant from the Canadian Foundation for Climate and Atmospheric Sciences. Also, this modeling study has led to a new set of physical, chemical and ecological experiments being conducted, in collaboration with the University of Waterloo, under an NSERC Strategic Grant, in both the nearshore and offshore of the east basin of Lake Erie to gather missing knowledge and data for the improvement of the water quality model.

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STUDY TITLE: Integrated Watershed Modeling

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STUDY TEAM: C. McCrimmon
PARTNERS: MSC-P&YR, NRC-CHC, University of Waterloo
CLIENTS: MSC, Greater Vancouver Regional District
FUNDING: Greater Vancouver Regional District

Introduction

Nutrients and sediments carried by runoffs from watersheds eventually reach rivers and lakes. Scientists already know these non-point source pollutants may affect significantly to water quality conditions in lakes, particularly those that receive no industrial or other point source input such as reservoirs. To determine accurately the pathway and transport of these non-point pollutants over the watersheds and in the lake, this study used a collection of mathematical models that simulate the hydrological, hydrodynamic and biochemical processes in watersheds and lakes. By calibrating and verifying the model results with observed data, we gained important scientific insight and estimated the pollution impact to lake water quality condition by using the best available information.

Study Areas: Seymour Watershed, B.C.

Results

The results shows that the effects of non-point source pollutants on lake water quality condition depend on a complex relationship between precipitation, river flow, river nutrient concentration and the nutrient concentrations the lake. As an example, this study found that for the Seymour Lake, under certain meteorological conditions and management strategies, the river flow peaked behind the rainfall by about 6 hours and the nutrient concentrations in the river and at inlet to the lake peaked closely with the hydrological flow, whereas ammonia and nitrate concentrations behaved differently at the intake (near the lake outlet) with more prolonged responses (Figure). This time lag of both water quantity and quality responses relative to a precipition event could be an important consideration for reservoir operation and management for which the forecast of intake water quality. The model results can be also used to design an integrated set of observational programs to monitoring the water quality conditions in the lake. In the study, the capability of integrating hydrological flow model, watershed non-point source model and lake hydrodynamic and water quality model has enabled futher investigation into various watershed management scenarios including water quality impact due sediment erosion, land slides and forest fires.

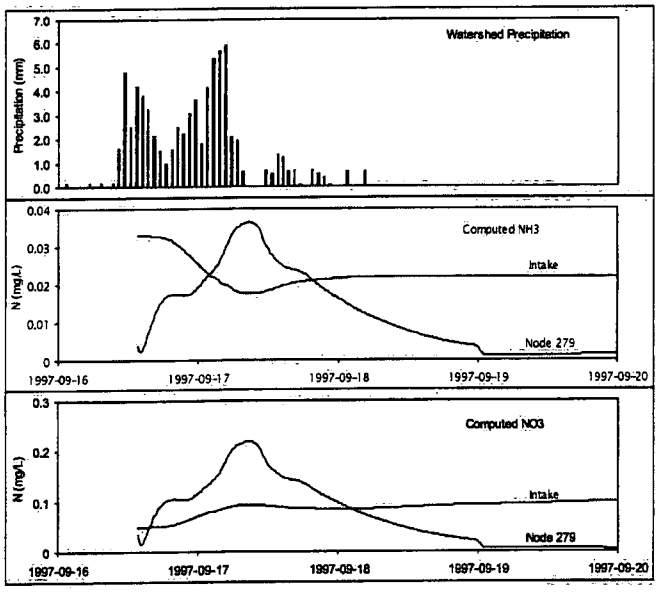

Figure. Time series for (from top) observed precipitation, computed ammonia and nitrate concenttrations at water intake (near the lake outlet) and at node 279 (near the lake inlet) for Lake Seymour, B.C. for a precipitation event duing September 17-18, 1997.

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STUDY TITLE: Study of Water Quality Influence on Waterfowl Habitat in Ontario

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STUDY TEAM: P. Fong
PARTNERS: Canada Wildlife Service, Ontario Region
CLIENTS: CWS- OR
FUNDING: CWS-OR

Introduction

Intensive effort has been devoted to identifying habitat features necessary for maintaining viable populations of particular plant and animal species. The usual approach is to identify, in brief time intervals and in small geographic areas, habitat associations of focal species. A common problem with this approach is that models fail to predict distribution of focal species in different time intervals and geographic areas. We took a major step to sound stewardship of biodivesity in aquatic ecosystems of Ontario by identifying habitat requirements for common waterbird species, including the common loon (*Gavia immer*) and several anatids (hereafter, collectively referred to as waterfowl) in the forested landscape of central and northeastern Ontario. The study area is characterized by low productivity and sparsely distributed populations of aquatic birds. Despite sparse distributions, large portions of some North American waterfowl populations are produced in Ontario, simply because of the enormous

landmass involved. Waterfowl habitat in Ontario north and east of the Great Lakes is being degraded by anthropogenic influences, including acid precipitation, mercury, and ultraviolet radiation, as well as forestry, hydroelectric development, mining, and other human encroachments. This study involves various knowledge-based methods to predict waterfowl populations based on water quality and habitat. This research is on going in collaboration with colleagues at CWS-OR.

Study Areas: Ontario with Parry Sound District as Pilot

Results

The hypothesis was that waterfowl and other wildlife require specific habitat features to feed and successfully reproduce. The assumption was that chemical, landscape and biotic information that was obtained from a variety of sources included direct or indirect measures of those features. Habitat associations are correlative, and do not necessarily identify crucial resources. In the Parry Sound District, CWS Ontario Region has done surveys for many projects over the years. This valuable information now resides in the WILDSPACE Decision Support System. All data from the WILDSPACE Decision Support System for the loon indicated pairs over the years are extracted. The parameters in the study include indicated pairs of loons, shape index and area of the drainage, number of neighbours that have similar shape and area, island presence/absence information, water quality variables such as pH. Two methods will be used for prediction: case-based reasoning (CBR) and probabilistic neural network (PNN). These methods are similar in a sense that they are both based on distances from the unknown case (to be predicted) to the training cases. They differ in the number of training cases to use and in how the final classification metric is computed. CBR uses the "closest" n cases or neighbours (in this study, 3 neighbours are used), while PNN uses all cases in the training set. The first target waterfowl species was the common loon. Preliminary results showed that both methods have predictive capability with the case-based reasoning slightly better at 65% correct while the probabilistic neural network was at 58% correct. However, these results are still very preliminary. Further research is required and the scope of the study area is needed to broaden to all of Ontario.

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STUDY TITLE: Canada-Wide Water Quality Data Referencing Network

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PARTNERS:	CCME, NWRI/WQMB, ECB/PYR, ECB/OR, ECB/PNR, University of Guelph
CLIENTS:	CISE, Public
FUNDING:	CISE

Introduction

The Canadian Council of Ministers of the Environment (CCME) Water Quality Task Group has identified the need to develop a Canada-wide Water Quality Data Referencing Network to be made available over the Internet. Currently, various database methodologies and computer networks are used

by federal, provincial and territorial environment agencies to provide access to surface, ground and drinking water quality data. The data referencing network is a comprehensive Internet tool that uses map- and text-based queries to provide access to federal/ provincial/ territorial water quality monitoring information.

Stage 1 of this project has focused on inventories of water quality monitoring activities. Stage 2 will provide access to water quality data that have been generated by federal/ provincial/ territorial agencies. This will be available in a searchable web service. Other activities that will take place in Stage 2 include building decision Support capabilities, interpretation of integrated federal, provincial and territorial data, linkages to biological effects data, and working with local governments and other Canadian Information for the Environment (CISE) partners.

The development of the Canada-Wide Water Quality Data Referencing Network has been supported by the CISE.

Study Areas: Canada

Results

This project has progressed along on schedule. About 99% of the available information from data partners has been processed. So far, information for over 3,000 sites from the federal Environmental Monitoring Inventory program was assembled and over 6,000 sites provided by provincial and territorial partners were also entered into our network. The information has been grouped into the following categories: Name of Water Body, Station Number, Geo-reference, Sampling Frequency, Parameters, Contacts, Data Availability, Partners, Program Focus, Water Uses and Project. A prototype of the system was presented at the Experts Workshop on Water Quality Monitoring, October 16-18, 2002 in Vancouver, B.C., organized by Environment Canada. Because of new data entries and changes in contact information, such updates and repairs will be an on-going feature of this data referencing network.

While the focus was on the inventory information of water quality databases, work had begun on possible data access with participating partners. Exchange of ideas and development of possible linkage with another CISE pilot project on water quality data for British Columbia developed by Pacific and Yukon Region, Environment Canada, was started. Similarly, there were linkages to the summary water quality databases in Ontario Region, Environment Canada, and the Northern Rivers Ecosystem Initiative. In summary, a working Canada-wide network is developed and has gone beyond the proof of concept to become a focus for water quality information that will contribute to the future development of CISE.

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STUDY TITLE: Integrated Acid Rain Assessment Modeling

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STUDY TEAM: D.C.L. Lam, W.G. Booty, R.C. McCrimmon
PARTNERS: MSC, NWRI/AEIRB, CWS-OR, P&C
CLIENTS: CCME, 2004 Acid Rain Assessment Report
FUNDING: Acid Rain Fund

Introduction

While there have been many scientific studies of acidification processes, the combined knowledge of the air, water, soil sciences and wildlife, including interactions with social economical aspects, has not been fully explored. Recently, several modeling efforts have been conducted to integrate scientific and socio-economical models for environmental assessment. This approach to integrated assessment modeling will provide advice for the 2004 Canadian Acid Rain Assessment Report and is also used to support CCME in the negotiation of emission reduction between Eastern Canada and the New England States of the United States.

This approach differs from other modeling efforts in that it provides an open architecture framework that accepts any component model that can be linked to other component models in the casual chain, be it an existing trajectory model for airborne pollutants or a new fish presence-absence model. The emphasis is on overcoming problems with linkages of these models and on the development of the integrated assessment model (IAM) as a decision-support system.

Study Areas: Canada

Results

This project has several new developments in this fiscal year. Most noticeably, the new 70 site Source Recepter Matrix from MSC has been integrated into the IAM. This allows the research on new scenarios gaming and provides advice on the emission reduction. The steady state water chemistry (SSWC) model is also integrated into the IAM. This model also allows for calculating critical loads of acidifying depositions (sulphur and nitrogen) for surface water on a regional scale. This allows the calculation of critical loads of acidity and their present exceedances. The results of the SSWC model can be directly compared to the expert choice already within the IAM. Although it is preliminary, it is likely that the SSWC model can become part of the expert choice models. This will enhance the quality of the water chemistry modeling with the IAM.

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STUDY TITLE: Non-Piont Source Modeling Technical Support for Conservation Authorities with AOC Watersheds

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STUDY TEAM:	David Lam, Luis Leon, Oskar Resler
PARTNERS:	Ontario Ministry of Environment
CLIENTS:	Great Lakes Sustainability Fund (GLSF), Toronto Region Conservation Authority, Hamilton Region CA, Halton CA, Raisin CA, Niagara Ca, Essex Region CA, Ducks Unlimited, Environment Canada – Ontario Region
FUNDING:	GL2020, GLSF, Ontario Ministry of Environment

Introduction

The Great Lakes Water Quality Agreement (GLWQA) signed by the U.S. and Canada specifies key provisions for control measures for nutrients and critical pollutants. Section 4 emphasizes the importance of demonstration projects on urban and rural watersheds to advance knowledge and enhance information. One of the objectives of our research is to develop modeling capabilities that would provide watershed managers with a tool that would enable them to design and target Best Management Practices (BMPs) that would be effective in improving water quality conditions in rural watersheds. A Federal-Provincial Study Agreement was established between the National Water Research Institute (NWRI) and the Standards Development Branch (SDB), Ontario Ministry of Environment (MOE) in conjunction with funding from the Great Lakes Sustainability Fund to provide non-point source water quality modeling technology transfer to MOE regional offices and Conservation Authorities which have Great Lakes Areas of Concern within their jurisdiction, in support of the Great Lakes 2020 program.

Study Areas: Ontario AOCs

Results

A wide range of available NPS models were evaluated and the AGNPS model was selected to examine BMPs because of its ability to concurrently simulate water quantity and quality in different parts of a watershed. It also lends itself well to interfacing with GIS systems to expedite data input and display/interpret model results. An interface has been developed for the AGNPS model using the RAISON for Windows Decision Support System developed at NWRI. It drastically reduces time-consuming data input tasks for the model as well as providing scenario evaluation tools. The model was calibrated and verified for the Duffins Creek watershed, which drains into Lake Ontario at Ajax, 10 km east of Metropolitan Toronto. The model has been evaluated for a wide range of storm events and provided accurate prediction of runoff and of nutrient loads. Training was provided to employees of 7 Ontario Conservation authorities, personnel from Ontario Region and the Great Lakes Sustainability Fund, and also from Ducks Unlimited. A beta version of the new AGNPS model interface, which runs within the RAISON Object System, has been provided to Ontario Ministry of Environment. Study results were published in a journal publication and several reports.

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STUDY TITLE: Environmental Effects Monitoring: Statistical Analysis Tool

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STUDY TEAM:	David Lam, Isaac Wong, Oskar Resler, Alex Storey, Philip Fong, Catherine Chen
PARTNERS:	NWRI Saskatoon: Monique Dube, Rick Lowell, Jason Inkster
	NEEM: Lise Trudel, Gilles Champagne
	Jacques Whitford Environment Ltd: Bruce Kilgour
CLIENTS:	National Environmental Effects Monitoring Office, NREI
FUNDING:	NEEM, NREI

Introduction

Currently, pulp and paper and mining industries are required to conduct Environmental Effects Monitoring under the Pulp and Paper Effluent Regulations (PPER). Environmental Effects Monitoring (EEM) is a scientific tool that assesses the effects of effluent from industrial or other sources on fish, fish habitat and the human use of fisheries resources Environment Canada's National Environmental Effects Monitoring Office found it necessary to develop a simple, user-friendly software package that implements the statistical methods set forth by the EEM Science Committee. This was found to be necessary as it was determined that consultants performing EEM for pulp and paper mills were not consistently interpreting the EEM data. Also, an intensive analysis for the Northern Rivers Ecosystem Initiative (NREI) was requested that uses the EEM data for 5 mills operating in Alberta. The analysis consists of comparing bio-indicators for benthic invertebrates and fish between reference populations and exposure populations to determine if statistical differences (i.e., effects) exist at a specific site within the Basin. This would serve as an initial attempt to develop a nation wide system for the EEM with users including industries, consultants, Regional EEM Coordinators, National EEM Office, and Scientists involved in EEM-related research.

Study Areas: 5 Alberta Pulp and Paper Mills

Results

The Environmental Effects Monitoring Statistics Analysis Tool (EEM-SAT) was developed and tested for 5 pulp and paper mills to evaluate bioindicators for cumulative impacts within the Peace-Athabasca Rivers Basins. The system was evaluated by the EEM Science Committee/NEEM team and found to be extremely useful. The system has also been provided to the NREI Steering Committee. The outputs of the EEM-SAT have been incorporated into the EcoAtlas product, which is being used in the NREI Integrated Environmental Effects Monitoring project.

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STUDY TITLE: Water Quality Modeling Based on Changes in Water Quantity

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STUDY TEAM:	David Lam, Oskar Resler, Luis Leon
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CLIENTS:	Wendy Leger and Robert Read, Water Use and Supply Project, Boundary Water Issues Division, MSC – Ontario Region
FUNDING:	Water Issues Division, MSC – Ontario Region

Introduction

This research represents a pilot project that is being carried out to establish a methodology for assessing the sensitivity of watershed stream water quality to changes in water quantity caused by climate change. The pilot watershed is the Duffins Creek watershed, which is located in the east of Toronto. It falls under the jurisdiction of the Toronto and Region Conservation Authority. It was selected because of the large existing data and knowledge base that has been developed over the years. In addition, new watershed strategies have been developed that have been supported by a number of technical studies. A surface water quality study evaluated water quality conditions during dry and wet weather (Stantec/Aquafor Beech). The Agricultural Non-Point Source model (AGNPS) model was calibrated for the Duffins Creek Watershed (Leon et al. 2002) and a wet weather event-based evaluation (TRCA, Jan. 2003) was carried out using the AGNPS model.

Study Areas: Duffins Creek Watershed

Results

Scenarios of climate change analyzed in this project were drawn from two internationally recognized climate models: the Canadian Centre for Climate Modeling and Analysis (CCCma) CGCM1 and the Hadley Centre HadCM2. The climate change precipitation scenario values for the extreme wet and dry conditions from the two climate change models were used in the AGNPS non-point source model to generate stream flow and water chemistry data for the climate change conditions. These were compared to the baseline storm events originally developed during the calibration of the model. Overall, both of the two wet climate change conditions result in slightly lower concentrations of nitrogen and phosphorus and elevated peak flows for most of the subwatersheds. The dry climate change scenarios predict slightly higher concentrations of nitrogen and phosphorus and lower peak flows. However, in the Urfe and West Duffins Creek subwatersheds, phosphorus concentrations are not predicted to change despite the significant changes in peak flows. The Chemical Oxygen Demand concentrations do not change consistently with the wet and dry conditions in the different watersheds.

Even within the same watershed, subwatersheds can have different levels of sensitivity to climate change. These results illustrate why a deterministic model that combines the complex interactions of processes is required to predict the behaviour of watersheds to stressors rather than relying on simple, non-interconnected functions.

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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 B_{12}

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

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. 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. This year soil and water samples from another area at Aberdeen called Cluster 13 were received for testing.

Study Areas: Aberdeen Proving Grounds, Maryland.

Results

Two twelve-week pilot tests using *in situ* vitamin B_{12}-catalyzed reductive dechlorination were conducted in the falls of 1999 and 2000 at Graces Quarters, Aberdeen Proving Ground, Maryland. Groundwater at the site is contaminated with 1,1,2,2-tetrachloroethane (TeCA), carbon tetrachloride (CT), trichloroethene (TCE), tetrachloroethene (PCE), and chloroform (CF). The first phase of the test was halted because of biological fouling of the chemical injection/recirculation well and the near-by formation. For the second phase, further biofouling was prevented by the addition of Tolcide® as a bacteriostatic agent and by the addition of the vitamin-B_{12}/titanium citrate concentrate in weekly pulses instead of continuously. Four months after the end of the treatment, no trace of Tolcide® could be found in the aquifer. The titanium citrate that was added as a reducing agent was found to have significantly decreased the Eh in a 10 m diameter around the recirculation well. Several monitoring wells surrounding the treatment well exhibited methanogenic conditions. In addition, Denaturing Gradient Gel-Electrophoresis (DGGE) analysis of aquifer samples showed changes in bacterial population in areas that had received the vitamin B_{12} treatment.

In the fall of 2001, a post-treatment phase was conducted where the recirculation well was used without further chemical addition, to determine the effectiveness of the *in-situ* 'biofilter' that had been generated. At the end of the pilot tests, total VOC concentrations greater than 1,000 µg/L were still present at QRP9C, located 80 ft away from the point of injection, and concentrations at QRP8C, 35 ft from the point of injection, exceeded 500 µg/L. Before restarting the pumps, a new baseline sampling showed a significant degradation of VOCs in 8C, with most of the TeCA being transformed to a mixture *cis*-dichloroethene (cis-DCE) and 1,2-dichloroethane (DCA). The pump was started at a rate of 4 gallons-per-minute (gpm), but the rate was gradually reduced to 1 gpm because of biosolids and iron oxide fouling. Biodegradation of the VOCs being brought in from beyond the previous treatment zone, 30 m radial distance from the recirculation well, was observed. CT, TeCA and TCE amounting to a total concentration of 2,000 mg/L were completely degraded along the flow path to a mixture of DCA and

cis- and *trans*-DCE, totalling 450 $\mu g/L$. The co-metabolic biodegradation was sustained by residual amounts of acetate, which had been generated by the biodegradation of glucose and citrate in the active treatment period. Degradation of CT was complete, without the accumulation of CF or DCM. While the most abundant and longer lived degradation product was *cis*-DCE, its concentration declined with time and distance. Only small amounts (less than 20 $\mu g/L$) of vinyl chloride were formed. These results indicate that continuous treatment with vitamin B_{12} is not necessary and that alternating chemical addition with periods of pumping alone may be a cost-effective strategy for *in-situ* remediation of mixtures of chlorinated solvents.

This year, groundwater and aquifer material from other areas at Aberdeen Proving Grounds called Cluster 13 and the Bush River were received for laboratory testing. These sites are contaminated by the same compounds but have either much higher concentrations or are in a different geologic formation with much finer materials. Laboratory testing is ongoing, but preliminary results show that while the same treatment is possible, much higher concentrations will be needed.

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STUDY TITLE: Sediment Restoration

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STUDY TEAM:	Jay Guo, Leslie Miller, Tanya Parr
PARTNERS:	Redlog Inc
CLIENTS:	Hong Kong City
FUNDING:	clients

Introduction

NWRI continues to support commercialization of its sediment treatment technology. The new technology involves 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 are testing remediation technology to treat old oil spill residuals for a confidential client at a site in the Middle East. Many kilometers of beaches are fouled with oil. Full-scale sediment remediation by our licensee was completed in Hong Kong.

Study Areas: Middle East, Hong Kong, Japan

Results

The bench-scale treatments of sediments from the Middle East established a treatment dose proportional to sediment parameters. Equipment was designed, built and tested for treatment of intertidal sediments in situ. These beach treatments are on-going.

We published a paper reviewing how sediment dissolution of phosphorus in Japan is enhancing algal growth. Air pollution, especially sulphur loading can enhance eutrophication by enhancing dissolution of vivianite (ferrous phosphate) in sediments.

The full-scale treatment of 22 hectares of sediments with NWRI equipment was completed successively in Hong Kong. A sublicense is being negotiated to use the process again on a similar new project elsewhere in Hong Kong.

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

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PARTNERS:	University of Waterloo (D. Blowes, Professor; K. Sasaki (Visiting Professor)
CLIENTS:	Province of Manitoba, Agrium, Falconbridge, Placer Dome
FUNDING:	Province of Manitoba, Agrium, NSERC

Introduction

Active and abandoned mines are the largest point source of metals released to the environment. Old mine sites around the world continue to release elevated concentrations of metals to groundwater and surface waters, decades to centuries after mining activities cease. Initial oxidation of sulfide minerals in mine wastes results in the production of acid 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 discharged to surface water bodies. At certain sites, even under neutral conditions, the release of undesirable elements such as arsenic can also occur. Laboratory, field and modeling studies are being conducted to evaluate the mechanisms controlling the attenuation of metals and arsenic at five 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 on aquifer solids 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 tailings impoundments, in 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.

Abandoned Mine Buildings - Sherridon, Manitoba

Study Areas: Field studies will be conducted at the Sherridon and Lynn Lake mines in Northern Manitoba (2003). Laboratory studies will be conducted on tailings and aquifer materials collected at mine sites in Ontario.

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 four base-metal and one gold mine site. Two sites are active, and three have been abandoned between 20 and 70 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, seepage meters and mini-piezometers were installed in the lake sediments adjacent to the tailings areas. Samples of lake water, 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 between 2000 and 2003. Laboratory column experiments were carried out between 2000 and 2002 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 at all field sites. Reactive solute transport model calculations were made to predict the long-term release of metals from the tailings impoundments. Metals and arsenic will continue to be released from the tailings for many more decades in the absence of effective remedial action.

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STUDY TITLE: Biological Barriers in Fractured Bedrock

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

FUNDING: PERD and GL2020

Introduction

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) (Figure 1). The objectives are to 1- monitor the changes in hydraulic conductivity 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.

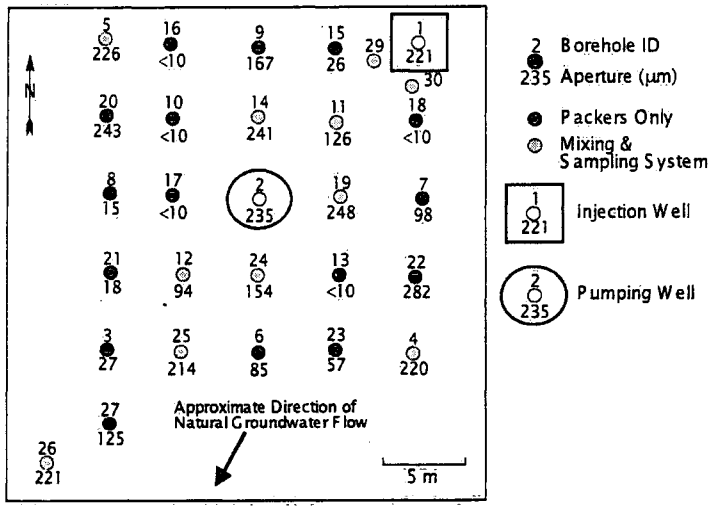

Figure 1. Schematic of field site and borehole layout.

Study Area: Mississauga, Ontario

Results

Laboratory activities consisted of optimizing the biofilm development to help in the design of the full-scale biobarrier demonstration. A large-scale planar fracture, made of two glass-sheet of 2.0 m × 0.6 m separated by a 1.5-mm wire, was used to monitor the biofilm development, its resistance to starvation, and its persistence to high groundwater velocities. When biostimulated with invertose (50 g/L at 0.3 mL/min), the groundwater microbial community developed a biofilm that covered 700 cm^2 after 50 days. The biofilm structure resisted to the starvation conditions (i.e. stopping the nutrient injection) as well as an increase of the groundwater velocity from 5 m/d to 30 m/d. However, a significant detachment of

sessile bacteria (0.5 to 1 log bact./mL) was measured. The changes in the microbial community and the ecotoxicological responses due to this biostimulation were small in the planar fracture. Indeed, phylogenic affiliations of bacterial DNA sequences, excised from a denaturing gradient electrophoresis (DGGE), showed that dominant species (> 1 - 2 % of the total community) were closely related to the genus *Caulobacter*, for both the groundwater and the biofilm. The ecotoxicological responses from three biotests—bioluminescence inhibition of *Vibrio fischeri*, lethality of *Daphnia magna*, and growth inhibition of Lemna minor—were not significant.

At the demonstration site, located in Mississauga on the property of Petro Canada Lubricants, a biostimulation experiment was prepared and background data was collected. To optimize the monitoring of the fracture bioclogging, 3 boreholes were added to the 27 existing ones; they were drilled, developed, and instrumented. A data acquisition system was installed for the on-line monitoring of the redox potential (Eh), temperature, and pressure to collect information on seasonal variations. Point dilution tests are being prepared for the characterization of the flow in the fracture prior to the biobarrier development. On average over one year of groundwater monitoring in pre-clogging conditions, the groundwater showed a high salinity throughout the site (Figure 2-A).

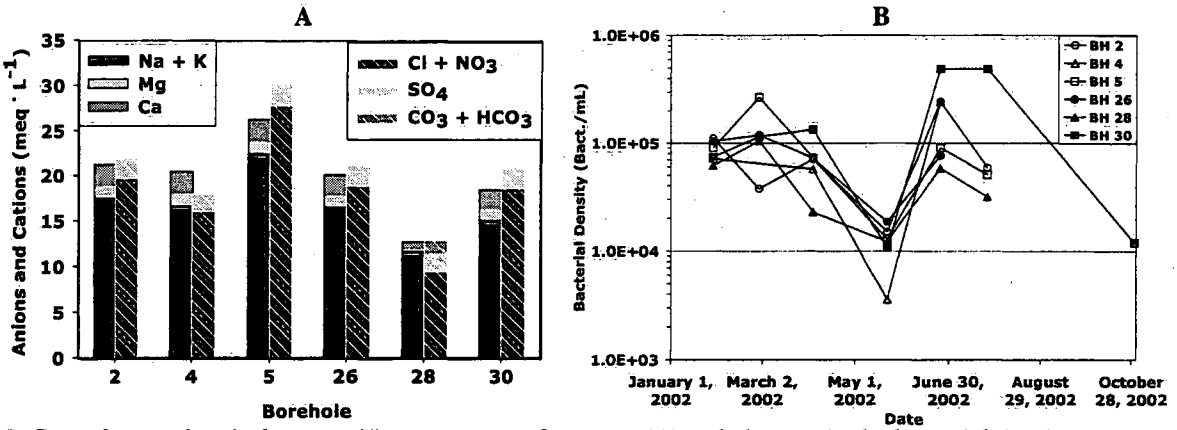

Figure 2. Groundwater chemical composition on average for a year (A) and changes in the bacterial density over a year (B) for 6 monitoring boreholes.

BH 28, located 100 m outside the monitoring grid, had significantly lower anions and cations concentrations, a sign that this well might have more connections with surface water. On the contrary, BH 5 had a significantly higher ions concentrations, which could be explained its location in a tighter area thus reducing the dilution with surface water. The groundwater bacterial density was maintained in the 5 log · mL^{-1} except for the spring months, reaching 4 log · mL^{-1}, which might be the result of dilution by the rain ands snow melt events (Figure 2-B). Additional assessment of the groundwater bacteria will give insights into the changes in the diversity and the partioning from groundwater (planktonic) to the rock surface (sessile).

Point dilution tests were initiated by injecting a tracer composed of 700 µL of a mixture of 1 g/L Lissamine FF and 30 g/L of KBr and 3 mL of deionized water (Figure 3). As expected, all the boreholes except BH28 showed a pronounced increase in groundwater velocity during active pumping. No change in the up-gradient borehole (BH28) was detected indicating that BH28 could effectively be used to monitor natural changes in the ambient flow. Conducting point dilution tests in BH28 was intended to avoid falsely attributing natural or seasonal changes in velocity to bioclogging in the fracture.

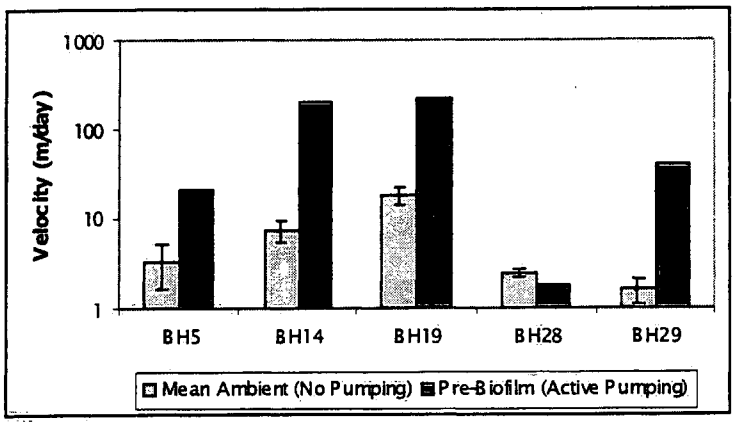

Figure 3. Groundwater velocities from selected boreholes under ambient and active pumping conditions (pre-biofilm development). Error bars describing the variability in ambient velocities is indicated by +/- 1 standard deviation.

The promising results obtained in the laboratory showing the potential of bioclogging a fracture media for the control of groundwater were scaled-up for a field demonstration in Mississauga, Ontario. After instrumenting 29 boreholes, which isolate a shale fracture of 165 µm on average, background data and pre-clogging conditions were measured for comparison with the bioclogging conditions. Biostimulation with molasses and a nitrate source was initiated on a 3-week injection and 1-week starvation cycle. *In situ* monitoring and monthly groundwater sampling are ongoing to document the efficiency of the biobarrier development.

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STUDY TITLE : Attenuation of an Ethanol-BTEX Plume in a Fractured Rock Model Undergoing Biostimulation

STUDY LEADER: Nathalie Ross
STUDY TEAM: Helena Steer, Pamela Grande, James Barker
PARTNERS: Petro-Canada and University of Waterloo
FUNDING: PERD

Introduction

Oxygenates designate a group of chemicals added to gasoline to reduce air pollution problems. Among them, ethanol is blended at 5 to 10 % by volume in Canadian gasoline and is expected to replace other oxygenates, such as MTBE. The petroleum industry, along with environmental scientists, has to address the issue of bioremediation of gasohol spills and leaks in groundwater.

The biobarrier represents a promising method as a means to intercept/degrade gasohol in fractured bedrock. Previous studies, shown the capacity of a biofilm, formed by groundwater micro-organisms, to biotransform contaminants. An ongoing project, conducted at NWRI, is focusing on the hydrogeology and the stability of the biobarrier formation at a large laboratory scale and field scale. The present project addresses the specific case of a gasohol plume.

Results

The research activities were focused on three objectives during the first year. First, the analytical methods had to be developed for the measurement of BTEX and ethanol at concentrations found in groundwater. Using gas chromatography, detection limits of 2 µg/L and 250 µg/L were obtained respectively for BTEX and ethanol. These methods are used for microcosm studies and flow-through experiments.

Second, the effects of a BTEX/ethanol contacted groundwater on biofilm growth/thickness were assessed in two experimental designs using 96-well microplates. Using standard deviation from triplicates, these experimental designs allowed 32 experimental units (8 treatments at 4 levels) to be compared over 20 days of biofilm growth. At concentrations susceptible to be found in groundwater, ethanol did not impair biofilm thickness when compared to controls. The significant effects of BTEX as single components on biofilm thickness were similar (Figure 1). This assessment provided initial toxicity results and helped selecting experimental conditions for the large-scale experiment.

Third, a flow through experiment was designed to measure the capacity of a biofilm to contain/degrade a BTEX/ethanol plume (Figure 2). Using groundwater from a fracture rock site (Mississauga, Ontario) and stimulating biofilm growth by indigenous bacteria, this ongoing experiment includes physicochemical analyses (light transmittance, Eh, and BTEX/ethanol concentrations) and microbiological analyses (bacterial enumeration and bacterial identification). This laboratory work will document on the effects of ethanol cosolvency, which could increase the groundwater concentration of BTEX in aquifers, and of depletion of electron acceptors in groundwater due to the preferential consumption of ethanol by groundwater bacterial community.

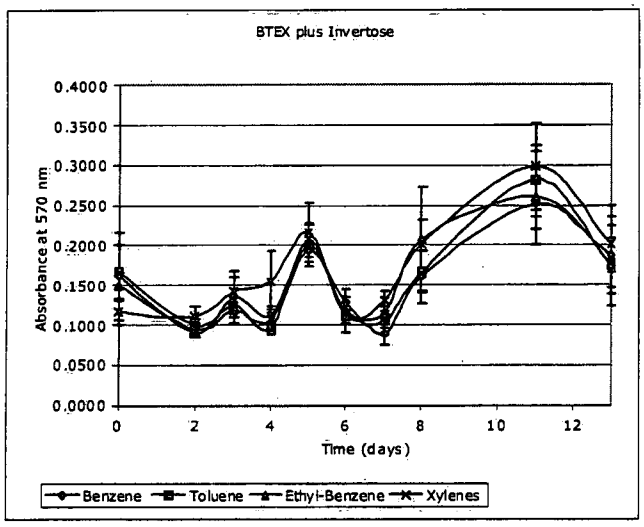

Figure 1. Biofilm development in presence of BTEX

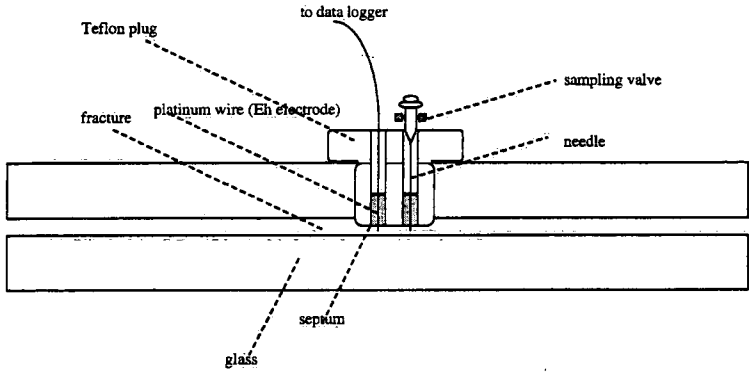

Figure 2. Schematic of the fracture plane apparatus for the development of biofilm to control a BTEX/Ethanol plume in groundwater

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STUDY TITLE : Biosafety of Bioremediation Approaches in a Tetrachloroethylene-Contamianted Aquifer

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PARTNERS: Environment Canada, Canadian Wildlife Services, and University of Toronto

FUNDING: EMBRR

Introduction

Concerns regarding the fate of micro-organisms injected in the environment contributed to the development of the New Substances Notification (NSN) Regulations under CEPA. To provide scientific evidence of the environmental fate and ecological effects of micro-organisms used for groundwater treatment, three bioremediation approaches—natural attenuation (NA), biostimulation (ST; addition of nutrients), and bioaugmentation (AU; addition of bacteria and nutrients)—were compared in a large-scale model aquifer (Figure 1).

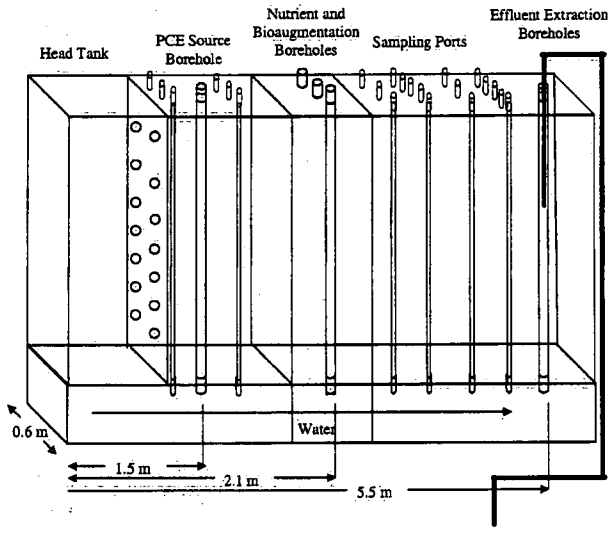

Figure 1. Cross-sectional view of one lane of the model aquifer. The nomenclature used for the sampling ports was as follows: lane (NA, ST, or AU), length from the head tank (ft), width from the center of the lane (A and E = 20 cm, B and D = 10 cm, and C = 0 cm), depth (ft); (ex. AU11D3).

The assessment of the biosafety was conducted in the Aquatic Ecosystem Restoration Evaluation Facility (AQUEREF) using on-site groundwater. The objectives were 1- to evaluate the physical, chemical, and biological changes in the environment due to the bioremediation technique; 2- to measure the ecological effects, selecting biotests based on well established methods and potential receptors widely spread in Canada including Ontario-native amphibians; and 3- to monitor the presence and the persistence of potential pathogens.

Results

After the model aquifer was designed, the flow conditions established, and the initial conditions tested, a 250-day bioremediation phase was monitored including chemical, microbiological, and ecotoxicological analyses. This represented the last year of the initial funding. EMBRR renewed the funding for an

additional 3-year period, which included specific objectives on the fate of KB1 (the AU culture) and a field investigation on groundwater ecotoxicology.

Fate of VOCs in the Model Aquifer

The evolution of the VOC concentrations at monitoring points 4C4 show the dissolution of the PCE from the source prior to stimulating or augmenting (Figure 2). The
fluctuation in the data reflects the source heterogeneity and possible escapes of DNAPL blobs from the source; nevertheless, the three different sources were relatively similar and provided an average input. concentration of 200 μmoles/L for the first 50 days, after which they started to decline exponentially.

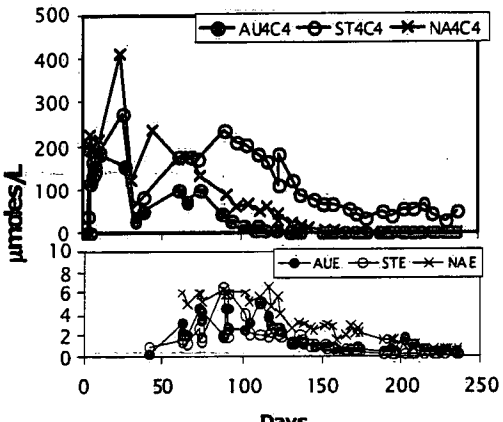

Figure 2. Source dissolution in the three treatments and the effluents concentrations. The source contained 10% tetrachloroethylene and 90% silicone oil.

The effluent concentrations peaked simultaneously in the three lanes at about 100 days before declining as well.

Microbiological Monitoring

The bacterial density in groundwater was consistent over time and space (Table 1). The density of bacteria attached to the soil was 7 orders of magnitude higher than in suspension in the groundwater, indicating that the majority of active bacteria were attached. Therefore, the partitioning of the bioaugmentation culture, KB-1 isolated from a TCE-contaminated site, might be preferentially attached to the soil particles.

Table 1. Enumeration of total bacteria using BacLight™

Sample	Groundwater (log total bacteria / ml)		Soil (log total bacteria / g)
	June 2002	September 2002	July 2002
Holding tank		5.25	
NA6C4	5.53		
NA8C4	5.65		
NA15C5	5.37	5.23	
NA-soil composite			12.01
ST15C5		5.43	
ST-soil composite			12.06
AU15C5		5.01	
AU-soil composite			11.71

Assessment of the Impacts of Bioremediation using Amphibian Larvae

There was no significant difference in the survivorship between the control group and those exposed to any of the three treatments ($p > 0.05$, Table 2). Of the survivors, there was no significant difference in the proportion of individuals to reach metamorphic transformation within the 100-d period. There was a significant difference in weight and SVL of *Xenopus* froglets with controls being smaller than animals exposed to the three effluents. However, no obvious bacterially induced lesions were observed in tadpoles or transformed froglets.

Table 2. Endpoints measured on *Xenopus* tadpoles exposed to effluents from the model aquifer

Treatment	Survivorship t = 68 d (%)	Survivorship t = 100 d (%)	Transformed (%)	Weight (g)	Snout Vent Length (mm)
NA	66.3 ±17.4	70.0 ±20.3	38.4 ±14.8	0.44 ±0.20	16.12 ±0.27
ST	66.7 ±27.8	65.4 ±25.0	48.1 ±14.6	0.39 ±0.20	15.84 ±0.23
AU	60.6 ±5.8	58.4 ±4.3	52.3 ±11.5	0.44 ±0.20	13.26 ±0.21
Control	88.3 ±1.4	70.2 ±11.4	32.0 ±14.0	0.36 ±0.20	15.23 ±0.20

The results suggest that the bioremediation approaches had no negative impact on amphibian embryos. Additional information on the partitioning/identifying of the bacterial population in the three lanes will help in assessing the biosafety of bioaugmentation compared to the biostimulation and the natural attenuation approaches.

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STUDY TITLE : Combined Sewer Overflows and Stormwater Runoff

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CLIENTS: EC, biotechnology and industrial supporters
FUNDING: EC

Introduction

Surface washoff generated during rainstorms 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. 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 how the microbial community structure of bed sediments is impacted by the effluent from combined sewer and stormwater overflows, 2) characterizing and

identifying contributing sources of pollutants to sewer systems, 3) assessing the fate of CSO sediments within the Kenilworth boat slip.

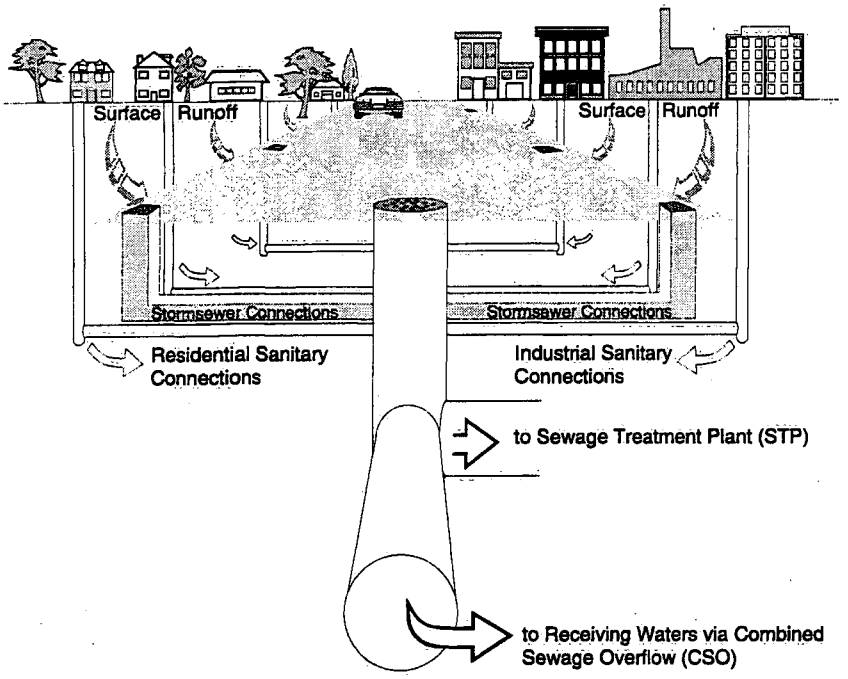
Study Areas: Toronto Harbour and Hamilton Harbour

Results

The fate of contaminated sediments originating from the Kenilworth sewershed within Hamilton Harbour is unknown. The transport of these sediments thorough the combined sewer system, in association with storm flow, has been effectively modeled using a storm water management model (PCSWIMM). Current modeling efforts are associated with assessing the frequency, magnitude and fate of contaminants entering the Kenilworth boat slip via the Kenilworth combined sewer outfall.

Kenilworth combined sewer outfall (Hamilton)

Surface runoff from urbanized areas can represent a significant source of contaminants to receiving water bodies. Results from metal analysis of multiple street dust samples have been integrated into a GIS system. This process has allowed the identification of "hot spots" for metals such as lead within the Kenilworth Sewershed. Further work is continuing on the bioavailability of metals within the urban environment. Such identification and assessment of bioavailability will assist in determining the best remedial measures and best management practices to prevent metals contamination in the future.



Schematic of surface water/sediment transport routes through the urban system.

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 that are responsible for these differences.

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STUDY TITLE: Subsurface Remediation Under Anaerobic Conditions, and with Humic Substances

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CLIENTS:	Program of Energy R3esearch and Development (PERD), Health Canada, Canadian Biotechnology Strategy (CBS), City of Kingston oil and gas sector, Canadian environmental consultant industry
FUNDING:	PERD, Health Canada, CBS, City of Kingston, A-base

Introduction

The focus of this study is the research and development of new techniques for understanding and improving the remediation of groundwater and soil that has been contaminated by organic chemicals, such as aromatic hydrocarbons.

PERD funding was received in 2002 for a new investigation: to examine the role of sulfate reduction in the bioremediation of hydrocarbons in groundwater. This research includes field investigations at oil and gas sites in Alberta and supporting laboratory tests. Previous data has suggested that sulfate reduction may play a key role in the natural attenuation of hydrocarbons at upstream oil and gas sites in Western Canada, and that there may be potential to enhance *in-situ* bioremediation linked to sulfate reduction. External collaborators include researchers at Komex International Ltd., the University of Alberta, and the University of Calgary, and the Saskatchewan Research Council.

Another area of this research examines the use of aqueous humic substances as 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 presence of the aqueous humic substances may also promote *in-situ* biodegradation of contaminants, such as aromatic hydrocarbons. 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. In 2002, a multi-year research project was initiated to field test the use of commercial humic products for remediation of an aquifer contaminated by hydrocarbons at Moose Factory, Ontario. This project is funded by Health Canada.

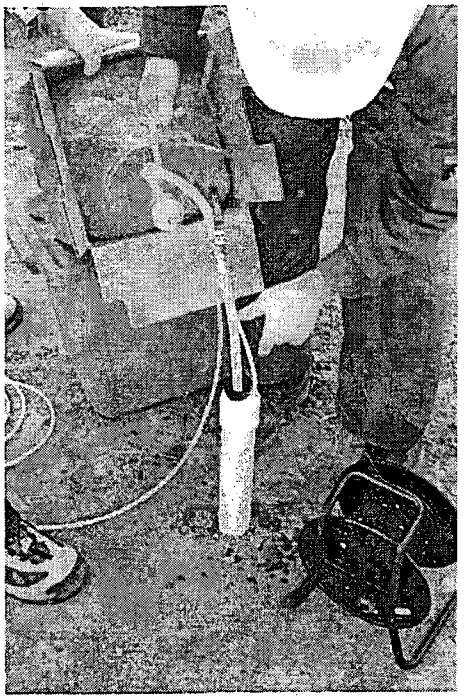
Also in 2002, a pilot scale phytoremediation study was initiated at a former municipal landfill site in Kingston, Ontario. This investigation examines the potential role that willow plantations may play in reducing the impact of ammonia-contaminated groundwater on adjacent surface water. This research is funded by the Canadian Biotechnology Strategy and the City of Kingston.

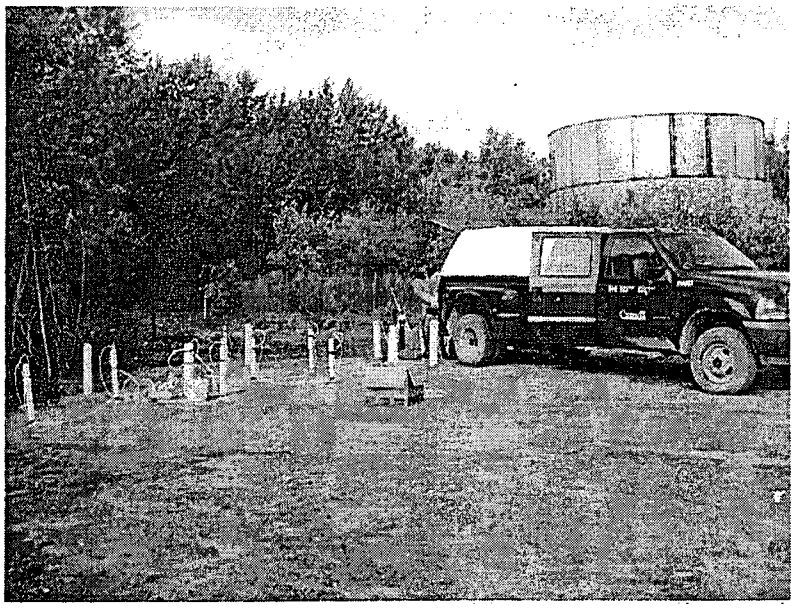
This Study is an important contribution toward Environment Canada's Clean Environment theme. The intended result is that the environmental and human health threats posed by toxic substances and other substances of concern are prevented or reduced. The anticipated result is the development of novel groundwater remediation technologies, of interest to the groundwater remediation service industry in Canada, which will also be useful for cleaning up Federal contaminated sites.

Study Areas: Field investigations at Moose Factory, Ontario, at a rural site near Lloydminster Alberta, at another rural site northwest of Calgary, Alberta, and at Kingston, Ontario; laboratory testing at Burlington, Ontario.

Results

Field investigations at the two Alberta sites indicated that bacterial sulfate reduction plays an important role in the biodegradation of hydrocarbons under low temperature, anaerobic conditions. Parallel laboratory microcosm experiments at 5°C with groundwater collected at these sites suggested potential for enhancing the bacterial sulfate reduction in the subsurface at contaminated sites. An assessment of the Moose Factory site was conducted, followed by installation of a network of treatment and monitoring wells, and initial pilot scale testing of the humic-mediated remediation process. Also, preliminary results were obtained from laboratory tests of both aerobic and anaerobic bioremediation of contaminated soil from the Moose Factory site. The first phase of the phytoremediation project at Kingston went ahead. A report of the results of automated monitoring and groundwater sampling is in progress.





Left: Test injection of a 2000 mg/L sulfate solution with a bromide tracer at an Alberta field test site, June 2002. Follow-up sampling indicated bacterial sulfate reduction linked to hydrocarbon degradation was important.

Right: Pilot humic-assisted remediation test site at Moose Factory, Ontario. An aboveground storage tank at the source of the petroleum contaminant plume is visible in background.

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STUDY TITLE: Immobilization of Contaminants, FY 2002-2003

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CLIENTS:	Ontario Region EC, OMEE, HH RAP
FUNDING:	NWRI, GLSF

Introduction

The current research is concerned with physical and chemical characterization of contaminated sediments in Hamilton Harbour. Fine-grained organic sediments of the Harbour are contaminated with metals, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). Such information is required in order for the Hamilton Harbour RAP to begin implementation of the first COA goal of

restoring environmental quality and beneficial uses of the Harbour. Data from Randle Reef and Windermere Arm, two areas of the Harbour with severe contamination problems, have been compiled, analyzed and interpereted.

Study Areas: Hamilton Harbour (Windermere Arm, Randle Reef)

Results

Windermere Arm

Windermere Arm is a 50-ha narrow channel located in the south-eastern portion of Hamilton Harbour. Sediments within the Arm have historically been contaminated with metals, PAHs, and to a lesser extent, PCBs. Sedimentological, geotechnical and geochemical investigations have been undertaken to determine the degree and the spatial extent of contamination. The thickness of contaminated sediment and their degree of contamination vary widely within the study site. Information on the thickness of contamination obtained from logging and chemical analysis of sediment cores agrees in general with the results of *in situ* penetrometer testing. Concentrations of Zn and Pb in some sub-samples are above the Severe Effect Level (SEL) for benthos set by the Ontario sediment quality guidelines. On average, surficial sediments tend to have lower metal concentrations than deeper sediments, probably due to the reduction of industrial point discharges. Apart from the two main boat slips, concentrations of PAHs are relatively low and in agreement with previously reported values. In contrast, new results yield higher values of PCB concentrations than previously reported, and 21 sub-samples of surficial sediment analysed yielded the total PCB values greater than 1 μg/g. These high surficial values require further investigation in order to determine whether contamination originates outside the study area or it is due to physical disturbance of older sediments. Extensive physical disturbance noted in several cores suggest that more contaminated historical sediments are at risk of being disturbed and re-exposed to the water column.

Randle Reef

The stratigraphy of Randle Reef is very mixed and complex. Sediment cores retrieved just metres apart from each other have often been found to be significantly different in composition, texture and layering. This suggests a man-made origin of the deposit and combination of sediment deposition, mixing and disturbance that will not likely ever be fully understood. The widely differing geotechnical and chemical data extracted from the first few sets of cores retrieved resulted in the continuation of sediment sampling in more closely spaced core and grab sample sets. The varying sets of sediments samples collected over the years has led to Randle Reef being the most sampled area of the Harbour to date.

All of the known sets of sediment samples conducted at Randle Reef have been desribed in a recent report. This have included the type of sediment sampling, the geotechnical properties of sediment measured from cores, and the concentrations of PAHs found in the sample sets. The historical sequence of sampling and the varying methodologies used have been also described.

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