



Canadian Association on Water Quality



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## **BOOK OF ABSTRACTS**

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Canada Centre for Inland Waters  
Burlington, Ontario

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### **MESSAGE FROM THE PROGRAM CHAIR**

It is with great pleasure that we welcome you to the 44<sup>th</sup> Central Canadian Symposium on Water Quality Research. This year's theme, "Science Meets Policy", builds on the backbone of the Symposia from previous years, and promises to deliver a strong and diverse technical program. Topics, ranging from the Great Lakes Water Quality Agreement to the application of genomics information in regulatory policies to water treatment technologies and the effects of groundwater and surface interactions on water quality, will benefit a broad range of delegates interested in a wide range of water quality issues. In addition, our plenary speaker, Dr. Derek Muir, will open the Symposium with a presentation on persistent and "pseudo-persistent" chemicals in the aquatic environment. On behalf of the organizing committee, welcome to Burlington. We wish you a successful and informative Symposium.

Veronique Hiriart-Baer  
Environment Canada  
Program Chair

# 44<sup>TH</sup> CENTRAL CANADIAN SYMPOSIUM ON WATER QUALITY RESEARCH

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## PLENARY PRESENTATION

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### **Evaluating Persistent and “Pseudo-Persistent” Chemicals in the Aquatic Environment**

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The vast majority of the more than 30,000 existing chemical substances widely used in commerce, along with a much greater number of minor use commercial chemicals, are not monitored in environmental media. Except for a relatively small group tracked by Environment Canada’s National Pollutant Release Inventory (~400) little is known about the physical-chemical properties or ecotoxicity of these chemicals, or their actual release into the environment. This includes pharmaceuticals, food additives and pesticides (representing ~5000 substances) for which considerable information is available on properties but less on releases, environmental fate and ecotoxicity. Apart from highly volatile substances which will mainly enter the atmosphere directly, most commercial chemicals will enter waste water treatment systems or land fills at some point in their life cycle. They may then enter surface waters and ground waters depending on the extent of biotransformation, and on the degradation and the properties of the matrix they are associated with. Assessment and regulation of chemicals focuses mainly on substances that are persistent (P), bioaccumulative (B) and toxic (T) and Environment Canada’s recent assessment of the Domestic Substances list used PB&T criteria. However, it is increasingly recognized that “pseudo-persistence”, whereby commonly used chemicals and their metabolites, continually enter waters resulting in chronic exposures of aquatic organisms is an important issue, particularly for pharmaceuticals and personal care products. Where chemical monitoring and assessment resources are limited should priority be given to “pseudo-persistent” chemicals? This presentation will attempt to address this question by reviewing some relevant examples of studies on persistent and pseudo-persistent chemicals entering Canadian waters and waste effluents.

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# Advances in Aquatic Environmental Monitoring

Chairs: Chris Jones and Lee Grapentine

## **Are Brown Bullhead (*Ameiurus nebulosus*) in the Cornwall Area of Concern Exposed to Environmental Estrogens?**

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Environment Canada is researching the health of fish and wildlife at the various Areas of Concern (AOCs) on the Canadian side of the Great Lakes watershed. For the purposes of our study, consider the Cornwall AOC to consist of three zones: an upstream reference zone at Morrisburg, an impact zone in the vicinity of the Cornwall Bridge, and a far-field, or downstream zone located at Gray's Creek. At each site, we took 20 adult male and 20 adult female brown bullhead (*Ameiurus nebulosus*) by electrofishing. Plasma vitellogenin (Vtg), which forms in the liver and sequesters in the ovaries, is normally absent from the plasma of males but present in females. Exposure to environmental estrogens (EEs), however, can induce Vtg expression in males, making Vtg useful as an indicator of exposure to putative EEs. Moreover, estrogen mimics can potentially have anti-estrogenic effects in female fish by blocking the estrogen receptor. We measured Vtg in plasma samples by gel electrophoresis, followed by silver staining, and densitometry. In 2004, three males at the reference zone, three males at the downstream zone, and four males at the impact zone had detectable concentrations of Vtg. In 2005, only one male at the exposed site had detectable Vtg. In 2004, Vtg and the liver somatic index (LSI) were significantly depressed in females at the impact zone compared to the downstream and reference zones ( $p < 0.05$ ), whereas site effects were absent for the gonad somatic index (GSI) and condition factor index (CFI) indices. In 2005, Vtg, GSI, LSI, and CFI were depressed in females at the impact zone. The male-fish data suggest a possible low-level exposure to estrogen mimics at all three zones. The depressed Vtg in the plasma of female fish at the impact zone, which is consistent with reduced LSI (both years) and GSI (2005), could reflect exposure to environmental contaminants. A reduction in the concentration of egg yolk protein could have health implications for the developing embryos and emergent larvae.

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# **Influence of Tributaries on the Perfluorinated Acid Content in the Water Columns of the Great Lakes**

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The sources and fate of perfluoroalkyl acids (PFAs) in the Laurentian great lakes is not well understood. PFAs are a class of persistent organic pollutants that are ubiquitous and are found in all environmental compartments. Certain PFAs are deleterious to biota (e.g. perfluorooctane sulfonate (PFOS)) and bioaccumulative. Although efforts have been undertaken to reduce or eliminate them, their continuing presence in rain, water and biological samples give cause for concern. The water columns of each of the 5 lakes were sampled since 2000 for analysis of PFAs. In addition, PFA measurements were performed on tributaries, municipal waste water treatment plants and precipitation in order to assess relative contributions of each to the lakes. Using the results from samples from a land-locked lake and the precipitation, the contribution from rain to the perfluorooctanoate (PFOA) loadings are found to be less than 0.01 ng/L/year. Samples from tributaries to Lake Superior show minimum contribution to the PFA concentrations in Lake Superior (<0.1 ng/L), indicating that for this lake, precipitation is a major contributor to the PFA content. The PFA content of Lake Superior is consistently lower than the other Great Lakes. Near shore samples collected on Lake Michigan have higher PFOA (~5 ng/L) concentrations than mid-lake samples (2.8 ng/L). The water column and surface waters of Lake Erie are strongly influenced by the PFA values in the tributaries (>2 ng/L for PFOS and PFOA) and greater than an order of magnitude than would be expected from precipitation. Lake Ontario samples show the lake is well mixed with respect to PFAs over the spring, summer and fall, and are influenced by tributary contributions and the discharges of municipal waste water treatment plants (MWWPs).

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## Effects of Antidepressants on Fathead Minnows

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Fathead minnows were exposed for a lifecycle to environmentally-relevant concentrations of venlafaxine (Effexor™) or to a mixture of the top five detected selective serotonin reuptake inhibitor (SSRI) antidepressants at concentrations similar to Canadian municipal wastewater effluent (MWW). Exposure concentrations (nominal) were: venlafaxine 1000, 10,000 or 100,000 ng/L, SSRI mixture: venlafaxine 2700 ng/L, citalopram 300 ng/L, bupropion 100 ng/L, fluoxetine 130 ng/L and sertraline 20 ng/L, or ten times the SSRI mixture concentrations. Measured concentrations of venlafaxine were about 81 % of nominal concentrations. Exposures began with 30 fertilized fathead minnow eggs and fish were examined during their growth development and reproduction until 160 days post-hatch. F1 were raised to 16 dph to assess changes in growth. Fish exposed for a lifecycle showed increased egg production in the highest venlafaxine concentration, and males appeared to be more aggressive as measured by decreased time to physically contact (hit or push) a ‘dummy’ intruder fish held near the nest. There were very few changes observed in growth or reproduction, but it is unclear what the increased male aggression may mean in the natural environment.

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# Water Pollution Analysis in a Small Lake in Western Mexico

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Lake Zapotlán is a small (1100 ha) endorheic lake in western Mexico. The Lake is an internationally recognized RAMSAR site, home to many migratory species of waterfowl. It receives point source pollution from partially treated sewage from Ciudad Guzman (population 85,000) and Gomez Farias (population 12,000), as well as non-point sources, including storm water, agricultural, and land clearing runoff from numerous farms and from deforestation surrounding the Lake. Anthropogenic activities in the basin are putting the ecological sustainability of the Lake at risk. The Lake is hypertrophic and exhibits blooms of green algae and possibly cyanobacteria throughout much of the year. Along the shoreline of the Lake, extensive beds of bulrush, called locally “tule” (*Typha latifolia*), are found, as well as floating mats of water hyacinth (*Eichhornia crassipes*) likely due to excessive nutrient levels in the Lake. Untreated sewage also flows into the lake causing excessive E.coli levels, endangering human health for the upcoming Pan American games set to take place in 2011. E.coli levels in Lake Zapotlan as well as a nutrient (nitrogen and phosphorus) comparison over the last decade will be discussed.

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# What Qualifies as a Reference-Site: Defining Criteria for Minimal Impact

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The Reference Condition Approach has been proposed as an alternate experimental design for bioassessments in which no controls are available. In this approach, minimally impacted reference sites are used as a benchmark against which impairment is judged. One of the Reference Condition Approach's challenges lies in determining what qualifies as a reference-site. Herein a systematic method of selecting reference-sites from a set of candidate sampling locations is described. On the basis of community composition, water chemistry, and exposure to agricultural stress, the condition of systematically defined reference-sites is compared against that of hand-picked reference-sites (selected using professional judgment) and test-sites (impacted by agriculture). Systematically defined reference-sites more closely aligned with natural land-cover than hand-picked reference-sites and test-sites did, and they were more chemically and biologically pristine. The systematic method can be used in any area, as long as the geo-spatial data used to set criteria for minimal impact is available.

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# Quantifying the Factors that Influence Flow Response to Storm Events in Headwater

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How climate, geology and land use specifically affect flow conditions in headwater streams is poorly understood and hampers decision makers ability to manage impacts from development. In 2007, crest stage gauges and physical measurements of stream condition were used to quantify peak flow responses at 110 sites located on headwater streams on the north shore of Lake Ontario. Rain fall to each catchment was measured using spline procedures from 20+ rain gauge stations. The relationship between peak discharge and rainfall was quantified as a flashiness index and regressed to catchment attributes of drainage area, geology, slope and a land cover index. Residuals of this model were regressed against the area of tile drainage in each catchment to determine the degree to which this attribute independently explained flow condition. Finally, the flashiness index was compared to a hindcasted reference condition as a means of quantifying the degree of alteration in flow condition within the study area. This presentation will highlight the field procedures used and their reliability, the study findings and the implications of this study to protecting fish habitat in downstream reaches.

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## Bioassessment of Wet-Weather Flow Impacts on Fine Sediments in Urban Waters: Coupling Two Different Approaches

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Stormwater ponds have been widely used to control increased volumes and rates of surface runoff resulting from urbanization. As receiving waters, they are under the influence of intermittent pollution from urban wet-weather discharges. Meanwhile they offer new aquatic habitats balancing the transformation of initial ecosystems and their associated biodiversity. Bioassessment of stormwater facilities is therefore crucial for the preservation and rehabilitation of biodiversity in urban areas.

Among the modern assessment methods, the NWRI (Burlington, ON, Canada) adopted the sediment triad approach assessing the sediment chemistry and toxicity, and the benthic community structure. Another technique developed by the *Cemagref* (Lyon, France) assesses the quality of sediments through an index-based method using the oligochaete species assemblage as an indicator. Limitations in both techniques have led to the need for adopting a complementary approach combining both methods in order to advance the bioassessment of urban hydrosystems.

The short-term research objectives of this collaborative project are both conceptual and experimental. We aim to (i) better assess the biological quality of sediment in stormwater ponds, (ii) define criteria for a “good” ecological potential adapted to each water-body, and (iii) identify the most detrimental pollutants.

Field applications of the two methods started in August 2008 at 8 selected sites in the Terraview-Willowfield stormwater facility in Toronto, Ontario. Initial results indicate that several contaminants (among PAHs and heavy metals) exceeded the Probable Effect Limit (Canadian Sediment Quality Guidelines) within the facility. The deepest sites showed strong signs of benthos depletion; however, the pollution is attenuated as both sediment chemistry and benthos diversity improved at the outlet of each pond. Oligochaete indices showed similar trends as the benthos indicators. The biological status defined by the *Cemagref* method ranged from “bad” at most sites to “moderate” at the outlet of the ponds, revealing unsuitable environmental conditions for biodiversity preservation.

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# The Use of Principal Component Analysis for an Assessment of the Health Status of Wild Fish from Wheatley Harbour, Ontario

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Several types of multivariate statistical analyses have been developed in the last decades, which could be effectively used for the interpretation of biological data, yet considerable resistance remains toward their regular application. For example, Principal Component Analysis (PCA) could be used to summarize large data sets into a smaller number of independent variables. In the present study, the applicability of PCA for analysis of biological data was investigated, using a data set from the Wheatley Harbour Area of Concern, with the objective to determine whether the resulting principal components could successfully summarize and explain differences between exposed and reference sites.

The health status of wild brown bullhead (*Ictalurus nebulosus*) and goldfish (*Carassius auratus*) from Wheatley Harbour Area of Concern was assessed using various measures of overall fish health and endocrine function. In a preliminary approach, a series of PCAs were performed, the first three components of which were retained for further analyses. General physiological characteristics (e.g. fork length, total weight, and weight of the liver and gonads) were mostly represented on the first principal component, while the second principal component was usually characterized by plasma parameters (e.g., plasma 17 $\beta$ -estradiol, testosterone, ketotestosterone and vitellogenin). Site differences were evaluated by multivariate analysis of variance, using the first three principal components as independent variables. The present study demonstrated that the use of Principal Component Analysis permitted to summarize complex data into a smaller number of variables, which explained relatively well the variability found within the dataset, and for which significant site differences were detected. Although the mechanisms underlying the observed differences remain to be established, the present study confirms the usefulness of multivariate analysis for summarizing and analyzing large data sets.

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# Canadian Aquatic Biomonitoring Network (CABIN): A National Approach to Biological Monitoring

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The Canadian Aquatic Biomonitoring Network, CABIN, is Canada's first nationally designed and implemented biological monitoring program for aquatic ecosystem health. After more than 10 years of research-oriented development and testing, CABIN was launched nationally in 2006. CABIN achieves consistent, comparable, and scientifically defensible data by providing a nationally standardized protocol for the collection, identification and use of benthic macroinvertebrates and associated aquatic habitat information.

CABIN endorses the use of the Reference Condition Approach (RCA) for assessing the health of aquatic biological communities. In RCA, reference sites that are minimally affected by human use define baseline conditions for assessing potentially impaired sites. The reference sites are chosen within a variety of geographic regions and stream orders to capture the diversity of natural habitats within a study area. The types of biological communities that are expected to occur within a range of natural habitats are then defined for regions covered by the CABIN network.

A predictive model is then developed from this database of reference sites which defines the relationship between the habitat and the biological communities on a watershed basis (e.g., Fraser River Basin). The relationship provides users with the range of acceptable biological communities that should exist at a test site in a given habitat if it is undisturbed by human activities. The similarity of the community at a test site compared to reference sites is calculated using multivariate statistical methods. A divergence between the test and reference communities suggests water quality and aquatic ecosystem impairment, and acts as a signal to conduct additional focused monitoring that can determine the cause of impairment and measure the performance of management efforts.

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# Getting Our Feet Wet: Preliminary Data on Algal Blooms and Nutrients in Lake of the Woods, Year 1

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Lake of the Woods (LOW) is a large extremely complex international water body which spans Minnesota, Manitoba, and Ontario. Water levels in this lake are regulated by four dams controlling inflow at the south end from the Rainy River, and outflow (through 2 generating stations) to the northern Winnipeg River. The total drainage area is  $\sim 55,600\text{km}^2$ , with by far the largest single input via the Rainy River in the south (70% hydrologic load; draining  $\sim 47,000\text{km}^2$ ). The remaining drainage areas around the lake are relatively uncharted ( $\sim 8,800\text{km}^2$ ). LOW consists of two regions with contrasting physical and chemical characteristics; a large mixed south basin, and a complex northern region consisting of numerous interconnected smaller sub-basins with different depths and mixing regimes. These sub-basins receive different hydrological and material inputs from both the South Basin and Canadian Shield drainage, resulting in N-S gradients of productivity and water chemistry which are logistically challenging to study.

Recently, there have been growing concerns with the implications of severe, potentially toxic blooms of cyanobacteria, widely perceived to be increasing in frequency and distribution in LOW. Such blooms are usually driven by high nutrient levels; however despite a large database collected by US-Canadian partners, the sources, bioavailability and transport/sequestration of nutrients in LOW are not well understood. An initial Environment Canada assessment and modelling exercise identified key knowledge gaps which have prevented the development of a scientifically based sustainable LOW management plan. As part of a larger initiative to assess and remediate water quality in the Winnipeg River Basin, Environment Canada, in partnership with provincial and state agencies, has initiated a nutrient assessment plan addressing these data-gaps, and is implementing a 3yr field study targeting three key components of the basin: the Rainy River at the south end, selected sites in the major basins within the lake, and the discharge at the northern end via the Winnipeg River.

This talk presents an overview of the issues, the key goals of the initiative and preliminary data collected by Environment Canada during the first field year of this project.

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# Evaluation of Spatial and Temporal Coverage of a Water Quality Monitoring Program

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All environmental monitoring schemes demand scrutiny and adaptive adjustment, and yet must strike a balance between long term strategic commitment and contemporary relevance and affordability. The criteria for evaluating the information content of a database are complex, and so require flexible and accessible tools to assist in assessment. This problem is particularly challenging with surface water quality databases where the river network, rather than the spatial coordinates, is the most appropriate frame of reference. Here, the provincial and municipal surface water data for the Thames River are used to develop visualisation tools for assessing the temporal, spatial and compositional coverage of the data.

The first problem relates to developing a rendering for site position in a river network that preserves the upstream-downstream rather than spatial relations. Here an upstream ordering algorithm is proposed that assigns each site a unique network index number, permitting the whole monitoring network to be projected on a single, though discontinuous axis.

With spatial position reduced to a single axis, it is possible to create a temporal-spatial surface for projecting the sampling regime. When the time axis is calendar date, the duration of monitoring activity can be projected for the whole network, revealing significant modulation of the monitoring regime. Disaggregation of the sites by catchment area emphasises the major loss of monitoring capability in 1997 with significant redesign of the sampling network in the subsequent recovery.

The shifts in coverage suggest that monitoring is largely responsive to policy innovations rather than the more prosaic commitment to base-line data. As result, there is a surprising lack of long-duration, regular frequency data despite nearly half a century of monitoring. Given the rising concern over environmental changes, a higher priority needs to be assigned to continuity.

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## **Towards an Ontario Stream Monitoring Network: A New Way of Doing Business**

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In Ontario monitoring environmental health is the mandate of thousands of individuals representing NGO's, private sector, municipal, provincial and federal agencies. All share a common interest in tracking change in ecosystem health, but for years, their efforts have been on parallel tracks that precluded a comprehensive picture of the true state of the ecosystem. Methodologies differ, bureaucratic barriers, professional mistrust, incompatibility of data and lack of knowledge of how to conduct large scale surveys or integrate methodologies all contributed to a sense that integrated comprehensive monitoring was unachievable. Recently, a grassroots initiative has established that a network of like minded organizations can develop a broad-based stream monitoring program. The group recognizes the benefits in sharing data collected using comparable methods and in sharing the responsibility for analyzing the data to further scientific understanding around large scale questions. The network works because each partner has a responsibility to help develop and adopt standard protocols, establish, use and share applications for data management, share in designating priorities for analysis and providing training and support for field crews. In the demonstration area, two universities, 6 conservation authorities, 3 federal departments and two provincial ministries have collectively obtained field data from over 2500 sites in the last twelve years. Recently, both provincial and federal officials have begun working on the tools that would enable this network approach to be institutionalized and stable. This presentation will focus on why a network approach can achieve much more than traditional approaches to monitoring ecosystem health and some of the outcomes from the approach. Finally, a synopsis of recent innovations such as a web-based data management system (OSIS) and an overall framework for stream monitoring will be presented. The intention of this presentation is to encourage the network approach and to offer a forum for the discussion of benefits and impediments to its success.

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# The Effects of Municipal Wastewater Effluent on Fish Communities in the Speed River

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The City of Guelph, as part of the Golden Horseshoe, has been identified as an area to focus future urban growth under Ontario's 'Places to Grow' initiative. As such, the potential impacts on fish communities of current municipal wastewater effluent (MWWE) were evaluated to determine if the assimilative capacity of the Speed River has been exceeded under present discharge conditions. Nine 100 m reaches of the Speed River were sampled by backpack electroshocker at areas upstream and downstream of Guelph's wastewater treatment plant. Concurrent detailed habitat surveys were conducted for each site to assess influences on fish community composition. Rainbow darter (*Etheostoma caeruleum*) and greenside darter (*Etheostoma blennioides*) dominated the Speed River fish community; tissues from these fish and crayfish (*species currently being determined*) were sampled for stable isotope analysis. Length frequency graphs demonstrated no greenside darter young of the year were found downstream of the MWWE outfall in August. Detailed analyses of both fish community structure and signatures of carbon and nitrogen isotopes (to assess nutrient dynamics) will be available shortly. Collectively, these analyses will help determine if the MWWE, riverine habitat, or other localized inputs are influencing fish populations downstream of Guelph's MWWE outfall.

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## Cancer Regulating Proteins in Neoplastic *Mytilus edulis* and *M. trossulus* from Contaminated Sites in the Greater Vancouver Region

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Haemocytic leukemia affects bivalve species and is fatal in most cases. Although the disease etiology awaits full understanding, contaminant exposure, abnormal temperatures, or viral infections alone or in combination may play roles. Incidences of the disease tend to be more prevalent in contaminated areas, which may indicate its ability to serve as a bioindicator of contaminant exposure. As with human leukemia, a characteristic of the disease is overproduction of haemocytes, the equivalent to white blood cells in vertebrates. In human cancers, a family of proteins termed the p53 family plays a key role in preventing tumour growth and cancer progression. p53 proteins are the “guardians of the genome” and regulate the transcription of genes involved in DNA repair and tumour suppression. A starting hypothesis was that the p53 family of proteins might malfunction in haemocytic leukemia, through either down-regulation or some other mechanism. Previous work by others used western blotting to show that proteins from the p53 family are present in normal and leukemic individuals from various salt water mussel and clam species, including *Mytilus edulis*, *Mytilus trossulus* and *Mya arenaria*. p53 appeared to be expressed in all cell types, whereas p97 was down-regulated in leukemic cells. Western blot analysis confirmed that an antibody recognizing a homodimerization domain of p63/p73, recognized a 73 kDa band in leukemic cells that was absent, or weakly expressed, in normal cells in both *Mytilus trossulus* and *Mytilus edulis*. This homodimerization domain is not present in p53 and the antibody does not appear to cross-react with p97 in normal cells. This up-regulated 73 kDa protein may be an alternate form of p73, which has been modified in some way and has become an oncogene responsible for leukemic cell proliferation. Although the 73 kDa protein needs to be identified, it has strong potential as a biomarker protein for haemocytic leukemia. The proposed biomarker may be useful for the identification of moderately or incipiently leukemic individuals. The ability to identify and enumerate individuals from the early stages of disease progression could give a broader picture of the true incidence of this disease. Future directions of this work include the application of similar procedures to freshwater bivalve species found in the Great Lakes and surrounding water bodies.

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# Development of a Novel DNA-Based Detection Method for *Enterococcus* species in Lake Ontario based on the 16S-23S rRNA Internal Transcribed Spacer (ITS) Region Gene

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The enterococci are normal members of the gastrointestinal flora of humans and animals, and are used as indicators of potential fecal pollution in recreational and marine water around the world. Conventional methods for the detection of enterococci may take up to several days to confirm identification; therefore more rapid detection methods are warranted. The aim of the present study was to establish a rapid and reliable DNA-based PCR assay to detect *Enterococcus* at the genus-specific level using the conserved distal and proximal sequences of the 16S-23S rRNA internal transcribed spacer (ITS) region. The specificity of the primers was confirmed with 26 *Enterococcus* reference strains, as well as 40 reference strains of other species that served as negative controls. The newly-developed protocol was validated by testing putative *Enterococcus* isolates from water samples from various sources such as two beaches in Hamilton Harbour, a combined sewer overflow (CSO) tank, wastewater treatment plant final effluents, drinking water intakes and offshore sites of western Lake Ontario. In addition, a second species-specific PCR assay and protocol was developed for *Enterococcus faecium* using the variable sequence of the 16S-23S rRNA ITS region gene to be exploring possible host-specific markers for microbial source tracking. Further screening of putative *Enterococcus* isolates from these water sources is underway, and the results will be presented at the upcoming meeting.

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# Long-Term Trend Analysis of Water Quality in Lake Biwa

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Lake Biwa is the largest freshwater lake in Japan, located in west-central Japanese mainland. We report the result of long-term trend analysis of time series of Chlorophyll A in Lake Biwa. The concentration of Chlorophyll A is a barometer of phytoplankton growth. The higher the concentration, the worse the water quality and the more probable we have the danger of red tides and blue-green algae. Data has been observed through the water quality investigations conducted by Shiga Prefecture and the Ministry of Land, Infrastructure, Transport and Tourism. Data are generally observed from April 1979 to March 2003, measured at the fixed points once in a month, though the data lengths and the observed items vary.

The first part of this presentation works on the removal of seasonal pattern from a given time series. Because the periodic pattern due to yearly climate change or some general social activities is a nuisance for trend-analysis, it should be removed in advance. Based on the trend estimates obtained by the observation sites, we show a contour plot of the Chlorophyll A concentration for a given time point via spatial smoothing and interpolation.

After this preliminary stage, we obtain the trend series of measured substance by every monitoring point. In the next step, we examine the significance of the estimated trend via formal statistical tests. We report the results of two different kinds of unit root tests that are standard tools in the context of time series analysis. Generally speaking, we witnessed the existence of trend at almost every site. If we regard the estimated trend as data, the results often support the existence of deterministic trend. On the other hand, when we use the seasonally adjusted data, stochastic trend is supported in many cases.

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## Endocrine Disruption in Rainbow Trout Following Intra-Peritoneal Injection of Pulp and Paper Mill Effluent Extracts

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Endocrine disruption effects due to Chilean pulp and paper mill effluents obtained from non-treated, primary and secondary treated effluents) were extracted (solid phase extraction, SPE) and evaluated using immature triploid rainbow trout (*Oncorhynchus mykiss*) in pulse and chronic-exposure toxicity experiments. The protocol used involved the use of intra-peritoneal injections of extracts, corrected for individual fish weight and several laboratory steroid and phytosterol standards. The pulse exposure indicate significant induction of the cytochrome P4501A1 (EROD activity) in liver and plasma vitellogenin (VTG) in fish injected with untreated and primary treated effluent extracts were observed after 7 days, similar to the increased VTG levels found for 17- $\beta$ -estradiol injected fish and different from the early increase observed in fish injected with secondary treated effluent extract. Those result were later confirmed in the chronic multiple injection experiment, where the same differential effects pattern were found. Additionally, a differential increase in plasma steroid testosterone and 17 $\beta$ -estradiol concentrations occurred in fish injected with all the mill effluent extracts and being related to the early induction of the CYP19a (aromatase) gene expression in fish gonad. These results indicate differential effects due to the effluent treatment and confirm that the endocrine disruptive effects of Chilean pulp and paper mill in trout previously demonstrated under laboratory and field condition, continue to be estrogenic.

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# Advances in Wastewater Treatment Technologies and Approaches

Chairs: Hongde Zhou, Wayne Parker, and Jim Higgins

# Application of Aerobic and Anaerobic Respirometry for Optimization of Wastewater Treatment

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This paper describes studies on an aerobic and anaerobic treatment of an industrial wastewater, contaminated with phenol (560 mg L<sup>-1</sup>) and formaldehyde (480 mg L<sup>-1</sup>), using both aerobic and anaerobic respirometry.

Returned activated sludge (RAS) was the source of biomass used in the aerobic studies, digester biomass (DB) was used in anaerobic experiments. Respirometric tests demonstrated that the aerobic system corroborated with the Haldane model for the inhibitory wastes, while data obtained during the anaerobic experiments complied with the Monod model for non-inhibitory wastes. Aerobic treatment of the wastewater/sewage mixture (1:1) removed 46% of formaldehyde and 48% of phenol. For the same wastewater content, the anaerobic removal of formaldehyde and phenol was 73% and 76%, respectively.

Results of respirometric tests, biokinetic calculations, and chemical analyses indicated that the anaerobic process was a preferred technology for the investigated wastewater treatment. It has been demonstrated that the anaerobic respirometry can be successfully applied for an investigation of anaerobic processes in a way similar to the aerobic respirometry for aerobic processes.

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# Simultaneous Sludge Solids and Pathogens Reduction, Settling and Dewatering (SSPRSD) Using Filamentous Fungal Strain Isolated from Wastewater Sludge

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One of the major problems in wastewater treatment process is sludge bulking. Most often bulking is caused by excessive growth of filamentous microorganisms that extends from flocs into the bulk solution and interfere with compaction, settling, thickening and concentration of activated sludge. In general, sludge settling is enhanced by the addition of expensive synthetic flocculants. To minimize the use of synthetic flocculants, an alternative and novel approach is the use of bioflocculants, which are economical and ecofriendly.

The role of filamentous fungal (FF) strain in bioflocculation of sludge is always uncertain. It is widely known that the presence of excessive filamentous microbial strains in activated sludge may lead to operational problems. Many researchers also stated that, filamentous microbial strains were acting as a backbone to form larger and stronger bioflocs than bacterial biopolymers. Further studies are required to verify these facts.

We have isolated a strain of filamentous fungi from sludge which when grown in activated sludge simultaneously reduces solids, improves sludge dewatering and substantially eliminate sludge pathogens. To understand the role of filamentous fungi in sludge settling and dewatering, the isolated fungi was inoculated with both spores and pellets (beads) into sterilized and nonsterilized sludge having different suspended-solids concentrations. Biofloc formation, sludge settling, sludge degradation, change in pH of fungal-grown medium, zeta potential, and microscopic analysis of bioflocs were performed. The suspended-solids concentration was found to decrease by 40 to 60% over a 5 d period, which was much higher than control (aerobic digestion). The capillary-suction time for sludge dewatering was also lower than the control. The isolated fungal strain was well adapted to form biofloc and to interact with natural microbial flora.

The solids degradation, pathogen removal and biodegradation of pollutants (persist in sludge) was monitored during the SSPRSD process as per standard methods. The results revealed that FF strain effectively performed the SSPRSD processes and pathogen reduction at 35°C and inoculum concentrations ( $10^6$  spores/mL). The detailed methodology and results will be presented and discussed.

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# A New Theory for the Ecology of Activated Sludge Bacteria: the Heterotroph-Specialist Model

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Determining the ecological role of heterotrophic species in activated sludge microbial communities (ASMCs) is fundamental to solving problems like those associated with filamentous bacteria. Based on the niche exclusion principle where two competing species cannot occupy the same niche, we proposed that ASMCs consist of non-competing specialists – hereafter the Heterotroph-Specialists Model (HSM). This study aims at testing this model by comparing the cellular level of RNA in microorganisms either containing PHB or not. Under the HSM which classifies heterotrophs as consumers of slowly degradable or readily degradable substrates, we predict that the RNA level will be higher for the populations containing PHB.

This prediction was tested on samples from nine AS wastewater treatment plants: six regular plants and three plants performing enhanced biological phosphorus removal (EBPR). Samples were retrieved at one third the length of the main basin, immediately fixed using PFA and methanol, and kept at  $-80^{\circ}\text{C}$  until analysis. For analysis, samples were resuspended in PBS buffer, disaggregated with a mechanical blender and dyed with the fluorescent dyes RNASelect, Nile Red and 7AAD to quantify the cellular concentration of RNA, PHB and DNA, respectively. Cell components were then detected using a flow cytometer. Two subpopulations were characterized using the Nile Red/7AAD ratio: a high ratio was interpreted as PHB positive and a low ratio was interpreted as PHB negative. The median RNA signal from the event distributions in each subpopulation were higher in the *PHB Positive* subpopulations than in the *No PHB* subpopulations in the non-EBPR biomass samples (paired t-test,  $p < 0.05$ ); while in the EBPR biomass samples, there is a tendency but no statistical evidence, ( $p > 0.1$ ) towards lower RNA in the *High PHB* subpopulations. Because of differences in PHB and growth metabolisms between regular heterotrophs and EBPR heterotrophs, this result is in agreement with the prediction of the HSM.

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# Transformation of Estrogenic Steroids in Sewage Treatment Plants: A Critical Review

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Estrogenic steroids (ESs) are especially difficult to transform in sewage treatment plants (STPs) as they are recalcitrant to chemical treatment, non-volatile, and are a non-growth substrate for micro-organisms. Recent advances in measurement of trace contaminants, with particular contributions from gas and liquid chromatography coupled with tandem mass spectrometry, have enabled the study of removal mechanisms of ESs. Early work focused on overall removal from STPs in different countries using similar treatment facilities with different process conditions. More recent work has focused on quantifying removal mechanisms and process conditions that affect them. Sorption studies have focused on identifying tendencies to help model removal using thermodynamic equilibrium with some attention given to kinetics.

Sorption distribution coefficients ( $K_d$ ) for sorption of ESs to biological sludge have been measured by a number of researchers for conventional activated sludge (CAS) and similar processes in different locations. Other researchers have determined the dependence of sorption on process conditions like pH, oxygen regime, and particle size. Methods to determine the sorption coefficient are varied and need standardization as they may affect results. Desorption due to heightened pH and sorption hysteresis have also been observed, which are of particular concern for sludge disposal after conditioning. Observation of sorption kinetics has so far been indirect, and vary from minutes to hours depending on the particular estrogenic steroid and the type of sludge.

Estrogenic steroids are not a growth substrate for micro-organisms and thus may only be digested by cometabolism. Conventional activated sludge plants have shown removal of SEs to vary depending on the type. Other wastewater processes have given different rates of microbial uptake, where different oxygen regimes have been shown to greatly affect rates of uptake.

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# Membrane Pervaporation to Reuse Contaminated Water for Agriculture Irrigation

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A novel membrane pervaporation technology for plants to extract reclaimed water directly from hydrophilic, dense polymeric membrane modules embedded into the soil was experimentally evaluated. A sweeping air pervaporation unit was designed to examine the effects of membrane configuration (hollow fiber (HF) and corrugated sheet (CS) membranes), feed temperature, feed pressure and contaminant concentration on membrane performance. Secondly, a bench-scale soil-pervaporation membrane unit was also built to evaluate its performance in terms of soil water content, soil electrical conductivity, water permeate flux and contaminant enrichment factors using borate, selenate, sodium chloride and glucose as model compounds. The results showed that the maximum water permeate fluxes that could be extracted from the membrane ranged from 2.9 to 4.3 L/m<sup>2</sup>/d and 2.0 to 3.7 L/m<sup>2</sup>/d for HF and CS membrane modules using the SAP unit. Similarly, water fluxes from the membrane into the soil ranged from 0.21 to 1.04 L/m<sup>2</sup>/d, using CS modules and between 0.50 and 1.00 L/m<sup>2</sup>/d for HF modules using the SP unit. In all the cases, the average enrichment factors for glucose, selenate, borate and sodium chloride were 0.18, 0.08, 0.20 and 0.23, respectively. A mathematical model was developed to simulate the performance of the membrane buried in the soil. It was developed based on the chemical potential gradient of water established between the feed and the permeate sides of the membrane. The proposed model fitted the experimental data well and was easily adapted to all the tested conditions. The controlling parameters of the water permeate flux were the porosity, the particle-size distribution, the residual water of the soil and the permeability coefficient of the membrane. On the basis of the mass transfer results within the limitations of the experimental scope, the new pervaporation membrane-soil-plant system can be then optimized and designed using the proposed model. Thus, it was concluded that this membrane has promise either to treat brackish ground water or to reuse wastewater for crop microirrigation.

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# Biofilm Formation in Full-Scale Submerged Membrane Bioreactors to Treat Municipal Wastewater

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Biofouling is a main contributor to membrane fouling in operating submerged membrane bioreactors (SMBR). Biofilm that is formed on membrane fibres covers membrane surfaces and thus causes serious biofouling. However, the mechanisms and kinetics of biofilm formation are not well understood, and effective control strategies remain to be improved.

Thus, the purpose of this study is to map the spatial formation of biofilm at different SMBR operating conditions in three full-scale SMBR that have been operated for 1-3 years. From each SMBR, nine full-length membrane fibres were sampled from different zones. Five 5-cm segments were clipped from each fibre along its height in SMBR. The segments were stained with six fluorescent dyes in series for labelling living cells, dead cells, polysaccharides, proteins, and lipids. The stained samples were observed with confocal laser scanning microscopy (CLSM), and digital CLSM images were taken for quantifying biofilm thickness and analyzing the spatial distribution of biofilm components including bacteria and extracellular polymeric substances (EPS) such as carbohydrates, proteins, and lipids. Total biological activities on membrane hollow fibres were measured using respirometric methods in order to establish the relationship between biofilm thickness and oxygen uptake rate.

The results show that under normal SMBR operating conditions, the biofilm thickness formed on membrane fibres ranged 50-120  $\mu\text{m}$ , depending on the hydrodynamic conditions from air sparging. Biofilm thickness varied greatly along the hollow fibres due to the non-uniform shear induced by sparging air. Furthermore, biofilm was found to form by initially attaching lipids/proteins to the membrane fibre followed by continual compaction of carbohydrates. Biofilm consisted of patchy heterogeneous colonies. Larger globular formations occurred with carbohydrates. Different membrane cleaning procedures were also evaluated for their effectiveness for removal of biofilm by comparing the biofilm topography and thickness before and after membrane cleaning operation.

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# **Efficacy of a Hybrid Subsurface Flow Constructed Wetland for the Treatment of Aquaculture Wastewater**

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Aquaculture facilities produce a variety of pollutants that may be harmful to the aquatic environment, including solids and nutrients which primarily arise from uneaten feed and waste produced by fish. The sustainability of the aquaculture industry involves minimizing environmental impacts from the release of wastewaters, in order to protect native aquatic ecosystems. Constructed wetlands are an example of a sustainable technology that has been used to successfully treat aquaculture wastewaters worldwide.

This research program is examining the ability of a hybrid subsurface flow constructed wetland to treat land-based aquaculture wastewater in a cold climate. The wetland is located on the Haliburton Highlands Outdoor Association (HHOA) property in Haliburton, ON. The HHOA facility uses groundwater as a source of water for the production of fish, and discharges their wastewater to a surface stream after treatment by means of a settling pond. Although the hatchery is currently meeting and exceeding its discharge parameter requirements, this project will allow the hatchery to further improve treatment of its wastewater and minimize water volumes required for effluent dilution. The project involves a long list of partners, which demonstrates that there is a great interest among stakeholders to make aquaculture operations and the use of constructed wetlands for wastewater treatment as sustainable as possible. A successful demonstration of a constructed wetland in Haliburton County would also facilitate the transfer of this technology to other locations in the country.

The primary objectives of this research are: 1) examination of different hybrid wetland operational modes (horizontal flow with variable recirculation loops to vertical flow and primary settling tank, and effluent filtration for enhanced phosphorus removal), to maximize solids and nutrient removal; 2) assessment of the treatment of fish pathogens and antibiotics common to land based cold-water aquaculture facilities; and 3) assessment of how the presence of aquaculture antibiotics affects the treatment performance of the constructed wetland. Details of the design and initial operation of this system will be presented.

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# **Knee Deep in “It”: Understanding Plant Community Responses to Sewage Inundation in the Canadian Arctic for Treatment Wetland Construction**

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The current practice of municipal wastewater treatment in many secluded Nunavut communities is carried out through the discharge of waste into natural wetland complexes. With recent population growth in the Canadian Arctic it has been acknowledged that characterizing the ability of natural wetlands to treat wastewater (sewage) is of importance.

We characterized six Kivalliq Region wetlands that were inundated by daily municipal sewage for surface water quality, subsurface water quality and plant community composition from the point of influence to effluence. A minimum of 40 sample points were assessed for each wetland complex for nine water quality parameters (including and not limited to  $\text{NH}_4^+$ ,  $\text{PO}_4^-$ ,  $\text{NO}_3^-$ ), and plant composition; species being identified to genus level or lower. We then performed a multivariate ordination analysis on the plant community to determine which species were most directly related to the biochemical characteristics of the sewage discharged into the wetland complexes.

Initial results of the wetland characterization have shown that natural wetlands in the Kivalliq Region of Nunavut successfully treat sewage during summer months. Analysis of plant community response to the sewage inundation is ongoing, and is posed to contribute to our knowledge of appropriate plant selection to maximize treatment in constructed treatment wetlands in cold climates.

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# Sludge Retention Time and Pretreatment Conditions Effects on Mesophilic and Thermophilic Sludge Digestion

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Activated sludge produced from systems operating at different sludge retention times (SRT), namely 4,7 and 15 days were subject to microwave thermal pretreatment at different final temperatures. The pretreatment temperatures were 100, 150 and 175°C. These sludges were then digested at mesophilic and thermophilic conditions and the evolution of the digestion process was monitored. A factorial design was used in order to test all the conditions and possible interactions between the type of sludge, pretreatment condition and digestion temperature.

The results show that thermophilic digestion produces always more biogas than mesophilic digestion of the same type of sludge subject to the same pretreatment conditions. On mesophilic tests, biogas production was higher in the initial days and reached the final value sooner than the thermophilic tests. Thermophilic tests showed slower production rates in the initial stage of digestion, as a result of inhibition phenomena. This inhibition was reversible since production rates increased after initial lag phase.

Tests proved that microwave pretreatment can increase biogas production in comparison with the control tests for all SRT sludges tested. The greatest improvement was measured in the sludge with higher SRT, so with theoretical lower biodegradability. Increase was higher with higher pretreatment temperatures, though higher pretreatment temperatures also cause longer lag periods specially for thermophilic tests.

Mesophilic conditions showed higher sensitivity to change in sludge type and pretreatment conditions, with higher biogas productions associated with higher pretreatment conditions and increase of biogas production associated with higher SRT sludge. For thermophilic tests, variation on both parameters (SRT and pretreatment temperature) also caused change in the performance of the digestion, but the magnitude of change was significantly lower, suggesting less influence of tested parameters in digestion performance.

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# Tracing Sulfur in Digestion of Sludges from Municipal Wastewater Treatment

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There is limited information on the quantities and forms of sulfur that are present in raw sludges and on the rate and extent to which sulfur is transformed from one form to another in anaerobic digestion. The objectives of this work were to develop analytical methods for measuring the sulfur content of various sludge fractions (total sulfur, soluble sulfur, sulfate, and solid phase fixed sulfur, volatile sulfur compounds (VSCs)) and to determine the rate and extent of key sulfur conversion processes in mesophilic anaerobic digestion.

It has been found that most sulfur is eventually reduced and fixed in the solid phase by heavy metals during anaerobic digestion. In raw sludge (mixture of primary and secondary sludge from Waterloo Wastewater Treatment Plant) the concentration of soluble sulfur was in the range of 7 to 15 mg/L while in digested sludge this concentration was in the range of 2~3 mg/L. The solid phase fixed sulfur concentration was approximately 4.6 mg S/g TSS in feed sludge and increased to as high as 15 mg S/g TSS after digestion.

Although the quantities of VSCs released in the biogas were negligible as compared to the total amount of sulfur in the sludge, VSCs have extremely low odor threshold values and can be significant odor sources when released in fugitive emissions of biogases. A series of batch digestion tests have been conducted to verify the importance of methanogens in the VSCs' decay and to determine the generation and degradation rates of VSCs.

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# Development of Protocols for Predicting the Impact of Ozonation On WAS Digestibility

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Pre-treatment of waste activated sludges (WAS) prior to digestion processes is of increasing interest to wastewater treatment utilities. While there has been considerable study of pre-treatment processes, a common approach to describing the impact of pretreatments on sludge biodegradability has not been developed. In addition there has been little evaluation of the interaction between WAS characteristics and pre-treatment efficiency. In this study, a range of physical, chemical and biological responses were evaluated to assess the impact of ozonation (as a model of chemical pre-treatment processes) on WAS properties. WAS that was generated at differing SRT was employed to facilitate an assessment of the interaction between pre-treatment and WAS properties. The overall objective was to develop protocols that can be employed to characterize the impact of pre-treatment processes on WAS digestion

SBRs were operated on municipal wastewater at SRT's of 1.95, 7 and 15 days to provide WAS for this study. WAS was ozonated for differing times to achieve varying levels of pre-treatment. Samples were characterized for particle size distribution, solids, COD and nitrogen. Respirometry, biochemical methane potential (BMP) and biochemical acid potential (BAP) tests were conducted to characterize bacterial activity as well as digestibility.

Soluble COD fractions were observed to increase with pretreatment intensity. The results suggest that there are components present in short SRT sludges that are more susceptible to solubilization by ozone. Respirometry revealed that ozonation caused more than 95% inactivation of heterotrophs and a reduction in rbCOD. BMP tests demonstrated lags in CH<sub>4</sub> production for the pre-treated sludges. VFA accumulation appeared to partially inhibit methanogenesis. Ozonation did not increase the ultimate digestibility of the shorter SRT sludges while a high dose of ozone increased the digestibility of the 15 day SRT sludge. The BAP test was a good indicator of the impact of pretreatment processes on the rates of hydrolysis/acidification and WAS digestibility.

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## **Energy & Mass Balance – A Tool to Evaluate Enhanced Methane Production in Anaerobic Sludge Digestion**

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The problem of wastewater management is taking a serious shape due to increase in urbanization and industrialization. Large consumption of energy and simultaneously producing large amount of sludge and greenhouse gases in an unsustainable manner remains a significant environmental issue. The sustainable energy and other recourses can be recovered during the wastewater treatment and it can be considered as recourses recovery process. The microbial fermentation of organic matter present in the wastewater has a potential to produce biogas (CO<sub>2</sub> and CH<sub>4</sub>), bio-ethanol, hydrogen gas and electric current.

The biogas yield and methane content in anaerobic digestion of excess sludge can be improved by assorted pre-treatment methods (Thermal, Physical, chemical, mechanical, and biological and physicochemical treatment process). Present study is to execute the mass and energy balance, to evaluate the current pre-treatment techniques (pulse power technique & Ultrasonic) to enhance the anaerobic sludge digestion for methane generation. Mass and energy balance is essential in economical and environmental perspective and in particular for investigating the general performance of the available data for optimizing the wastewater treatment.

The Mass and energy balance is done for the above process pulse power technique and steam explosion process. The detail results will be presented.

The mass balance gives the loss of carbon in terms of CO<sub>2</sub> (greenhouse gas-GHG production) and methane production, methane loss in the system. The net carbon balance will give the idea of maximum methane generation associated with different systems.

The energy in to system, GHG produced from the system with energy input and power generated from the methane utilization. The net balance will give the stability of different processes in respect of economy as well as GHG emissions.

Thus net mass and energy balance will help the decision makers to choose the best possible system carrying the local and economical legislation.

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# Greenhouse Gas Emissions Analysis of Biosolids Management Options

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It is widely acknowledged that emissions of greenhouse gas (GHG) by human society are causing climate change on a global scale. Wastewater and sludge (biosolids) treatment can contribute to greenhouse gases through production of CH<sub>4</sub> or CO<sub>2</sub> or N<sub>2</sub>O from treatment processes or from CO<sub>2</sub> produced from the energy required for treatment. Biodegradation of the organic fraction of waste has long been known to produce greenhouse gases.

In this study, the evaluation of greenhouse gas emissions of the two wastewater sludge (biosolids) management options was considered: composting and landfill. Composting is an aerobic process and a large fraction of the degradable organic carbon (DOC) in the waste material is converted into carbon dioxide (CO<sub>2</sub>). CH<sub>4</sub> is formed in anaerobic sections of the compost, but it is oxidised to a large extent in the aerobic sections of the compost. Composting can also produce emissions of N<sub>2</sub>O. The range of the estimated emissions varies from less than 0.5 percent to 5 percent of the initial nitrogen content of the material. Landfills are well known as potential source of methane in the atmosphere, as the conditions in most of the landfills are anaerobic and rich in degradable organic material.

Specifically, this study analyzed the options with regard to greenhouse gas emissions and energy consumption.

The results of this study showed that composting reduces greenhouse gas emission significantly compared to landfilling of organic waste. Another aspect of greenhouse gas mitigation is the replacement of fossil fuel by the produced biogas. The detail results are showed in the presentation. Ultimately, the study will offer decision makers a means to compare and balance the environmental effects with other, technical or operational factors when selecting specific technologies for wastewater treatment and sludge disposal.

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# Ultrasonic Cavitation and Ultraviolet Irradiation for Enhanced Disinfection of Primary and Secondary Effluents

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This study examines the effects of sequential ultrasound cavitation (UC) and ultraviolet (UV) treatment on the disinfection of primary and secondary effluents. UC is provided using a 20 kHz probe-type Branson Sonifier with a 1.6 cm diameter tip. Subsequent UV dose response is determined using the collimated beam method and membrane filtration bacterial enumeration. For both primary and secondary effluents, pre-treatment with ultrasound caused a decrease in the number of UV resistant organisms. Also for both primary and secondary effluents an increase in the disinfection rate constant of dispersed, or “free-floating” bacteria was observed. The ratio of the change in tailing threshold to the change in particle counts for the ultrasonic probe exceeds used that of previous work using ultrasonic baths. This result is consistent with bacteria being dislodged from particles without significant changes in particle size, possibly due to microjets eroding the particle surface.

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# The Impacts of UV/H<sub>2</sub>O<sub>2</sub> Treatment or UV Alone and Subsequent Chlor(am)ination on Nitrosamine Formation

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The discovery of N-Nitrosodimethylamine (NDMA) in drinking water at ppt levels has been a concern due to its potential carcinogenic properties. Research into the formation mechanisms of NDMA revealed that it is formed during chlorination and chloramination disinfection. Recently other nitrosamine compounds have been detected in drinking water including N-Nitrosomorpholine (NMor), N-Nitrosopyrrolidine (NPyr), and N-Nitrosopiperidine (NPip). While there has been research into the formation and removal of NDMA in drinking water, little attention has been paid to these other nitrosamine compounds, which have similar carcinogenic properties.

This study examines the effects of UV direct photolysis and advanced oxidation, followed by chlorination or chloramination on the formation potential of 8 different nitrosamine compounds. The 8 different nitrosamine compounds include NDMA, NPyr, NPip, NMor, N-Nitrosodiethylamine (NDEA), N-Nitrosodipropylamine (NDPA), N-Nitrosomethylethylamine (NMEA), and N-Nitrosodibutylamine (NDBA). Model nitrosamine precursors are used and include 3 known precursors of NDMA, and 8 suspected model precursors. Bench scale nitrosamine formation potential experiments are being completed using these 11 precursors to examine the effects of advanced oxidation, using hydrogen peroxide and UV, and direct photolysis prior to chlorine disinfection to determine their impacts on nitrosamine formation.

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# Ultraviolet Disinfection of *E. coli* in Municipal Wastewater: Effects of Microbial Population Source

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Quantitative Microbial Risk Assessment requires (quantitative) data of the inactivation or removal of pathogenic micro-organisms by water and wastewater treatment processes. Recently, ultraviolet (UV) irradiation has emerged as a viable alternative for water/wastewater disinfection. Laboratory dose-response data from collimated-beam experiments are commonly used as a basis for determining the necessary delivered UV dose for full-scale UV systems as measured by UV intensity and exposure time. In this work, UV disinfection of the bacterial indicator *E. coli* was assessed at bench-scale from secondary wastewater samples (final combined effluent); specifically, UV disinfection of a laboratory strain of log phase *Escherichia coli*, ATCC 11229 added to autoclaved wastewater samples was compared to disinfection of indigenous populations of *E. coli*. A bench-scale collimated beam apparatus was used in combination with a low-pressure UV lamp apparatus during the experiments. Samples were exposed to UV irradiation at five fluences (10, 20, 40, 60, and 80 mJ/cm<sup>2</sup>). The usage of laboratory cultivated organisms resulted in reproducible, approximately 4- to 5-log inactivation of viable *E. coli* by UV irradiation at a fluence of 10 mJ/cm<sup>2</sup>. In contrast, approximately 2-log inactivation of culturable, indigenous *E. coli* was achieved in secondary wastewater samples. This work underscores the importance of proper regulatory consideration and design of bench- and pilot-scale experiments to demonstrate UV disinfection of municipal wastewater.

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# Biological Removal and Sequestration of Chromium in Ground Water Using Paper Waste Products as a Carbon Source and as Adsorption Sites.

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Previous work with other metals had demonstrated that pulp mill paper biosolids readily supported sulphate reducing bacterial growth and therefore could be utilized in a biological system designed to reduce and sequester metals such as Zn, Fe, Cu and Ni – metals that would form sulphides. Paper biosolids from the pulp and paper industry were employed in this system (a vertical sub-surface flow engineered wetlands or anaerobic bioreactor) contained in a large cell designed to readily create and maintain anaerobic conditions. Subsequent studies confirmed that recycled paper waste biosolids could also be utilized as a carbon source for bacteria.

Chromium does not form sulphides. Previous researchers had demonstrated that it is readily reduced to the insoluble Cr(III) form in an anaerobic environment to form insoluble hydroxides. However, it could possibly be oxidized and hence become mobile again if conditions in the anaerobic system were to change to aerobic ones.

Concentrations of soluble Cr(VI) (~ 0.2 ppm) were treated in a column study to test the efficiency of bacterial processes to reduce the soluble form to insoluble Cr(III) with the resulting formation of insoluble chromium hydroxides. The carbon source for the test was recycled magazine paper waste. This product was chosen because it was hypothesized that the high kaolinite content would provide adsorption sites for both Cr(VI) and Cr(III). Following successful removal of Cr(VI) to low parts per trillion concentrations (near the method detection limit) in a 6-week ported column experiment, samples of the biosolid were analyzed to determine the adsorption curves for both Cr species. The results were then used to develop an adsorption model that supported the hypothesis.

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# Post Treatment of Azo-Dyeing Wastewater Using an Inexpensive Biomaterial “Chitosan”

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Azo dyes represent the largest class of dyes in use today. Approximately, 10-15% of the dyes are released to the environment during dyeing process in different industries. It was found that anaerobic treatment was not sufficient enough to eliminate the total color and organic matter from the azo-dyes containing simulated textile wastewater (data to be published). Therefore, polishing treatment was used to achieve the total elimination of color and reduce the organic matter.

The effluents used in this experiment were the azo-dyes containing effluents which were degraded by anaerobic bacteria from up-flow anaerobic sludge blanket (UASB) followed by expanded granular sludge blanket (EGSB) and EGSB reactors. The effluents at different dye concentration coming out from the anaerobic (UASB followed by EGSB and EGSB) reactors were treated using environmental friendly inexpensive biomaterial chitosan. The objective of this study was to use chitosan for the total elimination of color as well as to reduce the organic matter. This study showed that the chitosan was efficient for the elimination of total color. Moreover, it was found that chitosan were effective to reduce chemical oxygen demand (COD), total suspended solids (TSS), volatile suspended solids (VSS) and the absorbance spectra at ultra violet region which are suspected to correspond to aromatic amine derivatives.

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## **Assessing the Ability of Treatment Wetlands to Mitigate Contaminants from Wood Waste Leachate in Ontario.**

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There is growing concern and awareness regarding the adverse effects of contaminants leaching from wood waste at saw mill sites in Ontario. A sawmill site in Central Ontario is at times experiencing high levels of iron, copper, zinc, phenols, and tannins and lignins, in the surface water near the mill site. The large amounts of wood waste produced and stored on site may be the source of these contaminants. This study is investigating leaching of contaminants from wood waste and the ability of surface and subsurface flow treatment wetlands to remove metals and other organic compounds from runoff associated with mill sites. Advances in understanding the characteristics of leachate associated with wood waste and in finding practical treatment methods will promote source water protection and help in maintaining watershed health.

This past summer data were collected and preliminary analyses are being conducted to better understand the behavior of the contaminants spatially and temporally in the natural wetlands found on site. Surface water samples taken from the site throughout spring, summer and fall had iron levels over Provincial Water Quality Objectives and averaged, 5.78 mgL<sup>-1</sup>. Saturation testing of wood chips, sawdust, and bark from Eastern Hemlock, White Spruce, and Sugar Maple were undertaken to determine the source of the contaminants and to determine the leachate potential between species when exposed to different temperatures and temporal regimes. To understand how to mitigate the effects of the contaminants, microcosms will be constructed to determine the effectiveness of wetland designs by using unactivated carbon as an addition to substrate media for sequestering or removing metals and organic compounds.

Leachates from wood waste can be toxic in the environment unless treated at the source. This research has the potential to promote sustainable and effective saw mill practices through optimization of treatment wetland design and through the development of best management practices and guidelines around wood waste management in this important resource industry.

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# The Removal of Sulfonamide Antibiotics During Ultrafiltration: The Impact of Surfactants and Sediments

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Over the course of the past decade, the occurrence of pharmaceuticals and personal care products (PPCPs) in the environment has been an emerging issue that has recently attracted public attention in mainstream media reports. Uncontrolled environmental exposure to PPCPs could have toxic consequences for exposed aquatic organisms, as well as for ecosystem and human health. The development of a treatment strategy for the *in-situ* remediation of PPCPs from wastewater effluent would provide a critical means of source control to limit environmental exposure to PPCPs.

Our study of the membrane filtration of PPCPs has shown that the Micellar Enhanced Ultrafiltration (MEUF) technique holds promise in terms of improving separation efficiency in wastewater treatment. In MEUF, contaminants are sorbed by micelles that are formed by surfactants that are present at concentrations in excess of their critical micelle concentration (cmc). As a consequence, the micellar-bound contaminants experience an increase in effective molecular size, allowing them to be retained by membranes that possess molecular-weight cut-offs that are significantly greater than the size of free (i.e., unbound) contaminants.

Here, we present results from preliminary studies on the efficacy of MEUF with the surfactant cetyltrimethylammonium bromide (CTABr) for the removal of selected sulfonamide antibiotics (sulfasalazine, sulfamerazine, sulfaguanidine, sulfathiazole) from tap water. The experiments involve bench-scale ultrafiltration of aqueous samples of sulfonamides using regenerated cellulose (RC) membrane filters of different pore sizes. The sulfonamide concentration in permeate and retentate was determined using both UV-visible spectrophotometry and HPLC/MSMS. Rejection coefficients, ranging from 0 % to 100 %, were calculated for each sulfonamide in the presence and absence of surfactant. Furthermore, the impact of Lake Erie sediment on MEUF efficiency was evaluated. While the presence of CTABr micelles improved separation efficiency for all three sulfonamides to a significant degree, the addition of sediment to the surfactant resulted in enhanced sulfonamide removal, with complete removal for sulfathiazole and sulfamerazine. The concentration of surfactant present in permeate and retentate, as well as the cmc, were determined using conductivity measurements. The implications of our findings are discussed in the context of wastewater and drinking water treatment processes.

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# Advances in Water Treatment Technologies and Approaches

Chairs: Ron Hoffman and Kirsten Exall

# The Application of Artificial Neural Networks for Optimization

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Removal of fine particles through granular media filtration is an important process in drinking water treatment to ensure the adequate removal of pathogens enmeshed within or on the surface of those particles, as pathogens such as *Giardia* and *Cryptosporidium* are known to be resistant to chlorine disinfection. Plant performance is typically monitored post-filtration, in terms of filtered water turbidity levels. However, particle counts may provide better insight into treatment efficiency, as they have been correlated with the removal of *Giardia* and *Cryptosporidium*, and possess a greater sensitivity for detecting small changes in filtration efficiency. Thus, to minimize the passage of *Giardia* and *Cryptosporidium* into filtered water, the treatment process could be optimized in terms of post-filtration particle counts. Optimization in drinking water treatment is not a simple task, as each unit process depends upon a number of different interrelated variables, which are known to influence filtration performance. To optimize a filtration process in real-time, accurate process models must be developed.

This presentation will focus on the feasibility of applying artificial neural network models (ANNs), trained on historical plant data, for the prediction of total particle counts and particle counts in specific size ranges, post-filtration. In addition, this presentation will address the feasibility of applying inverse ANNs for the prediction of plant input variables (i.e. alum dosage) based on desired particle count limits. The results of models developed for the Elgin water treatment facility south of London, Ontario will be examined.

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# Impact of UV/H<sub>2</sub>O<sub>2</sub> or UV Photolysis on Subsequent Chlorine Stability and DBP Formation Potential

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Advanced oxidation processes are relatively well established in the fields of groundwater and soil remediation, however they have not yet become widespread within the drinking water industry. Their efficacy has been proven by recent studies when treating micro-pollutants such as pesticides, nitrosamines and other potentially toxic components. However, there is little experience about possible side effects to the treatment. Preliminary research indicates that alterations of natural organic matter properties due to advanced oxidation may affect several important water quality parameters and may negatively or positively influence downstream processes within the treatment plant and within the distribution system.

This study is meant to provide a general understanding of the potential impact of UV-H<sub>2</sub>O<sub>2</sub> on the disinfection process. In particular, the impact of UV-H<sub>2</sub>O<sub>2</sub> on chlorine stability and disinfection by-product formation was studied using both laboratory experiments, and a full-scale water quality monitoring campaign at the City of Cornwall, Ontario, which recently installed the world's first UV-H<sub>2</sub>O<sub>2</sub> system for taste and odour control.

The results indicated that the treatment doesn't have the ability to mineralize the natural organic matter (NOM) in the water. Experiments show the organic matter being only altered, with its reactivity towards chlorine increasing. Interestingly, the increased reactivity with chlorine is accompanied by a reduction in trihalomethane formation. This leads to the concern that other disinfection by-products might be formed. Additional work is ongoing to study the potential formation of biodegradable organic carbon when using UV-H<sub>2</sub>O<sub>2</sub>, and to better identify changes in the properties of the NOM. This information will be included in the presentation.

In addition to the scientific aspect of this study, a comprehensive review of UV-H<sub>2</sub>O<sub>2</sub> implementation at Cornwall was undertaken. A number of operational challenges were experienced with retrofitting UV-H<sub>2</sub>O<sub>2</sub> into an existing treatment plant. This presentation will discuss some of the implementation challenges, and describe the solutions that were found.

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# Removal of Easily Biodegradable Carbon by Drinking Water Biofiltration --- Developing a Quantitative Basis for Comparison

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The use of rapid biological filtration in drinking water treatment has recently received increased interest from the water industry. A primary treatment objective is the removal of biodegradable organic matter (BOM) to produce more microbiologically stable water in the distribution system and to reduce levels of disinfection byproducts. A frequently used parameter for quantifying BOM is Assimilable Organic Carbon (AOC). AOC removal depends on several factors, such as filtration contact time, raw water quality, temperature, media and media diameter and pre-oxidation. A new parameter, dimensionless contact time,  $X^*$ , has been previously developed to integrate a number of these factors and provide a conceptual basis for biofiltration design. In general, removals increase with increasing  $X^*$ , but in a less-than-proportional way.

This objective of this presentation is to apply the  $X^*$  concept to a number of AOC removal investigations reported in the literature, to enable quantitative comparisons and interpretations. Using the reported removals,  $X^*$  values for each reported study were estimated based on a previously developed relationship between  $X^*$  and percentage removal. Results showed that the  $X^*$  value, which integrates information about media, operating condition and biodegradation kinetics, was a better indicator than contact time alone to predict and assess AOC removal by biofiltration. The results also showed that a number of biofilters were significantly over-designed for AOC removal.

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## Statistical Analysis of Ottawa Lead in Tap Water Data from 1997 to 2008

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Lead concentrations in tap water from customer homes in the City of Ottawa were measured from 1997 to 2008. Other water quality parameters measured for each home included Cl<sub>2</sub>, pH, temperature, alkalinity, hardness, turbidity and conductivity. All samples were collected using a five-minute fully flushed sampling protocol in accordance with previous sampling protocols. In addition, extended 30-minute and 6-hour stagnation sampling protocols were used on a trial basis in some homes. Additional 30-minute stagnation samples were collected in accordance with the new Ontario Drinking Water Standard for lead (2007).

The objective of this study was to analyze the lead data collected from 1997 to 2008 for trends through statistical analysis to obtain a better understanding of sampling protocols and corrosion control measures. A comparison of different sampling protocols used by the City of Ottawa was conducted to identify if there were any statistically significant differences. Furthermore, the treated water pH was changed in 2002 from 8.5 to 9.2 and was found to be statistically significant at the 95% confidence level ( $p < 0.05$ ). Regression models were developed to predict lead concentrations in tap water based on parameters including pH, alkalinity, and temperature. Findings show limitations in using multiple linear regression models to predict lead release based on water quality parameters. Instead, a logistic regression model to predict a categorical response of 0 (less than 10 µg/L) and 1 (greater than or equal to 10 µg/L) was developed and shown to be valid for predicting whether a home would have lead concentrations above 10 µg/L, which is the current Health Canada guideline and the Ontario Drinking Water Standard for lead.

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# Pilot-Scale Removal of NDMA, EDCs, and PPCPs by Ozone, BAF, or Membranes

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The presence of various trace organic pollutants in water, including endocrine disrupting compounds (EDCs), pharmaceuticals and personal care products (PPCPs), and n-nitrosodimethylamine (NDMA), is a growing concern for North American drinking water plants. Although comprehensive research has been completed on treatment of these compounds at bench-scale, limited work has been conducted at pilot- and full-scale. The University of Toronto and Trent University were partners on a pilot-scale investigation of the removal of these compounds at the Contra Costa Water District's Bollman Water Treatment Plant (near Oakland, California). Three advanced treatment trains were tested: ozonation with biologically active filtration (BAF), ozone combined with hydrogen peroxide ("peroxone"), and nanofiltration.

Ozonation, at an applied dose of 1 mg/L, was found to result in removal efficiencies greater than 80% for all of the compounds except ibuprofen, atrazine, and iopromide. Peroxone and ozonation were found to generate similar removal efficiencies. Biologically active filtration (BAF) following ozonation was observed to provide removal of a number of the compounds of interest, suggesting that certain EDCs and PPCPs are readily biodegradable. Nanofiltration was highly effective, achieving removal efficiencies greater than 80% for every analyte of interest.

The presentation of these results will be accompanied by a brief discussion of the current regulatory and public health significance of EDCs, PPCPs, and NDMA, and an overview of similar studies undertaken elsewhere so that generalizations can be made about preferred treatment strategies for these compounds.

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# Removal of Certain Taste and Odor Compounds from Drinking Water Using UV-Based Advanced Oxidation Processes

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The UV-hydrogen peroxide advanced oxidation process may gain some popularity in drinking water treatment where plants are already using UV for disinfection, and where periodic taste and odor control is required. The ability to operate at low UV doses for disinfection and then increase UV doses and introduce hydrogen peroxide when needed for T&O control is an attractive process flexibility.

This laboratory study examined the reaction rates of geosmin and MIB in a UV+H<sub>2</sub>O<sub>2</sub> system via three parallel mechanisms: reaction with hydrogen peroxide, direct UV photolysis, and reaction with hydroxyl radicals. A competition kinetics method determined the reaction rate constants with hydroxyl radicals to be 1.21E10 and 8.04E9 M<sup>-1</sup>s<sup>-1</sup>, respectively, for geosmin and MIB. Direct photolysis and reaction with hydrogen peroxide were determined to be very minor but not completely negligible contributors to geosmin and MIB decay under laboratory conditions representative of full-scale treatment.

This study also investigated geosmin and MIB degradation kinetics in the presence of UV light combined with either nitrate (NO<sub>3</sub>), or chlorine (HOCl). The experiment indicated that geosmin and MIB decay rates increased with the following order of treatments: UV < UV/NO<sub>3</sub> < UV/H<sub>2</sub>O<sub>2</sub> < UV/HOCl, for the same concentration of oxidants (0.2 mM). This leads to the intriguing possibility of using HOCl together with UV in an advanced oxidation system. Our results indicate that a chlorine concentration in the order of 10 mg/L could serve for T&O control. A problem with this approach is disinfection by-product formation due to such high chlorine doses, however some waters that experience T&O problems, notably the Great Lakes, have low DBP formation potential. Experiments are currently underway to examine trihalomethane (THM) and haloacetic acid (HA) formation under laboratory conditions that simulate UV-HOCl treatment for geosmin and MIB, using water from Lake Ontario.

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# Selection of Representative Emerging Contaminants for Removal Studies, A Statistical Approach

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Micropollutants such as endocrine disrupting chemicals (EDCs) and pharmaceuticals and personal care products (PPCPs) may pose a serious problem to drinking water. In order to assess the effectiveness of water treatment processes for these micropollutants, removal efficiencies of all contaminants of interest should be assessed. Considering the large number of compounds detected in water this is not feasible. It is therefore highly desirable to develop models based on a small number of carefully selected representative compounds, and to apply these models to predict the behavior of the other unstudied compounds without experimentation. The overall goal of this research is to develop quantitative structure-property relationships (QSPRs) to predict removal of emerging contaminants by oxidation processes.

This paper describes the first step towards building these models – namely to systematically select a group of representative micropollutants, which will serve as training set to develop QSPR models. A well developed optimized selection strategy was applied, which combined principal component analysis (PCA) and statistical experimental design. In this research, the initial dataset contained 183 micropollutants, mostly emerging contaminants, collected from the peer reviewed literature. Each compound was characterized by 34 molecular descriptors (i.e. these are variables used in QSPR modeling). This resulted in a large complex multivariate dataset to which PCA was applied. As a result of PCA, 5 principal components were identified which captured 82.7% (43.7%, 13.6%, 12.0%, 6.9%, and 6.5%) of the variation in the initial dataset. In order to select representative compounds a D-optimal onion design was then applied to the resulting principal components. In total, 23 compounds were selected as structurally representative compounds which covered the chemical domain (meaning the chemical characteristics of all compounds) in a well-balanced manner and captured the majority of the information.

The lack of experimental data and the overwhelming number of compounds has increased the importance of QSPR to predict the properties of compounds not yet tested. The combination of PCA and experimental design method provides a sound tool to select the representative compounds on which the QSPR models will be built. Overall this approach will provide guidance on the efficiency of removal processes while minimizing time and cost.

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# Removal of Perchlorate ( $\text{ClO}_4^-$ ) from Water Using Pulsed Arc Electrohydraulic Discharge (PAED)

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The contamination of surface and ground water systems by perchlorate ( $\text{ClO}_4^-$ ) is of growing concern, as chronic exposure to this compound causes adverse health and environmental effects. Additionally, perchlorate is highly mobile, nonreactive, and stable. Therefore it has the ability to travel large distances in the environment, and is difficult to remove from contaminated media. Advanced water treatment technology is required to decompose perchlorate into innocuous compounds. The purpose of this research is to examine the reduction of perchlorate in an aqueous solution using pulsed arc electrohydraulic discharge (PAED).

PAED is a direct thermal plasma water treatment technology that injects energy into an aqueous solution inducing a plasma zone, which results in the generation of several water treatment mechanisms. The PAED system employed in these experiments utilizes a 0.3 kJ/pulse spark-gap type power supply connected to a pair of submerged titanium electrodes inside a 3 L stainless steel cylindrical reactor producing a pulsed arc plasma channel. The system generates strong pressure waves, UV radiation and radical formation (e.g.,  $\text{O}_3$ ,  $\text{OH}^\cdot$ , etc.) in the region near the arc discharge. PAED system has successfully removed chemicals and inactivated microorganisms in dilute aqueous solutions. Previous research has also demonstrated the potential of PAED to reduce oxidized pollutants, such as nitrate. Therefore, it is postulated that PAED has the potential to remove perchlorate via the reduction mechanism. For highly oxidized chemical compound treatment, a non-toxic, inexpensive and soluble electron donor is added to the solution to promote the reduction process.

Fractional factorial experiments were designed to screen out insignificant factors, and to determine the optimal operating parameters of the PAED system for the reduction of perchlorate. This presentation will discuss the parameters employed in the factorial experiments and discuss the results in terms of perchlorate reduction achieved, and associated PAED performance characteristics.

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# Catalytic Degradation of Salicylic Acid with Iron Oxide and Ozonation

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Membrane filtration and ozonation are two means of treating surface waters that have, in recent years, become more widely accepted. Previous research conducted on an iron oxide-coated ceramic membrane filtration system using ozonation indicated that model contaminants such as salicylic acid could be catalytically degraded on the membrane surface.

The degradation of salicylic acid is currently being investigated in order to further elucidate what is happening mechanistically during catalytic degradation with ozone. Studies are being conducted in a 1.5 L reactor vessel containing an aqueous suspension of iron oxide nanoparticles of varying concentrations. Ozone is then bubbled through the solution at a constant inlet gaseous concentration. Samples are analyzed at regular intervals to determine pH and aqueous ozone concentrations. High performance liquid chromatography is employed to determine the concentrations of salicylic acid and some of the by-products, namely 2,3 dihydroxybenzoic acid and 2,5 dihydroxybenzoic acid, that are thought to result from the interaction of salicylic acid with hydroxyl radicals. Gaseous ozone is monitored by UV spectrophotometry and the absorbance is recorded at corresponding aqueous sampling times.

The effect of varying the iron oxide surface area, and hence the membrane surface area, is also being evaluated. A similar study involving the effect of titanium dioxide rather than iron oxide nanoparticles will also be completed. Future research will include challenging the system for the removal of various pharmaceutical chemicals from surface waters.

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## Pilot Tests to Evaluate the Performance of Cationic Activated Silica Polymer as Coagulant Aid

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This study used the dual train conventional treatment pilot plant, at the Walkerton Clean Water Centre (Centre), to investigate the effects of Cationic Activated Silica (CAS-100), as a coagulant aid, on the coagulation and flocculation process and the treated water quality. The feed water to the pilot plant was collected from Lake Ontario.

The trial runs included:

- Comparison of Polyaluminium Chloride (PACl) used in one train of the pilot plant with PACl and CAS-100 used in the other train;
- Comparison of alum used in one train with alum and CAS-100 used in the other.

Throughout the study, the two trains of the pilot plant monitored on-line for temperature, turbidity, particle counts, pH, flow, and headloss. Grab samples were collected to test for water quality parameters such as turbidity, pH, alkalinity, UV transmittance, dissolved organic carbon (DOC), residual aluminium, E-coli, total coliform and Heterotrophic Plate Counts.

The effluents of the sand/anthracite filters were sampled to conduct simulated distribution system trihalomethanes (SDS-THMs) tests. The SDS-THMs were carried out under rigorously controlled laboratory conditions, using chlorine dosages of 4 and 6 mg/L. The results showed that when CAS-100 was used the flocs formed were larger and heavier. The settled water turbidity was lower in the train of the pilot plant using CAS-100.

Furthermore, CAS-100 assisted in having shorter ripening period after filters backwash. However, filter headloss increased faster when CAS-100 was used. The results of this study showed marginal gain in trihalomethanes reduction when CAS-100 was used. The water tested had, however, a very low level of THMs precursors as shown by the low levels of SDS –THMs of the raw water (38.2 µg/L).

Residual aluminum reduction was substantially lower when CAS-100 was used, the residual aluminium ranged between 50 and 80 µg/L. The main finding is the potential of CAS-100 to reduce the residual aluminum in the treated water and the duration of the filter ripening period.

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## Technology for On-Site Monitoring of *E. coli* and Coliforms in Source Water and Drinking Water

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We have developed a new detector for *Escherichia coli* and coliform bacteria in samples ranging from treated drinking water to sewage. The test is rapid and able to detect single viable organisms, yet simple enough to use on-site with minimal user training. No user visual interpretation of the test result is required. The test has been certified by AOAC and demonstrated in a number of field site trials, and approved for use in licensed laboratories by the Ontario Ministry of the Environment.

We have modified the standard tests using fluorogenic “targeted substrates” to detect glucuronidase and galactosidase enzymes as indicators for *E. coli* and Total Coliform, respectively. A standard 100 mL sample is added to a single-use test cartridge containing custom substrates and a fibre-optic-coupled polymer probe element. The cartridge includes a polymer element which extracts product molecules created by the target organisms, and fluorescence of the products is measured in the polymer. Signals from the polymer are insensitive to sample colour, turbidity and other fluorescent materials, providing more reliable detection.

The test has been demonstrated on samples from drinking water to sewage, with no change in the analysis method and no need for dilutions. Single organisms were detected in under 18 h, with raw sewage detected in approximately 2 h. The bacteria are quantified using the continuous signal and a simple model for growth kinetics. A simple scheme has been developed for verifying or adjusting the calibration function for a new site or type of bacteria using a small number of samples. Results for a variety of sample types and locations will be presented.

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## Fractal Dimensions and Settling of Flocs

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Properties of individual flocs determine the settling behaviour of the sludge; this is especially pronounced at very low and high solids concentrations. At low solids concentrations, floc settle as individual particles; this type of settling can be modeled with Stokes' law. At very high solids concentration, flocs settle together as a blanket; in this type of settling, floc consolidation and dewatering properties play an important role. Properties of individual flocs can be described best using the concepts of fractal geometry. Fractal dimensions of flocs can be determined directly from flocs' microscopic images or indirectly from settling velocity of the flocs.

In this study fractal dimensions of flocs formed in lime/soda softening were determined directly on floc 3D images with box counting method. Fractal dimensions of chemical coagulation flocs have not been determined directly in 3D before. Such directly determined fractal dimensions  $3D_B$  were compared with the fractal dimensions-  $D_m$  determined indirectly from the floc settling velocity. The application of various fractal dimensions for predictions of floc settling is discussed.

Table 1. Fractal dimensions of various types of flocs

	FRACTAL DIMENSIONS			
	$(1D_B)$	$(2D_B)$	$(3D_B)$	$(D_m)$
Lime softening flocs (Vahedi & Gorczyca 2008)	1.09	1.91	2.71	1.82
Alum coagulation flocs (Gorczyca 1991, Gorczyca & Ganczarzyk 1996, 1999)	1.13-1.25	1.91-1.99	N.A.	1.37-1.79
Ferric coagulation flocs (Bahrami & Gorczyca 2008)	1.11- 1.16	1.94-1.99	N.A.	N.A.
Activated sludge flocs (Li & Ganczarzyk 1989, Ganczarzyk 1995 )	1.04-1.32	N.A.	N.A.	1.45-2.0
(Ganczarzyk 1996)	1.21	1.88-1.99	N.A.	N.A.
(Cousin & Ganczarzyk 1998)	1.28-1.40	1.83-1.99	N.A.	NA
(Chu et al. 2004)	1.35-1.48	1.72-1.81	2.46-2.70	1.3-1.55

The fractal dimensions determined indirectly from the settling rates of the flocs ( $D_m$ ) appear very different from the  $3D_B$  fractal determined directly on floc's image.  $D_m$  is always smaller than  $3D_B$  and its values span over the range of  $1D_B$  and  $2D_B$  fractal dimensions which describe floc's properties in 2 dimensions. Therefore, the preliminary results of this work suggest that settling of flocs can be predicted based on analyses of flocs in 2D only. \*

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# **An Overview of Disinfectant Residual Degradation and Disinfectant Byproduct Formation in Distribution Systems**

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Maintenance of secondary disinfectant (mainly free chlorine and chloramine) in the distribution system is effective to inactivate microorganisms and control biofilm formation. However, the presence of these disinfectant residuals promotes undesirable disinfection byproduct (DBP) formation, such as haloacetic acids (HAA9) associated with chlorination and nitrosamines during chloramination. These DBPs have been recognized as suspected carcinogens and pose a potential health risk to humans. Corrosion is another issue causing water quality deterioration in distribution systems. Common materials used for the construction of a distribution system including in-home connections are copper, lead and iron. Corrosion of these materials can increase the concentration of these metals in the water and is a health and aesthetic concern. In recent years, considerable efforts have been made to understand the mechanisms of metal release from pipes and corrosion scales, the interactions between the corrosion products and disinfectant residuals, and effective strategies to control corrosion in distribution systems (e.g., phosphate-based corrosion inhibitor addition). However, limited and inconsistent information is available regarding the formation and variation of HAA9 and nitrosamines (especially NDMA) in distribution systems under the influence of pipe corrosion and the presence of the phosphate-based corrosion inhibitors.

This presentation will give an overview of how disinfectant residuals (mainly free chlorine and monochloramine) degrade and DBP concentrations (mainly HAA9 and nitrosamines) vary spatially and temporally in the distribution system. Significant influential factors affecting disinfectant residual degradation and DBP formation will be summarized, and the role of pipe corrosion will be discussed in detail. In addition, some experimental results from the bench-scale studies with respect to the interactive effects of disinfectant residual, pipe corrosion and corrosion inhibitor type (orthophosphate and polyphosphate) on HAA9 and nitrosamine formation will be presented.

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# Applications of Remote Sensing and Geomatics Technologies in Watershed Health

Chairs: Raul Ponce-Hernandez and Frank Kenny

# Spatial Analysis of Contaminant Trends in Lake St. Clair: 1970, 1974, and 2001

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Lake St. Clair is an integral part of the Great Lakes system. It formally belongs to the Lake Erie watershed although there has been some interest in recognizing the lake as an “official” Great Lake. Important transportation routes for natural resources and manufactured products bisect the lake and it is also used for drinking water and recreational purposes. The St. Clair River, which flows into the lake from the northeast, is a major source of deposited contaminants. Sediment sampling surveys were conducted in 1970, 1974, and 2001 by Environment Canada as part of the Great Lakes Sediment Assessment Program. The surveys were similar in terms of the total number and location of the stations that were sampled. Trends in metallic (copper, lead, mercury, nickel, zinc) and organic (PP'-DDE, PP'-DDT) contaminant concentrations were examined from 1970 to 1974 and 1974 to 2001 using GIS-based kriging techniques. Spatial interpolation techniques such as kriging allow for areal comparison of sediment contamination trends. This is a considerable advantage when compared with traditional dot maps. The results for the contaminants were highly variable. In areas where historically high concentrations were found in 1970 (e.g. mercury), even higher estimates were generated for 1974, before the concentrations decreased by 2001. Other contaminants (e.g. PP'-DDE) were relatively low in 1970, higher in 1974, before declining by the 2001 survey. Finally, some concentrations remained low throughout the three surveys (e.g. zinc, PP'-DDT) and the estimation trends were relatively constant over time. In general, contaminant concentrations in 2001 were lower than they were in the 1970s. The kriged estimation surfaces provide valuable information that can be used to analyze the spatial distribution of contamination. They also provide an additional communication tool and means of influencing management options and decisions.

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# **Progress Towards an Agricultural Resource Inventory in the Southern Part of the Lake Huron Watershed**

S.J. SWEENEY,<sup>1\*</sup> J.D. ASPINALL, D. BIHARI, J. BIRCHMORE, AND E. POLLOCK

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Agriculture, in the southern part of Ontario's Lake Huron watershed, has been implicated as a non-point source contributor to water quality problems in its tributaries and at beaches without benefit of a detailed assessment of the actual spatial distribution of the farming activities in this region. Agricultural activities, particularly field cropping, involve land applications of nutrients and/or manure (a microbial source) in specific locations at specific amounts and at specific times of the year. A detailed agricultural resource inventory (ARI) of all farm fields in the watershed would provide the requisite information to properly examine this important issue.

Lake Huron watershed ARI mapping coverage currently extends along the coast from Grand Bend to north of Kincardine and then inland for distances of between 20 and 50 kilometres. It includes all of Huron County, most of the Ausable-Bayfield Conservation Authority (ABCA) and Maitland Valley Conservation Authority (MVCA) territory and most of the Saugeen Valley Conservation Authority's (SVCA's) coastal watersheds. The ARI mapping process involves creating a seamless, digital framework of all landscape features – including farm fields and farmsteads - from base imagery with a resolution of at least 30cm X 30cm. Each farm field is assigned a unique identifier so that its attribute information can be specifically assigned to it in the GIS database. These attributes include tillage and cropping system information that has been collected through direct visual field observations and extracted from satellite imagery analyses.

This multiple-year ARI database will permit detailed understanding of the farm land management practices within the Lake Huron watershed. The spatial distributions of crop rotations and the various tillage systems (conventional through to no-till) can now be assessed for their proximity to water flow pathways, water quality observation points and any areas of episodic beach impairment with algae or E. coli.

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# Indicator Monitoring of Domestic Military Training Activities Using Satellite Remote Sensing

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The Canadian forces trains on nearly two million hectares of land across Canada in which the sustainable use of these lands are essential in our armed forces' military readiness and future training activities. Effective natural resource management of the vast scale of lands without compromising the natural landscape led to the Department of National Defence (DND) to establish an environmental monitoring program utilizing satellite remote sensing. Significant importance by the DND on comprehensive environmental assessments has been placed to ensure that the operational training activities do not irreversibly alter the natural landscape. This presentation will outline the proceeding project work that led to the establishment of the current Geomatics and Earth Observation Center for Environmental Management (GEOCHEM) office at the Royal Military College of Canada (RMC), with a case example of the current work monitoring natural indicators for a significant military base. The issue of scale will be discussed with specific examples highlighting the challenges of such large environmental assessments. Watershed management using high resolution imagery integrated with GIS will also be discussed.

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# Advances in Method Development for Automated Landform Recognition and Segmentation from High Resolution Digital Elevation Models

J. D. ASPINALL<sup>1\*</sup>

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Ontario's heritage of county-level soil mapping was amassed over a six decade time period. Work from that era was presented on maps that were hand-drafted at scales ranging from 1:25,000 to 1:126,720. Subsequently, with the advent of geographic information systems, these maps were digitized to become the current provincial digital soil information layer. Numerous accuracy issues with these digital map products have been identified and need to be addressed. Their rectification requires untold hours with manual digitizing methods. Automated procedures are needed in order to solve this problem.

High resolution digital elevation models (DEM's), at sub-metre accuracy, permit landforms and their component elements to be identified and studied in great detail. This is a key element of soil unit discrimination for automated mapping purposes. Unit boundary lines must be drawn in meaningful places in order for the map to have value to its users. Decisions about what to include and what to exclude in each mapping unit factor heavily in boundary line placement. This study's approach harnessed the power of a suite of spatial analysis subroutines to reliably isolate individual landforms. It then segmented them using additional subroutines that address the relative positions of their element slope types. This automated mapping approach is, therefore, consistent with the original field work that partitioned the landscape to produce the unit boundaries on Ontario's heritage soil maps.

Soil mapping success with this new method is straightforward to assess. The resulting digital soil maps can be produced at a range of spatial scales. An important advance with this new technique is that the variability within each soil unit, presented at any of these scales, can be determined spatially.

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# **A Remote Sensing Based Approach to Monitoring Watershed Ecosystem Health and Degradation at Source and the Impacts of Changes on Watershed Primary Productivity and Water Quality.**

R. PONCE-HERNANDEZ<sup>1\*</sup>

<sup>1</sup>*Applied Geomatics Remote Sensing and Land Resource Laboratory, Environmental and Resources Studies Program and Department of Geography, Trent University, Peterborough, Ontario, Canada*

The temporal or permanent decline in productivity of the land to a state from which it cannot recover unaided, related to a baseline of past condition, is the main indicator of ecosystem degradation, FAO (2008). A substantial body of work on ecosystem decline is based on NPP as indicator of degradation and a variety of methods have been proposed for its estimation at multiple scales from global to local (Alexandrov and Oikawa, 1997; Ramussen, 1998; Seaquist et al, 2003; Running et al, 2004; Bai et al, 2008).

This paper introduces an approach based on multi-temporal and multi-resolution satellite imagery to identify and map the spatial trends of NPP dynamics over the confines of watersheds. Low resolution (AVHRR) imagery time series, combined with high resolution (Landsat and ETM+) imagery time series are used for relating band-ratio indices (NDVI and GVI) to ground measurements of NPP and photosynthetic active radiation (PAR) in order to develop a model of NPP prediction over space and time. Upscaling and downscaling procedures inherent to the scale transfers are examined. Time-series analysis enable the identification of trends of NPP decline and ecosystem degradation. The results are compared to trends derived from data on NDVI and NPP that can be obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS). The vegetation rain use efficiency (RUE) as related to its NPP allows for speculation about the potential impacts of NPP decline on water quality at source.

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# **Towards Developing a Spatial Watershed Fabric for Ontario's Far North Using Remotely Sensed Inputs**

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In 2008 the government of Ontario announced a major Land Use Planning initiative for Ontario's Far North region. This immense area is roughly defined as north of 51 degrees latitude and represents approximately 44% of the land area of the province (470,000 km<sup>2</sup>). For reference this area is more than twice the size of Great Britain.

A significant and accelerated component of this initiative is base and natural resource thematic map compilation. The establishment of this geospatial fabric is viewed as essential for the success of subsequent planning activities. The Water Resources Information Program of the Ontario Ministry of Natural Resources has been tasked with developing a spatial watershed fabric for this region that is consistent and can be integrated with existing products for the remainder of the province. The size of this area, the dearth of existing natural resource mapping and inventories combined with the very limited access makes utilizing spaceborne remote sensing technologies the most logical and cost effective development option.

In this presentation for the purpose of deriving watershed data layers, we will examine existing hydrology related datasets (e.g. NRCan's NHN), available multispectral imagery (e.g. Landsat, SPOT, Quickbird), available and potential Radar imagery (RADARSAT I and II, TerraSAR) and satellite derived elevation data products (Shuttle Radar Topography Mission - SRTM, Satellite Softcopy Photogrammetry). This presentation will also highlight our proposed processing methods, our in-development flow routing toolbox and proposed metadata development tools.

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# Bisphenol A

Chairs: Miriam Diamond and Sean Backus

## **BPA in the Canadian Environment**

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Bisphenol A (BPA) is a high-volume (> 6-billion pounds per year) production chemical used to make epoxy resins and polycarbonate plastic. Of particular concern is the use of BPA in plastic containers used to store and heat food and beverages, and to line metal cans. In addition, potential environmental sources of BPA contamination are due to: its use in myriad applications ranging from polycarbonate casings for cell phones and computers to dental fillings, car parts, CDs, and thermal inks used to print receipts; losses at production sites, leaching from landfill, and presence in indoor air due to releases from products. As a result of its wide range of uses, BPA is found throughout the environment. Environmental monitoring, which is intended to inform management actions and to support policy decisions undertaken in Canada, will assist with evaluating the efficacy of existing chemical management programs. The current technical session highlights recent science that supports the safe management of BPA in Canada. The focus is on current environmental research and monitoring in Canada directed towards improving our understanding of BPA and the implication of risk management and control strategies undertaken.

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## **The Environmental Screening Assessment of Bisphenol A Under the Canadian Environmental Protection Act (CEPA 1999).**

J. PASTERNAK,<sup>1\*</sup> L. SUFFREDINE,<sup>2</sup> AND D. GUTZMAN<sup>3</sup>

<sup>1</sup>*Environment Canada*

Pursuant to section 74 of the Canadian Environmental Protection Act, 1999 (CEPA 1999), the Ministers of the Environment and of Health have conducted a screening assessment of bisphenol A. This substance was identified as a result of the categorization of the Domestic Substances List as a high priority for action under the Ministerial Challenge, since it was considered to pose the greatest potential for exposure to individuals in Canada and had been classified by the European Commission on the basis of reproductive toxicity. Bisphenol A also met the ecological categorization criterion for inherent toxicity to aquatic organisms, but it did not meet the ecological categorization criteria for persistence or bioaccumulation potential. An environmental and human health screening assessment report (SAR) was undertaken. This presentation provides an overview of the considerations identified in the ecological component of the SAR. On the basis of expected continued or increasing exposure of biota and information indicating the potential for long-term adverse effects to organisms within the range of concentrations currently measured in the environment, it was considered appropriate to apply a precautionary approach when characterizing risk. As such, the SAR concluded that bisphenol A is entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity.

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## **Bisphenol A – What We Have Learned in the Last Ten Years**

**B. LEE,<sup>1\*</sup> T. PEART,<sup>1</sup> L. SVOBODA,<sup>1</sup> S. BACKUS,<sup>1</sup> AND S.A. SMYTH<sup>1</sup>**

<sup>1</sup>*Environment Canada*

Bisphenol A (BPA) is a high production volume chemical used worldwide for the production of polycarbonate plastics, which have a wide variety of applications in consumer and industrial products such as beverage containers, medical devices, electronics, and automotive parts. BPA is also used in the manufacture of epoxy resins and can be found in liners of metal cans for food and beverages, adhesives, and dental sealants. Studies have indicated that BPA biodegrades readily under aerobic conditions but is much more persistent under anaerobic conditions. It is also known as a weak endocrine-disrupting chemical, and is considered toxic to aquatic organisms. In October 2008, BPA was declared toxic to the environment as well as to human health.

In order to provide supporting evidence regarding its releases to the Canadian aquatic environment, we have developed different versions of analytical methods for the determination of BPA in surface water, wastewater, sediment, and sewage sludge samples since 1999. Details of the analytical procedures including solid-phase extraction, supercritical fluid and microwave-assisted extractions, chemical derivatization, and GC-MS analysis will be discussed.

While environmental occurrence of BPA was reported as early as 1977, there was virtually no information for this chemical in the Canadian environment until 2000. Since then, we have gathered a wealth of information regarding its occurrence and fate in municipal wastewaters and sludge, in wastewater samples generated by various industrial groups, as well as in pulp and paper mill effluents and sludge. Results will be discussed.

In support of the federal Chemicals Management Plan, a large monitoring and surveillance program for BPA is underway. Samples from all environmental compartments as well as from wastewater and waste (leachate) treatment processes across Canada are being collected to evaluate the occurrence and fate of BPA in wastewater treatment and waste management, and the level of contamination in the water, sediment, and biota of the receiving environment. Initial findings of this study will be presented.

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# **Modelling Microconstituent Fate and Transport in the Environment: Dynamic Behaviour of Bisphenol A in Wastewater Treatment Plants**

P.A. VANROLLEGHEM,<sup>1\*</sup> F. CLOUTIER,<sup>1</sup> E. LINDBLOM,<sup>2</sup> AND P.S. MIKKELSEN<sup>2</sup>

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The influent of WWTPs contains organic microconstituents originating from the chemical, pharmaceutical and hormonal products released by hospitals, industries and households. At the treatment plant, their concentration can be reduced significantly (but not completely!) by biological degradation processes next to sorption/desorption and volatilization (e.g. perfumes). Hence, part of all these pollutants is rejected into the receiving waters and this in potentially toxic concentrations.

Various models are nowadays available to simulate the behavior of wastewater treatment plants. However, they have mainly been developed to describe the removal of organic matter (COD, BOD), nitrogen and phosphorus, and so far little attention has been devoted to model the fate of such specific compounds. As a result the currently available models used for design and operation of treatment plants cannot be used to describe the behavior of microconstituents in the wide variety of treatment plants in use today.

Thus, a model was developed with the objective to optimize the performance of treatment plants (both design and operation) in terms of eliminating microconstituents. In the presentation special attention will be drawn on the need for a dynamic rather than a steady state model and on the fact that the model must at the same time consider the fate of the microconstituents and of the traditional pollutants (COD, N, P). The work will be illustrated with a confrontation of the model's predictions with experimental data on Bisphenol-A obtained at a full-scale treatment plant.

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# Rapid and Sensitive Determination of Bisphenol A in River Water

J. MARTIN<sup>1</sup> AND J. VUKOVIC<sup>1\*</sup>

<sup>1</sup>*Waters Corporation, Milford, MA*

Bisphenol A (BPA), a known endocrine disruptor, is manufactured in excess of six billion pounds per year. Commonly used in a variety of industrial manufacturing processes and domestic products, BPA can also occur in environmental waters. Having been shown to stimulate endocrine disruption at ng/L levels, analyte enrichment is often required to achieve the required detection limits. Solid-Phase Extraction (SPE) is considered to be the most appropriate technique for the extraction of endocrine disruptors, including BPA, from aqueous samples. A UPLC/MS/MS method, in conjunction with sample enrichment via SPE, has been developed which allows for the detection of Bisphenol A at a LOD of 2 ng/L in under 4 minutes.

Building upon previous LC/MS/MS based work, this new method allows for the rapid determination of Bisphenol A, and other endocrine disruptors, in surface water with a 68% reduction in the total run time. This was achieved while demonstrating LODs for solvent standards of less than 0.1 ng/mL and 2 ng/L for matrix-matched standards (200 mL sample volume of river water). The associated SPE method provides excellent recoveries and reproducibility.

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# An Overview of Bisphenol A

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In April 2008 Health Canada declared Bisphenol A (BPA) “CEPA toxic” (CEPA is the Canadian Environmental Protection Act). The designation arose because of concerns about potential neurodevelopmental and behavioural effects at doses ranging from those equal to current levels in the general public to doses 1-2 orders of magnitude greater.

BPA is the monomer used to create the polymer used in numerous applications from polycarbonate drinking bottles (including baby bottles), food containers; compact discs, coatings on eye glasses; the epoxy linings of tin cans, drinking water storage tanks; thermal paper (that you get from a cash register); adhesives and putties; car parts; and tooth fillings to name a few uses. Production in the mid-2004 was reported to be ~1.024 million tonnes, of which most was used in polycarbonate resins.

Since BPA is rapidly excreted within a day and median levels in urine of 394 American adults was 1.28 µg/L with detection in 95% of individuals (NHANES III survey, Calafat et al. 2005), it stands to reason that our exposure must be frequent if not constant. According to a variety of studies, the exposure of infants to BPA comes from breast milk, milk or formula contained in a BPA baby bottle, and/or infant formula stored in epoxy-lined cans. Adult exposure comes from foods in contact with epoxy-lined cans, polycarbonate food containers and table ware. BPA’s short half-life and relatively low hydrophobicity suggest minimal exposure to humans via foods coming from terrestrial and/or aquatic food webs due to minimal bioconcentration and/or biomagnification in food webs.

This paper introduces the some of the many facets of BPA and explores its ubiquity and our exposure, and touches on toxicity.

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# Bisphenol A Regulation of Synaptic Plasticity in the Hippocampus and Cerebral Cortex

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Since the 1950s, the synthetic chemical bisphenol A (BPA) has been employed in manufacturing a wide range of plastics, including dental prostheses and sealants, the polycarbonate lining of food cans, baby bottles and the clear plastic cages used to house laboratory animals. More than 6 billion pounds of BPA-containing polycarbonates are produced annually. The ester bond linking BPA into plastics can be hydrolyzed, at a rate that increases under acidic or basic conditions as well as at elevated temperatures. Thus, BPA leaches out of polycarbonate containers into food and beverages under normal conditions of use. While exposure measurement data indicate that human beings are widely exposed to BPA, there is still considerable debate about whether BPA exposure represents a health risk.

BPA has been classified as a weak estrogen because of its relatively low affinity for the nuclear estrogen receptors (ERs), ER $\alpha$  and ER $\beta$ , and its weak bioactivity in standard tests of estrogenicity. Recently, however, it has become clear that BPA exhibits variable potency in different bioassay systems, particularly systems that may in part reflect membrane receptor-mediated actions of hormones. For example, low dose BPA administration interferes with the development of non-reproductive behaviors in female and male rodents, as well as blocking some of the effects of estrogen and androgen on the reproductive tract. This presentation will review evidence indicating that BPA may exert multiple hormone-agonist and -antagonist effects in mammals, via selective activation of hormone response pathways. Some of these effects have serious implications for human health, in particular the inhibition by BPA of synaptic remodeling processes in the brain that contribute to maintenance of normal cognitive function.

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## Real Progress: Canada's Approach to regulating BPA

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In October 2008, the Government of Canada designated BPA as “toxic” because of its effect on human health. Their associated ban of the import, sale, and advertisement of baby bottles containing BPA and placement of industry controls on the amount of BPA allowed in canned baby food set an international precedent. However, in light of additional health and environmental concerns, ongoing action is needed. The continual translation of research into advocacy is necessary to ensure governments eliminate BPA in canned food and thereby reduce harmful fetal and breast-feeding exposures. Such a broad-reaching measure is also necessary to reduce the potentially harmful wastewater levels and protect fish from low-level, toxic exposures.

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# Drinking Water Source Protection

Chairs: Simon Gautrey and Lawrence Moore

## Approaches to Intake Protection Zone Delineation

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Under the Clean Water Act, the Ministry of the Environment requires the development of source water protection plans for all intakes in Ontario. Baird has been involved in the delineation of Intake Protection Zones (IPZs) for 53 municipal intakes in Ontario, including all four types defined in the *Technical Rules*: 29 in Type A (Great Lakes); 8 in Type B (Connecting Channels); 2 in Type C (Inland Rivers); and 14 in Type D (Inland Lakes or water bodies not covered in the other types).

A standard approach was taken in the delineation of the IPZ-2s. Site-specific two or three-dimensional hydrodynamic models have been developed, with domains extending over much of the Great Lakes basin. The modeling procedure considered the unique local inputs and driving forces present on the various water-bodies. Reverse particle tracking using neutrally buoyant particles with random walk diffusion was used to delineate the IPZ-2s. The influence of physical processes such as downwelling, wave induced currents and density flows was considered. The level of uncertainty in the delineation was described. Some discussion of issues related to international and provincial boundaries was also provided.

The assumptions and challenges associated with delineating the IPZ-2s will be summarized for each intake type. Findings will be presented. A modeling approach for the delineation of the IPZ-3s will also be presented.

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## **Intake Vulnerability on the St. Clair River**

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Understanding the transport of spilled contaminants and their effect on drinking water intakes is essential in the assessment of intake vulnerability. The vulnerability of six intakes located on the U.S. side of the St. Clair River was assessed using a three-dimensional hydrodynamic model. Baird's in-house 3-D MISED model was applied to the Huron-Erie Corridor to assess transport mechanisms affecting seven hypothetical contaminant release scenarios in the St. Clair River, under high and low flow conditions. The model was calibrated with water levels and flow data collected by the U.S. Army Corps of Engineers and the U.S. Geological Survey in the spring of 2002.

The vulnerability of each intake was assessed based on the U.S. Environmental Protection Agency's Maximum Contaminant Limits (MCL) for Drinking Water. The amount of time before contaminants reached each intake after a spill and the duration of time that the MCL were exceeded are summarized. Four distinct mixing zones were identified from the contaminant release scenarios. Zone 1 was defined as the pre-contact zone, before contaminants released on the Canadian side of the river make contact with the U.S. side of the river. The second and third zones were identified as mixing zones, after contact has been made with the U.S. side of the river and the contaminant mixes across the entire width of the river (Zone 2 is partially mixed and Zone 3 is fully mixed). Dilution of the contaminant occurs in the fourth and final zone.

The study revealed the importance of cross-channel mixing in the transport of contaminants in the St. Clair River and raised the important issue of international boundaries in source water protection and planning. The findings in the study provided valuable information that may help operators respond to future spills in the St. Clair River.

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# Occurrence of Waterborne Pathogens at Offshore Drinking Water Intakes in Lake Ontario

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The Collaborative Study to Protect Lake Ontario Drinking Water began field studies in 2007 to investigate the occurrence of waterborne pathogens and water quality indicators at offshore drinking water intakes in Lake Ontario. Investigations have focused on bacterial pathogens (*Campylobacter* and *Aeromonas* species), protozoan pathogens (*Cryptosporidium* and *Giardia*), enteric viruses (culturable enteric viruses), and microbial water quality indicators like *E. coli*, *Enterococcus*, *Clostridium perfringens*, and a *Bacteroides* DNA marker for human fecal pollution. Lake-wide research cruises to date have rarely detected the microbial water quality indicators in water samples collected further than two km offshore. A pilot study started in 2007 near the mouth of the Credit River found that offshore intake water at three nearby drinking water treatment plants typically had low numbers of *E. coli* (< 5 CFU/100mL), and only rare occurrence of *Campylobacter* species and the human *Bacteroides* DNA marker. However, *E. coli* concentrations could exceed 200 CFU/100mL at locations two km offshore associated with storm events. In 2008, *Cryptosporidium* and *Giardia*, but not enteric viruses, were detected at each offshore intake, although protozoa concentrations were low. The preliminary results suggest waterborne pathogens occur sporadically at offshore intake sites.

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## A Simplified Method for the Sample Preparation for Drinking Water Organic Analyses

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The Trace Organic section of the City of Toronto laboratory was established in 1992 to develop methods and analyze Toronto's drinking water for a wide range of organic parameters. Drinking water in Toronto area historically has contained only a limited number of organic compounds, detected at low Method Detection Limits (MDLs) in the ng/L (ppt) range. The problem of chemical interference during the sample extraction process was not significant. To save the cost and resource, a simplified sample preparation procedure for a single extraction was developed for the consolidation of semi-volatile organic analytical groups in drinking water covering more than 200 parameters.

A single neutral dichloromethane Liquid/Liquid Extraction (LLE) from a 1 L sample was performed. The extract was concentrated to 1.0 mL and divided into two equal portions. One 0.5 mL dichloromethane extract aliquot was analyzed by a Gas Chromatograph-Mass Spectrometer (GC-MS) for 62 Base-Neutral compounds with MDLs of ~0.3 µg/L; 21 Acid compounds with MDLs of ~0.4 µg/L; 45 Pesticide/Herbicide compounds with MDLs of ~0.1 µg/L; 7 Haloacetonitrile compounds with MDLs of ~0.06 µg/L; 9 Taste/Odour compounds with MDLs of 5 ng/L; one Nonylphenol with an MDL of 0.4 µg/L plus Open-Characterization analysis. It was also analyzed by a GC-Time of Flight Detector for 41 NP Pesticide/Herbicide compounds (triazine herbicides, carbamates, organophosphorous pesticides and N-containing herbicides) with MDLs of ~0.1 µg/L; plus Open-Characterization analysis. The second portion of the dichloromethane extract was exchanged into isoctane and analyzed by a GC-Nitrogen Phosphorous Detector (NPD) for 54 NP Pesticide/Herbicide compounds (triazine herbicides, carbamates, OP pesticides and N-containing herbicides) with MDLs of ~0.03 µg/L. The same extract was also analyzed by a GC-dual Electron Capture Detectors (ECDs) for 51 Organochlorine OC Pesticide/Herbicide compounds with MDLs of ~2 ng/L; and 7 Polychlorinated Biphenyls (PCBs) plus Chlordane/Strobane/Toxaphene with MDLs of ~0.02 µg/L.

All analyses were successfully accomplished using a single dichloromethane LLE from a 1 L sample. The exceptions are some Haloacetic Acids (HAAs) and Phenoxyacid Herbicides parameters, which require Micro Extraction followed by diazomethane derivatization. This automated procedure has the advantage of reducing solvent usage and sample preparation time. It is a simple, effective, automated technique targeted to save time and reduce cost. It can be adopted for use by most low-budget organic laboratories for analyzing drinking water samples.

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# Quantifying *E. coli* Removal in Single, Saturated, Variable-Aperture Fractures

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More than 96 percent of the Earth's freshwater is stored in the subsurface as groundwater. This invaluable natural resource is relied upon by nations all over the world; in Canada alone, more than 10 million people depend on groundwater for their potable water supply. Thus, understanding the mechanisms which jeopardize this resource is imperative to the health and safety of people all over the globe who depend on groundwater. Traditionally, it has been thought that porous media (i.e.: silts, sands) provide significant filtration of pathogens and contaminants, while fractures in the subsurface act as highways allowing a large fraction of pathogens to travel large distances very quickly thereby contaminating otherwise clean groundwater. Recent research, however, has indicated that this may not be accurate. Therefore, the goal of this paper is to quantify the number of microorganisms retained by fractures, and relate the retention rate to the aperture field characteristics and groundwater flow rates.

To achieve this goal, the transport of *E.coli* (RS2G) through single, saturated, dolomitic limestone fractures is being quantified at the laboratory scale. *E. coli* are injected at the upstream end of the fractured rock sample and collected at the downstream end. The effects of different aperture field characteristics and flowrates on the recovery of *E.coli* will then be quantified. Preliminary data indicate that the degree of microorganism removal achieved is dependent on the size of the equivalent aperture and the specific discharge, and less so on the variability of the aperture field. In this presentation, data from a series of laboratory-scale experiments will be presented, and the relationship between microorganism retention, fracture aperture field characteristics and flow rates will be examined.

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# A Comparison of Bicolloid and Colloid Transport in Single, Saturated Fractures

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The presence of pathogens in groundwater presents serious issues to those who depend on it for their potable water supply. As development encroaches over sensitive aquifers, and land uses change, the understanding of the fate and transport of pathogens through the subsurface is becoming more important. A range of colloids and biocolloids have been employed as indicators for the presence of pathogens; however, no generally suitable indicator has been agreed upon in the literature for fractured rock environments. Therefore, the goal of this research is to compare the transport of several common indicators, including *E. coli* (RS2G) and nylon microspheres, in single, saturated, variable aperture fractures.

This goal was achieved through a series of laboratory-scale experiments conducted in three saturated fractures. *E. coli* were injected in the upstream end of the fracture under a range of flow rates, and the downstream breakthrough curves were measured. The percentage of *E. coli* recovery was calculated to evaluate the retention capacity of the fractures. Similar experiments were conducted using nylon microspheres. Due to the very different properties of the *E. coli* and microspheres, the breakthrough curves for these two indicators were quite different. This presentation will examine the differences between the breakthrough curves of the colloids and biocolloids, and offer reasons for these differences.

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# **The Well Vulnerability Concept in the Identification of Agricultural Areas for the Effective Application of Beneficial Management Practices**

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Nitrate in groundwater above the health standard of 10 mg/L Nitrate-N represents a serious health risk. The largest non-point source of groundwater contamination worldwide is nitrate originating from fertilizer application on farm fields.

For Waterloo Region, groundwater is the main source of drinking water. The Region draws approximately 75% of its municipal water supply from over 100 wells, mostly clustered in well fields. The Mannheim well field, situated in a rural area with fertile farmland planted mostly in corn, provides about 30% of the Region's water needs. Recent trends of increasing nitrate concentrations have led to an initiative by the Region to implement Beneficial Management Practices (BMPs), whereby the Region buys up sensitive lands within a Wellhead Protection Area (WHPA) and leases the fields back to the farmer under certain restrictions on fertilizer application. Areas already carrying high nitrate concentration can then recover as fresh water gradually flushes out the nitrate.

In this study, the concept of well vulnerability is used to identify the optimum location within a WHPA to apply BMPs. Well vulnerability measures expressing the impact of a contaminant source anywhere within the WHPA of a well include the maximum concentration expected in the well water, the time taken to reach that concentration, the time taken to reach some threshold concentration such as the drinking water limit, and the exposure time to above-threshold concentrations. Flow/transport modelling is used for the analysis.

By means of scenario analysis, our study demonstrates the effectiveness of BMP application within selected areas. Areas immediately surrounding the well are the obvious choice, but high-vulnerability areas lying farther away can be just as effective. The results give the concentration change to be expected, the time frame for the change to take effect, and the long-term evolution of the nitrate concentration in the well water under BMP. Thus well vulnerability modelling becomes a powerful tool for identifying areas for effective BMP application.

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## **Assessment of the Potential Impact of Beneficial Management Practices: Case Study in the Thornton Well Field, Woodstock, ON**

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Beneath lands surrounding municipal well fields in agricultural settings, excess crop nutrients may percolate through the unsaturated zone and eventually reach the water table, resulting in elevated nitrate concentrations in the public supply wells. Beneficial Management Practices (BMPs), which involve changing land-use practices to minimize excess nutrient leaching, have been applied on regional scales. An example in Ontario is the Thornton Well Field, which is the primary drinking water supply for the City of Woodstock, Ontario. Elevated levels of nitrate have been monitored in this well field for over a decade and municipal officials have implemented regional BMPs within the wellhead protection area. The wells are completed in glacial deposits, common for groundwater resource development throughout southern Ontario. In designing and implementing regional BMPs, the selection of lands to be targeted along with the nutrient loading schedules must be carefully considered. The effects of land-use changes on the concentration at the supply wells, however, are usually slow and difficult to monitor. Therefore, there is a need for a long-term predictive tool to support the decision making process. In order to quantitatively assess the BMP performance at the Woodstock site, a detailed numerical modeling strategy was developed. Physically-based models supported by extensive field data were applied for performance evaluation of different BMP scenarios. Simulations employed the integration of models developed at different spatial scales in order to capture the nature of the hydrogeologic system and complexity of the varying land use practices. Groundwater flow and nitrate transport were simulated using FeFlow. The modeling tools were used to compare the potential influence of several different BMP strategies focusing specifically on the predicted decrease in nitrate concentration in the wells and the time periods required to achieve maximum reductions. These results are being considered to support the long-term management strategies for this critical groundwater supply.

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## The Science Behind the Clean Water Act, 2006

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The *Clean Water Act, 2006* came into force on July 3<sup>rd</sup>, 2007. It ensures communities are able to protect their municipal drinking water supplies through developing collaborative, locally driven, science-based protection plans. Communities will identify potential risks to local water sources through the development of an assessment report. Ontario Regulation 287/07 and Director's Technical Rules released in the fall of 2008 spell out the technical requirements for the completion of the assessment report.

The assessment report provides the scientific basis and process to identify significant drinking water threats, which will in turn contribute to the development of source protection plans. These plans will include policies that stipulate what tools will be used to address significant drinking water threats. Some of these policies may require that risk management plans be developed to address significant drinking water threats and will require that a combination of risk management measures be used to mitigate risks posed by significant drinking water threats.

This session will provide an overview and update of the source protection program under the *Clean Water Act, 2006*. The session will specifically focus on the science behind the assessment report technical requirements, including groundwater and surface water vulnerability analysis, and threats assessment and issues evaluation.

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## Paleolimnological Tools for Source Water Protection Studies: A Case Study

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One required element of Source Water Protection Studies is the identification of threats to ground and surface water quality. Algae blooms in eutrophic lakes can represent a threat to drinking water quality by producing cyanotoxins and taste and odour problems in surface waters. Nutrient enrichment, however, is not readily accommodated in the existing SWPP guidance. In order to develop effective management measures, causes of the nutrient enrichment have to be identified and the susceptibility to and frequency of blooms needs to be assessed. Any proposal to site a new drinking water supply should also be informed by the past history of algal blooms and nutrient status. Paleolimnological techniques have been widely used to provide information on background nutrient status and to investigate sources of enrichment but they have not been applied to the SWPP process. They provide a valuable means of assessing the likelihood of future algal blooms based on past history, using both direct evidence of algal pigments preserved in sediments, or by reconstructing historic phosphorus concentrations.

Here we present a case study in Callander Bay (Lake Nipissing), where a paleolimnological study was designed to support a parallel Source-Water Protection Study for the North Bay-Mattawa Conservation Authority. A sediment core was obtained in Winter 2008, dated and analysed for fossil diatom algae. Diatom-inference models for the quantitative reconstruction of total phosphorus were applied and the reconstructed recent value validated using measured data. We describe the contribution the study made to Source Water Protection in this case and discuss implications for future studies.

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# Performance Comparison of Large Diameter Residential Drinking Water Wells

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Published scientific work suggests that residential large diameter drinking water wells are at a higher risk of contamination from surface water impacts than drilled wells. The possibility of a higher incidence of contamination of large diameter wells is attributed to site selection and construction problems such as leaking joints in the well casing, ineffective annular sealant placed between the well casing and the formation, poorly fitted lids with inadequate air filtration, wells location down gradient of septic effluent sources, and depth limitations due to improper equipment used to advance the well which results in shallow wells often situated in topographical lows. In some situations flaws in the well design were deliberate measures intended to capture surface water at sites with low groundwater yield.

Historically, residential drinking water well performance studies have focussed on existing wells; however, uncertainty in the actual well construction methods and materials, and well age and maintenance efforts have been problematic. The objective of this investigation is to assess several design changes that are thought to improve the structural integrity of large diameter wells and to determine whether one design is more prone to contamination than the others. Four large diameter residential wells have been installed at our study site in Lindsay ON. Three of these wells are constructed with enhanced construction methods (2 using a cement tile casing and 1 using a galvanized steel casing) and annular sealants, while the fourth was constructed using historical methods. An automated water extraction system removes ~1000 L/day from each well to mimic residential usage. A combination of laboratory and field testing is being used to collect pertinent data required for this performance assessment. This presentation will include a description of the well construction methods and materials, and discuss the data collected to date and ongoing well performance assessment efforts.

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# Windmill Aeration as an Effective Method of Improving Water Quality in Urban Water Bodies

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A windmill aeration system is proposed to be installed at Seneca Lake, a water body situated at the headwater area of the East Humber River watershed and surrounded by 259 hectares of wetland on the Oak Ridges Moraine.

Negative water quality impacts facing urban water bodies such as Seneca Lake include excessive nutrient levels, algal blooms, and stagnation. These problems often result in (and are the result thereof) a lack of O<sub>2</sub> in the hypolimnion due to thermal stratification. A stratified, anaerobic hypolimnion greatly stresses fish, amphibian and invertebrate populations which require sufficient levels of O<sub>2</sub> year-round.

When excessive nutrients are introduced to a water body via external loading, algae populations thrive and 'bloom'. Once they die, they sink to the hypolimnion and provide nourishment for aerobic bacteria, which in turn consume O<sub>2</sub> as they decompose the algae. Anaerobic bacteria eventually take over and begin producing toxic gasses such as hydrogen sulfide (H<sub>2</sub>S) and methane (CH<sub>4</sub>). The result is an increasingly eutrophic, murky, odorous water body.

Windmill aeration can halt this cycle by maintaining a relatively consistent supply of O<sub>2</sub> to the hypolimnion. As fresh, O<sub>2</sub>-rich water circulates, the lake destratifies, amorphous solids adsorb and store nutrients in sediment, and algae populations are thus controlled.

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# Effects of Groundwater-Surface water Interaction on Water Quality

Chairs: Jim Roy and Allan Crowe

# Characterizing Groundwater Discharge to Surface Water in Southern Ontario

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The discharge of groundwater to surface water features such as wetlands, lakes, and rivers is the endpoint of the process of shallow groundwater recharge, flow, and discharge and is critical to the maintenance of in-stream conditions in southern Ontario during periods of otherwise low flow. For example, groundwater discharge sustains surface water levels and flow between precipitation and snow melting events, thereby maintaining both water quantity and quality. Aquatic habitat and species are also dependent on the relatively constant quantity, temperature, and chemistry of groundwater discharge. Application of hydrograph separation to streamflow monitoring information for southern Ontario results in estimates of baseflow that can be interpreted relative to geological information to distinguish the component that is due to groundwater discharge and characterize the average rate and spatial variation of this discharge. Interpretations using geological mapping and stratigraphy associate higher rates of groundwater discharge, and therefore recharge and flow, with coarse textured sediments such as sand and gravel and lower rates with fine textured sediments such as clay. The interpretations indicate that roughly one-half of streamflow in southern Ontario is due to groundwater discharge, which highlights the importance of adequately representing groundwater and ground and surface water interaction in efforts to manage water quantity and quality. Natural factors such as terrain and human factors such as land and water use also influence groundwater recharge, flow, and discharge. Characteristics such as the persistence of groundwater discharge during periods of reduced water availability require further study in order to more fully understand the role of groundwater within the hydrologic cycle of southern Ontario.

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# Low Altitude and Land-Based Infrared Thermography to Identify Groundwater Discharge in NWT Rivers: Advantages and Limitations

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Groundwater discharge areas in tributaries of the Mackenzie River in the Northwest Territories (NWT), Canada, provide thermal refugia for fish by preventing river reaches from freezing in winter and creating areas of stable riverbed temperatures conducive to spawning. Infrared thermography uses heat as a tracer to locate these groundwater discharge areas by identifying where temperature contrasts exist between surface water and groundwater. Conventional methods of acquiring thermal images from satellites and airplanes tend to be expensive, often lack the resolution necessary to identify small discharge locations, and do not allow real time decisions to investigate and ground truth identified temperature anomalies. This study developed a solution to these problems that uses a handheld FLIR ThermoCam P25 infrared camera, visual video camera, infrared video capture system, and GPS in a low flying helicopter and on the ground. The advantage of such a system was its ability to: inexpensively and efficiently characterize several kilometer long reaches of river; identify springs and seeps along the rivers on a submeter scale; and allow for flexible real-time decision making to confirm anomalies and direct water quality sampling. The technique has limitations that are common to other infrared imaging methods such as: difficulty differentiating spatial anomalies from temporal influences; occurrence of different emissivity materials within the acquired images; and only being able to measure temperatures of surfaces (e.g., it cannot “see” into or through water to directly detect smaller discharges beneath rivers). Issues specifically associated with using handheld imaging equipment include: the need to properly georeference images; and accounting for water emissivity changes caused by oblique angles of imaging. Overall, the handheld system proved to be a useful reconnaissance tool for identifying surficial expressions of ground water discharges, assessing longitudinal temperature profiles in the river, and locating potential areas of hyporheic zone discharge.

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# Flow Regime of an Intermediate Scale Stream in South Western Ontario

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Runoff from intermediate (~100km<sup>2</sup>) scale catchments can be difficult to predict if there is high variability in the active channel network. Hourly discharge data from Medway Creek (205km<sup>2</sup>) in south western Ontario, shows two discrete modes of response under dry and wet conditions attributed to channel network condition. Distributed monitoring through a 42 km reach indicates that dry conditions have surprisingly sustained baseflow and local scale runoff, but COMPLETE censure of catchment scale runoff events. This surprising outcome can be attributed to a strong groundwater component to flow, significantly enhanced by capture of the upper 60 km<sup>2</sup> by a gravel pit. The natural drainage system of swamps and incised valleys has been significantly disrupted by municipal and agricultural drainage. Capture of the upstream flows by the large gravel pit may have resulted in significant restoration of the natural flow regime.

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# Novel Strategies for Surface Water Monitoring and Communication

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Current water quality monitoring is focused on determining the composition of relatively infrequent samples from sparsely distributed sites in a watershed. The resulting sparse data set may fail to identify transient or point source contamination, limiting understanding on processes and pathways of these contaminants. An alternative strategy is to undertake more restricted analysis of more frequent and densely sampled sites along a stream transect. Here ~weekly fluorescence spectra were obtained for near baseflow conditions from 30 sites along a 41km transect of Medway Creek in London Ontario. Fluorescence is an inexpensive surrogate for organic water composition indicative of source water.

The resulting 20 month data body precludes simple analysis and communication, so novel visualization tools have been developed. Fluorescence spectra were normalised to a grand median spectrum, allowing extraction of a fluorescence deviance indicative of water quality. These values were plotted for each sample on a distance upstream-day field. Upstream eutrophication occurred in summer, but with marked groundwater inputs in middle reaches and degeneration downstream. The resulting figures allow rapid identification of reaches and periods of concern, of value to environmental management and intervention.

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## Modelling *E. Coli* Transport and Persistence at the Groundwater-Beach-Lake Interface

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A numerical model was developed to study groundwater-lake interaction at beaches of the Great Lakes and transport of *E. coli* between beaches and the lakes. The model simulates 2-D transient groundwater flow below beaches and interaction with a lake using the finite element technique, and *E. coli* transport and persistence using the particle tracking technique, in response to fluctuating lake levels, variable groundwater recharge, fluctuating water table, and varying sources and levels of *E. coli*. Simulations were undertaken to examine the role of wave run-up during storms (storm duration, extent of wave run-up), physical and hydrological conditions at beaches (hydraulic conductivity, water table slope), groundwater-lake interaction, and *E. coli* factors (attachment, detachment, die-off, growth), on *E. coli* levels and persistence in the swash zone. Simulations show that infiltration of lake water and associated *E. coli* during wave run-up during a storm can rapidly produce the high levels of *E. coli* typically seen at the swash zone. But continual groundwater flow towards the lake from the beach limits the distance inland below the beach that *E. coli* can migrate to only a couple of metres beyond the maximum extent of wave run-up. After a storm, groundwater flow from the beach also affects *E. coli* persistence by a groundwater discharge at the shoreline also discharge *E. coli* back into the adjacent lake. *E. coli* attachment, detachment, and rates of growth and die-off affect *E. coli* levels and persistence of *E. coli* at the swash zone.

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# Quantifying Groundwater Discharge at the Lake-Groundwater-Beach Interface at Recreational Beaches

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Levels of the fecal indicator bacteria, *Escherichia coli* (*E. coli*), are often detected in exceedance of recreational water quality standards at beaches throughout the Great Lakes, resulting these areas being posted as potentially unsafe for swimming. It is well documented that in most coastal environments groundwater flow beneath a beach is toward the lake, and the majority of discharge occurs within a few meters from the shoreline. Thus groundwater is a potentially significant pathway for the delivery of *E. coli* to the shoreline. In this study, field work was conducted to (1) quantify the flux of groundwater, and (2) estimate the amount of *E. coli* discharging across the groundwater-lake interface at the shoreline of beaches of the Great Lakes. Data was collected by installing an array of seepage meters at the shorelines of Lake Huron, Lake Ontario, and Hamilton Harbour. Seepage meters consist of an inverted bucket that is pushed into the lakebed and attached to a collection bag. Discharging groundwater flows through the bucket and into the bag, and a flux can be calculated by dividing the volume retrieved over the duration of test. These results were compared numeric modelling simulations, and hydraulic head measurements monitored through piezometers. Near-shore groundwater samples were also analysed for *E. coli* levels and nutrient concentrations where the collection of accurate samples was feasible. Results show that groundwater seepage flux rates in the near-shore zone are spatially and temporally variable. At the sites examined in this study, flux values ranged from approximately  $10^0$  to  $10^{-3}$  cm/hr, which is within the range reported in the literature, and those predicted by our numeric modelling. This variability was observed to occur contemporaneously with fluctuations in wave run-up and infiltration, water table slope, and lake elevation. These results provide support to the hypothesis that beach groundwater, particularly that influenced by wave run-up, is indeed an important pathway through which *E. coli* can contaminate lake water at the shoreline.

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## **The Role of Groundwater-Stream Interaction on the Presence of *E. coli* in Groundwater below Beaches at Lake Huron, Ontario**

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High levels of *E. coli* in lake water is the leading cause of beach postings throughout the Great Lakes. Recent studies have shown that *E. coli* is also present in groundwater below some beaches. Research was conducted at three streams flowing across beaches on the shore of Lake Huron, south of Kincardine, to assess the possibility that streams can deliver *E. coli* to groundwater below beaches. Groundwater, lake water and streams were analysed for *E. coli*. Water table elevations and hydraulic conductivities of beach sand were measured to characterize groundwater-stream interaction and *E. coli* movement in this environment. Water table elevations indicate groundwater below beaches adjacent to streams flows toward the stream. *E. coli* were not detected in groundwater below the beach away from the stream. Although *E. coli* were detected in groundwater within a few meters of streams, the levels of *E. coli* decreased substantially away from the creek. This suggests the *E. coli* in groundwater infiltrates from a stream through short-term groundwater flow reversals during river stage increases or infiltrates downward during bank overflow; both are possible occurrences during storm events. A barrier bar exists between a stream and the lake, and groundwater flow here is from the stream towards the lake. Elevated levels of *E. coli* occur in the groundwater below the barrier bars due to transport from the creek. It is also likely that additional *E. coli* from the lake infiltrates into the barrier bar due to wave runoff and overflow of the barrier bar. In general, streams do not appear to contribute to *E. coli* levels found in groundwater below beaches. However, due to the close proximity of the water table to the surface and high levels of *E. coli* in the barrier bars, this region is the most likely for human contact to occur.

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# Improved Understanding of Mechanisms Impacting Colloid and Pathogen Transport in Saturated GUDI Environments

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It is widely accepted that riverbank filtration (RBF) can provide substantial reductions in the concentrations of both microbial and chemical contaminants while providing more consistent water quality to subsequent treatment processes. Factors such as experimental scale, subsurface heterogeneity, and variable flow paths and fluxes have made it difficult to relate laboratory outcomes to field performance. While it is generally understood that parameters such as ionic strength, the presence of natural organic matter (NOM), and media size and shape characteristics affect pathogen transport in porous media, one major limiting factor in the development of regulatory credits and predictive models is the lack of understanding of the concurrent effects of such parameters. To provide guidance for assessing the efficacy of RBF processes, the present investigation is focused on evaluating the concurrent effects of these parameters on pathogen transport in RBF environments. A factorial design experiment was executed to examine the effects of the factors using five colloids: two sizes of fluorescent microspheres (1.1 $\mu$ M and 4.5  $\mu$ M) as tracers; an environmental surface water isolate of *Salmonella typhimurium* bacteria (a known human pathogen); PR772 bacteriophage (virus surrogate, similar to PRD1); and inactivated *Cryptosporidium* parasite. The data indicate that there are significant confounding influences of the four factors on the transport of the selected colloids and biocolloids; thereby underscoring that regulations should (at present) be based more on pilot-scale demonstrations rather than being too heavily based on more theoretically determined parameters such as set back distances and physical porous media characteristics. The results also indicate that the suite of organisms being studied may also significantly impact transport outcomes, which also emphasizes the need to develop represent pilot-scale performance approaches for demonstrating effective in situ (subsurface) filtration.

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# Screening of Groundwater Quality Discharging to Selected Urban Rivers

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Contaminated groundwater discharging to surface water can adversely affect aquatic ecosystems. In urban and industrialized areas, groundwater-quality impacts to surface-water ecosystems have been generally detected as a consequence of land-based investigations of groundwater contamination. Beyond the local scale, there have been few studies that have examined the nature and extent of contaminant loading to aquatic ecosystems from groundwater discharge. In this preliminary study, we report on an approach to screening urban rivers and streams, at the reach-scale, for contaminants in discharging groundwater. The methodology used a drive-point technique to sample groundwater from below the stream bed (e.g. typically 50 cm) at an interval of approximately 10 m along the river. Groundwater samples were analyzed for a range of contaminants and general chemistry. This screening method was performed in three urban rivers with at least one known source of groundwater contamination in proximity. The known contaminant plumes at each site were detected and roughly delineated using the screening methodology. In addition, areas of previously-unknown groundwater contamination were also identified at each site. These preliminary findings suggest that this approach may be useful for assessing cumulative impacts of contaminated groundwater discharging to surface water ecosystems.

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# Evaluation of Stormwater Infiltration Trench Performance and Potential for Groundwater Contamination

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Stormwater infiltration practices, namely infiltration trenches, are source control mechanisms that are implemented in urban developments with reduced natural permeable surfaces. Urbanization leads to increased quantity and decreased quality of urban runoff that may pose acute or chronic threats to receiving water quality. As a result, infiltration practices are designed to encourage infiltration of non-point source pollution into the ground as a means of water quality management and flood protection.

Conventionally, infiltration trenches are installed as storage reservoirs for urban runoff that are comprised of an excavated trench that is backfilled with a coarse porous medium. The underlying subsoil acts as a filter to remove solid particles and associated pollutants from the fluid within the porous media, prior to discharging into the saturated zone. Despite the development of design criteria for infiltration trenches, these systems continue to fail (i.e., overflow, headloss development, or chemical breakthrough). The limited research on the long-term performance of these systems has emphasized the role of physical filtration mechanisms within porous media filters to address concerns surrounding system failure, namely groundwater contamination and filter clogging.

A continuous macroscopic depth filtration model was developed to investigate the clogging potential of the underlying sand filter. The computer simulation model is based on theory from fixed-bed granular filtration of monodisperse suspensions and utilizes site specific filtration trench design, meteorological, and filtration modelling parameters. The performance model also evaluates the total mass of deposited suspended solids and the associated heavy metals which may threaten groundwater quality.

This continuous model furthers the understanding of temporal and spatial changes in system performance for the development of more appropriate design criteria and more suitable maintenance regimes. Experimental investigations verify a significant reduction in hydraulic conductivity and buildup of headloss within the upper layers of the filter due to continuous deposition of fine suspended solids.

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## Groundwater Discharge Affects Alpine Lake and Stream Algal Communities

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Aquatic ecosystems in groundwater-dominated streams in alpine watersheds commonly differ from those in streams dominated by glacier-melt or runoff of snow melt and precipitation. However, the role of groundwater discharge zones on the patchiness of aquatic ecosystems in alpine streams and lakes has received little attention to date. Here we report on two sites in the Lake O'Hara watershed in the Canadian Rocky Mountains where groundwater discharge has altered the water quality and benthic algae taxonomic composition. At one site, groundwater discharges as a large spring to a lake outlet stream, altering properties such as temperature, pH, major ion and nutrient concentrations, and turbidity, both down stream and across the stream width. These changes correspond to a change in algae species and abundances, and a substantial increase in algal biomass. At the other site, a subsurface plume of treated sewage water with elevated nutrient and major ion concentrations is identified discharging to a lake. This discharge area coincides with elevated chlorophyll a levels and a major shift in taxonomic composition to taxa that are commonly associated with anthropogenic nutrient loading.

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# Emerging Contaminants Issues

Chairs: Vimal Balakrishnan and Peter Vanrolleghem

# Glyphosate Detection in Water by Enzyme-Linked Immunosorbent Assay (ELISA)

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Glyphosate is a broad-spectrum herbicide that is commonly used for weed control. Laboratory toxicology studies have shown that glyphosate-containing products negatively impact health. In Ontario, glyphosate-containing herbicides are sold under names such as Roundup<sup>®</sup> and Glyfos<sup>®</sup>. Glyphosate is regulated under the *Safe Drinking Water Act, 2002* (SDWA), Ontario Regulation 169/03; the Ontario Drinking Water Quality Standard (ODWQS) maximum acceptable concentration (MAC) is 0.28 mg/L or 280 ng/mL.

The objective of this study was to determine whether an enzyme-linked immunosorbent assay (ELISA) in microplate format would be able to either quantify or qualitatively screen glyphosate in water samples. ELISA is a cost-effective, biochemical method. Currently, liquid chromatography-mass spectrometry (LC-MS) is used to quantify glyphosate in water samples. ELISA has a narrow dynamic range of 0.15 to 5 ng/mL and quantitation is achieved using serial 10-fold dilution of the sample. Four concentrations of glyphosate ranging from 20 to 160 ng/mL in deionized water were examined both with and without sodium thiosulphate preservative. Results showed that ELISA is not affected by preservation of the sample. ELISA appeared to be more accurate than LC-MS based on average recovery (103% versus 87%, respectively) and the square of correlation between observed and expected results (0.995 versus 0.804, respectively). This feasibility study showed that ELISA could be accepted to quantitatively measure glyphosate at one-tenth of the MAC. Furthermore, the use of ELISA as a qualitative screening method would reduce LC-MS workload by 97%, based on the results of 502 water samples submitted to the Ontario Ministry of the Environment in 2007.

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# Groundwater Nitrate and Nitrous Oxide in the Black Brook Watershed: Insights from Stable Isotopes

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Nitrate is a common contaminant of groundwater in agricultural areas, largely due to the over-application of nitrogen fertilizers and manure. In order to design effective nitrogen (N) management strategies that reduce N loading to surface water and groundwater resources, detailed information is required about the sources and fate of nitrate in the sub-surface. Several studies are currently underway at the Black Brook Watershed (BBW), located near Grand Falls, New Brunswick. The BBW is part of Agriculture and Agri-Food Canada's, Watershed Evaluation of Beneficial Management Practices (WEBs) program, and is within the province's potato producing region. Current research at the site includes the use of stable isotope analysis of nitrate ( $\text{NO}_3^-$ ) and nitrous oxide ( $\text{N}_2\text{O}$ ) to: 1) determine the dominant source(s) of nitrate to groundwater, 2) determine if natural nitrate attenuation by denitrification is occurring, and 3) test the feasibility of using  $\text{N}_2\text{O}$ , an alternate product of denitrification, as a sensitive indicator of denitrification activity in groundwaters.

Groundwater was sampled for chemical and isotopic analyses from domestic and municipal wells and piezometers in November 2007, May/June 2008, and October/November 2008. Groundwater nitrate concentrations ranged 0.04 to >20 mg N/L, with an average value of 8.3 mg N/L. Nitrate isotope analysis completed to date indicates that groundwater nitrate is predominately derived from the nitrification of chemical N-fertilizers. Nitrate isotope data did not show any evidence of denitrification activity. However, denitrification rates may be small or denitrification may proceed to completion in microzones and therefore not be detectible through the measurement of nitrate concentrations or isotopic ratios. Dissolved  $\text{N}_2\text{O}$  concentrations were 1 to 1,000 times atmospheric equilibrium levels, indicating the presence of a source of  $\text{N}_2\text{O}$  to groundwater. Isotopic analysis of  $\text{N}_2\text{O}$  ( $\delta^{18}\text{O}$ ,  $\delta^{15}\text{N}$ ) will be used to confirm whether or not groundwater  $\text{N}_2\text{O}$  is being produced by denitrification.

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# Plant $^{15}\text{N}$ as an Indicator of Soil Nitrogen Cycling in an Agricultural Catchment

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When nitrogen (N) availability exceeds biological demand, excess N, especially nitrate ( $\text{NO}_3^-$ ), may subsequently pollute ground and surface water. Excess N has several potential fates, which are controlled by the net effects of numerous N cycling reactions in the soil that are often difficult to measure directly. N cycling in soils is controlled in large part by soil moisture, as it affects microbial activity and soil redox conditions. Stable isotope geochemistry is a powerful tool that provides information on N sources and processes. This study uses crop N isotope ratios ( $^{15}\text{N}/^{14}\text{N}$ ;  $\delta^{15}\text{N}$ ) to provide insights into the net effects of soil N cycling and N fate. This research was conducted at the Strawberry Creek Watershed (SCW), an agricultural research watershed located between Kitchener-Waterloo and Guelph, Ontario.

The SCW exhibits elevated  $\text{NO}_3^-$  concentrations in groundwater, tile discharge, and the stream itself. Previous isotopic work revealed that this nitrate is largely derived from chemical fertilizer and manure applications. Field-scale hydrological processes lead to areas where the fate of applied N differs, which has an isotopic effect on the residual N that is available to plants. Results of this study indicate significant patterns in the  $\delta^{15}\text{N}$  signature of plant tissue, in both temporal and spatial scales. At the plot-scale where soil conditions are similar, there is little to no variation in foliar  $\delta^{15}\text{N}$  values, but at the field-scale there appears to be a significant amount of variability that is related to soil moisture and N loss. Effective agricultural N management requires a better understanding of N fate in the soil zone to reduce  $\text{NO}_3^-$  leaching to ground and surface water.

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# **NO<sub>3</sub><sup>-</sup> and N<sub>2</sub>O at the Strawberry Creek Catchment: Tracing Sources and Processes Using Stable Isotopes**

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Nitrate (NO<sub>3</sub><sup>-</sup>) contamination in agricultural watersheds is a widespread problem that threatens local drinking supplies and downstream ecology. Conventional agricultural practises are a significant source of nitrous oxide (N<sub>2</sub>O), a potent and long-lived greenhouse gas. Stable isotope ratios of NO<sub>3</sub><sup>-</sup> and N<sub>2</sub>O (<sup>15</sup>N/<sup>14</sup>N and <sup>18</sup>O/<sup>16</sup>O) were successfully used in an agricultural setting to identify sources of NO<sub>3</sub><sup>-</sup> contamination and elucidate nitrogen (N) cycling processes that are often difficult to identify using traditional geochemical approaches alone. Concentrations and stable isotope ratios of NO<sub>3</sub><sup>-</sup> and N<sub>2</sub>O were measured in a first-order catchment near Merryhill, ON. Samples were collected in the catchment during baseflow, storm and snowmelt conditions from riparian-zone groundwaters, agricultural drainage tiles, and at the outflow of Strawberry Creek.

NO<sub>3</sub><sup>-</sup> inputs from tile drainage was mainly derived from the nitrification of soil organic N and manure fertilizer N. NO<sub>3</sub><sup>-</sup> present in the stream was mainly influenced by tile inputs during periods of high stream flow and groundwater inputs during low flow periods. There was little evidence of denitrification in the drainage tiles, but δ<sup>15</sup>N-NO<sub>3</sub><sup>-</sup> and δ<sup>18</sup>O-NO<sub>3</sub><sup>-</sup> results showed that in-stream denitrification had occurred.

Throughout the entire study drainage tiles and the stream were a source of atmospheric N<sub>2</sub>O, and this was independent of hydrological conditions. δ<sup>15</sup>N-N<sub>2</sub>O and δ<sup>18</sup>O-N<sub>2</sub>O data suggests that denitrification was the dominant production pathway. Additionally, isotopic analysis of stream N<sub>2</sub>O revealed that gas exchange between the dissolved and atmospheric pools of N<sub>2</sub>O was significant.

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# The Gendered Implications of Chronic Chemical Exposures through Canadian Drinking Water: Preliminary Research Findings

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This research evaluates, from a precautionary perspective, the gendered impact of chronic low level chemical exposures that arise from Canadian drinking water sources. The project consists of matching current drinking water data with emerging epidemiological research that links chronic low level chemical exposures, at certain key developmental stages, with various environmental health harms.

There is a growing base of evidence linking low level exposures to lead, nitrates and other chemicals routinely found in Canadian drinking water sources to various subclinical adverse health outcomes. These results call into question previously considered “safe” levels of chemical exposures. For some chemicals, it is increasingly clear that no threshold for health effects exists, particularly when considering exposures during certain key windows of vulnerability, such as the prenatal, postnatal, and adolescent phases. As trace amounts of a range of chemicals are routinely found in Canadian drinking water, there is reason to re-assess what the adverse health impacts of these chemicals might be, based on the latest evidence in environmental health research.

This paper presents the preliminary findings from five case studies to highlight the low-dose chronic exposures to chemical contaminants that affect Canadian drinking water sources and the evidence of gendered environmental health risks associated with those levels of exposure. The locations and contaminants presented are: Eastern Ontario (Lead); Abbotsford, British Columbia (Nitrates); Pickering, Port Hope, and Pembroke, Ontario (Tritium); Fort Chipewyan, Alberta (Arsenic); and Hay River, Northwest Territories (Cadmium). The results of this study will be used to inform policy making on relevant standards and other regulatory aspects of the Canadian drinking water supply.

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# Environmental Modeling

Chairs: Ferdous Ahmed and Onita Basu

## **Calibration and Testing of a Simple Mass Balance Model for Quantifying Stormwater Management Benefits of Extensive Green Roofs**

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The accelerated urban growth has affected many of the earth's natural processes. Impervious surfaces like asphalt, concrete rooftops, roads, and parking lots are replacing the natural landscape which is affecting delicate ecological balances. The increase of impervious area due to urbanization also increases the volume and rate of urban stormwater runoff. High peak flows from intense rainfall events result in increased stream flow velocities, can scour stream beds and increase stream bank erosion. To aid in the management of stormwater runoff a variety of stormwater best management practices (BMPs) have been developed. More specifically, most regulations are centered around structural (constructed) BMPs, which typically have focused on attenuating peak discharges of rainfall events by detaining or retaining stormwater. Greenroofs have been used as a stormwater BMP for over two decades in Germany and have now been gaining popularity in the United States for over a decade but the progress has been slow. One reason is the lack of published data on their performance, especially in the United States. Further, the performance of greenroofs is expected to be greatly influenced by regional differences in hydrology, climate, and the design configuration of the roof itself. There is therefore need to conduct research on the performance of greenroofs at a variety of locations throughout North America.

A ~3500 sq ft extensive green roof at Lawrence Technological University in Southfield, MI, USA has been instrumented to monitor both rainfall and green roof runoff. Data has been collected for eighteen storm events between April – October 2008. Based on this data, a mass balance model has been calibrated and tested to simulate stormwater management benefits of the green roof. The results show good agreement between measurements and model predictions for both green roof peak runoff rate and total runoff volume. The approach used is thus expected to be useful for evaluating the benefits of extensive green roofs as a structural BMP for stormwater management.

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# Environmental Risk Assessment and Adaptive Management Implementation in Hamilton Harbour

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In water quality assessment and management, mathematical models are used to understand ecological processes, to predict aquatic ecosystem dynamics, to evaluate management alternatives/climatic scenarios, and to support the policy making process. Environmental models involve substantial uncertainty due to the structure of the models and parameters used. Failure to account for model uncertainty could provide flawed results and lead to the misallocation of limited resources during the costly implementation of environmental management schemes. Our study aims to develop a Bayesian Network of eutrophication models for the Hamilton Harbour in Western Lake Ontario and make use of Bayesian uncertainty analysis techniques for rigorously assessing the uncertainty in model predictions. Bayes' Theorem provides a convenient means to combine existing information (prior) with current observations (likelihood) for projecting future ecosystem response (posterior). Therefore, we believe that the Bayesian techniques are more informative than the conventional model calibration practices (i.e., mere adjustment of model parameters until the discrepancy between model outputs and observed data is minimized) and can be used to refine our knowledge of model input parameters, and obtain predictions along with uncertainty bounds for modelled output variables. Some of the anticipated benefits from this research, such as the elucidation of the key causal links associated with the formation of toxic cyanobacteria (*Microcystis*) blooms, the estimation of critical loads for pollutants based on acceptable probabilities of compliance with water quality goals, the optimization of the sampling design of future monitoring programs of the system, and the alignment with the policy practice of adaptive management, will aid stakeholders and policy makers when making decisions for sustainable environmental management in the Hamilton Harbour.

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# Comprehensive Review and Compilation of Pre-treatments for Anaerobic Digestion in Municipal Wastewater Treatment Plants

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Municipal wastewater treatment plants (WWTPs) using anaerobic digestion (AD) processes to handle secondary sludge (WAS) are common-place. Advantages to AD as compared to aerobic digestion are well known and include waste conversion to methane, low nutrient needs, and no oxygen requirement. Methane production benefits sludge handling/disposal and energy demands. As populations grow worldwide and sludge land-use policies become more stringent WWTPs can experience difficulties performing within environmental and financial constraints.

Hydrolysis of organic matter is considered to be the rate-limiting step in WAS degradation. Where WWTPs have disproportionately high sludge handling/disposal costs, treat wastes of low biodegradability, and/or generate minimal daily biogas, pre-treatments (PTs) can be incorporated as sustainable improvements. Such PTs include mechanical, thermal, chemical, biological, and combinations of these. PTs further hydrolyse the WAS feed, thus improving the AD step.

A thorough review of pre-treatment studies has been completed. Qualitative benefits based on observations such as particle size and volatile fatty acids distribution have been gathered. Quantitative benefits based on results such as chemical oxygen demand (COD) solubilization, volatile suspended solids (VSS) reduction, and biogas production have been compiled in a comparative model using Microsoft Excel. A preferred process is prescribed based on the assembled result ranges and WWTP operators/designers data inputs (e.g. sludge characteristics and digestion parameters). Once complete, the model will also base its output on the energy/economic balances of pre-treatment incorporation. Field-contacts have been established to obtain relevant unit capabilities and operation/maintenance costs. Though many variables affect PT/AD performances and few full-scale results are available, this tool can guide design through comparison and/or demonstrate feasibility through environmental/financial impacts.

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## Using Watershed Models to Derive Design Flood Flows

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A mathematical model of the Tay River basin has been used to estimate the design flows for the purpose of floodplain mapping. The model comprises of several rainfall-runoff modules, a river and lake network, and water control structures – all connected together. Long-term precipitation and temperature data have been used to simulate the runoff from the watershed, which are then routed through the rivers and lakes. The simulated flow hydrograph was then used for estimating the design flows. Peak annual flows were extracted from the flow series, and a standard flood frequency analysis was performed. This yielded the design flood flows with return periods ranging from 2 to 500 years. These values were compared with other estimates and found to be reasonable.

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# Modeling Total Phosphorus Load to a Large Lake with Infrequent Historical Monitoring

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Lake of the Woods (LoW) is a large (385,000ha), freshwater lake, that is within the boundaries of the provinces of Ontario and Manitoba and the state of Minnesota. With the presence of toxin-producing cyanobacteria, and seasonally-elevated nutrient concentrations recorded, there are increasing concerns that LoW water quality has deteriorated in the recent years. In addition to local concerns in the three jurisdictions, the issue of LoW water quality has wider significance to Winnipeg. Nutrient loading to Lake Winnipeg via the Winnipeg River watershed is the second largest source of nutrients to Lake Winnipeg (after the Red River), with more than half of the Winnipeg River flow originating from LoW. Shoal Lake, also closely connected to LoW, is the main source of drinking water to Winnipeg. Thus, a clear understanding of the nutrient sources influencing LoW water quality is needed to not only provide lake management goals for LoW, but also Lake Winnipeg and Shoal Lake. A comprehensive review of both the natural and anthropogenic sources of phosphorus to LoW has been compiled using existing hydrology and nutrient data collected by various agencies. Mass balance measurements have been utilized to evaluate total phosphorus (TP) loading to the lake. Due to the size and hydrological complexity of LoW, there is a lack of TP monitoring data available, especially within catchment tributaries. Thus, the use of nutrient flux models that incorporate land-use and climate variables has been initiated to predict annual TP fluxes and address the role of anthropogenic phosphorus loading to LoW. In particular, the integrated catchments model of phosphorus dynamics (INCA-P), a mass-balance model which tracks the temporal variations in the hydrological flow paths and phosphorus stores, in both the land and in-stream components of the catchment, has been used to stimulate flow and TP concentrations within tributaries predicted to have a greater influence on the overall LoW TP budget.

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# Landscape-Scale Control on Carbon Budget of Lake Simcoe: A Process-Based Modelling Approach.

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This study presents a landscape scale modelling of dissolved organic carbon (DOC) dynamics in Lake Simcoe. The hypothesis that increasing human development in Lake Simcoe catchment will provoke changes in land use that will alter DOC export to Lake Simcoe was tested. Lake Simcoe catchment has experienced increasing population growth in the past decades. This has led to more rigorous catchment manipulation and land use changes. Land use change enhances mineralization of soil carbon and modifies DOC fluxes to the riverine aquatic systems as a result of altered terrestrial-aquatic carbon mediated processes. This will have impact on the future of Lake Simcoe water resources as DOC impair water quality and influence other water quality parameters such as trace metal toxicity and nutrient dynamics. However, less is known about the effect of land use changes on DOC fluxes in the environment. We have used a processed based biogeochemical model (INCA-C) to evaluate the potential effect of land use changes on the export of DOC to Lake Simcoe. The results show that increasing modification of land use within the Lake Simcoe watershed has large quantitative impact on the carbon budget of Lake Simcoe.

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# Predicting the Frequency of Water Quality Standard Violations Using Bayesian Calibration of Eutrophication Models

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The water quality standard setting process usually relies on mathematical models with strong mechanistic basis, as this provides assurance that the model will more realistically project the effects of alternative management schemes. From an operational standpoint, the interpretation of model results should be coupled with rigorous error analysis and explicit consideration of the predictive uncertainty and natural variability. In this study, our main objective is to attain effective model calibration and rigorous uncertainty assessment by integrating environmental mathematical modeling with Bayesian analysis. We use a complex aquatic biogeochemical model that simulates multiple elemental cycles (org. C, N, P, Si, O), multiple functional phytoplankton (diatoms, green algae and cyanobacteria) and zooplankton (copepods and cladocerans) groups. The Bayesian calibration framework is illustrated using three synthetic datasets that represent oligo-, meso- and eutrophic lake conditions. Scientific knowledge, expert judgment, and observational data were used to formulate prior probability distributions and characterize the uncertainty pertaining to a subset of the model parameters, i.e., a vector comprising the 35 most influential parameters based on an earlier sensitivity analysis of the model. Our study also underscores the lack of perfect simulators of natural system dynamics using a statistical formulation that explicitly accounts for the discrepancy between mathematical models and environmental systems. The model reproduces the key epilimnetic temporal patterns and provides realistic estimates of predictive uncertainty for water quality variables of environmental management interest. Our analysis also demonstrates how the Bayesian parameter estimation can be used for assessing the exceedance frequency and confidence of compliance of different water quality criteria. The proposed methodological framework can be very useful in the policy-making process and can facilitate environmental management decisions in the Laurentian Great Lakes region.

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# Modeling of Mobility of 17 $\alpha$ -Ethinylestradiol in Different Environmental Conditions

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The presence of the endocrine disrupting compounds (EDCs) in the environment has become an emerging interest worldwide, because of their possible effects on ecosystems. A number of studies have correlated its occurrence to adverse effects in wildlife and fish, however, these compounds might also interfere with the reproduction of humans, live-stock and wild-living animals. The synthetic estrogenic compounds were found to be highly persistent in the environment. For example, 17 $\alpha$ -ethinylestradiol (EE2), which is a widely used in hormone replacement therapy and oral contraceptive formulations, has been detected in the nanogram per liter range in discharged domestic effluents, surface and ground waters, and subsequently in drinking water. As a result of its substantial potency and estrogenic activity, 17 $\alpha$ -ethinylestradiol (EE2) has been chosen as the probe compound in this study.

The aim of this research was to achieve a deeper insight in the partitioning of synthetic steroidal estrogenic compounds into different environmental matrices including colloids (clay minerals, iron oxide and humic acid). The sorption of EE2 was studied under different pH values, carefully chosen to reflect its effect on aqueous chemistry as well as sorbent and sorbate charge. The experimental investigation permitted on development of a model predicting partitioning of EE2 to suspended particles and water column. In addition, a model showing EE2 behavior in soil layers was introduced. The validation of this model showed a good consistent with experimental data. This approach permitted to assess a potential mobility of such EE2 in subsurface and surface water.

The outcome from this study relates to the partitioning of EE2 in a large spectra of environmental conditions, e.g. to uppermost sediments, to suspended materials transported by water current, effect of effluent quality discharged from municipal and industrial WWTP. The results also show a possible transport of EE2 into groundwater across geological strata.

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## **Sedimentological Analysis and 3-Dimensional Modeling of a Shallow Quaternary Aquifer in the Georgetown Region, Ontario.**

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The Regional Municipality of Halton is undertaking an in-depth study of the aquifers in the Georgetown region with the aim of protecting existing groundwater resources and identifying new and sustainable sources of potable water. Georgetown residents are currently supplied with drinking water from aquifers that lie within thick successions of Quaternary age sediment infilling buried bedrock valleys. However, relatively little is known of the three dimensional extent, geometry, or lateral and vertical connectivity of these aquifers. This research project involves detailed sedimentological analysis of the Maple Formation, a sand- and gravel-rich unit of Quaternary sediment that is exposed in several sand and gravel pits in the village of Limehouse, in the Georgetown area, and which may serve as an important near-surface aquifer or aquifer recharge zone. Integration of field data with waterwell records and borehole data allows the creation of a computer-based 3-dimensional model of the structure of the Maple Formation.

Sedimentological logging and analysis of the exposed Maple formation shows it to consist of interbedded gravels, sands, silts and clays. Gravels are poorly to well sorted and occur as a locally continuous unit of large (>1m) gravel foresets that overlie laminated and rippled sands. These cross bedded gravels are in turn overlain by an extensive unit of massive, rippled, laminated and channelized clays, silts and fine sands. The Maple Formation is interpreted as an assemblage of ice-contact outwash and glaciolacustrine sediments that represent rapid sedimentation within a northwest-southeast trending buried bedrock valley re-entrant in the Niagara Escarpment. The locally continuous coarse sediment (gravels) sealed by extensive fine-grained materials (silts and clays) provide an excellent depositional analog with which to model the structure of more deeply buried aquifers within valley infill sediments of the Georgetown area.

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## **SubWet 2.0: A Modeling Approach to Treatment Wetland Design, Evaluation, and Management**

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The United Nations Millennium Development Goal Number 7, Targets 9 and 10 call for reversing the loss of environmental resources as well as halving by 2015 the proportion of people without access to safe drinking water and sanitation. Untreated domestic and industrial wastewater discharges are some of the main causes of water quality degradation, alteration of ecosystems and water related diseases amongst others. Treatment of sewage using appropriate technological approaches prior to disposal has become a priority in the present decade and will continue into the future.

To support the above mentioned goals, the United Nations Environment Programme promotes and facilitates Environmentally Sound Technologies (ESTs) and related capacity building activities in a variety of focal areas including Water and Sanitation. Phytotechnology, considered as a technological approach based on the use of the benefits and services that plants provide to mankind and nature is becoming a popular approach to sanitation. Due to its characteristics and when compared to other conventional approaches Phytotechnology is comparatively less costly, requires less energy and does not require highly skill personnel for its application. The use of natural and artificially constructed wetlands is considered as one of the efficient applications of Phytotechnology for wastewater treatment. The applications require solid scientific information coupled with the use of models to replicate the occurring process and provide practical tools for sanitation.

UNEP-DTIE-IETC has developed SubWet, software to be used in the design of subsurface horizontal flow systems artificial wetlands for water quality improvement and treatment. Originally designed for warm climates, SubWet 2.0 is an upgraded version that accommodates temperate and cold climatic conditions including summer Arctic and temperate winter conditions. The model simulates removals of nitrogen (including nitrogen in ammonia, nitrate and organic matter), phosphorus and BOD<sub>5</sub> in mg/l and the corresponding removal efficiencies (in %).

SubWet 2.0 has been developed to support decision-making processes by assisting experts and water managers in the design and evaluation of constructed wetlands to improve water quality and treat domestic wastewater. Furthermore, SubWet 2.0 can also be used as a tool to improve the efficiency of low or non-performing systems. Due to its characteristics this software is very useful for training technicians and students who are interested in modeling natural and artificial wetlands used for wastewater treatment and can also be used as a tool by engineers, and regulators.

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# Genomics Data in Risk Assessments and Application in Regulatory Policies

Chairs: Bin Zhu and François Gagne

## Generation and Validation of Survival Data of *Bacillus* Strains on the Domestic Substance List in Water Microcosms

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Microbial biotechnology products (wild-type or genetically modified) are used for industrial production, bioremediation, bio-control, etc. After their commercial release, live cells may persist and disseminate in the environment. One component required by regulatory agencies is the development of methods for detecting the survival of live cells and the generation of persistence trend data in relevant environments. In this study, the persistence of some *Bacillus subtilis* strains on the Domestic Substances List (DSL) was monitored after introduction into river water microcosms containing indigenous microbial communities. During incubation, some cells may lose viability but still carry DNA; DNA-based detection methods may overestimate the number of live cells. Propidium monoazide (PMA) was reported to be highly selective in penetrating only into dead bacterial cells with damaged membranes but not to live cells with intact cell membranes and walls. We tested and verified the effectiveness of PMA in binding DNA of dead cells in the *B. subtilis* strains. Subsequently, we used PMA to treat *Bacillus* cells sampled from river water microcosms. DNA of *Bacillus* cells was quantified by real time PCR, and then converted to the number of live cells. The results showed that live cells of the *B. subtilis* strains can persist from only a few days to one hundred days after introduction into the microcosms at  $10^7$  cells/mL. To validate the data from real time PCR analyses, diffusion chambers containing *B. subtilis* strains were incubated in flow river water to investigate the persistence of live cells by plating. The result from diffusion chamber experiments was consistent with that of real time PCR analyses, validating the effectiveness of real time PCR analyses.

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# The Strategic Applications of Genomics in the Environment Program

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Established in 1999, Environment Canada has been an active participant of the Federal Government's Genomics Research and Development Initiative (GRDI) by delivering its Genomics R&D funding through the Strategic Applications of Genomics in the Environment (STAGE) program. Under the aegis of this program, the Department has focused its department-wide environmental genomics activities exclusively towards support for the establishment of internal expertise in the responsible application of genomic technologies - with the resultant science based evidence being made available freely to EC staff with the responsibilities for regulatory, assessment and enforcement. The technology has now matured and has the potential to provide decision- and policy-makers with a better understanding of how and why different species differ in sensitivity and response to toxic compounds, and how this work can influence future policies and regulations concerning risk assessments, standardized test methods, notification and handling of toxic substances, and prevention or treatment of environmental contamination.

The Science and Technology Integration Division is now in the process of determining the future direction of the STAGE program, which will be guided by the proposed new GRDI model with an expanded role to foster a strategic, focused, flexible and collaborative approach. It would be divided into three components to support:

- 1) Individual department/agency priorities and mandates through predetermined allocations based on business case analyses and aligned to common directions but retaining independence;
- 2) Shared strategic priorities addressing enduring and emerging issues through allocations based on a horizontal competitive process. and
- 3) Common functions for increased effectiveness and rationalization of resources and expertise.

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## **Occurrence of the Transgenic Corn cry1Ab Gene in Freshwater Mussels (*Elliptio Complanata*) near Corn Fields: Evidence of Exposure by Bacterial Ingestion.**

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The purpose of this study was to examine the contamination of cry1 and cry1Ab genes from *Bacillus thuringiensis* and transgenic corn in feral freshwater mussels collected from sites located in proximity of corn fields. In addition, mussels were transplanted for 2 months to a site in the Huron River, upstream to the Richelieu River, which is subject to intensive corn farming. Mussels were significantly contaminated by both genes in their gills, digestive glands, and gonads, as determined by qPCR methodology. Gene sequence analysis confirmed the presence of transgenic corn cry1Ab gene in mussel tissues. In an attempt to explain the presence of the transgene in mussel tissues, heterotrophic bacteria were grown from surface water and sediment samples on agar plates in the Richelieu River in May and August. The transgene was found at two out of six surface water samples and in one sediment sample. A significant correlation was obtained between the levels of cry1 from Bt and cry1Ab from transgenic corn. The study revealed that exposure to transgenic corn cry1Ab gene in mussels seems to proceed by ingestion of microorganisms during feeding.

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# DNA Microarray Detection of Virulence and Antibiotic Resistance Genes in *Escherichia coli* Isolates from Fecal Sources of Contamination in Hamilton Harbour

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The monitoring of water for microbial contamination from fecal sources conventionally relies on the detection of indicator organisms such as *Escherichia coli*. Different strains of *E. coli* can be either harmless commensals or pathotypes. Culture-based methods of detection, such as membrane filtration, do not provide detailed information about pathogenic potential or source of contamination. A DNA microarray was designed capable of simultaneously screening *E. coli* isolates for 450 virulence factors and antibiotic resistance genes. The gene profiles generated allow the assignment of isolates into different *E. coli* pathotypes (e.g. extra-intestinal pathogenic *E. coli* or ExPEC). Furthermore it can be used to identify individual host specific probes that may be used to identify the source of *E. coli* contamination in water. A previous study found that 29% of 308 *E. coli* isolates collected from Hamilton Harbour, Ontario were potentially pathogenic\*. An additional 300 isolates from fecal sources of contamination (treated and untreated sewage, droppings from Canada Geese, ducks, gulls, cats, dogs and beach sand) were analyzed. Results show differences in virulence factors and antibiotic resistance are found in isolates originating from different fecal sources.

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\* K. Hamelin, G. Bruant, A. El Shaarawi, S. Hill, T. A. Edge, S. Bekal, J. M. Fairbrother, J. Harel, C. Maynard, L. Masson, and R. Brousseau. A virulence and antimicrobial resistance DNA microarray detects a high frequency of virulence genes in *Escherichia coli* isolates from Great Lakes recreational waters. *Applied and Environmental Microbiology* 72 (6):4200-4206, 2006.

## Using DNA Microarray Technology to Test *E. coli* Pathogenicity in Wastewater Effluents

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Standards for the microbiological quality of waters do not consider the distribution of pathogenic and non-pathogenic strains in natural populations of bacteria. The risk to humans is proportional to the exposure to pathogenic strains, which may vary for the same total count of a population of interest. We used *E. coli* as a model organism to evaluate this hypothesis, and determined the distribution of potentially pathogenic and non-pathogenic *E. coli* using DNA microarray technology.

Three sets of 35 *E. coli* isolates were obtained from effluent samples from a biofilter, advanced physicochemical, and activated sludge wastewater treatment plant, prior to disinfection. The customized DNA microarray was used to simultaneously test for the presence of over 200 virulence or virulence related genes in the genome of the various isolates. Determining the virulence gene composition of individual isolates enabled their classification into pathotypes and phylogenetic groups in addition to providing information on endogenous antibiotic resistance genes.

Potentially virulent *E. coli* isolates comprised 48.6% of *E. coli* isolates from the biofilter effluent, 45.7% from the physicochemical effluent and a surprisingly low 5.7% from the activated sludge effluent. For comparative purposes, prior work showed that only 28.6% of *E. coli* isolates taken from natural waters in the Great Lakes were potentially pathogenic.

Regarding the presence of antibiotic resistance genes, both virulent and non-virulent *E. coli* isolates carrying antibiotic resistance outnumbered those not carrying resistance genes, for all three plants.

The ability to differentiate pathogenic vs. non-pathogenic *E. coli* isolates may give a better indication of the risk of exposure to pathogens, compared to using the total number of indicator organisms.

The reasons for differences in the effluents from the three treatment plants can only be speculative at this point.

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# Biotic and Abiotic Factors that Trigger Toxin Production in Cyanobacteria

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The biological function of cyanobacterial toxins like microcystin (MC) in aquatic foodwebs, and the biotic and abiotic factors that trigger toxin production have not been clarified. Investigations of the effect of direct and indirect grazing on toxin production and colony formation in toxic and non-toxic *Microcystis* strains have led to an array of conflicting studies in this field. Additionally, only a limited number of molecular studies are available.

In this context, a phylogenetic analysis showed that the *mcy* genes responsible for toxin production in cyanobacteria emerged early in Earth's history (before the metazoan lineage) and have been lost in many cyanobacterial lineages. Hence, it seems unlikely that microcystins evolved as a means in defence against grazing. Another study in this field demonstrated that MC and other peptides released from disrupted *Microcystis* cells can stimulate the McyB (protein) content and MC production in remaining undisrupted cells.

To re-evaluate these results in our testing system, we used batch cultures with *Microcystis aeruginosa* strain PCC7806 (toxic wildtype and non-toxic mutant) and *Daphnia magna* as direct and indirect grazer. In our treatments with high and low light conditions, we determined growth (biovolume), survival time of *Daphnia* individuals, relative cellular microcystin content and aggregate formation. Our results show that direct grazing and the presence of disrupted *Microcystis* cells did not significantly increase the cellular MC content of the undisrupted cells. An indirect effect of *D. magna* (via medium) on the cellular toxin production was not observed. Furthermore, the non-toxic mutant of strain *Microcystis* PCC7806 is ingested with a higher rate than the toxic wildtype strain, and the survival time of *D. magna* is shorter in a toxic culture than in the non-toxic (mutant) culture.

In our future work we will evaluate genome-wide gene expression effects with quantitative reverse-transcription PCR and micro-arrays. The goal of these studies is to come to an understanding of biotic and abiotic factors that trigger toxin production in cyanobacteria.

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# Great Lakes Nearshore Water Quality Issues: Nutrient Perspective

Chairs: Ralph Smith and Todd Howell

# When the Rains Came: Water Quality at a Northern Nearshore Study Area in Lake Ontario in Two Summers of Contrasting Runoff

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Incidents of benthic algal fouling (mainly by *Cladophora*) of shorelines and water intakes have prompted studies of factors related to the distribution of *Cladophora* in the vicinity of the Pickering Nuclear Generating Station on the north shore of Lake Ontario. A grid of >24 stations from the 30 to 2 m isobaths was sampled ten or more times from May through October in two summers along a 15 km length of shore to determine the distribution and dynamics of environmental factors relevant to *Cladophora* growth. In 2007 summer rainfall and runoff were below average while 2008 had record high summer rainfall and high runoff. Despite the presence of a water pollution control plant outfall and a moderate sized tributary (Duffins Creek) in the study area, many water quality parameters (including total and dissolved reactive phosphorus, suspended solids and chlorophyll *a*) were at relatively low concentrations most of the time in both years and throughout most of the study area. Here we will show and discuss the differences that were observed between the wet and dry summers and what they reveal about the influence of local sources in the study area.

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# Hydrodynamic and Point Source Influences on Water Quality at a Northern Nearshore Study Area in Lake Ontario: Insights from Three Dimensional Modeling.

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Assessing the role of local sources of nutrients in the ecology of the nearshore zone of large lakes is a challenging task, partly because of the dynamic transport and exchange processes that influence the fate of local inputs in the lake. Three dimensional hydrodynamic models can be used to simulate such physical processes and can also be coupled with ecological models to include a basic representation of nutrient transformations and biological utilization over time and space. For nearshore habitats of large lakes, a problem is that the spatial resolution that is needed to make the model useful for the nearshore is prohibitively demanding of computing resources at the whole lake scale, yet the nearshore cannot be realistically modeled in isolation from the rest of the lake. Here we present one solution to this problem for a nearshore study area along the northern shore of Lake Ontario, using the hydrodynamic model ELCOM together with its ecological partner CAEDYM. We will show how the model helps to reveal the interactions of a local tributary (Duffins Creek), a sewage diffuser and heated effluent from a generating station with the study area.

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# Comprehensive Watershed Management for Control of *Cyanobacteria* in Small Freshwater Lakes

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Over 200 inland lakes in Quebec are exhibiting symptoms of *cyanobacteria* (blue-green algae) growth, with the consequent presence of cyanotoxins (microcystins) in some of these systems. Significant loss of these lakes as drinking water resources, recreational amenities and ecological habitat has been or will be experienced. One system (Petit Lac Saint-François, PLSF) is particularly severely impacted (classified as hyper-eutrophic: lake phosphorus levels up to 350 µg/L, microcystin concentrations up to 60 µg/L, lake transparency less than 10 cm). Due to its small size (1.7 km by 0.8 km; average depth 1.4 m) and very well delineated watershed, PLSF is serving as a template system for: 1) the application of integrated watershed management to control lake nutrient loadings; 2) for assessment of the important 'triggers' for *cyanobacteria* growth; and 3) for possible restoration of impacted lakes.

The four-phase approach being taken includes 1) characterization of nutrient sources, loading pathways and lake impacts; 2) reduction of nutrient loading at source; 3) interception of nutrients in transit, and 4) in-lake neutralization. Results from Phase 1 indicate that there are a number of point- and diffuse loading sources to the lake, including agricultural field drainage, stormwater runoff from the small lakeside village, sediment resuspension and seasonal waterfowl populations. Cyanobacterial spatial-temporal distribution is complex, as indicated by *in-lake* fluorometric assessment, with strong influences by rainfall/runoff and wind speed and direction.

Based on these results, a series of source control/reduction measures (Phase 2) will be tested in collaboration with the provincial authorities and local stakeholders. These include reduced nutrient content in animal feeds and better fertilization practices (e.g. reduction of nutrient run-off after application using biochar). A P-index assessing nutrient *source* and *transport* factors has identified critical watershed areas for Phase 3 source control measures like *edge-of-field* and *in-stream* bio-reactive filters, treatment wetlands and interception systems as agricultural best management practices. Low impact development (LID) approaches to control nutrient loading in urban stormwater runoff will also be applied.

Given the impact of cyanotoxins on lake- and public health and the increasing frequency of detection in Canadian lakes, this work demonstrates an effective and integrated scientific and public participatory approach to addressing this problem in lakes in Canada and around the world.

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## **Impact of Weather and Temperature on the Occurrence of Thermophilic Campylobacters at Lake Ontario Beaches**

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*Campylobacter* species are widely distributed in the aquatic environment and commonly inhabit the intestinal tract of humans and a variety of domestic and wild animals, including cattle, sheep, pigs and birds. A two year study was carried out to investigate and evaluate the impact of weather and seasonal temperature on the occurrence of thermophilic *Campylobacter* species such as *C. jejuni*, *C. coli*, and *C. lari* at Pier4 and Bayfront beaches in Hamilton Harbour at Lake Ontario. In 2007 and 2008, a bi-weekly water sampling was carried out at both beaches from March to December including spring, summer and fall seasons. The samples were collected at a single transect from three different depth zones (sand pore water, ankle depth water and chest depth water) at each beach. In addition, fresh fecal droppings from Canada Geese and ring-billed gulls were also collected, since they are highly mobile and a potentially important source of contamination of aquatic environment. The water and fecal samples were processed for the isolation and detection of *Campylobacter* species using culture and molecular-based assays. A comparative analysis has been conducted to observe the impact of seasonal temperature as well as weather condition (such as precipitation events) on the occurrence of these three species at these two freshwater beaches.

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## Detection and Quantification of Indicator *E. coli* and Bacterial Pathogens Associated With *Cladophora* in Lake Ontario.

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The extensive growth of *Cladophora* algae in the nearshore environment of Lake Ontario and the subsequent shoreline fouling of algal mats has been documented in recent years. Beyond the aesthetic impairment caused by the rotting mats on beaches, no evidence of adverse health effects have been demonstrated. Recent studies have demonstrated that fresh *Cladophora* and rotting mats may promote the survival, or possibly growth of *Escherichia coli*, a water quality indicator. Limited studies in Lake Michigan have also indicated that bacterial pathogens might also be associated with *Cladophora*. However, the importance of this association, in terms of water quality monitoring or public health, remains unclear.

In order to investigate the importance of the association between bacteria and *Cladophora*, methods were developed to quantify the presence of *E. coli* and representative pathogenic bacteria (*Salmonella enterica*, *Listeria* spp. and *E. coli* O157:H7). Between April and October 2008, four different sites along the shore of Lake Ontario were sampled twice monthly in the nearshore environment for attached and detached *Cladophora*. Bacterial DNA was extracted from algal samples following an optimized method to ensure appropriate recovery of the attached bacteria and subjected to quantitative PCR to detect and quantify the presence of the target bacterial species. In addition to molecular detection, culture based methods were also used to determine the level of thermotolerant coliforms in representative samples.

Results obtained to-date indicate a large variability in the occurrence and concentration of the indicator bacteria, *E. coli*, in association with *Cladophora* samples. Contamination levels based on the nature and location of the samples (free floating, attached, mats) along with preliminary data on the association of bacterial pathogens are presented. These data provide insight into the potential impact that bacteria/*Cladophora* association may have on water quality in the nearshore environment of Lake Ontario.

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# Spatial and Temporal Patterns in Nitrogen Compounds in the Nearshore of Eastern Lake Huron

E.T. HOWELL<sup>1\*</sup>

<sup>1</sup>*Environmental Monitoring and Reporting Branch, Ontario Ministry of the Environment*

The significance of nitrogen pollution for the nearshore ecosystems of the Great Lakes is unclear. The view that phosphorus is the primary limiting nutrient of autotrophic productivity is generally accepted. More challenging is the question of significance of nitrogen pollution in the face of widespread point and non-point sources of nitrogen loading. The nearshore of eastern Lake Huron periodically exhibits enriched nitrogen levels predominately in the form of nitrate. Seasonal and short-term elevation of nitrates in coastal tributaries correspond with temporally variable levels in the nearshore. Nitrate concentrations in the nearshore are positively correlated with conductivity on a broad basis confirming the interpretation of nitrate as a tracer of land-based input. Total phosphorus concentrations in the nearshore are generally low and the prevailing oligotrophic conditions appear little affected by the periodically augmented nitrogen supply. Chlorophyll a levels show little correspondence with nitrogen compounds beyond the covariation with phosphorus. Despite the loading of nitrates, concentrations in the nearshore infrequently exceed the CCME criterion for the protection of aquatic life unlike tributaries where concentrations periodically exceed criterion.

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## Stability of Sediment Phosphorus in Lake Winnipeg

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<sup>2</sup>*retired, Environment Canada*

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Sediments from three sites in the South Basin of Lake Winnipeg were amended in the laboratory with substrates that are capable of altering the stability and solubility of precipitated phosphorus: sulphate, iron, sewage solids and two types of organic-C, straw and blue-green algae. After incubation, the porewater of the sediments was analyzed for major ions and metals. The sediments at two stations in the south basin were already very reducing (4.3 mg/g and 2.4 mg/g AVS) when they were collected and addition of more organic matter had no effect on porewater phosphorus concentrations which were high (8.06 mg/L and 9.51 mg/L). Iron at 2.1 g/L and 4.2 g/L was effective at precipitating 79% and 96% respectively of porewater phosphorus at these two sites. The site near the Winnipeg River was much more oxic and likely these sediments were glacial clays, not recent sediments. These sediments near the Winnipeg River had low concentrations of porewater phosphorus (0.09 mg/L). Chemical calculations indicated that vivianite would dissolve in the two most reducing stations and would not form at any station.

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# Great Lakes Water Quality Agreement

Chairs: Gail Krantzberg and Chris Marvin

## Great Lakes, Great Responsibilities

G. KRANTZBERG<sup>1\*</sup>

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On April 15, 1972, Prime Minister Pierre Trudeau and President Richard Nixon signed the GLWQA. This Agreement expresses the commitment of Canada and the United States to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem. The GLWQA has had substantial influence on the cleanup and restoration of the region. The progress made since 1972 is evidenced by the documentation by scientists of the presence of spawning lake whitefish, the resurgence of cormorant population, the rediscovery of sturgeon populations, and the return of nesting and fledging bald eagles. Threats to the Great Lakes in the face of climate change, invasive species, habitat loss, and more, demand a renewal and revitalization of the GLWQA. The time is now to renovate the binational promises and renovate the governance regime. The inability to stem the re-emergence of threats to the integrity of the ecosystem is symptomatic of the accountability complex for the Great Lakes basin ecosystem. A move toward greater integration in the Basin can be generated if scientists, policy professionals and political leaders increasingly recognize the limitations of current approaches and are willing to devise binational alternatives.

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# The Great Lakes Science-Policy Dialogue at the Ontario Ministry of the Environment

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This session explores 'science meets policy' dynamics within a public agency. Through a case study of the dialogue between Great Lakes research science and policy priorities in the Ontario Ministry of the Environment (MOE), the authors discuss lessons learned on both process and contents. As with many areas of aquatic ecosystem governance, the Great Lakes present seemingly intractable challenges: a highly changeable and diverse ecosystem subject to pressures and stressors at multiple scales; an array of agencies with partial or limited authority and accountability; scarcity of resources for monitoring, analysis, science communication, policy development and program implementation. Even within a single agency, science and policy experts may experience differences in culture, language and management priorities, and perspectives. Despite these challenges, MOE has developed formal and informal mechanisms to promote and enhance the exchange of information and ideas between Great Lakes science and policy experts. Recent outcomes of the agency's active science-policy exchange will also be discussed, including emerging science needs to support policy priorities, and policy actions driven by science findings. Four areas of focus for this discussion will be: Great Lakes phosphorus and the nearshore shunt; Great Lakes water quantity issues; Great Lakes toxic chemical concerns; and pathogens at Great Lakes beaches and drinking water intakes.

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## Science Meets Policy – And Politics!

M. DIAMOND<sup>1\*</sup> \_

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There seem to be three routes by which environmental legislation and policy are made, modified and/or prioritized: (1) public pressure, (2) inside interest group lobbying, and (3) through the avenues of government science and policy often together with academic science. My experience suggests that the 1<sup>st</sup> and 2<sup>nd</sup> routes are the fastest but our governmental scientific and academic machinery stresses the later.

Following a successful era of high profile activities in the late 1970s, 1980s and early 1990s, current public and governmental awareness of Great Lakes issues is low. Politically motivated budget cuts to Great Lakes programs in federal and provincial departments and the International Joint Commission, as well as to academic research funds in the 1990s, have reduced our capacity to conduct Great Lakes science and the visibility of Great Lakes issues. More recent changes to funding priorities and research capacity within mostly federal and to some extent provincial government agencies have put up road blocks to conducting policy-driven science. Reductions in opportunities for public and academic involvement in Great Lakes programs have further eroded support for, and the visibility of Great Lakes issues.

A positive view of this situation is that funding cuts were in response to successes in solving the critical issues of eutrophication and fisheries collapse that we saw in the 1960s and 1970s. A cynical view is that the political decisions to reduce funding, and thus opportunities for public and academic involvement (that maintain political pressure), have allowed the eclipsing of pressing Great Lakes issues such as habitat destruction, invasive species, effects of climate change, and challenges to nearshore water quality by other political priorities such as tax cuts.

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# Linking Policy Outcomes to Science Objectives

Chairs: Jackie McCall and Catherine Jefferson

# Surveying the Science Information Needs of Conservation Authorities in Ontario

G. KRANTZBERG<sup>1</sup>, K. SCHAEFER<sup>2</sup> & G. SHEIKHELDIN<sup>3\*</sup>

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<sup>3</sup>*Science Horizons Internship Program, Environment Canada, August 2008 – February 2009*

Nowadays, traditional science-policy communication approaches that ‘push’ science findings to undefined audiences, leaving them to sift through and pick from it what might suit them and what might not, are being challenged by new approaches that deliberately translate science knowledge to targeted audiences. In these new approaches, knowledge brokers play an increasingly important role, and the quality, amount and level of science presented are determined by the user needs (‘pull’ approach), in this case the policy community.

Following this new approach, this paper presents and discusses the findings of a research project that seeks to identify the science needs of Ontario’s Conservation Authorities (CAs). This research was designed to gather empirical data on the use of and access to science by CAs’ senior staff to inform the range of typical initiatives carried out by CAs, which are the collaborative creation of Ontario’s municipalities serving as the responsible governance bodies that manage and protect the quality and quantity of essential natural resources, such as water, at the watershed level. Some of the initiatives carried out by CAs, among other responsibilities, are source water protection (SWP) planning processes required by the new Clean Water Act 2006. This research used a survey instrument in trying to illuminate:

- How science is used and accessed in CAs and what form of communication enables the use of science.
- When science is used in the decision-making process and how uncertainty is dealt with.
- Whether the above are influenced by the CA’s size and capacity
- Whether the above vary by the maturity or newness of the activity

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## Lake Simcoe: An Ontario Example of Linking Science to Policy Development

J. McCALL<sup>1\*</sup>

<sup>1</sup>*Ministry of Agriculture, Food and Rural Affairs, Guelph*

The Ontario government recently passed into law the Lake Simcoe Protection Act (2008). The Act authorizes a (draft) Protection Plan that details policies to restore and protect the ecological health of the lake using a watershed-based approach. Policies are based on the following principles:

- science forms the plan's base; ongoing research and monitoring are integral components of implementation
- the plan adopts an adaptive management approach and will evolve as new information becomes available
- the plan will be implemented with provincial leadership, and all stakeholders have a role, including municipalities and the Conservation Authority, First Nations, sector-based participants (e.g. farmers, land developers, tourist operators, environmentalists, non-government organisations), and the public
- implementation includes a combination of legally binding policies and strategic actions that are voluntary or stewardship based

The draft protection plan was developed with the assistance of a multi-ministry policy team, and two government-appointed advisory committees: one for science, and one for stakeholders. This approach led to a partnership-based, long-term plan accompanied by a \$20 million government commitment over four years. The draft plan is being consulted upon from January to March, 2009, and will be finalized based on feedback.

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# **The Science of Clear Language: Communicating Water Policy Effectively to Public Audiences**

D. SHURA<sup>1\*</sup>

<sup>1</sup>*Renaissance Communications Ltd.*

Great science doesn't always make for great reading -- whether in print or on the web. The language of water policy is not accessible to all audiences, especially the general public. And even a well-written document will not serve readers well if poorly organized. But there are proven ways to cut through the complexity. Find out how clear language experts approach this challenge, drawing on the lessons of cognitive psychology and literacy research to improve the reader experience.

Topics will include:

- Why scientists need clear language
- The challenges: low science and reading literacy
- How clear language helps: the research
- Clear language guidelines for communicating with the public
- A new writing model.

The presentation will illustrate the clear writing principles with a number of before and after examples drawn from water policy and other branches of conservation science.

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## Comparison of Community, Population and Individual Responses of Fish Along Gradient of Multiple Municipal Wastewater Effluents in Canada

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Municipal Wastewater Effluent discharge (MWWE) is the largest by volume discharge into the Canadian aquatic receiving environment and discharge rates will rise with projected increased human population density in urban areas. MWWE or sewage is a mixture of domestic and industrial wastes, and Pharmaceuticals and Personal Care Products (PPCPs). The Grand River watershed in the province of Ontario receives the outflow of 29 sewage treatment plants and runoff from agriculture, aggregate and industrial activities. In 2005 and 2007, field studies upstream and downstream of 2 municipal discharges assessed fish communities (diversity and abundance), populations (age-distribution, growth rates) and individual responses in terms of growth (condition factor), reproduction (in vitro sex steroid production, gonadosomatic indices, histology). Fish [greenside (*Etheostoma blennioides*) and rainbow darters (*Etheostoma caeruleum*)] collected downstream of the Kitchener and Waterloo municipal wastewater plants were longer and heavier when compared to reference fish collections. This could be a reflection of the increase diversity and abundance of the benthic invertebrate community observed downstream of the discharges. Although fish populations did not display effects to MMWE exposure, individual exposed fish demonstrated physiological alterations in sex steroid productive capacity. Fish community assessments also demonstrated increases in fish abundance, diversity and evenness in the composition of the river fauna downstream of the MMWE discharges when compared to reference fish communities with similar habitat characteristics.

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# Water Policy: Engaging Science and the Public

Chair: Bob Sneyd

# **Integrated Watershed Management Incorporating Public Input to the Science and Policy Table: Caledon Case Study**

H. BRETON<sup>1\*</sup>

<sup>1</sup>*Conservation Ontario*

Public dialogue involving complex natural environments, especially in emotionally charged situations where land use changes are viewed negatively, takes time, sound science and building relationships on mutual trust. If public buy in is to be achieved, meaningful engagement must be carefully planned to meet the needs of the community.

This presentation will highlight how an Integrated Watershed Management (IWM) process can utilize science and social learning to engage all stakeholders to build consensus. Focus on water quality issues related to urbanization and in particular stormwater management and sewage treatment plant effluent will be discussed. The process of carrying out technical analyses, ongoing liaison with the public and eventual incorporation of results into municipal planning and master planning documents will be presented.

Building relationships with the public and allowing opportunities for information exchange that include explanation of the results of scientific assessments in an understandable and clear format is essential. Incorporation of findings and recommendations of watershed and subwatershed plans into municipal land use and master servicing plans having buy-in from local citizens is key to ensuring that a healthy environment is maintained or restored.

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# **Bridging the Science-Policy Discourse for Water Resource Management**

GAIL KRANTZBERG<sup>1\*</sup>

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The engineering and science - policy interface is of fundamental importance if we are to achieve sustainable ecosystems, where humans are part of, not distinct from, the environment. Successfully navigating the interface is no simple matter. It is generally so that policymakers are not well versed in engineering and science. It is also generally so that many engineers are unfamiliar with the process of formulating and implementing public policy. As a result, there is an inherent tendency for engineering and public policy to operate in separate professional worlds. Presently the interchange between what is traditionally regarded as the distinct disciplines is under-developed and functions poorly. Simply stated, the scientist or engineer tends to observe a problem and examine the biological, chemical, and physical factors affecting the issue. The policymaker may frame the same issue in terms of the likely economic and political consequences of making a particular decision at a particular time. Engineers training in public policy would accelerate efforts towards a sustainable future.

This presentation will examine how science can influence policy and conversely how policy pushes scientific analysis for water resource management at a regional, national, and international scale.

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## **Local Capacity Building: The Water Guardians Network Experience**

M. LAYTON<sup>1\*</sup>

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The Water Guardians Network (WGN) is a group of 38 Ontario NGOs ranging from national environmental organizations to local watershed groups. The WGN was founded after passage of the Ontario Clean Water Act, 2006 to support source water protection efforts across the province. The WGN plays three principal roles. First, it supports the environmental representatives on the province's 19 Source Protection Committees, the bodies responsible for developing and applying each Source Protection Area's and Region's source protection plan. Secondly, it promotes source protection in Ontario communities through educational pamphlets, financial assistance, online forums, information sessions, and workshops: through the work of its member groups, the WGN provides a much needed bridge between the development and interpretation of source water protection policy, current scientific research and the public. Lastly, it coordinates collective action for strengthening source protection through the use of regional and local media, and through written submissions to Source Protection Committees and various Ontario ministries.

The purpose of our paper is to discuss the WGN's experience of the source protection process in Ontario. In the paper, we will trace the work of the WGN from its inception to the present, discuss its ongoing relevance in Ontario source protection planning and the development of source protection plans, and explore its effectiveness as a capacity building tool. Of key importance is the development of strategies that strengthen community participation in the development of local science - based Source Protection Plans. We will list important successes of the WGN, as well as stress challenges in the source protection legislation that the WGN is working to overcome.

The WGN's source protection experience is already providing a model for environmental groups outside of Ontario in their work on linking water governance issues with public understanding and participation.

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## **Policy Research Initiative on Sustainable Grassroots Engagement: Saving Canadian Lakes and Rivers**

B. SNEYD<sup>1\*</sup>

<sup>1</sup>*Centre for Sustainable Watersheds*

Safeguarding Canada's water resources is the shared responsibility of a myriad of agencies and jurisdictions, coast to coast to coast. We place a lot of faith in the best of science, guided by enlightened policy, to meet this objective. Yet in the face of daunting pressures from every side, we understand more than ever before, the magnitude of this challenge and the fragility of those resources.

Among the myriad of smaller lakes and rivers upstream of the Great Lakes, rivers and oceans, we often overlook the most significant partner that has the potential to implement our science and realize the most visionary of policies: communities themselves, with the irreplaceable leadership of the countless thousands of small Environmental Non-Governmental Organizations (ENGOS) that dot the country.

For several years now, Centre for Sustainable Watersheds (CSW) has been developing policy components that couple guiding principles and timely science to explore ways to engage and sustain those grassroots organizations. They may or may not belong to a regional or provincial umbrella association. But it is those individual local groups with a unique understanding of their waterway which are fundamental. In the end, after all, who else can really 'save' our lakes and rivers?

This presentation will outline the broad 'waterscape' of CSW's preliminary policy work, touching on:

- Recreational water use and shoreline best practices protective of both wildlife and human health outreach, education and broad public awareness
  - Credible long-term monitoring, data collection, data management and sharing capabilities
- sustainable capacity building support for local ENGOS

We welcome input and suggestions from participants during the discussion period.

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## Great Lakes Science Needs from the Municipal Perspective

S. RANG<sup>1\*</sup>

<sup>1</sup>*Acting Deputy Director, Great Lakes and St. Lawrence Cities Initiative*

The Great Lakes and St. Lawrence Cities Initiative is a binational group of about 60 municipalities from around the Great Lakes, interested in water quality, quantity and waterfront vitality (see [www.glslcities.org](http://www.glslcities.org)). Recently the Cities Initiative, on behalf of all Ontario municipalities, has been coordinating municipal advice into the Canada Ontario Agreement on the Great Lakes. Municipalities have an important role to play in the Great Lakes as they are responsible for many programs on water quality and quantity and understand local conditions and needs.

As part of the discussions, municipalities have been focusing on the nearshore zone, as the zone where most activities happen. Many municipalities are interested in reducing alga, protecting and restoring wetlands and improving beaches in the nearshore zone, yet are faced with many questions on how best to accomplish these goals. These goals become even more complicated with climate change and invasive species. The presentation will discuss some of these challenges and municipal experiences.

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## The Ottawa-Gatineau Watershed Atlas

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Watershed based decision-making in the Ottawa River watershed basin is currently hindered by the jurisdictional fragmentation of information. Data and information are critical for developing and implementing Watershed Management Plans, however each province is moving towards watershed management without recognizing the inter-jurisdictional nature of the Ottawa-Gatineau region.

In addition, public understanding and opportunities for engagement in water issues is limited. Providing community members with easy access to water-related data at their local watershed level, allows users to transform data into relevant knowledge. By supporting the data with a wealth of contextual information, the public can share responsibility for the management of this watershed.

The Ottawa Gatineau Watershed Atlas Project (OGWA) project enables integration of watershed management on both sides of the Ottawa River in addition to providing a comprehensive public educational tool. The project takes an ecosystem approach using a watershed boundary rather than political boundaries, bringing together collaborating partners, data, and information from both provinces.

The project uses interactive Geographic Information System (GIS) and web technology to facilitate improved communication and data sharing between water practitioners, decision-makers and the public. OGWA provides an interactive atlas tool where communities can learn about their local watershed, monitor local environmental conditions, and contribute information and data for inclusion in the Atlas.

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# **Gateway Through the Maze of Water Policy Research: Toward Overcoming the Roadblocks to Engagement**

K. GOODMAN<sup>1\*</sup>

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The pressing need for improved access and sharing of water information has been widely recognized since the turn of the century. This is as true of water policy information as it is of other bodies of research, to say nothing of multi-jurisdictional practitioners and organizations immersed in field work, data collection and analysis.

Over the last three years Centre for Sustainable Watersheds (CSW) developed Water Connections as a national Internet portal or gateway to water information. As the first step access point, the potential of this broad public service will grow as organizations and agencies join in, making their information available to the common search tools provided.

One important step in this direction is currently nearing completion, in partnership with the Gordon Foundation, as CSW builds the first stage of a Water Policy Directory. It will become an added functionality to Water Connections.

Without centralized access, the sheer volume of policy research from the broad range of government and non-governmental sources is overwhelming. As this directory comes on line and is expanded, many benefits will follow:

- capacity to co-relate objectives and findings from a complexity of disparate sources
- improved ability to identify gaps, minimize redundancies and scope future research
- increased potential for collaborative initiatives and funding
- greater transparency in the relationship between policy research and science
- broadened target audience, grassroots understanding and engagement
- enhanced decision-making and policy delivery

This presentation will give the first preview of how the Water Policy Directory will work, as well as its potential to open the interconnected world of policy and science to a new level of public understanding and cooperation.

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# Enhancing Canada's Oversight of Laboratory Biosafety and Biosecurity: Bill C-11

M. HEISZ<sup>1\*</sup>

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What do *Listeria*, *E. coli*, *Salmonella*, *B. anthracis* and the ebola virus all have in common? They are all human pathogens, and as such, should be handled according to the nationally accepted biosafety standards, as detailed in the "Laboratory Biosafety Guidelines". However, there is no universal application of these guidelines within Canada; application of these standards is limited to only those individuals that import human pathogens into Canada. This potentially has the result that two laboratories working side by side, working on the same organism, one an importer, the other not, may have different biosafety practises in place, based on the application or non-application of the Laboratory Biosafety Guidelines. Bill C-11, the Human Pathogens and Toxins Act, introduced in parliament February 9, 2009, levels this playing field; this bill provides for the universal application of standard biosafety practises, standard reporting requirements and uniform penalties for all people that work with human pathogens in Canada, as well as setting the framework for a federally run laboratory licensing system.

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# Water Quality, Quantity and Conservation: Agricultural Perspective

Chairs: David Armitage and Tiffany Svensson

## Assessing the Risk of Microbial Contaminant Occurrence Within the Wellhead Protection Area of a Municipal Well Field in an Agricultural Setting

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Contaminated groundwater accounts for approximately 70% of all reported waterborne disease outbreaks in the USA every year. In order to reduce the risks to the public, government authorities are implementing legislation to protect sources of drinking water from microbial contamination. The nature of microbial transport in groundwater, however, is not well understood. In order to develop additional understanding of this issue, this project monitored the occurrence of various bacterial indicators (total coliforms (TC), aerobic endospores and *E. coli*) over a year within a vulnerable wellhead protection area of a municipal well field located near Woodstock, Ontario. Samples were collected from a network of over 20 monitoring wells located along and perpendicular to the groundwater flow direction within the study area. Samples were also obtained from surface water and tile drains during winter and spring melt and from the municipal wells. More than 450 samples were collected and analyzed. Microbial counts ranging from <1 to 40 000 cfu/100ml of TC, <1 to 22 000 for the aerobic endospores, and <1 to 12 000 cfu/100mL *E. coli* were detected within the monitoring network and surface waters. The data indicate that the elevated microbial concentrations in both tile drain and shallow aquifer systems appear to correlate to ephemeral hydrologic events (e.g. intense melt periods). Microbial occurrence in the municipal wells, however, was very infrequent suggesting that even under conditions of aquifer vulnerability and proximity to pollution sources, risk to the drinking water source appears to be very low. A weak, time-lagged correlation between microbial occurrence and ephemeral hydrologic events was, however, also observed in the municipal wells. The data sets are being augmented with age dating information and the combined information is being used to support predictive numerical analysis to improve the quantification of microbial risk from a source water protection policy context.

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# Fractured Bedrock Aquifers and Agriculture: Importance of Source Protection in this Vulnerable Setting

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Fractured bedrock aquifers, particularly those with minimal overburden protection, are vulnerable to contamination. In agricultural areas, land-applied materials such as manure and pesticides are potentially disperse sources that can degrade water quality. As fractured bedrock aquifers are widely used for water supply, especially in rural areas of Eastern Ontario, a thorough understanding of the impacts of specific agricultural activity on water quality is imperative.

To investigate this, a hydrogeological study was conducted at a field site near Perth, Ontario, in order to determine the impacts of cattle pasturing on water quality. At this location, a fractured gneissic aquifer is overlain by a thin till veneer (0 to 4 m soil depth). Ten multilevel wells, located downgradient from a pasture field, were installed, hydraulically tested and completed as multilevel piezometers. Monthly water quality sampling of nitrate, *E. coli* and dissolved organic carbon was conducted for 15 months to investigate the spatial and temporal variation of concentrations. Two 5-day intensive sampling rounds were carried out under baseflow and recharge conditions to determine if concentrations arriving at the well receptors varied on a daily scale.

Results of the monthly sampling rounds showed elevated nitrate and bacterial concentrations (exceeding drinking water guidelines) at some locations. Temporal and spatial variations of the concentrations were significant. From the intensive sampling rounds, it was found that nitrate concentrations were fairly consistent on a daily scale, while bacterial concentrations varied daily. Also, higher bacterial concentrations were observed during periods of recharge. As measured dissolved organic carbon levels were low, denitrification may be limited.

It is evident that periodic and disperse sources, dilution from recharge, and heterogeneous flow systems lead to varied, unpredictable and potentially unsafe contaminant concentrations, which may not be captured by annual or even monthly monitoring. In order to preserve the integrity of water quality in bedrock aquifers, nutrient management and land-use practices must reflect this sensitivity.

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## **Progress in Adoption of Beneficial Management Practices and Environmental Farm Plans Under the Agricultural Policy Framework 2005-2008**

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The federal-provincial Agricultural Policy Framework (APF) 2005-2008 provided an historic boost to the adoption of Environmental Farm Plans (EFP) and environmental Beneficial Management Practices (BMP) by Ontario farmers. During 2005-08, 11,778 farm businesses or 23.8% of Ontario farms completed the latest version of the EFP. 8,867 farms had those EFPs peer-reviewed. 5,683 farms or 12% of Ontario farms went on to implement 13,726 BMPs under the associated cost sharing programs to implement nutrient management, riparian management, improved pest management, water well management or other environmental practices. Only BMPs identified through the EFP priority setting process at the individual farm level are eligible for funding. The 13,726 BMPs resulted in an investment of at least \$200 million including over \$100 million from farmers.

Exploratory data analysis was undertaken of BMPs adopted by farms of different commodities and their geographic distribution. Cross-tabulation of BMPs adopted by farms of different commodity types (dairy, beef, field crops, horticulture etc.), show the BMPs adopted address key environmental issues for each commodity. County-level summary data was used to explore spatial correlations between adoption rates of different BMPs and variables in the 2006 agricultural census. So for example, nutrient management BMP adoption was most highly correlated with the numbers of livestock farms. Soil management BMP adoption was very highly correlated with numbers of field crop farms. Product and waste management and irrigation management BMP adoption was most highly correlated with the numbers of horticultural operations and greenhouses. Methods to assess the contributions of BMP adoption to improvements in environmental quality and reduction in risk are being considered. Results illustrate how the EFP effectively guides each farmer's decision to adopt appropriate BMP based on the characteristics of each farm and their local conditions.

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## **Rural Well Owners Dealing with Water Shortages**

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Summer 2007 was an exceptionally dry summer and many rural well owners reported problems with their water supply. Well owners explored different solutions some showing a lack of understanding of basic hydrogeological concepts that would have allowed a productive solution. This talk will describe some of the situations well owners encountered during this dry summer, and will focus particular attention on a case study of a well owner who had water tanked into their well. These actions lead to a loss of supply. In exploring solutions to this situation, many issues that arise across Ontario were encountered – small lot size, difficulty with access and costs. Well owners have also reported problems with wells collapsing during saturated conditions following extreme drought. These problems are more pronounced in shallow dug wells but highlight a situation with shallow aquifers.

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# Impact of Incorporation and Pre-Tillage Combined with Surface Application of Liquid Swine Manure on Survival and Transport of Faecal Bacteria and Pathogens

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Survival of pathogenic microorganisms after land application of manure poses a risk of contaminating source waters. This work was carried out to study the persistence of *E.coli*, *Clostridium perfringens* and *Salmonella* in manure amended soils under different tillage and incorporation methods and to evaluate the impact on transport of faecal bacteria to tile water, groundwater and overland flow. The experiment was conducted on an instrumented field site at the University of Guelph Elora Research station in the spring of 2007 and 2008. Treatments were; no manure, surface applied manure, surface applied and incorporated, surface applied on pre-tilled soil, surface applied on pre-tilled soil and incorporated. Water samples from overland flow collectors, tile monitors, pan lysimeters and ground water wells were taken after rain events. *E.coli* was enumerated using Petrifilm<sup>TM</sup> EC method in 2007 and m-FC medium with BCIG in 2008. *Clostridium perfringens* were enumerated using on m-CP agar. Presence or absence of *Salmonella spp.* in soil samples was detected using PCR techniques. *E.coli* and *C. perfringens* concentrations in manure were  $4 \times 10^4$ / ml and  $1.1 \times 10^3$ / ml in 2007 and  $4.5 \times 10^3$ / ml and  $2.2 \times 10^3$ / ml in 2008 respectively. Increased bacterial concentration was observed following rainfall events immediately after manure application in all water samples. Tillage prior to manure application (with or without incorporation) significantly reduced the movement of bacteria to tile flow and groundwater. Within 50 days after manure application (DAM) levels of all pathogens were not detectable in water samples. However, heavy rainfall accompanied by a rise in water table in August (70 DAM) led to the re-appearance of both *E.coli* and *Salmonella spp.* in tile waters. These pathogens remained detectable until 98 DAM, indicating prolonged survival of fecal bacteria in these systems. In conclusion, pre-tillage minimized the movement of pathogens to tile and groundwater within 1 month after manure application, likely due to decreased macropore flow, but had no impact on the re-appearance of pathogens later in the season.

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# **Developing Capacity for Multi-User Agricultural Group Projects in Ontario - An Overview of a Recent Irrigation Project in Southern Ontario**

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While organizing as self-directed groups to access water for agricultural purposes is a common and effective water management option in Western Canada, it is a less common alternative in Eastern Canada. As the size and complexity of farming operations in Ontario increases, having irrigation water available when and where it is required requires significant cooperation amongst agricultural water takers.

Over the past several years, the Leamington Area Drip Irrigators Inc (LADII) have planned, organized and developed a producer-owned irrigation water delivery system which will supply water drawn from Lake Erie to approximately 2000 ha of field tomato lands in the Leamington area of Essex County. As part of developing this unique project, a number of technical and regulatory issues were resolved by the LADII project team and their consultants including:

- Addressing applicability of the Great Lakes Charter and Annex
- Assessing practical water supply/conservation measures
- Demonstrating effective management of water delivery
- Developing an organizational structure (in the absence of an Irrigation Act)
- Choosing a technically defensible lake intake pump site
- Providing 3<sup>rd</sup>-party assessment of local drip irrigation effectiveness and demands
- Balancing differences between typical municipal and irrigation standards
- Satisfying the requirements of the federal environmental act (CEAA)

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## Whitemans Creek Low Water Response Pilot Project

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The spring, summer and fall of 2007 were particularly dry in the Whitemans Creek watershed and some water users experienced shortages. Low flow conditions provided an excellent opportunity to *test existing low water response policy* by piloting the hypothetical implications of a Level 3 low water declaration.

The goal of the pilot was not to stop irrigation completely but rather to *manage water demands* in order to share dwindling resources and *protect the ecology of Whitemans Creek*. While there was consensus with the water takers and stakeholders on the value of conservation and efficiency in water use, the suggestion that individual crops be selectively allocated more or less water based on market value was considered unacceptable. Subsequent to group *consultation on low water response and irrigation best management practices*, the following recommendations were proposed to mitigate extreme low water conditions:

- Ban all aesthetic outside water use
- Eliminate gun irrigation during heat of day or high wind conditions
- Ensure water management best practices are being maximized
- All water permit holders must reduce water use by 20%
- Deep well permit holders and efficient irrigation systems must reduce water use by only 10%
- Reduce the water use requirements for the next planting of multiple harvest vegetable crops, such as broccoli, by 20%
- Monitor the results and consider needs for further reductions

The agricultural community were invited to comment upon the effectiveness of the recommendations, the barriers to their implementation as well as proposing short and long term approaches to overcoming the barriers. As a result, they identified that recommendations proposed in response to Level 3 conditions may not be sufficient to reactively reduce demand from the agricultural sector. In the long term, pro-active efforts should be made to reduce reliance on instream takings through improvements to irrigation infrastructure.

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# Water Quality Survey of the Big Creek Watershed, Norfolk County, Ontario

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As a preliminary step towards future water resources research by Environment Canada in Norfolk County, a water quality survey of Big Creek and its tributaries was completed during baseflow conditions, when stream flow is dominated by groundwater inputs. The Big Creek Watershed encompasses an area of approximately 725 km<sup>2</sup>, located predominantly in Norfolk County, with headwaters extending north into Oxford and Brant Counties. The surficial geology of the area is dominated by the Norfolk Sand Plain, a silty sand deposit that ranges in thickness from <1 to >25m. Land-use is largely agricultural, including crops such as tobacco, ginseng, vegetables, corn and soybeans. Crop irrigation from streams, ponds, and groundwater is common, with more than 50% of all water taking permits issued in Ontario coming from within the Norfolk Sand Plain. The combination of intensive agriculture, irrigation, and sandy soils make the unconfined surficial aquifer potentially susceptible to impacts.

Big Creek and its tributaries were sampled at multiple locations during baseflow conditions between 4-Feb-2008 and 4-Mar-2008. Water quality parameters analyzed include: major anions and cations, trace metals, E. coli, dissolved nitrous oxide, and nitrate and water stable isotope ratios. Water quality parameters showed trends based on location in the watershed and stream order. For example, nitrate concentrations ranged from 0.5 to >12 mg N/L (average = 3 mg N/L) and were generally highest in the headwaters. Dissolved N<sub>2</sub>O concentrations ranged from 1 to >5 times atmospheric equilibrium concentrations, indicating that these streams are a source of N<sub>2</sub>O to the atmosphere along the entire length. The N<sub>2</sub>O in streams is likely the result of denitrification, either within stream sediments or within the groundwater flow system. Highlights of the water quality survey results will be discussed as part of the presentation.

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# Development of an Integrated Water Resource Management Strategy for Innisfil Creek

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The Innisfil Creek subwatershed represents the most intensely farmed, irrigation-dependent area within the jurisdiction of the Nottawasaga Valley Conservation Authority (NVCA). Although water requirement and use is not constant or persistent, the total consumptive surface water use periodically exceeds the available surface water supplies; potentially negatively impacting the natural functions of the ecosystem. Extensive water taking for field and golf course irrigation and other factors typically reduces stream flows significantly during most summers. With the recent drought-induced low water conditions experienced in 2007, it has become evident that a water use strategy is required for the Innisfil Creek subwatershed. Recognizing this, the NVCA with funding received from the Agricultural Adaptation Council has initiated the development of an integrated water resource management strategy (IWRMS) for all large-scale water users in the Innisfil Creek subwatershed; targeting predominantly surface water users.

The locally-developed integrated water resource management strategy for the water takers of Innisfil Creek addresses water resource adequacy, financial viability, community sustainability, stakeholder understanding and support, leadership development, and operational optimization and resiliency. This dynamic framework is based on the guiding principles of: water as an economic good, using an ecosystem approach, stakeholder participation, and goal-oriented. It builds on the knowledge of the existing water demand and potential local alternative water supplies that was completed as the first stage of this endeavor. The results from this project have lead to a collective framework of water takers that locally manage water takings and BMP adoption which, among other benefits, will have a positive impact on creek flow.

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