BOOK OF ABSTRACTS

Thirty-Seventh Central Canadian Symposium on Water Pollution Research

Chaired by
DR. JOHN H. CAREY
EXECUTIVE DIRECTOR
NATIONAL WATER RESEARCH INSTITUTE
ENVIRONMENT CANADA

February 4 & 5, 2002
Canada Centre for Inland Waters
Burlington, Ontario

Co-sponsors:
Canadian Association on Water Quality
National Water Research Institute

In co-operation with:
Canadian Water and Wastewater Association, Dalhousie University, Great Lakes Sustainability Fund, Health Canada, University of Calgary, University of Toronto, Water Environment Association of Ontario, Western Lake Ontario Research Consortium

Monday, 16:30 – Auditorium:	**CAWQ Annual General Meeting**
Monday, 17:00 – Main Mall:	**Reception**
Tuesday, 16:40 – Auditorium:	**Philip H. Jones Award** **Concluding remarks from** **M.N. Lywood, President, CAWQ**

PROGRAM SUMMARY

MONDAY, FEBRUARY 4th				
07:45	**Registration: Main Mall**			
08:30	**Welcome to NWRI and Symposium announcements: Auditorium – A.T. Bielak, Organizing Committee Chair** **Opening Remarks: Auditorium – M.N. Lywood, President, CAWQ**			
08:45	**Plenary: Auditorium – P. Huck, Professor and NSERC Chairholder in Water Treatment** **"Robustness of Drinking Water Systems – Some Lessons from Walkerton"**			
	SESSION 1		**SESSION 2**	
	Session Theme – Auditorium	**Number of Oral Presentations (25 Minutes Each)**	**Session Theme – North/South Seminar Room**	**Number of Oral Presentations (25 Minutes Each)**
09:35	Endocrine Disrupting Compounds	3	Drinking Water: Water Treatment	3
10:50	**Coffee Break – Main Mall**			
11:15	Endocrine Disrupting Compounds	3	Drinking Water: Water Treatment	3
12:30	**Lunch – Main Mall**			
13:30	Endocrine Disrupting Compounds	3	Drinking Water: Water Treatment	3
14:45	No Presentation		Groundwater	1
15:10	Endocrine Disrupting Compounds	3	Groundwater	3
16:30	**CAWQ Annual General Meeting – Auditorium**			
17:00	**Reception and Poster Displays – Main Mall**			

PROGRAM SUMMARY

TUESDAY, FEBRUARY 5th				
07:30	**Registration: Main Mall**			
	SESSION 1		**SESSION 2**	
	Session Theme – Auditorium	**Number of Oral Presentations (25 Minutes Each)**	**Session Theme – North/South Seminar Room**	**Number of Oral Presentations (25 Minutes Each)**
8:00	Urban Wet-Weather Pollution: Stormwater Management and Combined Sewer Overflow (CSO) Control	5	Drinking Water: Taste and Odour Compounds and Toxins	5
10:05	**Coffee Break – Main Mall**			
10:25	Urban Wet-Weather Pollution: Stormwater Management and Combined Sewer Overflow (CSO) Control	3	Drinking Water: Taste and Odour Compounds and Toxins	3
11:40	Innovative Wastewater Treatment Technologies and the Environmental Effects of Wastewater Discharge	2	Drinking Water: Taste and Odour Compounds and Toxins	2
12:30	**Lunch – Main Mall**			
13:15	Innovative Wastewater Treatment Technologies and the Environmental Effects of Wastewater Discharge	8	Drinking Water: Waterborne Pathogens	5
16:40	**Philip H. Jones Award and Concluding Remarks by M.N. Lywood – Auditorium**			

Note: There are 58 oral presentations, 18 poster displays and a number of commercial presentations.

Monday, February 4th
Oral Presentations

07:45	**Registration: Main Mall**	
08:30	**Welcome to NWRI and Symposium announcements: Auditorium – A.T. Bielak, Organizing Committee Chair** **Opening Remarks: Auditorium – M.N. LYWOOD, President, CAWQ**	
08:45	**Plenary: Auditorium – P. HUCK, Professor and NSERC Chairholder in Water Treatment "Robustness of Drinking Water Systems - Some Lessons from Walkerton"**	
	SESSION 1	**SESSION 2**
	AUDITORIUM **Endocrine Disrupting Compounds** **Chair: J. PARROTT**	**NORTH/SOUTH SEMINAR ROOM** **Drinking Water: Water Treatment** **Chair: J. LAWRENCE AND D. ELLISON**
09:35	Evidence of Endocrine Disruption in Marine (*Mya arenaria*) and Freshwater (*Elliptio complanata*) Bivalves: Case Studies from the Saguenay Fjord and Greater Montreal Area of the Saint-Lawrence River C. BLAISE AND F. GAGNÉ	Trends in Water Treatment to Meet Present and Future Challenges J. LAWRENCE
10:00	Development of Testing Methods for Endocrine Disrupting Compounds in an Estuarine Killifish (*Fundulus heteroclitus*): Effects of an Estrogen Agonist and an Estrogen Antagonist D.L. MACLATCHY, C.I. GILMAN, A.R. BELYEA, S.C. COURTENAY AND G.J. VAN DER KRAAK	Raw and Treated Water for Rural Areas in Saskatchewan H.G. PETERSON, S.B. WATSON, N.J. RUECKER AND S.L. BRAITHWAITE
10:25	Development of Fathead Minnow Lifecycle Tests for Detection of Reproductive Toxicants in Effluents J. PARROTT, M. BAKER, B. BLUNT AND C. WOOD	Benefits of a Biocidal Pretreatment for the Coagulation of High DOC, Cold Water L. BRAUL, T. VIRARAGHAVAN AND R. CULLIMORE
10:50	**Coffee Break – Main Mall**	
11:15	Biochemical and Physiological Effects in Wild Fathead Minnows from a Lake Experimentally Treated with the Synthetic Estrogen, Ethynylestradiol K. KIDD, V. PALACE, R.E. EVANS AND K. WAUTIER	Characterization of Particles in Slow Sand Filtration D. LONDON* AND B. GORCZYCA
11:40	Effects of Endocrine Disruptors on Growth and Physiology of Atlantic Salmon S. BROWN, J.T. ARSENAULT, K. HAYA, L.E. BURRIDGE, J.G. EALES, D.L. MACLATCHY, R.E. EVANS, B.K. BURNISON, J.P. SHERRY, D.T. BENNIE AND W.L. FAIRCHILD	Update on the Use of Granular Activated Carbon in Ontario R. ABERNETHY
12:05	An ELISA for Atlantic Salmon (*Salmo salar*) Vg and its Use in Measuring the Response of Salmon Smolts to 17β-estradiol and 4-nonylphenol Treatments J. SHERRY, C. TINSON, K. HAYA, L. BURRIDGE, W. FAIRCHILD AND S. BROWN	UV Disinfection and Reactor Validation Y.A. LAWRYSHYN AND W. CAIRNS
12:30	**Lunch – Main Mall**	

13:30	Use of Binding Assays for Sex Steroid Binding Protein to Investigate Endocrine Disruption in Fish Exposed to Pulp Mill Effluent A.C. PRYCE, L.M. HEWITT, M.E. MCMASTER AND G.J. VAN DER KRAAK	A Kinetic Model for Autotrophic Denitrification Using Sulfur:Limestone Reactors A. DARBI AND T. VIRARAGHAVAN
13:55	Isolation of Compounds from Bleached Kraft Mill Recovery Condensates Associated with Testosterone Depressions in Mummichog (*Fundulus heteroclitus*) M. HEWITT, S.A. SMYTH, M. DUBÉ, C. GILMAN AND D. MACLATCHY	Sulfate Removal from Water A. DARBI, T. VIRARAGHAVAN, Y.-C. JIN, L. BRAUL AND D. CORKAL
14:20	Development of an Investigation of Cause Approach for Assessing Pulp Mill Effluent Effects on Fish M. DUBÉ, D. MACLATCHY AND M. HEWITT	Presence and Removal of Arsenic from Rural Water Supplies in Canada Using Biological Filtration H. PETERSON AND J. SKETCHELL
		NORTH/SOUTH SEMINAR ROOM **Groundwater** **Chair: N. ROSS**
14:45	No Presentation	Geochemical Heterogeneity and Transient Groundwater Flow Within a High-Sulfide Tailings Impoundment M. MONCUR,* C.J. PTACEK, D.W. BLOWES AND R.G. MCGREGOR
15:10	Reproductive Endocrine Function in Wild Fish Exposed to Pulp and Paper Mill Effluents and Municipal Sewage Wastes in Northern Alberta, Canada M. MCMASTER, G. TETREAULT, M. HEWITT, J. PARROTT, J. SHERRY, M. KOLI, G. VAN DER KRAAK, K. OAKES, C. PORTT AND N. DENSLOW	Biobarriers in Fractured Bedrock: Bioclogging of a Lab-Scale Planar Fracture N. ROSS, G. BICKERTON, J. VORALEK, K. NOVAKOWSKI, B.M. YAZICIOGLU, C. KENNEDY, J. SMEGAL, L. DESCHÊNES, R. SAMSON AND S. LESAGE
15:35	Effect of Pulp and Paper Mill Effluent on Retinoic Acid in Fish: Disruption via Retinoic Acid Receptor Mediated Events and Non-retinoic Acid Receptor Mediated Events D. ALSOP,* S. BROWN, M. HEWITT, K. OAKES AND G. VAN DER KRAAK	Biosafety of Bioremediation Techniques: Characterization of the Pilot Sand Aquifer and Experimental Design N. ROSS, L. CAMASSO,* K. MILLAR, G. BICKERTON, J. VORALEK, S. BROWN, H. STEER, C. ROBINSON, C. ROULEAU AND S. LESAGE
16:00	Assessing Vitamin A Status in Contaminant Exposed Fish S.B. BROWN	Direct Injection for *In Situ* Reduction of Chlorinated Solvents in Groundwater S. LESAGE, K. MILLAR, S. BROWN, C.S. MOWDER, T. LLEWELLYN, S.R. FORMAN, D. GREEN, H. MCINTOSH AND G. DELONG
16:30	**CAWQ Annual General Meeting – Auditorium**	
17:00	**Reception and Poster Displays – Main Mall**	

* Competing for the Philip H. Jones Award.

Tuesday, February 5th
Oral Presentations

07:30	**Registration – Main Mall**	
	SESSION 1	**SESSION 2**
	AUDITORIUM **Urban Wet-Weather Pollution: Stormwater Management and Combined Sewer Overflow (CSO) Control** **Chair: J. MARSALEK**	**NORTH/SOUTH SEMINAR ROOM** **Drinking Water: Taste and Odour Compounds and Toxins** **Chair: L. MOORE**
08:00	Great Lakes Sustainability Fund Urban Drainage Program S. KOK, P. SETO AND S. SKOG	Physical Processes Controlling Taste and Odour: Lake Ontario R.Y. RAO, M.G. SKAFEL, C.R. MURTHY AND E.T. HOWELL
08:25	Field Investigations of Urban Wet-Weather Runoff Effects on Freshwater Benthic Invertebrate Communities L. GRAPENTINE, Q. ROCHFORT, J. MARSALEK AND C. LOGAN	Testing Ideas on the Biological Source of the Taste and Odour-Causing Compound Geosmin in Western Lake Ontario T. HOWELL, L. HEINTSCH, P. CHEUNG AND J. WINTER
08:50	Laboratory Investigations of Wet-Weather Pollution Stressors Affecting Benthic Community Structure Using Artificial Substrates Q. ROCHFORT, L. GRAPENTINE, J. MARSALEK AND B. KRISHNAPPAN	Aquatic Odour in Lake Ontario: Tracing Origins Through a Complex System S.B. WATSON, M. CHARLTON, B. BROWNLEE, M. SKAFEL, T. HOWELL, L. MOORE, J. RIDAL AND B. ZAITLIN
09:15	A Look Back at Seven Years of Stormwater Management System Monitoring: What Have We Learned? A. FARRELL AND R. SCHECKENBERGER	Abundance and Distribution of Cyanobacteria in Hamilton Harbour and Adjoining Area of Lake Ontario on September 6 and 20, 2001 T. HOWELL, L. HEINTSCH AND J. WINTER
09:40	The Use of Very Large Sub-surface Flow Wetlands to Treat Glycol-Contaminated Stormwater from Aircraft De-icing Operations J. HIGGINS AND M. MACLEAN	Toxic Algal Blooms in a Mesotrophic System? Hamilton Harbour Revisited S.B. WATSON, M.N. CHARLTON AND J.E. MILNE
10:05	**Coffee Break – Main Mall**	
		NORTH/SOUTH SEMINAR ROOM **Drinking Water: Taste and Odour Compounds and Toxins** **Chair: S. WATSON**
10:25	Characterization and Treatability Study on Windsor CSO J.-G. LI, S. DHANVANTARI, T. TOURALIAS, K. WOODS, H. HORNECK, D. AVERILL AND N. BISWAS	Identification Using HPLC and Fluorometric Detection of Microcystin-LR and YR in Lake Winnipeg and Lake of the Woods and its Implication Towards Lake Water Quality C.R. HERBERT, H.J. KLING AND M.P. STAINTON
10:50	Design and Monitoring Considerations for Wet-Weather Pollution Control Facilities D.W. AVERILL AND T. VAN SETERS	Potential Application of Elevated Potassium Concentrations to Control Undesirable Cyanobacterial Taxa in Lakes C. NALEWAJKO, S.B. WATSON AND T. MURPHY
11:15	Performance of a Pilot Plant for Windsor CSO Treatment J.G. LI, S. DHANVANTARI, T. TOURALIAS, K. WOODS, H. HORNECK, D. AVERILL AND N. BISWAS	Total Phosphorus Budgets and Nitrogen Loads: Lake Simcoe, Ontario (1990-1998) J.G. WINTER, P.J. DILLON, M.N. FUTTER, K.H. NICHOLLS, W.A. SCHEIDER AND L.D. SCOTT

	AUDITORIUM **Innovative Wastewater Treatment Technologies and the Environmental Effects of Wastewater Discharge** **Chair: P. SETO**	
11:40	Application of Humates for Nutrients Removal from Wastewater J. KOCHANY AND W. SMITH	Getting to the Bottom of Taste and Odours in St. Lawrence River Water: The Role of Periphyton J. RIDAL AND S. WATSON
12:05	The Role of Cyanobacteria in Pulp and Paper Waste Treatment Systems A.E. KIRKWOOD,* C. NALEWAJKO AND R.R. FULTHORPE	Influence of Algae Decomposition on Water Quality in the Dnieper River and Role of the Institute of Hydrobiology in the Ecological Research A. SHULYARENKO AND L. ZHURAVLEVA
12:30	**Lunch – Main Mall**	
		NORTH/SOUTH SEMINAR ROOM **Drinking Water: Waterborne Pathogens** **Chair: T. EDGE**
13:15	Removal of Cadmium from Aqueous Solutions Using Edible Mushrooms (*Agaricus Bisporus* and *Lentinus Edulus*) T. MATHIALAGAN* AND T. VIRARAGHAVAN	*Escherichia coli* 0157:H7 in Surface Waters in Southern Alberta V.P.J. GANNON, T.A. GRAHAM, S. READ, K. ZIEBELL, J. MORI, J. THOMAS, B. SELINGER AND J. BYRNE
13:40	Biological Nutrient Removal in Poland: Case Studies of Successes and Problems J.A. OLESZKIEWICZ	Potential Applications of 5' Nuclease ("REAL-TIME") Quantitative PCR for Microbial Water Diagnostics I.V. FOULDS, R.A. GUY, A. KAPOOR AND P.A. HORGEN
14:05	Dynamic Simulation of Food Processing Facility Effluent Treatment S.D. SNOWLING AND W.J. MALYK	The Use of RT-PCR for the Detection of Enteric Viruses in Prairie Surface Drinking Water Supplies N.J. RUECKER,*♣ G.S. FOUT, H.G. PETERSON, S. WATSON, J. LAWRENCE, G.D. APPLEYARD AND N. CHRISTOFI
14:30	Innovative Biological Treatment Processes for Water and Wastewater C.N. MULLIGAN	No Presentation
14:55	Disruption of Biogenic Amine Levels and Their Metabolism in Freshwater Mussels Exposed to a Municipal Effluent F. GAGNÉ AND C. BLAISE	Pathogen Inactivation in Municipal Sludge: Low-Dose Lime and Fly-Ash Treatment J.A. OLESZKIEWICZ, G. BUJOCZEK, J. BREWSTER, R.S. REIMERS AND M. ABU-ORF
15:20	Environmental Evaluation of Land-Applied Pulp Mill Biosolids: Monitoring Fate of Sludge Constituents in Forest Ecosystems and Assessing Impact Using Ecologically Relevant Organisms I.-V. BOSTAN, L.H. MCCARTHY, E. BANDELJ AND K. YAMBAO	Environmental Dimensions of Pathogens and Water Security – Core Science Capacity Gaps T. EDGE AND R. KENT

15:45	Photo-transformation of Resin Acids in Saale River Water, Germany D.W. MCMARTIN,* J.V. HEADLEY AND J.A. GILLIES	No Presentation
16:10	A Review of Water and Wastewater Management Techniques A.A. MAHMOOD* AND C.N. MULLIGAN	No Presentation
16:40	Auditorium: Philip H. Jones Award and Concluding Remarks by M.N. Lywood	

* Competing for the Philip H. Jones Award

♣ N.J. Ruecker is the recipient of the Great Lakes Sustainability Fund Travel Award.

POSTER DISPLAYS
(MAIN MALL)

Poster displays are available in the Main Mall on both Monday, February 4th and Tuesday, February 5th. The authors will be in attendance at their poster presentations during the Reception on Monday, February 4th at 17:00.

SESSION THEME	POSTER DISPLAY
Endocrine Disrupting Compounds	Waterborne 17α-ethynylestradiol Affects Aggressive Behaviour of Male Fathead Minnows (*Pimephales promelas)* under Artificial Spawning Conditions A.R. MAJEWSKI, V. PALACE, P. BLANCHFIELD AND K. WAUTIER
	Effects of Chlorinated Solvents on Three North American Amphibian Species T.V. MCDANIEL, P.A. MARTIN, R.N. ROSS, S. BROWN, K. MILLAR, S. LESAGE AND B. PAULI
	A Critical Assessment of the Potential Wildlife Toxicity of Glyphosate in Ontario with Consideration for Endocrine Disruption P.A. MARTIN, P. TAKACS AND J. STRUGER
	A Critical Assessment of the Potential Wildlife Toxicity of Atrazine in Ontario with Consideration for Endocrine Disruption J. STRUGER, P.A. MARTIN AND P. TAKACS
	Odours from Pulp Mill Effluent Treatment Ponds: The Origin of Significant Levels of Geosmin and 2-Methylisoborneol (MIB) S.B. WATSON, J. RIDAL, B. ZAITLIN AND A. LO
Groundwater	Iron Speciation and Metal Availability in Mine Tailings and a Mine Drainage Impacted Aquifer N.A. DOERR,*♠ C.J. PTACEK AND D.W. BLOWES
	Mobility of Arsenic in an Aquifer Impacted by Mine Tailings C. WALKER,* C.J. PTACEK AND D.W. BLOWES
Urban Wet-Weather Pollution: Stormwater Management and Combined Sewer Overflow (CSO) Control	Combined Sewer Overflows in Hamilton — An Update M. STIRRUP AND D. MARCHANT
Drinking Water: Taste and Odour Compounds and Toxins	Geosmin and 2-Methylisoborneol Production and Growth of Actinomycetes in Water E. EBBENS, B. ZAITLIN AND S. WATSON
	A New Planktic Species of *Pseudanabaena* (Cyanoprokaryota, Oscillatoriales) from North American Large Lakes H.J. KLING AND S. WATSON
	Project Coordination: Taste and Odour Research Consortium, 2001 Y. MACABUAG, L. MOORE AND T. KUCHTA
	Microcystins as Initiators of Avian Botulism? T.P. MURPHY, K. IRVINE, J. FREIDHOFF, J. DAVIES, M. CHARLTON AND S. WATSON

* Competing for the Philip H. Jones Award.

♠ N. Doerr is the recipient of the Western Lake Ontario Research Consortium Travel Award.

Innovative Wastewater Treatment Technologies and the Environmental Effects of Wastewater Discharge	Role of Planktonic Algae in Removal of Zn from Constructed Wetlands — Modelling of Algae/Plants Competitive Removal M. ELEKTOROWICZ, B. KERIN, P. LI AND A. EL-HAWARI
	Modelling of the Phosphorus Fate due to Agriculture Activities in the L'Assomption River Watershed M. ELEKTOROWICZ AND C. GALANG
Drinking Water: Waterborne Pathogens	Quantitative Detection of Waterborne Pathogens by Real-Time PCR A. KAPOOR, R.A. GUY, I.V. FOULDS, A. CASTLE, C. GUBALA, U. KRULL AND P.A. HORGEN
Water Pollution	Sediment Biostabilization in a Wave-Dominated Environment N. ROSS, I. DROPPO, M. SKAFEL, K. MILLAR, C. JASKOT, D. DOEDE AND S. HILL
	Uptake and Tissue Distribution of Thallium in Fish C. ROULEAU, Z. XIONG AND G. PACEPAVICIUS
	Uptake and Tissue Distribution of Perchloro- and Trichloroethylene in Tadpole and Adult of American Toad T.V. MCDANIEL, C. ROULEAU, P.A. MARTIN, N. ROSS AND S. LESAGE
	A Canadian Guidance Framework for Phosphorus in Freshwater Systems S.L. ROE, R. FLETCHER, D.J. SPRY AND P.-Y. CAUX

NOTE: There will be a number of displays in the Main Mall including:

- **AssayNet Canada Inc.**
- **Centennial Concrete Pipe & Products Inc.-Stormceptor**
- **Environmental Commissioner of Ontario**

ORGANIZING COMMITTEE
CHAIR: A. BIELAK

PROGRAM COMMITTEE
CHAIR: S. WATSON

ENDOCRINE DISRUPTING COMPOUNDS
CHAIR: J. PARROTT

DRINKING WATER: WATER TREATMENT
CHAIRS: J. LAWRENCE AND D. ELLISON

- R. HOFMANN
- R. ANDREWS
- G. GAGNON

GROUNDWATER
CHAIR: N. ROSS

URBAN WET-WEATHER POLLUTION: STORMWATER MANAGEMENT AND COMBINED SEWER OVERFLOW (CSO) CONTROL
CHAIR: J. MARSALEK

DRINKING WATER: TASTE AND ODOUR COMPOUNDS AND TOXINS
CHAIRS: S. WATSON AND L. MOORE

- P. CHAMBERS
- M. CHARLTON

INNOVATIVE WASTEWATER TREATMENT TECHNOLOGIES AND THE ENVIRONMENTAL EFFECTS OF WASTEWATER DISCHARGE
CHAIR: P. SETO

DRINKING WATER: WATERBORNE PATHOGENS
CHAIR: T. EDGE

ARRANGEMENTS COMMITTEE
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Endocrine Disrupting Compounds

Chair: JOANNE PARROTT

Evidence of Endocrine Disruption in Marine (*Mya arenaria*) and Freshwater (*Elliptio complanata*) Bivalves: Case Studies from the Saguenay Fjord and Greater Montreal Area of the Saint-Lawrence River

CHRISTIAN BLAISE* AND FRANÇOIS GAGNÉ

Centre Saint-Laurent, Environment Canada, 105 McGill, Montréal, Quebec H2Y 2E7

Because of their sessile and filter-feeding characteristics, molluscan shellfish are relevant bioindicators to assess exposure and effects of contaminants over space and time. As other oviparous organisms (e.g., fish, amphibians), bivalves are known to produce vitellin-like (egg yolk) proteins (Vn) presumably under estrogen receptor mediation. Measuring Vn in animals exposed to mixtures of contaminants that may be present in aquatic systems allows information to be gathered on potential (anti)estrogenic effects which may be at play. After confirming that bivalve Vn is a Zn- and Ca-containing glycolipophosphoprotein similar in constitution to yolk protein found in fish, we used an alkali labile phosphate (ALP) method to indirectly measure Vn expression in field-exposed animals. The ALP method was employed in two studies to identify areas having the potential to affect the estrogenicity of bivalves. The first of these was conducted on *Mya arenaria* soft-shell clams collected at selected sites in the Saguenay River (Quebec, Canada), while the second examined the freshwater mussel *Elliptio complanata* exposed to a municipal effluent plume in the St. Lawrence River (Quebec, Canada). Field work conducted in the Saguenay fjord revealed significant ALP level differences in clams collected at specific sites during temporal (May to October, 1997) and spatial (June, 1997) surveys, suggesting the presence and influence of (anti)estrogenic chemicals. A second survey, undertaken at selected intertidal zones in 1998, further indicated that gonadal and Vn chemical properties can be altered by contaminants. A third survey, recently carried out in May 2001, suggests that androgenic effects might be impacting particular areas based on increased male/female ratio results obtained with *Mya* clams. From 1999 to 2001, caged bivalve exposures were also performed with *E. complanata* in the Saint Lawrence River to study the impact that a major municipal treatment plant effluent might have on aquatic fauna. Vn levels in mussel gonads were consistently more elevated in animals exposed at downstream sites over an upstream site and soft tissue chemical analysis gave some evidence of accumulation by estrogen-inducing contaminants. Overall, results of these two investigations demonstrate that aquatic systems receiving either mixed and diffuse pollution (Saguenay fjord) or urban pollution (Saint Lawrence River in the Greater Montreal area) are subject to inputs of bioavailable contaminants capable of inducing (anti)estrogenic effects in bivalves. Long-term experiments are in progress to test the hypothesis that urban effluents can significantly increase the number of females in caged freshwater mussels.

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Development of Testing Methods for Endocrine Disrupting Compounds in an Estuarine Killifish (*Fundulus heteroclitus*): Effects of an Estrogen Agonist and an Estrogen Antagonist

D.L. MACLATCHY,[1*] C.I. GILMAN,[1] A.R. BELYEA,[1] S.C. COURTENAY[2] AND G.J. VAN DER KRAAK[3]

[1] *Department of Biology and Canadian Rivers Institute, University of New Brunswick, Saint John, New Brunswick*
[2] *Gulf Fisheries Centre, Fisheries and Oceans Canada, Moncton, New Brunswick*
[3] *Department of Zoology, University of Guelph, Guelph, Ontario*

We are interested in determining reproductive endpoints in adult prespawning fish that are sensitive to endocrine disruption. Using the estuarine killifish, *Fundulus heteroclitus*, we have developed a 7- to 15-day (daily renewal) static exposure laboratory protocol to assess changes in plasma steroids, plasma vitellogenin, and *in vitro* gonadal steroidogenesis. Using cold temperatures (4^{o}C) and short daylength (8hL:16hD) we artificially regress fish for a minimum of one month. Following regression, fish are placed in warmer temperatures (18^{o}C) and long daylength (16hL:8hD) to stimulate gonadal development for 1 to 2 weeks. In these experiments, fish were then exposed (via waterborne exposure) for 7 to 15 days to either an estrogen agonist [ethynylestradiol (EE)], or an estrogen antagonist [ZM-189,154 (ZM)]. Responses of plasma steroids and *in vitro* gonadal steroid production are dependent on concentration and exposure period. Low concentrations (1–50 ng/L) require a minimum 15-day exposure for effects to be observable. Higher concentrations (100–1000 ng/L) are effective by 7 days. In general, both EE and ZM depress plasma testosterone in males with little effect on females. Low doses of EE increase plasma estradiol, while high doses depress it. EE increases plasma vitellogenin levels in males and females, in a dose-dependent fashion. Future goals are use of the bioassay to determine effects and mechanisms of action of putative EDSs and complex mixtures on sensitive endocrine endpoints.

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Development of Fathead Minnow Lifecycle Tests for Detection of Reproductive Toxicants in Effluents

JOANNE PARROTT,[1*] MARK BAKER,[1] BEV BLUNT[1] AND CRAIG WOOD[2]

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The goal of this study was to assess the use of fathead minnow full lifecycle assay for detection of known endocrine disrupting substances (EDS). As well, we wanted to determine whether this assay could detect reproductive effects on fish from exposure to potential weak EDS mixtures, such as pulp mill effluents. Fathead minnow eggs exposed to ethinylestradiol (EE2, 0–32 ng/L) or methyltestosterone (MT, 0–3.2 μg/L) in a flow-through exposure system showed dramatic changes in growth (length, weight) of fish at high concentrations. Changes were seen as soon as 30 days post-hatch, however the most sensitive indicators of reproductive change required full lifecycle exposures (150 days post-hatch). Egg fertilization was one of the most sensitive indicators, and was reduced in fish exposed to the lowest concentrations of EE2 (0.32 ng/L). Juvenile fish exposed to EE2 showed similar changes in fertilization success, but effects were not as dramatic as fish exposed for an entire lifecycle. Development of secondary sex characteristics was also a very sensitive indicator, with 30 day-old fish exposed to MT showing premature male sex characteristics such as tubercles. These changes were more dramatic in older fish (at 60 and 90 days post-hatch), which showed premature male sex characteristics at very low MT concentrations (0.1 μg/L). Physiological alterations at 150 days (changes in liver size, gonad size, fecundity) and sex ratios were less sensitive, with changes seen about 3.2 ng EE2/L. The assay, developed with known EDS, proved to be useful for detection of reproductive changes caused by real-life effluent mixtures. Lifecycle exposures of fathead minnow eggs to bleached sulphite mill effluent (BSME) showed the most sensitive endpoint to be egg laying (which was reduced in 10% effluent and above). Changes in secondary sex characteristics, growth, and physiological changes were also seen. The full lifecycle assay provides a definitive test for reproductive/EDS effects, but it is a lengthy procedure. Shortening the test has been possible by using juvenile fish and following them to adulthood, as the most sensitive indicators that we have examined have been sex characteristics and reproduction. However, the trade-off for the shorter tests is a decrease in sensitivity.

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Biochemical and Physiological Effects in Wild Fathead Minnows from a Lake Experimentally Treated with the Synthetic Estrogen, Ethynylestradiol

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Effects of a potent hormone mimic are currently being examined in fish from a lake experimentally treated with the synthetic estrogen, ethynylestradiol (EE2). EE2 was added to Lake 260, a small Precambrian shield lake in the Experimental Lakes Area (ELA) of Northwestern Ontario, from late May to the end of October 2001. Concentrations of EE2 in epilimnetic waters ranged between 4.5 and 8.1 ng/L, with a seasonal mean of 6.1 ng/L. Male fathead minnows (*Pimephales promelas*) captured from Lake 260 after EE2 additions began contained 9000-fold higher concentrations of the egg yolk precursor vitellogenin, than was detected in fish captured from the same lake prior to the EE2 additions, or when compared to fatheads from reference lakes during the same sample time. Histological examination of tissues from EE2-exposed male fatheads in Lake 260 showed widespread fibrosis and inhibited development of testicular tissue. Intertubular edema, hyaline degeneration in the proximal tubules, thinning of the Bowman's capsule, eosinophilic deposits in the glomerular tuft, and some enlargement of the tubules was also observed in the kidney. Whole lake additions of EE2 will continue in Lake 260 during the 2002 ice-free season. Further studies will examine the relationships between biochemical and histological alterations and population-levels effects.

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Effects of Endocrine Disruptors on Growth and Physiology of Atlantic Salmon

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We recently identified relationships between historical applications of an insecticide containing 4-nonylphenol (4-NP) and catch data for Atlantic salmon populations. To test the hypothesis that 4-NP impairs parr-smolt transformation, we exposed Atlantic salmon smolts to a range of environmentally relevant, pulse doses of waterborne 4-NP (4 to 200 µg/L). We also exposed smolts to a sustained doses of estradiol (E2) (100 ng/L). Osmoregulatory (plasma and tissue ions, gill ATPase), biochemical (glucose/glycogen), and endocrine (thyroid hormones, thyroid hormone deiodinases, vitellogenin, steroids, growth hormone and insulin-like growth factor) parameters were measured on smolts. There were no treatment-related increases in mortality during a sea water challenge soon after exposure, however, subsequent growth in sea water was impaired in about 25 to 35% of fish from various treatment groups (5% in control). Vitellogenin was increased in exposed fish but there were few discernable effects on osmoregulatory and steroid hormone parameters. Changes in plasma thyroid hormones and growth factors as well as deiodination activity in brain and liver occurred during parr-smolt transformation, and these activities were also altered by 4-NP and E2, with as yet undetermined effects on other aspects of smoltification. If the effects exerted by 4-NP are due to its steroidogenic potential, then steroidogenic activity stemming from other sources (e.g., domestic sewage, agricultural wastes or phytoestrogens from pulp mills) might influence present day salmon populations.

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An ELISA for Atlantic Salmon (*Salmo salar*) Vg and its Use in Measuring the Response of Salmon Smolts to 17ß-estradiol and 4-nonylphenol Treatments

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Fairchild et al. (1999, Environmental Health Perspectives 107:349–357) used an epidemiological approach to associate declines in returning populations of Atlantic salmon (*Salmo salar*) in several Eastern Canada rivers to applications of Matacil® 1.8D in forest spray operations to control Spruce budworm. A plausible mechanistic link was suggested to 4-nonylphenol, which is the diluent in commercial formulations of the insecticide. Laboratory experiments with salmon smolts demonstrated that 4-NP could impair subsequent growth and survival in sea water. Since 4-NP is a known environmental estrogen and toxicant, we wish to test whether its action in smolts is mediated by an estrogenic mechanism, or whether some other mode of action is involved. The egg yolk protein vitellogenin (Vg) was selected as a response signal for the estrogenic pathway since it can be induced by various estrogenic chemicals including 4-NP. An indirect competitive binding enzyme-linked-immunosorbent-assay, which was based on commercially available antibodies, was developed and optimized. The ELISA was used to measure Vg in the plasma of salmon smolts that had been exposed to 17ß-estradiol and 4-nonylphenol under a flow-through regime. The ELISA data was confirmed by PAGE and Western Blotting techniques. The preliminary experimental data show that both test chemicals induced Vg in a dose-dependent manner in the exposed smolts.

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Use of Binding Assays for Sex Steroid Binding Protein to Investigate Endocrine Disruption in Fish Exposed to Pulp Mill Effluent

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Effluents released from pulp and paper mills have a wide range of reproductive effects on fish in the receiving environment. Some of the observed effects (reduced steroid levels, reduced gonad size, etc.) may occur through interaction of chemicals with hormone receptors. We have been using competitive ligand binding assays to screen complex mixtures for ligands that interact with hormone receptors and binding proteins to investigate this pathway in fish responses. Sex steroid binding protein (SBP) is present in the plasma of most animal classes and binds the sex steroids estradiol and testosterone to protect them from metabolism as they are transported from steroidogenic to target tissues. SBP has been used as a screening tool to determine estrogenicity and androgenicity in samples and we report on the ability of this assay to evaluate bioavailable compounds in pulp mill effluent with hormonal activity. Past experiments have looked at binding of pulp and paper mill effluents to SBP in laboratory species, such as goldfish (*Carassius auratus*), but not to SBP from wild fish. We have modified the goldfish SBP assay to allow us to examine SBP in white sucker (*Catostomus commersoni*), a species commonly exposed to pulp and paper mill effluents in Canada. Ligands accumulated in the livers of effluent-exposed white sucker were tested for binding to SBP in both goldfish and white sucker to determine whether the same pattern of binding is observed in both species. The assay will also be used to compare SBP binding characteristics in white sucker from reference and exposed sites, which may be related to the reproductive alterations observed in this species.

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Isolation of Compounds from Bleached Kraft Mill Recovery Condensates Associated with Testosterone Depressions in Mummichog (*Fundulus heteroclitus*)

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Previous studies have identified chemical recovery condensates as a primary source of hormonally active substances within a Canadian bleached kraft pulp mill. Although reverse osmosis treatment of condensates raises the exposure threshold that alters circulating levels of testosterone in mummichog (*Fundulus heteroclitus*), the responsible chemicals have not been characterized. In this study, a solid phase extraction (SPE) method was developed to isolate chemical recovery condensate extractives for evaluation of hormonal activity. Condensates generated during softwood and hardwood pulp production were investigated for their relative potential to affect both circulating and gonadal production of sex steroids in mummichog. Mummichog were exposed to whole condensates, extracts from suspended particulates (>1 μm), two fractions from SPE, and residual condensates after SPE. The distribution of bioactivity among condensate fractions were similar for both wood furnishes. In both sexes, significant depressions in circulating testosterone and *in vitro* gonadal testosterone production were associated with exposure to whole condensates, particulate extracts, one SPE fraction and residual material after SPE. An optimized SPE method subsequently demonstrated complete recovery of polar, bioavailable chemicals that reduced testosterone levels in both sexes. Characterizations of active fractions by GC-MS showed the presence of extractives with molecular masses ≥240 amu possessing functionalities consistent with lignin degradation products. This study provides the first isolation of chemicals derived from pulp production associated with impaired reproductive performance in fish.

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Development of an Investigation of Cause Approach for Assessing Pulp Mill Effluent Effects on Fish

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Determination of an effect is only the initial step for environmental protection. Once an effect is defined, the cause of the effect requires identification so that mitigation can be assessed. We have developed an investigation of cause approach for the pulp and paper industry in an effort to identify the stressors contributing to reproductive-endocrine effects in fish. The approach emphasizes a tiered implementation of progressively more detailed questions related to stressor identification. Is there an effect of final mill effluent on fish reproductive-endocrine function? Is this effect mill-related? Where does the source of the effect originate from within the mill (waste stream)? What are the characteristics of the chemicals within the identified waste stream? What are the identities of the chemicals within the identified waste stream? Artificial stream studies were conducted at a bleached kraft pulp mill in Saint John, NB, where mummichog (*Fundulus heteroclitus*) were exposed to environmentally relevant concentrations (1%) of final mill effluent. Plasma testosterone was significantly depressed (>85%) in males and females relative to control fish. The in-mill source of these responses was then identified by exposing fish to waste streams that were ultimately discharged to the environment and represented key stages in the process. The waste streams were tested in isolation and in combination building a cumulative effects assessment within the process from the pulping stage to the effluent discharge stage. This approach identified chemical recovery condensates as the waste stream "furthest up" in the process affecting mummichog sex steroids. Bioactivity of the recovery condensates was confirmed using acute toxicity tests. Laboratory exposures for 7-d and 21-d also confirmed that condensates depressed mummichog sex steroids. Preliminary chemical characterization of the condensates showed that weak black liquor carryover was not responsible for the sex steroid depressions. Common plant phytosterols (ß-sitosterol) were also not detected in the condensates. This research has now progressed to the stage in the investigation of cause approach where the hormonally active substances in the condensates have been isolated (see Hewitt et al., this session). This research also led to installation of reverse osmosis technology in the mill to treat the condensate stream before discharge. Focused application of this treatment technology resulted in a final effluent that did not depress sex steroids in mummichog at an environmentally relevant exposure concentration.

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Reproductive Endocrine Function in Wild Fish Exposed to Pulp and Paper Mill Effluents and Municipal Sewage Wastes in Northern Alberta, Canada

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We have conducted studies through the Northern Rivers Ecosystem Initiative and the Toxic Substances Research Initiative examining reproductive endocrine function in wild fish downstream of three mills within the Northern River Basins. Although these are the major sources of effluent input into these systems, effluents from the municipal sewage systems associated with the two towns in the area are also discharged into these rivers. We are using a suite of reproductive endocrine endpoints that we have developed over the last several years to evaluate endocrine function in wild fish and to separate out the effects of the various discharges. Although fish downstream of all of the discharge sites demonstrate responses related to nutrient input (increased growth, and condition) relative to the reference fish, separation of the discharge locations is also possible using our endocrine tools. Fish downstream of the sewage discharge at one location demonstrate altered reproductive steroid profiles as well as induced vitellogenin levels. These fish also demonstrate altered gonadal steroid productive capacity. We are continuing to evaluate other endocrine endpoints such as circulating gonadotropin levels, quantifying gonadal apoptosis, and assessing steroid receptor levels. Effluent extracts are also being tested using a number of in vitro endocrine assays to evaluate both the estrogenic and androgenic components in the effluents from the various sites.

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COMPETING FOR THE PHILIP H. JONES AWARD

Effect of Pulp and Paper Mill Effluent on Retinoic Acid in Fish: Disruption via Retinoic Acid Receptor Mediated Events and Non-retinoic Acid Receptor Mediated Events

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A classic example of xenobiotic induced endocrine disruption involves the toxicant binding to a hormone receptor and thereby upsetting hormone signalling. However, other mechanisms may also contribute to the disruption of normal hormone signalling. We have found that extracts from pulp and paper mill effluent can act in this classic definition of an endocrine disrupter and displace retinoic acid from rainbow trout retinoic acid receptors *in vitro*. However, we have also found that fish exposed to the effluent *in vivo* have depleted hepatic retinoid stores (retinoic acid precursors), as well as decreased retinoic acid receptor levels. These latter effects of the pulp and paper mill effluent may represent new modes of endocrine disruption.

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Assessing Vitamin A Status in Contaminant Exposed Fish

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Retinoids (vitamin A compounds) have received attention as indicators of exposure to a variety of environmental contaminants. For example, it has long been noted that alterations in vitamin A homeostasis occurs in fish-eating birds from contaminated regions in the Great Lakes basin. To determine the extent that retinoid dynamics in predatory fish might also be influenced by contaminants, we experimentally exposed lake trout to planar halogenated hydrocarbons and examined the levels of hepatic retinoids in collections of feral fishes. Decreases in levels of both circulating retinoids and tissue storage forms represent a consistent response of fish to planar halogenated hydrocarbons. Field monitoring studies showed that lake trout inhabiting Lake Ontario have altered retinoid profiles relative to fish from reference locations. However, the observed differences were more suggestive of influence by dietary factors. Fish species collected in the vicinity of pulp mill inputs had diminished stores of hepatic retinoids. In most cases, lower levels of hepatic retinoids were also associated with elevated hepatic MFO activity. Depleted retinoids appear to offer the potential to indicate long-term exposure to certain contaminants. However, analytical distinction between retinoid types will be important toward developing a complete understanding of retinoid status. The long-term functional consequences of the disturbed vitamin A metabolism in fishes are not completely understood. However considering the key role that vitamin A plays in vision, differentiation and growth, the probability of interactive effects between vitamin A dynamics and contaminant toxicity cannot be ignored.

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Drinking Water: Water Treatment

Chairs: JOHN LAWRENCE AND DUNCAN ELLISON

Trends in Water Treatment to Meet Present and Future Challenges

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The numerous "boil water" advisories that have occurred in Canada in recent years indicate that conventional treatment practices are becoming inadequate to cope with the degraded raw water conditions prevailing in some areas of the country. Conventional treatment, which has served society well for nearly a century, focuses on particulate removal and disinfection. However, some of the heavily degraded source waters facing treatment engineers today pose challenges that cannot be adequately addressed by using only these treatments and require more sophisticated technologies. Some of the immediate challenges include high levels of pathogens (bacteria, viruses, protozoa) for which normal disinfection is inadequate, algal toxins and associated taste and odour events, pesticides and heavy metals (Pb, Cd, Cu, Hg, As). In some areas, high levels of DOC can be a serious problem particularly in small rural areas that have minimal treatment. Future threats to source waters may include pharmaceutical and veterinary drug residues, personal-care product residues and endocrine disrupting chemicals, EDCs. This presentation will review some of the recent advances that are being made in water treatment practices to address these concerns.

Where feasible, the most effective way of ensuring safe drinking water is protection of the source. Approaches that can be used for source protection include limiting public access and recreational activities and eliminating or limiting potentially deleterious effects from industry, agriculture (pesticides, fertilizer and manure management), aquaculture and urban development. Understanding the pathways by which microbiological organisms and chemical contaminants reach the source water often allow preventative measures to be taken that drastically reduce the overall risk of contamination. Such measures are gaining increasing public acceptance.

Many of the advanced technologies to improve drinking water quality are based on membrane filtration. Depending on pore size, membrane filtration can be used for ultra-filtration, nano-filtration or reverse osmosis. Today, membranes are much more rugged and reliable than their predecessors and the price has fallen by as much as 10-fold since 1994. Membranes are particularly effective for removing fine particulates, including many pathogens.

Chlorine has been the predominant disinfectant of choice in drinking water treatment in North America. However, recent outbreaks of waterborne diseases caused by cysts and viruses is necessitating an evaluation of alternative agents such as chlorine dioxide, ozone and ultraviolet light that can be more effective against these types of organisms. The move towards alternative disinfects is also being driven by the health implications of chlorinated disinfection by-products.

Processes for the removal of trace levels of pharmaceuticals, veterinary drugs, pesticides and EDCs are still mostly at the research stage. Levels of hydrophobic pesticides can be effectively reduced by adsorption on to activated carbon. Hydrophilic drug residues (such as 5-methyl-1,3,4-thiadiazole-2-thiol [MMTD]) have been successfully treated at the bench scale with UV and UV/H_2O_2 while other attempts have been made using ozone oxidation.

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Raw and Treated Water for Rural Areas in Saskatchewan

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The effectiveness of water treatment is highly dependent on source water quality and the type of treatment applied. Ideally, water treatment plants (WTPs) should monitor raw water characteristics on a continual basis and apply the most appropriate treatment technologies available. In reality, most WTPs fall short of one or both of these goals, particularly in smaller communities which frequently need to treat poor quality source waters. In a preliminary survey, we assessed both source water quality and treatment effectiveness among selected sites in rural Saskatchewan communities. Physical, chemical and microbial properties of four source waters were compared. Raw water from the South Saskatchewan River was monitored upstream and downstream from the City of Saskatoon. The river is considered a good quality source water, however we did detect a deterioration in the water quality after the city. River water quality was compared to water from two reservoirs that historically have provided poor quality source waters for two rural communities. Turbidity and particle size distributions varied among source waters but were generally elevated in the reservoirs, while dissolved organic carbon (DOC) in these reservoir samples were up to ten times higher than in the river. The river water contained higher concentrations of coliform and heterotrophic bacteria than the reservoir waters. Treatment processes for these water sources vary from chlorination alone, to combinations of coagulation, sedimentation, filtration and chlorination. When the river is used as a source water even chlorination alone appeared to produce water of reasonable quality although treatment prior to chlorination improved the quality of the water. For the reservoirs the water treatment processes were less effective indicating that the types of water quality problems that occur in reservoirs are more difficult to treat. This preliminary survey underscores several important points. 1) There can be a wide discrepancy in source water quality within a (relatively) small geographic area. 2) Simple treatment processes which provide adequate quality treated water from good source waters can be ineffective when applied to poor quality source waters. 3) For the same raw water quality, a lack of community resources can result in large differences in WTP effectiveness. These points raise concerns over the quality and the potential safety of treated water delivered in rural areas.

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Benefits of a Biocidal Pretreatment for the Coagulation of High DOC, Cold Water

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Small prairie farm reservoirs are usually low in turbidity and contain high concentrations of dissolved organic carbon (DOC). They are commonly treated with aluminum sulphate in late fall. The water temperature is usually below 3°C, and this often produces poor results.

Laboratory studies were completed to investigate the effect of various biocidal pretreatments on coagulation of high DOC water. The biocidal pretreatments were designed to determine the biological component in the coagulation process and included filtration and boiling, and the addition of copper sulphate, peroxide and chlorine. The treated water was tested for biological activity using the BART™ biological activity reaction test. For the coagulation treatment, aluminum sulphate and ferric chloride were used with water temperatures of 1.5°C and 20°C. Turbidity, particle count, total suspended solids (TSS), DOC, UV_{254} absorbance, colour, and alkalinity were analyzed to determine improvements in coagulation performance.

From the results of the biological activity tests it was shown that the biocidal treatments reduced the bacteria population by more than three logs. This compared to coagulation without biocidal treatments that showed an average bacteria removal of 0.85 logs. In addition, the biocides tested were also found to significantly improve the removal of turbidity, particles and TSS at both 1.5°C and 20°C. By comparing different concentrations of biocides it was determined that the required dosage of biocide to improve coagulation results was relatively small, and increasing the dosage did not improve results. Of the biocides tested, the chlorine pre-treatment was found to be the most effective with improved particle removal and significant reductions in the size of the remaining particles. This resulted in improvements in TSS removal greater than one log. With the exception of chlorine, the biocides tested did not affect the DOC, UV_{254} absorbance or colour. Pretreatment with chlorine consistently improved the UV_{254} absorbance and colour removal, but DOC removal was not noticeably affected.

From these laboratory studies there is significant evidence that the biocides, by significantly impairing microbial activity, enhanced the impact of the coagulation process. This would indicate that the process of coagulation does significantly interact with the microbial flora in the water and that these factors should be considered in future modelling of coagulation processes in water and wastewaters.

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COMPETING FOR THE PHILIP H. JONES AWARD

Characterization of Particles in Slow Sand Filtration

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Microscopic analysis of water within the system can indicate what size of filter media is required, and can be used to monitor filter performance. This study investigated a malfunctioning slow sand filter in a water treatment facility in a First Nations community in Northern Ontario. There has been a boil-water advisory in the community due to high turbidity in the drinking water. The slow sand filters in the plant clogged frequently resulting in outflow volumes significantly below plant design capacity.

Water samples were taken at various points before and after slow sand filtration. Particles suspended in raw and filtered water were isolated and analyzed microscopically. An image analysis system was used to determine the size distribution of the particles in each sample.

Raw water supply for the plant contained large, predominantly microbial aggregates. The distribution of particle sizes in raw water was bimodal; there was a population of small particles with sizes less than 1 mm and a population of large particles with sizes smaller than 1.9 mm. It is expected that the large particles (60% of total particle number) would settle out in the wet well and only small particles (40%) would actually be in contact with the filter media (an on-line particle analysis in the plant will be conducted shortly to confirm this hypothesis).

The size of small particles, therefore, would determine the grain size of filter media. The average size of small particles in raw water was 0.6 mm, whereas the size of the sand in the top layer of the filter varied from 0.2 to 0.3 mm. Microscopic analysis thus indicated that the filter media contains particles that are too small to be effective, and this is the cause of premature filter clogging.

Microscopic inspection of the particles present in the effluent of the sand filter showed that the water contained predominantly single (not aggregated) mineral particles. More than 60% of these particles were smaller than 0.01 mm. Similar particles were found to be present in the unused filter media, as supplied by the manufacturer. Microscopic analysis of finished water indicated, therefore, that particles causing high turbidity did not originate from the raw water supply but from the filter media.

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Update on the Use of Granular Activated Carbon in Ontario

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The use of Granular Activated Carbon (GAC) for drinking water treatment has increased dramatically in Southern Ontario over the last several years. The recent addition of GAC to large drinking water filtration plants in Durham, Toronto, Peel, Hamilton and Niagara has increased the installed GAC base from under 2000 metric tonnes in 1999 to over 13,000 metric tonnes in 2002.

The primary objective for most municipalities for installing GAC was for taste and odour control. GAC is a proven technology for the removal of many taste and odour causing compounds common in Ontario source waters such as 2-methylisoborneol and geosmin. However, as trace levels of other natural and synthetic chemicals such as endocrine disruptors, algal metabolites, PCBs, and traces of numerous synthetic organic chemicals are discovered in Ontario source waters, there is a growing interest and body of research in the ability of GAC to remove these chemicals at the drinking water plant.

The purpose of this presentation is to:

- Review the success of installed virgin and reactivated GAC for removing taste and odour at Ontario drinking water plants;
- Review existing research on the ability of GAC to remove endocrine disruptors;
- Review existing research of the ability of GAC to remove algal metabolites such as microcystin;
- Review existing research on the ability of GAC to remove PCBs and dioxins;
- Review existing research on the ability of GAC to remove other synthetic organic chemicals; and
- Review existing research on the ability of GAC to remove organic metal compounds such as arsenic, mercury, and chromium organic compounds.

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UV Disinfection and Reactor Validation

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Disinfection by ultraviolet light (UV) has received wide endorsement as an important contribution to the multiple barrier approach for protection of public health. UV can be used both to disinfect wastewater discharged to the environment, and to disinfect that water when it is picked up again for human consumption. UV readily blocks infectivity by such chlorine-resistant pathogens as *Cryptosporidium parvum*, *Giardia lamblia* and *Legionella pneumophila*. Multiple disinfectant use is now being discussed to broaden the spectrum of pathogens that can be inactivated by using disinfectants in their most strategically advantageous dose and function. UV as a primary disinfectant inactivates pathogens from *Cryptosporidium* through the bacteria to the viruses (e.g., rotavirus) without production of by-products. A quick low-dose pulse of chlorine afterwards provides redundancy for the UV-sensitive viruses and extends the virus protection to even the more UV-resistant viruses. Conversion of the chlorine to chloramine at the entry to the distribution line creates the better biofilm control agent and limits the production of the regulated chlorination disinfection by-products produced by chlorine. This integrated strategy will be illustrated with reference to specific microbes within the total spectrum of pathogens.

Optimizing these multiple barrier strategies requires attention to validation of the concepts and technologies involved. UV technology validation ensures that the equipment can deliver the target UV design dose, and that the monitoring/control technology modulates the dose appropriately with changes in water quality or operating conditions.

The standard for UV technology validation is called a bioassay, and involves sending a challenge organism through the reactor being tested. The challenge organism's UV-dose response is calibrated empirically in an ideal laboratory reactor. The harvested sample of these challenge organisms at the exit of the reactor being tested is compared to the UV-dose-response curve to assess the effective UV dose delivered by the reactor.

Real reactors are not ideal in their hydraulic behaviour, and this creates the need to validate the reactor. The nature of this non-ideality will be illustrated with the aid of experimental and computational fluid dynamic data.

The non-ideality of UV reactors also has implications for modifying the validation protocols and interpreting the bioassay in terms of the ability of the reactor to inactivate a target pathogen identified in regulations versus the challenge organism used during the bioassay. These implications for validation protocols and bioassay interpretation will be illustrated.

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A Kinetic Model for Autotrophic Denitrification using Sulfur:Limestone Reactors

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Autotrophic denitrification of groundwater by *Thiobacillus denitrificans* in sulfur limestone upflow reactor and in batch experiments was studied in order to establish the process kinetics of denitrification in order to predict effluent concentration. Experiments were performed using a water of 60 and 90 mg NO_3-N/L and with sulfur and limestone particles of an average size of 3.5 mm. The results showed clearly that nitrate was completely removed with 60 mg NO_3-N/L and with 90 mg NO_3-N/L as influent concentrations. The results showed that the autotrophic denitrification rates in sulfur:limestone reactors can be described by half-order kinetics. The half-order reaction rate constants were estimated as 1.27 and 1.54 $mg^{1/2}/L^{1/2}$ h for influent concentrations of 60 and 90 mg NO_3-N/L, respectively. The batch experiments using deionized water and tap water with an initial concentration of 27 mg NO_3-N/L showed that the half-order reaction constants ($k_{1/2v}$) were 0.017 and 0.016 $mg^{1/2}/L^{1/2}$ h, respectively.

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Sulfate Removal from Water

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Sulfate is a substance that occurs naturally in groundwater. Concerns regarding the health effects from sulfate in drinking water have been raised because of reports that diarrhea may be associated with water that contains high levels of sulfate. In the livestock production industry, there is a concern that high levels of sulfate in water can adversely affect productivity. Different methods can be used in removing sulfate from water. Proven technologies are ion-exchange, nanofiltration, reverse osmosis, and electrodialysis. A few earlier studies showed that the use of bentonite/kaolinite for sulfate removal produced encouraging results. Therefore, experimental work was undertaken to examine in detail the feasibility of such a process. Laboratory studies using bentonite/kaolinite showed poor or no removal in the case of high sulfate water. Ion exchange and nanofiltration were found to be effective in removing sulfate to a higher degree. Ion exchange is likely to be more reliable than nanofiltration because of the sensitivity of the nanofiltration process to total dissolved solids and biofouling.

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Presence and Removal of Arsenic from Rural Water Supplies in Canada using Biological Filtration

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The urgent need to find removal techniques for arsenic (As) in drinking water supplies has focused on physical and chemical removal techniques. This includes conventional processes, such as coagulation, iron-manganese removal and sorption processes including ion exchange, activated alumina, and iron-coated sand. Different types of membranes, micro-, ultra-, nano- and reverse osmosis, are also used. The potential for using biological treatment for arsenic removal has not been addressed. There are, however, several characteristics of arsenic in water that makes it suitable for microbial removal processes. Arsenic exists in several different states with the major health concern centred around As^{3+} and to a lesser extent As^{5+}, which are present as inorganic ions. Organic arsenic compounds are of lesser health concern and are also typically only a small percentage of the arsenic pool. As^{3+} is much more difficult to remove from water than As^{5+} and one of the key goals in arsenic removal is to oxidize the As^{3+} to As^{5+}. Conventional processes use oxidizing compounds, such as chlorine, ozone, potassium permanganate etc. However, microorganisms can both reduce As^{5+} to As^{3+} and they can oxidize As^{3+} to As^{5+}. In addition, they can metabolize organic arsenic complexes and potentially release As^{3+} or As^{5+} into the water. The goal with biological treatment of arsenic is to move all the dissolved arsenic compounds into a particulate state either as part of the microbial biomass or as organic/inorganic flocs that can be easily separated out. The key in a biological reactor is therefore to establish conditions where these reactions are achieved. Biological reactors have been used in rural Canada on an experimental basis for more than five years with consistent arsenic removal rates exceeding 90% irrespective of season. These reactors remove 99% of the iron, and can also remove dissolved organic material and when properly designed can remove manganese. The arsenic-enriched biomass/organic-inorganic floc can be removed without replacing the support material in contrast to several sorption technologies. No chemicals are required for biological arsenic removal and with no requirement for media replacement, biological arsenic removal promises to be an inexpensive and effective technology suitable for the treatment of arsenic in rural areas around the world.

While the presence of arsenic in regional water supplies in Western Canada were considered to be of quite limited concern, new guidelines for allowable arsenic levels have prompted a re-evaluation of its importance in rural groundwater sources across the Province of Saskatchewan. It is anticipated that future guidelines will be less than 10 micrograms/L and a large proportion of Saskatchewan well waters will then need to be treated to be in regulatory compliance. For Western Canada, arsenic has therefore gone from not being a problem to an emerging contaminant potentially affecting the health of many rural people. Efforts to proactively avoid negative health effects of arsenic-tainted water will therefore be required. Monitoring of arsenic levels combined with R&D to find cost-effective solutions to remove the arsenic from rural water supplies form essential parts of a provincial arsenic mitigation strategy.

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Groundwater

Chair: NATHALIE ROSS

COMPETING FOR THE PHILIP H. JONES AWARD

Geochemical Heterogeneity and Transient Groundwater Flow Within a High-Sulfide Tailings Impoundment

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During the oxidation of high-sulfide mine tailings, secondary precipitates accumulate at grain surfaces and in interparticle voids. Extensive formation of hardpans can control the geochemical evolution of the tailings pore water and the physical flow system. Field studies were conducted at a high-sulfide tailings pile in Sherridon, Manitoba, that has oxidized for 70 years. The unoxidized tailings contain nearly equal proportions of pyrite and pyrrhotite. In the near surface oxidation zone, these sulfides are completely obliterated. Sulfide oxidation has led to very high concentrations of dissolved iron (in excess of 40 g/L), sulfate (in excess of 120 g/L), elevated concentrations of trace metals and the generation of low pH conditions (pH < 1). Extensive accumulations of jarosite, goethite, melanterite and gypsum form discontinuous hardpans near the tailings surface and a massive continuous hardpan approximately 1 m below the tailings surface. During and shortly after storm events, the water content above the continuous hardpan layer is sufficiently high to cause lateral flow of water. The highest concentrations of dissolved metals are observed directly above and within the massive hardpan layer. Surface seeps along the flanks of the tailings and surface water adjacent to the site have a composition most similar to the composition of water directly above the hardpan. These results suggest that shallow lateral flow of water due to a transient perched water table is resulting in higher contaminant loadings than predicted assuming discharge is only derived from the much deeper primary water table. Through this combination of physical and chemical processes, the hardpan appears to enhance metal loadings rather than act as a protective barrier. Directly below the hardpans, high concentrations of iron and sulfate occur deep in the saturated zone of the tailings, suggesting that the formation of hardpan layers do not prevent deeper recharge to the water table.

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Biobarriers in Fractured Bedrock: Bioclogging of a Lab-Scale Planar Fracture

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The development of biological barriers, by stimulating groundwater bacteria, has the potential to effectively contain polluted groundwater in fractured media. A large-scale planar fracture apparatus (2.0×0.60 m, fracture aperture = 1.5 mm), made of two sheets of 2-cm thick glass, has been designed to conduct a biostimulation experiment and to validate a bacterial transport model. Aerated groundwater, maintained at 10°C and having a bacterial density of 6.5×10^5 bact./mL, was pumped into the fracture at a velocity of 5 m/d. The biostimulation was achieved by injecting invertose (50 g/L pumped at 0.3 mL/min) in a borehole located 40 cm downgradient of the inlet reservoir. This borehole was equipped with a double-packer system, allowing the isolation of the fracture zone, and a mixing motor ($v \cong 50$ rpm). Fifteen ports were installed within the fracture to monitor Eh, using platinum electrodes, and to sample both groundwater and biofilms. The biofilm development was measured with an electronic sensor, which transformed differences in light intensity into a millivolt signal. The fracture bioclogging was assessed by conducting tracer tests, using potassium bromide (KBr) as a conservative tracer. The density and viability of planktonic bacteria, as well as the concentration of planktonic extracellular polymeric substances (EPS), were monitored over 100 days. To simulate the processes, a computer model was developed incorporating the advective and dispersive transport of bacteria undergoing growth, death, adsorption, and desorption/detachment.

After five days, biofilm clusters were visible downgradient from the borehole; clusters that assumed the shape of the flowlines after 15 days. Slowly, the clusters extended to a more uniform biofilm covering an area of 700 cm^2 after 50 days. Evidence of the fracture bioclogging was measured by a two-hour retardation of the KBr tracer peak concentration over a distance of 1.3 m. As the biofilm was forming, Eh decreased from 200 to 400 mV to 0 to 100 mV. The biostimulation enhanced the planktonic bacterial growth by up to an order of magnitude, but after the biofilm was well established ($t \cong 30$ d), no significant difference was measured upgradient and downgradient of the borehole. Planktonic EPS reached its peak concentration (330 mg/L) after the first 10 days of biostimulation, then decreased by 90% over ten days, which coincided with a period of accelerated biofilm formation. The overall data of the biofilm development experiment are being explored quantitatively using the analytical solution solved using the Laplace transform method for both uniform and time-varying bacterial input concentrations. This glass planar fracture apparatus allowed visualization and measurement of the extent to which biofilm developed when groundwater bacteria were stimulated with a simple carbon source. These results will contribute to the full-scale development of the biological barrier concept in fractured rock.

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COMPETING FOR THE PHILIP H. JONES AWARD

Biosafety of Bioremediation Techniques: Characterization of the Pilot Sand Aquifer and Experimental Design

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Concerns about the ecological risks of introducing microorganisms in the environment has led to the creation of regulations that need to be supported by scientific evidence. In this pilot study, the safety of solvent bioremediation techniques is assessed by comparing natural attenuation, biostimulation, and bioaugmentation with respect to their effects on the physicochemical and biological environment. A stainless-steel basin (2.3 m wide, 6.5 m long, and 2 m deep), separated into three parallel lanes, was filled with clean, medium-sized sand. In each lane, groundwater was pumped into a head tank, and a flow of 0.15 m day^{-1} was established through a withdrawal well. This pilot aquifer was characterized for water dispersivity, velocity, and flow field by conducting tracer tests (potassium bromide and Lissamine). A concept of a continuous source of contaminant was developed by mixing PCE with sand and silicone oil inserted in a meshed sock slid in a source well located 1 m downgradient of each head tank. The processes are monitored through 198 sampling ports and 27 Eh probes that are distributed in a grid along three depths and nine longitudinal transects.

The experimental design of the natural attenuation approach will consist of monitoring the biotransformation of PCE (to TCE, *cis*- and *trans*-DCE, and VC), the concentration of electron acceptors and reactive products (O_2, NO^{3-}, NO^{2-}, Fe^{3+}, Fe^{2+}, SO_4^{2-}, S^{2-}, H_2 and CH_4), and the ecotoxicity of the treated groundwater (Microtox, Toxi-Chromotest, *Lemna minor*, and *Daphnia magna*). The biostimulation of the groundwater microbial population will be achieved by injecting methanol as an electron donor. For the bioaugmentation approach, an adapted microbial culture, obtained from sediment samples collected at a TCE-contaminated site in southern Ontario, will be added after anaerobic conditions are obtained. To ensure that neither the biostimulation nor the bioaugmentation are contributing to the growth of potential pathogens, the presence of two protozoa (*Cryptosporidium parvum* and *Giardia lambia*) and nine bacteria, or group of bacteria (total coliform, *Escherichia coli*, faecal streptococci, *Pseudomonas aeruginosa*, *Salmonella*, *Shigella*, *Campylobacter jejuni*, *Yersinia*, and *Vibrio cholera*), will be tested. This study will be used to help define regulatory requirements for various bioremediation scenarios regarding The New Substances Notification Regulations of the *Canadian Environmental Protection Act*.

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Direct Injection for *In Situ* Reduction of Chlorinated Solvents in Groundwater

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Previously conducted field tests at Aberdeen Proving Ground (APG), Maryland, have demonstrated that vitamin B_{12} concentrate (a buffered mixture of titanium citrate and vitamin B_{12}) can be added into the subsurface using a recirculation well as an *in situ* chemical mixer. This approach successfully dechlorinated a mixture of 1,1,2,2-tetrachloroethane, carbon tetrachloride, trichloroethene, and tetrachloroethene in groundwater with total volatile organic compound concentrations up to 7000 µg/L. While the use of a recirculation well to deliver treatment to the aquifer was effective, a limited, defined source area containing residual product may be remediated more economically by direct application of the vitamin B_{12} concentrate using geoprobes.

The vitamin B_{12} concentrate was made according to a method developed at NWRI. First, titanium oxalate is made by soaking titanium metal in a solution of oxalic acid. The chelating agent is then exchanged to citrate, and the mixture is buffered with a mixture of sodium and calcium carbonate. Sugar is added as a preferential carbon source to citrate and to act as a long-term source of energy for the bacteria that continue the remediation post-treatment.

In August 2001, approximately 600 gallons of vitamin B_{12} concentrate were injected, using direct push technology, into the subsurface at Graces Quarters, APG, to treat the bottom 10 feet of the surficial aquifer in a 25-foot by 25-foot area. The saturated thickness in this area is approximately 12 ft, located between 10 and 22 ft below ground surface. Sixteen direct push technology locations were used, spaced 5 feet apart, for injection. Ten gallons of the concentrate was injected at 2-foot intervals using a direct push rig equipped with a drive point and a 2-foot perforated drive stem. The 2-foot depth intervals for injection were alternated at adjacent injection locations.

Six piezometers and one monitoring well were used for monitoring purposes. Groundwater samples were collected prior to treatment, 1 week following concentrate injection, and monthly for 3 months. Samples were analyzed for VOCs; dissolved gases (methane, ethane, and ethane); volatile fatty acids (VFAs); dissolved iron, titanium, and arsenic; and chloride. Eh, pH, and dissolved oxygen (DO) data were collected in the field during each sampling event. Prior to treatment, total VOC concentrations in the area were on the order of 2000 µg/L.

The injection of the treatment resulted in a rapid reduction of Eh from +200 in the control areas to approximately –500 at QDP-3, 4 and 5. The Eh remained negative for over two months, returning to positive values gradually as the aquifer solids oxidized the titanium. The initial reaction with the chlorinated solvents was very rapid. On average within one week, the concentration of 1,1,2,2-tetrachloroethane and of trichloroethene were reduced in half after one week with the concurrent formation of *cis*- and *trans*-dichloroethene, whereas more than 80% of the carbon tetrachloride was degraded. Biological activity was also apparent with the presence of acetate formed from the degradation of glucose. Longer-term monitoring will be needed to determine whether a single application was sufficient to effectively treat the pilot area.

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Urban Wet-Weather Pollution: Stormwater Management and Combined Sewer Overflow (CSO) Control

Chair: JIRI MARSALEK

Great Lakes Sustainability Fund Urban Drainage Program

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Announced in July 2000, the Government of Canada's Great Lakes Sustainability Fund (GLSF) is a five-year, $30 million program that is a component of the Great Lakes Program. The aim of the Great Lakes Program is to complete federal actions to restore beneficial uses in environmentally degraded areas, known as Areas of Concern, in the Great Lakes basin.

The GLSF provides funding support for completion of these federal actions, building upon the successes of its predecessor programs, the Great Lakes Cleanup Fund (1990 to 1994) and the Great Lakes 2000 Cleanup Fund (1995 to 2000).

Impairments in beneficial uses in the AOCs have been, in part, caused by discharges from combined sewer overflows (CSOs), stormwater and sewage treatment plants (STPs). To assist municipalities in addressing the problems posed by urban drainage (CSOs and stormwater), the Sustainability Fund supports the development and demonstration of innovative, cost-effective technologies and approaches. These projects include high-rate treatment of CSOs, real-time control of CSOs, performance assessment of stormwater treatment technologies, pollution prevention and control plans, and development of stormwater management planning tools for urban areas. Projects are carried out in collaboration with the Ontario Ministry of the Environment, municipalities and conservation authorities. This presentation highlights the findings of selected Sustainability Fund projects focused on CSOs and stormwater.

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Field Investigations of Urban Wet-Weather Runoff Effects on Freshwater Benthic Invertebrate Communities

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Urban stormwater and combined sewer overflow (CSO) discharges are important sources of contaminants, sediment, and flow-related stress to receiving waters. Over the past several years, systematic investigations of sediment chemistry, sediment toxicity and benthic community structure at field sites representing a range of exposure environments were conducted in Hamilton, Toronto, Oshawa and Kingston, Ontario.

In 1998, benthic conditions were surveyed in streams, stormwater management ponds and lake nearshore exposed to urban wet-weather discharges. Results showed that while sediments sampled were contaminated (with metals and/or PAHs) and enriched with nutrients, biological degradation (as sediment toxicity or altered benthic community structure) was not evident. In the following year, several sites upstream and downstream of stormwater outfalls in two watersheds were assessed. Both sediment toxicity and benthic community structure bore no relation to either exposure to CSO/stormwater discharges (i.e., location above or below outfalls) or to measured sediment contaminant concentration.

In 2000, a comprehensive assessment focused on two untreated stormwater outfalls discharging to Toronto streams. Effects on benthic invertebrates were examined using colonized artificial substrates reciprocally transplanted between locations upstream and downstream of the outfalls. In the same locations, *in situ* toxicity tests were performed with caged amphipods. Bioavailability of contaminants (metals and PAHs) was measured in caged and field-collected organisms. Benthic community structure was found to be significantly altered on substrates below outfalls relative to those upstream. The direction of the community shift was similar in both streams. Caged amphipods exhibited no outfall-associated toxicity and only low bioaccumulation of contaminants. These results suggest that effects of stormwater discharges on benthic invertebrates are caused by factors other than contaminants.

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Laboratory Investigations of Wet-Weather Pollution Stressors Affecting Benthic Community Structure Using Artificial Substrates

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Previous in situ research upstream and downstream of untreated stormwater discharges demonstrated significant impacts on benthic community structures. A variety of stormwater stressors potentially affecting benthic communities were tested using laboratory flumes, in order to link the stressors with the observed changes. Artificial substrates, 12-cm square and made from gravel (2 cm) embedded in concrete, were placed at four sites upstream and downstream of untreated stormwater discharge points in two streams to be colonized by benthos over a period of 8 weeks. Once communities had become established, the artificial substrates were removed from the streams and tested in the laboratory.

Shear stress effects were tested in a rotating circular flume, capable of simulating low, medium and high shear stress flows (equivalent to storm flow conditions). In each case half of the substrate was sampled before and the other half after a two-hour flow exposure, and each half was analyzed for benthic community structure. Results did not indicate any changes that could be attributed to shear stress conditions.

Sediment burial testing was conducted using clean fine sand (<400 μm). Artificial substrates were completely covered and placed, along with control substrates (which were not buried), in recirculating flumes. Covered substrates were removed after exposures of 24, 48 and 96 hours and analyzed for benthic community structure. No strong correlation between duration of burial and change in benthic community structure was observed, although buried substrate populations were less abundant relative to unburied substrates.

An experiment using highway runoff exposed substrates to both chemical and physical stressors. Dilutions of 50%, 25% and a control were made using laboratory de-chlorinated tap water. One half of the substrate was sampled prior to exposure and the remainder after a two-hour exposure to stormwater effluent, and both were analyzed for benthic community structure. Greatest change in the benthic communities was observed for substrates exposed to 50% effluent, and least change for control substrates. Overall, results suggest a combination of stressors may be required to significantly alter community structure.

As preliminary investigations, these experiments help to shape further studies identifying stressors in wet-weather discharges that are important to benthic community structure and health. Recent work has focused on studying impacts resulting from chloride (road salt) addition as well as sediment burial using contaminated sediments.

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A Look Back at Seven Years of Stormwater Management System Monitoring: What Have We Learned?

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The construction of the Dartnall Road Interchange, as part of Hamilton's Lincoln Alexander Expressway, involved the removal of some 200 m of the Red Hill Creek on the escarpment and the construction of associated compensation works including three wetlands. As part of a formal Compensation Plan to facilitate interchange implementation, the Department of Fisheries and Oceans required that a seven-year monitoring program be implemented, in order to evaluate the effectiveness of the environmental infrastructure in satisfying the key objectives of providing aquatic and terrestrial habitat, and maintaining a stable ecosystem with maximum stormwater quality benefits.

This paper takes an introspective look back at the quantitative and qualitative monitoring data obtained over the seven-year period. The data include wetland water quality inflow/outflow (sediment, nutrients, metals), forebay sediment (chemical composition and accumulation), stream morphology and natural heritage system (terrestrial and aquatic).

The data and associated analysis has provided a unique local database for performance evaluation of environmental management systems. The "lessons learned" may assist future infrastructure to be planned and designed to optimize overall performance, while minimizing future maintenance needs.

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The Use of Very Large Sub-surface Flow Wetlands to Treat Glycol-Contaminated Stormwater from Aircraft De-icing Operations

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Controlling stormwater runoff at large public and industrial facilities is a matter of increasing environmental concern and now has a major effect on the design and permitting of development projects relating to them. In addition to the usual pollutants in industrial stormwater, runoff at airports will contain leakage/spillage from aircraft fueling and de-fueling. In cold weather areas, surface and aircraft de-icing/anti-icing chemicals will also be important pollutants, and in some cases will be the dominant ones.

All of the pollutants found in airport runoff, including glycols, can be treated and removed to low levels in well-designed constructed wetland systems. These wetlands can be designed in a manner so as to not provide habitat for or attract waterfowl, which can be a hazard at airports due to the danger of bird strikes by aircraft. This is possible by using sub-surface flow wetlands. These sub-surface flow (SSF) or gravel bed wetlands have no surface water to attract waterfowl and also can be planted with types of vegetation, which have little or no food or habitat value for fauna. About 600,000 litres of ethylene glycol are used annually for aircraft de-icing at the Edmonton International Airport (EIA). About 10 to 20% of the glycol is now being recovered. This small fraction of the glycol, which is collected in vacuum trucks, is disposed of by being bled slowly into local sanitary sewers. Most of the rest enters surface runoff. Since most aircraft de-icing occurs during cold weather periods, much of the spilt glycol accumulates in contaminated snow and soil, being released with runoff when a thaw occurs. The soils at EIA are tight clays so little infiltration occurs.

Surface runoff from EIA property is collected in ditches from which it enters a nearby cold-water stream. EIA is expanding and this will result in more de-icing requirements and even higher glycol levels in the runoff. In several instances in the past, volumes of glycol-contaminated water impounded were such that discharges had to occur when contaminant levels in the runoff were still too high. This, coupled with odours at times and continuing development elsewhere on the airport property, resulted in the airport's stormwater management system being unsatisfactory. The EIA's operator, the Edmonton Regional Airports Authority, decided to update its stormwater management system and, at the same time, to install a treatment wetland system as part of it to handle glycol-contaminated stormwater. Jacques Whitford Environment Limited was selected to design the SSF wetland system. The purpose of this wetland is to allow continuous discharge of cleaned-up runoff throughout the frost-free period of the year. Effluent will meet guidelines and the criteria of both Environment Canada and Alberta Environment.

In order to design the new SSF wetland, a four-month, pilot-scale wetland treatability test was carried out using an existing pilot scale SSF wetland test unit consisting of three vegetated, 1.2-m^2 surface (each) cells. The treatability test was necessary to determine the degradation factors for the contaminated runoff needed to design the full-scale facilities. The resulting design was for a twelve cell (each almost 50 m to a side), three train, 2.7-ha surface area SSF wetland system that was vegetated and commissioned in August of 2001. It is capable of handling up to 230,000 m^3 of glycol-contaminated runoff annually containing up to ~1350 mg/L of glycol at flow rates of up to 1400 m^3/day of stormwater and at temperatures down to 5^oC. It is the largest constructed wetland in the world treating glycol-contaminated airport stormwater runoff, the largest SSF wetland in Canada, and one of the largest SSF wetlands in North America. The paper reviews results of the feasibility study carried out to define design parameters and scale up kinetics, the detailed design that resulted from it, the SSF wetland's construction, and its start-up and early operations. It also compares the Edmonton SSF wetland system with a similar facility soon to start up at Heathrow Airport in the UK.

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Characterization and Treatability Study on Windsor CSO

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Combined sewer overflows (CSOs) are considered as significant pollution sources to the Detroit River. Results of previous studies, commissioned by the City of Windsor and funded in part by the Federal Government, indicate that retention treatment basins (RTBs) combined with chemical coagulation/flocculation would be feasible to achieve the requirements of the Ontario Ministry of Environment guidelines (Procedure F-5-5) for CSO treatment along the Windsor Riverfront. However, additional information on parameters for the design of RTBs is needed.

During the period from March 20 to June 19, 2001, long column and jar tests were undertaken at the Lou Romano Water Reclamation Plant (LRWRP) in Windsor. One objective of the study was to develop settling rate distribution curves under both chemically aided and un-aided conditions, and to examine the performance of polymer flocculation in improving settleability.

Long column tests were conducted on wet-weather sewage at the LRWRP during CSO events. When a polymer was used in conjunction with long column tests, polymer flocculation was performed as batch operations and flocculated samples were carefully transferred into the settling column. The jar test method was employed in this study for the selection of the most suitable polymer and the dosage that would provide optimum settling characteristics. The results of the long column tests show that the characteristics of the wet-weather sewage at the LRWRP during CSO events were similar to those of samples collected at actual overflow sites along the Windsor Riverfront. Settling rate distributions demonstrated that polymer addition to CSO significantly improved the settling characteristics. It was concluded that greater solid removal efficiency would be achieved with polymer addition than without.

The results from this study will provide essential information on the selection of polymer type, optimal dosage and settling rate distribution curves to be used in the evaluation of a pilot plant comprised of a RTB.

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Design and Monitoring Considerations for Wet-Weather Pollution Control Facilities

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Facilities designed for the control of stormwater and combined sewer overflows (CSO) are often cost effective and unobtrusive. They may be ingeniously fitted into cramped locations. However, they are often very difficult to monitor. Consequently, questions regarding performance and conformity with design objectives and regulations are very difficult to address. Furthermore, monitoring programs tend to be limited not only by the design of the facilities, but also by resource limitations and inadequate planning. The result of these constraints is that investments in pollution control facilities continue to be made without any real understanding of their effectiveness.

This paper describes factors to consider in the design and monitoring of stormwater and CSO control facilities. Examples are drawn from several projects in which the Stormwater Assessment Monitoring and Performance (SWAMP) Program has participated since the mid-1990s. Reassessment of many of the associated data sets is currently under way and will be substantially completed in time for the Symposium.

The paper highlights some fundamental design and monitoring concepts, including the implications of *detention* for flow attenuation and *retention* for quality control. With respect to the design of storage and treatment facilities, emphasis is placed on the inclusion of flow measurement devices and sampling access points. In the design of monitoring studies, important considerations include the placement of sensors, the need for back-up and overlapping monitoring systems, equipment calibration, and the significance of flow-proportioned sampling. With respect to data analysis, mass balance principles, graphical analysis of time-series data, and data correlation techniques are discussed. The results of studies conducted with full-scale storage tanks, ponds and stormwater infiltration systems are used as examples. Statistical and numerical simulation considerations related to design and monitoring are introduced. The proposed paper will also serve as a summary and introduction to a forthcoming SWAMP report on monitoring methodology.

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Performance of a Pilot Plant for Windsor CSO Treatment

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Combined sewer overflows (CSOs) are considered a significant pollution source to the Detroit River. CSO control measures for the riverfront area within the City of Windsor have been evaluated in previous studies. The use of Retention Treatment Basins (RTBs) was identified as one component of an overall CSO control program.

One of the objectives of this study is to examine the performance of a pilot plant comprised of a RTB utilizing polymer-aided flocculation, for the treatment of CSO. In order to increase the surface-loading rate of the RTB and lower the capital cost of constructing RTBs, the use of cationic polymeric flocculants was studied.

This project, funded in part by the Federal Government, is being conducted by the University of Windsor and the City of Windsor, and in conjunction with Stantec Consulting Ltd. The pilot plant has been constructed at the Lou Romano Water Reclamation Plant (LRWRP) in Windsor. The principal process units are a constant-head tank for flow distribution, a polymer feeding system, two mixing systems, and a RTB. Only one of two mixing systems, an in-line static mixer or a mechanical mixer was in operation at any given time.

The wet-weather sewage at the LRWRP during CSO events was used as CSO samples for this study. Experimental results were obtained from a series of pilot plant tests conducted for eight CSO events, which occurred during the period from July 21 to November 30, 2001. The effects of polymers and their dosages on effluent quality from the RTB were investigated. The relationship between overflow rate (OFR) and total suspended solids (TSS) removal for Windsor CSO has been established. The results demonstrate that the use of polymer allow the surface loading rate through the RTB to be increased significantly, resulting in smaller treatment units.

The results from this study will provide full-scale design parameters including facility size and geometry, polymer dosage and predicted treatment efficiency to comply with the Ontario Ministry of Environment guidelines (Procedure F-5-5).

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Drinking Water: Taste and Odour Compounds and Toxins

Chair: SUSAN WATSON

Physical Processes Controlling Taste and Odour: Lake Ontario

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During the late summer months drinking water from Lake Ontario is susceptible to earthy taste and odour, undesirable properties in drinking water. This water quality problem is detectable at low levels and is difficult to treat. The taste and odour is caused by geosmin, a secondary metabolite of Cyanobacteria and Actinomycete bacteria. Based on evidence of geosmin concentrations and water temperatures at the intakes it was hypothesized that the events coincide with downwelling events along the affected shoreline. In 2000 an intensive field investigation in the western end of Lake Ontario was undertaken to gain new information about the source and distribution of geosmin. As part of the investigation, current meters and temperature sensors were deployed at several water treatment plant intakes. A land-based tower at Toronto Island Airport provided hourly wind speeds and directions from August 1 to September 30, 2000.

The temperature variations along the northwest shore of Lake Ontario were found to be strongly linked to the winds from westerly directions causing upwelling and easterly winds inducing downwelling and warming of coastal waters. The strong westward-directed wind stress (~1.5 dynes/cm^2) on August 26, 2000, caused strong downwelling along the north shore and upwelling along the southwestern corner of the lake. The downwelling along the north shore persisted till September 6, 2000, under the influence of weak to moderate westward winds. AVHRR images during this period also showed a strong downwelling along the north shore and upwelling along the south shore of Lake Ontario. Downwelling currents were particularly strong along the north shore and flowed in a westward direction. Along the north shore of Lake Ontario during this episode, the mean currents were directed onshore in the surface layer (~10 m), and flowed in an offshore direction below it. This wind-driven circulation supports the hypothesis that geosmin was transported from offshore surface waters to the coastal surface waters along the north shore of Lake Ontario during taste and odour episodes.

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Testing Ideas on the Biological Source of the Taste and Odour-Causing Compound Geosmin in Western Lake Ontario

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The source of the geosmin, a naturally occurring compound produced by cyanobacteria and actinomycete bacteria, which has afflicted western Lake Ontario in recent years remains uncertain despite efforts to identify the key producers. In 2000 the Ontario Ministry of the Environment, in collaboration with the Lake Ontario Taste and Odour Research Consortium, investigated the origins of taste and odour problems in western Lake Ontario. Although geosmin levels in 2000 were low, patterns of occurrence with similarity to previous years were detected and suggested a mode of production and candidate organisms. In 2001 a sampling program was devised to examine contrasts in patterns of occurrence of geosmin as suggested by the hypothesized mode of production.

Previous study indicated that there were widespread late-summer pulses in geosmin in western Lake Ontario. At water intakes the pulses appeared to be associated with warming of water at depth due to downwelling. The pattern suggested that geosmin was produced in the lake epilimnion by planktonic organisms, possibly cyanobacteria.

In 2001 concentrations of geosmin and composition of phytoplankton were monitored at two locations where the occurrence of geosmin was expected to exhibit contrasting patterns. A nearshore location was sampled at intake depth via samples of raw water collected from the R.L. Clark (City of Toronto) water plant. Offshore epilimnion (surface) samples were obtained from a site offshore of Mississauga. It was anticipated that geosmin concentrations would increase sooner, and reach higher levels, in the lake epilimnion than at intake depth and that abundance of cyanobacteria would be correlated with geosmin levels in the samples from the epilimnion. Further, the relative concentrations of geosmin at sites were expected to be related to water temperature such that when temperatures were similar at the two locations, as might be encountered during deep mixing, geosmin levels would be similar. Alternatively, when temperatures at intake depth were cooler than the lake epilimnion the geosmin concentration at intake depth would be lower than the epilimnion.

Concentrations of geosmin observed in 2001 were low (<16 ng/L) with the exception of a lake epilimnion sample from late August with 36 ng/L. Geosmin concentrations increased in both sample sets over August and while concentrations were slightly higher in the lake epilimnion samples than in raw water from the R.L. Clark intake, the differences are subtle. The cyanobacteria *Anabaena lemmermannii* was moderately abundant (64–118 µg/L) in the epilimnion samples from August but was not abundant in the intake samples. Biomass of other cyanobacteria was low. Water temperatures in the nearshore at a depth similar to the R.L. Clark intake did not reach surface temperatures during the period in August when geosmin concentrations were rising.

The pattern of occurrence of geosmin at the two sites monitored is consistent with the expected patterns, however, the low levels of geosmin experienced limits interpretation. Continued monitoring of geosmin and phytoplankton composition in which paired observations are made at water plant intakes and offshore sites is suggested. The results also suggest that investigation of the ecology of A. *lemmermannii* is warranted.

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Aquatic Odour in Lake Ontario: Tracing Origins Through a Complex System

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Although considered non-toxic to humans, drinking water taste and odour (T/O) undermines consumer confidence and costs the water industry millions per annum. Lake Ontario represents an important source of drinking water for millions of consumers. The lake shows significant transition in response to watershed and climate changes, and to invasive exotics such as Dreissenids, all of which impact temperature and light climate regimes, nutrient recycling and aquatic habitat. In the past decade, the lake developed erratic and severe late summer T/O, primarily caused by the biological metabolites geosmin and 2-methylisoborneol (MIB). These metabolites can be produced by Cyanobacteria and/or Actinomycetes in diverse aquatic and terrestrial habitat zones. Only certain species within these two groups produce odour, which varies with growth and environment. Particularly within the Great Lakes, both production and transport are influenced by large-scale heterogeneity in climate, watershed, basin, diffuse/point-source loading and lake circulation. In response to these outbreaks, a multifaceted research team of industry, government and universities was established to identify the biological source(s) and environmental triggers of these events, and develop predictive and remediative tools. Here we summarize our progress and current understanding of these events, derived from water treatment plant (WTP) data and three years of combined field and laboratory studies.

Early work identified two odour patterns, often occurring in separate years: abrupt and severe geosmin outbreaks in the western lake, and prolonged MIB episodes in the eastern lake. Our combined research has now shown that in the W. basin, geosmin production: i) is indigenous; ii) peaks annually, but only periodically at nuisance levels; iii) most likely originates from offshore planktonic Cyanobacteria, not Actinomycetes; iv) may be favoured by extended warm temperatures; and v) may require wind-induced downwelling for significant spatial transport to WTP intakes. In contrast, in the East, MIB and to a lesser extent, geosmin production: i) also occur annually, but may ii) be derived from the periphyton and mussel beds in littoral areas; iii) originate from both Cyanobacteria and Actinomycetes; iv) be promoted by local point-source urban runoff; and iv) occur on a continual, rather than episodic basis via the hydrological disturbance and sloughing off of periphyton biofilms.

Given the complexity of the problem, these insights represent significant progress, largely made possible via the collective expertise, facilities and resources associated with the research consortium.

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Abundance and Distribution of Cyanobacteria in Hamilton Harbour and Adjoining Area of Lake Ontario on September 6 and 20, 2001

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Preliminary surveys were conducted in September 2001 by the Ontario Ministry of the Environment to investigate the abundance and distribution of cyanobacteria in Hamilton Harbour and the adjacent area of Lake Ontario, upon reports that a toxic bloom of cyanobacteria was occurring in the harbour. In addition to examining the abundance of cyanobacteria in the area, an objective was to examine the movement of water out of Hamilton Harbour, potentially causing elevated levels of cyanobacteria in the nearshore of Lake Ontario in the Burlington/Hamilton area, recognizing that the results would provide only a snapshot of conditions on the days of survey.

Submersible fluorometers for the algal pigments chlorophyll a, phycocyanin and phycoerthyrin were used to map the distribution of pigment fluorescence over the area. Phytoplankton samples for identification and enumeration of cyanobacteria were collected. Additional sensors (e.g., conductivity, UV fluorescence, turbidity) deployed either on a profiler or over a surface track were used to detect the movement of water originating from Hamilton Harbour into the nearshore of Lake Ontario.

Cyanobacteria were abundant in the plankton of Hamilton Harbour on September 6, 2001. Biomass was composed largely of *Aphanizomenon flos-aquae*, *Microcystis viridis* and a second unidentified *Microcystis* species. Total cyanobacterial biovolume varied from 4.5 to 9.0 mm^3/L among the harbour samples and from 0.005 to 1.8 mm^3/L among the lake samples. Biovolume of cyanobacteria in the lake declined with distance from the Burlington Canal. Cyanobacterial biovolume in the harbour on September 20 was lower than on September 6. Total cyanobacterial biovolume varied from 0.19 to 1.2 mm^3/L among harbour samples. *Microcystis viridis* and an unidentified *Microcystis* species continued to be abundant on September 20. *Aphanizomenon flos-aquae*, while abundant in some samples, had declined in relative abundance.

A single experimental analysis for selected microcystins was conducted on water collected on September 6 and confirmed the presence of microcystins in Hamilton Harbour. Microcystin-RR and microcystin-LR were detected at concentrations of approximately 5 and 2 µg/L, respectively. Microcystin was detected (microcystin-RR: concentrations of 0.5 µg/L) in only 1 of 12 samples analyzed from September 20.

On the two days of survey the biomass of cyanobacteria was concentrated in Hamilton Harbour. The biomass of cyanobacteria appeared to be low in the nearshore of Lake Ontario except in areas where water discharging from the harbour through the Burlington Canal was mixing with lake water. At the time of survey on September 6 the harbour plume was directed towards the Burlington shores. During the time of survey on September 20 the harbour plume into Lake Ontario was directed offshore.

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Toxic Algal Blooms in a Mesotrophic System? Hamilton Harbour Revisited

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Hamilton Harbour has a history of water quality issues, arising from intense localized urban and industrial discharge. In the 1980s and 1990s however, algal biomass generally fell below that predicted by the high dissolved nutrient levels. The biomass was dominated by chlorophytes, and rarely developed the Cyanobacteria blooms typical of eutrophic systems. Mixing, low residence time, high N:P ratios (>100:1) and low transparency from suspended particulates were identified at the time as key factors controlling phytoplankton biomass and composition. More recently, human activity again has led directly or indirectly to significant changes in the Harbour and lake. Remediation in the late 1990s reduced nutrient levels somewhat. The widespread invasion of Dressneid mussels has increased nutrient recycling and water column transparency in Lake Ontario and may be having an effect in the harbour. These changes are correlated with disturbing trends in the phytoplankton community. While summer chlorophyll levels show some reduction overall, there has been a shift towards the development of prolonged blooms of potentially toxic Cyanobacteria.

In 1999, a severe late-summer blue-green algal bloom in Hamilton Harbour coincided with a significant taste and odour event across the western basin of Lake Ontario. Preliminary evidence suggested the two water quality issues were not linked. Noxious, localized harbour blooms reoccurred to a lesser extent in 2000 and were particularly noticeable in 2001, but lakewide taste and odour showed a marked abatement. No noxious bloom was observed in the lake during this period, except that introduced periodically from the Harbour plume. Preliminary surface samples taken August to September 2000 showed a mixed assemblage of phytoflagellates, dinoflagellates, diatoms, chlorophytes and potentially toxic blue-greens, notably *Aphanizomenon flos-aquae*, *A. issatchenkoi*, *Lyngbya borgei*, *Microcystis viridis*, *M. wesenbergii* and *Anabaena spiroides*. Nostocales showed low heterocytes frequency, indicating little N limitation. A far more severe bloom in 2001 (mid-July to October) was dominated by many of these, and other potentially toxic cyanobacteria, which showed distinct temporal, vertical and horizontal heterogeneity. Non N_2-fixing biota such as *Microcystis* and *Lyngbya* species were predominant throughout most of the event, while N_2-fixing Nostocales increased in abundance towards the end of September.

These taxa were not present in any significant abundance in the lake in 2000 and 2001, except as isolated patches and in enriched inshore zones in the East Basin. There was no marked increase in the nutrient status of the harbour during 2001 that would account for the particularly severe blue-green bloom. Therefore while outbreaks of noxious algal blooms in these inshore zones likely are initiated in response to high local nutrient levels, their dominance by non-fixing taxa indicate that community composition is moderated largely by factors other than high N:P ratios, such as increased water clarity. Clearly, the recent appearance of these blooms is a major concern. The harbour is used for recreation and industrial water supply and the surrounding lake areas are important for drinking water and recreational use. Preliminary analyses in 2001 confirmed the presence of microcystins, which present a health risk.

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Identification using HPLC and Fluorometric Detection of Microcystin-LR and YR in Lake Winnipeg and Lake of the Woods and its Implication Towards Lake Water Quality

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Lake Winnipeg is the largest freshwater body in Manitoba and tenth largest in the world. A lakewide survey conducted in 1999 by the Department of Fisheries and Oceans in conjunction with the Canadian Coast Guard found that nutrient concentrations, particularly in the North Basin, have increased considerably since previous surveys conducted in 1969 and 1996. Quantified phytoplankton analysis also pointed toward an increasing dominance by cyanophytes (blue-green algae), particularly in the North Basin, including large blooms of species such as *Microcystis flos-aquae, M. aeuroginosa*, *Aphanizomenon flos aquae* and several species of *Anabaena*. The *Microcystis* and *Aphanizomenon* species are known producers of the toxin Microcystin.

Lake of the Woods is a large (16,156,800 ha) international lake, situated primarily in Northwestern Ontario with a small portion in Minnesota. Its river system also connects it to Shoal Lake in Manitoba, the source of drinking water for the City of Winnipeg. In addition to being a very important recreational area, the Lake of the Woods watershed also directly supplies the majority of drinking and household use water to the cottage owners located on its shores. During the summers of 1998 to 2000, volunteers with cottages located on Lake of the Woods brought water samples into the Freshwater Institute in Winnipeg, Manitoba, for biological, chemical and algal metabolite analysis. During the summer of 2001, sixteen "adopt-a-stations" were also set up in order to obtain a better overall view of the lake water quality. Water samples from these stations were also tested for algal metabolites, chemistry and biological parameters.

Using HPLC with fluorometric detection, and following the method of Carmichael and Brittain (2000), we have analyzed water and plankton net haul samples taken from Lake Winnipeg and Lake of the Woods during August 1999 to 2001, including some incidental fish, clam and crayfish tissue samples. We have combined this with the biological and chemical analysis in order to generate a better overall picture of the water quality in these lakes.

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Potential Application of Elevated Potassium Concentrations to Control Undesirable Cyanobacterial Taxa in Lakes

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Following literature reports on the absence of *Microcystis* from ponds with elevated potassium concentrations relative to sodium (low Na/K ratios) and growth depression at low Na/K ratios in culture, we examined the effects of a range of KCl concentrations and Na/K ratios on the growth of several cyanobacteria and green algae isolated from a diversity of aquatic systems in culture media. Our goal was to test the feasibility of using KCl enrichments and manipulations of Na/K ratios as a means of controlling undesirable cyanobacterial taxa in lakes.

Growth of some cyanobacteria taxa was depressed by KCl concentrations in the 1- to 10-mM range but there were definite differences in susceptibility among the species and between the two taxonomic groups tested. Irradiance and diel photoperiod appeared to play key roles, increasing KCl toxicity at higher light intensities and continuous illumination. Preliminary evidence suggested that this effect was related to photosystem function and cell energetics. We detected treatment-related changes in cell fluorescence, particularly with some cyanobacteria. Elevated K affected population and per capita production of the odourous metabolite geosmin in one cyanobacteria species, a process that is coupled with cell energetics and photosystem structure. On the other hand, at KCl concentrations that depressed growth there was no change in short-term (2 hr) or long-term (22 hr) photosynthetic C^{14} uptake, indicating that growth depression was not the result of decreased carbon fixation, but perhaps a result of increased net energy consumption channeled towards the removal of excess intracellular K^+. Other ions such as Na^+ and Cl^- modified the responses of some taxa to K^+. The effect of Na/K ratios was ambiguous but in the absence of added Cl^- in the medium, addition of low KCl concentrations stimulated growth of some species and prevented chlorophyll bleaching at high irradiances.

We conclude that cyanobacteria (and other algal taxa) respond to elevated K^+ in a more complex manner than implied by current literature. The interactive effects of irradiance and other ions such as sodium and chloride limit the feasibility of using potassium manipulations to control undesirable cyanobacteria.

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Total Phosphorus Budgets and Nitrogen Loads: Lake Simcoe, Ontario (1990–1998)

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Lake Simcoe is the largest lake in southern Ontario, excluding the Laurentian Great Lakes. Water quality problems in the lake since the 1970s have been attributed to a threefold increase in total phosphorus loading from pre-settlement rates. Problems include recruitment failure of the native cold-water fish such as lake trout (*Salvelinus namaycush*), lake whitefish (*Coregonus clupeaformis*) and lake herring (*Coregonus artedii*), and excessive growths of aquatic macrophytes and algae. Concern over phosphorus loading to the lake resulted in studies to identify and measure sources of phosphorus, and to recommend remedial measures to reduce these inputs through a Lake Simcoe Environmental Management Strategy.

In this paper we present estimates of annual total phosphorus loading to Lake Simcoe from 1990 to 1998 in order to evaluate the magnitude of sources, and to improve existing budget estimates. Total nitrogen loads from a portion of the catchment and from atmospheric deposition were also measured.

Mean concentrations of phosphorus and nitrogen over the study period were highest in rivers draining subcatchments with the highest proportions of vegetable polders and urban development, and lowest in those draining a higher proportion of forest and scrubland. The mean annual exports of phosphorus and nitrogen measured were highest from vegetable polders (109 and 2540 kg/km^2/yr respectively). High phosphorus export (65 kg/km^2/yr), was also measured from the subcatchment with the highest proportion of urban land. Export from mixed agricultural subcatchments ranged from 11 to 27 kg/km^2/yr for phosphorus and 220 to 790 kg/km^2/yr for nitrogen ranged from 6 to 7 kg/km^2/yr for phosphorus and 170 to 270 kg/km^2/yr for nitrogen. Mean (1995 to 1998) atmospheric deposition directly to the lake was 56 kg/km^2/yr for phosphorus and 920 kg/km^2/yr for nitrogen. The largest sources in annual phosphorus budgets were atmospheric deposition (23 to 56%), the tributaries (17 to 49%) and urban non-point sources (9 to 22%).

The annual load of phosphorus to the lake ranged from 85 to 157 t over the study period, remaining well above a 75 t/yr management target, and concentrations of nitrogen and phosphorus in tributaries draining agricultural and urban areas were above levels recommended to avoid excessive plant growth. Continued efforts are thus required to reduce nutrient inputs to Lake Simcoe from non-point sources.

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Getting to the Bottom of Taste and Odours in St. Lawrence River Water: The Role of Periphyton

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Episodes of unpleasant taste and odour (T/O) in drinking water from the St. Lawrence River (SLR) have developed annually since the early 1990s, and are prolonged, usually beginning in late summer and diminishing only in late fall. The major causes of this odour are two earthy, musty volatile organic compounds (VOCs), geosmin and 2-methylisoborneol (MIB), that are produced by certain biota and impart odours and tastes to water. Our previous research showed little evidence to support the hypothesis that plankton create T/O problems in the river. On the other hand, our preliminary study of live periphyton samples collected off rocks from different SLR locations near Cornwall (October 2000) showed high amounts of VOCs, which increased concentrations in overlying water samples up to 100 times when they were released upon cell disruption.

In 2001, we conducted a more thorough investigation of periphyton biofilms at selected sites in the upper SLR. We hypothesized that VOC production by periphyton biofilms is affected by environmental conditions, such as water depth, temperature, light, and nutrients. Overlying water and periphyton samples were collected at sites near Kingston and Cornwall. At each of these two locations, sites were selected above and below the major urban centres, and 3 to 5 rocks sampled inshore and ~10 m offshore for MIB and geosmin, periphyton biomass and taxonomic structure, nutrients and % organic matter. At the same time, overlying water was sampled for these parameters and temperature, dissolved oxygen, conductivity, light and current speed.

Our initial results are consistent with data from 2000, and show that periphyton is a high potential source of T/O compounds, particularly MIB. September and November periphyton samples consistently showed highest levels of the two compounds below Cornwall offshore, up to ~100 ng/cm^2 MIB and geosmin. Kingston periphyton yielded less (1–20 ng/cm^2 MIB; 0.1–5 ng/cm^2 geosmin), with both compounds higher at inshore areas. Despite within-site and between date variation, periphyton generally yielded more MIB than geosmin—consistent with the higher MIB versus geosmin in overlying water at all sites (20–70 ng/L and 2–20 ng/L, respectively). These observations have important implications for other areas in the river and Great Lakes, which demonstrate similar odour patterns and chemistry and where a more extensive shallow inshore area has potential to support similar periphytic growth.

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The Influence of Algal Decomposition on Water Quality in the Dnieper River, and the Role of the Institute of Hydrobiology in the Ecological Research

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Current urban and industrial development is having increasingly negative effects on natural water quality in the Ukraine and other countries. As a result, ecological problems arise for the fishing industry, for water supplies and recreation. In particular, intensive blooms of algae occur during the warm period of the year. In Ukraine, these are especially prevalent in the Dnieper River and its reservoirs, the largest river in this country and main source of water supply for 60% of the population. The Dnieper catchment area occupies more than half the territory of Ukraine. A cascade of six reservoirs regulates the river, with a total combined storage capacity of 43,8 km^3. They were constructed to develop irrigation in the semi-arid south Ukraine, and improve water supplies for industrial, agricultural, urban, navigational and recreational uses. Generally, these goals have been achieved, but at the same time serious ecological problems have developed, seen in the significant degradation of the river water quality. Since the reservoir construction, dissolved organic matter and nutrients in the water have increased, while during the annual warm period, heavy blooms of blue-green, green and diatom algae appear. Oxygen deficits in the water cause periodic death of fish in winter and summer. In addition, secondary pollution of the water occurs through desorption of heavy metals, organic substances and nutrients from sediments. This problem is related directly to large changes in water levels in reservoirs during intensive operation of the hydropower stations, particularly in the Kremenchutske and Kahovske reservoirs, which have considerable differences between normal and dead volume water levels. During low reservoir water levels, the release of chemical substances from bottom sediments increases as the hydrostatic pressure decreases. This also causes large shallow areas to dry up, and an associated die-off of water plants. During subsequent repeat flooding, these plants decompose with an associated severe oxygen demand and release of organic matter, nitrogen and phosphorus etc. into the water. These changes have had profound effects not only on aquatic organisms but also on the potential for the use of river water for human use, particularly as a source of drinking water.

The Institute of Hydrobiology is one of the main research institutions in Ukraine for investigations, assessments and consulting in the fields of hydroecology, hydrobiology, water protection and management of water resources. About 300 people currently are working in various subdivisions of the Institute. The main objective of the research of our scientists is the Dnieper and its reservoirs and tributaries. Our main goal and current tasks are to improve water quality and the ecological situation in aquatic systems of the Dnieper River.

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Innovative Wastewater Treatment Technologies and the Environmental Effects of Wastewater Discharge

Chair: PETER SETO

Application of Humates for Nutrients Removal from Wastewater

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An efficient removal of nitrogen and phosphorus from wastewater has become an important issue at wastewater treatment plants. Biological methods are proven to be the most economical to deal with this issue. Their application however, requires substantial capital costs to modify existing treatment systems. In addition, biological methods are very sensitive to the presence of inhibitory substances, particularly heavy metals. While phosphorus concentration can be controlled by addition of aluminum or ferric salts, nitrogen removal is typically achieved by nitrification and denitrification.

Humic substances are natural components of soil and natural waters. They are formed during humification of organic matter by soil microorganisms. Humic substances have been found to enhance biotic and abiotic degradation of phenols, hydrocarbons and pesticides in the aquatic environment. They are generally recognized to be responsible for the binding of major parts of metal ions in the water and soil environment. Typically, 2 to 6% of topsoil weight is comprised of humic substances but at several locations, humic substances accumulated over time in huge deposits of humates that can be mined.

Conestoga-Rovers & Associates (CRA) has recently initiated treatability studies on the application of humates in wastewater treatment. The studies were conducted on wastewater and activated sludge from Hamilton WWTP with humates from New Mexico. The studies included biochemical tests using respirometric technique and chemical tests. The purpose of the biochemical tests was to investigate the effect of humates addition on nitrification and phosphate removal. The purpose of chemical tests was to evaluate the application of humates for immobilization of heavy metals and phosphorus.

The results of biochemical studies indicate that humates can detoxify inhibitors of nitrification and stimulate denitrification. It has also been found that a relatively small dose of humates can replace aluminum and iron salts for phosphorus removal in a biological treatment system. An important advantage of using humates versus metal salts is that they do not increase concentration of metals in biosolids. The results of chemical tests demonstrate that humates can efficiently remove heavy metals from water. They can also be used for phosphorus and ammonia removal in abiotic systems. Since humates are entirely compatible with the natural environment, exhausted humates used for phosphorus and ammonia treatment can be applied as fertilizing material in agriculture.

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COMPETING FOR THE PHILIP H. JONES AWARD

The Role of Cyanobacteria in Pulp and Paper Waste Treatment Systems

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We are investigating the role of cyanobacteria in biological waste-treatment systems used by the pulp and paper industry. Pulp and paper secondary treatment systems are designed to support the growth of heterotrophic bacterial populations for the reduction of organic waste, including organochlorines. Not until recently has it been determined that cyanobacterial communities exist in these systems as well. Our findings have shown cyanobacteria to be important members of the microbial community in geographically dispersed pulp and paper treatment systems around the world. Experiments using whole effluent from three mills indicated that toxicity removal during biological treatment is affected by the presence of cyanobacteria. The two softwood-based effluents had decreased toxicity reduction when cyanobacterial biomass increased. In contrast, the hardwood-based effluent had increased toxicity removal as cyanobacterial biomass increased. Growth assays with cyanobacterial isolates clearly indicated that many of the important genera benefit from the utilization of organic compounds such as glucose and acetate. This ability to add and remove organic compounds may have important implications for waste-treatment performance, particularly with respect to cyanobacterial interactions with the heterotrophic community. Mixed-culture as well as cyanobacterial exudate experiments both show that cyanobacteria do indeed affect bacterial biodegradation, depending on the strain and exudates involved. From a waste management perspective, the main conclusions of our work suggest that cyanobacterial communities in pulp and paper waste-treatment systems have a mixed role. Although they do not appear to be contributing directly to waste treatment, their interactions with the heterotrophic microbial community can affect the biodegradation efficiency of organic contaminant removal.

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COMPETING FOR THE PHILIP H. JONES AWARD

Removal of Cadmium from Aqueous Solutions using Edible Mushrooms (*Agaricus bisporus* and *Lentinus edulus*)

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Fungal organisms can remove heavy metals from aqueous solutions. Macro fungi such as *Agaricus bisporus* and *Lentinus edulus* (Japanese shiitake), commonly called mushrooms, are edible and grown commercially. Laboratory batch studies were conducted at room temperature (21±1°C) to determine the potential of these fungal biomasses for adsorption of cadmium from aqueous solutions containing 1 mg/L cadmium. The equilibrium time for adsorption was found to be 6 h and 1 h for *A. bisporus* and *L. edulus*, respectively. Cadmium removals were found to be 82% and 40% with *A. bisporus* and *L. edulus*, respectively. The optimum initial pH was found to be 4 and 5 for *A. bisporus* and *L. edulus*, respectively. Isotherm studies are in progress. Results from batch studies indicated that biomasses of *A. bisporus and L. edulus* are promising adsorbents for removing cadmium from aqueous solutions.

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Biological Nutrient Removal in Poland: Case Studies of Successes and Problems

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With the rate of construction of new wastewater treatment plants reaching 300 per year, Poland seems like a heaven for designers, operators and researchers of the biological nutrient removal (BNR) processes. Significant and well-placed government loans, through the National Environmental Protection Fund, were extended to the municipalities which have also often privatized the water and wastewater facilities thus generating their own revenue. The whole operation of massive financial investment led to frantic design by various companies, some with less and some with more BNR experience. At the time, Northern and Central Europe were suffering from the Scandinavian perception of BNR processes as being applicable to warm climates only. Hence heavy emphasis on chemical precipitation led to less than optimal design.

The paper will start with a general overview of the technologies used in both large and small municipalities and then, through case studies, illustrate some of the most often recurring design and operational issues, e.g., excessive reliance on chemicals, high DO in internal recycles, scum retention, VFA fermentation problems and issues related to sludge liquor return.

Various approaches to the design process used will be presented with a more detailed discussion of the design based on bench-scale, pilot and full-scale studies followed by modelling and simulation. Besides reliance on ferrous chemicals, one issue faced by municipalities was over-design, as many of the earlier plants were based on the first edition of German ATV standards for biological nutrient removal plants, which led to overly generous hydraulic and solids residence times. Some plants were inadvertently over-designed hydraulically due to drastic decrease in water use, often the result of newly implemented water rates and metering, while the greenfield plants would be designed based on unit water use data from the late eighties. The operators soon found out that the popular axiom, "the bigger the better" in the case of BNR processes, led to difficulties in process operation such as the increased effluent concentration of orthophosphates due to secondary phosphorus release.

The papers will also elaborate on research that led to the discovery of "faster nitrifiers"—a major correction of the endogenous decay rates which led to various changes in the design, particularly the ratio of the anoxic and aerobic zones.

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Dynamic Simulation of Food Processing Facility Effluent Treatment

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Dynamic simulation of wastewater treatment processes was used to select among several options for upgrade of an industrial effluent treatment plant. A covered anaerobic lagoon (CAL) treating the effluent of a food processing facility needed to be drained for repairs, without shutting down the factory. As a further complication, the factory effluent flow was discontinuous, leading to a complex set of options for the timing of the draining/treatment. Dynamic simulation technology was successfully used to simulate the process, and to evaluate several treatment timing options. The simulation was able to highlight the most effective option.

The simulation results also indicated that supplemental methanol treatment was required. Further modelling exercises helped to determine the optimal timing and quantity of methanol addition.

The selected draining/treatment schedule is currently being implemented, and validation of the model results will be completed once the CAL draining is complete.

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Innovative Biological Treatment Processes for Water and Wastewater

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Biological treatment of wastewater has been employed successfully for many types of industries. The major biological treatment processes for wastewater include activated sludge processes, aerated lagoons or stabilization ponds, trickling filters or fixed-film reactors, and anaerobic processes. Biological treatment is commonly used as a secondary treatment. The major groups of biological processes include aerobic, anaerobic and a combination of both. The systems are divided into suspended or attached growth processes for the removal of BOD, nitrification, denitrification, stabilization and phosphorus removal. Aerobic processes including activated sludge, trickling filters, aerated lagoons and rotating biological contactors (RBC) have been used extensively. However, the supply of air is expensive in addition to the large amounts of sludge that must be sent for disposal. Recently, significant developments have been made in the area of anaerobic waste treatment. Treatment is now reliable and retention times are low. A net production of methane also makes these systems attractive. Tertiary treatment is often in the form of sand filtration, adsorption, chemical oxidation and ozonation. Nutrient removal can be achieved by a combination of biological and chemical processes or biological alone. Although biological nutrient removal had been perceived as emerging and costly, these processes are now efficient and cost effective. New developments such as the Annamox process for ammonia removal are also highly promising. Selection of the appropriate process will depend on the effluent quality limitations, lowest wastewater availability of land, and costs (capital, operating and maintenance). Other processes such as biosorption are under development and will be able to compete with ion exchange processes once these processes are further developed. If space is available, wetlands can be used to remove biological oxygen demand (BOD), total suspended solids (TSS), nutrients and heavy metals. These, among others, are described in this paper, in terms of applications, design requirements, stage of development, future research needs and costs.

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Disruption of Biogenic Amine Levels and their Metabolism in Freshwater Mussels Exposed to a Municipal Effluent

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We examined the potential effects of municipal wastewaters on the metabolism of biogenic amines. Surface water samples were first obtained from sites upstream and downstream along the dispersion plume of a municipal effluent, and extracts prepared using a solid phase C8 mini-column. The potential effects of these extracts were then examined by determining: 1) serotonin uptake by HT_7 human receptors in transfected Chinese hamster ovary cells, and 2) monoamine oxidase (MAO) activity and vitellogenin expression in trout hepatocytes. Furthermore, levels of catecholamines, serotonin with its major metabolite 5-hydroxyindolacetate (5-HIA), and MAO activity were determined in nerve tissues of mussels exposed for 98 days at 1.5 km upstream and 8 km downstream of a major urban effluent outfall. Results showed that extracts prepared from surface water samples influenced by the effluent plume contained compounds capable of activating human serotonin receptors and inducing both MAO and vitellogenin in hepatocytes. Activation of the serotonin receptor was significantly correlated with levels of excreted vitellogenin in the extracellular medium ($R = 0.95$, $p < 0.01$) and with MAO activity ($R = 0.99$, $p < 0.01$) in rainbow trout hepatocytes. Moreover, mussels at the downstream site had depressed levels of serotonin and catecholamines and increased levels of MAO activity in nerve ganglia. Hence, municipal effluents appear to release compounds that are capable of disrupting the normal metabolism of biogenic amines in freshwater mussels and in fish hepatocytes. We also observed that these extracts were capable of activating human serotonin receptors in transfected Chinese hamster ovary cells and MAO activity in hepatocytes. Serotonin and catecholamines are involved in the sexual differentiation process in fish and in the spawning process and maturation of oocytes in bivalves. This initial study suggests that reduced levels of serotonin and increased activity of MAO in nerve ganglia could have disruptive effects on the reproductive cycle and sex ratio of oviparous organisms in rivers contaminated by municipal wastewaters.

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Environmental Evaluation of Land-Applied Pulp Mill Biosolids: Monitoring Fate of Sludge Constituents in Forest Ecosystems and Assessing Impact using Ecologically Relevant Organisms

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Land application of pulp mill biosolids has several potential benefits, including an inexpensive alternative to fertilizers for agricultural use. However, critical long-term assessment of these land applications and their impact on terrestrial and receiving-water biota have not been established. Bioassays with distinct endpoints that include an array of relevant organisms in order to assess the possible toxic effects of pulp mill biosolid land application are clearly needed. The current study has incorporated several test organisms that include vertebrate and invertebrate animals, and plant groups found in soil and receiving freshwaters. These include the green algae *Selenastrum capricornutum*, the terrestrial plant *Brassica rapa* and waterborne duckweed *Lemna minor*. The water column invertebrate *Daphnia magna* and the benthic organism *Hyalella azteca*, along with the mosquitofish *Gambusia affinis* were also utilized. Lastly, the terrestrial invertebrate earthworm *Lumbricus terrestris* was also examined in land application experiments. A laboratory set-up was developed for the collection of water runoff from soil samples treated with and without biosolids. A small-scale mesocosm incorporating many of the aforementioned aquatic species have helped foster an understanding of the potential conditions occurring in receiving waters proximal to biosolid-amended soil at the macro level.

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COMPETING FOR THE PHILIP H. JONES AWARD

Photo-transformation of Resin Acids in Saale River Water, Germany

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The Saale River is the Elbe's major tributary in Thuringia, Germany, that receives organics inputs from several industrial facilities including pulp and paper mills. Resin acids constitute a major class of polar organics and environmental toxins derived from pulp and paper processing of softwoods. The four most prevalent resin acids in pulp and paper mill effluents—abietic, dehydroabietic, isopimaric, and pimaric acids—were measured in the river at maximum concentrations of 330 to 370 μg/L, between April and August, 2001. Under UV irradiation at 254 nm in laboratory experiments, the resin acids were observed to undergo facile photo-transformation in Saale River samples with pseudo-first-order kinetics. The half-life values were between 1.1 and 1.9 hours, indicating that UV 254 nm radiation may be an effective treatment of resin acids in effluents or receiving waters.

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A Review of Water and Wastewater Management Techniques

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The following paper provides a general description of geographic information systems and outlines several research attempts towards wider application and adoption of this technology in civil engineering. The literature survey covers such areas as water pollution, waste collection, soil liquefaction, slope stability and rainfall runoff applications and the adoption of suitable computing technologies for incorporation into geographic information systems. It concludes with some recommendations for areas of future research.

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Drinking Water: Waterborne Pathogens

Chair: TOM EDGE

Escherichia coli O157:H7 in Surface Waters in Southern Alberta

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E. coli O157:H7 is associated with haemorrhagic colitis and the haemolytic uremic syndrome in humans. Southern Alberta has the highest rate of gastrointestinal illness in the province and *E. coli* O157:H7 infection rates in this region are among the highest in Canada. *E. coli* O157:H7 infections have been associated with living in rural areas with high cattle population densities in Canada and Scotland. Cattle are known to be a reservoir of this pathogen and excrete the organism in their faeces. In southern Alberta, there is a very large cattle feedlot industry. Some of the rural human illness associated with this pathogen may be foodborne and due to the consumption of contaminated beef, raw milk and raw vegetables, from animal contact or secondary infections such as occur in daycare centre and in family outbreaks. Recently, attention has focused on outbreaks of *E. coli* O157:H7 infection associated with drinking water and recreational use of water and there has been much public concern about the safety and quality of water in this region. We have tested river and irrigation water in the Oldman River basin in southern Alberta for the presence of *E. coli* O157:H7 as well as indicators of faecal pollution such as *Salmonella* spp., total coliform and faecal *E. coli*. We isolated *E. coli* O157:H7 from 9/758 (1.2%) of rural water samples and one or more times from 8/33 (24.2%) sampling sites in 2000 and from 16/806 (2.0%) of rural water samples and one or more times from 13/40 (32.5%) sampling sites in 2001. *E. coli* O157:H7 and *Salmonella* spp. isolations and coliform/*E. coli* counts peak during the summer months. Certain sites had multiple pathogen isolations and high indicator bacteria counts in the same year and from year to year. Pulsed-field gel electrophoresis and phage typing are being used to compare *E. coli* O157:H7 isolates from water to those from cattle and humans in this region. Other bacterial typing methods are being used to try and trace sources of faecal pollution of these waters. Human consumption of inadequately treated water in this region, especially during summer months represents a significant risk of infection with this pathogen. There are also likely to be risks associated with recreational activities such as swimming and using this water for irrigation and processing of raw edible plants. Consumption of untreated waters by animals is likely to maintain this pathogen in this reservoir. The information generated in this study should be useful in designing optimal public health intervention strategies.

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Potential Applications of 5' Nuclease ("REAL-TIME") Quantitative PCR for Microbial Water Diagnostics

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Quantitative analysis of water pathogens presents many technical challenges, yet ensuring that drinking and recreational water is free of microbes is an important public health issue. We have been engaged in the analysis of waterborne microbes by using the 5' nuclease PCR technology. There are many real-time PCR instruments and chemistries that have recently emerged on the marketplace for quantitative PCR analysis. This exciting new molecular technology is ideally suited for diagnostics. GenBank has been used to access sequence specificity and design oligonucleotides for target microorganisms, each of which have a primer set and fluorescently labelled probe. Initial studies were done on spiked water samples of 1 mL. Thus far, environmental sample collection has been with 50- to 250-mL volumes concentrated onto a polyethersulfonic membrane by vacuum filtration, followed by DNA extraction. Numerous DNA extraction methodologies have been, and continue to be, examined for their efficacy with various target microbes. Our initial results from environmental sampling have shown potential for the application of this technology to "real world" samples. Real-time PCR is more accurate and sensitive in its quantitation than traditional endpoint PCR, with a reduced risk of contamination and faster throughput for sample analysis. It is also less time consuming than many of the traditional culture or enzyme based techniques, with the potential for multiple pathogen analysis simultaneously by multiplex 5' nuclease PCR. For these reasons real-time PCR has proven very promising for applications to the field of microbial water quality analysis. The potentials and corresponding precautions of 5' nuclease PCR technology will be addressed as they relate to the enumeration of waterborne microbes.

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COMPETING FOR THE PHILIP H. JONES AWARD
N.J. Ruecker is the recipient of the Great Lakes Sustainability Fund Travel Award

The Use of RT-PCR for the Detection of Enteric Viruses in Prairie Surface Drinking Water Supplies

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Concerns over the microbial safety of drinking water supplies have focused on bacteria and parasites, while the occurrence of pathogenic waterborne viruses has been largely ignored. Lack of confidence and interpretation of the current analytical methods, high costs, and poor availability of competent laboratories mean that water supplies are not routinely monitored for viruses. This is despite the fact that pathogenic viruses are estimated to account for more than 50% of waterborne diseases. Reverse transcriptase polymerase chain reaction (RT-PCR) is used widely to detect selected viruses in clinical samples, but the application of RT-PCR to source waters is complicated by two major factors: 1) Relative to clinical samples, surface waters contain low numbers of pathogenic viruses and therefore require the concentration of larger sample volumes. 2) Environmental samples often contain many other substances which are inhibitory to RT-PCR reactions. These other substances inevitably become concentrated along with the virus particles. Without purification of the target viruses to remove inhibitors, false negatives are likely to occur, with serious health implications. We tested an RT-PCR method by screening four prairie surface water supplies for the presence of major enteric viruses (enterovirus, reovirus, rotavirus, Hepatitis A and calicivirus). At the same time we tested for the presence of other microbes, and measured a range of water-quality parameters. The presence of coliform bacteria, high particle and turbidity levels as well as dissolved inorganic and organic material indicate that the source waters studied were of poor quality. No viruses were detected in the samples. However, the same samples seeded with virus resulted in few confirmed positive results. We argue that there is clearly a critical need to develop methods which are robust, that can be used to detect waterborne viruses with confidence, particularly for waters of poor quality. This is especially important, as there is a greater potential for the contamination of water supplies with rising human population densities and increasing industrial water usage.

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Pathogen Inactivated in Municipal Sludge: Low-Dose Lime and Fly-Ash Treatment

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Disinfection of municipal sewage sludge after mesophilic anaerobic digestion traditionally calls for large doses of lime which raises the pH to 12 and after several hours the pH may drop to 11 to 11.5. U.S. EPA considers such sludge as Class A product—if 24 h of elevated pH can be demonstrated. The authors will report on pathogen survival rates in a new process that treats the sludge at much lower doses of lime and/or fly-ash. Anoxic storage is used over an extended period of time. Mechanism of disinfection and bench scale results will be presented. The indicator pathogens used included fecal coliform, salmonella, *Clostridium perfringens* and Ascaris eggs. The latter were spiked and recovered using the Cornell University-Tulane University procedure modified at the University of Manitoba.

Results indicate low pathogen levels following treatments with doses as low as 30 mg CaO/g TS, with the thermophilic *Clostridium p.* requiring the highest dose of over 100 mg/g TS (equivalent to approximately 30 mg/g wet solids in the dewatered cake).

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Environmental Dimensions of Pathogens and Water Security — Core Science Capacity Gaps

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Public concerns over health threats from environmental-borne microbial pathogens are growing at an alarming rate. Recent global events and government reactions have clearly focused efforts at enhancing our response and prevention capacity related to biological threats, particularly as they relate to public security and critical infrastructure such as water. While the use of biological weapons is often viewed as a low probability event, central to emergency response and prevention is the capacity to better understand the nature of this threat. A brief overview is provided of the nature of the threat of biological weapons and its environmental dimensions. Conventional and emerging microbial pathogens associated with water system contamination and waterborne disease outbreaks will be reviewed, along with associated threats to water infrastructure security. Scientific and technology needs for detecting and responding to biological weapons in water will be identified. Many of the current gaps in knowledge and availability of research, monitoring and surveillance tools already pose significant challenges for dealing with ongoing waterborne pathogen threats to ambient and drinking water security across Canada.

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Posters

Waterborne 17α-ethynylestradiol Affects Aggressive Behaviour of Male Fathead Minnows (*Pimephales promelas*) under Artificial Spawning Conditions

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The potential threat of xenoestrogens in the environment to human and fish populations has resulted in an intensive global effort to identify and develop biomarkers that are suitable for determining the estrogen mimicking capacity of chemicals, however few studies have examined the effects of contaminants on behavioural endpoints. Among fishes, courtship behaviour and nesting defense are strong predictors of male reproductive success. Three studies were conducted to assess impacts of exposure to environmentally relevant concentrations of the estrogenic contaminant 17α-ethynylestradiol (EE2) on the ability of male breeding fathead minnows (*Pimephales promelas*) to establish and defend a spawning territory. Fathead minnows were exposed to nominal concentrations of EE2 (2 and 8 ng L^{-1}) for 27 days, while temperature and photoperiod were gradually optimized with respect to spawning conditions (24^{o}C, 16:8h light:dark). In experiment 1, control (ethanol only) males (C) were paired in competition with treated males (L = low dose, H = high dose) for a single nest-site. In experiment 2, males were paired in competition for a nest-site with individuals from their own treatment groups. Solitary males from each treatment group were allowed to occupy a nest-site prior to the introduction of a second male from the same treatment group in experiment 3. Video records of latency to nesting, nest-site acquisition and rates of aggression were quantified and compared among trial types. In experiment 1, nest-site acquisition was significantly higher for control males when paired with high dose males. Rates of aggressive behaviour were also significantly higher for control males when results from both trial types (Cvs.L and Cvs.H) were combined in experiment 1. Exposure to EE2 did not significantly impact a male's ability to defend a territory (i.e., nesting aggression). A significant difference in overall aggression (i.e., the summed rates of aggression of both individuals in a pair) was observed across trial types in experiment 1, with Cvs.L and Cvs.H trials showing higher levels of aggression than Cvs.C trials. No difference in the combined total rates of aggression was detected across treatment groups in experiment 2. These results indicate that exposure to EE2 impairs the ability of male fathead minnows to compete and acquire territories when compared to unexposed individuals. This study also establishes, for the first time, that the male reproductive behaviour of fathead minnows is a potential biomarker for xenoestrogens in the environment.

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Effects of Chlorinated Solvents on Three North American Amphibian Species

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Tetrachloroethylene (PCE), a dry-cleaning and degreasing solvent, can enter groundwater through accidental leaks or spills and has been reported at concentrations as high as 75 mg/L in Canadian aquifers. Amphibians in wetlands fed by contaminated groundwater may be exposed to PCE and its degradation products but little information on the impacts of these compounds on indigenous amphibians exists. Using a modified version of the Frog Embryo Teratogenesis Assay—protocol for exposure and effects assessment, we examined the effects of PCE and its degradation product trichloroethylene (TCE), on three North American amphibian species: wood frogs (*Rana sylvatica*), green frogs (*R. clamitans*) and spotted salamanders (*Ambystoma maculatum*). Subsequently, chronic exposures to PCE and TCE were conducted on the larvae of American toads. Both PCE and TCE were teratogenic to amphibian embryos. EC50s of PCE and TCE for both wood frogs and green frogs was 12 mg/L and 40 mg/L, respectively. The survivorship of embryos was not compromised at these concentrations. Results from this study will be incorporated into a battery of bioassays used to monitor the safety of bioremediation techniques applied to groundwater contaminated with PCE.

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A Critical Assessment of the Potential Wildlife Toxicity of Glyphosate in Ontario with Consideration for Endocrine Disruption

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Our objective was to identify the potential for adverse effects to wildlife at environmentally relevant concentrations of glyphosate in Ontario, Canada. An in-depth review of the environmental toxicity, environmental concentrations, and potential for endocrine disruption was completed. The profile included a brief description of active ingredients, use patterns in Ontario, occurrence in surrounding natural environments, associated acute and chronic toxicity and potential for endocrine disruption, evaluation of risk to wildlife and recommendations for research and monitoring. Our review revealed that there is insufficient data on environmental concentrations of glyphosate in surface water and sediments to properly evaluate biological exposure in agricultural and urban ecosystems of southern Ontario. The endocrine effects of glyphosate and surfactants used in formulations have yet to be evaluated thoroughly. It may be unlikely that direct estrogenic effects could occur from exposure to the active ingredient, but some non-ionic surfactants have been known to cause this response. We recommend a more comprehensive monitoring program of surface water and sediment concentrations of glyphosate be implemented in agricultural and urban areas in Ontario, with relevant detection limits. There is a particular need for sediment data given the chemical attributes of the compound. The availability and effects of glyphosate to benthic invertebrates should be studied due to its accumulation and long half life in sediments. Few studies have actually assessed endpoints associated with endocrine disruption; more research must be conducted to provide this information for glyphosate and its surfactants.

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A Critical Assessment of the Potential Wildlife Toxicity of Atrazine in Ontario with Consideration for Endocrine Disruption

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Our objective was to identify the potential for adverse effects to wildlife at environmentally relevant concentrations of atrazine in Ontario, Canada. An in-depth review of the environmental toxicity, environmental concentrations, and potential for endocrine disruption was completed. The profile included a brief description of active ingredients, use patterns in Ontario, occurrence in surrounding natural environments, associated acute and chronic toxicity and potential for endocrine disruption, evaluation of risk to wildlife and recommendations for further action. Our review revealed that atrazine is frequently detected in surface waters of southern Ontario, often exceeding the Canadian Water Quality Guideline for the protection of aquatic life of 1.8 μg/L. There is strong evidence that endocrine disruption in aquatic organisms can occur at and below this guideline concentration. Atrazine can disrupt the neuroendocrine system at concentrations which occur in the environment. However, atrazine seems to be non-estrogenic in rodent and human studies, but does bind to alligator estrogen receptor sites. It is antiandrogenic and possesses several, as of yet not well understood mechanisms of toxic action on the neuroendocrine system. We recommend that, in Canada, Best Management Practices, such as buffer strips and grassed swales, must be implemented to reduce herbicide inputs into surface waters in high risk and ecologically sensitive areas. A revised Canadian Water Quality Guideline for the protection of aquatic life should be considered for atrazine because numerous effects in aquatic organisms have been reported around the guideline concentration. Consideration should be given to the issue of mixtures and additive effects of closely related compounds.

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Odours from Pulp Mill Effluent Treatment Ponds: The Origin of Significant Levels of Geosmin and 2-Methylisoborneol (MIB)

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While the pulp and paper industry traditionally is associated with sharp/acrid odours from sulphur-containing compounds in stack emissions, the wastewater process ponds can contribute significantly to malodours. The major malodourous compounds are inorganic and organic reduced sulphur compounds (e.g., hydrogen sulphides, mercaptans, thiols) that are by-products of the pulping process. Sulphur-reducing/oxidizing bacteria (e.g., *Thiothrix*) are a major component of the microbial biomass in the activated sludge, and considerable industry attention is devoted to their control and mitigation via aeration, and pH and nutrient manipulation.

This study, however, focused on identifying the source(s) of earthy/musty odours from the wastewater treatment ponds of a mixed hardwood pulp mill. To date, the chemical and biological source(s) of these odours in pulp mills have not been identified. Samples were taken from different locations in a major pulp mill on three occasions, September to December 2001. These were analyzed for specific volatile organic compounds (VOCs) with earthy/muddy musty odours: geosmin, MIB, 2,4,6-trichloroanisole (TCA), 2-isopropyl-3-methoxypyrazine and 2-isobutyl-3-methoxypyrazine, using headspace solid-phase microextraction-GC-MS. Samples were examined microscopically and plated on a growth media for gram-positive and -negative bacteria.

In all cases, the activated sludge produced significant amounts of MIB, and particularly geosmin. Levels of these compounds reached *ca.* 25 and 90 μg/L respectively, two- to nine-thousand times their odour threshold concentrations (OTCs). Geosmin and MIB were present at ambient river concentrations in samples taken at the inflow to the plant. They were still detectable downstream, at levels above OTCs but much reduced from those in the sludge (ca 95–99%). Considerable variation in geosmin and MIB over the three sampling occasions coincided with changes in plant-manipulated N:P, but geosmin was consistently predominant. None of the other target analytes were found. Plates yielded a mix of gram-negative bacteria, but gram-positive filamentous Actinomycetes, known to produce geosmin and/or MIB, were not detected, even though these aerobic bacteria metabolize cellulose. Instead, all samples from the aeration basin contained high numbers of Cyanobacteria, also major geosmin/MIB producers. In all cases, this biota was dominated by non-N_2-fixing filamentous Oscillatoriales (cf. *Leptolyngbya*); other taxa (e.g., *Chroococcus*) were minor components.

From this preliminary study we conclude: i) geosmin and MIB can make significant contributions to the airborne malodours produced in this paper mill; ii) there is considerable temporal variation in levels of geosmin/MIB; iii) these compounds are generated by biota in the aerated sludge; and iv) evidence points to filamentous Cyanobacteria, not Actinomycetes, as the major VOC source(s). Further study is underway to identify which of the blue-green taxa present in the sludge are the major geosmin/MIB producers, and whether the variation in VOC levels is related to changes in nutrients (specifically N:P ratios), which may affect Cyanobacterial abundance and/or community composition, or cellular VOC production. Given the recently reported widespread occurrence of Cyanobacteria in similar waste treatment systems, it is likely that geosmin and MIB are important VOCs in many pulp mills.

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COMPETING FOR THE PHILIP H. JONES AWARD
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Iron Speciation and Metal Availability in Mine Tailings and a Mine Drainage Impacted Aquifer

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At the Nickel Rim tailings impoundment (Sudbury, Ont.), sulfide-rich mine tailings above the water table have been oxidizing and generating acidic, metal-rich water for over 50 years. Although the acidic water has largely been neutralized by buffering minerals within the tailings and the downgradient aquifer, and metals have been attenuated, changing geochemical conditions have the potential to release metals currently found in the tailings and aquifer solids. To determine the availability of metals for redissolution, as well as to determine the ability of the tailings and aquifer to buffer waters with high and low oxidation potentials, chemical extractions were conducted on cores of tailings and aquifer material, and samples of groundwater from the tailings and aquifer were analyzed. It was found that a small layer of tailings within the aquifer, through which water is infiltrating, is leading to the accumulation of metals in the aquifer. Furthermore, an oxidized peat layer within the aquifer appears to be accumulating poorly crystalline, oxidized iron, which could potentially be released by a reducing plume. In the tailings, the greatest potential for the reductive dissolution of iron exists in the top metre of the solid phase, where oxidation has occurred. Metals such as Cr and Cu appear to be accumulating in the hardpan within the tailings. Other metals, such as Al, have accumulated just below the hardpan. These metals are likely being released by the dissolution of sulfides, or by the dissolution of gangue minerals by neutralization reactions. As the water is buffered and the pH rises, the metals precipitate from solution.

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COMPETING FOR THE PHILIP H. JONES AWARD

Mobility of Arsenic in an Aquifer Impacted by Mine Tailings

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Inherent to the extraction of some gold ores is the mobilization of naturally occurring arsenic. In addition to concentrating gold, the ore enrichment process accumulates arsenic in the mill tailings, resulting in an increased potential for leaching into groundwater systems. This release and potential transport of arsenic is a principal environmental concern for the gold mining industry. At the Campbell Gold Mine (Balmertown, Ontario), high concentrations of dissolved arsenic derived from the reductive dissolution of arsenic-bearing iron oxides are observed near the base of the tailings impoundment. Concentrations decrease, however, along the groundwater flow path in the underlying aquifer, suggesting that arsenic is partially attenuated. Groundwater measurements suggest that leachate from the impoundment reacts with aquifer sediment in a sequence of redox-dependent reactions which have direct influences on arsenic mobility. As groundwater flows across a peat layer underlying the impoundment, conditions become strongly reduced. Calculations using the geochemical speciation program MINTEQA2 indicate super-saturation in this region with respect to the solid phase As_2S_3 (orpiment), the phase most readily formed by arsenic in the presence of aqueous sulfide. Optical microscopy revealed the presence of secondary pyrite. Concentrations of arsenic and reduced species drop off sharply as the reduced plume exits the peat layer and encounters aquifer sediment containing up to 3000 mg/kg of reducible iron. Arsenic which escapes the region of reduced water undergoes oxidation coupled to the reductive dissolution of iron oxides, and arsenate is adsorbed by iron oxides down-gradient. As the reduced plume overcomes the oxidation potential of aquifer sediment, iron oxides are dissolved and adsorbed arsenic is re-released.

The capacity of the aquifer to sequester arsenic was quantified in column experiments. Under moderately reducing conditions, a quasi-steady state was achieved after 20 pore volumes, wherein 60% of the total arsenic mass introduced to the system was retained on the column sediment. Calculations using the geochemical speciation program MINTEQA2 indicate super-saturation with respect to orpiment, however, further sediment analyses are required to confirm its presence or absence. In a subsequent experiment, the ability of aquifer sediment to oxidize arsenic under mildly reducing conditions was confirmed. Leaching column results suggest that adsorbed arsenic may represent an additional concern at mine closure. Aquifer material directly underlying the tailings has the potential to release arsenic at concentrations of up to 5 mg/L for many pore volumes under different geochemical conditions.

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Combined Sewer Overflows in Hamilton — An Update

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The City of Hamilton owns and operates one of the largest and most complex combined sewer systems (CSS) on the Great Lakes. Over 2100 km of sewers collect sanitary and combined sewage from an area of approximately 54 km^2 and convey it to the Woodward Avenue Wastewater Treatment Plant (WWTP). Nearly 200 diversion structures regulate the amount of flow reaching the WWTP. During dry weather or light rainfall, the CSS conveys all flows to the Woodward WWTP. During heavy rainstorms, inflows exceed the capacity of the CSS and excess combined sewage is diverted to local receiving waters at up to 23 locations. These combined sewer overflows (CSOs) are necessary in order to prevent basement flooding and to protect the Woodward Avenue WWTP against hydraulic overloading that could upset the treatment processes.

CSOs have long been identified as a significant source of pollution to Hamilton Harbour and Cootes Paradise. The City's Pollution Control Plan (PCP), completed in 1991, estimated that on average, Hamilton's CSOs are active 23 times per year and collectively discharge over 4.8 million m^3 of CSO to local receiving waters each year. The PCP recommended the construction of 10 to 12 CSO detention storage facilities to control Hamilton's CSOs. To date, five CSO storage tanks have been built by the City, at a cost of approximately $47 million.

The PCP is now over 10 years old. In November 2000, Environment Canada's Great Lakes Sustainability Fund approved funding for a study to consider recent advances in CSO control technology and to update Hamilton's CSO control program. The project includes a review of existing CSS maintenance programs, an investigation of innovative options for CSO control including operational improvements and CSO storage and/or treatment, and development of a new CSO control implementation program including a sustainable funding program and implementation schedule. The project is part of a larger City effort aimed at developing an overall Hamilton Harbour Water Quality Strategic Plan for the improvement of Hamilton Harbour water quality.

An important component of the study is a review of the operation and performance of Hamilton's existing CSS, based upon long-term continuous simulation. The average annual CSO frequencies, volumes and pollutant loads estimated by the PCP were based upon the simulation of a single typical year, and the required CSO control storage volumes for each outfall were estimated using a single-event, design storm analysis. These analyses do not provide a complete or accurate picture of the performance of Hamilton's CSS over time. The original hydrologic and hydraulic simulation models have been updated and used to estimate the long-term performance of Hamilton's CSS. 30 years of local rainfall data (from 1970 to 2000) were used to more accurately determine the response of the CSS to precipitation events, and to estimate long-term CSO frequencies, volumes and pollutant loads discharged from Hamilton's CSO outfalls.

This paper describes the methodology used for the simulations, the results of the simulations, and the implications of the results on the design of future CSO control measures at Hamilton's remaining CSO outfalls.

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Geosmin and 2-Methylisoborneol Production and Growth of Actinomycetes in Water

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Certain actinomycetes produce 2-methylisoborneol (MIB) and geosmin, compounds that contribute to taste and odour in drinking water. These organisms are abundant in soil, and are introduced into surface waters during major runoff periods. Some species may exist as residents in aquatic environments. Many strains isolated from terrestrial and aquatic environments are capable of high growth and odour production in culture on artificial media, but it is not known if they grow or produce these compounds in aquatic environments, particularly during cooler periods at spring runoff. This research was undertaken to determine if selected actinomycetes are capable of growth or odour production at low, cool temperatures in water. Four actinomycetes isolated from different environments within the Great Lakes basin were grown in nonsterile Lake Ontario water at 0, 4 and 14°C for 28 days. Samples were taken at intervals for biomass estimation. Geosmin and MIB production was measured from cultures at 14 days. Preliminary results showed that two of the four isolates maintained stable abundance in lake water over the full period at 14°C, but declined at cooler temperatures. One isolate maintained stable abundances at 0 and 14°C and the fourth isolate maintained a stable population at 0°C but declined at higher temperatures. Geosmin and/or MIB were detected in all cultures at 14°C after 14 days, regardless of biomass. These results show that: 1) some actinomycetes are capable of growth and odour production in nonsterile environments, and 2) low temperatures associated with spring runoff may actually promote growth and odour production of certain actinomycetes. Odour production by actinomycetes may be complex, with some production by terrestrial actinomycetes which have been introduced into surface waters, and some production by resident aquatic species, with temperature acting as a strong influence on the species that are active at any given time.

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A New Planktic Species of *Pseudanabaena* (Cyanoprokaryota, Oscillatoriales) from North American Large Lakes

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A new species of *Pseudanabaena* (Cyanoprokaryota, Oscillatoriales) from the plankton of North American large lakes is documented including pertinent ecological and distributional data. This species differs from previously described *Pseudanabaena* species with respect to the characteristic undulating and coiling filament structure. *Pseudanabaena contorta* spec. nova appears to be specific to large North American temperate lakes with a drainage basin that is not totally Precambrian shield. It was a consistent but minor component of the planktic cyanoprokaryote populations during the spring and summer months in Lake Superior and Lake Ontario as well as other large Ontario and northern Saskatchewan lakes. Comparisons are made with other common taste and odour producing species of this genus.

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Project Coordination: Taste and Odour Research Consortium, 2001

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In 2001 the Western Lake Ontario Research Consortium continued its efforts to find the cause of taste and odour and to develop tools to assist utilities in managing taste and odour issues. Unique among the elements of this project is the collaboration of federal, provincial and utility sectors in the investigation and communication of the biological and physical elements involved in taste and odour.

The Research Consortium was formed in early 1999, and drew participation from the Ontario Ministry of the Environment (MoE), National Water Research Institute (NWRI/Environment Canada), Ontario Clean Water Agency (OCWA), Region of Peel, Region of Hamilton-Wentworth (now the City of Hamilton), Durham Region, Region of Niagara, Halton Region, and the City of Toronto. In 2001, Monroe County, New York, began participating in the Consortium.

Research conducted by MoE and NWRI scientists is partially supported by the affiliated utilities and coordinated by OCWA. Over the last three years over $1 million in research has been completed under the umbrella of the Consortium. Significant insight has been gained into the production of taste and odour chemicals and their movement to water utility intakes.

In 2002, significant research will continue. Major goals for project coordination include a website to showcase the project and make information readily available to the public. For participating municipalities, this will demonstrate their commitment to provide quality drinking water to the public. A research database is also being developed to centralize the increasing quantity of new and historical data and to aid in determining which of the environmental and climatic factors may be assisting in the formation of taste and odour compounds.

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Microcystins as Initiators of Avian Botulism?

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Water samples were collected for microcystin analysis, nutrients and algal enumeration from Hamilton Harbour (Lake Ontario), Wendt Beach (Lake Erie) and Presque Isle (Lake Erie). Microcystin concentrations varied largely and were present at acute toxicity levels only in some wind-concentrated scums of blue-green algae (mainly Microcystis) in Hamilton Harbour. In Hamilton Harbour, microcystin-RR was the main microcystin with microcystin-YR and LR also present. The two worst samples of August 17 and September 7 contained 60 µg/L and 400 µg/L, respectively. Dead birds were seen in the scums but in general the death of various birds at all sites cannot be directly related to microcystin analysis. The concentrations of microcystins at the Lake Erie sites were less than 1 µg/L but yet dead birds were common. The major limitation with this approach is that current analysis (Eliza and HPLC) methods are unable to measure covalently bound microcystins, the form that is assimilated into the food chain.

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Role of Planktonic Algae in Removal of Zn from Constructed Wetlands — Modelling of Algae/Plants Competitive Removal

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Constructed wetlands are a relatively inexpensive and publicly accepted method for improving water quality. The objective of this project was to model the flow of zinc through a wetland constructed for the removal of heavy metals from industrial wastewater. Particular attention was paid for the conditions of the completive removal of zinc within algae/plants system. With an understanding of the source/sink relationship within such a system, critical parameters can be adjusted to achieve optimal, long-term removal of zinc, thus reducing its discharge to the St. Lawrence River. Three different light regimes were simulated in order to emphasize the role of planktonic algae in the wetland. Three species of algae (*Oscillatoria*, *Scenedemus*, *Mougetia*) and rooted plants (a composite value) were considered as primary sinks of zinc in the model.

The ModelMaker Software was applied to construct the compartmental model of a constructed wetland which is able to "treat" 1700 m^3/d of wastewater containing 1.9 g/m^3 of zinc. This modelling was able to demonstrate the Zn uptake when the wastewater was flowing into the newly constructed wetland but also long-term changes within Zn content.

Results showed that approximately 70% of zinc was removed under high light conditions and 62% under low light. Uptake of Zn varies by species with *Oscillatoria* sp. showing the highest affinity under both high and low light conditions. Under low light conditions, Zn uptake by plants is much more significant because there is less algal biomass to competitively remove Zn. However, the dominant influence of algal biomass is apparent when considering the ultimate level of Zn discharged to St. Lawrence. Under high light levels, Zn levels in the St. Lawrence are maintained at the lower level than under low light conditions. The developed model could serve as a useful management tool for designing and maintaining a constructed wetland. This model can be modified by adding new components to the developed framework. The variables such as sediments adsorption and Zn precipitation seem to be required in particular conditions.

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Modelling of the Phosphorus Fate due to Agriculture Activities in the L'Assomption River Watershed

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Agricultural pollution is one of the leading sources of water quality impacts to rivers, lakes, and estuaries, and also a major contributor to groundwater contamination and wetlands degradation. The L'Assomption River watershed is considered one of the most polluted river watersheds in Quebec. Although industrial and urban waste contributes to the water pollution in the river watershed, agricultural activities, both point and non-point sources, seem to be the major cause of water pollution in the L'Assomption River watershed. The objective of this project was to determine agricultural activities in the L'Assomption River watershed, determine the types of pollution coming from agriculture, and evaluate the impacts of agricultural pollution on the L'Assomption water quality.

The L'Assomption River watershed is located on the north shore of the Saint Lawrence immediately downstream from Montreal. Agricultural activities play a major role in the L'Assomption River watershed. In 1995, 1305 farm producers owned 60,221 hectares of cropland and 73,563 animals. The L'Assomption River watershed is mainly composed of corn and hog farms; in the basin are: animal feed, 40%; common field crops (such as corn and soya), 31%; and cereals, 19%. More than 54,200 hectares are dedicated to these crops. The remaining 6000 hectares are used for other crops such as tobacco and potatoes (6%). Less than 200 hectares are used for fruit production (4%). Livestock produced in the basin are hogs (52%), dairy cows (20%), fowl (20%), beef cows (6%), and others (2%). In the L'Assomption River watershed, the manure from farms produces 5400 tonnes of nitrogen and 1250 tonnes of phosphorus annually. In the L'Assomption River watershed, the annual use of pesticides is about 2.2 kg active ingredients per hectare, while the average Quebec use is 1.3.

Water quality in the L'Assomption River is good until the town of Joliette. Joliette does not have a secondary municipal wastewater treatment plant. After Joliette, water also continues to deteriorate because of agricultural activities, such as hog and corn production. The model simulation focused on the area below Joliette, because this area has the worst water quality in the basin. The affected tributaries (lower part of the Ouareau, the St. Esprit and the Achigan) and sub-tributaries such as the Point du Jour, St-Georges, Vacher, and St-Pierre are also evaluated because of agricultural activities in these areas.

The software ModelMaker, by Cherwell Scientific, was used to simulate phosphorus loading from farms and model phosphorus concentrations over time in the L'Assomption River watershed. Non-point source pollution was modelled by using different compartments to represent a river section, and adding a point source loading to each section. The river was divided into different sections to reflect changes in agricultural loadings because of proximity to the Ouareau, St. Esprit, and Achigan tributaries, as well as loadings from different farms in the L'Assomption River area. Each tributary receives a certain amount of loading per day from farms. Data was obtained by performing a literature review on the subject. This model simulated phosphorus loading of kg/day. Since the criteria for eutrophication of rivers in Quebec is the phosphorus concentration about 0.03 mg/L, it was useful to determine how many days it takes before the concentration goes below 0.03 mg/L after loading of phosphorus. In the L'Assomption River itself, the worst sections were near the St-Esprit and the l'Achigan tributaries. This is because many farms are located in the St-Esprit and the Achigan sub-basins. The municipalities of Assomption and LeGardeur also have a low water quality, due their location close to farms and near the lower end of the river. The section near LeGardeur, which is the municipality located close to the mouth of the L'Assomption River, before the St. Lawrence River, was the worst water quality. As for the tributaries, the St. Esprit River is the worst, mostly because of its large phosphorus loading and the low depth and flow. The St. Esprit sub-basin is one of the most agriculturally intensive areas in the watershed. The model simulation indicated that its concentration after 10 days is 0.32, which is extremely above the eutrophication level. The L'Achigan River also does not recover, and its concentration stays above 0.03 mg/L. The St. Lawrence River was found to be affected by agricultural pollution from the L'Assomption River, even 40 km downstream.

This project was designed to make a rapid assessment of the water quality problem in the L'Assomption River basin by reviewing existing data and modelling phosphorus contamination. It identified the main agricultural activities in the L'Assomption River watershed, their impacts on surface water quality, and described possible measures to control pollution from agriculture.

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Quantitative Detection of Waterborne Pathogens by Real-Time PCR

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We have adopted the technique of 5' nuclease real-time PCR for the quantitation of pathogens in water. This technique is a sequence-specific detection method to assay microbiological water quality. A primer set is used in combination with a fluorescently labelled sequence-specific probe to detect a specific target organism. The 5' to 3' exonuclease activity of *Taq* Polymerase cleaves the 5' fluorescent label from the probe as extension from the primer proceeds and enables target detection by the real-time instrument. The quantity of target DNA is determined from known standards that are used to produce a linear regression of fluorescence versus starting gene copy number in a sample. We have developed assays for the detection of three target organisms thus far: *E. coli*, microcystin-producing cyanobacteria and the protozoan *Giardia*.

This assay has been successfully applied to monitor bottled water and samples from Ontario lakes for the presence of *E. coli*. Samples were concentrated onto a membrane prior to DNA extraction. *E. coli* DNA was detected with primers and a Taqman® probe designed to hybridize to a region of the *lacZ* gene, encoding β-galactosidase. We were able to detect down to three copies per sample. From a study of eleven brands of bottled water, including domestic and imported, we were able to detect 3 to 14 cells in four brands of bottled water from three separate lots. Use of selective media showed that some of these brands of bottled water do indeed contain viable cells. For environmental samples, three lakes were monitored and from 3 to 300 cells/mL were detected using real-time PCR.

To monitor for the presence of toxic microcystin-producing cyanobacteria a primer set and Taqman® probe were designed to detect the microcystin synthestase gene. These oligonucleotides allow for the selective detection of toxic *Microcystis aeruginosa* species. To develop a detection system for the cyst stage of the waterborne protozoan *Giardia*, Taqman® primers and probes were designed based on the sequence of the β-giardin gene. Using real-time PCR, a standard curve generated from 10-fold serial dilutions of *Giardia* DNA was obtained, with a linear range across 5 logs of DNA concentration. With this method we were able to detect one cyst of *Giardia*, approximately 0.3 pg of DNA. Real-time PCR is an ideal methodology for rapid pathogen detection; a run can be completed in less than 2 hours, and has the specificity and capability for quantitation of multiple targets in a single sample. Using this approach, our goal is to develop a multiplex assay for simultaneous detection of *E. coli*, microcystin-producing cyanobacteria, *Giardia* and eventually *Cryptosporidium*.

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Sediment Biostabilization in a Wave-Dominated Environment

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The development of biofilms on contaminated bed sediments can reduce erosion and contaminant transport. The concept of biostabilization was studied without contamination in a flume (0.3×13 m) using kaolinite clay (bed thickness = 1.5 cm), Hamilton Harbour water (1300 L) under wave conditions ranging from 0.5 to 5.5 cm, and two different stages of biofilm growth. Prior to the generation of waves, a phase of clay settling (2 days) was followed by a phase of biofilm growth (9 and 21 days) under quiescent conditions. The clay was injected as a slurry between two wave energy transmitting membranes (WETMs) positioned 1.25 m apart within the flume to isolate the study area. The biofilm growth was promoted by creating 24-hour daylight conditions and by injecting fresh harbour water at a rate of 130 L d^{-1}. To assess the biofilm growth, frosted-glass slides, embedded in the flume outside the WETMs, were sampled periodically for analysis of carbohydrate concentration. The stability of the kaolinite bed was measured by optical and gravimetrical changes of suspended sediment concentrations relative to wave height (bed shear) (i.e., critical bed shear stress for erosion corresponds to the bed shear [wave height] at which suspended solid concentrations increased above ambient levels). The diversity and the density of the planktonic bacterial community were determined by denaturating gel gradient electrophoresis (DGGE) and the BacLight® kit, respectively. Sessile algae were identified by direct observation under the microscope.

Initially, the harbour water had a bacterial density of 2.3×10^5 bact. mL^{-1}, which led to a biofilm accumulation on the slides of 42 µg carbohydrate cm^{-2} and 570 µg carbohydrate cm^{-2} after a growth period of 9 and 21 days, respectively. Although the biofilm thickness increased with time, the stabilization of the bed was more efficient with the 9-day biofilm. Visually, this could be explained by the generation of gas bubbles which lifted the biofilm up to 2 to 3 cm above the bed after 15 days of growth. Preliminary analyses of the gas suggested the production of O_2, which is relevant with the identification of green and blue-green algae in the biofilm. These visual observations were corroborated by the failure of the kaolinite clay bed that occurred under waves of 3.5 cm for a 9-day biofilm, whereas waves of 1.6 cm were sufficient to erode the bed covered with the 21-day biofilm. After sequential increases of waves from 0.5 cm to 3.5 cm, the suspended solids reached 370 mg L^{-1} with the 9-day biofilm experiment compared to 710 mg L^{-1} with the 21-day biofilm. This preliminary study suggests a potential application of biofilms to reduce sediment erosion and mass transfer by increasing the cohesion of sediment beds in wave environments.

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Uptake and Tissue Distribution of Perchloro- and Trichloroethylene in Tadpole and Adult of American Toad

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Perchloroethylene (PCE) and trichloroethylene (TCE) are common industrial solvents used primarily for dry cleaning (PCE) and industrial degreasing (PCE and TCE). Previous studies have demonstrated that PCE and TCE are both toxic to amphibians, however the distribution and metabolism of these compounds have not been studied in an amphibian model. We present the results of a preliminary experiment in which the uptake and distribution of waterborne radiolabelled PCE and TCE in American toads (*Bufo americanus*) was studied using whole-body autoradiography. Separate groups of tadpoles and adult were exposed to ^{14}C-PCE and ^{14}C-TCE (37 kBq/L of natural groundwater) for 96 h. The animals were then embedded, frozen, and 20-µm-thick whole-body cryosections were collected. Sections were applied to a phosphor screen at -20^{o}C first, to detect volatile compounds, and at room temperature afterward, to reveal the distribution of PCE, TCE, and their metabolites. Accumulation of PCE and its metabolites was not seen in the tissues of either tadpoles or adults. Uptake of TCE in adults was higher than in tadpoles after 96 h of exposure, with bioconcentration factor values of 120 and 60, respectively. The radiolabel was also distributed differently throughout the bodies of adults and larvae. For adults, I_C value (I_C = concentration index = concentration in tissue/concentration in whole body) was highest for the gallbladder (14), followed by intestinal content (5), kidney (3), and liver (2). In tadpoles however, the distribution of the radiolabel within the body was more uniform, with I_C values of 4 for gall bladder, 2 for intestine and kidney, and 3 for the liver. Furthermore, when sections were held at room temperature the decline in overall radioactivity was significantly greater ($p < 0.05$) in tadpoles (42% ± 5) than in adults (34% ± 5). This may be related to a lower metabolism rate in the former if metabolites are less volatile than the parent compound. The different fate of TCE observed in adult and larval American toad stresses the importance of considering all life stages of amphibians when assessing the risks posed by environmental contaminants.

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Uptake and Tissue Distribution of Thallium in Fish

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Dissolved thallium concentrations in the Great Lakes are generally below 10 ng/L, but higher concentrations were found at sites such as Hamilton Harbour, Ontario (range 23–36 ng/L), and near coal-fired electrical generating stations (50–175 ng/L) (Cheam et al., J. Great Lakes Res., 1995, 21:384, and Water Qual. Res. J. Canada, 2000, 35:581). Other countries have also reported high thallium levels, suggesting that thallium is a global environmental pollutant. However, little is known about the uptake and tissue distribution of this toxic metal in aquatic fauna. We exposed rainbow trout (*Oncorhynchus mykiss*) to water containing ^{204}Tl(I) (4.6 kBq/L, 47 ng Tl/L) to quantify the uptake and study the fine-scale distribution of this metal, using quantitative whole-body autoradiography. Data obtained from a 17-d exposure followed by a 14-d elimination period allowed to estimate to 200 the bioconcentration factor of thallium in this fish species. A value of 17 ± 3 d was found for the biological half-life. Radioactive thallium was found in all tissues, but the brain. Highest levels were found in the liver, with I_C value of 13.3 ± 1.5 after 17 d of exposure (I_C = concentration index = concentration in organ/whole body average concentration), whereas values of I_C for gills, kidney and gastrointestinal tract were comprised between 2 and 5. Significant concentrations of ^{204}Tl were also found in bones ($I_C \approx$ 1.5–2) and muscle ($I_C \approx$ 0.5–0.8), with muscle actually accounting for 40 to 50% of the ^{204}Tl body burden. This indicates that thallium(I) behaves quite differently from other metal ions, such as Cd(II), Hg(II), and Ni(II), since the latter do not accumulate in bones and muscle of fish upon exposure via water. Dissolved thallium(I) is easily accumulated by fish and further work is needed to assess the potential threat that may represent elevated thallium levels in the aquatic environment.

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A Canadian Guidance Framework for Phosphorus in Freshwater Systems

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Elevated levels of phosphorus can have many negative effects on aquatic ecosystems. Currently, no national guidelines for phosphorus exist and as such, phosphorus is on the list of priority pollutants for the Canadian Council of Ministers of the Environment (CCME). The water quality guideline development protocol for Canada is intended to deal specifically with toxic substances and provide numerical limits or narrative statements based on the most current, scientifically defensible toxicological data available. Phosphorus does not fit this protocol well as it is essentially non-toxic to aquatic organisms at levels present in the environment; however, secondary effects, such as eutrophication are a serious concern. Setting phosphorus guidelines by the protocol is difficult due to the subjective nature of what constitutes impairment. Some of the effects of phosphorus are aesthetic and, therefore, its management requires consideration of societal values. A number of approaches used by other jurisdictions for setting phosphorus guidelines were examined and a framework-based approach that includes elements of the Australian model is proposed. The framework presented here accommodates the non-toxic endpoints associated with phosphorus and can be incorporated into existing management strategies. It provides a tiered approach in which water bodies are marked for further assessment by comparing their trophic status to predefined 'trigger ranges.' The trigger ranges are selected according to the levels of phosphorus observed in the reference or baseline condition of a lake or river. Should the upper limit of these ranges be exceeded, or are likely to be exceeded, further modelling is recommended. When modelling suggests a likelihood that phosphorus levels will result in an undesired change in the local system, a management decision must be made. The effectiveness of the management decision is assessed through monitoring.

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