Detailed Briefing Note on Canada's Experimental Lakes Area (ELA)

Canada's Experimental Lakes Area (ELA) is a unique, world-renowned freshwater and fisheries research facility located in a pristine area of northwestern Ontario. The ELA began in 1968 and is jointly operated by Fisheries and Oceans Canada and Environment Canada. It is unique because an agreement with the Governments of Canada and the Province of Ontario allows ecosystem-scale experiments to be performed on a group of 58 lakes and their terrestrial drainage basins, a strategy not possible anywhere else in the world. Each study lasts from years to decades. The pristine setting is important because it allows researchers to understand the impacts of one specific environmental problem without the confusion of other human activities. Lakes that are manipulated are compared to ELA lakes in their natural condition that have been monitored for the past 44 years. This approach greatly increases the sensitivities of the studies, at the same time the small size of the lakes makes experimental manipulations practical and affordable. If closed, it is highly unlikely a facility like the ELA and its team of dedicated scientists would be recreated elsewhere.

Work done at the ELA provides scientific understanding of how ecosystems operate in the real world. Many of the experimental studies at ELA focus on impacts to lake trout, whitefish and northern pike. These fish are important in Canada for commercial, recreational and subsistence fisheries. This understanding has been used repeatedly to develop environmental regulations that are effective and efficient. Whole ecosystem manipulations have produced unexpected results that could not have been found in the laboratory. These results were critical in developing regulations and approaches that were not only effective but saved billions of dollars by providing sufficient information to avoid costly mistakes by taking the wrong approach.

The ELA has a high-quality staff with expertise in all aspects of the lake environment. The field station has excellent new facilities for research and housing. Because of its renown and truly unique scientific capabilities, the ELA also attracts other outstanding researchers from universities all over Canada and the world. These researchers not only bring their expertise, but also significant financial and human support for the various experiments. The ELA has also generated industry support for its experiments.

The ELA has made significant contributions to improving water quality and fisheries in Canada, and elsewhere in the world, through the experimental manipulations carried out on its lakes and through the long term monitoring of lakes in their natural condition. For example, early work at the ELA showed the importance of controlling phosphorus to reduce algal blooms in lakes. These results influenced the decisions of government agencies to remove phosphorus alone from wastewater, rather than phosphorus and nitrogen together, a much more expensive approach. Research on acidification at the ELA showed the sensitivity of the lake food chain to acid rain and consequent deleterious effects on fish populations. This research influenced the regulation of sulphur dioxide emissions from smokestacks, as part of the Clean Air Act, in Canada and the USA. Another whole-ecosystem experiment showed that mercury, an important contaminant of fish, is deposited onto lakes primarily from the atmosphere, demonstrating the importance of controlling mercury emissions to the atmosphere from burning fossil fuels and incinerating wastes. In other whole-lake research, the addition of an estrogen-like chemical produced feminized male fish and stopped reproduction. When addition of the hormone ceased, reproduction resumed and the fish recovered. ELA research supported by the hydroelectric power industry determined what areas to avoid flooding when selecting sites for new power generation operations in order to minimize greenhouse gas emissions and mercury level increases in fish. ELA research has been put into practice by industry to more sustainably produce hydroelectric power. These few examples highlight the unintended consequences to inland waters and fish populations that can only be effectively understood through long-term, whole-ecosystem study, and additionally highlight how environmental research is required and beneficial for sustainable development in Canada and around the world. There are many more examples of research done at the ELA (see details below), which demonstrate the power of whole-ecosystem manipulations to address important environmental questions.

The other important approach of ELA has been the long term monitoring of the lakes in their natural condition. This allows for comparison to impacted systems and for the estimation of the impact of climate on lakes. This record is now 44 years long. It covers hydrology, chemistry, and biology from algae to lake trout, using consistent methods throughout. This long term record shows how lakes change simply due to natural variation, and due to trends in global scale factors such as climate and atmospheric inputs.

Three obvious measures of the usefulness of the ELA are 1) its high number of publications, which continues to grow (see www.experimentallakesarea.ca/images/ELA%20Publications%20 Listing.pdf), 2) the large number of students and scientists who have received training, education and experience in freshwater environmental science and whose understanding of ecosystems has been enriched by their time at the ELA and 3) its effect on policies and regulations, which have led to improved fish habitat, cleaner water, and healthier ecosystems. Research at ELA has saved billions of dollars in unnecessary and costly regulations such as the needless control of nitrogen in wastewater treatment to control algal blooms in lakes.

NEW AND ONGOING RESEARCH:

1. Impacts of Nanosilver on Lakes (2011-present)

Project Leaders: Dr. Chris Metcalfe (Trent University)
Dr. Maggie Xenopoulos (Trent University)
Dr. Paul Frost (Trent University)
Dr. Holger Hintelmann (Trent University)
Dr. Michael Paterson (Fisheries & Oceans Canada)

Key Question: Nanotechnology is an industry growing exponentially and projected to reach close to $3 trillion globally in 2014. Although nanotechnology promises to greatly improve our lives, the health and environmental hazards are not fully understood. Nanosilver is currently the most widely used engineered nanomaterial. Nanosilver has hundreds of applications and products because of its germ-killing powers. Silver nanoparticles are found in socks, baby bottles, cutting boards and washing machines. Because of this, silver nanoparticles have the potential to enter the aquatic environment through wastewater discharges where they can be toxic to aquatic bacteria and algae. The impacts of nanosilver on whole lake ecosystems and food webs are not yet known. Many physical, chemical and ecological interactions required to fully assess the fate and effects of silver nanoparticles in lakes and rivers cannot be captured by lab-based studies.

Key Findings: Starting next year, researchers at ELA were planning to add nanosilver to a small lake in very small amounts to develop key information on its environmental fate and toxicity. If ELA is closed, this work will not proceed. Several graduate students are associated with this project and their fate is now uncertain.

Key implications: This information is urgently needed because there are no specific policies for managing the risk of nanomaterials in the environment.

Key Partners: Trent University, Environment Canada, Fisheries & Oceans Canada

2. Climate Impacts on Lakes and their Watersheds (2008-present)

Project Leaders: Dr. Paul Blanchfield (Fisheries & Oceans Canada)
Dr. Chris Spence (Environment Canada)

Key Questions: Future scenarios predict a warmer, more arid climate for areas of the Canadian Boreal Shield. Inland lakes and their watersheds will be negatively impacted through reductions in the amount of water available as well as through reductions in the delivery of essential nutrients to lakes that will subsequently limit production of recreational and commercial fish species. Drier conditions will also invoke new restrictions for downstream development and production of hydroelectric power. We are conducting the first direct manipulation of water flow to a lake to test the impacts of climate warming.

Key Findings: The timelines to understand climate-level impacts to boreal lakes is on the order of years to decades. After 3 years of background study we began the climate manipulation in the fall of 2010. Dramatic reductions in water input to the study lake (by 80%) occurred through large-scale catchment redirection of water. Preliminary data indicate initial modest increases in water clarity and increased heat penetration into the lake. Continuation of this study is necessary to determine the subsequent habitat reduction and population-level changes to lake trout, a cold-water top predatory fish.

Key Implications: This study will demonstrate the climate induced changes that are occurring in Canadian lakes and produce predictive models for the kinds of adaptation which will face the organisms in the lakes and the people using them. With closure of the ELA facility, the climate warming experiment will not proceed long enough to understand the magnitude of the impacts to boreal lakes and the fisheries they support. A Ph.D. student who started in January 2012 will not continue on this study.

Key Partners: Environment Canada, Fisheries & Oceans Canada's Centre for Aquatic Habitat Research, University of Manitoba, University of Waterloo

3. Ecological Impacts of Transgenic Fish (2008-present)

Project Leaders: Dr. Paul Blanchfield (Fisheries & Oceans Canada)
Dr. Robert Devlin (Fisheries & Oceans Canada, Vancouver)

Key Questions: Growing demand for fish protein to feed the human population has resulted in dramatic increases in the production of fish through commercial aquaculture (fish farming). Selective breeding has allowed fish species reared specifically for aquaculture to achieve a much higher growth rate than they would attain naturally. Genetically modified strains of fish (called transgenic fish) have the potential to achieve even greater growth rates than selective breeding and are being proposed for future use in fish farms. All data on the growth and survival of transgenic fish have come from contained laboratory facilities and to date we have no understanding of the fate of these fish in the natural environment, nor can we adequately predict the ecological impacts these fish may have based on laboratory data. We have begun a 3-Phase study at the ELA to address the ecosystem impacts of transgenic fish.

Key Findings: Phase 1 of our study occurred over the past 3 years and involved monitoring of ELA lakes prior to and after stocking with different strains of rainbow trout – a wild strain and a strain selectively bred for use in aquaculture. Findings show that growth rates of the aquaculture fish strain were much greater than the wild strain and much greater than expected.

Key Implications: Phase 1 of this study has demonstrated that our understanding of the growth and survival of fish that escape from aquaculture facilities is far from complete. The next phase of this research was to employ a growth hormone treatment that resulted in fish growth similar to what has been observed for transgenic fish, followed by Phase 3, which would have examined transgenic fish in the wild. ELA is the only place where such a study of this sensitivity, duration and magnitude can be carried out. Previous applications to conduct this research in other lakes in Canada have been denied. Funding from DFO to continue with Phase 2 of this study has been offered for this year, but with closure of the ELA facility, support of this study is waning. DFO has developed future scenarios that suggest transgenic fish will be a significant part of commercial aquaculture production in Canada, yet ELA is the only place where the research can be conducted to provide the required regulatory advice.

Key Partners: Fisheries & Oceans Canada's Centre for Aquatic Biotechnology Regulatory Research

4. Fate & Toxicity of Flame Retardants in Aquatic Ecosystems (2007-present)

Project Leaders: Dr. Derek Muir (Environment Canada)
Dr. Gregg Tomy (Fisheries & Oceans Canada)
Ms. Diane Orihel (University of Alberta)

Key Questions: Since the 1960s, polybrominated diphenyl ethers (PBDEs) have been used as flame retardants in commercial and household products, including electronics, building materials, upholstery fabric, and foam furniture. Studies have established that PBDEs are endocrine disruptors, developmental neurotoxins, and possible carcinogens. The release of the brominated flame retardant called decabromodiphenyl ether ("DecaBDE") to the environment is a serious concern because of the potential of this chemical to break down into more toxic metabolites. Whereas degradation of DecaBDE has been demonstrated in the laboratory, the extent to which this process occurs in the natural environment is unknown. At ELA, DecaBDE was added to enclosures (large tubes extending from the lake surface to the lake bottom) to examine the degradation of DecaBDE in the aquatic environment, and to assess whether DecaBDE and its breakdown products are accumulated by invertebrates and fish.

Key Findings: Breakdown products of DecaBDE were detected in sediments, invertebrates, and fish collected from the enclosures after 1-3 months. Fish and invertebrates contained toxic breakdown products (i.e., tetra to hepta-BDEs) that are currently listed as persistent organic pollutants ("POPs") under the Stockholm Convention.

Key Implications: These findings will be considered in risk assessments of DecaBDE in Canada, United States, and the European Union.

Key Partners: Fisheries & Oceans Canada, Environment Canada, University of Alberta

5. Linking Atmospheric Mercury Deposition and Mercury in Fish (2001-present) "METAALICUS" Experiment

Project Leaders: Dr. John Rudd (Fisheries & Oceans Canada, now R & K Research Inc.)
Dr. Michael Paterson (Fisheries & Oceans Canada)
Dr. Paul Blanchfield (Fisheries & Oceans Canada
Dr. David Krabbenhoft (United States Geological Survey)
Dr. Vince St. Louis (University of Alberta)
Dr. Cynthia Gilmour (Smithsonian Environmental Research Center)
Mr. Reed Harris (Reed Harris Environmental Ltd.)
Dr. Cheryl Podemski (Fisheries & Oceans Canada)
Dr. Holger Hintelmann (Trent University)
Dr. Marc Amyot (University of Montreal)
Dr. Carol Kelly (University of Manitoba; now R & K Research Inc.)

Key Questions: Fish from remote lakes around the world have become contaminated with mercury, a neurotoxin and endocrine disruptor. For example, more than 80% of the lakes listed in the Guide to Eating Ontario Sport Fish currently have mercury consumption advisories. This elevated mercury comes with precipitation in a similar way as acid rain did from the burning of coal. The United States Environmental Protection Agency and Environment Canada have proposed regulations that would force power companies to add mercury scrubbers to their smoke stacks, with a potential cost of billions of dollars. Because of the large costs, power companies sought hard evidence that reductions of mercury deposition from the atmosphere would reduce mercury in fish.

Key Findings: The experiment showed that most of the large store of legacy mercury, which has been collecting in the sediments of lakes over past decades, no longer participates in the ongoing mercury pollution of lakes. Instead it is newly deposited mercury entering lakes directly from the atmosphere and as runoff from watersheds that is causing the present day problem. Thus, regulations that control atmospheric emissions of mercury will result in a positive response (decline) of mercury concentrations in fish. This decline in mercury concentrations will be two phased – a quick response to reduced direct inputs of mercury from the atmosphere in rain, and a slower response as mercury inputs from the watershed decline.

Key Implications: This research demonstrated that reductions in mercury deposition will result in decreases in mercury in fish and how much reduction will be needed. These findings have already been used by the USEPA to establish new regulations controlling the atmospheric emissions of mercury from coal-fired power plants. This experiment is ongoing at the time of the announcement of ELA's closure.

Key Publications

Harris,R.C., Rudd,J.W.M., Amyot,M., Babiarz,C.L., Beaty,K.G., Blanchfield,P.J., Bodaly,R.A., Branfireum,B.A., Gilmour,C.C., Graydon,J.A., Heyes,A., Hintelmann,H., Hurley,J.P., Kelly,C.A., Krabbenhoft,D.P., Lindberg,S.E., Mason,R.P., Paterson,M.J., Podemski,C.L., Robinson,A., Sandilands,K.A., Southworth,G.R., St.Louis,V.L., and Tate,M.T. 2007. Whole-ecosystem study shows rapid fish-mercury response to changes in mercury deposition. Proc. Nat. Acad. Sci. USA **104**: 16586-16591.

Orihel,D.M., Paterson,M.J., Blanchfield,P.J., Bodaly,R.A., and Hintelmann,H. 2007. Experimental evidence of a linear relationship between inorganic mercury loading and methylmercury accumulation by aquatic biota. Environ. Sci. Technol. **41**: 4952-4958.

Graydon,J.A., St.Louis,V.L., Lindberg,S.E., Sandilands,K.A., Rudd,J.W.M., Kelly,C.A., Harris,R., Tate,M.T., Krabbenhoft,D.P., Emmerton,C.A., Asmath,H., and Richardson,M. 2012. The role of terrestrial vegetation in atmospheric Hg deposition: Pools and fluxes of spike and ambient Hg from the METAALICUS experiment. Global Biogeochem. Cycles **26**: GB1022.

Key Partners: Electric Power Research Institute (EPRI), USA, NSERC, Environment Canada, U.S. Environmental Protection Agency, U.S. Geological Survey, U.S. Department of Energy, State of Wisconsin, Southern Company (USA), Manitoba Hydro, Alberta Heritage Fund, University of Alberta, University of Wisconsin, Carleton University, University of Maryland, Smithsonian Environmental Research Center, University of Toronto, Trent University, Oak Ridge National Laboratory, University of Connecticut, Tetra Tech Inc. (USA), University of Montreal.

6. Understanding Lake Eutrophication – the role of nitrogen (1990-present)

Project Leaders: Dr. David Schindler (University of Alberta)
Dr. Michael Paterson (Fisheries & Oceans Canada)
Dr. Lewis Molot (York University)
Dr. Derek Muir (Environment Canada)
Dr. Sherry Schiff (University of Waterloo)
Dr. Sue Watson (Environment Canada)

Key Questions: In recent years, whole-lake studies at ELA have investigated the role of nitrogen in promoting the development of blue-green algae, an especially noxious and toxic group of algae.

Key Findings: For 44 years, researchers at ELA have continuously added phosphorus to a small lake in conjunction with different amounts of nitrogen. Since 1990, no nitrogen has been added to the lake. Despite the absence of any artificial nitrogen inputs, algal blooms have not diminished. These studies demonstrated that efforts to control blue-green algae should focus on the control of phosphorus and that treatment for nitrogen was unnecessary.

Key Implications: Because treatment for nitrogen is more expensive than treatment for phosphorous, the results of this research will potentially save municipalities and governments billions of dollars world-wide.

Key Publications:

Paterson,M.J., Schindler,D.W., Hecky,R.E., Findlay,D.L., and Rondeau,K.J. 2011. Comment: Lake 227 shows clearly that controlling inputs of nitrogen will not reduce or prevent eutrophication of lakes. Limnol. Oceanogr. **56**: 1545-1547.

Schindler,D.W., Hecky, R.E., Findlay,D.L., Stainton,M.P., Parker,B.R., Paterson,M.J., Beaty, K.G., Lyng,M., and Kasian,S.E.M. 2008. Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. Proc. Nat. Acad. Sci. USA **105**: 11254-11258.

Key Partners: Natural Science and Engineering Research Council (NSERC), University of Alberta, York University, University of Waterloo, University of Guelph, Environment Canada

7. Climate Impacts on Lakes and their Watersheds (1968-present)

Project Leaders: Dr. David Schindler (Fisheries & Oceans Canada; University of Alberta)
Dr. Michael Paterson (Fisheries & Oceans Canada)

Key Questions: Changes in the climate are likely to dramatically affect lakes in terms of water quality and quantity and, in turn, the ability of lakes to support recreational and commercial fisheries. Cold-water fish species, such as lake trout, are intensively studied as they are sentinels for climate change and will be among the first to be extirpated as cold-water habitat is reduced under a warming climate.

Key Findings: As concern and awareness has spread concerning climate change, scientists around the world have struggled to fully understand the implications. It is not possible to determine the impact of climate change in one year or even 5 year studies. At ELA, researchers have amassed one of the longest (44 years) and most complete (hydrology, chemistry, biology from algae to fish) data sets on changes to all aspects of lakes in response to changes in climate. The methodology has been carefully managed to be consistent over the full period. Analyses based on this 44-year data set have provided crucial information for the development of models predicting responses of lakes to future climate change.

Key Implications: This research has demonstrated the nature of climate induced changes that are occurring in Canadian lakes and has been used to produce predictive models for the kinds of adaptation that will face the organisms in the lakes and the people using them. With closure of the ELA facility, this exceptional monitoring program will be ended.

Key Publications:

Schindler,D.W., Beaty,K.G., Fee,E.J., Cruikshank,D.R., DeBruyn,E.R., Findlay,D.L., Linsey,G.A., Shearer,J.A., Stainton,M.P., and Turner,M.A. 1990. Effects of climatic warming on lakes of the central boreal forest. Science **250**: 967-970.

Schindler, D.W., Curtis,P.J., Parker,B.R., and Stainton, M.P. 1996. Consequences of climatic warming and lake acidification for UV-B penetration in North American boreal lakes. Nature **379**: 705-708.

Schindler,D.W., Bayley,S.E., Parker,B.R., Beaty,K.G., Cruikshank,D.R., Fee,E.J., Schindler,E.U., and Stainton,M.P. 1996. The effects of climatic warming on the properties of boreal lakes and streams at the Experimental Lakes Area, northwestern Ontario. Limnol. Oceanogr. **41**: 1004-1017.

Findlay,D.L., Kasian,S.E.M., Stainton,M.P., Beaty,K., and Lyng,M. 2001. Climatic influences on algal populations of boreal forest lakes in the Experimental Lakes Area. Limnol. Oceanogr. **46**: 1784-1793.

Jansen, W., and Hesslein,R.H. 2004. Potential effects of climate warming on fish habitats in temperate zone lakes with special reference to Lake 239 of the experimental lakes area (ELA), north-western Ontario. Environ. Biol. Fishes **70**: 1-22.

Plumb,J.M., and Blanchfield,P.J. 2009. Performance of temperature and dissolved oxygen criteria to predict habitat use by lake trout (*Salvelinus namaycush*). Can. J. Fish. Aquat. Sci. **66**: 2011–2023

Key Partners: Environment Canada, University of Alberta

PAST RESEARCH:

1. Environmental Impacts of Freshwater Aquaculture (2001-2010)

Project Leaders: Dr. Cheryl Podemski (Fisheries & Oceans Canada)
Dr. Paul Blanchfield (Fisheries & Oceans Canada)
Dr. Rebecca Rooney (University of Manitoba; now University of Waterloo)

Key Question: There is increasing need for fish from aquaculture (fish farming) to close the increasing gap between demand and supply from traditional wild fisheries. Currently, there are relatively few freshwater aquaculture operations in Canada, but there have been calls to develop this industry further. Expansion of freshwater aquaculture in Canada has been hampered by insufficient information about its environmental impacts and uncertainty about how to effectively regulate the industry.

Key Findings: To address some of these uncertainties, researchers installed an experimental aquaculture operation (fish farm) in a lake at ELA and studied its effects in detail. The farm resulted in local changes to the sediment habitat and organisms. Nutrients from the farm wastes recirculated into the lake and had a mild but easily measurable impact on the algal productivity and biomass in the whole lake. This also resulted in reduced oxygen concentrations in the deep waters of the lake.

Key Implications: Results from this project will contribute to legislation regulating freshwater aquaculture in Canada. More importantly, the results have led to continued work with the industry to help it reduce the environmental impacts of its farming operations.

Key Publications:

Azevedo,P.A., Podemski,C.L., Hesslein,R.H., Kasian,S.E.M., Findlay,D.L., and Bureau,D.P. 2011. Estimation of waste outputs by a rainbow trout cage farm using a nutritional approach and monitoring of lake water quality. Aquaculture **311**: 175–186.

Findlay,D.L., Podemski,C.L., and Kasian,S.E.M. 2009. Aquaculture impacts on the algal and bacterial communities in a small boreal forest lake. Can. J. Fish. Aquat. Sci. **66**: 1936-1948.

Rooney,R., and Podemski,C.L. 2009. Effects of an experimental rainbow trout (*Oncorhynchus mykiss*) farm on invertebrate community composition. Can. J. Fish. Aquat.Sci. **66**: 1949–1964.

Key Partners: Northern Ontario Aquaculture Association, Martin Mills Inc.

2. Effects of Endocrine Disrupting Compounds on Fish (2000-2003)

Project Leaders: Dr. Karen Kidd (Fisheries & Oceans Canada; now University of New Brunswick)
Dr. Vince Palace (Fisheries & Oceans Canada)
Dr. Paul Blanchfield (Fisheries & Oceans Canada)

Key Question: In the 1990s, considerable concern developed about the possible effects of artificial estrogen (used in birth control pills) and other common chemicals that mimic the properties of the estrogens that control reproduction in humans and wildlife. Populations of fish and other wildlife downstream of sewage treatment plants often showed signs of "feminization" where, in the most severe cases, male fish developed eggs; these feminization effects were due to the estrogen-mimicking chemicals that were not removed by sewage treatment. Environmental protection agencies around the world developed expensive tests for the estrogenic properties of new chemicals, but it was uncertain how meaningful these tests were in the "real world" and whether the feminized male fish could still successfully reproduce.

Key Findings: At ELA, artificial estrogen from birth control pills was added to a small lake for several years at levels found in effluents from sewage treatment plants. Male fish became feminized and were unable to properly develop their sperm, and eggs produced by female fish did not develop correctly. These effects on fish reproduction led to the collapse of the fish population. Once additions of the estrogen stopped, fish reproduction returned to normal and the population rebounded.

Key Implications: The study showed that fish populations living downstream of sewage treatment plant outfalls are at risk when even very low estrogen levels are found in their waters. Better municipal wastewater treatment is needed to ensure that estrogens and their mimics are removed from water before it is discharged to lakes and rivers.

Key Publications:

Kidd,K.A., Blanchfield,P.J., Mills,K.H., Palace,V.P., Evans,R.E., Lazorchak, J.M., and Flick,R.W. 2007. Collapse of a fish population after exposure to a synthetic estrogen. Proc. Nat. Acad. Sci. USA **104**: 8897-8901.

Palace,V.P., Evans,R.E., Wautier,K.G., Mills, K.H., Blanchfield,P.J., Park,B.J., Baron,C.L., and Kidd,K.A. 2009. Interspecies differences in biochemical, histopathological, and population responses in four wild fish species exposed to ethynylestradiol added to a whole lake. Can. J. Fish. Aquat. Sci. **66**: 1920-1935.

Key Partners: Environment Canada, University of Guelph, University of Manitoba, University of Kansas, U.S. Environmental Protection Agency, Bayer Schering Pharma AG.

3. Impacts of Hydro Reservoir Development on Greenhouse Gases (1999-2003)

Project Leaders: Dr. Carol Kelly (University of Manitoba, now R & K Research)
Dr. Drew Bodaly (Fisheries & Oceans Canada; now retired)
Dr. John Rudd (Fisheries & Oceans Canada; now R & K Research)
Dr. Vince St.Louis (University of Alberta)

Key Questions: Hydroelectric power was believed to be relatively free of greenhouse gas emissions but studies in newer boreal and tropical reservoirs suggested this was not the case.

Key Findings: Whole-lake reservoir studies at ELA have quantified greenhouse gas emissions from reservoirs. Countering claims that reservoirs were greenhouse-gas free, these studies demonstrated that hydroelectric reservoirs produced greenhouse gases, caused by the decomposition of flooded soils and vegetation. Flooded wetlands produced much more greenhouse gases in the long term than did flooded upland areas, showing that avoiding the flooding of wetland areas could minimize this problem.

Key Implications: With the strong support of the results of the ELA experiments, reservoirs are now included in global accounts of human greenhouse gas emissions. Emissions from most Canadian reservoirs are far lower than for carbon-based fuel sources such as coal, but flooding of peatlands, which contain very large stores of decomposable organic carbon, should be avoided. These types of reservoirs are large producers of greenhouse gases. Thus, this research provided critical information on how to build reservoirs so as to minimize greenhouse gas emissions and this advice has been adopted by power companies such as Manitoba Hydro and Hydro Quebec. Instrumentation and methods for accurate estimation and reporting of greenhouse gas emissions developed at ELA have been adopted by both Manitoba Hydro and Hydro Quebec.

Key Publications:

Bodaly,R.A., Beaty,K.G., Majewski,A.R., Paterson,M.J., Rolfhus,K.R., Penn,A.F., St. Louis,V.L., Hall,B.D., Matthews,C.J., Cherewyk,K.A., Mailman,M., Hurley,J.P., Schiff,S.L., and Venkiteswaren,J.J. 2004. Experimenting with hydroelectric reservoirs. Environ. Sci. Technol. **38**: 347A-352A.

Matthews,C.J.D., Joyce,E.M., St. Louis,V.L., Schiff,S.L., Venkiteswaren,J.J., Hall,B.D., Bodaly,R.A., and Beaty,K.G. 2005. Carbon dioxide and methane production in small reservoirs flooding upland boreal forest. Ecosystems **8**: 267-285.

Key Partners: Manitoba Hydro, Hydro Quebec, NSERC, The Canadian Foundation for Climate and Atmospheric Science, Environment Canada, University of Alberta, University of Wisconsin, University of Waterloo, University of Manitoba.

4. Impacts of Hydro Reservoir Development on Mercury Cycling (1991-2007)

Project Leaders: Dr. John Rudd (Fisheries & Oceans Canada; now R & K Research Inc.)
Dr. Carol Kelly (University of Manitoba; now R & K Research Inc.)
Dr. Vince St. Louis (University of Alberta)
Dr. Drew Bodaly (Fisheries & Oceans Canada, now retired)

Key Questions: The construction of new reservoirs usually results in dramatic increases of mercury in fish. Mercury is a potent neurotoxin that can threaten human health and high levels in fish frequently result in the closure of commercial fisheries. These impacts have been especially serious in northern Canada where they have caused disruption of the way of life for many aboriginal communities. This research was intended to study the dynamics of mercury cycling in reservoirs and to determine the relative impacts of flooding different types of terrain, such as wetlands and uplands.

Key Findings: Increases of mercury in fish result from the decomposition of flooded soils and vegetation that stimulate the conversion of inorganic mercury to toxic methyl mercury that accumulates in the food chain. Studies at ELA provided critical insight into how reservoir development affects mercury cycling and found that flooding forested uplands has much less impact than flooding wetlands.

Key Implications: This research has been used by power companies such as Manitoba Hydro and Hydro Quebec to design and build new reservoirs that minimize mercury impacts.

Key Publications:

Kelly,C.A., Rudd,J.W.M., Bodaly,R.A., Roulet,N.P., St. Louis,V.L., Heyes,A., Moore,T.R., Schiff,S., Aravena,R., Scott,K.J., Dyck,B., Harris,R., Warner,B., and Edwards,G. 1997. Increases in fluxes of greenhouse gases and methyl mercury following flooding of an experimental reservoir. Environ. Sci. Technol. **31**: 1334-1344.

St. Louis,V.L., Rudd,J.W.M., Kelly,C.A., Bodaly,R.A., Paterson,M.J., Beaty,K.G., Hesslein,R.H., Heyes,A., and Majewski,A.R. 2004. The rise and fall of mercury methylation in an experimental reservoir. Environ. Sci. Technol. **38**: 1348-1358.

Key Partners: Manitoba Hydro, Ontario Hydro, Quebec Hydro, NSERC, University of Manitoba, McGill University, University of Waterloo, University of Toronto, University of Guelph, University of Maryland, University of Alberta.

5. Effects of Acid Rain on Lakes (1976-2004)

Project Leaders: Dr. David Schindler (Fisheries & Oceans Canada; now University of Alberta)
Dr. Robert Cook (Oak Ridge National Laboratory, USA)
Dr. John Rudd (Fisheries and Oceans Canada; now R & K Research)
Dr. Carol Kelly (University of Manitoba; now R & K Research)
Dr. Michael Turner (Fisheries & Oceans Canada; now retired)
Dr. Raymond Hesslein (Fisheries & Oceans Canada; now retired)
Dr. Ken Mills (Fisheries & Oceans Canada; now retired)

Key Questions: In the 1970s and 1980s, concern developed about the loss of fish populations in hundreds of thousands of lakes in eastern North America and northern Europe. Scientists surmised that these losses were probably the result of lake acidification caused by emissions of sulfur dioxide and nitrogen from coal-fired power plants. Power companies argued that this could not be the case because laboratory toxicity studies indicated that most fish species were not affected by acidic water.

Key Findings: To test these ideas, scientists added sulfuric acid to lakes at ELA to mimic the effects of acid rain. They demonstrated that even moderate increases in acidification resulted in dramatic impacts to aquatic food webs and caused the collapse of fish populations. This was because populations of important food items for fish died out, causing them to starve. Also, key processes in the lakes that buffered them from acid inputs were disrupted.

Key Implications: Research at ELA contributed strongly to changes in the Clean Air Act that restricted emissions of sulfur dioxide to the atmosphere in Canada and the United States. The whole lake experiments show unequivocally how much acidity could be tolerated before adverse effects were seen, and that lakes could recover if emissions were reduced. These findings were crucial in getting acceptance of emissions controls and in determining how much emissions needed to be reduced. Since the implementation of the Clean Air Act ELA researchers have been able to track the decrease in sulfuric acid deposition through its long term monitoring program.

Key Publications:

Schindler,D.W., Mills,K.H., Malley,D.F., Findlay,D.L., Shearer,J.A., Davies,I.J., Turner,M.A., Linsey,G.A., and Cruikshank,D.R. 1985. Long-term ecosystem stress: the effects of years of acidification on a small lake. Science **228**: 1395-1401.

Schindler,D.W., Turner,M.A., Stainton,M.P., and Linsey,G.A. 1986. Natural sources of acid neutralizing capacity in low alkalinity lakes of the Precambrian Shield. Science **232**: 844-847.

Rudd,J.W.M., Kelly,C.A., Schindler,D.W., and Turner,M.A. 1988. Disruption of the nitrogen cycle in acidified lakes. Science **240**: 1515-1517.

Mills,K.H., Chalanchuk,S.M., and Allan,D.J. 2000. Recovery of fish populations in Lake 223 from experimental acidification. Can. J. Fish. Aquat. Sci. **57**: 192-204.

Key Partners: Alberta Oil Sands Research Program (AOSERP), NSERC, Electric Power Research Institute

6. Understanding Lake Eutrophication – the role of phosphorus (1968-present)

Project Leaders: Dr. David Schindler (Fisheries & Oceans Canada; now University of Alberta)

Key Questions: ELA was created in 1968 to study the problem of eutrophication or excessive algal growth in lakes. Research on this topic has continued at ELA until the present day and eutrophication remains one of the most important water quality problems world-wide. Algal blooms associated with eutrophication can cause fish kills, unsightly scums diminish recreational and waterfront property values, and toxic algae may threaten drinking water quality.

Key Findings: Early research at ELA demonstrated that phosphorus was the most important nutrient causing eutrophication in freshwater lakes. Whole-lake experiments used additions of phosphorus, nitrogen, and carbon and clearly demonstrated that small-scale studies suggesting that carbon was the most important nutrient were incorrect.

Key Implications: These studies and the dramatic photos they generated were instrumental in convincing policy makers around the world to restrict phosphorus inputs to lakes. Phosphorus treatment of sewage is now standard practice and many governments have banned the use of phosphorus in detergents.

Key Publications:

Schindler,D.W. 1974. Eutrophication and recovery in experimental lakes: implications for lake management. Science **184**: 897-899.

Schindler,D.W. 1977. Evolution of phosphorus limitation in lakes. Science **195**: 260-262.

Schindler,D.W. 1980. The effect of fertilization with phosphorus and nitrogen versus phosphorus alone on eutrophication of experimental lakes. Limnol. Oceanogr. **25**: 1149-1152.

Mills,K.H. 1985. Responses of Lake Whitefish (*Coregonus clupeaformis*) to fertilization of Lake 226, the Experimental Lakes Area. Can. J. Fish. Aquat. Sci. **42**: 129-138.

Key Partners: Lamont Doherty Earth Observatory (Columbia University, New York)

7. Ecosystem Recovery from Lake Acidification (1992-2008)

Project Leaders: Dr. Michael Turner (Fisheries and Oceans Canada)
Dr. Raymond Hesslein (Fisheries and Oceans Canada)
Dr. Rolf Vinebrooke (U. Alberta)

Key Questions: Little was known about the ability of Canada's boreal forest lakes to recover from chronic acidification despite substantial knowledge of the impacts of acidification. To better define the recovery potential of these lakes from acidification, researchers studied a lake that had been acidified experimentally for years and was allowed to return to natural pH.

Key Findings: Expectations for the recovery of aquatic ecosystems often proved incorrect and overly optimistic. The study lake did recover once the stress of acidification was reduced. However, recovery was on a path that was different from the original acidification and even full pH recovery did not result in complete ecosystem restoration within the timeframe of the study.

Key Implications: It is necessary to lower expectations of the rate of recovery of aquatic habitat because recovery timelines could be longer than is hoped for, and will likely be asynchronous with pH impacts. The policy implications of this study are many and included support of DFO's Habitat Management Policy, and the testing of the suitability of current acidifying emissions standards.

Key Publications

Jeffries,D.R., Clair,T.A., Couture,S., Dillon,P.J., Dupont,J., Keller,W., McNicol,D.K., Turner,M.A., Vet,R., and Weeber,R. 2003. Assessing the recovery of lakes in southeastern Canada from the effects of acidic deposition. Ambio **32**: 176-182.

Christensen,M.R., Graham,M.D., Vinebrooke,R.D., and Turner,M.A. 2006. Multiple anthropogenic stressors cause unpredictable ecosystem impacts. Global Change Biology **12**: 2316–2322.

See the several ecosystem recovery articles in the November 2009 ELA issue of Can. J. Fish. Aquat. Sci. **66**: 1831-2023.

Key Partners: Ducks Unlimited, Environment Canada, Saskatchewan Watershed Authority, U. of Alberta, U. of Western Ontario

To request a spokesperson available to speak about research at ELA, please email: media@saveela.org