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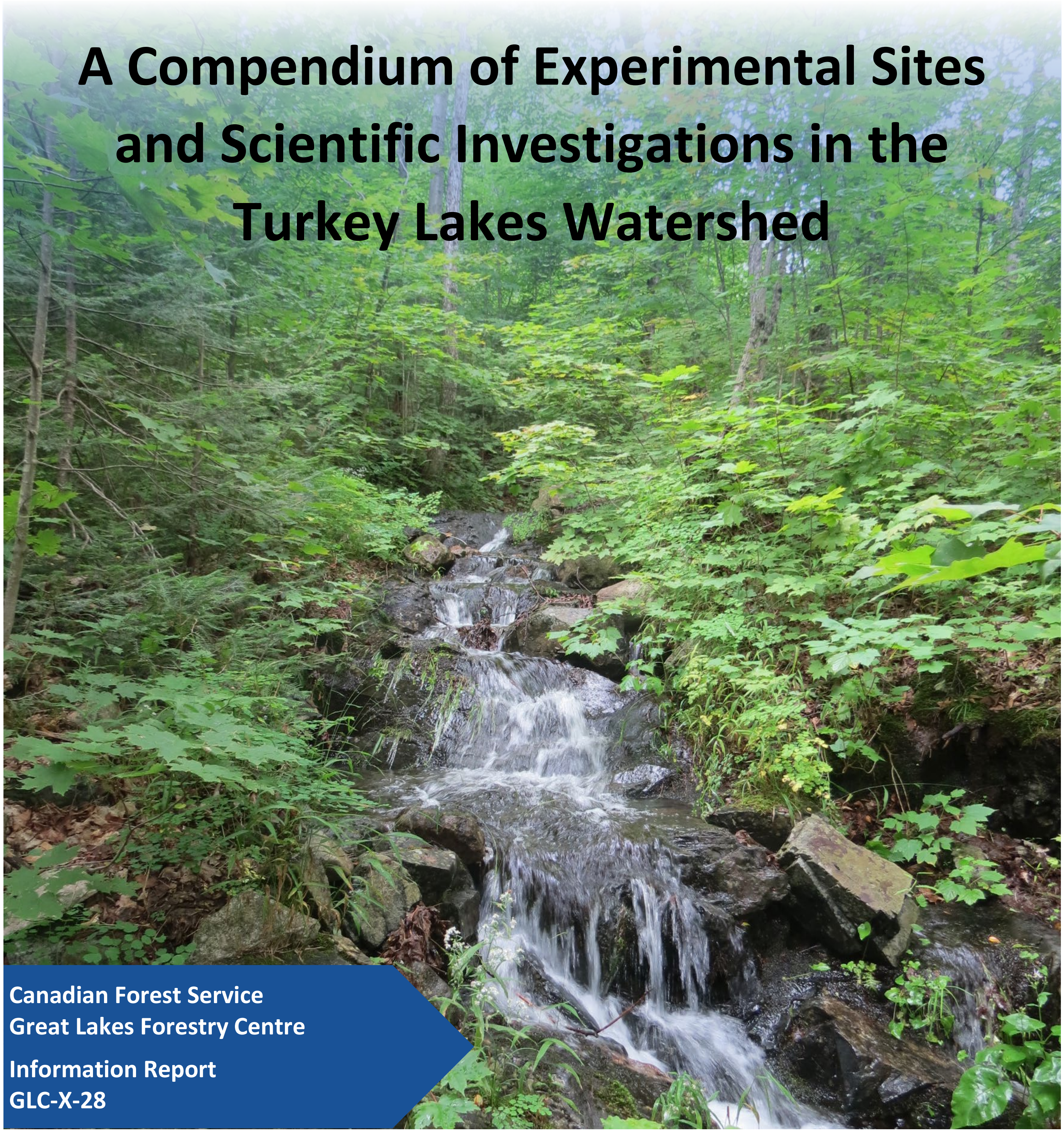
A Compendium of Experimental Sites and Scientific Investigations in the Turkey Lakes Watershed



Canadian Forest Service
Great Lakes Forestry Centre

Information Report
GLC-X-28

Canada

The Great Lakes Forestry Centre, Sault Ste. Marie, Ontario

The Great Lakes Forestry Centre is one of five research centres within the Canadian Forest Service, which is the national and international voice for Canada's forest sector. One of the core mandates of the Service is to conduct scientific research on Canada's forests. This research can be used to inform forest management planning and policy decisions and to assist the forest industry, the public and other scientists. The research projects cover diverse forestry related issues including climate change, forest fires, pests, and remote sensing. The results of this research are distributed in the form of scientific and technical reports and other publications.

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INTRODUCTION

FOREWORD

The Turkey Lakes Watershed (TLW) study is a federal, interdepartmental study established in 1979 to investigate the effects of acid rain on terrestrial and aquatic ecosystems. The 10.5 km^2 watershed, located in the Eastern Temperate Mixed Forest on the Canadian Shield, has been the site of multidisciplinary studies on biogeochemical and ecological processes conducted across plot to catchment scales (Figure1). The whole-ecosystem investigative approach was adopted from the outset and has allowed research to evolve from its original (and continuing) acidification focus to include investigations on the effects of climate change, forest harvesting and other forest ecosystem perturbations. The extensive scientific and support infrastructure allows for collection of a comprehensive data record essential for understanding long-term environmental trends. These data have contributed to over 400 published research papers and graduate theses. The watershed has also figured prominently in many continent-wide comparisons advancing fundamental watershed theory, as well the importance of "uniqueness of place". The knowledge gained at TLW has influenced pollutant emission and natural resource management policies provincially, nationally and internationally (Webster et al. 2020). This compendium provides a summary of those investigations, listing publications in 12 different categories: Site Overview, Atmospheric/Meteorology, Vegetation - Forest/Understory, Soils, Hydrology – Soil Water/Ground Water, Hydrology – Streams, Hydrology – Lakes, Water Birds, Fish and

Aquatic Communities, Modelling and Remote Sensing, Internal Reports and Theses, and Harvesting Impacts Project.

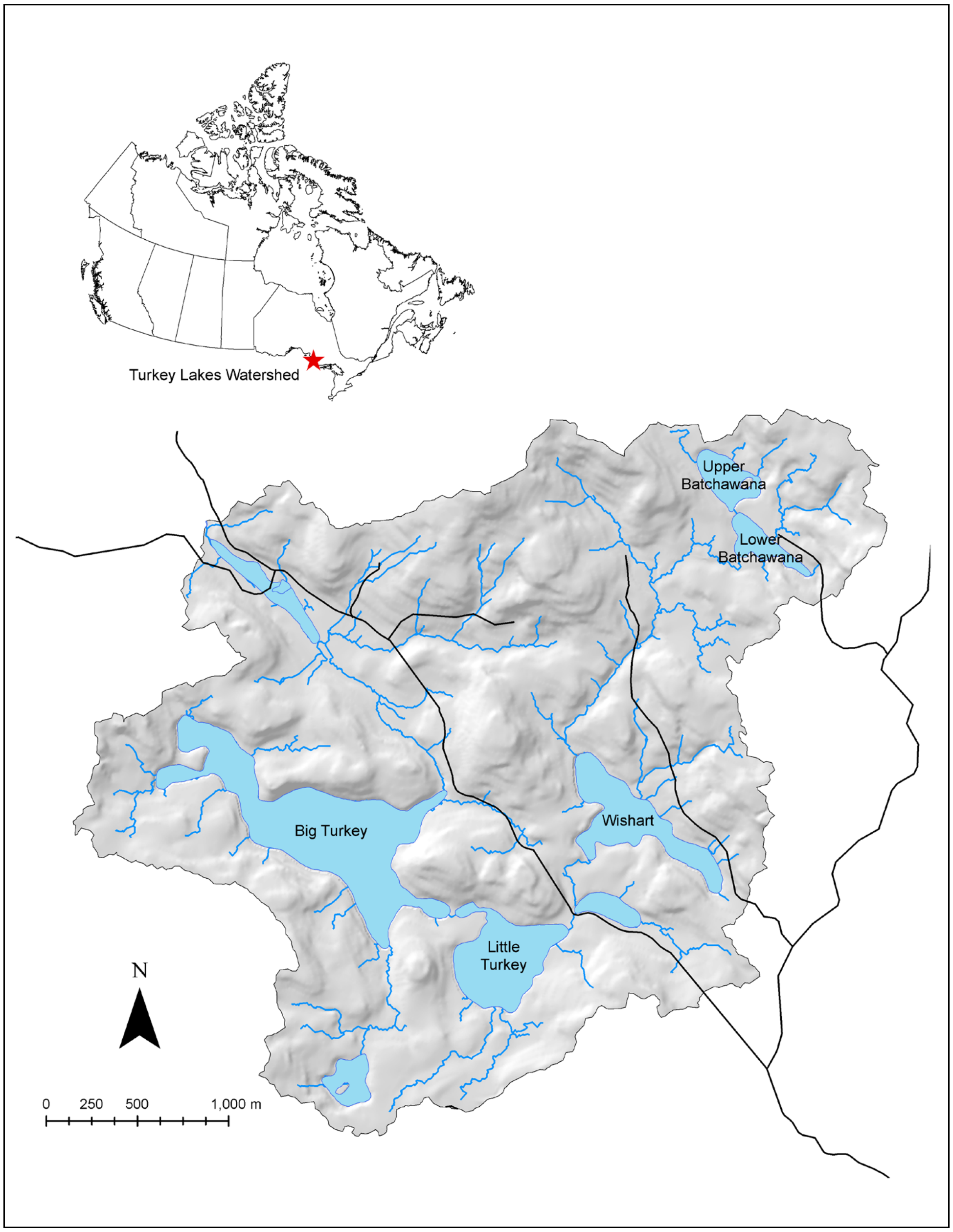


Figure 1. Location of the TLW in Ontario

HISTORY

In the late 1970s it was identified that acid rain was a threat to Canada's eastern forests, but the impact was expected to vary across the landscape due to differences in climate, magnitude of acidic deposition, and ecosystem characteristics. As a result, a network of five research basins were selected for intensive whole-ecosystem monitoring and research. The major study sites developed, from east to west were: Kejimkujik in Nova Scotia, Lac LaFlamme north of Quebec City, the Muskoka lakes, Turkey Lakes, and the Experimental Lakes Are (ELA) in eastern, central and western Ontario respectively. The Long Range Transport of Air Pollutants (LRTAP) network was established recognizing that no single basin could address all aspects of atmospheric, aquatic, and terrestrial research, but taken together, they could make substantial contributions to understanding the national assessment of acid rain impacts (Jeffries et al. 1988).

The decision to establish one of the LRTAP research basins in the Algoma region of central Ontario was motivated initially by two factors: first, a perceived need to fill a gap not covered by the other basins, i.e., investigate LRTAP effects under conditions of significant though not maximum deposition levels in a terrain of only moderate sensitivity; and second, a desire to utilize interdisciplinary expertise of a truly integrated watershed study that was already resident in Sault Ste. Marie at the Great Lakes Forestry Centre (Canadian Forestry Service, Department of Natural Resources) and the Great Lakes Laboratory for Fisheries and Aquatic Science (Department of Fisheries and Oceans) (Jeffries et al. 1988).

A systematic process was initiated to select the field site. Essential basin criteria included: (1) an undisturbed, interconnected, cascading lake chain progressing downstream from a headwater lake, (2) hydrological systems that were amenable to weir construction and accurate flow measurement, (3) geochemical conditions that were regionally representative, (4) location within daily commuting distance of Sault Ste. Marie (maximum 50 - 70 km) and having reasonable access, (5) an intact, typical and representative, mature, homogeneous Great Lakes – St. Lawrence forest, (6) a gradation in fish population characteristics within the lake chain, (7) self-sustaining fish stocks, and (8) and a salmonid population (brook and/or lake trout) within at least one of the lakes. It was assumed that if acceptable basin characteristics were found for fish, the characteristics of lower aquatic biota populations would also be "representative" of other lakes in the region (Jeffries et al. 1988).

By using the simplest logistical criterion (i.e., distance from Sault Ste. Marie), approximately 100 potential candidates were identified on topographic maps. Consideration of existing information (mostly on fish stocks but also other geological and hydrological data) eliminated 70% from further consideration. The remaining basins were visually inspected to determine whether suitable forest conditions existed and, in the end, 8 specific candidates were sampled chemically and biologically to ascertain overall suitability. It turned out that the most restrictive criterion was the combination of basin access and the existence of an intact, mature forest since almost all forest access in the Algoma District has been gained by the construction of logging roads. Also, construction of logging roads usually resulted in substantially increased recreational usage of the lakes and sometimes cottage development; both of these factors reduced the attractiveness of a number of sites. Of the three acceptable sites left at the end of the selection process, the TLW was ultimately chosen as the best overall candidate. It is located approximately 50 km north of Sault Ste. Marie and, while this was near the outer limit of the distance criterion, it was truly remote and undeveloped, and access was gained at relatively low cost by re-establishing a road previously used to service a nearby but now abandoned fire tower. The association of the road with the fire tower rather than logging accounts for the relatively intact nature of the surrounding forest (Jeffries et al. 1988).

ACHIEVEMENTS

Over more than 40 years, ongoing research and monitoring by researchers at the TLW has led to a number of achievements including major advancements in water and ecosystem science, contributions to Canadian and international policy on air pollution and air quality issues, water resource management, sustainable forest management guidelines and practices, and climate change assessment and adaptation:

- Contributions to the development of the Canada-US Air Quality Agreement in 1991;
- Ongoing contributions to agreement progress reports and Canadian Acid Rain Assessments, Canada-Ontario Agreement on Water Quality and Canada-US Great Lakes Water Quality Agreement, Forest Management Guidelines in Ontario and other jurisdictions, and a Blueprint for Forest Carbon Science in Canada.
- Results have been used in other international fora, e.g. the United Nations Economic Commission for Europe International Cooperative Programs on Acidification and Integrated Monitoring;
- Provides input to other high profile policy issues related to cumulative effects, drinking water treatability and ecosystem resilience to climate change;
- Tracks the effects of natural and anthropogenic disturbances on forests, and assesses mitigation or adaptation policies implemented by government and industry;
- More than 400 scientific publications;
- Ongoing public outreach has included tours and training for high school, college, universities, researchers, managers and policy makers;
- Host to a continuing number of MSc and PhD theses; and
- Collection of scientific partners with common goals and objectives.

PARTNERSHIPS

As a multi-disciplinary study, cooperative relationships have grown among government, industry, and academia. Each has assisted in maintaining the field and laboratory infrastructure needed to develop the consistent, long-term research datasets that are its hallmark. Environment and Climate Change Canada (ECCC), Natural Resources Canada (NRCan), and Fisheries and Oceans Canada (DFO) are three federal departments with central funding responsibility, while Ontario Ministry of Natural Resources and Forestry (OMNRF) bears administrative responsibility for the Crown Land reserve of TLW.

Partnerships since the inception of the study include:

Government, First Nation, Industrial
Natural Resources Canada, Canadian Forest Service
Environment and Climate Change Canada, Atmospheric Science and Technology Directorate
Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Science
Environment and Climate Change Canada, Water Science and Technology Directorate
Environment and Climate Change Canada, Canadian Wildlife Service
Ontario Ministry of Natural Resources and Forestry
Batchewana First Nation of Ojibways
Clergue Forest Management Inc.
Boniferro Mill Works Inc.
Meakin Forest Enterprises

University
Lake Superior State University
Laurentian University
McGill University
McMaster University
Michigan Technological University
Queen’s University
State University of New York
Trent University
University of British Columbia
University of Cambridge
University of Guelph
University of Michigan
University of New Brunswick
University of Saskatchewan

The site is reserved for research use by the OMNRF and remains exempt from commercial forestry and mineral exploration. A base camp is located near the watershed. Analyses of water, soil and vegetation samples are performed in the Water Chemistry Laboratory and Soil and Plant Laboratory at the Great Lakes Forestry Centre in Sault Ste. Marie.

SITE CHARACTERISTICS

TLW is a relatively undisturbed, uneven-aged tolerant hardwood forest that is dominated by mature to over-mature sugar maple (*Acer saccharum* Marsh.) that is over 150 years old. Minor components include yellow birch (*Betula alleghaniensis* Britton), red maple (*Acer rubrum* L.), ironwood (*Ostrya virginiana* (Mill.) K. Koch), white spruce (*Picea glauca* (Moench) Voss) and white pine (*Pinus strobus* L.). On upland sites, ninety percent of the basal area is sugar maples, 9% are other hardwoods, and 1% is conifer. On lowland sites, the conifer proportion is greater. Prior to research monitoring at TLW, there was no disturbance since a mid-1950s harvest of veneer/sawlog quality yellow birch and white pine. Stands regenerate through gap dynamics and are in equilibrium as far as above-ground net phytomass accumulation. Gross growth is significant but mortality offsets growth gains.

The TLW drainage system consists of first order streams and a cascading chain of 4 lakes. The Batchawana (separated into upper and lower basins), Wishart, Little Turkey and Big Turkey Lakes (surface areas of 6, 6, 19, 19 and 52 ha, respectively) are connected by Norberg Creek, which drains into Lake Superior via the Batchawana River. The relatively high amount of precipitation received at the TLW causes the lakes to flush fairly rapidly. Water renewal times vary from 0.2 years at Wishart to 1.2 years at Batchawana North.

The terrain is rugged with total relief of 300m from Batchawana Mountain (626 m) to the watershed outlet (Figure 2). The site is almost entirely underlain by Precambrian silicate greenstone (i.e. metamorphosed basalt) with only small outcrops of more felsic igneous rock occurring north of Batchawana Lake and near the main inflow to Little Turkey Lake (Semkin and Jeffries 1983) (Figure 3). A two-component glacial till overlies the bedrock. Till thickness varies from <1 m at high-elevation locations (with frequent surface exposure of bedrock) to 1-2 m at lower elevation, and with the occasional occurrence of extremely deep till sequences (up to 70 m) when valleys in the bedrock have been entirely filled (Elliot 1985). The till is more felsic than underlying bedrock showing that the material was likely primarily derived from the large granitic intrusions that occur just north of the basin (Kusmirski and Cowell 1983). They contain a small but measurable amount of $CaCO_3$ (0-2%) that increases with depth and is higher on average at lower elevation locations (Craig and Johnston 1983).

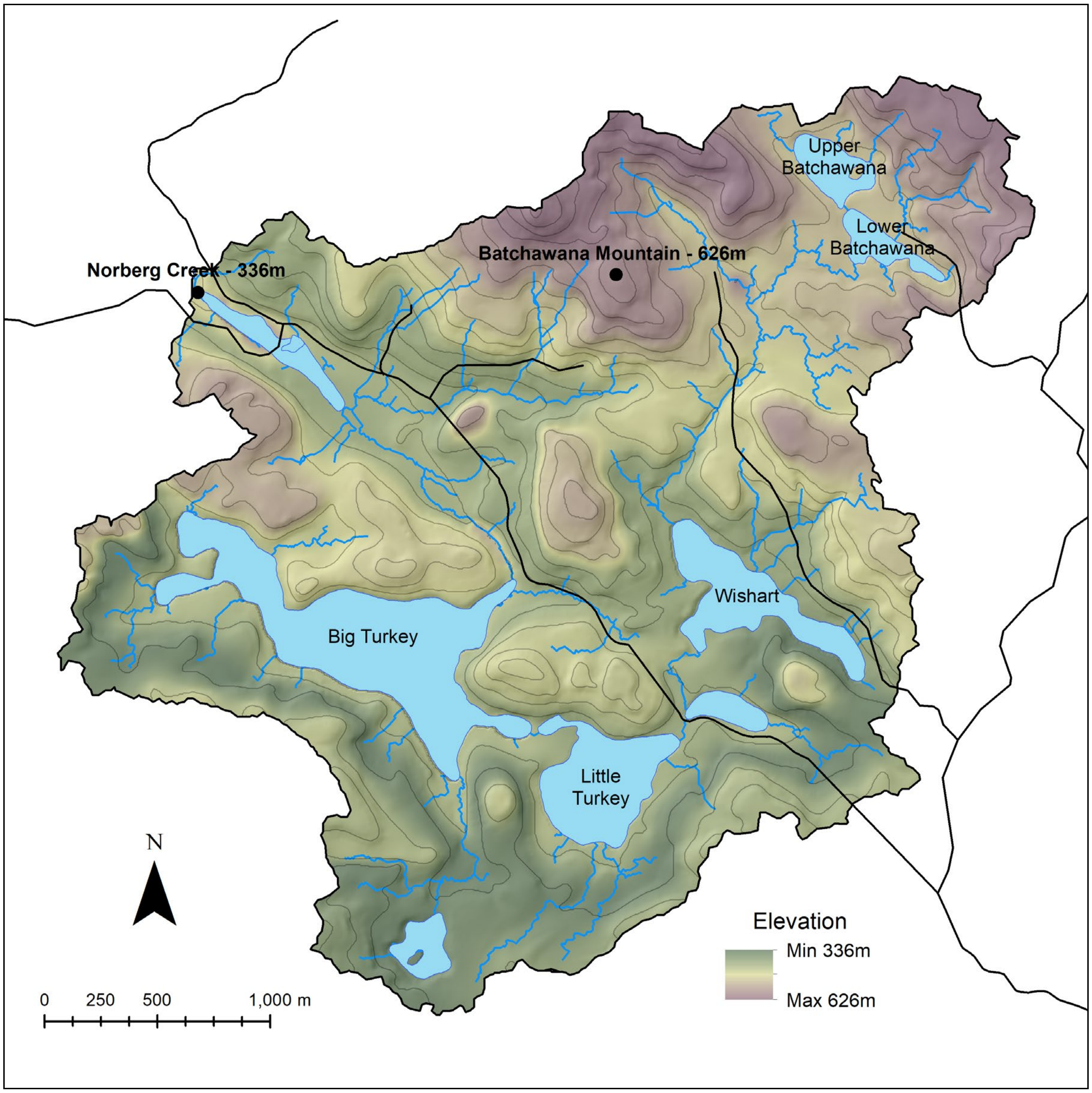


Figure 2. Topographic map of TLW, with highest point at Batchawana Mountain (626 m) and the watershed outflow at Norbert Creek (336 m).

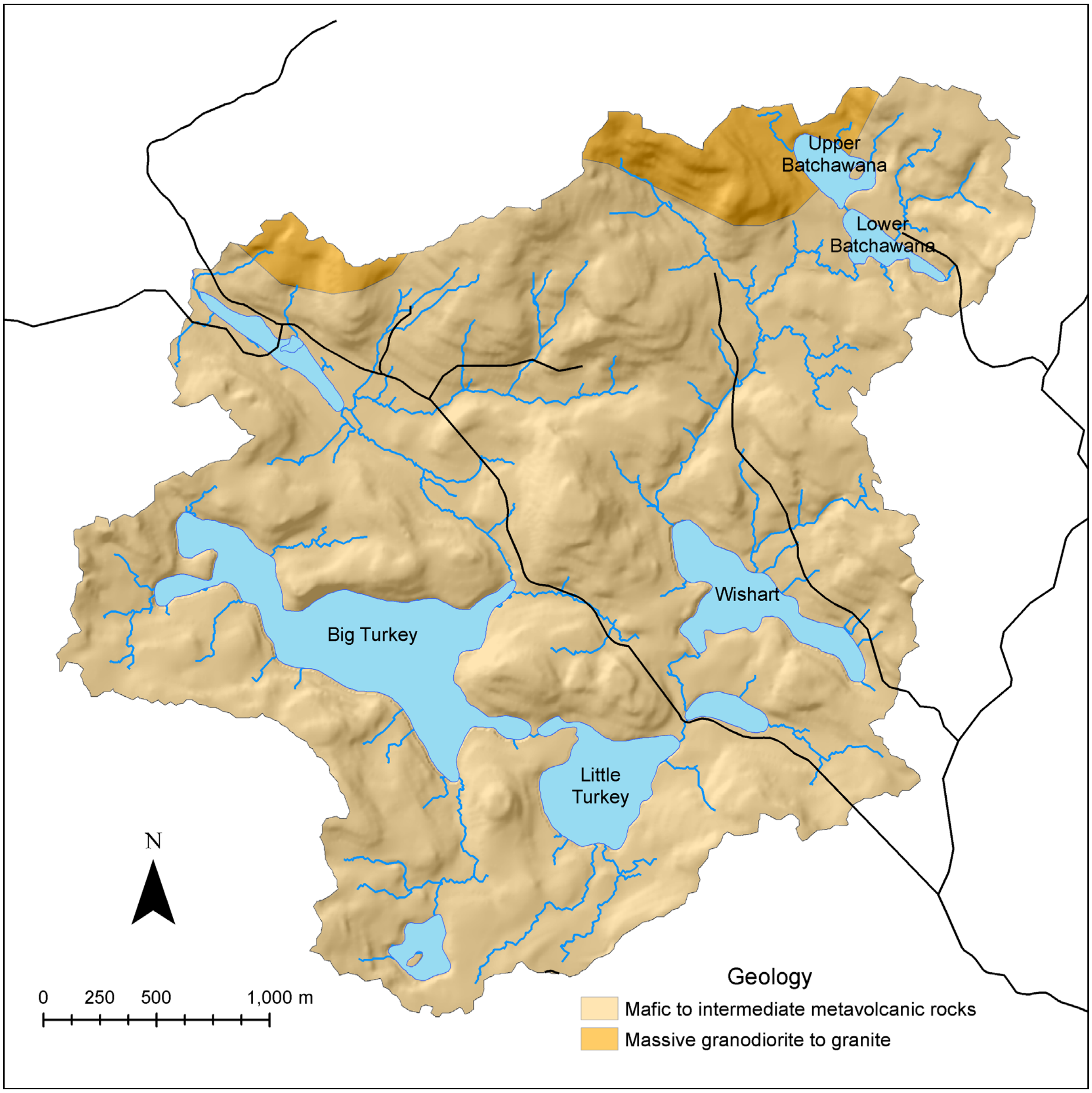


Figure 3. Geology of the Turkey Lakes Watershed.

Soils have developed in a stony, silty-loam ablation till that overlies bedrock or sandy, compacted basal till at about 0.5 m depth. TLW soils are predominantly podzolic with well-developed organic horizons (LFH layers) and accumulation of organic matter (10%), iron and aluminum in the B horizon. The pH of the mineral soil is 4.0 at the surface, increasing to 5.5 at depth.

The high relief and leeward position relative to Lake Superior influences the quantity of precipitation at the site. The mean annual precipitation for the period 1980 to 2017 was 1203 mm (unpublished data). Approximately a third of the precipitation falls as snow (Semkin et al. 2012), with snow cover developing typically in late October – November and melting during the March – April period. Average annual temperature over the 1980 to 2017 period was 4.5 °C (unpublished data). The TLW is showing evidence of climate change. While there have not been substantive changes in average annual precipitation, there have been other indicators of change. These include (Buttle et al. 2018; Hazlett, unpublished data): increasing annual air temperatures (0.3 ° C per decade, primarily driven by higher autumn temperatures), increasing potential evapotranspiration (PET), increasing growing degree days, lengthening of the growing season, more ice-free days on lakes (driven by later initial ice formation), and less precipitation falling as snow (e.g., in December).

ATMOSPHERIC/METEOROLOGY






Atmospheric/Meteorology publications are primarily papers reporting atmospheric deposition rates. Much of the research in this category was conducted by Environment and Climate Change Canada (ECCC). The ECCC Algoma CAPMoN (Canadian Air and Precipitation Monitoring Network) site

(47°02’01.2”N, 84°22’44.3”W), located about 600 m outside the watershed boundary, and has measured atmospheric chemistry at the site since 1980. Constituents monitored include wet deposition (rain or snow) of major ions, (inferential) dry deposition and concentrations of acid-forming gases and particles. A meteorological station at the CAPMON site measures air temperature, wind speed and direction, relative humidity and vapour pressure, barometric pressure and solar radiation. Natural Resources Canada – Canadian Forest Service staff from the Great Lakes Forestry Centre have collected precipitation volume and measured precipitation chemistry from two sites within TLW since 1980 (Figure 4).

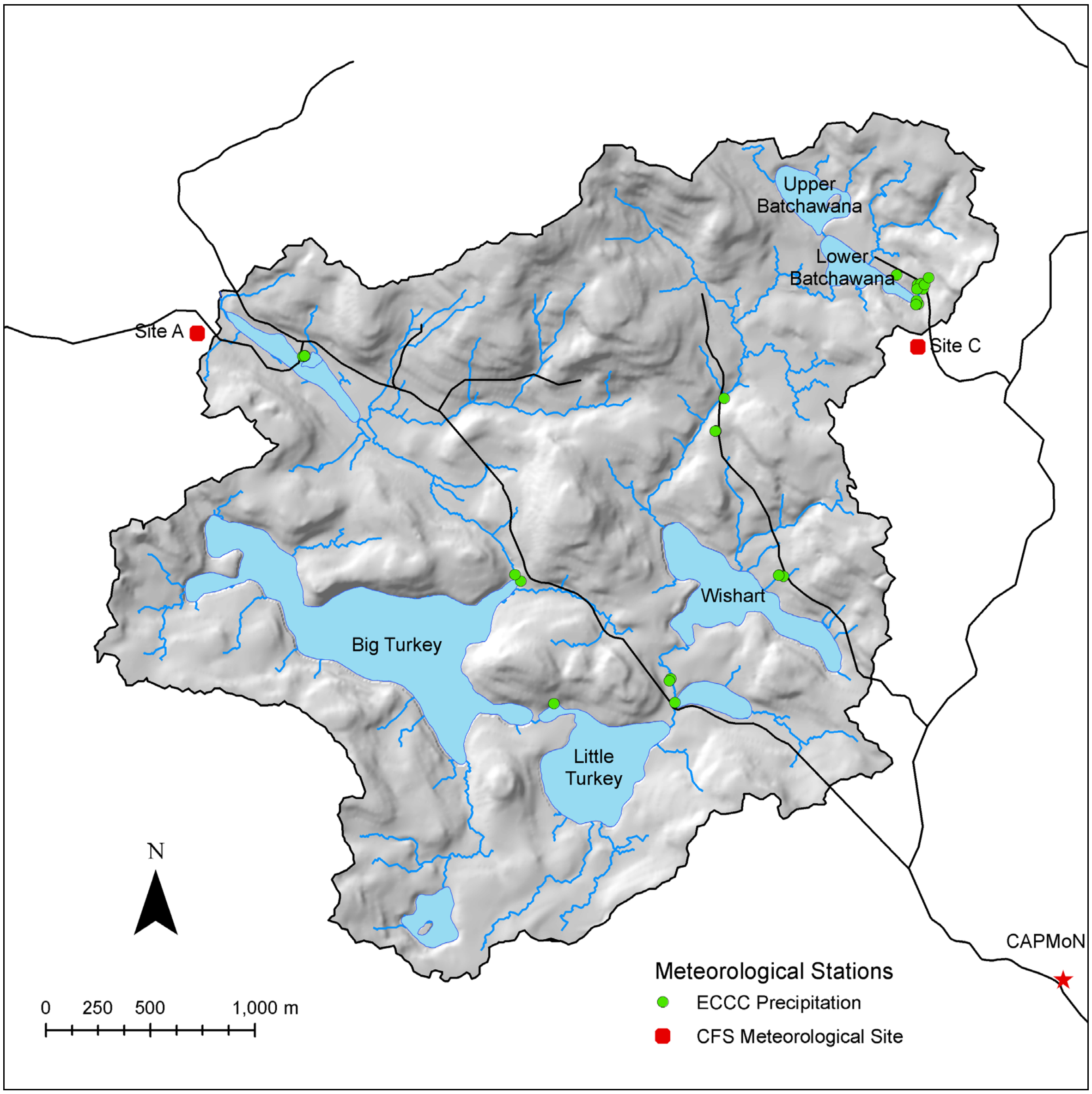


Figure 4. Meteorological station locations at the TLW.

PUBLICATIONS

1997 Canadian Acid Rain Assessment Volume 2: Atmospheric Science Assessment Report. 1997. Department of Environment, 260p (+4 Appendices). (97-02).

An assessment of the adequacy of the scientific information needed to establish current and future source-receptor relationships and to determine whether further control of acid gas emissions (beyond those required by the Canada/US Air Quality Agreement) is needed to reduce acidic deposition to acceptable levels. This is the first national assessment since 1990 (cf. 90-05). Data from the TLW CAPMoN site was extensively used and commonly referenced as "Algoma" in the report.

Barrie, L.A., H.A. Wiebe, K. Anlauf and P. Fellin. 1982. Data Report: Results of the Canadian Air and Precipitation Monitoring Network APN - July 1980 to December 1981. Atmos. Environ. Serv. Rep., AQRB-82-009-T, 7 pp (+ 7 Appendices). (82-13).

Report summarizes daily air concentration and wet-only precipitation data collected in TLW (called "Algoma" in the report). Data is segregated by month and a statistical summary is provided for each month.

Barrie, L.A. and A. Sirois. 1986. Wet and dry deposition of sulphates and nitrates in eastern Canada: 1979-1982. Wat. Air Soil Pollut. 30: 303-310. (86-19).

Relative quantities of the wet and dry components of SO_4 and NO_3 deposition are assessed at six eastern Canadian locations including the TLW. Dry deposition is approximately 20% of total. Seasonal variations and episodicity are discussed.

Buehler, S.S. and R.A. Hites. 2002. The Great Lakes Integrated Atmospheric Deposition Network. Environ. Sci. Technol. 36, 354A - 359A. (02-05).

A joint USA/Canada network to measure atmospheric concentrations of toxic substances near the Great Lakes was established in 1990. The International Atmospheric Deposition Network consists of monitoring stations on each of the Great Lakes, the TLW representing Lake Superior. A long-term data set measuring temporal and spatial trends of toxic organics in precipitation and in the atmosphere as well as PCB and PAH loadings, provide a valuable resource for government and university researchers attempting to pinpoint possible sources of pollutants entering the Great Lakes.

Burniston, D.A., W.J.M. Strachan, J.T. Hoff and F. Wania. 2007. Changes in surface area and concentrations of semivolatile organic contaminants in aging snow. Environ. Sci. Technol. 41, 4932-4937. (07-02).

Five snowpacks at the TLW were sampled during the winter of 1999/2000 to measure specific snow surface area and concentrations of organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs). Fresh snow was compared with aged snow samples, which lost half the initial surface area during aging. OCPs and PCBs were lost at the same rate except when snow aged at a colder temperature. The contaminants concentrations increased in snowpacks aged during rising temperatures. While surface area decreases clearly contribute to the loss of semivolatile organic compounds from metamorphosing snowpacks, other confounding factors play a role in determining concentration changes, in particular in wet snow.

Chan, C.-H., D.J. Williams, M.A. Neilson, B. Harrison and M.L. Archer. 2003. Spatial and temporal trends in the concentrations of selected organochlorine pesticides (OCs) and polynuclear aromatic hydrocarbons (PAHs) in Great Lakes Basin precipitation, 1986 to 1999. J. Great Lakes Res., 29, 448-459 (03-10).

Organochlorine pesticides and polynuclear aromatic hydrocarbons from nine precipitation stations in the Great Lakes Basin, including the TLW. Summary concentration statistics were reported for 1995-1999. Variation of the volume-weighted means ranged between 9 and 90%. Both north-south and within-lake basin differences in spatial concentration distribution were observed. HCHs have declined in the past 10 years while OCs showed seasonal concentration patterns.

Environment Canada, Meteorological Service of Canada. 2005. 2004 Canadian Acid Deposition Science Assessment, H.A. Morrison (ed.) 12 Chapt., 437 p. (05-14).

The TLW is one of the major sources of scientific data contributing to the assessment of acid deposition in Canada - the effect of emissions reductions in Canada and the US, status of soils, lakes and rivers, and estimation of critical loads. This 12-chapter Canada-wide study undertaken in 2004 offers a summary of key results as well as a review of the effects of acid deposition across Canada.

Federal/Provincial Research and Monitoring Coordinating Committee. 1990. The 1990 Canadian long-range transport of air pollutants and acid deposition assessment report, Part 3: Atmospheric Sciences, 362 pp. (90-05).

A major assessment report. Acid rain has been monitored across Canada at many stations, including TLW, from 1980. Various mathematical models have also been developed over this period. Seasonal trends are documented.

Foster, N.W. 1989. Acidic deposition: what is fact, what is speculation, what is needed? Wat. Air Soil Pollut. 48: 299-306. (89-03).

Findings from literature and the symposium indicate that air pollutants in Europe and N. America are implicated in forest damage. Mechanisms are discussed. Interactions of air pollutants and natural stresses need examining.

Foster, N.W., I.K. Morrison and J.A. Nicolson. 1983. Acid precipitation - forest ecosystem studies at the Turkey Lakes Watershed. For. Res. Newsl., GLFRC, 8 pp, Summer 1983. (83-24).

Report summarizes the rationale behind the Great Lakes Forestry Centre's studies in the TLW, describes the field measurements and operations in progress, and presents preliminary conclusions based on data from the first 1-2 years of sampling. Data on the composition of precipitation, throughfall, soil percolates, and stream waters are given as well as preliminary terrestrial basin input-output budgets.

Foster, N.W., J.A. Nicolson and I.K. Morrison. 1983. Acid deposition and element cycling in eastern North America forests. Proc. Conf. on Acid Rain and For. Resourc., Quebec City. (see 91-07) (83-13).

Report presents a review of the current knowledge of the relationship between atmospheric deposition of acids and element fluxes in major eastern North American forests. Nitrogen and sulphur are emphasized and the TLW forest is used as a point of reference. Information from several other locations is also presented.

Jeffries, D.S. 1995. Freshwater acidification in Canada caused by atmospheric deposition of nitrogen pollutants: a preliminary assessment of existing information. NWRI Contribution No. 95-116, 68p. (95-02).

This report attempts to determine whether sufficient data exists to form a policy for control of NO_x *emissions. A table is presented showing percent of low, moderate and high concentrations of* NO_3 *across Canada in data segregated to reflect the seasonal concentration cycle normally observed for* NO_3*. Recommendations are made as to future work needed to calculate critical loads and fill in gaps in current knowledge.*

Joshi, S.R. 1987. Early Canadian results in the long-range transport of Chernobyl radioactivity. Sci. Total Environ. 63: 125-137. (87-02).

The occurrence of Chernobyl-derived radionuclides in TLW precipitation is documented. Use of the radionuclides for delineating tropospheric transport processes is also discussed.

Joshi, S.R. 1988. The fallout of Chernobyl radioactivity in Central Ontario, Canada. J. Environ. Radioactivity 6: 203-211. (88-01).

Levels of Chernobyl-derived radionuclides in TLW bulk deposition samples are evaluated. The tropospheric residence time of the radionuclides was estimated to be approximately 14 days.

Lam, D.C.L., K.J. Puckett, I. Wong, M.D. Moran, G. Fenech, D.S. Jeffries, M.P. Olson, D.M. Whelpdale, D.K. McNicol, Y.K.G. Mariam and C.K. Minns. 1998. An integrated acid rain assessment model for Canada: from source emission to ecological impact. Water Quality Research Journal of Canada 33(1), 1-17. (98-10).

This paper describes a new approach to integrated assessment modelling by providing an open architecture framework for linking models together in a decision support system, and to provide advice on Canada's post-2000 emission control strategies for acid rain issues.

Monteith, D.T., J.L. Stoddard, C.D. Evans, H.A. de Wit, M. Forsius, T. Høgåsen, A. Wilander, B.L. Skjelkvåle, D.S. Jeffries, J. Vuorenmaa, B. Keller, J. Kopácek and J. Vesely. 2007. Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry. Nature 450, 537-540 + Appendix. (07-04).

The TLW is among 522 lakes and streams in North America and Northern Europe for which modelled time series data explains rising dissolved organic carbon (DOC) levels in terms of changes in deposition chemistry and acid sensitivity of catchments. DOC concentrations have increased in proportion to decreases in anthropogenic sulphur and sea-salt deposition. Changes in organic acidity have buffered acid deposition and the rise in DOC is linked to recovery from acidification. Increased export of DOC to the oceans may be a result of increasing solubility of organic matter.

Morrison, I.K., N.W. Foster and J.A. Nicolson. 1980. Impact of long-range transport of air pollutants on forest ecosystems. For. Res. Newsl., GLFRC, 3 pp, Spring 1980. (82-09).

Gives background information on acidic precipitation, potential effects on forests in general and to the forest type in the TLW in particular, and other physical characteristics of the TLW basin.

Nriagu, J.O., D.A. Holdway and R.D. Coker. 1987. Biogenic sulfur and the acidity of rainfall in remote areas of Canada. Science 237: 1189-1192. (87-01).

The isotopic composition of SO_4 *in bulk precipitation at the TLW was used to infer that up to 30% of the acidifying sulphur burden in remote areas of Canada might originate from biogenic sources. The importance of biological re-emission of previously deposited S is discussed.*

Scott, B.F., C. Spencer, D.C.G. Muir, J. Martin, R. Barra, H. Bootsma, K. Jones and A.E. Johnson. 2001. Comparison of environmental levels of HAAS in the southern and northern hemispheres. NWRI Contribution 01-008, 11p. (01-01).

Soils, precipitation and conifer needles were analyzed from Chile, Canada, Malawi, and the U.K. to assess global concentrations of haloacteic acids (HAA). Precipitation from the TLW (Algoma CAPMoN samples) and two other more remote CAPMoN stations were included in the study. The TLW samples tended to have the highest HAA values, particularly trichloroacetic acid which ranged from 160 to 2400 ng/l. Overall results indicate higher HAAs in the northern hemisphere, but significant concentrations in the southern hemisphere as well.

Scott, B.F., C. Spencer, J.W. Martin, R. Barra, H.A. Bootsma, K.C. Jones, A.E. Johnston and D.C.G. Muir. 2005. Comparison of haloacetic acids in the environment of the northern and southern hemispheres. Environ. Sci. Technol. 39, 8664-8670. (05-08).

A study to examine the global distribution of haloacetic acids (HAA) included precipitation samples from the TLW (Algoma) along with some from Malawi, Chile and the U.K. The Canadian samples were highest in HAA and Malawi samples were the lowest. Overall results of the study indicated that concentrations of HAAs while greatest in the northern hemisphere are also significant in the less industrialized southern hemisphere.

Scott, B.F., D. Mactavish, C. Spencer, W.J. Strachan and D.C.G. Muir. 2000. Haloacetic acids in Canadian lake waters and precipitation. Environ. Sci. Technol., 34, 4266-4272. (00-10).

Haloacetic acids (HAAs) in surface waters and precipitation were measured across Canada, including precipitation from the TLW (Algoma) monitoring site. Daily precipitation levels varied from <10 to 2400 ng/l HAA depending on source trajectories, urban centers being major contributors of trifluoroacetic acid and the chloroacetic acids. Atmospheric transport and deposition distributes the contaminants to Canadian ecosystems.

Semkin, R.G., D.S. Jeffries, R. Neureuther, G. Lahaie, M. McAulay, F. Norouzian and J. Franklyn. 2012. Summary of hydrological and meteorological measurements in the Turkey Lakes Watershed, Algoma, Ontario, 1980-2010. Water Science and Technology Directorate Contribution No. 11-145. Environment Canada, National Water Research Institute, Burlington, ON, 85 p. (12-08).

This report represents an update of the hydrometeorological summary report for the 1980-1999 period in support of ongoing research into the effects of atmospheric deposition (particularly acidic precipitation) on aquatic and terrestrial ecosystems in TLW. Results are presented for: precipitation quantity and hydrology at six gauging stations; 24-hour mean air temperature; wind speed and direction; relative humidity and vapour pressure; barometric pressure; solar radiation; basin-wide surveys of snow water equivalent during the periods of accumulation and ablation; and the impact of the El Niňo/La Niňa Southern Oscillation on precipitation and hydrology in the watershed and on long-wave solar radiation.

Semkin, R.G., D.S. Jeffries, R. Neureuther, G. Lahaie, F. Norouzian and J. Franklyn. 2001. Summary of hydrological and meteorological measurements in the Turkey Lakes Watershed, Algoma, Ontario, 1980-1999. National Water Research Institute Contribution No. 01-192, 42p. (01-03).

Hydrological and meteorological measurements made at the TLW since 1980 are summarized, including mean daily air temperature, wind speed and direction, relative humidity, barometric pressure and solar radiation. Precipitation quantity and gauged streamflow, along with basin-wide surveys of snow water equivalent are also provided.

Semkin, R.G. and D.S. Jeffries. 1986. Bulk deposition of ions in the Turkey Lakes Watershed. Wat. Pollut. Res. J. Can. 21(4): 474-485. (86-06).

The composition and deposition of major ions in the TLW is evaluated using weekly bulk precipitation samples. Seasonal variations in concentrations are discussed and overall deposition compared to other locations.

Sirois, A, R. Vet and D. MacTavish. 2001. Atmospheric deposition to the Turkey Lakes Watershed: temporal variations and characteristics. Ecosystems 4, 503-513. (00-09).

This paper investigates atmospheric concentrations and deposition fluxes of major ions to the TLW between 1980 and 1996. Precipitation acidity did not decline, probably as a result of a base cation decline. In keeping with the lower SO_2 emissions in North America during this period, the 17-year mean annual total has declined by 35%, while the annual total deposition of oxidized nitrogen shows a net increase of 10% since the 1980s. This reflects a 10% increase in emissions. Wet deposition accounted for two-thirds of total atmospheric deposition of S and N, and dry deposition of oxidized N was 95% dominated by gaseous HNO_3 deposition, as opposed to particulate NO_3. Total deposition of S and N was high during the measurement period.

Sirois, A. 1993. Temporal variation of sulphate and nitrate concentration in precipitation in eastern North America: 1979-1990. Atmospheric Environment 27A, 945-963. (93-07).

Precipitation chemistry data from 24 sites in both the US and Canada including the TLW CAPMoN site (Algoma) were modelled to investigate temporal variations. Two techniques, kernel smoothing regression and least-squares regression were used and gave similar results. It was seen that long-term trends were monotonic at only two sites. All sites showed statistically significant long-term trends for SO_4, (decreasing at TLW), but only 13 had significant trends for NO_3. (TLW NO_3 showed no trend). Complicated seasonal cycles at most sites dictate that long-term trend models need to be more complex than those used previously, and should be done in two stages, using first a smoothing technique and then a test for statistical significance (See 97-07 for similar analysis of 1979-1994 air concentrations).

Sirois, A. 1997. Temporal variation of oxides of sulphur and nitrogen in ambient air in eastern Canada: 1979-1994. Tellus, 49B, 270-291. (97-07).

A model to predict long-term trends and cycles was fitted to daily concentrations of six particulate and gaseous sulphur and nitrogen compounds using data from 8 CAPMoN sites, including the TLW (called Algoma in the paper). The analysis showed that long-term trends are neither linear nor monotonic. At TLW the statistically significant long-term trend explained between 0.8% (particulate SO_4) and 3.3% (HNO_3) of the total variance. Seasonal cycles were observed for all variables explaining between 0.9% (HNO_3) and 13.3% (SO_2) of the total variance. Auto-correlation is also an important component of the variance. SO_2 concentration declined throughout the time period although more steeply during the 1980s. Particulate NO_3 and SO_4 decreased during the first part of the record and then increased (See also 93-07).

Sirois, A. and L.A. Barrie. 1988. An estimate of the importance of dry deposition as a pathway from the atmosphere to the biosphere in eastern Canada. Tellus 40B: 59-80. (88-04).

Dry deposition of SO_4 and NO_3 over eastern Canada was estimated using data for six stations including the TLW. The relative importance of wet vs dry deposition is reported and the error evaluated. The episodic nature of both wet and dry components is also discussed.

Sirois, A. and R.J. Vet. 1988. Detailed analysis of sulphate and nitrate atmospheric deposition estimates at the Turkey Lakes Watershed. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 14-25. (88-09).

Wet, dry, and total SO_4 and NO_3 deposition to the TLW was estimated using daily measured precipitation and air concentrations. Total deposition (1980-1984) was 34-38 mmol/m^2/yr SO_4 and 38-47 mmol/m^2/yr NO_3. Dry deposition constitutes 14-25% of total. Deposition is highly episodic; 20% of daily events provides 60-70% of total deposition. Season cycles are also discussed.

Sirois, A. and W. Fricke. 1992. Regionally representative daily air concentrations of acid related substances in Canada; 1983-1987. Atmos. Environ. 26a (4): 593-607. (92-15).

Paper presents analyses of observed concentrations of particulate SO_4, NO_3, and NH, and gaseous SO_2 and HNO_3 at 9 sites across Canada, including TLW. The survey conducted by AES, shows highest concentrations at Longwoods in southern Ontario, and lowest in Newfoundland and Saskatchewan. SO_2 is highest in winter and lowest in summer. Gaseous SO_2 exceeds particulate SO_4 except during summer months with one exception, and gaseous HNO_3 is higher than particulate NO_3 except for autumn to spring at 3 sites. SO_4: NH and NO_3: NH molar ratios are given, and total SO_4 concentrations in molar units were observed to be between 2 and 20 times larger than total NO_3 concentrations.

Spoelstra, J., S.L. Schiff, D.S. Jeffries and R.G. Semkin. 2004. Effect of storage on the isotopic composition of nitrate in bulk precipitation. Environ. Sci. Technol. 38, 4723-4727. (04-03).

Nitrate isotopic ratios in precipitation samples from the TLW were used to detect changes in nitrate concentrations during storage. No production or assimilation of nitrate occurred, demonstrating that bulk collectors can be used to accumulate large volumes over an extended time period with no change in nitrate concentration.

Summers, P.W. 1995. Time trend of wet deposition acidifying potential at five ecological monitoring sites in eastern Canada. Water, Air, and Soil Pollution 85: 653-658. (95-18).

Using daily measurements from five CAPMoN monitoring sites in eastern Canada, data for AP (the acidifying potential of wet deposition), SO_4 and base cations were examined for trends during the period 1981 - 1993. At all sites the trend was downward for these parameters. At the TLW (called Algoma) and Dorset sites, the trend was highly significant. Predictions about ecosystem response to SO_2 emissions must take into account changes in base cation concentrations.

Summers, P.W., V.C. Bowersox and G.J. Stensland. 1986. The geographical distribution and temporal variations of acidic deposition in eastern North America. Wat. Air Soil Pollut. 31: 523-536. (86-18).

The deposition of major ions across eastern N. America is presented using data from several sources including the TLW (i.e. CAPMoN Algoma site). Variability, seasonal cycling, deposition episodicity, and relative contributions from wet and dry components are all discussed.

Ueno, D., C. Darling, M. Alaee, G. Pacepavicius, C. Teixeira, L. Campbell, R.J. Letcher, A. Bergman and G. Marsh. 2008. Hydroxylated Polybrominated Diphenyl Ethers (OH-PBDEs) in the abiotic environment: surface water and precipitation from Ontario, Canada. Environ. Sci. Technol. 42, 1657-1664. (08-01).

The TLW was the "northern remote site" in Ontario that was sampled for hydroxylated polybrominated diphenyl ethers in rain and snow during 2002-2004. OH-PBDEs have been used in flame retardants, polyurethane foams and fabric backing, and when entering the environment during use and disposal, may affect human health. Concentrations measured at the TLW were lower than in more southerly industrialized areas, but the study concludes that OH-PBDEs are ubiquitous in the abiotic environment.

Vet, R.J., A. Sirois, D.S. Jeffries, R.G. Semkin, N.W. Foster, P. Hazlett and C.H. Chan. 1988. A comparison of bulk, wet-only and wet-plus-dry deposition measurements at the Turkey Lakes Watershed. Can. J. Fish. Aquat. Sci. 45 (Suppl 1): 26-37. (88-10).

Report compares annual and seasonal deposition estimates determined from four different measurement methods, namely weekly and variable period bulk deposition, and daily and monthly wet-only deposition plus daily air concentration measurements. Expected and unexpected differences are discussed.

Vet, R.J., W.B. Sukloff, M.E. Still, C.S. McNair, J.B. Martin, W.F. Kobelka and A.J. Gaudenzi. 1989. Canadian Air and Precipitation Monitoring Network (CAPMoN) Precipitation Chemistry Data Summary 1987. Atmos. Environ. Serv. Rep. ARD-89-1, 451p. (89-08).

Report summarizes daily wet-only precipitation data for 1987 for stations in CAPMoN. TLW data are found in Appendix 3 (Algoma).

Vet, R.J., W.B. Sukloff, M.E. Still, J.B. Martin, W.F. Kobelka and A.J. Gaudenzi. 1988. Canadian Air and Precipitation Monitoring Network (CAPMoN) Precipitation Chemistry Data Summary 1986. Atmos. Environ. Serv. Rep. AQRB-88-02, 468 p. (88-31).

Report summarizes daily sample information and wet only precipitation concentrations for all stations in CAPMoN for 1986. TLW data are found under "Algoma".

Vet, R.J., W.B. Sukloff, M.E. Still, J.B. Martin, W.R. Kobelka, and A. Gaudenzi. 1988. Canadian Air and Precipitation Monitoring Network (CAPMoN) Precipitation Chemistry Data Summary 1985. Atmos. Environ. Serv. Rep. AQRB-88-01, 482 p. (88-30).

Report summarizes daily sample information and wet only precipitation concentrations for all stations in CAPMoN for 1985. TLW data are found under "Algoma".

Vet. R.J., W.B. Sukloff, M.E. Still, and R. Gilbert. 1986. Canadian Air and Precipitation Monitoring Network (CAPMoN) Precipitation Chemistry Data Summary 1983-1984. Atmos. Environ. Serv. Rep AQRB-86-001-M, 544 p. (86-23).

Report summarizes daily wet-only precipitation data for stations in CAPMoN. TLW data are found in Appendix 3 for 1984.

Wadleigh, M.A., H.P. Schwarcz and J.R. Kramer. 2001. Areal distribution of sulphur and oxygen isotopes in sulphate of rain over eastern North America. J. Geophys. Res. 106, No. D18, 20, 883 – 20, 895. (01-02).

Three rain events were simultaneously sampled during the summer of 1986 from the Mississippi River to the Atlantic coast, and from the Gulf of Mexico to subarctic Canada in order to measure sulphur and oxygen isotope distribution and to assess anthropogenic input. The TLW (Algoma) monitoring site was one of the collection sites. Sulphur isotope ratios were quite homogeneous averaging +3.41 + 0.95 per mil. The combination of sulphur and oxygen isotopes provided information on long range transport and oxidation mechanisms.

Wiebe, H.A., R.J. Vet, L.A. Barrie and K. Anlauf. 1985. Canadian Air and Precipitation Monitoring Network (APN) Final Data Report December 1982-1983. Atmos. Environ. Serv. Rep. ARQB-85-008-T, 7 pp (+ 8 Appendices). (85-14).

Report summarizes daily air concentrations and wet-only precipitation data for stations in the APN for the period December 1982-December 1983. TLW data are found in Appendix 2 (labelled "Algoma").

Zhang, L. A. Wiebe, R.Vet, C. Mihele, J.M. O'Brien, S. Iqbal and Z. Liang. 2008. Measurements of reactive oxidized nitrogen at eight Canadian rural sites. Atmos. Environ. 42: 8065-8078. (08-02).

The TLW was one of eight rural sites sampled between 2001 and 2005 to study partitioning of tropospheric reactive oxidized nitrogen (NO_y) across eastern Canada. Differences in budgets and partitioning of the eight chemical species comprising NO_y were observed between populated and remote (Algoma) areas. On average, NO_x contributed 50-80% to total NO_y during cold seasons and 30-60% during warm and hot seasons.

Zhang, L., J.R. Brook, R. Vet, A. Wiebe, C. Mihele, M. Shaw, J.M. O'Brien and S. Iqbal. 2005. Estimation of contributions of NO_2 and PAN to total atmospheric deposition of oxidized nitrogen across eastern Canada. Atmospheric Environment 39, 7030-7043. (05-09).

The TLW (Algoma) was one of 7 rural Canadian sites where total N dry deposition flux has been estimated for one year using measured and modelled parameters, including NO_2 and peroxyacetyl nitrate (PAN). HNO_3 contributes 47-68% of the total, while NO_2 is estimated to contribute 12-36% of the total. When the NO_2 modelled concentration is adjusted to account for a bias that makes the value too low, the NO_2 contribution can be higher than 50%, i.e., it may be more significant than HNO_3 in some areas. The omission of NO_2 and PAN in dry deposition and total N deposition calculations will have led to substantially underestimated values in the past.

Zhang, L., R. Vet, J.M. O'Brien, C. Mihele, Z. Liang and A. Wiebe. 2009. Dry deposition of individual nitrogen species at eight Canadian rural sites. J. Geophys. Res. 114, D02301, 13p. (09-01).

The TLW was one of eight rural sites sampled between 2001 and 2005 to study the relative contribution of nitrogen species to total dry and dry + wet nitrogen deposition. Air concentrations for oxidized nitrogen (NO_y) and major species comprising NO_y, and the two reduced species (NH_3, pNH_{4+}) were monitored for this period. It was found that the contribution of non-routinely measured nitrogen species is significant and contributes up to 50% of total nitrogen dry deposition. Current estimates of atmospheric nitrogen deposition can be improved by adding measurements for NO_2 and NH_3 to the air quality models.

Zhu, R., A.H. El-Shaarawi, X. Duan, Z. Wang and R. Ma. 2016. Assessing annual trends, monthly fluctuations and between-station relationship of sulphate deposition in the Turkey Lakes Watershed. Environmetrics 27 (5): 256-266. (16-09).

Air and water quality was assessed by studying sulphate deposition change over time from multiple monitoring stations in the TLW. Temporally correlated multivariate random effects were incorporated into a Gamma regression model to account for the temporal dependence within and between-station dependence in space. This approach was used to analyse monthly average sulphate depositions between 1983 and 2003. Results showed that annual trends in sulphate deposition had stabilized between 1994 and 2003, and sulphate deposition increased from upstream to downstream with monthly fluctuations higher in winter to lower in summer.

DATA AVAILABILITY

TLW data are available primarily from federal agencies of NRCAN-CFS, ECCC (Atmospheric Science and Technology Directorate [ASTD] and Water Science and Technology Directorate [WSTD] and Fisheries and Oceans Canada (DFO). Other datasets from university partners must be requested through specific researchers. Table 1 provides an overview of some of the key datasets and contact/URL for the data. Some are available through a public repository that does not issue DOIs, other data is available on request from the authors through collaborative projects.

TABLE 1: Description of data sets from Turkey Lakes Watershed, including agency responsible and contacts and/or links to data. Agency acronyms are Natural Resources Canada, Canadian Forest Service (NRCAN-CFS), Environment and Climate Change Canada (ECCC) Atmospheric Science and Technology Directorate (ECCC-ASTD) and Water Science and Technology Directorate (ECCC-WSTD), and Fisheries and Oceans Canada (DFO).

Data	Agency responsible	Description	Contact/Link
Air			
Atmospheric deposition	ECCC-ASTD	Concentration of major ions and nutrients in wet-only precipitation and air concentrations of various acidifying gases and particulates. Samples are collected at Algoma CAPMoN (side ID: CAPMCAON1ALG) station located just outside the watershed. Daily to weekly from 1980.	http://data.ec.gc.ca/data/air/monitor/monitoring-of-atmospheric-precipitation-chemistry/major-ions/
Bulk deposition	ECCC-WSTD NRCAN-CFS	Concentrations of major ions, nutrients and some metals in atmospheric bulk deposition. Co-located on Algoma CAPMoN platform located just outside the watershed. Daily to monthly from 1980.	Data available through collaborative projects. Contact Daniel.Houle2@nrcan-rncan.gc.ca.
Meteorology measurements (at CAPMoN site)	ECCC-WSTD NRCAN-CFS	Air temperature, wind speed and direction, relative humidity and vapour pressure, barometric pressure and solar radiation. Co-located on Algoma CAPMoN platform located just outside the watershed. Daily from 1980.	Data available through collaborative projects. Contact Stephanie.Nelson@nrcan-rncan.gc.ca.
Daily precipitation volumes and chemistry (at satellite sites within watershed)	NRCAN-CFS	Precipitation volume and measured chemistry from two sites within TLW (Headwater and Meadow locations). Weekly to biweekly 1980-present.	Data available through collaborative projects. Contact Stephanie.Nelson@nrcan-rncan.gc.ca.
S**nowpack chemistry and water equivalent**	ECCC-WSTD	Snowpack has been sampled during both the accumulation and ablation stages at up to 13 sites. Snow depth and a physical description of the snowpack recorded at each station as well as snow density, water equivalent and chemistry (pH, major ions, and nutrients). Monthly for winters 1980/81-2016/17.	https://open.canada.ca/data/en/dataset/beda0dbe-bcd7-49d3-9473-212e550dfbc6
Water			
Throughfall	NRCAN-CFS	Bulk throughfall volume and concentration of major ions, nutrients and some metals in throughfall samples collected during the leaf-on period at one site. Monthly 1980-present.	Data is available through collaborative projects. Contact Stephanie.Nelson@nrcan-rncan.gc.ca.
Forest floor percolate	NRCAN-CFS	Forest floor percolate volume and concentrations of major ions, nutrients and some metals in samples collected with zero-tension lysimeters below the F horizon at two slope positions (crest and middle slope) at one site. Monthly/more frequently during snowmelt.	Data is available through collaborative projects. Contact Stephanie.Nelson@nrcan-rncan.gc.ca.

Data	Agency responsible	Description	Contact/Link
Aquatic biodiversity			
Stream macroinvertebrates	NRCAN-CFS	Aquatic macroinvertebrates were collected by modified Surber samplers in early October from 1995 to 2009 (pre- and post-harvest experiment) from streams draining the selection (C34) and shelter cut (C33) watersheds, as well as from C42 as a reference stream. In addition, invertebrate collection and decomposition rates were intermittently collected by standardized leaf packs between 2000 and 2009.	Data is available through collaborative projects. Contact Stephanie.Nelson@nrcan-rncan.gc.ca.
Lake zooplankton, phytoplankton and chlorophyll-a	DFO	Zooplankton data includes date, gear type, depth of sample, counts, and the density and diversity (Number/L) of zooplankton in each lake. Data collection years range from 1980-95 and 1998-2000. Phytoplankton data includes species counts and number of cells per milliliter of lake water for each lake in 1980. Chlorophyll-a data includes sample volume information, analytical data and concentration of chlorophyll-a (mg/m^3) in the epilimnion of the lakes. Data collection years range from 1983-85, 1987-88, 1991-95, and 1998-2000.	Data is available through collaborative projects. Contact Karen.Smokorowski@dfo-mpo.gc.ca.
Fish	DFO	Includes date, gear type, species, length-weight, age, clip, and tag information for each lake. This information is subsequently used for catch-per-unit-effort, abundance, as well as biomass and production calculations. Data collection years range from 1980, 1985-96 and 1998-2003, 2005, 2008. Fish species include Brook Trout (*Salvelinus fontinalis*), White Sucker (*Catostomus commersoni*), Lake Trout (*S. namaycush*), Burbot (*Lota lota*), Northern Redbelly Dace (*Phoxinus eos*), Lake Chub (*Couesius plumbeus)*, Spottail Shiner (*Notropis hudsonius)*, Golden Shiner (*Notemigonus crysoleucas)*, Emerald Shiner (*N. atherinoides)*, Finescale Dace (*Chrosomus neogaeus)*, Fathead Minnow (*Pimephales promelas)*, and logperch (*Percina caprodes*).	Data is available through collaborative projects. Contact Karen.Smokorowski@dfo-mpo.gc.ca.
Land			
Overstory vegetation unharvested forest	NRCAN-CFS	Tree measurements in 31 unharvested PSPs (Permanent Sample Plots) established from 1980 to 1989 at different elevations across the watershed. They were established to study tree growth and species changes over time. Tree species, diameter at breast height (DBH), and height measurements are recorded within 0.10 ha circular plots at five-year intervals. 1980-present.	Data is available through collaborative projects. Contact Stephanie.Nelson@nrcan-rncan.gc.ca.

Data	Agency responsible	Description	Contact/Link
Overstory vegetation harvest impacts study	NRCAN-CFS	Tree measurements for 32 PSPs associated with the harvest impacts study. Plots (0.10 ha circular) are located within different harvest treatment blocks representing clearcut, selection, shelterwood and uncut control harvest treatments. Harvesting was done in 1997 and DBH and height of the trees >5 cm DBH including ingrowth were measured in 1997, 2002, 2008, 2013 and 2018.	Data is available through collaborative projects. Contact Stephanie.Nelson@nrcan-rncan.gc.ca.
Understory woody vegetation harvest impacts study	NRCAN-CFS	Understory woody vegetation was measured in approximately 200 5x5 m quadrats, associated with the harvest impacts study. Plots are located within different harvest treatment blocks and capture a variety of post-harvest canopy opening and soil disturbance combinations resulting from selection, shelterwood, and clearcut harvest operations. Data were collected in 2000, 2006, 2010, 2014 and 2019 and focused on the density and size of tree and shrub species > 0.3 m tall. Additional assessments of the density and size of tree and shrubs > 2 cm DBH were made in 36 adjacent 400 m^2 circular plots in 1999, 2004, 2010 and 2017.	Data is available through collaborative projects. Contact Stephanie.Nelson@nrcan-rncan.gc.ca.
Soil	NRCAN-CFS	Soil properties from four intensive study sites including one clearcut harvested and three unharvested sites. Data includes profile morphology and physical (horizon depth, bulk density, coarse fragment content, texture) and chemical (pH, cations, CEC, C, N, P) properties determined to quantify soil nutrient pools, Sites have been resampled 3 or 4 times since the mid-1980s to determine long-term soil change.	Data is available through collaborative projects. Contact Stephanie.Nelson@nrcan-rncan.gc.ca.

Data that is available to the public that is specific to the TLW is accessible by visiting both https://open.canada.ca/data/en/dataset/5742e8df-3864-46b8-b367-8f19c0c86b6c and https://open.canada.ca/en/open-maps . Natural Resources Canada continues to release TLW spatial data at the open-maps site.

The entire TLW reference list is also catalogued into 13 separate Ontario Research Sites (ORS) projects based on the subject area of each publication, but also including distinct entries for Internal Reports and Theses.

The ORS project reference ID numbers are listed below and can be accessed at the ORS website http://www.glfc.forestry.ca/ors/. In the following sections, each publication is referenced with an ORS publication number (i.e. 98-02) at the end of the citation, the first two numbers being the year published.

ORS Reference #909 - Turkey Lakes Site Overview

ORS Reference #910 - Turkey Lakes Atmospheric/Meteorology

ORS Reference #911 - Turkey Lakes Vegetation: Forest/Understory

ORS Reference #912 - Turkey Lakes Soils

ORS Reference #913 - Turkey Lakes Hydrology: Soil Water/Ground Water

ORS Reference #914 - Turkey Lakes Hydrology: Streams

ORS Reference #921 - Turkey Lakes Hydrology: Lakes

ORS Reference #922 - Turkey Lakes Waterbirds

ORS Reference #923 - Turkey Lakes Fish and Aquatic Communities

ORS Reference #941 - Turkey Lakes Internal Reports

ORS Reference #942 - Turkey Lakes Modelling and Remote Sensing

ORS Reference #943 - Turkey Lakes Theses

ORS Reference #944 - Turkey Lakes Harvesting Impacts Project

SITE OVERVIEW






Site Overview publications represent synthesis/review papers. In some cases, results are reported across several research subject areas for the TLW, while other outputs in this category have used TLW study data with data from other research sites to provide a regional, national or international assessment.

PUBLICATIONS

Anon. 1991."The three year report" on results from the International Co-operative Program on Assessment and Monitoring of Acidification of Rivers and Lakes 1987-1989. ICP Prog. Centre Report, Norwegian Institute for Water Research, Oslo, Norway. 205pp. (91-09).

> *Report is an interpretation of data gathered through the ECE International Co-operative Programme for the monitoring of long-range transboundary air pollution. Data from Europe, the U.K., US, and Canada are presented. The Canadian data are from Nova Scotia, Quebec, and the Turkey Lakes. Sulphate levels have been declining in most countries, while nitrate is increasing in Norway and Sweden. Models developed can be used to predict future changes and map critical loads, and will be increasingly useful as the database grows.*

Band, L.E., D.S. Mackay, I.F. Creed, R. Semkin and D. Jeffries. 1996. Ecosystem processes at the watershed scale: sensitivity to potential climate change. Limnol. Oceanogr. 41: 928-938. (96-02).

> *In a model to predict effects of climate change on forested watersheds, potential climate shifts in weather, forest canopy processes and forest cover were compared to control conditions in the TLW. Projections of temperature and precipitation changes alone gave different forecasts of climate change impact than those incorporating canopy effects. The model shows that terrestrial ecosystem processes significantly affect the impact of climate change.*

Damsleth, E., D.C.L. Lam, A.H. El-Shaarawi and R.F. Wright. 1987. Time series analysis of water chemistry in Canada and Norway. Nat. Wat. Res. Inst. Contribution No. 87-109, Burlington, Ont., 34 pp. (+ Appendix). (87-06).

> *Report presents results of the application of time series methods (for developing stochastic models) to ion data from the TLW and the Norwegian Project RAIN. The univariate models explained 80% of the total variability. Runoff is a significant explanatory variable in the TLW.*

Federal/Provincial Research and Monitoring Coordinating Committee. 1990. The 1990 Canadian long-range transport of air pollutants and acid deposition assessment report, Part 5: Terrestrial Effects, 105 pp. (90-07).

> *A major assessment report. Acid rain has been monitored across Canada at many stations, including TLW, from 1980. Various mathematical models have also been developed over this period. Seasonal trends are documented.*

Foster, N.W. 1987. Assessing the effects of regional air pollutants on forest ecosystems in Ontario. For. Res. Newsl., GLFC pp. 3-6, Fall 1987. (87-15).

> *An overview of GLFC research on evaluation of LRTAP effects on forests is presented. Among others, biogeochemical studies in the TLW are described. A short discussion of findings is included.*

Foster, N.W., F.D. Beall and D.P. Kreutzweiser. 2005. The role of forests in regulating water: The Turkey Lakes Watershed case study. The Forestry Chronicle 81,142-148. (05-10).

> *The TLW is cited as an example of a long-term integrated study of an undisturbed ecosystem, invaluable in aiding decisions regarding future management of forested catchments. The chemistry and biology of atmosphere, forests, soils, streams and lakes have been monitored for more than 20 years, and results include such findings as continued acidification of surface waters following the reduction of S emissions, and an improvement of water quality when partial forest cutting is used instead of clearcutting. Information from this study can contribute to an international dialogue on watershed and forest management decisions.*

International Co-operative Program on Integrated Monitoring of Air Pollution Effects on Ecosystems: Annual Synoptic Report. 1995. UN ECE Convention on Long-Range Transboundary Air Pollution, Finnish Environment Agency, Helsinki Finland, 75p. (95-12).

Evaluating the effects of N deposition is the main theme for this report. Section 1 summarizes monitoring activities; Section 2 gives background on impacts of N deposition in terrestrial ecosystems; and Section 3 presents an assessment of N processes, including input-output proton budgets for bulk deposition at 24 monitoring sites (including the TLW, the only North American site in this international program). Results from application of MAGIC, SAFE and SMART models are presented in Section 4, and Section 5 contains a summary and recommendations for future study.

Jeffries, D.S. 2002. Foreword: The Turkey Lakes Watershed study after two decades. Wat Air Soil Pollut: Focus 2: 1-3. (02-06).

An introduction to the third TLW journal issue. It and the previous TLW issue (Ecosystems 4: 501-567, 2001) contain papers presented at the 1999 TLW Workshop.

Jeffries, D.S. (ed.). 1997 Canadian Acid Rain Assessment Volume 3: The Effects on Canada's Lakes, Rivers and Wetlands. Department of Environment, 213p (97-03).

A national assessment of the aquatic effects of acid rain (the first since 1990, (cf. 90-06)) prepared in support of development of a national strategy for acid gas emission control, post 2000. Chemical and biological changes in aquatic effects since the 1980s, interactions between atmospheric stressors, effectiveness of existing critical and target loads, and the probable effect of planned SO_2 controls on aquatic ecosystems were evaluated. Information from the TLW (sometimes called "Algoma") was extensively cited, including a case study section.

Jeffries, D.S. 1992. A freshwater perspective on ecological monitoring in Canada: the example of the LRTAP Program. Proc. of the SOE Workshop on Ecological Monitoring, Occasional Paper Series #1, Toronto, ON, May 1992. 44-47. (92-17).

Research activities at the five LRTAP sites, Kejimkujik, Lac LaFlamme, Dorset, TLW and ELA. The ecological monitoring hierarchy, leading to policy development is described, and the importance of maintaining the monitoring sites is stressed.

Jeffries, D.S. 1998. Aquatic effects of acidic deposition in Canada. Water Report 97, Annual report, MYU K.K., Scientific Publishing Division, Tokyo, Japan, 99-104. (98-03).

Following the Canada/U.S. Air Quality Agreement in 1991, sulphate deposition has been reduced, but in southeastern Canada where many lakes are acidified, lake acidity has not significantly improved. Results are presented from the Algoma lake cluster surrounding the TLW. Further controls will be needed to achieve lower chemical damage levels. This is a very brief summary of 97-03.

Jeffries, D.S., I.K. Morrison and J.R.M Kelso. 1994. The Turkey Lakes Watershed Study. Proc. Parks Can. Ecol. Monitor. Workshop, University of Waterloo, Waterloo, Ont., 65-73. (95-01).

An update of 88-06.

Jeffries, D.S., I.K. Morrison, and J.R.M. Kelso. 1988. The Turkey Lakes Watershed Study. Proc. Can. Hydrol. Symp. No. 17, Banff, Alta., 117-126. (88-06).

Rationale for the study basin selection criteria, general basin description, research topics, and difficulties encountered are all presented. This is perhaps the most complete and concise review of why and how the TLW study has been conducted.

Jeffries, D.S., J.R.M. Kelso and I.K. Morrison. 1988. Physical, chemical, and biological characteristics of the Turkey Lakes watershed, central Ontario, Canada. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 3-12. (88-27).

> *Report summarizes the characteristics of the TLW and compares them to other calibrated basins in North America. It acts as the introductory paper to the TLW Special Volume. Additional information on the rationale for the TLW study may be found in the forward to the Special Volume (i.e. Kelso, J.R.M., CJFAS, 45(Suppl 1): 2, 1988) and 88-06.*

Jeffries, D.S., S.E. Doka, M.L. Mallory, F. Norouzian, A. Storey and I. Wong. 1998. Aquatic effects of acidic deposition in Canada: present and predicted future situation. Revue des Sciences de l'Eau, no spécial, 129-143. (98-02).

> *An assessment of the current status and trends in Canadian lake systems, and the predicted effect of emission controls required by the 1991 Canada/US Air Quality Agreement. The TLW is included in the Algoma cluster. Modelling indicates that the number of damaged lakes (pH<6) will decline, but without further controls, sensitive ecosystems will continue to be damaged. Much of the information is based on the assessment presented in 97-03. The paper contains an extended abstract in French.*

Jeffries, D.S. and N.W. Foster. 2001. The Turkey Lakes Watershed Study - milestones and prospects. Ecosystems 4, 501-502. (00-05).

> *A short summary of the TLW Study prepared as an introduction for the special volume published in Ecosystems.*

McNicol, D.K., M.L. Mallory and J.J. Kerekes. 1996. The Canadian Wildlife Service LRTAP Biomonitoring Program, Part 3. Site locations, physical, chemical and biological characteristics. Technical Report Series 248, Canadian Wildlife Service, 215p. (96-05).

> *This report gives detailed physical, chemical and biological characteristics of* Canadian Wildlife Service (*CWS) study areas, which include 600 wetlands and lakes in northeastern Ontario (including the TLW), and 46 lakes in Kejimkujik, Nova Scotia. Maps of the Food Chain Monitoring Program lakes in Ontario and data from the Canadian Lakes Loon Survey are also given. The document is intended as a reference for researchers studying the effects of acidification of aquatic ecosystems and the success of remedial strategies.*

McNicol, D.K., M.L. Mallory and M.L. Sechley. 1998. Acid rain and wildlife: an annotated bibliography of Canadian Wildlife Service (Ontario Region) LRTAP program publications (1980-1997). Technical Report Series 305, Canadian Wildlife Service, 85 p. (98-11).

> *This report provides a brief, one-page summary of the many and varied scientific papers and reports produced by Environment Canada staff, as well as various collaborators in other federal and provincial agencies, universities and non-government organizations, as part of the CWS (Ontario Region) LRTAP program between 1980 and 1998. These publications often deal with various cross-cutting environmental issues and topics, although the primary focus has always been acid rain and ecological effects. Scientific results are reported on both abiotic and biotic processes, including aquatic resource risk assessment, toxicological considerations, limnological and other chemical characteristics, as well as broad food-chain relationships (aquatic invertebrates, fish, amphibians, waterfowl, wetland birds, small mammals, wildlife habitat), and predictive modelling and statistics. Annotations are provided for all peer-reviewed scientific papers, graduate theses, and technical publications totalling 58 individual entries, of which many summarize studies conducted wholly or in part in the Algoma region, including the TLW.*

Morrison, I.K. 1984. Acid rain, forests and forestry. *In*: Stone, E.L. (ed.), Forest Soils and Treatment Impacts, Proc. Sixth N. Amer. For. Soils Conf., 1983, The University of Tennessee, Knoxville, TN, 209-219. (84-10).

This report provides a brief literature review covering the last decade on acid deposition and its possible influence on forest health and productivity. Topics covered include measuring forest growth, "artificial rain" experiments, tree crown leaching, soil biota and biological processes, soil acidification, base leaching and metal mobilization.

Morrison, I.K. 1984. Acid rain: a review of literature on acid deposition effects in forest ecosystems. Forestry Abstracts 45(8): 483-506, 1984. (84-11).

This report presents a comprehensive review of the literature (pre-1983) dealing with the effects of acid deposition on forest ecosystems. All aspects noted in 84-10 above are covered as well as discussion of sulphur and nitrogen cycles, site susceptibility, and disease and insect attack. Relationship of all of these factors to forest productivity is considered.

Morrison, I.K. 1993. Indirect effects and long-term risks of air pollution on tolerant hardwood forest ecosystems in central Canada. *In*: R. Schlaepfer (ed.), Long term implications of climate change and air pollution on forest ecosystems. Progress report of the IUFRO task force "Forest, Climate Change and Air Pollution". IUFRO World Series, vol. 4, Vienna. (93-05).

This one-page report summarizes the effects of SO_4 and NO_3 air pollutants on central Canadian forests. Atmospheric acidity is seen to be small compared to soil acidity and reserves of base cations in trees and soil. In the long term, air pollution may result in changes to surface waters. Information gaps and relevant publications are listed.

Morrison, I.K., D.A. Cameron, N.W. Foster and A. Groot. 1999. Forest research at the Turkey Lakes Watershed. The Forestry Chronicle 75, 395-399. (99-01).

The Turkey Lakes Watershed was chosen in 1979 for an interdisciplinary study of the impact on forests, lakes and streams of air pollutants deposited through long-range transport. A 20-year data base has been compiled. Throughout the years the site has also been used for several other studies, including participation in the Integrated Forest Study (IFS) (1986-1989) and ARNEWS biomonitoring (ongoing), a harvesting impacts study (initiated 1997), and recently the ECOLEAP project to test terrain and climate models and relate them to species distribution, abundance and productivity.

Moyes, J.C. 1987. Land use change evaluation of Canadian LRTAP calibrated watersheds. Environment Canada, Inland Waters/Lands Directorate, Working Paper No. 51, 111 p. (87-07).

Report documents historical and chronological land use changes in the five calibrated watersheds of eastern Canada including the TLW. It notes "the TLW offers a well documented, relatively undisturbed natural environment in which to perform monitoring of long-term deposition and impacts of acid precipitation".

Nicolson, J.A., N.W. Foster and I.K. Morrison. 1981. LRTAP Update, Turkey Lake Forest Watershed. For. Res. Newsl., GLFRC, 2 pp, Fall-Winter 1981. (82-10).

A brief description of the Great Lakes Forest Research Centre's studies in the TLW.

Shaw, M.A., S. Geiling, S. Barbour, I.J. Davies, E.A. Hamilton, A. Kemp, R. Reid, P.M. Ryan, N. Watson and W. White. 1992. The Department of Fisheries and Oceans national LRTAP biomonitoring programme: site location, physical and chemical characteristics. Can. Tech. Rep. Fish. Aquat. Sci. 1875: 87 p. (92-10).

Biomonitoring sites across Canada (including the TLW) were chosen in 1987 by the DFO to document changes in aquatic biota in response to the anticipated declines in sulphate deposition. This report summarizes physical and chemical characteristics of the chosen lakes and rivers, provides location maps and documents the sampling stations.

Webster, K.L., J.A. Leach, P.W. Hazlett, R.L. Fleming, E.J.S. Emilson, D. Houle, K.H.Y Chan, F. Norouzian, A.S. Cole, J.M. O’Brien, K.E. Smokorowski, S.A. Nelson and S.D. Yanni. 2020. Turkey Lakes Watershed, Ontario, Canada: 40 years of interdisciplinary whole-ecosystem research. Hydrological Processes, submitted. (20-03).

General discussion about the 40 years of interdisciplinary whole-ecosystem research at the TLW, including site description information, observation network details, current data availability, and a summary of the contributions to science and policy.

VEGETATION – FOREST/UNDERSTORY









Forest/Understory publications are primarily papers reporting forest stand conditions and element accumulation in forest biomass at permanent sample plots and at other locations throughout the watershed (Figure 5). Much of the research in this category has been conducted by Natural Resources Canada - Canadian Forest Service.

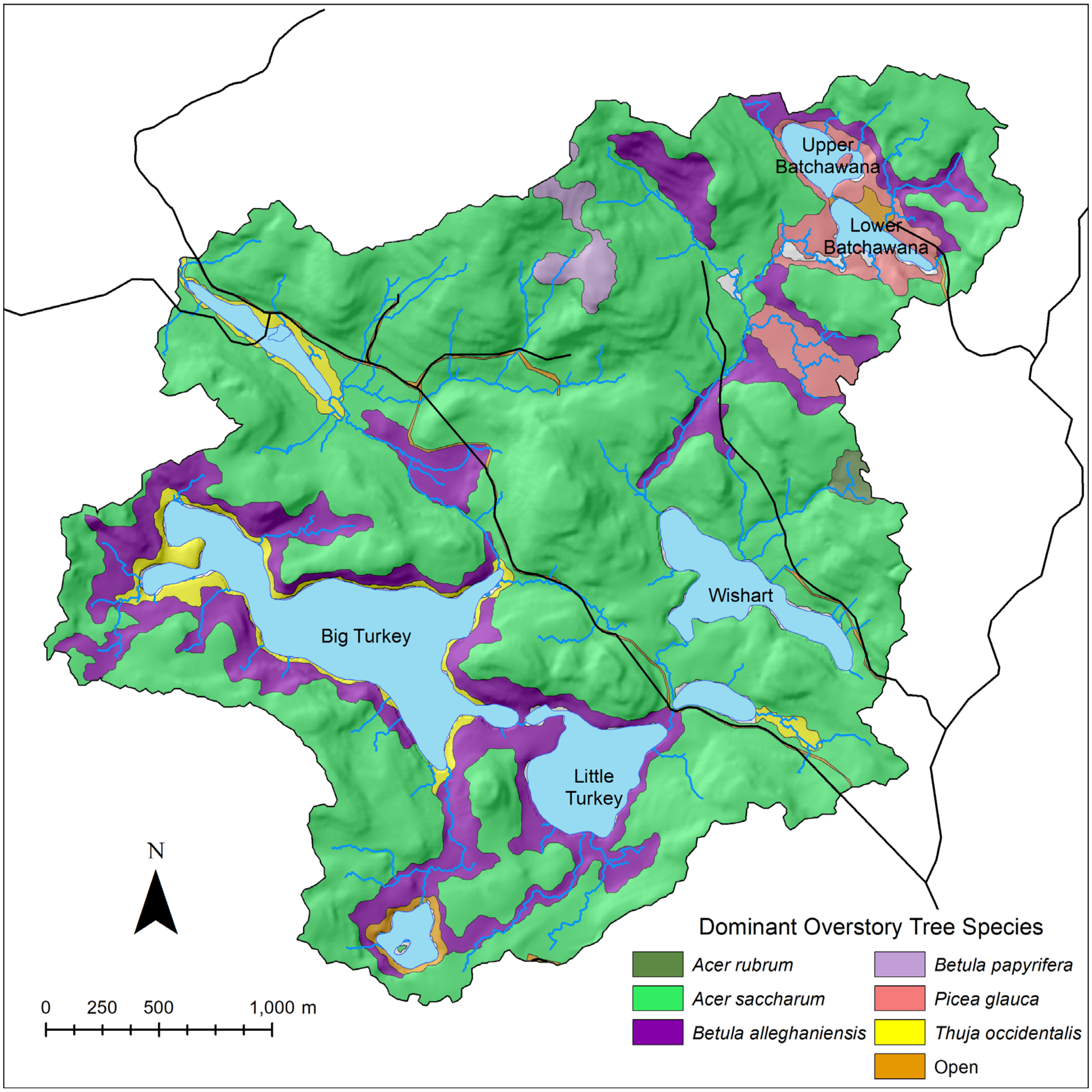


Figure 5. Forest cover map illustrating the dominant overstory tree species in the TLW

PUBLICATIONS

Caputo, J., C.M. Beier, P.M. Groffman, D.A. Burns, F.D. Beall, P.W. Hazlett and T.E. Yorks. 2016. Effects of harvesting forest biomass on water and climate regulation services: a synthesis of long-term ecosystem experiments in eastern North America. Ecosystems 19: 271-283, doi: 10.1007/s10021-015-9928-z. (16-01).

New methods assessing trade-offs between biomass harvestings and ecosystem services and their change over time were applied to long- term experimental post-harvest data from the TLW and nine other northern hardwood forest watersheds. Near-term trade-offs were observed between biomass harvesting and the ecosystem services of nutrition pollution remediation and greenhouse gas regulation. Both these ecosystem services recovered with forest vegetation regeneration. Biomass harvesting had relatively nominal and transient impacts on other ecosystem services.

Fleming, R.L. and K.A. Baldwin. 2008. Effects of harvest intensity and aspect on a boreal transition tolerant hardwood forest. I. Initial postharvest understory composition. Canadian Journal of Forest Research 38 (4), 685-697, doi:10.1139/X07-198. (08-06).

Disturbance effects on plant communities largely reflect the degree of overstory removal, soil disturbance, and attendant vegetation destruction. Partial and complete canopy removal and soil disturbance were assessed for their post-harvest impact on vascular plant cover, community responses, indicator species and diversity on north or south facing plots at the TLW 3-years after harvest. Community composition and diversity were primarily related to soil disturbance and aspect-related radiation exposure. Canopy opening did not have major influences on its own. Logging-related soil disturbance thus seems to be the predominant silvicultural factor (over canopy opening) affecting understory community response and diversity. Prominent aspect-related changes suggest that responses will be site and species specific.

Hall, P., W. Bowers, H. Hirvonen, G. Hogan, N. Foster, I. Morrison, K. Percy, R. Cox and P. Arp. 1997. Canadian Acid Rain Assessment Volume 4: The Effects on Canada's Forests. Department of Environment, 46p. (97-05).

In this report (the first since the 1990 Acid Rain Assessment), the effect of acidic deposition on forest soils and vegetation is reassessed in the light of improved knowledge of soil processes. Revised strategies for long-term forest management are indicated, as current target loads for deposition are seen to be too high for sensitive forest ecosystems. Effects on tree physiology and soil chemistry are examined (data from TLW is used extensively) and new critical loads for forest soils and vegetation have been developed.

Hogan, G.D. 1992. Physiological effects of direct impact of acidic deposition on foliage. Agric. Ecosystems Environ. 42: 307-319. (92-14).

Numerous studies including some in the TLW have examined the direct effects of acidic deposition on physiological processes or morphological indicators at the foliar level. Extreme pH values (less than pH 3.0) can affect cuticular structure, increase leaching of foliar cations, reduce photosynthesis and transpiration, and increase cuticular water loss. There is variation among species in the magnitude of the response and the effective pH at which a response is observed. The possibility of direct injury to forest vegetation from ambient rainfall is slight.

Hogan, G.D. and I.K. Morrison. 1988. Distribution of trace metals within the above ground phytomass of *Acer saccharum* Marsh, and *Betula alleghaniensis* Britt. at the Turkey Lakes Watershed. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 101-106. (88-17).

The distribution of Mn, Fe, Zn, Cu, Pb, Ni, and Cd in the stemwood, stembark, and foliage for the two most important tree species in the TLW was measured and evaluated. Foliage and stembark concentrations were highest. Some differences between species were observed. Data are compared to those from other locations.

Hogan, G.D. and N.W. Foster. 1989. Precipitation acidity and foliar cation loss from sugar maple. *In*: Boudreault, G. and G.B. Allard, ed., Atelier sur le déperissement dans les érablieres. Centre de recherche acericole, St.- Hyacinthe, Quebec: 24-28. (89-06).

A study to examine cation leaching of leaves as a cause of maple dieback at the TLW. Current levels of acidic deposition are not a threat to maple forests in the short term.

Morrison, I.K. 1985. Effect of crown position on foliar concentrations of 11 elements in *Acer saccharum* and *Betula alleghaniensis* trees on a till soil. Can. J. For. Res. 15:179- 183. (85-04).

The concentration of several elements in foliage from the crowns of sugar maple and yellow birch trees in the TLW is reported. Variability is related to species, location; other factors are discussed. Sampling strategies for obtaining acceptable error are suggested.

Morrison, I.K. 1991. Addition of organic matter and elements to the forest floor of an old growth *Acer saccharum* forest in the annual litter fall. Can. J. For. Res. 21: 462-468. (91-01).

Element deposition in litter fall was measured monthly for five years. Temporal and spatial distributions are examined. Results show little risk of leaching losses of base cations from foliage in response to acidic precipitation.

Morrison, I.K. 1991. Biomass and macroelements in a tolerant hardwood stand, Turkey Lakes Watershed, Ontario. *In*: Robitaille, G. and P.J. Rennie, (eds.), Effect of acid rain on forest resources. Proc. Conf. 14-17 June 1983, Sainte-Foy, Que. For. Can., Ottawa, Ont. Inf. Rep. DPC-X-35, 508-516. (91-03).

Data are presented showing that the most abundant element in the standing crop biomass was Ca, followed by N > K > Mg > S > P. In the annual litterfall, over a three-year period, the most abundant element was N. Data are also presented on total organic matter and elements in the forest floor, and the replenishment of leached bases by litterfall is discussed.

Morrison, I.K. 1991. Effect of trap dimensions on mass of litterfall collected in an *Acer saccharum* stand in northern Ontario. Can. J. For. Res. 21: 939-941. (91-02).

Four types of litter traps are compared over three growing seasons, the traps having two rim heights, (0.25 and 1.0 m) and two surface areas (.25 and 1 m^2). Height and surface areas affected the mass of litter trapped, and in general it was found that small traps near the ground should be avoided. From six to fourteen traps of each type were required to give representative sampling over three seasons, and over one season the number of traps needed increased.

Morrison, I.K. 1983. Biomass and macroelements in a tolerant hardwood stand, Turkey Lakes Watershed, Ontario. Proc. Conf. Acid Rain and For. Resourc., Quebec City, 1983. (see 91-03) (83-18).

Report presents data on the distribution of standing-crop biomass and of N, P, K, Ca, Mg, and S in the tree components of an old-growth sugar maple-yellow birch forest. Element flux via litterfall is discussed for a three-year period. The distribution of total organic matter and elements in the forest floor is also presented as well as the role of litterfall in replenishing bases removed by leaching and plant uptake.

Morrison, I.K., N.W. Foster and P.W. Hazlett. 1993. Carbon reserves, carbon cycling, and harvesting effects in three mature forest types in Canada. New Zealand Journal of Forestry Science, 23, 403-412. (93-04).

Carbon reserves in 3 forest ecosystems northeast of Lake Superior were contrasted in terms of content and distribution. The youngest stand, a 62-year old jack pine forest, contained the lowest reserves. The oldest, a 300-year old sugar maple forest in the TLW, had a carbon turnover three times that of the jack pine forest floor, and residual carbon was likewise three times greater in the sugar maple forest floor. Intensive harvesting of pine can remove up to 44% of the total carbon. Jack pine and black spruce stands could become infertile through full-tree harvesting because carbon and nutrients are stored in the forest floor.

Morrison, I.K. and G.D. Hogan. 1986. Trace element distribution within the tree phytomass and forest floor of a tolerant hardwood stand, Algoma, Ontario. Wat. Air Soil Pollut. 31: 493-500. (86-13).

Trace metal (Cu, Fe, Mn, Ni, Cd, Pb, Zn,) content of the various components of the forest phytomass in the TLW is evaluated. Relative concentration levels are presented and discussion of metal sources and availability are included. Some metals are lower than those reported for similar forests in the northeastern US.

Raynal, D.J., N.W. Foster, M.J. Mitchell and D.W. Johnson. 1992. Regional evaluations of acidic deposition effects on forests: eastern hardwoods. *In*: Johnson, D.W., and S.E. Lindberg, (eds), Atmospheric deposition and forest nutrient cycling. Springer-Verlag, New York, 526-534. (92-12).

Paper reviews the research on complex forest-atmosphere relationships within the IFS network, including nutrient budgets, toxicity of metals, (especially Al), Ca_{2+} *uptake, and* K^+ *and P deficiency. The network includes Huntington Forest in the Adirondacks, TLW, and the Coweeta Watershed in North Carolina.*

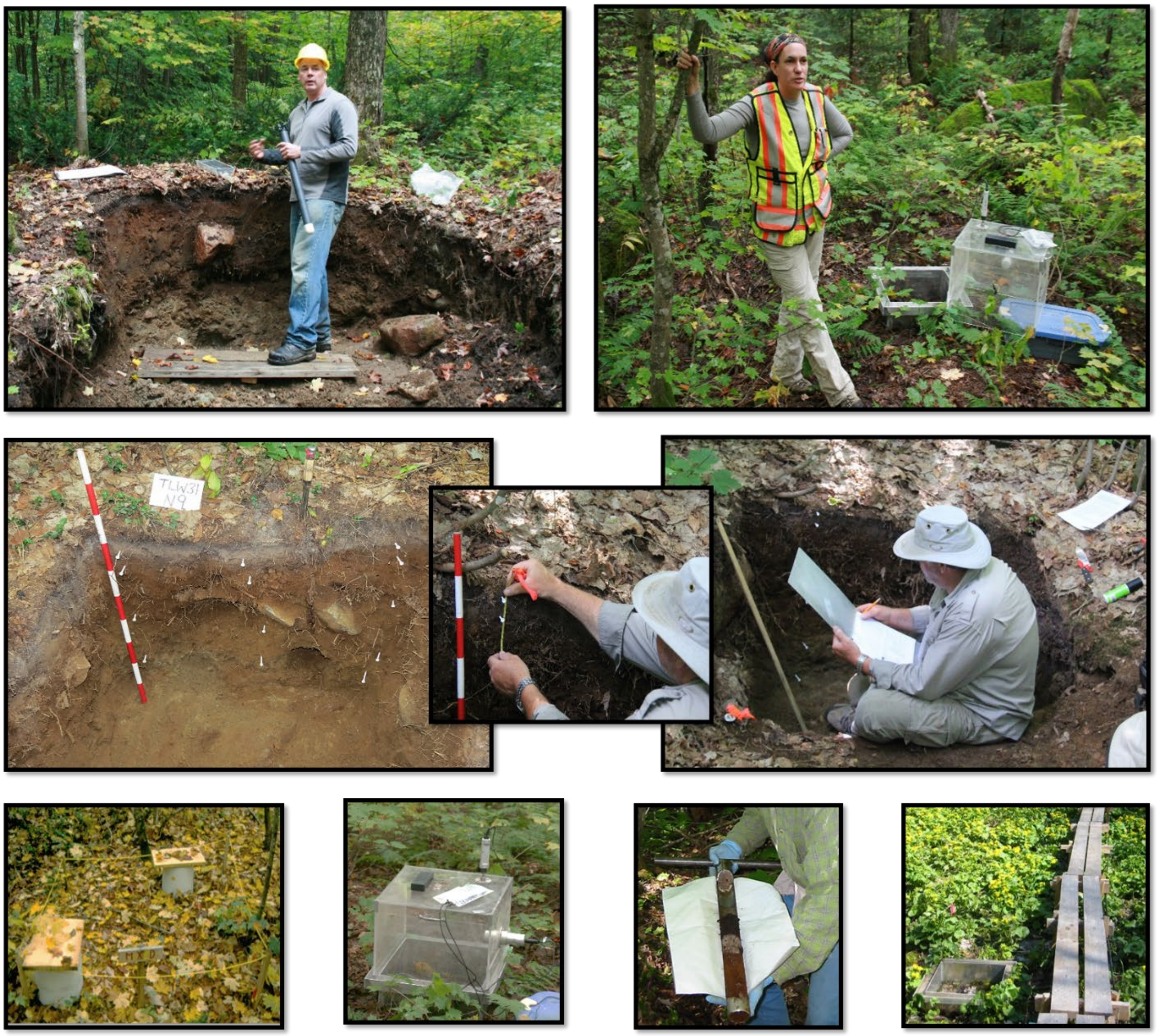
Van Miegroet, H, D.W. Cole and N.W. Foster. 1992. Nitrogen distribution and cycling. *In*: Johnson, D.W. and S.E. Lindberg, (eds), Atmospheric Deposition and forest nutrient cycling. Springer-Verlag, New York, 178-199. (92-13).

The N distribution in the IFS ecosystems, which includes the TLW, and factors controlling N saturation, retention and leaching are reviewed. The general concepts of the N cycle are discussed. The TLW is among the group of ecosystems with the highest total N content and leaching. See also 92-21.

Yin, X., N.W. Foster, I.K. Morrison and P.A. Arp. 1994. Tree-ring-based growth analysis for a sugar maple stand: relations to local climate and transient soil properties. Can. J. For. Res. 24: 1567-1574. (94-04).

Using the sugar maple forest in the TLW, variation in tree-ring-based growth analysis was explained using models to simulate soil moisture and temperatures, and to calculate ion concentrations in soil solution over the previous 40 years. Local weather records were also incorporated. Introducing transient soil properties into the growth analysis may greatly reduce the error variance.

SOILS



Soils publications are primarily papers reporting soil chemical conditions, element distribution in the soil profile and the impact of acid deposition and forest harvesting on forest soil processes at permanent sample plots and other locations throughout the watershed (Figure 6). Much of the research in this category has been conducted by Natural Resources Canada - Canadian Forest Service.

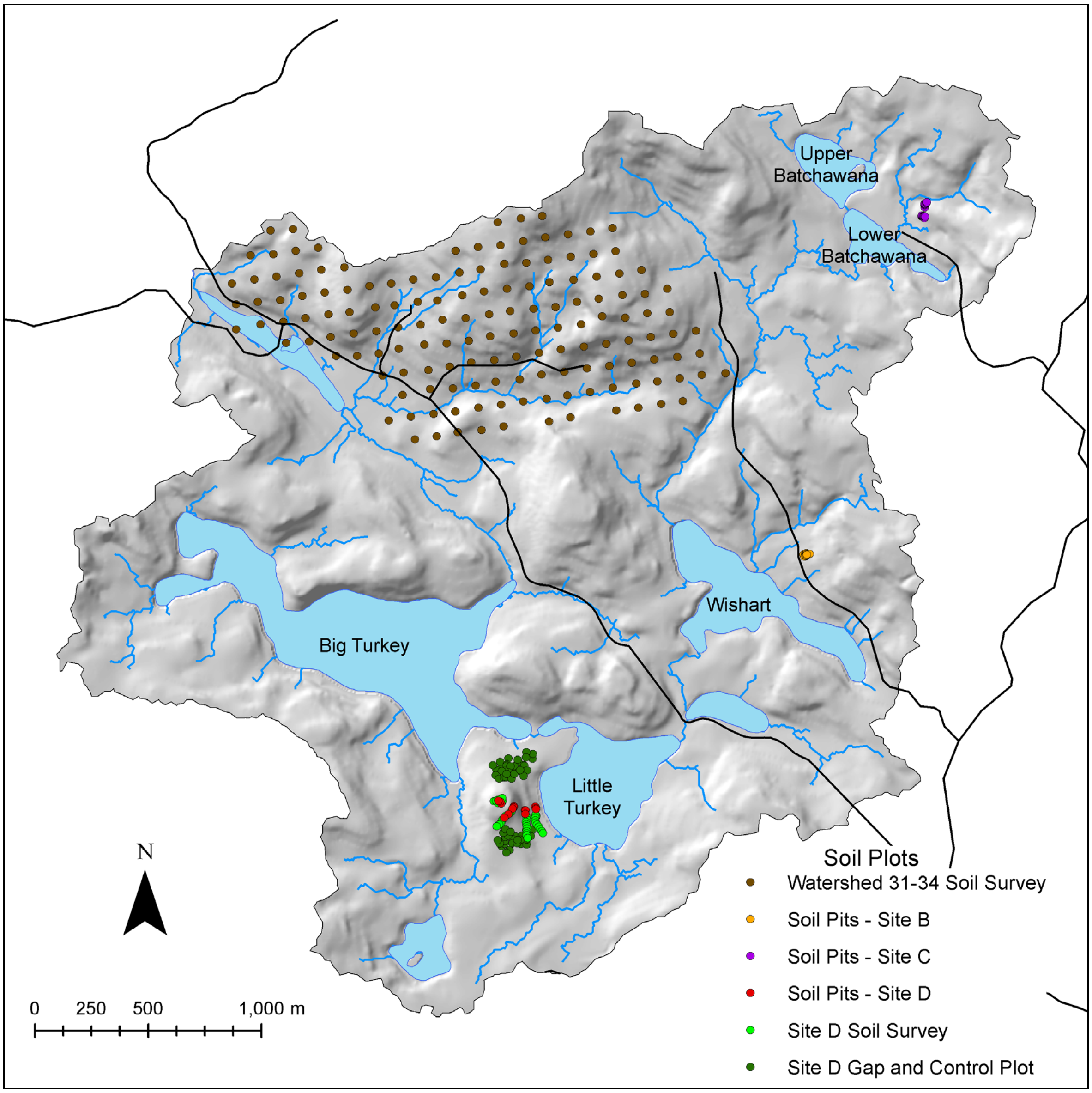


Figure 6. Soil plot locations in the TLW.

PUBLICATIONS

Bourbonniere, R.A., F.D. Beall and I.F. Creed. 2004. Carbon dioxide effluxes at the edge: importance of the ecotone between wetland and upland in forests. Geophysical Letters, submitted. (04-01).

> *Two catchments within the TLW were chosen as representative of the complex terrain in the watershed for purposes of measuring soil surface CO_2 effluxes in the ecotone, or transition boundary, between uplands and wetlands. This proves to be a zone of maximum soil CO_2 efflux and is therefore important in calculating soil carbon budgets in forests with complex terrains.*

Cole, D.W., H. Van Miegroet and N.W. Foster. 1992. Retention or loss of N in IFS sites and evaluation of relative importance of processes *In*: Johnson, D.W., and S.E. Lindberg (eds), Atmospheric deposition and forest nutrient cycling. Springer-Verlag, New York, 196-199. (92-20).

> *At the 17 IFS sites (which include the TLW), the majority of sites retain atmospheric N, but there is a wide variation in N leaching rates between sites. To account for these differences, many sources and sinks were evaluated, but it was found that atmospheric deposition and N mineralization together can explain two-thirds of the variation. The TLW is one of the five IFS sites exhibiting annual N export in excess of 10 kg.ha^{-1}. Loss of N from an ecosystem has important implications for site fertility and water quality, and deposition inputs play an important role in N loss. See also 92-13.*

Creed, I.F., C.G. Trick, L.E. Band and I.K. Morrison. 2002. Characterizing the spatial pattern of soil carbon and nitrogen pools in the Turkey Lakes Watershed: a comparison of regression techniques. Wat. Air Soil Pollut.: Focus 2, 81-102. (02-13).

> *Multiple linear regression models indicate that topography in the TLW accounts for a significant portion of the spatial heterogeneity in the organic C and total N pools of the watershed soils. Tree regression models explained a greater percent of the variance. Forest and topography are important in the development of soil properties, but are scale dependent.*

Creed, I.F., K.L. Webster, G.L. Braun, R.A. Bourbonnière and F.D. Beall. 2013. Topographically regulated traps of dissolved organic carbon create hotspots of soil carbon dioxide efflux in forests. Biogeochemistry 112 (1-3), 149-164, doi 10.1007/s10533-012-9713-4. (13-01).

> *Soil samples from three hillslope transects at the TLW were analyzed for DOC concentration in order to assess the contribution of topographically distributed DOC to soil CO_2 efflux. Samples of both mobile DOC and sorbed DOC in both surface (freshly fallen leaves (FFL) and forest floor) and near-surface (A-horizon or top 10cm of peat) soils were examined. DOC substrates from near-surface soil were most strongly related to median soil CO_2 efflux, and when combined with FFL, explained 81% of variance in CO_2 efflux. High concentrations of mobile DOC were found at the footslope, and high concentrations of sorbed DOC were found downhill at the toeslope.*

Eimers, C.M., P.J. Dillon, S.L. Schiff and D.S. Jeffries. 2003. The effects of drying and rewetting and increased temperature on sulphate release from upland and wetland material. Soil Biology and Biochemistry: 35, 1663-1673. (03-05).

> *Samples of upland and wetland soil from sub-basin 50 in the TLW were included in laboratory experiments to determine the effect of drying/re-wetting and increased temperature on SO_4 release from the primary S pools in wetland and upland soils. There was a small but immediate increase in SO_4 concentrations in forest floor (LFH) material. Peat showed a three- to four-fold increase in mobile SO_4 following drying-re-wetting. Temperature had a relatively lesser influence on SO_4 release. Mineral soils which contain a relatively larger pool of total S are not as responsive to changes in moisture or temperature.*

Enanga, E.M, I.F.Creed, T. Fairweather and N.J. Casson. 2017. Nitrous Oxide and Dinitrogen: The Missing flux in Nitrogen Budgets of Forested Catchments? *Environmental Science and Technology 51: 6036-6043. (17-01).*

The denitrification products nitrous oxide (N_2O) and dinitrogen (N_2) represent often unmeasured fluxes that may close the gap between explained nitrogen inputs and outputs in forested watersheds. Improved estimates of soil N_2O and N_2 efflux from forested landscapes may require consideration of topographic controls on N cycling and routing processes. Total N inputs, and total gaseous and dissolved N outputs were sampled in two catchments (soil N_2O efflux measurements collected at varying hillslope gradients) in TLW. Adding N_2O and N_2 effluxes to catchment nitrogen output reduced the discrepancy between nitrogen inputs and outputs and between nitrogen outputs from two catchments with different topographies. Annual nitrogen losses may be underestimated without accounting for denitrification products, especially during summer rainfall events.

Enanga, E. M., I. F. Creed, N. J. Casson and F. D. Beall. 2016. Summer storms trigger soil N_2O efflux episodes in forested catchments, Journal of Geophysical Research: Biogeosciences 121, 95–108, doi:10.1002/ 2015JG003027. (16-02).

Soil physical and chemical properties and N_2O and N_2 efflux were measured in catchment 38 at the TLW from 2005 to 2010. Hotspots and hot moments of soil N_2O and N_2 efflux were observed in topographic positions that accumulate precipitation. A consequence of the higher frequency of extreme precipitation events predicted under climate change scenarios is the shift from an aquatic to atmospheric fate for N, resulting in a significant forest N efflux. This in turn creates feedbacks for even warmer conditions due to increased effluxes of potent greenhouse gases.

Enanga, E.M., I.F Creed, T. Fairweather and N.J. Casson. 2016. Snow covered soils produce N_2O that is lost from forested catchments prior to snowmelt. Journal of Geophysical Research – Biogeosciences 121 (9): 2356-2368. (16-06).

The magnitude of net soil nitrous oxide (N_2O) production from a snow-covered catchment (C38 in TLW) was investigated. Topographic position was found not to affect net N_2O production despite significant variation in soil moisture, reduction-oxidation condition, and pore water DOC and nitrate. Soil temperatures did not vary among the topographic positions, suggesting temperatures at or above freezing point allow N_2O production to proceed under the snowpack. Redox conditions were lower at wetland positions compared to lowlands and uplands, suggesting biogeochemical pathway of N_2O production varies with topography. Thirty-one percent of the growing season N_2O-N production was exported to the atmosphere over the entire non-growing season. Results suggest that winter is an active time for gaseous N production in these forests and N_2O production under the snowpack represents an often unmonitored flux of N from catchments.

Foster, N., J. Spoelstra, P. Hazlett, S. Schiff, F. Beall, I. Creed and C. David. 2005. Heterogeneity in soil nitrogen within first-order forested catchments at the Turkey Lakes Watershed. Can. J. For. Res. 35, 797-805. (05-01).

N processes in soils at the TLW were examined to determine how they relate to N export. N concentrations in soils were highly variable. Higher exports from soils than from streams were not explained by differences in soil water N with topographic position or denitrification in lower landscape topographic position.

Foster, N.W. 1989. Influence of seasonal temperature on nitrogen and sulfur mineralization/immobilization in a maple-birch forest floor in central Ontario. Can. J. Soil Sci. 69: 501-514. (88-34).

Net mineralization of S and N, and nitrification in a F(Oe) horizon from the TLW were examined from May to September using a) buried bags, b) lysimeters, and c) closed flasks at 10^o, 20^o, or 30^{o}C. Over the 16 week period, $NO_{3+}NH$ extracted from the soil using the flasks at 20^{o}C was 30 kg/ha N and 9 kg/ha SO_4. Using buried bags (mean temperature = 15.2^{o}C), 33 kg/ha N and 4 kg/ha SO_4 were extracted. However, lysimeters exhibited a net N release of only 8 kg/ha and a net retention of 3 kg/ha SO_4. Mineralization was sensitive to temperature, and a shift from net mineralization to net immobilization of N occurred at maximum forest floor temperature.

Foster, N.W., I.K. Morrison, X. Yin and P.A. Arp. 1992. Impact of soil water deficits in a mature sugar maple forest: stand biogeochemistry. Can J. For. Res. 22: 1753-1760. (92-09).

Computer simulations have shown that severe soil water deficits during 1982-1983 and 1988-1989 caused reduction in growth for sugar maples at Turkey Lakes. Low NO_3 concentrations were observed during summer droughts, and correlate negatively with SO_4 levels in solution but positively with Ca_{2+} levels. Although dry summers may lead to a reduction in nitrogen leaching from soils, net cation leaching is unlikely to change.

Foster, N.W., M.J. Mitchell, I.K. Morrison and J.P. Shepard. 1992. Cycling of acid and base cations in deciduous stands of Huntington Forest, New York, and Turkey Lakes, Ontario. Can. J. For. Res. 22: 167-174. (92-05).

A comparison of annual nutrient fluxes is made between these two tolerant hardwood forests over a one-year period. Ca_{2+} was the dominant cation in both systems, but base cation leaching was five times greater at Turkey Lakes. Relative to throughfall, aluminum concentrations increased in forest floor and mineral soil solutions. TLW soils seem more sensitive to acidification. Natural soil acidity greatly exceeds acidity deposited from the atmosphere, so that any changes in acidity will be slow.

Foster, N.W. and J.A. Nicolson. 1984. Acid precipitation and water quality within a tolerant hardwood stand and soil. Proc. Int. For. Congress, Quebec City, 337-342. (84-12).

Soil properties and ion fluxes measured in TLW were used to determine whether acid deposition could lead to base leaching from the vegetation and soil. Base cation leaching was associated with organic acids, sulphate, nitrate, and bicarbonate depending on horizon. The large exchangeable base cation pool present in the soils suggests that it is unlikely that significant leaching will occur at present deposition levels.

Fournier, R.E., I.K. Morrison and A.A. Hopkin. 1994. Short range variability of soil chemistry in three acid soils in Ontario, Canada. Commun. Soil Sci. Plant Anal. 25: 3069- 3082. (94-03).

Twenty-five soil pits were sampled at three study areas, including the TLW, to check the variability of sampling and analytical methodologies used in Canada's Acid Rain National Early Warning System (ARNEWS). More samples are needed to obtain high-confidence results in mineral horizons, compared to forest floor soils. Micro-element parameters were most variable, and organic macro-elements and pH the least variable parameters.

Harrison, R.B., D.W. Johnson and D.E. Todd. 1989. Sulfate adsorption and desorption reversibility in a variety of forest soils. J. Environ. Qual. 18: 419-426. (89-09).

The TLW was one of 20 sites from Canada, the US, and Norway used by the IFS on the effects of atmospheric deposition. Relative SO_4 adsorption capacities and adsorption reversibility in forest soils were measured and compared between sites. The amount of SO_4 absorbed was a function of extractable Al, pH and native SO_4 levels. Inorganic SO_4 retention mechanisms dominated. An average of 36% of adsorbed SO_4 was not readily water soluble.

Hazlett, P.W., J.M. Curry and T.P. Weldon. Assessing decadal change in mineral soil cation chemistry at the Turkey Lakes Watershed. 2011. Soil Science Society of America Journal 75 (1), 287-305. doi:10.2136/sssaj2010.0090. (11-02).

Previous studies have provided evidence for the depletion of base cations in soil across decadal time scales, attributed to leaching due to elevated S and N levels. Soil horizons from seven plots in the tolerant hardwood forest at the TLW were analyzed for their chemical properties in 1986, 2003 and 2005. There were no statistically significant declines in pH or in exchangeable Ca, Mg or K concentrations; however Na concentrations decreased in deeper soil horizons. These results suggest that mineral weathering inputs provide stability to the exchangeable base cation pool despite large leaching loss at the TLW.

Hazlett, P., C. Emilson, G. Lawrence, I.Fernandez, R. Ouimet and S. Bailey. 2020. Reversal of forest soil acidification in the Northeaster United States and Eastern Canada: Site and soil factors contributing to recovery. 2020. Soil Systems.2020, 4, 54. doi:10.3390/soilsystems4030054. (20-02).

The degree of soil acidification recovery appears to vary and is not fully explained by deposition declines alone. Soil resampling chemistry data was assessed at TLW and 22 additional sites in the US and Canada, located across 25° longitude from eastern Maine to western Ontario. O and B horizons that were initially acidified to a greater degree showed greater recovery and B horizon recovery was further associated with an increase in recovery years and lower initial SO_4^{2-} *deposition. Predictions of where forest soils acidification reversal will occur across the landscape should be refined to acknowledge the importance of upper soil profile horizon chemistry rather than the more traditional approach using only parent material characteristics.*

Hern, J.A., G.K. Rutherford and G.W. vanLoon. 1985. Chemical and pedogenetic effects of simulated acid precipitation on two eastern Canadian forest soils. I. Non-metals. Can. J. For. Res. 15(5): 839-847. (85-05).

Artificial acidification of soil columns was conducted in both field and laboratory settings; pore-water anion and H^+ *concentrations were monitored over a two-year period. Some of the columns were sterilized to assess the effect of microbial processes. Sulphate adsorption,* H^+ *neutralization, and N processes were evaluated.*

Hern, J.A., G.K. Rutherford and G.W. vanLoon. 1988. Effects of simulated acid rain on the cation exchange capacities of two Podzolic soils, Canada. Geoderma 42: 105-114. (88-32).

Report presents results of an artificial acidification of reconstituted soil columns from the TLW and Montmorency Forest, Quebec. Only small changes in CEC were observed and the factors controlling this observation are discussed (see 87-14).

Laporte, M.F., L.C. Duchesne and I.K. Morrison. 2003. Effect of clearcutting, selection cutting, shelterwood cutting and microsites on soil surface CO_2 efflux in a tolerant hardwood ecosystem of northern Ontario. Forest Ecology and Management 174, 565-575. (03-07).

In 1998 a flow-through portable infrared CO_2 *gas analyzer was used in a section of the TLW in which harvesting impacts were being studied to examine the effects of selection cutting, shelterwood cutting and microsites on soil surface* CO_2 *efflux (SSCE). Selection and shelterwood cutting caused decreasing SSCE, while clearcutting effects were less than for other treatments but more than for the control. SSCE was higher on undisturbed microsites and demonstrated the importance of microsite distribution in treated areas.*

Lawrence, G.B., I.J. Fernandez, D.D. Richter, D.S. Ross, P.W. Hazlett, S.W. Bailey, R. Ouimet, R.A.F. Warby, A.H. Johnson, H. Lin, J.M. Kaste, A.G. Lapenis and T.J. Sullivan. 2013. Measuring environmental change in forest ecosystems by repeated soil sampling: a North American perspective. Journal of Environmental Quality 42 (3), 623-639, doi:10.2134/jeq2012.0378. (13-02).

This paper provides evidence for the use of soil resampling studies and study sites as an essential tool for environmental monitoring and assessment. Repeated sampling can provide insight into large-scale issues such as recovery from acidification, long-term N deposition, C sequestration, effects of climate change, impacts from invasive species and the increasing intensification of soil management. The TLW was one of 16 locations noted as using soil resampling methods to assess the impacts of environmental change. The paper also summarizes how temporal and spatial variability can be addressed with a variety of sampling approaches.

Lawrence, G.B., P.W. Hazlett, I.J. Fernandez, R. Ouimet, S.W. Bailey, W.C. Shortle, K.T. Smith and M.R. Antidormi. 2015. Declining acidic deposition begins reversal of forest-soil acidification in the northeastern U.S. and eastern Canada. Environmental Science and Technology 49 (22), 13103-13111, doi: 10.1021/acs.est.5b02904. (15-01).

Documentation of the effects of acidic deposition on soils has been limited, and little is known regarding soil response to ongoing decreases of acidic deposition. Resampling of soils in eastern Canada and the northeastern US was done at 27 sites, including the TLW, which were exposed to reductions in wet SO_4^{2-} deposition of 5.7-76% over intervals of 8-24 years. Decreases of exchangeable Al in the O horizon and increases in pH in the O and B horizons were seen at most sites. At all sites SO_4^{2-} reductions were positively correlated with ratios (final sampling/initial sampling) of base saturation and negatively correlated with exchangeable Al ratios in the O horizon. These results are unique as they show that the effects of acidic deposition in eastern Canada and the northeastern US have begun to reverse.

Lecki, N.A, Creed, I.F. 2016. Forest soil CO_2 efflux models improved by incorporating topographic controls on carbon content and sorption capacity of soils. Biogeochemistry 129 (3): 307-323. (16-07).

This study looks at improving modelling techniques to predict the fate of carbon in forest soils under changing environmental conditions. Soil CO_2 efflux was measured along varying topography in a catchment in TLW within a temperate sugar maple forest. When soil carbon content and sorption capacity were added to the models, the amount of explanation increased slightly on a gentle hillslope and substantially on a steep hillslope. Carbon content in organic-rich surface of the mineral soil was positively related and sorption capacity was negatively related to soil CO_2 efflux rates. More accurate estimates of forest soil CO_2 efflux must take into account topographic influences on the carbon pools, the environmental factors that affect rates of carbon transformation, and the physiochemical factors that determine the fraction of the carbon pool that can be transformed.

Lovett, G.M. and M.J. Mitchell. 2004. Sugar maple and nitrogen cycling in the forests of eastern North America. Front. Ecol. Environ. 2, 81-88. (04-07).

The TLW is one of a number of sugar maple-dominated watersheds studied to examine nitrogen cycling in forest soils. If the population of sugar maple increases because of anthropogenic stress on competitive tree species, the result will be lower N retention in the soils and increased leaching. Nitrate leaching contributes to the depletion of nutrient cations and causes acidification of streams and lakes and ultimately eutrophication of estuaries and coastal waters.

Moayeri, M., F-R. Meng, P.A. Arp and N.W. Foster. 2001. Evaluating critical soil acidification loads and exceedances for a deciduous forest at Turkey Lakes, Ontario. Ecosystems 4, 555-567. (00-03).

Critical soil acidification rates determined at the TLW using steady-state mass balance modelling were found to be high (900 to 1400 eq ha^{-1} y^{-1} *depending on the forest harvesting regime). As a consequence, critical load exceedance is low. Weathering of TLW soils provides a buffer against acid inputs and natural acidification. The TLW appears to be near or at N saturation.*

Morrison, I.K. 1990. Organic matter and mineral distribution in an old-growth *Acer saccharum* forest near the northern limit of its range. Can. J. For. Res. 20: 1332-1342. (90-02).

Two sites in the old-growth forest stand were compared with respect to total phytomass values and element concentrations. Growth processes are still influencing nutrient uptake, and weathering replenishes losses from the systems.

Morrison, I.K. and N.W. Foster. 2001. Fifteen-year changes in forest floor organic and element content and cycling at the Turkey Lakes Watershed. Ecosystems 4, 545-554. (00-06).

Samples of the L-(Oi), F-(Oe) and H-(Oa) layers collected in 1981 and 1996 were analyzed to evaluate chemical changes. Total organic matter and element contents remained unchanged except N, which increased significantly. On a real basis, there were significant increases in exchangeable Ca and Na and decreases in exchangeable NH_4 *and* SO_4*. In spite of significant changes in atmospheric inputs, it appears that active biological processes serve to impart stability to the mineral composition of the forest floor.*

Morse, J.L., J. Duran, F. Beall, E. Enanga, I.F.Creed, I. Fernandez and P.M. Groffman. 2015. Soil denitrification fluxes from three northeastern North American forests across a range of nitrogen deposition. Oecologia 177 (1), 17-27, DOI 10.1007/s00442-014-3117-1. (15-02).

Large amounts of N are unaccounted for in N balances at scales ranging from small watersheds to large regional drainage basins in northern forests. The missing N may be related to N-gas production by soil microbes. Samples were taken from the TLW and two other research sites, each differing in N enrichment. Fluxes of N_2 *and* N_2O *were quantified with intact-cores in the laboratory, and were tested for correlation with N availability, soil* O_2 *status and forest type. Total N-gas flux ranged from <1 to >100 kg N* $ha^{-1}yr^{-1}$*. These findings demonstrate that denitrification is an important and potentially underestimated term in N budgets of upland forests in northeastern North America.*

Oja, T., and P.A. Arp. 1998. Assessing atmospheric sulfur and nitrogen loads critical to the maintenance of upland forest soils. *In*: D.G. Maynard (ed.), Sulfur in the Environment, Chapter 10, p337-363. (98-05).

Critical S and N loads are formulated for IFS sites, (including the TLW), and data from Turkey Lakes and Huntington Forest in the Adirondacks are modelled for comparison using a steady-state mass balance approach. N leaching at the TLW site is accompanied by accelerated base cation leaching losses.

Ross, D.S., S.W, Bailey, R.D. Briggs, J. Curry, I.J. Fernandez, G. Fredriksen, C.L. Goodale, P.W. Hazlett, P.R. Heine, C.E. Johnson, J.T. Larson, G.B. Lawrence, R.K. Kolka, R. Ouimet, D. Paré, D.deB. Richter, C.D. Schimer and R.A. Warby. 2015. Inter-laboratory variation in the chemical analysis of acidic forest soil reference samples from eastern North America. Ecosphere 6 (5), 1-22, http://dx.doi.org/10.1890/ES14-00209.1. (15-03).

To determine the uncertainty associated with specific analytical methods for forest soils, samples from two soil horizons were collected and distributed to 15 laboratories in the eastern US and Canada where TLW samples are analyzed, including the GLFC. Soil properties measured included total organic carbon and nitrogen, pH and exchangeable cation. Overall, results were consistent despite some differences in methodology. Recommendations include a continuation of reference forest soil exchange programs to quantify the uncertainty associated with these analyses in conjunction with ongoing efforts to review and standardize laboratory methods.

Rutherford, G.K., G.W. vanLoon, S.F. Mortensen and J.A. Hern. 1985. Chemical and pedogenetic effects of simulated acid precipitation on two eastern Canadian forest soils. II. Metals. Can. J. For. Res. 15(5): 848-854. (85-06).

Metal (base cations, Al, Mn, and Fe) mobility was examined in the same study as 85-05.

Senar, O.E., Webster, K.L, Creed, I.F. 2018. Catchment-scale shifts in the magnitude and partitioning of carbon export in response to changing hydrologic connectivity in a northern hardwood forest. Journal of Geophysical Research: Biogeosciences 123 (8): 2337-2352. (18-04).

The results from a five-year study of a northern hardwood forested catchment (TLW) indicated that hydrologic connectivity affected both the magnitude and fate of carbon export. Atmospheric carbon export was the major pathway from the catchment; its rate was regulated by topographic position but enhanced or supressed through changes in soil moisture and hydrologic connectivity. Past trends suggest a shift to a warmer climate and changes in the timing, duration, and intensity of hydrologic connectivity that are leading to an increase in annual atmospheric carbon export but a decrease in annual aquatic carbon export, despite the intensification of autumn storms. The increase in atmospheric carbon export creates a positive feedback for climate warming that will further disrupt hydrologic connectivity and aquatic carbon export, with consequences for downstream streams and lakes.

Smith, G.K.M, N.W. Foster, P.W. Hazlett, I.K. Morrison and J.A. Nicolson. 1992. Mortality, climate and air pollution cause nitrogen imbalance in a tolerant hardwood forest soil. Forestry Canada, Ont. Region, Frontline Tech. Note No. 10, 4p. (92-04).

From 1981 to 1990, N cycling in a tolerant hardwood forest ecosystem was examined to assess the effects of both natural and management disturbances. The TLW with a stand of old sugar maples was the focus. Nitrogen saturation is attained naturally, although atmospheric additions of NH and NO_3 *make contributions. Disturbances can lead to increased leaching and acidity. Nutrients need to be conserved to maintain forest regrowth.*

Smith, G.K.M., N.W. Foster, P.W. Hazlett, I.K. Morrison and J.A. Nicolson. 1992. Acid rain increases nutrient leaching in a tolerant hardwood forest soil. Forestry Canada, Ont. Region, Frontline Tech. Note No. 12. (92-06).

Leaching of nutrient cations from forest soils by acidic anions such as SO_4 *and* NO_3 *can cause imbalances, which weaken trees. Most of the* NO_3 *comes from natural soil reactions, although some is deposited from the atmosphere. Some forest stands have more nutrient reserves and are better able to recover from harvesting or leaching by atmospheric* SO_4 *deposition, but full-tree harvesting may seriously deplete nutrients at a sensitive site.*

Snider, D.M., J. Spoelstra, S.L. Schiff and J.J. Venkiteswaran. 2010. Stable oxygen isotope ratios of nitrate produced from nitrification: 18O-labeled water incubations of agricultural and temperate forest soils. Environmental Science and Technology 44, 5358-5364. (10-03).

Organic-rich soil from the upland forest at the TLW along with mineral soils from a well-tilled agricultural area in Ontario were treated to establish a model to describe the formation of microbial NO_3- using 18O-labeled H_2O. The oxygen isotope exchange between the two types of soils varied widely and demonstrated that the microbial endmember cannot be successfully predicted at present.

Snider, D.M., J.J. Venkiteswaran, S.L. Schiff and J. Spoelstra. Deciphering the oxygen isotope composition of nitrous oxide produced by nitrification. 2012. Global Change Biology 18, 356-370, doi: 10.1111/j.1365-2486.2011.02547.x. (12-05).

In this study, fertilized agricultural soils and unfertilized temperate forest upland and wetland soils from the TLW were aerobically incubated with different 18O/16O waters, and conceptual and mathematical models were developed to systematically explain the d18O-N_2O formed by nitrification. The natural range of nitrifier d18O-N_2O is discussed and explained in terms of our conceptual model, and the controls that define aerobically produced d18O-N_2O are identified. Despite the highly complex nature of d18O-N_2O produced by nitrification the d18O range determined in this study and through the literature is narrow. As a result, in many situations d18O values may be used in conjunction with d15N-N_2O data to apportion nitrifier- and denitrifier-derived N_2O.

Snider, D.M., S.L. Schiff and J. Spoelstra. 2009. 15N/14N and 18O/16O stable isotope ratios of nitrous oxide produced during denitrification in temperate forest soils. Geochim. Cosmochim. Acta 73, 877-888. (09-02).

Soils from upland and wetland sites at the TLW were incubated at different moisture and temperature conditions. N_2O production increased with higher temperatures and soil moistures in all soils, and the rate of production was greater in the wetland soils. The oxygen isotope fractionation was complicated by exchange with water, and quantifying the 18O/16O ratios of N_2O may be useful for characterizing the microbial community in soils.

Spoelstra,J., S.L. Schiff, P.W. Hazlett, D.S. Jeffries and R.G. Semkin. 2007. The isotopic composition of nitrate produced from nitrification in a hardwood forest floor. Geochim. Cosmochim. Acta 71, 3757-3771. (07-01).

Three lysimeters were installed at the TLW in order to measure the isotopic composition of microbial nitrate produced in-situ in forest soils. Microbial nitrate in the forest floor was depleted in 15N relative to that exported in groundwater and headwater streams. It was hypothesized that 15N -depleted forest floor substrate is not detected in groundwater because of immobilization in the mineral soil and mixing with nitrate generated in the mineral soil. The current methods of calculating the d18O of microbial nitrate are shown to give a reasonable value for nitrate from nitrification at the TLW.

Thirukkumaran, C.M. and I.K. Morrison. 1996. Impact of simulated acid rain on microbial respiration, biomass, and metabolic quotient in a mature sugar maple (*Acer saccharum*) forest floor. Can. J. For. Res. 26: 1446-1453. (96-06)

During 1993/94, four plots on the forest floor at the TLW were experimentally acidified with H_2SO_4 and HNO_3, singly and in combination, to assess the effects on microbiological processes. No adverse effects could be measured in situ in 1994, but laboratory measurements showed microbial respiration ratios to be reduced in the L or FH layers when both acids were applied. Thus the possibility of damage due to soil acidification in the long-term is indicated.

Webster, K.L., I.F. Creed, F.D. Beall and R.A. Bourbonnière. 2008. Sensitivity of catchment-aggregated estimates of soil carbon dioxide efflux to topography under different climatic conditions. J. Geophys. Res. 113, G03040, 14p. (08-04).

Patterns of soil respiration (Rs) are important in estimating regional carbon budgets in a forested landscape. Two catchments at the TLW of differing topographic features were examined and it was found that a minimum of three features (upland, transition and wetland) were needed for accurate estimates of catchment-aggregated soil respiration (CAR). The critical transition zone had the highest rates of Rs under all climatic scenarios. Contributions to CAR become higher under warmer and drier conditions.

Webster, K.L., I.F. Creed, F.D. Beall and R.A. Bourbonnière. 2011. A topographic template for estimating soil carbon pools in forested catchments. Geoderma 160 (3-4), 457-467, doi:10.1016/j.geoderma.2010.10.016. (11-03).

Small and rare topographic features can have disproportionate effects on soil carbon pools/fluxes, as such, the description and quantification of heterogeneity in forest soil carbon pools is essential for the accuracy of landscape estimates. An automated method to classify topographic features was used to create a template for the collection of samples from different topographical features in a small catchment within the TLW. Significant heterogeneity was found among the classified topographic features in their soil carbon pools, but not in their canopy foliage. This heterogeneity reflects the importance of physical processes in shaping the distribution of soil carbon pools. The creation and application of a topographic template was useful for detecting, strategically sampling, mapping and scaling heterogeneity in forest soil carbon pools.

Webster, K.L., I.F. Creed, M.D. Skowronski and Y.H. Kaheil. 2009. Comparison of the performance of statistical models that predict soil respiration from forests. Soil Science Society of America Journal 73 (4), 1157-1167, doi:10.2136/sssaj2008.0310. (09-06).

Numerous statistical models have been developed to explain Rs as a function of physical and chemical conditions, but the performance of these models has not been adequately evaluated. Soils in the TLW were monitored for Rs and its physical and chemical drivers, and the data was used to fit statistical models and compare their performance. An exponential model in which the exponent is a polynomial expression, linear with respect to temperature and quadratic with respect to soil moisture explained 57% of the variance in Rs, and was improved to 71% following the inclusion of C quantity and substrate quality of the soils. These findings support the identification of Rs controls within an ecosystem in order to assess the generality of these controls on Rs across ecosystems using statistical models and analysis.

Webster, K.L., I.F. Creed, R.A. Bourbonnière and F.D. Beall. Controls on the heterogeneity of soil respiration in a tolerant hardwood forest. 2008. Journal of Geophysical Research 113, G03018, doi:10.1029/2008JG000706. (08-07).

The spatial and temporal distribution of Rs in forested landscapes and its control by environmental conditions and carbon pools has not been sufficiently investigated. An Rs monitoring strategy targeting different topographic features within the TLW revealed that critical transition zones yielded significantly larger Rs than adjacent upland or wetland portions of the catchments. Environmental conditions (soil temperature and moisture) explained the majority of variance in Rs. This study highlighted the critical transition zone as major sites of Rs because of the existing synchronicity between optimal temperature and moisture conditions during the growing season and the large pool of high quality substrate.

Webster, K.L., I.F. Creed, T. Malakoff and K. Delaney. Potential vulnerability of deep carbon deposits of forested swamps to drought. 2014. Soil Science Society of America Journal 78 (3), 1097-1107, doi:10.2136/sssaj2013.10.0436. (14-02).

Summer droughts are occurring with greater regularity and intensity due to climate warming. These changes raise concerns for the decomposition of C stores found beneath the water table in saturated peat. Saturated peat cores from the TLW underwent artificial drying and were monitored for daily CO_2 production and for potential drivers of CO_2 production (peat quality, microbial biomass, and enzyme activity) in order to measure the effect of desiccation on CO_2 production. CO_2 production was found to be highest in the top 30cm of the peat profile, at intermediate volumetric water contents. The low quality (high C/N) of peat in the catotelm limits rapid release of CO_2 with water table declines.

Yin, X, N.W. Foster and P.A. Arp. 1993. Solution concentrations of nutrient ions below the rooting zone of a sugar maple stand: relations to soil moisture, temperature, and season. Can. J. For. Res. 23: 617-624. (93-06).

Ion concentrations in soil solutions from the TLW forest floor were analyzed with respect to soil water characteristics, temperature and season. During the foliage period, NO_3 concentrations responded to forest floor percolation, soil water content and season, and during the non-foliage period related to season only. SO_4, Ca_{2+}, and Mg_{2+} varied with NO_3 concentrations, and to season to a lesser extent. K^+ and NH_{4+} were only weakly correlated to the other variables, reflecting an affinity with the soil colloids.

HYDROLOGY - SOIL WATER/GROUND WATER

Hydrology: Soil Water/Ground Water publications are primarily papers reporting shallow and deep soil profile water chemical conditions, at permanent sampling locations and at other opportunistic locations for specific projects (Figure 7 and 8). Much of the research in this category has been conducted by Natural Resources Canada - Canadian Forest Service, Environment and Climate Change Canada – National Water Research Institute and Environment and Climate Change Canada – National Hydrology Research Institute.

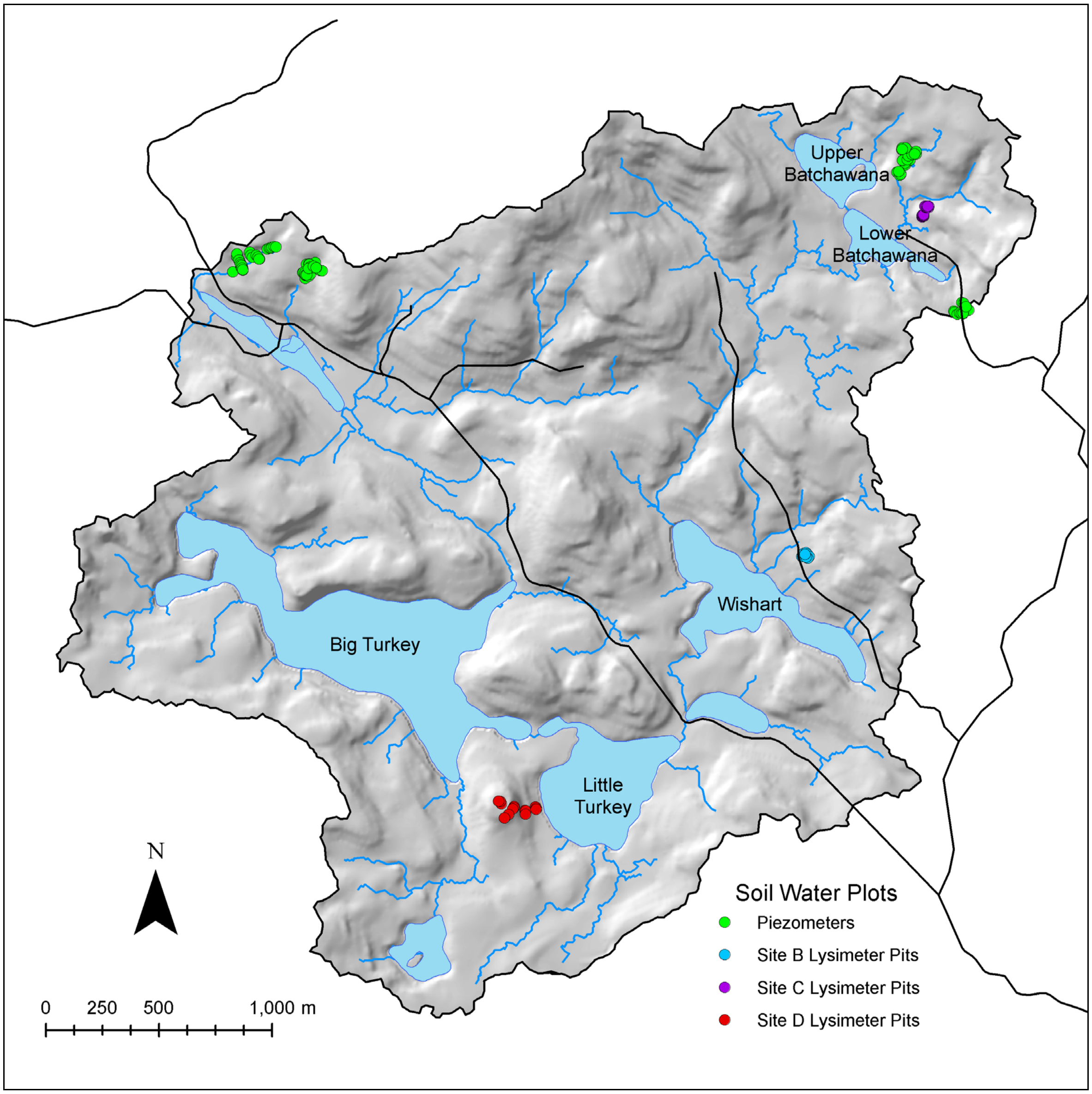


Figure 7. Soil water plots in the TLW.

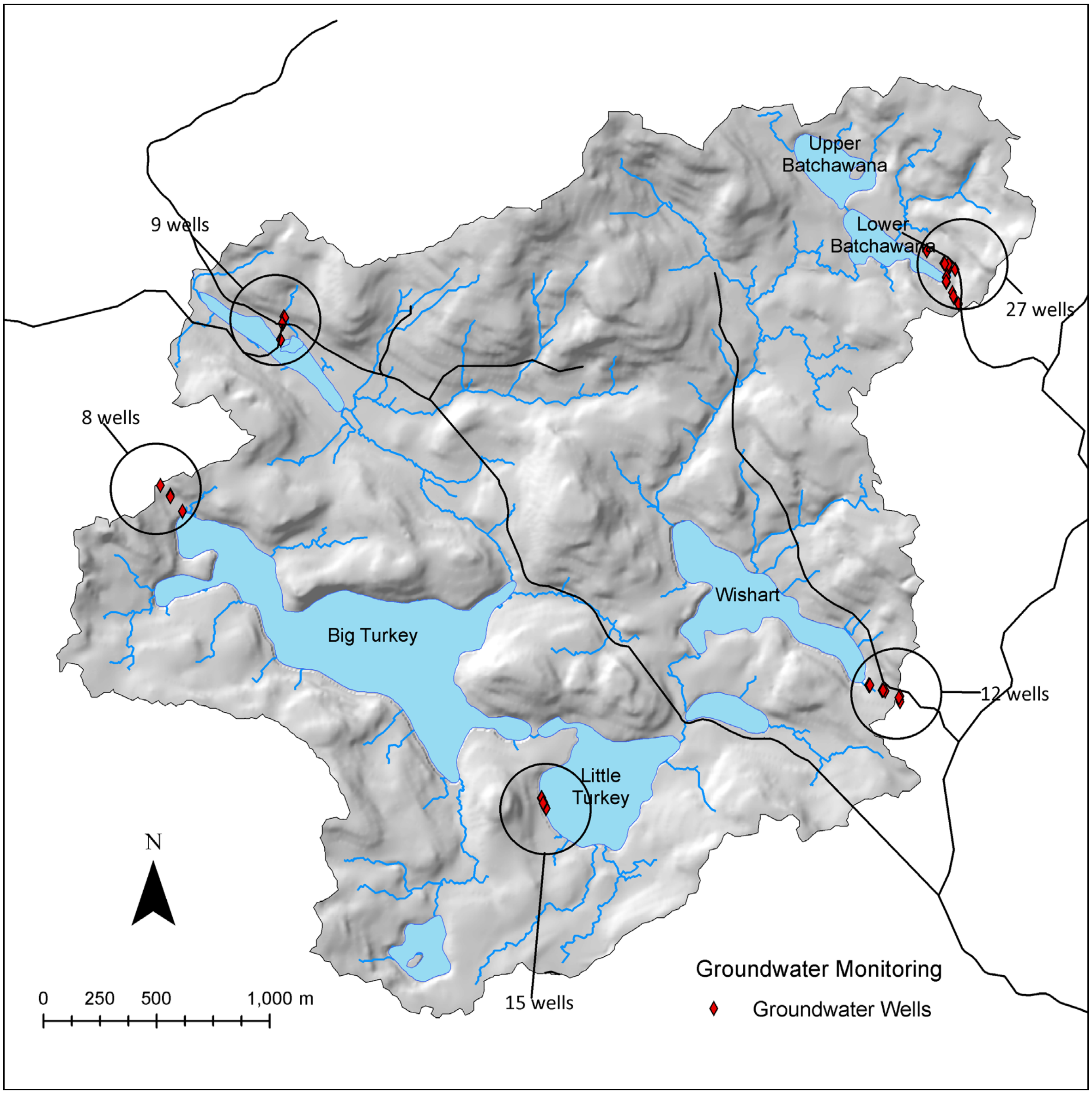


Figure 8. Groundwater wells located in the TLW.

PUBLICATIONS

Blancher, P.J. and D.K. McNicol. 1987. Peatland water chemistry in central Ontario in relation to acid deposition. Wat Air Soil Pollut 35: 217-232. (87-18).

The chemical variation of peatland waters in samples taken from the acidic Sudbury area and the less acidic Ranger Lake district (near the TLW) was statistically separated into three components related to natural organic, mineral and deposition sources. H^+ variation was related to organic C concentration, while sulphate was positively associated with acidity and Ca was negatively associated with acidity.

Bottomley, D.J., D. Craig and L.M. Johnston. 1984. Neutralization of acid runoff by groundwater discharge to streams in Canadian Precambrian Shield watersheds. J. Hydrol. 75: 1-16. (83-23).

Report presents an application of environmental isotope techniques during storm and snowmelt runoff from the Harp Lake and Turkey Lakes watersheds which indicate that sub-surface, pre-event water is a major component of the runoff hydrograph. Because the alkalinity of groundwater is large compared to the precipitation acidity of these regions, groundwater discharge results in significant neutralization of runoff acidity.

Buttle, J.M., P.W. Hazlett, C.D. Murray, I.F. Creed, D.S. Jeffries and R. Semkin. 2001. Prediction of groundwater characteristics in forested and harvested basins during spring snowmelt using a topographic index. Hydrological Processes 15: 3389-3407. (01-04).

Piezometric surface elevations were monitored during snowmelt in two sub-basins in the TLW (one mature hardwood and one clearcut) during the spring of 2000 to test a hypothesized link between groundwater characteristics and topographic indices. A relationship was not confirmed but the potential to use groundwater residence time to evaluate the effects of forest harvesting was discussed. d18O values were measured for input water and groundwater to establish groundwater residence times.

Chew, H., L.M. Johnston, D. Craig and K. Inch. 1988. Aluminum contamination of groundwater: spring melt in Chalk River and Turkey Lakes Watersheds -- preliminary results. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 66-71. (88-11).

Aluminum speciation of episodically acidified, near-surface groundwaters is reported for two watersheds in central Ontario. There are significant differences in the distribution of four species measured between the watersheds; pH appears to be the controlling factor. Differing carbonate content in the tills is also important.

Craig, D. and L.M. Johnston. 1988. Acid precipitation and groundwater chemistry at the Turkey Lakes Watershed. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 59-65. (88-14).

Groundwater chemistry in the TLW is dominated by weathering of carbonates present in the till. Flow pathways and flow rates account for variable groundwater quality. Hence the reservoir of acid-neutralizing capacity (ANC) provided by groundwaters for surface waters in the basin is highly site specific.

Craig, D. and L.M. Johnston. 1988. Acidification of shallow groundwaters during the spring melt period. Nordic Hydrol. 19: 89-98. (88-05).

Factors controlling the occurrence of episodic shallow groundwater acidification in the TLW are discussed. Acid neutralizing capacity (ANC) and pH depressions are observed when the H^+ loading rate exceeds the ANC supply rate by dissolution of $CaCO_3$ present in the till.

Creed, I.E., S.E. Sanford, F.D. Beall, L.A. Molot and P.J. Dillon. 2003. Cryptic wetlands: integrating hidden wetlands in regression models of the export of dissolved organic carbon from forested landscapes. Hydrological Processes 17, 3629-3648. (03-11).

Cryptic or hidden wetlands make an important contribution to DOC export in the TLW. Manually derived wetland areas using a global positioning system explained the variation in DOC export better than automatically derived estimates using a digital elevation model. Thus aerial photography and satellite imagery may not accurately record hidden wetland areas in forested landscapes.

Creed, I.F. and F.D. Beall. 2009. Distributed topographic indicators for predicting nitrogen export from headwater catchments. Wat. Resourc. Res. 45, W10407, 12p. (09-05).

With the objective of determining whether topographic indicators can be used as a means to predict spatial variation in dissolved N export from watersheds, data from the spring melt at the TLW were employed in a conceptual model of hydrologic flushing of dissolved N. Distributed topographic indicators proved to be good predictors of the majority of variation in N export, and thus may be useful in extrapolating variances in unmonitored watersheds.

Creed, I.F., L.E. Band, N.W. Foster, I.K. Morrison, J.A. Nicolson, R.S. Semkin and D.S. Jeffries. 1996. Regulation of nitrate-N release from temperate forests: a test of the N flushing hypothesis. Wat. Resourc. Res. 32: 3337-3354. (96-03).

Spatial and temporal variability in the release of nitrate-nitrogen from the TLW are investigated using a hydro-ecological model. Two mechanisms governing the release of N were indicated: N-flushing (spring snowmelt and autumn stormflow) and N-draining (slow release from groundwater of N translocated from upper soil layers during spring snowmelt).

Creed, I.F. and L.E. Band. 1998. Exploring functional similarity in the export of nitrate-N from forested catchments: a mechanistic modeling approach. Water Resources Research 34, 3079-3093. (98-08).
The functional similarity concept was applied to the export of NO_3^- - N from catchments within the TLW. The similarity indices, which are topographically based, explained up to 58% of the export variance where base concentrations of NO_3^- - N were not elevated. Where catchments are functionally similar, dissimilar N-export responses can be accounted and responses in other regions can be generalized. The similarity indices captured NO_3^- - N concentrations exported from shallow flow paths but did not capture NO_3^- exported from deep flow paths. Future similarity indices should include information about both flow paths.

Creed, I.F. and L.E. Band. 1998. Export of nitrogen from catchments within a temperate forest: evidence for a unifying mechanism regulated by variable source area dynamics. Water Resources Research 34, 3105-3120. (98-07).

The variability of N-export among forested catchments in the TLW is large. A rise in water table levels causing nutrients to be "flushed" from soils to surface water is important for explaining NO_3- export. Catchment-specific "flushing" behaviours were quantified using the time interval required for a decline in N concentration to 37% of their initial concentration. Topography is postulated to be the key to flushing variability and export of NO_3^- - N. Additional research is needed to understand processing and export of dissolved organic nitrogen (DON).

English, M.C., D.S. Jeffries, N.W. Foster and R.G. Semkin. 1986. A preliminary assessment of the chemical and hydrological interaction of acidic snowmelt water with the terrestrial portion of a Canadian Shield catchment. Wat. Air Soil Pollut. 31:27-34. (86-14).

Interaction of spring melt runoff with the terrestrial ecosystem is examined using an extremely large, hillslope snow lysimeter. Formation of ice lenses in the snowpack are responsible for lateral movement of meltwaters prior to contact with the ground. Subsurface waters are much more acidic in the lower portion of the hillslope than at the top.

English, M.D., R.G. Semkin, D.S. Jeffries, P.W. Hazlett, and N. Foster. 1987. Methodology for investigation of snowmelt hydrology and chemistry within an undisturbed Canadian Shield watershed. In: Jones, H.G. and W.J. Orville-Thomas (eds.), Seasonal snowcovers; physics, chemistry, hydrology. D. Reidel Publishing Co., Dordrecht, Holland, 467-499. (87-11).

This paper examines methodology involved in intensive snowmelt runoff studies in the TLW. These studies focus on understanding the pathways of snowmelt water within the snowpack and through the terrestrial portion of the ecosystem. Mixing of snowmelt or snowmelt induced runoff water and lake water is investigated.

Foster, N.W. 1985. Acid precipitation and soil solution chemistry within a maple-birch forest in Canada. Forest Ecol. and Managem. 12: 215-231. (85-03).

Ion fluxes through the forest canopy and soils of the TLW is discussed (see 85-02). Bulk deposition represents only a small proportion (17%) of the annual flux of cations reaching the forest floor but did constitute a greater proportion for SO_4 (85%) and NO_3 (45%). Both SO_4 and NO_3 are largely unreactive in the mineral soils and therefore play a dominant role in controlling cation mobility.

Foster, N.W. 1984. Neutralization of acid precipitation within a maple-birch ecosystem. TAPPI Journal 68(8):104-106. (84-13).

The influence of acid deposition on the ionic composition of throughfall, forest floor percolate, and mineral soil solution was studied. Rainfall acidity was reduced 50% on passage through the canopy and subsequently, almost all of the remainder was consumed on entry into the mineral soil horizons.

Foster, N.W. and J.A. Nicolson. 1983. Acid precipitation and vegetation interaction in the Turkey Lake Forest Watershed. Can. For. Serv. Res. Notes, 3(2): 6-7. (83-07).

The magnitude of the chemical changes of precipitation as it passes through the forest canopy and near surface soils is discussed. Data for 1980 and 1981 were analyzed. Tables of mean concentrations and inter-element correlations are presented.

Foster, N.W. and J.A. Nicolson. 1983. Ion transfer through a tolerant hardwood canopy, Turkey Lakes Watershed, Ontario. Proc. Conf. Acid Rain and For. Resourc., Quebec City. (see 91-05) (83-17).

The ionic composition of bulk precipitation, throughfall, and stemflow was determined and compared for 1981 in the sugar maple-yellow birch forest which dominates the TLW. During the dormant (leafless) season, throughfall and precipitation were similar except for K^+, while during the growing season throughfall was depleted in H^+ and NO_3- and enriched in Ca_{2+}, K^+, and SO_4 relative to precipitation. Throughfall was the major process of element transfer to the soil; stemflow accounted for only 1-10%. Comparison of results from other North American hardwood forests is presented.

Foster, N.W. and J.A. Nicolson. 1988. Acid deposition and nutrient leaching from deciduous vegetation and podzolic soils at the Turkey Lakes Watershed. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 96-100. (88-15).

Paper summarizes the changes in ion concentrations and fluxes (1981-1985) for precipitation as it passes through the canopy to the mineral soils. Hydrogen ion neutralization occurs both in the canopy and soils. Sulphate is an important counter-ion to K^+ leached from the vegetation. Acid deposition has only a minor effect on the composition of stemflow and forest floor percolate. Calcium and Mg_{2+} is leached from the mineral soils in association with SO_4 and NO_3. Sources of SO_4 and NO_3 are discussed.

Foster, N.W. and P.W. Hazlett. 1991. The influence of reductions in atmospheric sulphate deposition on ion leaching from podzolic soils under hardwood forest. *In*: Longhurst, J.W.S., (ed.), Acid deposition. Origins, impacts and abatement strategies. Springer- Verlag, New York, 179-191. (91-06).

Annual fluxes of SO_4 through the forest canopy and podzolic soil at TLW in central Canada decreased in response to reductions in atmospheric SO_4 deposition. Despite these reductions, there was no additional release of previously adsorbed SO_4 from the soil. In the absence of changes in NO_3 cycling, changes in SO_4 alone can reduce base leaching from the TLW soil. Controlling emissions to reduce SO_4 inputs to forested watersheds will reduce SO_4 leaching from podzolic soils similar to those examined in the TLW.

Foster, N.W. and P.W. Hazlett. 2002. Trends in water chemistry in a maple forest on a steep slope at the Turkey Lakes Watershed. Wat. Air Soil Pollut.: Focus 2, 23-36. (02-07).

The chemistry of bulk precipitation and soil percolate from the forest floor and below the main rooting zone of a mature maple forest on a steep slope were analyzed to identify monotonic trends. Over the monitoring period (1985-1998), SO_4 in precipitation, and SO_4, Ca and Mg in soil waters showed significant negative trends. From 1991 to 1998, only soil SO_4 declined during spring melt.

Foster, N.W., I.K. Morrison and J.A. Nicolson. 1986. Acidic deposition and ion leaching from podzolic soil under hardwood forest. Wat. Air Soil Pollut. 31: 879-889. (86-12).

The contribution of anthropogenic (SO_4 and NO_3) and natural organic acids to cation leaching from a podzolic soil is examined. Soils exhibit little SO_4 adsorption in the TLW. Current atmospheric inputs of SO_4 and NO_3 contribute significantly to cation leaching. Areal weathering rates needed to maintain soil base cation content at current levels are calculated.

Foster, N.W., J.A. Nicolson and I.K. Morrison. 1991. Acid deposition and element cycling in Eastern North American forests. *In*: Rennie, P.J., and G. Robitaille, (eds.), Effect of acid rain on forest resources. Proc. Conf. 14-17 June 1983, Sainte-Foy, Que. For. Can. Inf. Rep. DPC-X-35, 251-265. (91-07).

Paper reviews current knowledge on the relationship between atmospheric acid deposition and element fluxes in major Eastern North American forest types, with TLW as a reference. Atmospheric N input is insignificant compared with ecosystem concentrations, and the N cycle is maintained. Sulphate concentrations are 70% of the total base cation concentrations in soil waters and atmospheric input of SO_4-S contributes significantly to the loss of K^+, Ca_{2+}, Mg_{2+}, and Na^+. A reduction in sulphur emissions should reduce cation losses.

Foster, N.W., J.A. Nicolson and P.W. Hazlett. 1989. Temporal variation in nitrate and nutrient cations in drainage waters from a deciduous forest. J. Environ. Qual.18(2): 238- 244. (88-36).

Temporal variability of inorganic N in soil solutions and streamwaters (1984) was examined. Dormant season streamwater NO_3 levels were significantly, positively correlated with mineral soil-solution concentrations of NO_3 and Ca_{2+}. During snowmelt, mineral soil-solution NO_3 was higher than that passing through the forest floor. Elevated concentrations of NO_3 observed in streams during spring melt are derived from transport of this soil solution.

Foster, N.W., P.W. Hazlett, J.A. Nicolson and I.K. Morrison. 1989. Ion leaching from a sugar maple forest in response to acidic deposition and nitrification. Wat. Air Soil Pollut. 48: 251-261. (88-35).

Annual variation in ion deposition and soil leaching (1981-86) was examined. Throughfall input of SO_4 and NO_3-N ranged from 493-917 and 261-443 eg/ha/yr respectively. Nitrate concentrations in throughfall and forest floor percolate declined, but mineral soil-solution values increased. A shift in the relative importance of SO_4 vs NO_3 leaching of cations from the mineral soil (NO_3 increasing) was observed due to increased production of excess NO_3 within the soil column. The NO_3 efflux from the mineral soil (below the rooting zone) greatly exceeded atmospheric deposition while SO_4 efflux was only moderately greater.

Foster, N.W. and J.A. Nicolson. 1986. Trace elements in the hydrologic cycle of a tolerant hardwood forest ecosystem. Wat. Air Soil Pollut. 31: 501-508. (86-11).

Concentrations and annual (1983) fluxes of Fe, Al, Mn, Cu and Pb in bulk precipitation, throughfall, stemflow, forest floor percolate, mineral soil solution and streamflow are presented. The biogeochemical cycling of these metals is discussed. Atmospheric inputs and watershed outputs are low; however, intermediate portions of the cycle do exhibit higher concentrations for some metals.

Foster, N.W., and J.A. Nicolson. 1991. Ion transfer through a tolerant hardwood canopy, Turkey Lakes watershed, Ontario. *In*: Rennie, P.J. and G. Robitaille, (eds.), Effect of acid rain on forest resources. Proc.Conf. 14-17 June 1983, Sainte Foy, Que. For.Can., Inf. Rep. DPC-X-35, 419-427. (91-05).

During 1981, element concentrations in throughfall, precipitation and stemflow were measured in a sugar maple stand at TLW; growing and dormant seasons were compared. Throughfall was the main source for the transfer of elements to the soil, while stemflow contributed only 1-10% of the total. Throughfall was richer in bases and SO_4-S during the growing season. The role of H^+ in promoting base leaching from the forest canopy is discussed.

Hay, G.W., J.H. James and G.W. VanLoon. 1985. Solubilization effects of simulated acid rain on the organic matter of forest soils: preliminary results. Soil Science 139: 422-430. (85-07).

Pore water concentrations of organic carbon, total carbohydrate, fulvic acid, and ammonium-plus-amino nitrogen was evaluated for the same study as 85-05. Highest carbon concentrations occurred in the soil columns irrigated with the highest "rainfall" pH.

Hazlett, P.W. and N.W. Foster. 2002. Topographic controls of nitrogen, sulfur, and carbon transport from a tolerant hardwood hillslope. Wat. Air Soil Pollut.: Focus 2, 63-80. (02-12).

To examine nutrient budgets for steep slopes, lateral movement of water and nutrients on a one-hectare area at the TLW were measured during 1987-1990. Nutrient concentrations and fluxes varied with slope position, reflecting the soil horizons through which the water passed. Greater NO_3, SO_4 and DOC concentrations flowed from the upper slopes, while less-developed mineral soils on the lower slopes retained SO_4, N and C influencing nutrient input to the lake.

Hazlett, P.W., M.C. English and N.W. Foster. 1990. A volume recorder for lysimeter waters. Soil Sci. Soc. Am. J. 54: 1503-1505. (90-01).

Paper presents a design for a volume recorder to measure large volumes of water from lysimeters. The unit is compact, portable, and inexpensive, and can be used at year-round field locations.

Hazlett, P.W., M.C. English and N.W. Foster. 1992. Ion enrichment of snowmelt water by processes within a podzolic soil. J. Environ. Qual. 21(1): 102-109. (92-03).

The spring snowmelt of 1986 at the TLW was collected to determine ion concentrations in runoff, forest-floor percolate, and mineral soil percolate. Sulphate, NO_3 and Ca_{2+} concentrations increased as meltwater passed through forest-floor soils, while H^+ decreased. The steep topography of the area means that the runoff water strongly influences surface water chemistry in the spring.

Hazlett, P.W., R.G. Semkin and F.D. Beall. 2001. Hydrologic pathways during snowmelt in first order stream basins at the Turkey Lakes Watershed. Ecosystems 4, 527-535. (00-02).

Stream and soil water composition in two basins at the TLW during spring melt episodes of 1992-1996 were analyzed to determine snowmelt pathways and chemical response to episodic acidification. Dissolved SiO_2 and H^+ in stream and shallow soil water were positively correlated at both sites, indicating a significant contribution by shallow soil water to both stream flow and chemistry during snowmelt.

Hazlett, P.W. and N.W. Foster. 1989. Sources of acidity in forest-floor percolate from a maple-birch ecosystem. Wat. Air Soil Pollut.46: 87-97. (88-33).

Ion concentrations and fluxes in throughfall and forest-floor percolate from the TLW (collected 1982-84) were examined to determine sources of acidity and the extent of cation leaching from forest-floor horizons. H^+ deposition from throughfall accounted for 100% of the forest-floor flux in the dormant season and 40% in the growing season. Both internal watershed sources of NO_3 and organic anions and external sources of NO_3 and SO_4 influenced cation mobility in the forest floor.

Hendershot, W., F. Courchesne and D.S. Jeffries. 1996. Aluminum geochemistry at the catchment scale in watersheds influenced by acidic deposition. *In*: Sposito, G.A., (ed.), The Environmental Chemistry of Aluminum, 2nd Edition, CRC Press. Boca Raton, Fl., Chapter 10, 419-449. (95-03).

A significant revision of 88-03.

Jeffries, D.S. 1990. Snowpack storage of pollutants, release during melting, and impact on receiving surface waters. *In*: Norton, S.A., S.E. Lindberg and A.L. Page (eds.), Acid Precipitation, Vol. 4: Soils, Aquatic Processes, and Lake Acidification, Springer-Verlag, 107-132. (88-29).

This paper is a review of snowpack chemistry and the physical/chemical processes that control pollutant release during melting. It draws heavily on data and interpretation from the TLW to illustrate the points.

Jeffries, D.S., R.G. Semkin and M.C. English. 1987. Integrated snowmelt studies in the Turkey Lakes Watershed. Proc. Internat. Symp. on Acidification and Water Pathways, Bolkesjo, Norway, Vol. 2, 199-208. (87-10).

Report presents an overview of snowmelt studies conducted in the TLW to determine the physical and chemical processes that control the occurrence of episodic acidification in the TLW. (see 86-14, 86-17, 87-11).

Jeffries, D.S., T.A. Clair, P.J. Dillon, M. Papineau and M.P. Stainton. 1995. Trends in surface water acidification at ecological monitoring sites in southeastern Canada (1981- 1993). Water Air and Soil Pollution, 85: 577-582. (95-05).

Atmospheric deposition and surface water chemistry at five geologically sensitive sites in southeastern Canada have been monitored. Surface water data from nine stations in Quebec and central Ontario collected over 13 years were analyzed for monotonic trends. While Ontario sites (Experimental Lakes Area and TLW) show negative SO_4 trends, one station at TLW and one in Quebec (MTM) are continuing to acidify. Longer data records are needed to verify acidification recovery.

Jeffries, D.S. and W.H. Hendershot. 1987. Aluminum geochemistry at the catchment scale in watersheds influenced by acidic precipitation. *In*: Sposito, G. (ed.), Environmental chemistry of aluminum, CRC Press, Boca Raton, Florida, 279-302. (88-03).

Paper presents a review of the hydrological and geochemical factors that influence Al chemistry at the catchment scale. Data and interpretation from the TLW and basins in southern Quebec are used to present and illustrate the points made.

Johnson, D.W. and M.J. Mitchell. 1998. Responses of forest ecosystems to changing sulfur inputs. *In*: Sulfur in the Environment, D.G. Maynard (ed.) Marcel Dekker Inc., New York, N.Y. 1998, 371 pp. Chapter 7, p219-262. (98-12).

The Turkey Lakes Watershed is one of the sites considered in a review of sulphur cycling in forests, and especially the impact of decreased sulphur inputs. Of 28 forested sites throughout the world, the TLW ranks eleventh in the magnitude of atmospheric S input. A useful comparison of TLW characteristics to those from other catchments.

Johnston, L.M., D. Craig and D.J. Bottomley. 1985. Interaction des pluies acides et des eaux souterraines. Sciences et Techniques de l'Eau 18(2): 165-167. (85-08).

Paper summarizes three studies (at Chalk R., Harp L., and TLW) investigating the interaction of acidic deposition and groundwaters. The TLW section describes the determination of the groundwater fraction of spring melt streamwaters (1981) using 18O as presented in 83-23 (See also 86-03). The report concludes that the groundwater supply of ANC can be an important factor in reducing the effects of acidic deposition.

Johnston, L.M. and D. Craig. 1989. Groundwater and acid rain. Nat. Hydrol. Res. Inst. Contribution No. 89032, 8p. (89-05).

A discussion of the implications of groundwater acidification due to acidic precipitation. In groundwaters of the TLW, pH depressions are attributed to weathering of aluminum-silicate minerals, but these acid conditions could become permanent. Long-term monitoring is recommended.

Mitchell, M.J., N.W. Foster, J.P. Shepard and I.K. Morrison. 1992. Nutrient cycling in Huntington Forest and Turkey Lakes deciduous stands: nitrogen and sulfur. Can. J. For. Res. 22: 457-464. (92-08).

A comparison of biogeochemical cycling in these two hardwood sites, Turkey Lakes being the older, shows a much greater leaching of NO_3 at TLW. At HF, water leached from the forest floor through the mineral soils showed an increase in SO_4 flux. The C:N ratio at TLW was narrower (16:1 vs 34:1) and should favour accumulation of nitrogen and subsequent NO_3 leaching. Stand age and the absence of beech leaf litter at TLW contribute to higher NO_3 leaching.

Monteith, S.S., J.M. Buttle, P.W. Hazlett, F.D. Beall, R.G. Semkin and D.S. Jeffries. 2006. Paired-basin comparison of hydrological response in harvested and undisturbed hardwood forests during snowmelt in central Ontario: I. Streamflow, groundwater and flowpath behaviour. Hydrol. Process. 20, 1095-1116. (06-03).

In a paired-basin study at the TLW, impacts of forest harvesting on groundwater hydrology were examined. Topographic indices were evaluated but inconsistently explained variations between the two basins. Harvesting appears to have increased melt rates and thus the volume of stream runoff via surface and near-surface pathways.

Monteith, S.S., J.M. Buttle, P.W. Hazlett, F.D. Beall, R.G. Semkin and D.S. Jeffries. 2006. Paired-basin comparison of hydrological response in harvested and undisturbed hardwood forests during snowmelt in central Ontario: II. Streamflow sources and groundwater residence times. Hydrol. Process. 20, 1117-1136. (06-04).

In a paired-basin study at the TLW, event-water flux and contribution to peak streamflow during snowmelt was greater in a harvested basin 4 years after harvesting, possibly reflecting increased daily melt rates following harvesting. Both isotopic (d18O) and geochemical (chloride) tracers gave comparable hydrograph separation results (hence the latter is a conservative tracer at the TLW). Groundwater residence times did not vary with depth between basins. Spatial variations such as conductivity and till thickness are also important in understanding groundwater behaviour after harvesting.

Morrison, I.K. and N.W. Foster. 1986. Effects of acidic deposition on nutrient cycling in northern hardwood forests. *In*: Mroz, G.D. and D.D. Reed (eds.), Proc. Conf. Northern Hardwood Resource: Management and Potential, Houghton, Michigan, 139-155. (86-22).

Report presents a summary of the results from the GLFC intensive biogeochemical studies conducted in the TLW. Information on throughfall, forest floor percolate, mineral soil solution, till composition, vegetation and litter composition are included. Some differences were observed between the two sites of intensive study in the watershed; however, both still contain a large reserve for neutralization of present levels of acidic deposition.

Morrison, I.K., N.W. Foster and J.A. Nicolson. 1992. Influence of acid deposition on element cycling in mature sugar maple forest, Algoma, Canada. Wat. Air Soil Pollut. 61: 243-252. (92-07).

This study examines the impact of the long-range transport of air pollutants on biogeochemical processes in the sugar maple stands of the TLW. Throughfall is enriched in K^+, while the cations of the forest floor soil waters are dominated by Ca_{2+}. Atmospheric inputs of SO_4 and NO_3 are moderate, and distributed throughout the year, but they contribute to leaching of bases within the forest floor and upper mineral soil. Element recycling will probably preserve a balance at the site.

Murray, C.D. and J.M. Buttle. 2003. Impacts of clearcut harvesting on snow accumulation and melt in a northern hardwood forest. J. Hydrol. 271: 197-212. (03-02).

Snow depth and melt at a clearcut were compared to that at an undisturbed maple stand at the TLW. Daily melt was higher in the clearcut, but south-facing sites melted faster than north-facing sites in both cases. More meltwater is delivered from clearcut sites to the soil surface and receiving waters, and at a greater rate than that from the undisturbed forested stands.

Murray, C.D. and J.M. Buttle. 2005. Infiltration and soil water mixing on forested and harvested slopes during spring snowmelt, Turkey Lakes Watershed, central Ontario. Journal of Hydrology 306, 1-20. (05-02).

A combined hydrometric and isotopic tracer approach was used on a slope at the TLW to examine the effect of harvesting on water infiltration and storage in the soil profile. Pre-melt and daily water inputs were measured during the 2000 and 2001 snowmelts. Total water input was greater to the harvested soil surface relative to a forest site. Harvesting on slopes is seen to promote increased subsurface flow and overland flow during snowmelt.

Nicolson, J.A., D. Craig and N.W. Foster. 1987. Precipitation, surface and subsurface water chemistry in a tolerant hardwood forest basin. Proc. Internat. Symp. Acidification and Water Pathways, Bolkesjo, Norway, 91-100. (87-03).

Water quality in various compartments of the Wishart Lake terrestrial basin is evaluated. Shallow groundwaters are dominated by Ca_{2+} and SO_4, while deeper groundwaters and streams by Ca_{2+} and ANC. Geochemical weathering of $CaCO_3$ in the till is the major reaction controlling ANC levels. Hydrological pathways are important.

Schiff, S.L., J. Spoelstra, R.G. Semkin and D.S. Jeffries. 2005. Drought induced pulses of *SO_4* from a Canadian Shield wetland: use of S and O in SO_4 to determine sources of sulfur. Applied Geochemistry 20, 691-700. (05-03).

Stable isotopes of S and O are used to determine the source of high S in the watershed following drought conditions. S isotope measurements in streams and groundwater show that SO_4^{2-} is stored in the upper peat profile of the wetlands. O isotope values show that deep groundwater SO_4 is from organic S reduced and stored and not from a bedrock source.

Semkin, R.G. and D.S. Jeffries. 1988. Chemistry of atmospheric deposition, the snowpack, and snowmelt in the Turkey Lakes watershed. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 38-46. (88-25).

Report presents snow and snowmelt chemistry in the TLW. Comparison of bulk, wet-only and cumulative snowpack permitted evaluation of collector efficiencies and estimation of SO_4 and NO_3 dry deposition. Preferential elution of ions during snowmelt is discussed.

Semkin, R.G., D.S. Jeffries, R. Neureuther and M.D. Seymour. 1989. Major ion chemistry of the pre-melt snowpack, Turkey Lakes Watershed. Proc. Eastern Snow Conf., Quebec City. 277-281, 1989. (89-02).

During a nine-year study, snow cores from the TLW at 10-11 sites were analyzed for major ions and nutrients. H^+, NO_3, and SO_4 accounted for 70% of the snowpack composition. Results are compared with precipitation compositions measured at the CAPMoN network close to the watershed. In the snow core, SO_4 levels were lower than expected.

Semkin, R.G. and D.S. Jeffries. 1986. Storage and release of major ionic components from the snowpack in the Turkey Lakes Watershed. Wat. Air Soil Pollut. 31: 215-222. (86-17).

The chemistry of the snowpack and snowmelt was investigated in 1985. Ion concentrations were 2- to 10-fold higher in early meltwaters compared to the pre-melt snowpack. Fifty percent of the ions were lost during the first 30% of melting. Rain events exerted a major influence on meltwater composition.

Spoelstra, J., S.L. Schiff, R.J. Elgood, R.G. Semkin and D.S. Jeffries. 2001. Tracing the sources of exported nitrate in the Turkey Lakes Watershed using 15N/14N and 18O/16O isotopic ratios. Ecosystems 4, 536-544. (00-04).

Sources of nitrogen exported at basins 31 and 47 (lowland and highland respectively) of the TLW were identified using isotopes of nitrogen and oxygen (the isotopic signature of microbially amended nitrogen is quite different from that of N in atmospheric deposition). At the TLW, nitrification of ammonium appears to be the dominant source of exported N, even during snowmelt.

Thacker, D.J., G.K. Rutherford and G.W. vanLoon. 1987. The effects of simulated acid precipitation in the surface horizons of two eastern Canadian forest Podzol soils. Can. J. For. Res. 17: 1138-1143. (87-14).

Undisturbed soil cores from the TLW and Montmorency Forest (Quebec) were treated to 10m of simulated rain at 3 pH levels. Effects on cation leaching, base saturation, organic C, nitrogen, and others are described. The soils from the two sites behaved similarly. XRD analysis of the clay minerals was also performed.

Watmough, S.A., J. Aherne, C. Alewell, P. Arp, S. Bailey, T. Clair, P. Dillon, L. Duchesne, C. Eimers, I. Fernandez, N. Foster, T. Larssen, E. Miller, M. Mitchell and S. Page. 2005. Sulphate, nitrogen and base cation budgets at 21 forested catchments in Canada, the United States and Europe. Environmental Monitoring and Assessment 109, 1-36. (05-07).

The TLW was one of 21 forested catchments for which input-output budgets for forest soils were assessed to examine the problem of declining base cation levels as a result of acid deposition. SO_4 *concentration in deposition has decreased in 13 of 14 regions and in runoff for 14 of 17 regions.* NO_3^- *- N in deposition decreased in only 1 of 14 regions and in 4 of 17 for runoff. Despite reductions in* SO_4 *and* H^+ *deposition, soils continue to be acidified and the resulting losses of base cations are a concern.*

HYDROLOGY - STREAMS

Hydrology: Stream flows and chemistry are monitored on an ongoing basis at v-notch weirs. Although initially 20 catchments were identified, at this time 13 first-order catchments and six locations along the lake network (the later ending in 2019) within the watershed are monitored (Figure 9). These catchments vary in their topography from upland dominated with steep slopes to those having more moderate relief with swamps. Variation in stream hydrology and chemistry reflect these differences in basin topography and soils. The catchments have a snowmelt-dominated hydrologic regime. Much of the research in this category has been conducted by Environment and Climate Change Canada and Natural Resources Canada - Canadian Forest Service.

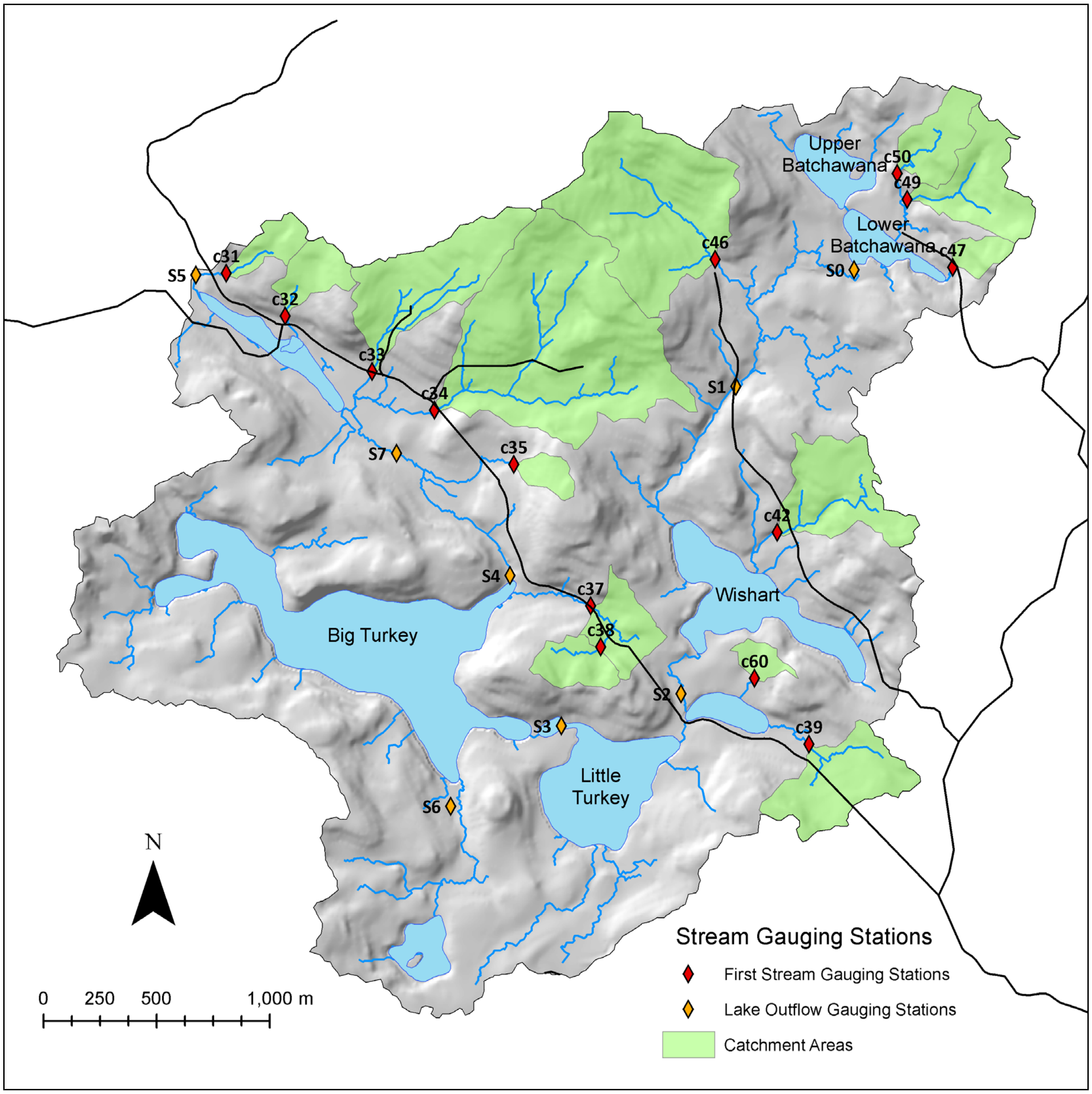


Figure 9. Hydrology map showing stream gauging stations and catchment areas in the TLW.

PUBLICATIONS

Beall, F.D., R.G. Semkin and D.S. Jeffries. 2001. Trends in the output of first-order basins at Turkey Lakes Watershed, 1982-96. Ecosystems 4, 514-526. (01-07).

The TLW has been monitored since 1981 to examine trends related to acidic deposition. The proportion of annual runoff has decreased in winter and increased in spring, Sulphate concentration has decreased but associated recovery responses are not uniform. Cation depletion may be retarding basin recovery from acidification.

Bobba, A.G., D.C. Lam, W.G. Booty, D.S. Jeffries and R.L. Thomas. 1990. Stochastic analysis of acid shocks generated by mixed hydrological processes. Water, Air, and Soil Pollution 53: 239-250. (90-09).

A stochastic model for predicting the probability distribution of the frequency, duration, and magnitude of acidic episodes was applied to stream data from the TLW and Mersey River in Kejimkujik Park, SW Nova Scotia. The model predicts that the maximum frequency of acidic episodes is three per year, 50% of which endure less than 15 days. The model can be used on any watershed affected by acid rain.

Bottomley, D.J., D. Craig and L.M. Johnston. 1986. Oxygen-18 studies of snowmelt runoff in a small Precambrian Shield watershed: implications for streamwater acidification in acid-sensitive terrain. J. Hydrol. 88: 213-234. (86-03).

The groundwater contribution to spring melt runoff in the TLW was evaluated using the 18O technique. At peak runoff, 50-60% is derived from pre-melt groundwater stored in the surficial deposits. Shallow groundwater on hillslopes is susceptible to episodic acidification; hence first order streams experience the greatest pH depressions.

Buttle, J.M., F.D. Beall, K.L. Webster, P.W. Hazlett, I.F. Creed, R.G. Semkin and D.S. Jeffries. 2018. Hydrologic response to recovery from differing silvicultural systems in a deciduous forest landscape with seasonal snow cover**.** Journal of Hydrology doi: 10.1016/j.jhydrol.2018.01.006 (18-02).

Results from a 31-year examination of hydrological response to and recovery from alternative harvesting strategies in a deciduous forest landscape with seasonal snow cover in the TLW. A quantitative means of assessing hydrologic recovery to harvesting was also developed. Clearcutting resulted in increased water year (WY) runoff and increased runoff in all seasons, with greatest relative increases in summer. Direct runoff and baseflow from treatment catchments generally increased after harvesting, although annual peak streamflow did not. Largest WY runoff, seasonal and direct runoff, and baseflow increases occurred in the selection harvest catchment, likely as a result of interception of hillslope runoff by a forest access road and redirection to the stream channel. Hydrologic recovery appeared to begin towards the end of the 31 years, but was incomplete for all harvesting strategies 15 years after harvesting. Harvesting enhanced the relative importance of surface and near-surface water pathways on catchment slopes for all treatments, with the clearcut catchment showing most pronounced and prolonged response.

Buttle, J.M., I.F. Creed and J.W. Pomeroy. 2000. Advances in Canadian forest hydrology, 1995-1998. Hydrol. Process., 14, 1551-1578. (00-12).

The TLW is included in a review of recent progress in understanding hydrological processes in forest landscapes across Canada. A model used by Creed et al. (TOPMODEL) describes flow processes in the TLW basin and postulates episodic N flushing leading to large stream N export. The harvesting project at TLW is listed with ten other forests as a site for monitoring potential impacts due to forest disturbance.

Buttle, J.M., K.L. Webster, P.W. Hazlett and D.S. Jeffries. 2018. Quickflow response to forest harvesting and recovery in a northern hardwood forest landscape. Hydrological Processes 33 (1): 47-65. (18-01).

Hydrologic response to forest harvesting was studied by evaluating catchment quickflow (QF, water delivered rapidly to the stream channel), a metric of high-flow events controlling a catchment's solute and sediment export. A 31-year examination of QF delivery from treatment (clearcut, selection, and shelterwood harvest) and control catchments in a deciduous forest landscape in TLW was conducted. Prior to harvesting, there was no significant increase in QF with P (precipitation) below a threshold P of 35-46mm; however, there was a significant QF vs P relationship below this threshold for all treatments postharvest. Clearcutting increased the number of QF events for the entire postharvest period and the first 9-year postharvest compared to the other treatments; nevertheless, evidence for inter treatment differences in total QF depth delivered from catchments during the growing season was inconclusive.

Christophersen, N., T.A. Clair, C.T. Driscoll, D.S. Jeffries, C. Neal and R. G. Semkin. 1994. Chapter 12 - Hydrochemical studies. *In*: Moldan, B. and J. Cerny (eds.), Biogeochemistry of small catchments: a tool for environmental research. John Wiley & Sons, New York, 285-297. (93-03).

Hydrochemical studies from established catchments in Canada, Norway, the U.K. and the US show the interplay between terrestrial and aquatic environments. Emphasis is placed on carbon cycling and the episodic acidification of streamwaters. The role of mathematical models in integrating the various short- and long-term processes controlling streamwater chemistry is discussed.

Creed, I. F., A.T. Spargo, J.A. Jones, J.M. Buttle, M.B. Adams, F.D. Beall, E.G. Booth, J.L. Campbell, D. Clow, K. Elder, M.B. Green, N.B. Grimm, C. Miniat, P. Ramlal, A. Saha, S. Sebestyen, D. Spittlehouse, S. Sterling, M.W. Williams, R. Winkler and H. Yao. 2014. Changing forest water yields in response to climate warming: results from long-term experimental watershed sites across North America. Global Change Biology 20(10), 3191-3208, doi: 10.1111/gcb.12615. (14-03).

Climate warming is projected to affect forest water yields but effects are expected to vary. Investigation of how forest type and age affect water yield resilience to climate warming was completed using variability in historical water yields over five-year cool and warm periods at catchments, including the TLW, across Canada and the US. Alpine sites showed greatest sensitivity to climate warming. Forest type appeared to influence the resilience of catchment water yields to climate warming, with conifer and deciduous catchments being more susceptible to climate warming than the more diverse mixed forest catchments.

Creed, I. F., G.Z. Sass, F.D. Beall, J.M. Buttle, R.D. Moore and M. Donnelly. 2011. Hydrological principles for water conservation within a changing forest landscape. A State of Knowledge report. Sustainable Forest Management Network, Edmonton, Alberta. Sustainable Forest Management Network, Edmonton, Alberta. 80 pp. (11-04).

This report presents a set of hydrological principles that can be used to inform forest policies and practices and be translated into actions for sustainable forest management in Canada. These principles were developed as part of a backcasting-from-principles approach to planning that envisions a desired future constrained set of principles, and then considers the policy and practical steps necessary to arrive there. Many of the concepts underlying the hydrological principles are currently represented in some provinces and territories and TLW research has contributed to their development. The principles outlined should serve as the first step in opening further dialogue between forest hydrologists, managers and policy makers.

Creed, I. F., G.Z. Sass, F.D. Beall, J.M. Buttle, R.D. Moore and M. Donnelly. 2011. Scientific theory, data and techniques for conservation of water resources within a changing forested landscape. A State of Knowledge report. Sustainable Forest Management Network, Edmonton, Alberta. Sustainable Forest Management Network, Edmonton, Alberta. 136 pp. (11-05).

The objective of this report was to review the state of science resources (including data and tools) behind the sustainable management of forests from the perspective of conserving water resources and minimizing adverse effects resulting from forest management activities. The report provides a current synthesis of field studies and available datasets, as well as the scientific achievements and challenges facing the application of digital tools including digital terrain analysis, remote sensing and hydrological modelling. The report gives recommendations with respect to future research and monitoring endeavours, analysis of integrated datasets and training of the next generation of forest hydrologists and forest managers to promote the practice of sustainable forest management. With many contributions to the body of literature, the TLW is an important component of the work summarized in this report.

Creed, I.F., G.Z. Sass, J.M. Buttle and J.A. Jones. 2001. Hydrological principles for sustainable management of forest ecosystems. Hydrological Processes 25 (13), 2152-2160, doi: 10.1002/hyp.8056 (11-01).

This commentary originates from a Canadian project seeking to synthesize the state of knowledge on the implications of forest management activities on water resources under a changing global climate. This synthesis included previous reviews of science based on decades of watershed studies, policy, planning and operational practices, as well as interviews and workshops with scientists and managers. Work at the TLW contributed to the synthesis of the principles, guidelines and framework outlined in the paper. These principles are embedded within a systems approach to guide forest management on its way to a desired future with safe and secure water supplies.

Creed, I.F., T. Hwang, B. Lutz and D. Way. 2015. Climate warming causes intensification of the hydrological cycle, resulting in changes to the vernal and autumnal windows in a northern temperate forest. Hydrological Processes 29: 3519-3534. (15-05).

An investigation into whether rising temperatures altered timing of snowmelt and snowpack accumulation or extended forest growing season length in the TLW. Vernal (spring) and autumnal (fall) windows were defined using archived satellite imagery to track changes in timing of snowpack loss/gain and canopy leaf on/off in the Batchawana watershed and TLW. Archived time series (1983-2009) of temperature, precipitation and discharge data for a nested set of catchments were used to track changes in magnitude, timing and partitioning of precipitation into evapotranspiration and discharge. Results indicated forest growth is not responding significantly to temperature increases during the windows, but hydrological cycling intensified with higher dryness index (PET/P) during summer growing season and earlier spring snowmelt discharges, and later more concentrated autumn storm discharges during the shoulder seasons.

Crossman, J., M.C. Eimers, N.J. Casson, D.A. Burns, J.L. Campbell, G.E. Likens, M.J. Mitchell, S.J. Nelson, J.B. Shanley, S.A. Watmough and K.L. Webster. 2016. Regional meteorological drivers and long term trends of winter-spring nitrate dynamics across watersheds in northeastern North America. Biogeochemistry 130 (3): 247-265. (16-05).

A 20-year period (1990/91-2009/10) in nine study sites across Canada and the US, including two catchments in the TLW, were selected for analysis to evaluate the contribution of winter rain-on-snow (ROS) events to annual and seasonal nitrate (N-NO_3) export and identified the regional meteorological drivers of interannual variability in ROS N-NO_3 export. ROS events contributed a significant proportion of annual and winter N-NO_3 export at the majority of sites. In years with a greater magnitude of ROS events, timing of the peak N-NO_3 export period (during spring melt) was redistributed to earlier in the year. Snowpack coverage was particularly important for explaining the site-specific ROS response. Results suggest catchment response to changes in N deposition is sensitive to climate change, a vulnerability that appears to vary in intensity throughout the seasonally snow-covered temperate region. Also, downstream nutrient stoichiometry and the community composition of phytoplankton and other algae are affected by sensitivity of stream N-NO_3 export to ROS events and potential earlier timing of N-NO_3 export relative to other nutrients.

Egginton, P., F. Beall and J. Buttle. 2014. Reforestation–climate change and water resource implications. The Forestry Chronicle 90 (4), 516-524. (14-04).

In a forested catchment, river discharge can be decreased or augmented by forest management practices such as appropriate species selection, density management and length of rotation. With the growing awareness of climate change and its impacts, the adequacy of our water supply is becoming an issue. At the same time, there is greater discussion about using our forests for carbon sequestration and biofuels. This paper outlines implications for annual and seasonal river flows after widespread reforestation and concludes that informed choices need to be made as to the overall objectives of forest management. Research at the TLW provided background knowledge that contributed to the concepts presented in this paper.

Jeffries, D.S., F.D. Beall, N.W. Foster, P.W. Hazlett, S.L. Schiff, R.G. Semkin and J. Spoelstra. 2007. How is the Turkey Lakes Watershed (central Ontario, Canada) responding to declining sulphur inputs? Environment Canada Water Science and Technology Directorate Contribution No. 05-373, 10p. (07-05).

This paper assesses the recovery of the TLW ecosystem in response to SO_2 emissions reductions in North America over the past 25 years. SO_4 deposition has declined in proportion to emissions reductions in most streams, but stream acidity has not recovered as expected, in part as a result of declining base cation concentrations. Episodic events resulted in 10-fold increases in SO_4 concentrations, and isotope studies reveal that re-oxidation of organic S was the primary source. Sulphur in wetland soils is released in the period following a drought. Daily and weekly monitoring of meteorological and atmospheric deposition continue at the TLW.

Jeffries, D.S., R.G. Semkin, F.D. Beall and J. Franklyn. 2002. Temporal trends in water chemistry in the Turkey Lakes Watershed, Ontario, Canada. Wat. Air Soil Pollut.: Focus 2, 5-22. (02-09).

Since 1980, SO_4 has been decreasing in the TLW as an apparent response to emissions reductions, yet there is little evidence of acidification recovery. Decreasing base cation concentrations compensate for declining SO_4. Groundwater showed increasing NO_3 concentrations. Stored S becomes mobilized from wetlands and soils following drought, influencing trends.

Jensen, M.J., N.K. Kaushik, P.T.S. Wong and J.B. Robinson. 1988. The effect of acid precipitation on microbial decomposition processes in sediment from streams in Turkey Lake watershed. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 159-169. (88-24).

Organic matter decomposition was examined under laboratory conditions using 14C techniques. Effect of acidity strongly depended on whether the stream sediment was settled (little effect) or suspended (decreased decomposition rate). The pH - decomposition rate relationship depended on the type of substrate used and, in particular, the amount of organic matter present.

Kerr, J.G., M.C. Eimers, I.F. Creed, M.B. Adams, F. Beall, D. Burns, J. L. Campbell, S.F. Christopher, T.A. Clair, F. Courchesne, L. Duchesne, I. Fernandez, D. Houle, D.S. Jeffries, G.E. Likens, M.J. Mitchell, J. Shanley and H. Yao. 2012. The effect of seasonal drying on sulphate dynamics in streams across southeastern Canada and the northeastern USA. Biogeochemistry 111 (1-3), 393-409, doi 10.1007/s10533-011-9664-12011. (12-01)

Peak stream SO_4^{2-} levels have been reported following periods of catchment drying. The regional extent of this relationship and the level of response were evaluated at 20 catchments including the TLW across southeastern Canada and northeastern US. The proportion of variance in annual SO_4^{2-} stream concentrations explained by seasonal drying concentrations was calculated using regression analysis. Of the 20 catchments, 13 exhibited a SO_4^{2-} concentration response to drying, and the response scores were positively associated with percent wetland and percent saturated area within the catchment. These results demonstrate that climate warming and catchment drying may affect catchment SO_4^{2-} dynamics.

Kreutzweiser, D.P., S.S. Capell and F.D. Beall. 2004. Effects of selective forest harvesting on organic matter inputs and accumulation in headwater streams. Northern Journal of Applied Forestry 21, 19-30. (04-04).

Time trend analyses were used to examine headwater stream organic matter inputs and accumulations in the TLW following selective harvesting. It was found that a harvesting intensity of 89% basal area removal resulted in a reduction of organic matter and accumulation in streams, but no significant reductions occurred for a 42% basal area removal. Harvesting impacts are reduced by retention of streamside trees and avoidance of felling into the streams.

Kreutzweiser, D.P. and S.S. Capell. 2001. Fine sediment deposition in streams after selective forest harvesting without riparian buffers. Can. J. For. Res. 31: 2134-2142. (01-05)

Selective harvesting was carried out in the forest of the TLW in 1997. This paper looks at the resulting fine sediment accumulation in the streams. Significant post-harvest increases in inorganic sediment bedloads were detected, but a greater increase was observed at a road-disturbance site where no harvesting was done. The current 30-m buffer in the riparian zone may not be necessary to prevent increased sediment loading to streams if care is taken to keep machinery and trees out of the stream channel while harvesting.

Krezek, C.C., J.M. Buttle, F.D. Beall, R.D. Moore, I.F. Creed, P.K. Sibley, U. Silins, K.J. Devito and C.A. Mendoza. 2008. HydroEcological Landscapes and Processes Project: A National-scale Forest Hydrology Initiative. Streamline Watershed Management Bulletin 12: 33-38. (08-09).

The HydroEcological Landscapes and Processes (HELP) project identifies commonalities and differences in terrestrial-aquatic linkages across Canada's forest landscapes through an analytically based classification system that will be the framework for quantifying hydrologic, geomorphic and ecologic processes for forested landscapes across the country. The HELP project combines results from multiple forest hydrology research sites in different ecozones across Canada including the TLW.

Laudon, H., P.J. Dillon, M.C. Eimers, R.G. Semkin and D.S. Jeffries. 2004. Climate induced episodic acidification of streams in Central Ontario. Environ.Sci.Technol. 38, 6009-6015. (04-06).

This study analyzed the hydrochemical effect of hydrological episodes preceded by drought in nine headwater streams in central Ontario and included three streams in the TLW: S1, S47 and S50. The lower the runoff preceding each episode, the larger the decline in ANC following the episode, for all streams except S47. Sulphate was the driving mechanism in all cases except S47 where NO_3 *was the most important factor. Thus* SO_4 *from anthropogenic sources stored in the stream catchments and released during episodes following drought can profoundly affect general recovery of lakes and streams from acidification.*

Leach, J. A., Buttle, J. M., Webster, K. L., Hazlett, P. W., and Jeffries, D. S. (2020). Travel times for snowmelt-dominated headwater catchments: Influences of wetlands and forest harvesting, and linkages to stream water quality. Hydrological Processes, 34(10), 2154-2175. (20-01).

Catchment travel times were estimated for the TLW headwater catchments. Results show that mean travel times can be variable for small geographic areas and are related to catchment characteristics, in particular flowpath length and wetland cover. In addition, forest harvesting appeared to decrease mean travel times. Estimated mean travel times had complex relationships with water quality patterns. Results suggest that biogeochemical processes, particularly those present in wetlands, may have a greater influence on water quality than catchment travel times.

Mengistu, S.G., C.G. Quick and I.F. Creed. 2013. Nutrient export from catchments on forested landscapes reveals complex nonstationary and stationary climate signals. Water Resources Research 49, doi:10.1002/wrcr.203022012. (13-03).

An analytical framework was used to detect nonstationary and stationary signals in yearly time series of nutrient export in four catchments (C35, C38, C37, C50) at the TLW. Both nonstationary and stationary signals were identified, and the combination of both explained the majority of the variation in nutrient export data. The catchment with low-water storage potential and low water loading was most sensitive to nonstationary and stationary climatic oscillations, suggesting that these hydrologic features are characteristic of the most effective sentinels of climate change.

Mengistu, S.G., I.F. Creed, K.L. Webster, E. Enanga and F.D. Beall. 2014. Searching for similarity in topographic controls on carbon, nitrogen and phosphorus export from forested headwater catchments. Hydrological Processes 28 (8), 3201-3216, doi: 10.1002/hyp.9862 (14-01).

Topography influences the hydrological processes that in turn affect biogeochemical export to surface water on forested landscapes. Annual DOC and DON, inorganic nitrogen (NO_3*-N) and total dissolved phosphorus exports were measured in catchments of the TLW. Topographic indicators: 1) hydrological storage potential and 2) hydrological flushing potential were designed in order to represent hydrological processes that influence nutrient export. Much of the variation in nutrient export among catchments was found to be attributable to topographic factors, although to differing degrees among nutrients. This study finds that topographic indicators are an effective tool to track biogeochemical exports to surface water from catchments on forest landscapes.*

Mitchell, M.J., G. Lovett, S. Bailey, F. Beall, D. Burns, D. Buso, D.T Clair, F. Courchesne, L. Duchesne, C. Eimers, I. Fernandez, D. Houle, D.S. Jeffries, G.E. Likens, M.D. Moran, C. Rogers, D. Schwede, J. Shanley, K.C. Weathers and R. Vet. 2010. Comparisons of watershed sulfur budgets in southeast Canada and northeast US: new approaches and implications. Biogeochemistry 103 (1-3), 181-207, doi:10.1007/s10533-010-9455-0. (10-04).

Deposition of anthropogenic S has acidified terrestrial and aquatic ecosystems in eastern North America. S deposition has been declining, however, and ecosystems have begun to recover. S mass balances were evaluated for 15 watershed sites in southeastern Canada and northeastern US (including the TLW). Most watersheds showed net annual losses of SO_4^{2-}. Net annual fluxes of SO_4^{2-} showed a strong relationship with hydrology as the largest net annual negative fluxes were associated with years of greatest precipitation and highest discharge amounts. Mobilization of internal S, likely from the mineralization of previously deposited S, contributed to stream fluxes and effected the rate of recovery from acidification.

Nicolson, J.A. 1983. Ion movement in terrestrial basins in the Turkey Lakes Forest Watershed. Proc. Conf. on Acid Rain and For. Resourc., Quebec City. (see 91-04) (83-16).

Report discusses stream composition, flow, export from, and mass balances for 20 small terrestrial basins in the TLW. Streams draining the basins with the shallowest soils generally had the lowest pH, alkalinity and conductivity. Considering input-output budgets, the basins were observed to retain nitrogen, lose basic cations, and be in approximate balance for sulphate. Chemical variability among the streams was large.

Nicolson, J.A. 1984. Ion concentrations in precipitation and streamwater in an Algoma maple-birch forest. Proc. Can. Hydrol. Symp., Quebec City, 125-135. (84-14).

Major ion concentrations, pH and conductivity were measured in precipitation and headwater streams during 1981 in TLW. Precipitation and stream loading rates were calculated, and causes of temporal and spatial variability discussed. Bicarbonate was the most important anion countering cation losses from low elevation, deep soils, while sulphate was more important for high elevation, thin soils.

Nicolson, J.A. 1987. Contributions of acid deposition to streamwater chemistry in three Precambrain Shield basins. Proc. Symp. Forest Hydrology and Watershed Management, Vancouver, B.C. IAHS-AISH Publ. No. 167, 89-98. (87-04).

Water and chemical budgets were examined for three undisturbed, forested catchments in northern Ontario (TLW, Nipigon, and ELA). Precipitation inputs and basin outputs are compared and specific watershed characteristics that control responses are noted. The results are compared with other catchments in Ontario, New Brunswick, and New Hampshire.

Nicolson, J.A. 1988. Water and chemical budgets for terrestrial basins at the Turkey Lakes Watershed. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 88-95. (88-16).

Paper summarizes ion budgets for 20 headwater streams in the TLW. Runoff is 28-63% of precipitation. Water, H^+ and NH output increased with elevation; ANC, Ca_{2+}, and NO_3 decreased. Nitrogen is strongly retained by the terrestrial basin while SO_4 is generally in balance. ANC balances cation loss at low elevation while SO_4 is more important at high elevations.

Nicolson, J.A. 1991. Ion movement in terrestrial basins in the Turkey Lakes forest watershed. *In*: Robitaille, G. and P.J. Rennie (eds.), Effect of acid rain on forest resources. Proc.Conf. 14-17 June 1983, Sainte Foy, Que. For. Can., Inf. Rep. DPC-X-35, 526-531. (91-04).

Ion movements are monitored in 20 feeder streams draining small basins in the TLW to assess their contribution to the main aquatic system and to estimate ecosystem changes. Nitrogen output is less than input in four of five watersheds. In all cases but one, SO_4 input and output is nearly in balance in four basins. Chemical variability between streams in a watershed can be large, and some areas are sensitive to increased H^+ load.

Sebestyen, S.D., D.S. Ross, J.B. Shanley, E.M. Elliott, C. Kendall, J.L. Campbell, D.B. Dail, I.J. Fernandez, C.L. Goodale, G.B. Lawrence, G.M. Lovett, P.J. McHale, K.J.Mitchell, S.J. Nelson, M.D. Shattuck, T.R. Wickman, R.T. Barnes, J.T. Bostic, A.R. Buda, D.A. Burns, K.N. Eshleman, J.C. Finlay, D.M. Nelson, H. Ohte, L.H. Pardo, L.A. Rose, R.D. Sabo, S.L. Schiff, J. Spoelstra,and K.W.J. Williar. 2019. Unprocessed atmospheric nitrate in waters of the Northern Forest Region in the U.S. and Canada. Environmental Science and Technology doi: 10.1021/acs.est.9b01276. (19-01).

Water chemistry and isotopic tracers of nitrate sources were measured across the northern forest region of the US and Canada and reanalyzed data from other studies was used to determine when, where, and how unprocessed atmospheric nitrate was transported in catchments. Six of 32 streams had high fractions (>20%) of unprocessed atmospheric nitrate during baseflow. Seventeen streams had high fractions during stormflow or snowmelt, which corresponded to large fractions in near-surface soil waters or groundwaters, but not deep groundwater. Lack of monitoring for atmospheric deposition among storms (large, sporadic events) may bias perceptions of occurrence; sustained monitoring of chronic nitrogen pollution effects on forests with nitrate source apportionments may offer insights needed to advance the science.

Semkin, R.G., D.S. Jeffries, R. Neureuther and M.D. Seymour. 1987. Data report: major ion composition and instantaneous discharge of stream waters in the Turkey Lakes Watershed. January 1980 to May 1986. Nat. Wat. Res. Inst. Contribution #88-03 4 pp. (+ Tables and Appendices). (87-12)

Report presents a statistical summary and data listing of the major ion chemistry and instantaneous discharge at six National Water Research Institute stream stations in the TLW for January 1980 to May 1986. Some data for a headwater stream draining into Turkey Lake is also included. Sampling, analytical and data processing methods are briefly discussed.

Semkin, R.G., D.S. Jeffries and R. Neureuther. 1984. Relationships between hydrological conditions and the ionic composition of stream waters in the Turkey Lakes Watershed. Proc. Can. Hydrol. Symp., Quebec City, 109-122. (84-05).

The report discusses the factors governing the spatial and temporal variations in ionic content of surface water in the TLW. Geological and hydrological factors are most important. High elevation streams where till thickness is minimum have lower pH, calcium, and alkalinity, and sulphate is the dominant anion. At low elevation where overburden thickness is greater, generally higher ionic concentrations occur, and alkalinity is the dominant anion. The high elevation waters experience the greatest temporal changes in concentration; these are often related to flow, particularly the hydrologic peaks associated with spring melt.

Semkin, R.G., D.S. Jeffries and T.A. Clair. 1994. Chapter 7 - Hydrochemical methods and relationships for study of stream output from small catchments. *In*: Moldan, B. and J. Cerny (eds.), Biogeochemistry of small catchments: A tool for environmental research. John Wiley & Sons, New York, 163-187. (93-02).

Various hydrochemical methods are documented to describe the physical and biogeochemical processes operating in small catchments, and to calculate the stream mass export. Sampling frequency is discussed, and the variability in streamwater chemistry is explained in terms of basin characteristics and streamflow regime.

Semkin, R.G., P.W. Hazlett, F.D. Beall and D.S. Jeffries. 2002. Development of stream water chemistry during spring melt in a northern hardwood forest. Wat. Air Soil Pollut.: Focus 2, 37-61. (02-14).

The role of snowmelt and subsurface hydrology in determining the chemistry of a small headwater stream in the TLW was evaluated for the spring melt periods 1992 to 1996. Pre-melt streamflow contributed 9% of the average spring melt measured at the basin outlet, while water flowing through the forest floor and upper mineral soil contributed 28% and 63% respectively.

Spoelstra, J., S.L. Schiff, R.G. Semkin, D.S. Jeffries and R.J. Elgood. 2010. Nitrate attenuation in a small temperate wetland following forest harvest. Forest Ecology and Management 259, 2333-2341, doi: 10.1016/j.foreco.2010.03.006. (10-02).

A wetland in the TLW watershed (catchment 31) was the focus of a nitrate attenuation study utilizing stable isotope techniques. Analysis of d18O, d15N demonstrated that concentrations of nitrate were significantly lower in outflow than in inflow to the wetland, and nitrate removal is even complete in some areas. Forest harvesting effects on aquatic systems could thus be reduced if small wetlands are preserved in the watershed.

Trick, C.G., I.F. Creed, M.F. Henry and D.S. Jeffries. 2002. Distribution of diatoms in a forested stream containing a series of interconnected lakes. Water, Air, and Soil Pollution: Focus 2: 103–128. (02-11).

A study of the diatom flora in the TLW revealed assemblages were shaped by DOC and DIC concentrations and by the species and concentration of N compounds along the stream path through the watershed. In the upper reaches where DOC and TKN are high, an acid-tolerant taxa dominated, while a different community was seen in the lowlands where DIC and NO_3-N are prevalent. Community abundance and diversity increased steadily downstream before decreasing near the watershed outlet. By imparting species-specific stresses, the flow regime further shaped the structure of the diatom community within the watershed.

Yeung, A.C.Y., D.P. Kreutzweiser and J.S. Richardson. 2019. Stronger effects of litter origin on the processing of conifer than broadleaf leaves: A test of home-field advantage of stream litter breakdown. Freshwater Biology. 64: 1755-1768. (19-04).

To date, findings are mixed about whether plant litter breakdown by stream decomposers is faster in locations where the litter originates from compared with other locations, a phenomenon known as home-field advantage (HFA). HFA may be influenced by litter quality and particularly decomposer groups (shredders versus microbes), rather than being an inherent consequence of the breakdown of locally native litter. A reciprocal transplant experiment was conducted in the Malcolm Knapp Research Forest in southwestern British Columbia and the TLW in central Ontario. Results of this study suggest that prior (evolutionary and/or contemporary) litter exposure could strongly influence the litter-processing capacity of microbial decomposers, but not shredders, at the community level. In particular, microbial decomposers specialised in degrading conifer litter probably had lower resource-use plasticity than those processing broadleaf litter. Inter-stream difference in riparian vegetation and habitat conditions could influence the HFA through altering the litter exposure history of decomposer communities. Findings highlight importance of prior litter-microbe interactions in determining rates of microbial decomposition of native and exotic litter species.

Yeung, A.C.Y., J.L. Musetta-Lambert, D.P. Kreutzweiser, P.K. Sibley and J.S. Richardson. 2018. Relations of interannual differences in stream litter breakdown with discharge: bioassessment implications**.** Ecosphere doi: 10.1002/ecs2.2423 (18-05).

This study quantified how interannual hydrologic differences contributed to the spatio-temporal variability of litter breakdown rate and its components (fragmentation, λ_f; and dissolution and microbial decomposition λ_m) in low-order unimpacted, perennial streams across three climatically similar regions in temperate Canada (including TLW). Contrary to the hypothesis, interannual hydrologic variability was unrelated to λ_f and poorly predicted λ_m and litter breakdown rates in coarse leaf bags (k_c) during fall within regions. Within-region spatial and temporal differences in k_c approximated or exceeded the range of natural variability suggested to characterize reference conditions by a bioassessment framework. There is a need to include other structural and functional indicators to ensure comprehensive stream bioassessments.

HYDROLOGY - LAKES

The TLW drainage system consists of first order streams and a cascading chain of four lakes. The Batchawana (separated into upper and lower basins), Wishart, Little Turkey and Big Turkey Lakes (surface areas of 6, 6, 19, 19 and 52 ha, respectively) are connected by Norberg Creek, which drains into Lake Superior via the Batchawana River (Figure 10). The lakes flush quite rapidly, with water renewal times ranging from 0.2 years at Wishart to 1.2 years at Upper Batchawana (Jeffries et al. 1988). Historically (1980 to 2019) lake temperature profile and chemistry, and lake outflow discharge and chemistry data were collected along the drainage network. Lakes publications are primarily papers reporting lake chemical conditions and the impact of acid deposition. Much of the research in this category has been conducted by Environment and Climate Change Canada – National Water Research Institute.

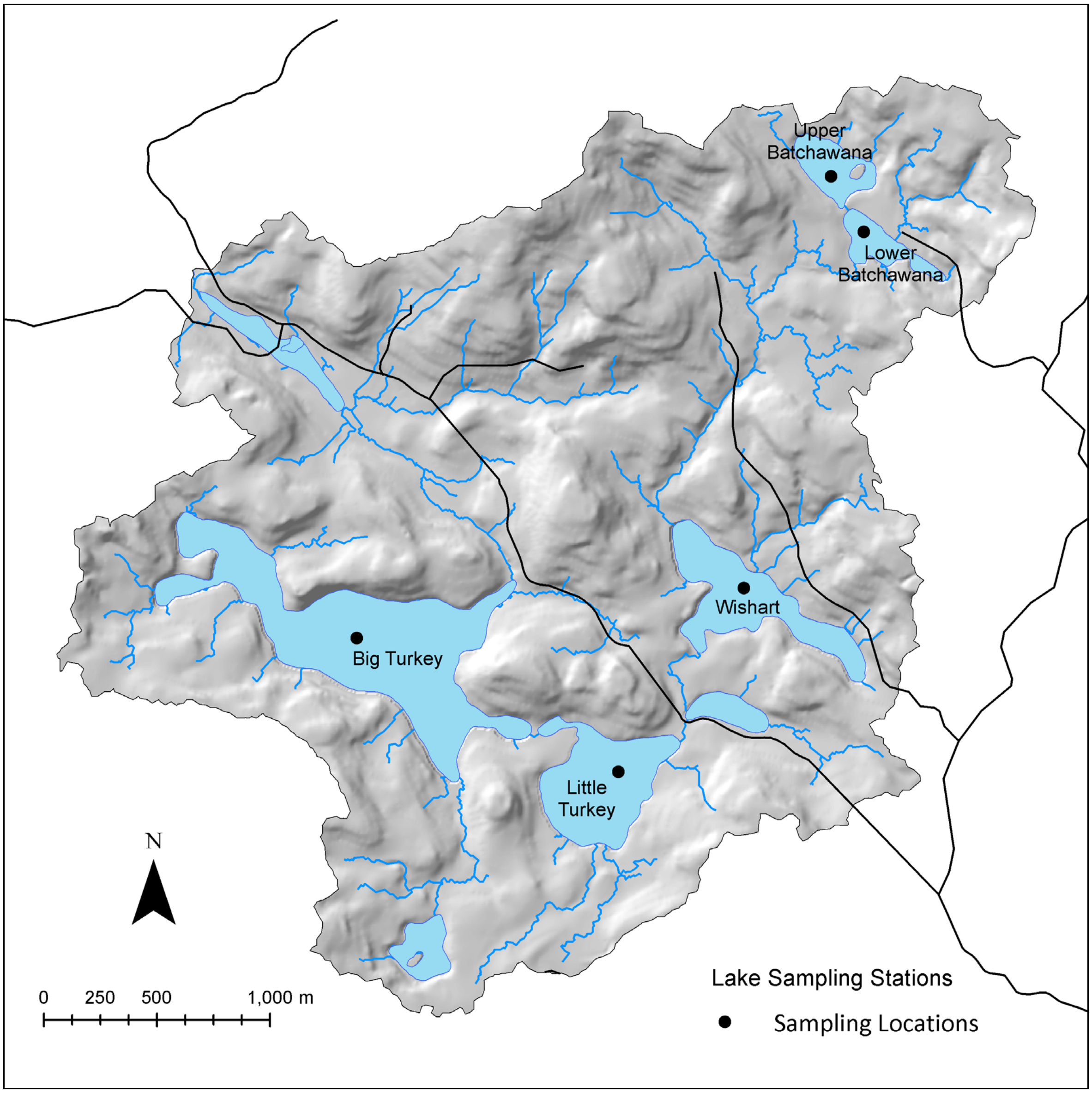


Figure 10. Lake sampling stations in the TLW.

PUBLICATIONS

Alaee, M., W.M.J. Strachan and W.M. Schertzer. 1995. Comparison between mass transfer coefficients of SF6 determined in a gas transfer flume and in several small lakes. NWRI Contribution No. 95-102, 11p, Tables, Graphs. (95-07).

Mass transfer coefficients of sulfur hexafluoride were measured in a linear gas transfer flume under different wind and wave conditions and compared to actual measurements made at Little Turkey Lake, TLW. Flux estimates of SF6 obtained from the flume were found to be in agreement with measured values.

Beck, K.K., A.S. Medeiros and S.A. Finkelstein. 2016. Drivers of Change in a 7300-Year Holocene Diatom Record from the Hemi-Boreal Region of Ontario, Canada. Plos One 10.1371/journal.pone.0159937 (16-03).

Potential drivers of long-term change in diatom assemblages at Wishart Lake were evaluated using a Holocene lake sediment record spanning the past 7300 years. Results illustrate the close connection between paleoclimate change, regional vegetation, watershed processes, and diatom assemblages and provides insight into the controls on abundance of Cyclotella sensu lato, a diatom taxonomic group that has shown significant increases and complex dynamics in the post-industrial era in lakes spanning temperate to Arctic regions.

Burnison, B.K., S.S. Rao, A.A. Jurkovic and D.J. Nuttley. 1986. Sediment microbial activity in acidic and non-acidic lakes, Wat. Pollut. Res. J. Can. 21(4): 560-571. (86-04).

Report presents the results of an evaluation of the effect of lake acidification on bacterial numbers and organic biodegradation rates in sediments. Samples from Turkey Lake were included in the study.

Clair, T.A., P.J. Dillon, J. Ion, D.S Jeffries, M. Papineau and R.J. Vet. 1995. Regional precipitation and surface water chemistry trends in southeastern Canada (1983-91). Can. J. Fish. Aquat. Sci., 52, 197-212. (95-01).

Surface water concentrations were analyzed at 111 sites from central Ontario to Newfoundland, and precipitation composition and deposition analyzed for trends at six sites, including Algoma at TLW. H^+ and SO_4 concentrations are decreasing in Ontario. In Quebec, pH and ANC are decreasing while NO_3 is increasing. At the Atlantic sites, pH and ANC are increasing. The 111 surface water sites were classified according to the acidification status: 60 are stable, 17 acidifying, and 34 improving.

Delorme, L.D., H.C. Duthie, S. R. Esterby, S. Smith and N.S. Harper. 1986. Prehistoric inferred pH changes in Batchawana Lake, Ontario from sedimentary diatom assemblages. Arch. Hydrobiol. 108(1): 1-22. (86-01).

Report presents an evaluation of long term changes in lake pH for Batchawana Lake using sediment diatoms. Most of the small changes recorded over the past several hundred years are attributed to climate.

Delorme, L.D., S.R. Esterby, H.C. Duthie and N.S. Harper. 1986. Sedimentary diatom analysis from the Turkey Lakes Watershed. Nat. Wat. Res. Inst. Contribution No. 86-71, Burlington, Ontario, 72 pp. (+ 4 Appendices). (86-02).

Report presents the evaluation as in 86-01 and extensive data summaries in appendices.

Durham, R.W. and S.R. Joshi. 1984. Lead-210 dating of sediments from some northern Ontario lakes. *In*: W.C. Mahaney (ed.), Quaternary dating methods, Elsevier Science Publishers B.V., Amsterdam, 75-85. (84-03).

> *Sedimentation rates were determined for 14 Ontario lakes including Batchawana (identified as upper headwater in the report: which basin not clear), Little Turkey, and Turkey Lakes in the TLW. Both 210Pb and 137Cs techniques were used to establish the sedimentation rates which ranged from 0.67 (Turkey L.) to 0.96 mm yr^{-1} (Batchawana Lake). A detailed description of the radiometric dating technique (calculations) is given.*

Duthie, H.C. and P.M. McKee. 1983. Lake sediment core analysis - LRTAP - Algoma Calibrated Watershed. Final Report, DSS Contract OSE80-00147, Beak Consultants, Mississauga, Ont., 223p. (83-25).

> *Report presents a brief description of concept of using changes in sedimentary diatom assemblages to infer historical changes in lake pH. Sampling and sample processing methods are also described. Most of the report contains data summaries (diatom taxa, calculated index values, various plots and statistical analyses) that were the primary input for later interpretive papers.*

Gibson, J.J., S.J. Birks, D.S. Jeffries, and Y. Yi. 2017. Regional trends in evaporation loss and water yield based on stable isotope mass balance of lakes: The Ontario Precambrian Shield surveys. Journal of Hydrology 544: 500-510. (17-02).

> *This study was undertaken to gain a better understanding of hydrology and geochemistry of watersheds in the region in order to better predict acid sensitivity of lakes. Stable isotopes of water, oxygen^{-18} and deuterium were measured in water samples from 300 lakes in the vicinity of Lake Superior, and also within the TLW. Evaporative isotopic enrichment of lake water was systematic across the regions, and its deviation from the isotopic composition of precipitation was used to estimate the evaporation/inflow to the lakes and runoff (water yield) based on a simple isotope mass balance model. Results suggest that a high proportion of lakes have relatively limited runoff, so basic information on the drainage structure of an area can be valuable for site-specific hydrologic assessments and critical loads assessment (low runoff systems tend to be less buffered and therefore are more sensitive to acidification. In TLW, isotope-based water yield is comparable in magnitude to hydrometric gauging estimates, although uncertainty related to stratification can be high for individual lakes, but would only be a minor influence on regional survey results.*

Jeffries, D.S. 1995. A preliminary assessment of nitrogen-based fresh water acidification in southeastern Canada. Water Air and Soil Pollution, 85: 433-438. (95-06)

> *A short paper summarizing the classification of regional nitrate concentrations in surface waters in an attempt to define areas of potential nitrogen based acidification. The seasonal cycle of nitrate extant at Turkey Lake is offered as evidence for developing nitrogen saturation. This paper uses information collected for and presented in 95-02.*

Jeffries, D.S., D.C.L. Lam, M.D. Moran and I. Wong. 1999. The effect of SO_2 emission controls on critical load exceedances for lakes in southeastern Canada. Water Science and Technology, 39(12), 165-171. (98-06).

> *Critical loads were determined for 4 lake clusters in SE Canada (including an Algoma cluster that surrounds the TLW) using pH 6 as a damage threshold. Using damage vs deposition relationships, the critical load for Algoma was determined to be 8.0 kg wet SO_4 $ha^{-1}.yr^{-1}$. Wet SO_4 deposition currently exceeds critical loading by 9.2 kg wet SO_4 $ha^{-1}.yr^{-1}$, and modelling shows that critical loads will be exceeded even after all SO_2 emission controls are implemented. The paper demonstrates the need for further controls on SO_2 emissions in North America.*

Jeffries, D.S., R.G. Semkin, R. Neureuther, M. Seymour and J.A. Nicolson. 1986. Influence of atmospheric deposition on lake mass balances in the Turkey Lakes Watershed, Central Ontario. Wat. Air Soil Pollut. 30: 1033-1044. (86-20).

Ion mass budgets for Batchawana L. South and Turkey L. are presented for the 81-83 water years. Atmospheric deposition is the primary input pathway for H^+ and NH. The lakes strongly retain H^+, weakly retain N species, and are in balance for other ions except Ca_{2+} and ANC. Excess output of Ca_{2+} and ANC (over input) is attributed to unmeasured groundwater inputs.

Jeffries, D.S., R.G. Semkin, R. Neureuther and M.D. Seymour. 1988. Ion mass budgets for lakes in the Turkey Lakes watershed, June 1981 - May 1983. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 26-37. (88-26).

Ion mass budgets for the 81-82 and 82-83 water years were presented for four lakes. Water and budgetary imbalances for certain ions, particularly Ca_{2+} and ANC in some lakes is explained by groundwater seepage. In-lake generation of ANC by SO_4 reduction is minor. Atmospheric deposition to the lakes' surfaces is the major input pathway for H^+, NH and sometimes NO_3.

Jeffries, D.S., T.A. Clair, S. Couture, P.J. Dillon, J. Dupont, W. Keller, D.K. McNicol, M.A. Turner, R. Vet and R. Weeber. 2003. Assessing the recovery of lakes in southeastern Canada from the effects of acidic deposition. Ambio 32: 176-182. (03-03).

Batchawana Lake in the TLW is included in an assessment of recovery from acidification by lakes in southeastern Canada following reductions in North America of SO_2 emissions. Although SO_4 concentrations have generally declined, pH and alkalinity have not increased as expected. Further emissions reductions will be necessary to effect chemical and biological recovery.

Jeffries, D.S., T.G. Brydges, P.J. Dillon and W. Keller. 2003. Monitoring the results of Canada/U.S.A. acid rain control programs: some lake responses. Environ. Monit. Assess. 88: 3-19. (03-04).

Batchawana Lake in the TLW is one of three intensively measured sites in southeastern Canada in which aquatic response to changes in acidic deposition has been assessed. Following emission reductions, recovery has been observed only in some lakes and is complicated by release of stored SO_4 following periods of drought, and reduced base cation concentrations. Monitoring and modelling must continue.

Jeffries, D.S. and R.G. Semkin. 1987. Variations in ion budgets within a chain of lakes, central Ontario, Canada. Proc. Internat. Symp. on Geochemistry and Monitoring of Representative Basins, Prague, Czechoslovakia, 19-21. (87-09).

Paper presents an overview of mass budgets determined for the four lakes in the TLW. It discusses the relative importance of various acidifying species, dominant input pathways, and biogeochemical processes (see 88-25).

Jeziorski, A., N.D. Yan, A.M. Paterson, A.M. DeSellas, M.A. Turner, D.S. Jeffries, B. Keller, R.C. Weeber, D.K. McNicol, M.E. Palmer, K. McIver, K. Arseneau, B.K. Ginn, B.F. Cumming and J.P. Smol. 2008. The widespread threat of calcium decline in fresh waters. Science 322: 1374-1377. (08-10).

The consequences of declining calcium concentrations in softwater boreal lakes for aquatic biota have not yet been reported. By examining crustacean zooplankton remains preserved in lake sediment cores this study documented near extirpations of calcium-rich Daphnia species, which are keystone herbivores in pelagic food webs, concurrent with declining lake-water calcium. The TLW lakes were part of the 770 Canadian Shield lakes examined, which showed 62% of the lakes with calcium concentrations approaching or below the threshold at which laboratory Daphnia populations suffer reduced survival and fecundity. The ecological impacts of environmental calcium loss are likely to be both widespread and pronounced.

Johnson, M.G. and D.B. McNeil. 1988. Fossil midge associations in relation to trophic and acidic state of the Turkey Lakes. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 136-144. (88-20).

Analysis of sediment cores suggest that all the lakes except Wishart Lake have been progressing to more oligotrophic conditions; trophic status of Wishart Lake has been relatively stable. There is little evidence of lake acidification except in the most recent sediments of the headwater (Batchawana Lake). There has likely never been a fish community in Batchawana Lake.

Johnson, M.G., L.R. Culp and S.E. George. 1986. Temporal and spatial trends in metal loadings to sediments of the Turkey Lakes, Ontario. Can. J. Fish. Aquat. Sci. 43(4): 754- 762. (86-08).

Metal concentrations in lake sediment cores were evaluated to assess their source. Variations in the profile of Pb, Cd, Hg and Zn concentrations (evaluated relative to 210Pb activity) showed that these metals had a significant anthropogenic origin. The inferred metal loadings to the sediments was compared to atmospheric loadings.

Keller, W. 2007. Implications of climate warming for Boreal Shield lakes: a review and synthesis. Environ. Rev. 15, 99-112. (07-03).

This is a review of the complex effects of climate warming on lakes of the Boreal Shield, including those at the TLW site. One such effect is the re-acidification of lakes following a drought, during which stored sulphur from atmospheric deposition becomes oxidized causing many physical and chemical changes. Biological interactions are difficult to predict, and more studies and modelling that consider stressor effects are needed.

Kelso, J.R.M., C.K. Minns, J.H. Lipsit and D.S. Jeffries. 1986. Headwater lake chemistry during the spring freshet in north-central Ontario. Wat. Air Soil Pollut. 29: 245-259. (86-09).

Paper presents an analysis of the reductions in ANC, base cations, and SO_4 in lake waters that occur during spring melt using a 30-lake survey conducted within and around the TLW. A simple model is developed that predicts changes in lake chemistry during spring melt given a few chemical and morphometric variables.

Kelso, J.R.M., M.A. Shaw and D.S. Jeffries. 1992. Contemporary (1979-1988) and inferred historical status of headwater lakes in North Central Ontario, Canada. Environ. Pollut. 78: 65-71. (92-01).

Fifty-six Canadian Shield lakes were sampled from 1979-88 to monitor changes in acidic deposition. Wet deposition of sulphate was highest in the late 1970s, at 83 meq.m^{-2}*. pH values increased 0.42 units from 1979-85, and decreased by 0.15 units between 1985 and 1988. Fish reappeared in 1987 when pH increased by 0.9 pH units, indicating that further water quality improvements could lead to increased fish populations in many Ontario lakes.*

Kelso, J.R.M., R.J. Love, J.H. Lipsit and R. Dermott. 1982. Chemical and biological status of headwater lakes in the Sault Ste. Marie District, Ontario. *In*: R.M. D'itri (ed.), Acid precipitation, effects on ecological systems, Ann Arbor Science Publishers, Ann Arbor, Michigan, 165-207. (82-11).

Report presents results of a survey of 85 headwater lakes in which an attempt is made to recognize relationships that may exist between the well-being of biological communities and chemical status. Biological communities reflected to varying degrees the acidic status of their aquatic habitat. Compared to plankton and benthic organisms, fish provide the most blatant response to changes in their habitat.

Kelso, J.R.M. and D.S. Jeffries. 1988. Response of headwater lakes to varying atmospheric deposition in north-central Ontario, 1979-1985. Can. J. Fish. Aquat. Sci., 45: 1905-1911. (88-02).

Paper discusses the causes of variations in chemistry observed for 54 Algoma lakes (including some of the Turkey Lakes) between 1979 and 1985. Lakes were surveyed on a three-year cycle. Changes in pH, ANC and Ca_{2+} *were related to either changing atmospheric deposition or terrestrial basin response. Two fishless lakes (in 1979) developed white sucker populations by 1986 through invasion into a more hospitable chemical environment. Water quality "recovery" in central Ontario extends beyond that observed near Sudbury.*

Laberge, C., D. Cluis, M.L. Mallory and D.K. McNicol. 2000. Rationalization of a regional network designed for trend detection of lake water quality in presence of spatial correlation. Environmetrics 12, 41-56, 2000. (00-07).

This paper uses water quality data collected in small water bodies in the Algoma region, including the TLW, to establish a sustainable, water quality survey protocol for the CWS (Ontario Region) LRTAP biomonitoring network by reducing the sampling intensity and/or frequency while maintaining a statistical trend detection capability.

Lam, D.C.L., A.G. Bobba, D.S. Jeffries and J.R.M. Kelso. 1984. Relationship of spatial gradients of production, buffering capacity, and hydrology in Turkey Lakes Watershed. ASTM STP 928: 42-53. (84-06).

The carbon uptake rate of phytoplankton was observed to increase from the poorly buffered headwater lake to the better buffered lakes downstream. Water pH, alkalinity, and dissolved inorganic carbon also increased in a parallel fashion and the report discusses the relationships among these observations. In particular, a hydrological model predicts that a greater groundwater component is present in the downstream waters and this can account for the above observations.

Maguire, R.J. 1984. Butyltin compounds and inorganic tin in sediments in Ontario. Environ. Sci. Technol., 18: 291-294. (83-20).

Report presents method for analysis of butyltin and inorganic tin species in sediments. Data are given for sediments collected from various lakes, rivers, and harbours in Ontario including the TLW (see 83-19). The presence of certain organotin species in harbour sediments shows that some butyltin species can be methylated in aquatic environments.

Maguire, R.J., Y.K. Chau, G.A. Bengert, E.J. Hale, P.T.S. Wong and O. Kramar. 1982. Occurrence of organotin compounds in Ontario lakes and rivers. Environ. Sci. Technol., 16(10): 698-702. (83-19).

Report presents first-time identification of butyltin and methyltin species in lakes, rivers, and harbours in Ontario including the TLW. Data for both unfiltered lakewater and the surface micro-layer are provided. It is suggested that occurrence of organotins in the remote TLW may be due to atmospheric transport. The lakes sampled are only identified by a number; they correspond as follows: #1 = Batchawana N.; #2 = Batchawana S.; #3 = Wishart; #4 = Little Turkey, and #5 = Turkey Lake.

Marmorek, D.R., R.M. MacQueen, C.H.R. Wedeles, J. Korman, P.J. Blancher and D.K. McNicol. 1996. Improving pH and alkalinity estimates for regional-scale acidification models: incorporation of dissolved organic carbon. Can. J. Fish. Aquat. Sci. 53: 1602- 1608. (96-01).

A DOC correction factor incorporated into a Gran titration curve was found to improve the accuracy of model projections in the TLW and eastern Canada, lowering average pH estimates by 0.1 - 0.4 units.

McNicol, D., M.L. Mallory, C. Laberge and D.A. Cluis. 1998. Recent temporal trends in the chemistry of small, acid-sensitive lakes in central Ontario, Canada. Wat. Air Soil Pollut. 105, 343-351. (98-04).

In central Ontario, 603 small water bodies (including some of the Turkey Lakes and others in the surrounding region) were monitored from 1988-1996 to determine their response to recent SO_2 emission reductions. DETECT software was used to look for significant monotonic trends. Sulphate concentrations declined in 27-56% of the lakes, base cations declined in 41-57%, but only 26-28% showed increasing trends for pH or ANC. Recovery of these ecosystems will depend on several environmental stressors, including acidification.

Morris, J.R. and W. Kwain. 1988. A study of metal accumulation trends in sediment cores from the Turkey lakes (Algoma, Ontario.) Can. J. Fish. Aquat. Sci. 45(Suppl 1): 145-154. (88-23).

Temporal (vertical) and spatial trends for Al, Mn, Pb, Zn, Cu, and Ni were investigated in 18 sediment cores. Using cumulative Al as an index of time, Pb and Zn both exhibit marked enrichment in recent sediments while Cu and Ni show a more modest increase. Metal accumulation rates vary among lakes and sites within a lake reflecting variation in dry matter sedimentation.

Morris, J.R. and W. Kwain. 1988. Sediment pH in profundal core samples from the Turkey Lakes, Algoma, Ontario. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 155-158. (88-22).

Sediment pH profiles are used to assess the pH history of the lakes. There is little evidence that the lakes are recently more acidic.

Muir, D.C.G., X. Wang, F. Yang, N. Nguyen, T.A. Jackson, M.S. Evans, M. Douglas, G. Köck, S. Lamoureux, R. Pienitz, J.P. Smol, W.F. Vincent and A. Dastoor. 2009. Spatial trends and historical deposition of mercury in eastern and northern Canada inferred from lake sediment cores. Environ. Sci. Technol., 43, 4802-4809. (09-03).

Batchawana Lake was classed as a mid-latitude lake in a survey of spatial trends and historical deposition of mercury conducted during 1998-2005. Dated lake sediment cores from 50 lakes in eastern and northern Canada were collected and analyzed, and increases in mercury deposition over time were observed in all the midlatitude cores. The observed trends support the view that there are significant anthropogenic mercury inputs into the Arctic.

Newell, A.D. and B.L. Skjelkvåle. 1997. Acidification trends in surface waters in the international program on acidification of rivers and lakes. Wat. Air Soil Pollut. 93: 27-57. (97-01)

Trend analyses were applied to surface-water chemistry data from both Europe and North America (including the TLW). SO_4 concentrations were decreasing at many sites from both continents, Ca_{2+} decreased at many European sites, and NO_3 increased at several sites in southern Norway and in eastern New York State. The declining base cation concentrations and increasing NO_3 may account for the lack of recovery from acidification. No correlations were found between surface water trends and changes in deposition.

Nriagu, J.O. and Y.K. Soon. 1984. Arylsulphatase activity in polluted lake sediments. Environ. Pollut. Ser. B., 8: 143-153. (84-02).

This report discusses the relationship between the enzyme activity of arylsulphatose in lake sediments with 1) the pH of the overlaying waters and 2) sediment metal concentrations. Data on chemical characteristics and enzyme activity of sediments for several lakes are presented including Turkey Lake which is considered to be the "remote and fairly pristine" member of the lake set.

Nriagu, J.O. and Y.K. Soon. 1985. Distribution and isotopic composition of sulfur in lake sediments of northern Ontario. Geochim. Cosmochim. Acta 49: 823-834. (85-12).

Sediment cores from lakes near Sudbury and the TLW were sectioned, the S component fractionated into six forms, and the isotopic composition of each fraction determined. In the TLW, pyrite formation is of minor importance in S diagenesis; rather, organic S forms predominate in the sediments. Plant detritus is hypothesized as the major contributor of S to the sediments. The situation in the far more polluted Sudbury environment is quite different.

Schiff, S.L. and R.F. Anderson. 1986. Alkalinity production in epilimnetic sediments: acidic and non-acidic lakes. Wat. Air Soil Pollut. 31: 941-948. (86-10).

In-lake ANC production occurring at the sediment-water interface was evaluated using sediment peepers in several lakes including Batchawana and Little Turkey Lake. Calcium and NH release and SO_4 consumption are the most important contributors to ANC production in non-acidic lake sediments. Large ANC gradients in the sediments may or may not indicate a large source of ANC for the lake depending on the fate of co-diffusing Fe, Mn, and NH.

Scott, B.F., C. Spencer, C.H. Marvin, D.C. MacTavish and D.C.G. Muir. 2002. Distribution of haloacetic acids in the water columns of the Laurentian Great Lakes and Lake Malawi. Environ. Sci. Technol. 36: 1893-1898. (02-01).

The TLW (Algoma) was part of a study to assess the influence of urbanization on concentrations and profiles of haloacetic acids (HAAs) in the Canadian Great Lakes and in Lake Malawi in Africa. Trifluoroacetic acid (TFA) concentrations were constant throughout the water column, but chloroacetic acid (CAA) concentrations varied with depth. TFAs increased from Lake Superior to Lake Ontario (18 to 150 mg/l). Precipitation (measured at the TLW) may be a major input of HAA to Lake Superior, especially since the lake has a retention time of 191 years. CAAs were highest in urbanized areas along the Detroit River, but low levels measured in the populous L. Malawi watershed indicate that population density alone is not a major source of HAAs. In general high HAA levels appear to parallel industrial activity.

Semkin, R.G., D.S. Jeffries, R. Neureuther and M.D. Seymour. 1987. Data report: major ion composition of lake waters in the Turkey Lakes Watershed January 1980 to May 1986. Nat. Wat. Res. Inst. Contribution 87-168, 6 pp. (+ Tables and Appendices). (87-13).

Report presents a statistical summary and data listing for lakes in the TLW. This is a companion to 87-12.

Shilts, W.W. and L.E. Farrel. 1982. Sub-bottom profiling of Canadian Shield lakes - implications for interpreting effects of acid rain. In: Current Research, Part B., Geological Survey of Canada, Paper 82-1B, 209-221. (82-12).

Distribution and physical characteristics of both modern and unconsolidated glacial sediments are reported for the material in the bottom of four Canadian Shield lakes including Big Turkey and Little Turkey Lakes. Three to five metres of gyttja overlies bedrock and glacial sediments in all but the steepest part of the lake basins. Anomalously high carbonate content in the drift adjacent to the lakes is reported.

Skjelkvåle, B.L., J.L. Stoddard, D.S. Jeffries, K. Tørseth, T. Høgåsen, J. Bowman, J. Mannio, D.T. Monteith, R. Mosello, M. Rogora, D. Rzychon, J. Vesely, J. Wieting, A. Wilander and A. Worsztynowicz. 2005. Regional scale evidence for improvements in surface water chemistry 1990-2001. Environ. Pollut. 137, 165-176. (05-04).

The TLW was considered part of the "Upper Midwest" region in an ICP Waters international monitoring program. The purpose was to ascertain the degree and extent of the impact of atmospheric pollution, especially acidification. Regional trends for 12 regions in Europe and N. America showed a decrease in SO_4 *concentrations from 1990-2001 at all but one site in Virginia. Fewer than half of the regions showed a decreasing trend in* NO_3*, perhaps because the time scale was too short. Emission controls appear to be effective in promoting reduced ecosystem acidification although recovery may be affected by other factors such as climate change and increased leaching of N.*

Stoddard, J.L., D.S. Jeffries, A. Lükewille, T.A. Clair, P.J Dillon, C.T. Driscoll, M. Forsius, M. Johannessen, J.S. Kahl, J.H. Kellogg, A. Kemp, J. Mannio, D. Monteith, P.S. Murdoch, S. Patrick, A. Rebsdorf, B.L. Skjelkvåle, M.P. Stainton, T. Traaen, H. van Dam, K.E. Webster, J. Wieting and A. Wilander. 1999. Regional trends in aquatic recovery from acidification in North America and Europe. Nature 401, 575-578. (99-04).

This paper presents an analysis of regional trends in surface water chemistry. Data from the TLW was included in the station grouping called "South-Central Ontario". Strong declines in SO_4 *concentrations in this region have not been matched by improving acidity conditions (i.e., increasing alkalinity) but rather by decreasing base cation concentrations. The paper speculates that alkalinity increases will not occur until acid anion concentrations decline to the point where base cation supply by primary weathering can compensate the base cation leaching.*

White, M.S., M.A. Xenopoulos, K. Hogsden, R.A. Metcalfe and P.J. Dillon. 2008. Natural lake level fluctuation and associated concordance with water quality and aquatic communities within small lakes of the Laurentian Great Lakes region. Hydrobiologia 613, 21-31. (08-03).

With three other areas in the Laurentian Great Lakes Watershed, the TLW was part of a study to reveal patterns of the effects of water level fluctuation on water quality and aquatic communities. Significant correlations with some water quality parameters were observed (DOC, Ca, conductivity, pH, SO_4*) while only macroinvertebrates were significantly affected by water level fluctuations. Thus, factors that disturb natural water levels such as climate change and water regulation could have damaging effects on lake ecosystems.*

Wong, P.T.S., H. Shear, Y.K. Chau, C. Nalewajko and S. Rhamey. 1986. Ultra-clean techniques in assessing the effects of metals on phytoplankton. Can. Tech. Rep. Fish. Aquat. Sci. No. 1462, 75-94. (86-05).

The effect on phytoplankton production of extremely low concentrations of metals derived from contaminated incubation equipment was evaluated. Samples from Little Turkey Lake (among others) were used in the study.

Zhang, J., J. Hudson, R. Neal, J. Sereda, T. Clair, M. Turner, D. Jeffries, P. Dillon, L. Molot, K. Somers and R. Hesslein. 2010. Long-term patterns of dissolved organic carbon in lakes across eastern Canada: evidence of a pronounced climate effect. Limnology and Oceanography 55, 30-42. (10-01).

Lakes of the TLW were among 55 lakes from five regions in eastern Canada analyzed for DOC dynamics during ice-free periods. At the TLW an increase of annual mean temperature did not correspond to changes in DOC. The long-term DOC pattern at TLW was not related to the variation in precipitation as it was elsewhere, and was only weakly related to the Southern Oscillation Index and the Pacific Decadal Oscillation.

WATER BIRDS

Water Birds publications are primarily papers reporting waterfowl populations and the impact of surface water acidification. Much of the research in this category has been conducted by Environment and Climate Change Canada – Canadian Wildlife Service.

PUBLICATIONS

Bendell, B.E. and D.K. McNicol. 1995. The diet of insectivorous ducklings and the acidification of small Ontario lakes. Can. J. Zool. 73: 2044-2051. (95-08).

The diets of four species of insectivorous ducks from small lakes in northeastern Ontario were examined. It was observed that lake acidification results in changes in the distribution of waterfowl broods and reproductive success, as prey is affected by changes in water chemistry.

Blancher, P.J. and D.K. McNicol. 1986. Investigations into the effects of acid precipitation on wetland-dwelling wildlife in Northeastern Ontario. Technical Report Series #2, Canadian Wildlife Service, Ontario Region. (86-24).

Bogs and fens at an area northeast of Sudbury (Wanapitei Lake area) were compared to those at Ranger Lake (TLW). Sulphate was the predominant anion at Wanapitei, while organic acids were more important at Ranger. No direct influence on mat vegetation was observed at either site. Aquatic organisms were negatively affected by low pHs. Wildlife inhabiting the peatlands was documented, and tree swallows were studied for the possible indirect effects of acid deposition on insectivorous species. More study is needed, but the potential for negative impact on wildlife by acidic deposition is indicated.

McNicol, D.K. 1999. The Canadian Wildlife Service acid rain biomonitoring program - monitoring and modelling the effects of acid rain on water birds in eastern Canada. Chapter 12. International Cooperative Program on Assessment and Monitoring of Rivers and Lakes (ICP - Waters) Report 50/99, 80-88. (99-03).

This paper discusses the history and current status of the acid rain problem in Canada, specifically as it pertains to ecological effects of acid rain in surface waters in eastern Canada, and provides an outline of the CWS Acid Rain Biomonitoring Program designed to verify the degree of environmental improvement achieved and the adequacy of acid rain control programs. Results of monitoring and modelling efforts together demonstrate that certain water birds, especially piscivores, are effective indicators of acidification. Predictions reported in this paper demonstrate that little improvement in habitat suitability for water birds will occur in eastern Canada, including Algoma, even with the strongest legislated emission reductions (post-2010), but that further recommended reductions should lead to substantial improvements in water quality and habitat suitability for some populations, as currently being observed in the heavily damaged (but recovering) Sudbury area.

McNicol, D.K. 2002. Relation of lake acidification and recovery to fish, Common Loon and Common Merganser occurrence in Algoma lakes. Wat. Air Soil Pollut.: Focus 2, 151-168. (02-08).

Logistic regression models were developed to predict the occurrence of fish, the common loon and the common merganser in relation to the physical and chemical characteristics of Algoma lakes (including the Turkey lakes). These models were linked to the Waterfowl Acidification Response Modelling System to assess the likely effect of expected and hypothetical reductions in North American SO_2 emissions on habitat quality in the Algoma Region.

McNicol, D.K. and P.J. Blancher. 1986. Breeding waterfowl as indicators of aquatic ecosystem acidification in wetlands of northeastern Ontario. Canadian Wildlife Service Ontario Region. Proceedings of Workshop on Birds as Bio-Indicators of Environmental Conditions, 19th World I.C.B.P. Conference, Kingston Ontario. 38p. (86-25).

In a study on the effects of aquatic acidification on waterfowl (including the Ranger Lake area near the TLW in Algoma) it was found that the populations of certain fish and other waterfowl food were reduced in the stressed areas, resulting in smaller broods for piscivores in those areas. Some macroinvertebrates flourished with the absence of fish, causing a change in customary diet for the waterfowl. Long-term biomonitoring is recommended on loons and selected duck species to generate trend data for acidification effects.

McNicol, D.K., J.J. Kerekes, M.L. Mallory, R.K. Ross and A.M. Scheuhammer. 1995. The Canadian Wildlife Service LRTAP Biomonitoring Program, Part 1. A strategy to monitor the biological recovery of aquatic ecosystems in eastern Canada from the effects of acid rain. Technical Report Series 245, Canadian Wildlife Service, 28p. (95-11).

In order to assess the impact of acid rain control programs in the US and Canada, long-term monitoring of aquatic ecosystem recovery has been conducted since 1987 by CWS in three regions of Ontario - Algoma (including the TLW), Muskoka and Sudbury, and in the Kejimkujik region of Nova Scotia. The breeding success of common loons, which is monitored through the volunteer-based Canadian Lakes Loon Survey, is also used as an indicator of the health of large oligotrophic lakes. Models (WARMS, RAISON/IAM) are being developed using all of this information to evaluate acid rain effects and to predict future changes and benefits of control strategies.

McNicol, D.K., M.L. Mallory and C.H.R. Wedeles. 1995. Assessing biological recovery of acid-sensitive lakes in Ontario, Canada. Wat. Air Soil Pollut. 85: 457-462. (95-10).

A model that estimates the effects of acid deposition on waterfowl was used to assess the responses to proposed reductions in SO_2 *emissions in three regions of Ontario (including the TLW in Algoma). The greatest improvements were predicted to occur in the Sudbury region. Algoma should see moderate improvement, while the maximum proposed emission reduction will be needed just to maintain current conditions in Muskoka.*

McNicol, D.K., P.J. Blancher and B.E. Bendell. 1987. Waterfowl as indicators of wetland acidification in Ontario. ICBP Technical Publication 6, 149-166. (87-19).

An acid-stressed lake in northeastern Ontario, (Wanapitei) and a non-stressed lake (Ranger Lake, near the TLW) were studied to monitor and compare the effects of high acidic deposition on waterfowl. The breeding success of the common loon and the common merganser is less at Wanapitei in direct response to a depletion in fish stocks due to low pH. The common loon and selected duck species should become part of a long-term biomonitoring program, since a decrease in breeding success is a good indicator of the negative impact of acidic deposition.

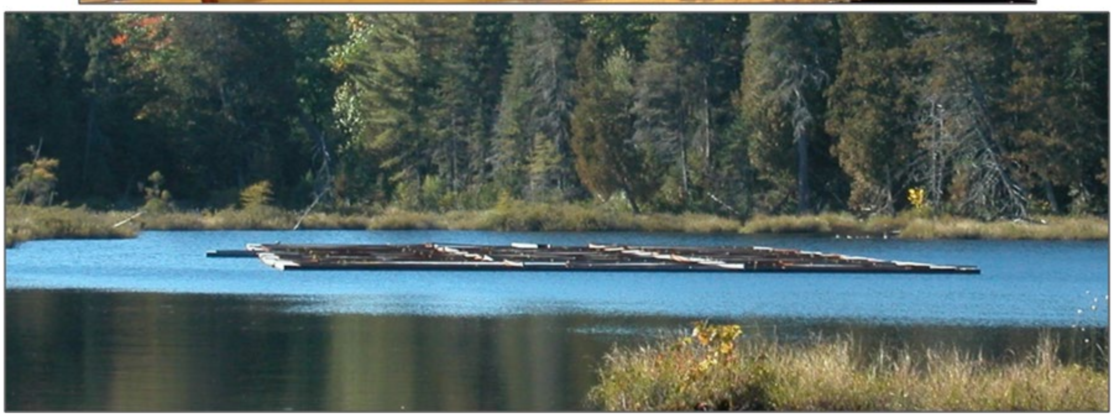
McNicol, D.K., B.E. Bendell and R.K. Ross. 1987. Studies of the effects of acidification on aquatic wildlife in Canada: Waterfowl and trophic relationships in small lakes in northern Ontario. Canadian Wildlife Service Occasional Paper No. 62, Ottawa, Ont., 76p. (87-08).

Report presents an evaluation of the effects on waterfowl due to ecological changes in aquatic ecosystems associated with acid precipitation. Aerial surveys of waterfowl were used including lakes in the Ranger Lake area of Algoma just south of the TLW.

Scheuhammer, A.M. 1991. Effects of acidification on the availability of toxic metals and calcium to wild birds and mammals. Environ. Pollut. 71: 329-375. (91-10).

The effects of acidification on wildlife in an aquatic environment include increased exposure to methyl-Hg for piscivores. Insectivores are at low risk from exposure to toxic metals. Of more importance is the decrease in available dietary Ca, as low pH leads to the extinction of molluscs and crustaceans. Lack of Ca is also known to affect egg-laying and egg-shell integrity in birds and the growth of hatchling birds and some mammals. Herbivores may risk higher exposure to Al, Pb and Cd as some macrophytes accumulate high concentrations of these metals under acidic conditions. The review includes information from the Ranger Lake area of Algoma, near the TLW.

FISH AND AQUATIC COMMUNITIES



Fish and Aquatic Communities publications are primarily papers reporting lake fish populations and biomass, stream microbial and invertebrate communities and the impact of acid deposition and forest harvesting. Much of the research in this category has been conducted by Fisheries and Oceans Canada – Great Lakes Laboratory for Fisheries and Aquatic Sciences, Environment and Climate Change Canada – Canadian Wildlife Service and Natural Resource Canada – Canadian Forest Service.

PUBLICATIONS

Bendell, B.E. and D.K. McNicol. 1987. Cyprinid assemblages, and the physical and chemical characteristics of small northern Ontario lakes. Environmental Biology of Fishes 19: 229-234. (87-17).

Cyprinids from 58 lakes in the Algoma district were sampled. Common shiner, creek chub and blacknose dace tended to occupy lakes with larger than average drainage areas. Pearl dace and fathead minnow occurred commonly in lakes with smaller drainage areas. Lakes without cyprinids were those more sensitive to acidification.

Bendell, B.E. and D.K. McNicol. 1987. Fish predation, lake acidity and the composition of aquatic insect assemblages. Hydrobiologia, 150: 193-202. (87-16).

Two sets of lakes, one near Sudbury and one near Ranger Lake (south of the TLW) were sampled to examine insect assemblages. Fishless lakes were found to contain a greater variety and abundance of insects. Fish predation is seen as the most important factor structuring aquatic insect assemblages and is responsible for changes coincident with acidification.

Brush, J.M., K.E. Smokorowski, J. Marty and M. Power. 2016. Fish feeding niche characterization over space and time in a natural boreal river. Ecohydrology 9: 1400-1409 (16-04).

Using a ten-year dataset from Batchawana River, temporal variability of fish feeding niche in response to variable flows and temperature or temporal consistency of spatial differences in fish feeding niche within a natural river were examined. The fish feeding niche was temporally invariant in the lower sampled river reaches, but increased over time in the upper reaches. Fish feeding niche was significantly larger in the lower than upper Batchawana River, but there were no significant differences in mean fish community between reaches. Results highlight that in natural undisturbed rivers, fish feeding niche appears to be temporally invariant in the face of naturally imposed environmental variability.

Collins, R.H., R.J. Love, J.R.M. Kelso, J.H. Lipsit and J.E. Moore. 1983. Phytoplankton production, as estimated by the 14C technique, and populations contributing to production 1980/81 in the Turkey Lakes Watershed. Can. Tech. Rep. Fish. and Aquat. Sci., No. 1191, 23 pp. (83-01).

Phytoplankton production was estimated for the ice-free seasons of 1980 and 1981 in each of the lakes in the TLW. Production was observed to increase downstream. Species contributing to production were identified. Highest summer production generally followed the shift of Cyanophyte species.

Daoust, K., D.P. Kreutzweiser, J. Guo, I.F. Creed, and P.K. Sibley. 2019. Climate-influenced catchment hydrology overrides forest management effects on stream benthic macroinvertebrates in a northern hardwood forest. Forest Ecology and Management 452 (2019) 117540. (19-02)

Field measurements in the Lower Batchawana Watershed and modelling were used to derive a comprehensive suite of physical, chemical, and biological variables to develop explanatory relationships between these variables and benthic macroinvertebrate community composition of headwater streams in managed forests. The variables related to hydrological patterns and processes (i.e., flow variability; conductivity) were most strongly associated with benthic macroinvertebrate community structure. Selection-based forest harvesting had no measurable adverse effects on benthic macroinvertebrate communities. This study helped to better define the relationships between physical, chemical and biological indicators of aquatic ecosystem function, providing information required to make effective monitoring and management decisions aimed at ensuring sustainability of forest-based aquatic ecosystem services, particularly in the face of a changing climate.

Dermott, R., J.R.M. Kelso and A. Douglas. 1986. The benthic fauna of 41 acid sensitive headwater lakes in north central Ontario. Wat. Air. Soil Pollut. 28: 283-292. (86-21).

> *The abundance and composition of benthic fauna in 41 lakes of central Ontario (including those in the TLW) was evaluated. No correlation with pH or ANC was observed. Other factors such as lake depth and sediment nature appear to be important factors governing benthos distribution.*

Dermott, R.M. 1985. Benthic fauna in a series of lakes displaying a gradient of pH. Hydrobiologia 128: 31-38. (85-11).

> *Benthic fauna (presence and abundance) were examined in the TLW and related to pH. There was little relation between pH or ANC and the abundance and biomass of benthic fauna at depths > 3 m. High littoral biomass in the lake with lowest pH (Batchawana) is related to the lack of fish predation.*

Dermott, R.M. 1988. Zoobenthic distribution and biomass in Turkey Lakes. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 108-114. (88-08).

> *The composition of benthic fauna in the four lakes of the TLW is dependent on absence of fish, depth, and hypolimnetic oxygen concentrations, rather than the chemical gradient in the watershed. Details of species composition and biomass are presented and evaluated.*

Doka, S.E., M.L. Mallory, D.K McNicol and C.K. Minns. 1997. Species richness and species occurrence of five taxonomic groups in relation to pH and other lake characteristics in southeastern Canada. Can. Tech. Rep. Fish. Aquat. Sci. 2179, 57p. (97-04).

> *Data from many sources were used to model the relationship between species richness and lake pH from Ontario to the Atlantic provinces. TLW data from the CWS northeastern Ontario biomonitoring program were included. Zooplankton and fish showed loss of taxonomic richness as pH decreased to less than 5.5, and benthic organisms were affected at pH <5.3. Overall evidence indicates damage (loss of species) to aquatic ecosystems at pH < 6. Maximum species diversity occurs at a pH of ~6. Knowledge of the effects of acidic precipitation is essential when assessing the combined effects of environmental stressors such as UV-B, toxics, and climate change. Results of the study were used in the 1997 Canadian Acid Rain assessment.*

Johnson, M.G., J.R.M. Kelso, O.C. McNeil and W.B. Morton. 1990. Fossil midge associations and the historical status of fish in acidified lakes. J. Paleolimnol. 3: 113-127. (90-04).

> *Chaoborid and chironomid (Diptera) fossils in sediments of nine Ontario Precambrian Shield lakes indicate that four fishless lakes were historically fishless, while four had fish in the past. One of them was periodically fishless. Chironomid fossil associations are substantially different in historically fishless and inhabited lakes. Fish reappeared in two lakes in which alkalinity and pH made a recovery. Diptera associations are shown to be valuable indicators for the historical status of fish in acidified lakes.*

Johnson, M.G., J.R.M. Kelso and S.E. George. 1988. Loadings of organochlorine contaminants and trace elements to two Ontario lake systems and their concentrations in fish. Can. J. Fish. Aquat. Sci. 45 (Suppl 1): 170-178. (88-21).

> *Report presents assessment of the inputs of various organic contaminants and trace metals on three lakes in the TLW (and two others) and their incorporation into fish. Atmospheric deposition was determined for several OCs and pesticides. Lake loading and/or lipophilicity could account for most of the variability of these substances in fish. Lead concentrations were proportional to loadings and Hg exhibited the greatest biomagnification.*

Kelso, J.R.M. and B.J. Shuter. 1989. Validity of the removal method for fish population estimation in a small lake. North Amer. J. Fish. Management 9: 471-476. (89-07).

Paper discusses the problems associated with using the removal method to estimate the abundance of lake fishes. Catchability is not constant. Three models fit the data but do not accurately predict abundance. Coordination of sampling is important for more accurate estimates.

Kelso, J.R.M. 1985. Standing stock and production of fish in a cascading system on the Canadian Shield. Can. J. Fish. Aquat. Sci. 42(7): 1315-1320. (85-13).

Fish biomass and productions is examined for the lowest three lakes in the TLW using mark-recapture techniques. Total fish biomass decreases downstream and with increasing lake depth. Salmonid flesh production is of greater relative significance downstream. Results were compared with observations from other N. American lakes.

Kelso, J.R.M. 1988. Fish community structure, biomass, and production in the Turkey Lakes Watershed, Ontario. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 115-120. (88-07).

Report summarizes fisheries community, biomass, and production studies in the TLW. Only the three downstream lakes support a native, reproducing fish stock. Biomass varied 3.3-fold but fish flesh production by only 1.5-fold. Both were strongly influenced by lake depth and also related to ANC and phytoplankton C assimilation. These conditions might be related to acidification and/or biogeographic factors.

Kelso, J.R.M. and J.H. Lipsit. 1988. Young-of-the-year fish community in nine lakes, varying in pH, on the Canadian Shield. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 121-126. (88-18).

Larval fish populations were sampled from lakes in the TLW and others near Sudbury to assess the impact of the rapid water quality changes that accompany spring runoff. Abundance was not strongly linked to lake pH or ANC; however, diversity was related. Monitoring of the larval fish community is proposed as an inexpensive, responsive, and reproducible measure of change in fish communities that are sensitive to acidification.

Kelso, J.R.M. and J.M. Gunn. 1984. Responses of fish communities to acidic waters in Ontario. *In*: Hendry, G.R. (ed.), Early biotic responses to advancing lake acidification, Butterworth Publishers, Boston, Mass, 105-115. (84-16).

Information is presented on observed symptoms and responses of fish communities in low pH lakes of Ontario. Topics covered include: community and population changes, changes in abundance, cases of lakes in terminal stage of fish loss, species tolerance, mixed community and recruitment failure, and contaminant levels in fish. Emphasis is placed on presentation of new material.

Kelso, J.R.M., M.A. Shaw, C.K. Minns and K.H. Mills. 1990. An evaluation of the effects of atmospheric acidic deposition on fish and the fishery resource of Canada. Can. J. Fish. Aquat. Sci. 47: 644-655. (90-03).

It is estimated that 390,000 lakes in eastern Canada are sensitive to acidification. Although fish losses are documented for Sudbury and Nova Scotia, acidification is probably more widespread. Recovery of fish populations and a rise in pH in Sudbury and Algoma lakes show that recovery is possible. Fish community responses depend on a variety of factors, making losses difficult to document. Reduction of acidifying pollutants is the recommended solution to the problem.

Kelso, J.R.M. and M.A. Shaw. 1995. Annual biomass and production of brook char (*Salvelinus fontinalis*) introduced into a historically fishless lake. Ecology of Freshwater Fish 4: 47-52. (95-17).

In 1985 brook char were introduced into the lower basin of Batchawana Lake in the TLW, which had been fishless for more that 150 years. Growth rates peaked in the following year, and the production to biomass ratio stabilized in the third year. Food resources in the lake did not become depleted. Organisms serving as food for the fish population depend on seasonal energy, thus periodic rather than continuous stocking is a better strategy.

Kelso, J.R.M. and M.G. Johnson. 1991. Factors related to the biomass and production of fish communities in small, oligotrophic lakes vulnerable to acidification. Can. J. Fish. Aquat. Sci. 48: 2523-2532. (91-08).

Biomass and production of the fish community was estimated in 19 small lakes from four watersheds. Nineteen species of fish were counted, with 4.5 species per lake, although >75% of each lake's population was confined to <3 species. Production was found to be related in equal measure to fish biomass, average fish size, and ANC.

Kreutzweiser, D.P., P.K. Sibley, J.S. Richardson and A.M. Gordon. 2012. Introduction and a theoretical basis for using disturbance by forest management activities to sustain aquatic ecosystems. Freshwater Science 31:224-231, doi: http://dx.doi.org/10.1899/11-114.1. (12-03).

Emulation of natural disturbance (END) principles can include intentional logging disturbance near water to emulate natural riparian disturbance. Integrating current scientific understanding of land-water linkages in forest watersheds including work done at TLW with general disturbance ecology suggests that periodic watershed and riparian disturbances may be natural renewal processes required for the long-term sustainability of aquatic ecosystems. This paper introduces the concepts of END and provides a theoretical basis for using END in riparian forests to sustain aquatic habitats and ecosystems.

Kreutzweiser, D.P., S.S. Capell and K.P. Good. 2005. Effects of fine sediment inputs from a logging road on stream insect communities: a large-scale experimental approach in a Canadian headwater stream. Aquatic Ecology 39, 55-66. (05-12).

A headwater stream in the TLW was manipulated to induce a seven-fold increase in sediment input over three years to examine the effect on aquatic insect communities. Apart from small reductions in diversity and richness of spring communities, there was little evidence of stress on benthic communities (total insect abundance or biomass). A larger-scale study would help to evaluate tolerance limits.

Kreutzweiser, D.P., S.S. Capell and K.P. Good. 2005. Macroinvertebrate community responses to selection logging in riparian and upland areas of headwater catchments in a northern hardwood forest. J. N. Am. Benthol. Soc. 24, 208-222. (05-11).

Two streams in three headwater catchments in the TLW were sampled over a five-year period (1995-1999) to determine the effect of low intensity versus moderate intensity logging on aquatic insect communities. It was found that up to 42% basal area removal caused little change to these communities, i.e., observed changes not larger than natural variation.

Kreutzweiser, D.P., S.S. Capell and K.P. Good. 2004. Stream invertebrate communities as indicators of logging disturbance in northern hardwood forests of Ontario. *In*: Scrimgeour, G.J., G. Eisler, B. McCulloch, U. Silins and M. Monita (eds.) Forest Land-Fish Conference II - Ecosystem Stewardship Through Collaboration, pp165-166. Proc. Forest-Land-Fish Conf. II, April 26-28, 2004, Edmonton, Alberta. (04-05).

> *The effects on aquatic insect communities of different logging intensities was examined two years before and three years after harvesting. At 29% basal area removal no changes were observed, at 42% removal small changes occurred, whereas at the high-intensity disturbance sites (89% removal) larger and more distinct changes in insect community structure were observed. This high-intensity logging is above normal harvesting rates. If the riparian code that prohibits tree removal within 3 m of stream edges is observed, harmful effects of harvesting are minimal.*

Kwain, W. and J.R.M. Kelso. 1988. Risk to salmonids of water quality in the Turkey Lakes Watershed as determined by bioassay. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 127-135. (88-19).

> *Report presents results of in-situ bioassay studies conducted to address the reason for the fishless state of Batchawana Lake. Spring pH depressions did not induce consistent mortality in caged fish. Whole-body ion concentrations were generally similar for fish caged in Batchawana Lake compared to those in the other three lakes; Pb and Hg levels were higher however. Factors beyond pH and trace metals likely contribute to the fishless condition of Batchawana Lake.*

Mallory, M.L., P.J. Blancher, P.J. Weatherhead and D.K. McNicol. 1994. Presence or absence of fish as a cue to macroinvertebrate abundance in boreal wetlands. Hydrobiologia 279/280: 345-351. (94-02).

> *The fish status of a wetland appears to be a good indicator of invertebrate abundance. Changes in acidity resulting from anthropogenic input may however change the reliability of this indicator and affect wetland selection for breeding by waterfowl.*

McNicol, D.K., B.E. Bendell and M.L. Mallory. 1995. Evaluating macroinvertebrate responses to recovery from acidification in small lakes in Ontario, Canada. Wat. Air Soil Pollut. 85: 451-456. (95-09).

> *Food chains in three acid-sensitive regions: Muskoka, Sudbury, and Algoma (including the TLW), were monitored to assess the effects of changing acid deposition on waterfowl and their prey. Abundance and distribution of benthic groups are related to pH, but the effect of fish in structuring the community must also be considered.*

McNicol, D.K., M.L. Mallory and B.E. Bendell. 1996. The Canadian Wildlife Service LRTAP Biomonitoring Program, Part 2. Food chain monitoring in Ontario Lakes: taxonomic codes and collections. Technical Report Series 246, Canadian Wildlife Service, 32p. (96-04).

> *Waterfowl prey (macroinvertebrates, fish, and amphibians) have been sampled at small lakes and wetlands in Algoma (including the TLW), Muskoka and Sudbury in order to assess changes in composition and abundance following acid rain abatement programs in Canada and the US Locations, identification keys and minimum pHs where the prey is caught are documented as a reference for researchers studying the same taxa or types of lakes.*

Naylor, B.J., R.W. Mackereth, D.P. Kreutzweiser and P.K. Sibley. Merging END concepts with protection of fish habitat and water quality in new direction for riparian forests in Ontario: a case study of science guiding policy and practice. 2012. Freshwater Science 31 (1):248-257, doi: http://dx.doi.org/10.1899/11-035.1. (12-02).

In Ontario the END paradigm has been used in the management of forests to conserve biological diversity and long-term health, but riparian forests have been excluded. This paper describes new forest management guidelines that integrate the protection of fish habitat and water quality with the desire to emulate natural disturbance patterns in riparian forest. Science-based knowledge from TLW and other research was used to develop these new forest management directions.

Pink, M., M.G. Fox and T.C. Pratt. 2007. Numerical and behavioural response of cyprinids to the introduction of predatory brook trout in two oligotrophic lakes in northern Ontario. Ecology of Freshwater Fish 16, 238-249. (07-07).

Four of the lakes in the TLW were part of a study conducted in 2003 and 2004 in which brook trout were added to Batchawana Lake North to examine the response of cyprinid prey species. No changes in abundance or habitat use patterns were observed among the cyprinids. The only consistent response by the prey fish was increased shoaling. Since predator-prey responses are difficult to predict in small-scale experiments, further whole-lake studies are needed.

Pink, M., T.C. Pratt and M.G. Fox. 2007. Use of underwater visual distance sampling for estimating habitat-specific population density. North American Journal of Fisheries Management 27, 246-255. (07-08).

Two methods of sampling fish population density were compared in five Ontario lakes, including four at the TLW. It was found that underwater visual distance sampling compares closely with the traditional mark-recapture techniques. Further, it has the advantage of being less intrusive, is able to determine age-0 fish abundance as well as school size and other information not obtained by mark-recapture.

Pratt, T.C. 2004. Habitat-specific production rate estimates from 5 Canadian Shield lakes. Canadian Science Advisory Secretariat, Res. Doc.2004/085, 18p. (04-09)

Four lakes from the TLW were used in a study to estimate habitat-specific production rates for the littoral zone fish population. These data assist assessing development proposals and their impact.

Pratt, T.C., K.E. Smokorowski and J.R. Muirhead. 2005. Development and experimental assessment of an underwater video technique for assessing fish-habitat relationships. Arch. Hydrobiol. 164, 547-571. (05-13).

Little Turkey Lake in the TLW was one of two lakes used in a study to assess the usefulness of an underwater video camera in assessing fish-habitat relationships. An improvement on site-level inferences of fish-habitat use could be achieved with longer filming duration, more sites, or a transect method of filming.

Rao, S.S. and B.J. Dutka. 1983. Influence of acid precipitation on bacterial populations in lakes. Hydrobiologia 98: 153-157. (83-02).

Bacterial abundance was measured in acid stressed soft water and non-acid stressed hard water lakes. Population densities for nitrogen and sulphur cycle bacteria were nearly an order of magnitude lower in acid stressed waters. Surface sediments in acid stressed lakes contained three- to four-fold more organic matter compared to non-stressed lakes. Methodology and data are presented.

Shalk, G., D.K. McNicol and M.L. Mallory. 2001. Leeches in acidified lakes of central Ontario, Canada: status and trends. Ecoscience 8, 421-429. (00-08).

Leeches collected in acid-sensitive lakes in Muskoka, Sudbury and Algoma (including the TLW) were examined to assess relationships between populations and certain chemical and physical characteristics of lakes. Thirteen species of leeches were trapped with species richness found to be high in lakes with high pH. Yet, leech occurrence, richness and abundance trends over a nine-year period in Sudbury area lakes showed no direct relationship to changes in lake chemistry, suggesting that leeches are not suitable as direct indicators of chemical recovery from acidification.

Shaw, M.A. and J.R.M. Kelso. 1992. Environmental factors influencing zooplankton species composition of lakes in north-central Ontario, Canada. Hydrobiologia, 241: 141- 154. (92-18).

One hundred thirty-two headwater lakes in six regions of north-central Ontario (including the Algoma, TLW area) were sampled to determine factors affecting populations of zooplankton. Larger lakes tended to support more species. Lake location influenced species composition with Algoma lakes.

Shaw, M.A., I.J. Davies, E.A. Hamilton, A. Kemp, R. Reid, P.M. Ryan, N. Watson, W. White and K.M. Murphy. 1995. The DFO national LRTAP biomonitoring program: Baseline characterization 1987-1989. Can. Tech. Rep. Fish. Aquat. Sci. 2032, 69p. (95-15).

The TLW is part of the DFO LRTAP biomonitoring program which includes 36 lakes and 21 rivers across eastern Canada considered to be sensitive to acidic deposition. This report characterizes fish and benthic communities in these areas, establishing a baseline for annual variability in species composition and abundance. Annual variability in acidic lakes is seen to be twice that of neutral lakes. Seasonal pH depression has deleterious effects on salmonid populations. Long-term monitoring is needed to identify trends, and to distinguish anthropogenic stress from natural variability.

Sibley, P.K., D.P. Kreutzweiser, B.J. Naylor, J.S. Richardson and A.M. Gordon. 2012. Emulation of natural disturbance (END) for riparian forest management: synthesis and recommendations. Freshwater Science 31(1):258-264. doi: http://dx.doi.org/10.1899/11-094.1. (12-04).

The application of END concepts to riparian forests has been evaluated in a limited but growing number of studies including the TLW. This paper critically examined 1) the historical, scientific, and practical foundations of applying END in riparian forest management as an alternative to fixed-width buffers, and 2) the extent to which mimicking natural disturbance and renewal processes can protect aquatic ecosystems through conservation of riparian and aquatic biodiversity. Future research areas, outstanding questions and uncertainties about the use of END in riparian forest management and initial guiding principles of END in riparian areas are addressed in this paper.

Smokorowski, K.E., T.C. Pratt, W.G. Cole, L.J. McEachern and E.C. Mallory. 2006. Effects on periphyton and macroinvertebrates from removal of submerged wood in three Ontario lakes. Can. J. Fish. Aquat. Sci. 63, 2038-2049. (06-02).

Lower Batchawana, Wishart and Little Turkey Lake from the TLW were included in a study of northern Ontario lakes in which submerged wood was removed from the lakes to examine the effects on biota and plant life. The removal did not change lake chemistry or invoke a response by the invertebrate population, but removal of a productive biomass made the lakes less attractive to fish.

Smokorowski, K.E. and J.R.M. Kelso. 2002. Trends in fish community structure, biomass, and production in three Algoma, Ontario lakes. Wat. Air Soil Pollut.: Focus 2, 129-150, 2002. (02-10).

Fisheries data for 20 years from Little Turkey and Wishart in the TLW and Quinn Lake SW of the TLW showed high interannual variability, but stability in terms of biomass and production. Species diversity remained stable, although the composition changed. Catch-per-unit effort was not necessarily a good measure of fishery decline since it does not reflect biotic interactions.

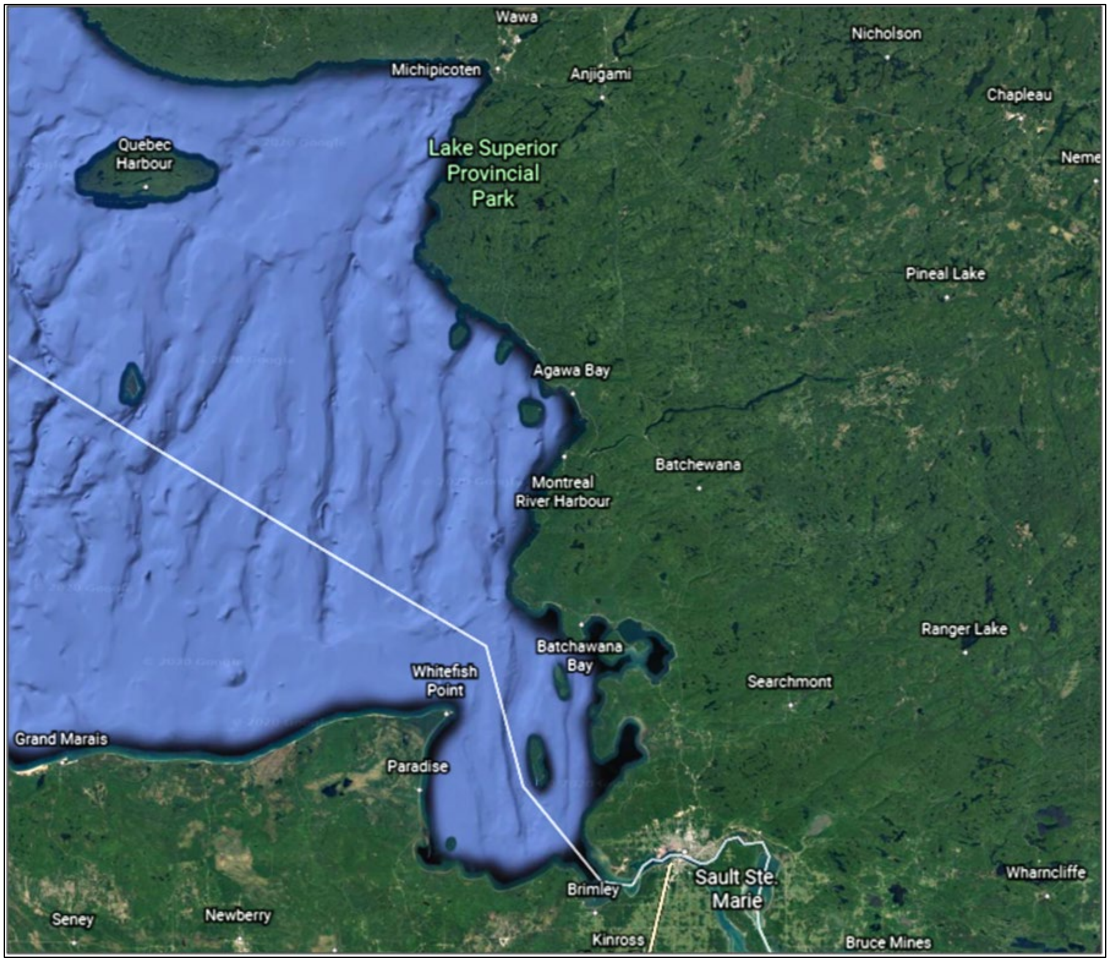
Smokorowski, K.E., J.L. Pearce, W.D. Geiling and T.C. Pratt. 2020. Wood removals from lakes may not necessarily elicit fish population responses. North American Journal of Fisheries Management, ISSN: 0275-5947. DOI: 10.1002/nafm.10543. 16pp. (20-04).

Experiment to test for direct linkages between whole-lake coarse woody habitat (CWH) availability and fish community abundance, biomass, and production. Removal of ~50% CWH from three lakes in Turkey Lakes Watershed while concurrently sampling them and two other unaffected lakes as controls in a before-after-control-impact design. Hypothesis was not supported because observed changes in measured fish community metrics were not attributed to the CWH removal. A number of factors including composition of the fish community, high availability of alternate habitat structure (rocks, macrophytes), large quantities of wood remaining in the lakes, and relative lack of littoral habitat use by piscivores, or low statistical power (small sample size, high variance) could be reasons for inability to directly link the wood removal to changes in the fish metrics. Therefore, authors still urge resource managers to be cautious when considering authorizing removal of CWH from lakes.

Wojtaszek, B.F., B. Staznik, D.T. Chartrand, G.R. Stephenson, and D.G. Thompson. 2004. Effects of Vision® herbicide on mortality, avoidance response, and growth of amphibian larvae in two forest wetlands. Environmental Toxicology and Chemistry, Vol. 23, No. 4, pp. 832-842. (04-12)

The effects of Vision® in two forested wetlands in the TLW in northern Ontario on amphibian larvae included substantial mortality and incidence of abnormal avoidance response only when concentrations exceeded expected environment concentrations (1.43 mg a.e./L, or 4.61mg/L of Vision). Larval growth rate and maximum size varied depending on site and species where mean growth rates and maximum sizes exposed to 1.43 mg a.e./L (expected environmental concentrations) treatment were the same or greater than controls. Overall results suggest that silvicultural use of Vision herbicide in accordance with product label and standard Canadian environmental regulations should have negligible adverse effects on sensitive larval life stages of native amphibians.

MODELLING AND REMOTE SENSING



Modelling and Remote Sensing publications are primarily papers reporting predictive modelling impacts of acid deposition and forest harvesting on ecosystem components and processes. LiDAR and hyperspectral remote sensing research has been conducted to predict forest structure and health. Research in this category has been conducted by all of the TLW Government of Canada scientists as well as university collaborators.

PUBLICATIONS

Aherne, J., T.A. Clair, I.F. Dennis, M. Gilliss, S. Couture, D. McNicol, R. Weeber, P.J. Dillon, W. Keller, D.S. Jeffries, S. Page, K. Timoffee, B.J. Cosby and P. Hettelingh (eds.) 2005. European Critical Loads and Dynamic Modelling, CCE Status Report 2005, 77-84. (05-15).

This chapter details the application of the soil-chemical model MAGIC to 502 lakes across eastern Canada, including the TLW watershed, to examine past and future acidification status of these acid-sensitive lakes. The model shows that current proposed emission agreements will not be sufficient to achieve ANC and pH targets in 20 years.

Arp, P.A. and T. Oja. 1992. Acid sulfate/nitrate loading of forest soils: Forest biomass and nutrient cycling modelling. *In*: Grennfelt, P. and E. Thörnelöf (eds.), Proc. Workshop on Critical Loads for Nitrogen, Lökeberg, Sweden, 307-357 (incl. Appendix). (92-16).

Paper presents a model for assessing acid sulphate/nitrate loads on forest soils. Nitrogen processes include soil nitrification of NH to NO_3. The model analyzes soil sensitivity to acidification and atmospheric deposition, and predicts long term trends for acidification of forest soils. The model is calibrated with TLW data.

Bhatti, J.S. and N.W. Foster. 1996. Computer model predicts diminished productivity of tolerant hardwood forest following full-tree harvesting. Technical Note No. 92, Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, Ontario. 4p. (96-07).

This note describes a model, ForSVA (Forest Soil Vegetation Atmospheric Model), that incorporates knowledge of ecosystem processes to predict the effects of various harvesting scenarios on an undisturbed tolerant hardwood forest. The model has been calibrated and validated at the TLW, using ten years of field data. It demonstrates that full-tree clear-cutting is a less sustainable practice than stem-only cutting. The impacts of harvesting on vegetation, nutrient cycles and water quality of the forest of the TLW were investigated.

Blancher, P.J., D.K. McNicol, R.K. Ross, C.H.R. Wedeles and P. Morrison. 1992. Towards a model of acidification effects on waterfowl in eastern Canada. Environ. Pollut. 78: 57- 63. (92-19).

Data from lakes in central Ontario, including a group near the TLW, were examined to determine relationships between the presence of nesting waterfowl and certain lake characteristics. It was shown that models of lake acidification along with knowledge of these relationships can be used to estimate the response of waterfowl to predicted changes in acidic deposition.

Bobba, A., D.S. Jeffries, W.G. Booty and V.P. Singh. 1995. Watershed acidification modelling. *In*: Singh, V.P. (ed.), Environmental Hydrology, Kluwer Academic Publishers, The Netherlands. Chapter 2, 13-68. (95-04).

This chapter gives an overview of process descriptions, assumptions, constraints and other considerations that enter into the development of deterministic watershed acidification models. Various approaches to acidification modelling are described. Four models (TMWAM, ETD, ILWAS and RAINS) are reviewed and a comparison of model performance is presented for the TLW.

Bobba, A.G. and D.C.L. Lam. 1988. Application of a hydrological model to the acidified Turkey Lakes Watershed. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 81-87. (88-13).

Report presents results of the application of a hydrological model to differing locations within the TLW. Close agreement was achieved with observed stream flow, groundwater flow, snowpack, and snowpack chemistry. Episodic events are effectively simulated. Hydrological coefficients vary from location to location due to geological and geomorphological factors. The coefficients are temporally constant.

Bobba, A.G., D.C.L. Lam, D.S. Jeffries, D. Bottomley, J.Y. Charette, P.J. Dillon and L. Logan. 1986. Modelling the hydrological regimes in acidified watersheds. Wat. Air Soil Pollut. 31:155-164. (86-16).

The hydrological model developed for the TLW was applied to the Lac Laflamme and Harp Lake watersheds to test its accuracy and portability. Model performance is reasonably good. Differences in calibration coefficients among the watersheds are discussed.

Bobba, A.G., V.P. Singhand L. Bengtsson. 2000. Application of environmental models to different hydrological systems. Ecological Modelling 125, 15-49. (00-01).

Hydrological processes were investigated through mathematical modelling of water quality. Using data from the TLW (Jan. 1981 – Dec. 1984) four watershed acidification models were applied to compute hydrogen ion, alkalinity and sulphate concentrations. The models TMWAM, ILWAS, ETD, and RAINS were used with the objective of deriving stochastic models to predict the probability of higher hydrogen ion concentration events due to snowmelt and rainfall in acid sensitive watersheds. The models need to be tested on long term data, and should include climatic scenarios.

Bobba, A.G. and D.C.L. Lam. 1990.Hydrological modeling of acidified Canadian watersheds. Ecological Modelling 50: 5-32. (90-08).

Data from the TLW were used to calibrate and confirm a hydrogeochemical model. The model reflects the role of hydrology in watershed acidification, with special linkage to soil and water chemistry, and contributes to the understanding of hydrogeochemical regimes in acidified Canadian watersheds.

Booty, W.G. and J.R. Kramer. 1984. Sensitivity analysis of a watershed acidification model. Phil. Trans. Royal Soc. London. 305B: 441-449. (84-15).

Report presents development for and application of a watershed acidification model to the Batchawana Lake Basin (see 83-12). The rate of acidification of surface waters is primarily dependent on soil infiltration-percolation rates, soil depth, and soil ANC. A method for estimating long term acidification is proposed.

Booty, W.G., A.G. Bobba, D.C.L. Lam and D.S. Jeffries. 1992. Application of four watershed acidification models to Batchawana Watershed, Canada. Environ. Pollut. 77: 243-252. (92-02).

Paper reviews four acidification models for the Batchawana watershed. Predicted and observed data for outflows and lake chemistry are compared for the period Jan. 1981 - Dec. 1984. The Turkey-Mersey Watershed Acidification Model (TMWAM) showed best results for pH, while the Enhanced Trickle-Down (ETD) was best for ANC. TMWAM adequately simulated SO_4, but the remaining three models performed poorly.

Boregowda, S. and G.G. Patry. 1985. Modelling of watershed acidification, Turkey Lakes Watershed. Final Report, DSS Contract 02SE.KW405-4-1662, McMaster University, Dept. Civil Eng., 55 pp. (+ Appendices). (85-10).

Final contract report detailing the development of a statistical model to simulate hydrological and chemical processes in the TLW. A short literature review and extensive evaluation of the statistical measures of model fit are included.

Clair, T.A., J. Aherne, I.F. Dennis, M. Gilliss, S. Couture, D. McNicol, R. Weeber, P.J. Dillon, W. Keller, D.S. Jeffries, S. Page, K. Timoffee and B.J. Cosby. 2007. Past and future changes to acidified eastern Canadian lakes: a geochemical modelling approach. Applied Geochemistry 22, 1189-1195. (07-06).

A model for acidification of groundwater in catchments (MAGIC) was applied to characterize the past and future chemistry of aquatic systems in eastern Canada. The TLW is one of the long-term monitoring sites among 500 lake sites used in the analysis. The model predicts that by 2030 ANC levels will be acceptable at more than 90% of the lakes in the Algoma area, but current emission controls will not be sufficient to improve ANC and pH levels in all parts of Canada.

Creed, I.F., F.D. Beall, T.A. Clair, P.J. Dillon and R.H. Hesslien. 2008. Predicting export of dissolved organic carbon from forested catchments in glaciated landscapes with shallow soils. Global Biogeochemical Cycles 22, GB4024, doi:10.1029/2008GB003294. (08-08).

This study presents a simple model of DOC loading to surface waters that is applicable to headwater catchments in forested regions on glaciated landscapes. Several watersheds, including the TLW, were assessed for annual DOC export, which was found to vary widely. It was hypothesized that the proportion of wetlands within the catchments would explain the majority of variation in average annual DOC export across catchments. Digital terrain analysis was used to identify wetlands using a digital elevation model. The proportion of wetlands explained 63% of the variance in average annual DOC export, which increased to 89% with the inclusion of regional climatic indicators. DOC export can be predicted accurately from headwater catchments in forested regions on glaciated landscapes using a simple model based on proportion of wetlands and climatic variables.

Damsleth E. and A.H. El-Shaarawi. 1989. ARMA models with double-exponentially distributed noise. J. Roy. Statist. Soc. B, 5(1): 61-69. (89-04).

The marginal and bivariate distributions generated from a standard autoregressive moving average scheme are derived, assuming the noise to have a double-exponential (Laplace) distribution. The distributions may differ substantially from their Gaussian counterparts. The AR(1) model with double-exponential noise is applied to a series of weekly measurements of sulphate concentration and is shown to give a significantly better fit when compared with the Gaussian model.

Hopkinson, C., L. Chasmer, K. Lim, P. Treitz and I. Creed. 2006. Towards a universal LIDAR canopy height indicator. Can. J. Remote Sensing 32, 139-152. (06-01).

The TLW was one of five sites chosen for a canopy height study using light detection and ranging (LiDAR). Four models were tested for accuracy in predicting tree height in forest canopies. The surveys were conducted between 2000 and 2005 using airborne laser terrain mapper (ALTM) sensors. First and last pulse returns (LSD) is shown to be a robust estimator of canopy height over a wide range of vegetation types and height classes.

Jeffries, D.S., D.C. Lam, A.G. Bobba and W.G. Booty. 1989. Modelling acidification processes in remote lakes. Proc. CEC Workshop on Acidification Processes in Remote Mountain Lakes, Pallanza Italy, 73-82. (89-01).

Report reviews several mathematical models that can be applied to remote lakes. The Turkey-Mersey model is emphasized. The addition of sub-models for within-lake processes is recommended.

Lam, D.C.L. 1986. Computer simulation of watershed acidification. Nat. Wat. Res. Inst., Contribution No. 86-12, Burlington, Ontario, 5 pp. (86-07).

Report describes development of a prototype expert computer system for the analysis of watershed acidification. Data from the TLW was extensively used in the development and testing of the system. The temporal and spatial changes in both terrestrial characteristics and aquatic chemistry are readily represented in the new system.

Lam, D.C.L., A.G. Bobba, D.S. Jeffries, and D. Craig. 1988. Modelling stream chemistry for the Turkey Lakes Watershed: comparison with 1981-1984 data. Can. J. Fish. Aquat. Sci. 45(Suppl 1): 72-80. (88-12).

Report presents results of the linkage of a hydrological (see 88-13) and a hydrogeochemical model to simulate the geochemical gradients observed in the TLW. The model was calibrated using data from 1981 and verified using 1982-1984 data. The simulation supports the hypothesis that increased groundwater input at low elevation locations accounts for the higher Ca_{2+} *and ANC observed there.*

Lam, D.C.L., S. Boregowda, A.G. Bobba, D.S. Jeffries and G.G. Patry. 1986. Interfacing hydrological and hydrogeochemical models for simulating streamwater chemistry in the Turkey Lakes Watershed, Canada. Wat. Air Soil Pollut. 31:149-154. (86-15).

Report presents results obtained by interfacing a hydrological (see 86-16) and hydrogeochemical model using TLW data. The model simulated the progressive downstream increase in pH, Ca_{2+}*, and ANC observed in the TLW by varying the proportion of groundwater to the total runoff. The model adequately reproduces episodic events.*

Lam, D.C.L. and A.G. Bobba. 1985. Modelling watershed runoff and basin acidification. *In*: Johansson, I. (ed.), Hydrological and hydrogeochemical mechanisms and model approaches to the acidification of ecological systems, NHP-Report No. 10, Internat. Hydrol. Program (IHP) Workshop, Uppsala, Sweden, 205-216. (84-08).

Hydrological model results show progressively increasing groundwater discharges on the stream pathways of the TLW. The results explain the observed spatial gradients of ANC, pH, Ca_{2+} *and* Mg_{2+}*. A general approach to interfacing hydrological and chemical interaction models is discussed.*

Lim, K., P. Treitz, I. Morrison and K. Baldwin. 2002. Estimating aboveground biomass using LIDAR remote sensing. *In*: Proc. Society of Photo-Optical Instrumentation Engineers, 4879: 289-296. (02-04).

Field data on biomass in the TLW were collected from 49 sites in July 2000 and used to confirm measurements from LiDAR data. The intensity return data (LHIR) proved to be the best predictor of total above-ground biomass.

Lim, K., P. Treitz, K. Baldwin, I. Morrison and J. Green. 2003. LIDAR remote sensing of biophysical properties of tolerant northern hardwood forests. Can. J. Remote Sensing, 29, 658-678. (03-06).

In August 2000 small footprint time-of-flight LiDAR data were collected in the TLW and used to estimate biophysical properties of the forest. The results showed that laser height metrics are capable of providing an estimate of properties, such as plot heights and stem densities, above-ground biomass and volume, and canopy-related measures.

Lim, K.S. and P.M. Treitz. 2004. Estimation of above ground forest biomass from airborne discrete return laser scanner data using canopy-based quantile estimators. Scand. J. For. Res. 19, 558-570. (04-08).

The forest at the TLW watershed was used to test a model correlating airborne discrete return laser scanner data with above ground biomass and components such as stemwood, stem bark, live branch and foliage. The model, based on laser height metrics, was able to estimate these components using canopy-based quantile estimators, although forests of different ages and maturity need further assessment and a single quantile of the distributions of laser canopy heights may not give an accurate estimation of forest parameters.

Lindsay, J.B. and I.F. Creed. 2005. Removal of artifact depressions from digital elevation models: towards a minimum impact approach. Hydrological Processes 19, 3113-3126. (05-06).

Digital elevation models (DEM) describing hydrological flow require corrections for artifact depressions that alter the model results. Four methods for removing such depressions were tested on a LiDAR DEM of the TLW to determine which had the least impact on the spatial and statistical distribution of elevation. Landscape with a large percentage of flat areas was most sensitive to depression removal.

Lindsay, J.B. and I.F. Creed. 2005. Sensitivity of digital landscapes to artifact depressions in remotely-sensed DEMs. Photogrammetric Engineering and Remote Sensing 71 (9), 1029-1036. (05-17).

LiDAR and interferometric synthetic aperture radar (INSAR) DEMs of 3 study areas including the TLW were used to evaluate the occurrence of artifact depressions caused by the representation of surfaces using grids and random elevation error. Flat landscapes containing extensive lakes experienced more depressions related to grid spacing and placement than high-relief areas. Stochastic modelling showed that error magnitude controlled the extent of vulnerability within a landscape to depressions caused by random error.

Lindsay, J.B. and I.F. Creed. 2006. Distinguishing actual and artefact depressions in digital elevation data. Computers and Geosciences 32, 1192–1204, doi:10.1016/j.cageo.2005.11.002. (06-06).

Five potential approaches for distinguishing artefacts from actual depressions in DEMs are described in this paper: ground inspection, examining the source data, classification approaches, knowledge-based approaches, and modelling approaches. A comparison of the depression validation approaches for a catchment at the TLW showed that the modelling approach performed slightly better than the other methods. While being highly automated and applicable to all landscape types, this approach also explicitly handles DEM uncertainty.

Lindsay, J.B., I.F. Creed and F.B. Beall. 2004. Drainage basin morphometrics for depressional landscapes. Water Resources Research 40, W09307, doi:10.1029/2004WR003322. (04-10).

This dissertation considers the practice of removing depressions (artifact and actual) and enforcing uninterrupted flow paths in DEMs for hydrogeomorphic applications. The TLW was used to evaluate several aspects of this practice. Preserving actual depressions in DEMs was found to be important for hydrogeomorphic applications involving simulated overland flow. Simple measures of size, position, and connectivity of depressions were found to explain a significant amount of variance in runoff from 12 headwater catchments at the TLW. Therefore, use of depressionless DEMs for hydro-geomorphic applications is not prudent.

Mengistu, S.G., Creed, I.F., Kulperger, R.J. and C.G. Quick. 2012. Russian nesting dolls effect – Using wavelet analysis to reveal non-stationary and nested stationary signals in water yield from catchments on a northern forested landscape. Hydrological Processes Vol. 27, Issue 5. https://doi.org/10.1002/hyp.9552. (12-09).

This study tested the hypothesis that a 28-year time series of water yields from four headwater catchments in the TLW contains signals of non-stationary climate change and naturally occurring stationary climate oscillations and that the effects of these signals are greater in catchments with lower rates of change in water loading and lower water storage capacity (small wetlands). The catchment with low water loading and low water storage was most sensitive to non-stationary and stationary signals, suggesting that these catchments act as sentinels to detect climatic signals. While it is likely that anthropogenic climate change impacts water yields, it is important to account for multiple nested climate oscillations to avoid exaggerating its effects.

Mengistu, S.G., A.A. Melkamu and F.A. Yassin. 2016. Assessment of the sensitivity of streamflow simulations to changes in patch resolution using GIS based hydro-ecologic model. Open Journal of Modern Hydrology doi: 10.4236/ojmh.2016.62007. (16-08).

This study investigates the impact of patch characterization on simulated flow regime, and on the calibration of the Regional Hydro-Ecologic Simulation Systems' (RHESSys) main hydrological parameters: saturated hydraulic conductivity and decay of saturated hydraulic conductivity with depth. Eight different patch configurations of a subcatchment of the TLW were used. The best simulation results were obtained for the patch configuration with the highest spatial variation of climate, stream network and hillslope conditions across the subcatchment. But, there are implications for the physical interpretation and transferability of the calibrated parameter values for different patch configurations.

Murphy, P.N.C., M. Castonguay, J. Ogilvie, M. Nasr, P. Hazlett, J. Bhatti and P.A. Arp. 2009. A geospatial and temporal framework for modeling gaseous N and other N losses from forest soils and basins, with application to the Turkey Lakes Watershed Project, in Ontario, Canada. For. Ecol. Manage. 258, 2304-2317. (09-04).

A digital elevation, hydrological modeling approach is applied to the TLW soils and basins to quantify the pre- and post-harvest N emissions and other N losses. The calibrated model suggests that nitrification and denitrification induced by harvesting are strongest during the first post-harvest year but drop to background levels in four-five years. Further studies are needed to determine whether increased N input due to harvesting leads to N immobilization in mineral soils.

Oja, T. and P.A. Arp. 1995. Dynamic modelling and the analysis of critical S and N loads. *In*: Hornung, M., M.A. Sutton and R.B. Wilson (eds.), Mapping and Modelling of Critical Loads for Nitrogen: a Workshop Report. Proceedings of the Grange-over-Sands Workshop, 24-26 October, 1994, pp 154-157. (95-16).

The ForSVA model was used to assess the critical loads of S and N to five upland forest sites including the TLW. Al:Ca ratios in the soil leachates were also checked. Critical loads are less than or equal to present loadings.

Oja, T. and P.A. Arp. 1997. A forest soil vegetation atmosphere model (ForSVA) II: Application to northern tolerant hardwoods. Ecological Modelling 95: 225-247. (97-06).

The forest soil-vegetation-atmosphere model (ForSVA) was used to simulate biomass growth and nutrient cycling at three sites, including the TLW. The model shows that acidifying compounds from current atmospheric deposition will increase base cation leaching at all three sites. This will lead to a decrease in soil pH and biomass growth, and reduce the longevity of the forest stands.

Sampson, P.H., G.H. Mohammed, P.J. Zarco-Tejada, J.R. Miller, T.L. Noland D. Irving, P.M. Treitz, S.J. Colombo and J. Freemantle. 2000. The Bioindicators of Forest Condition Project: a physiological, remote sensing approach. The Forestry Chronicle 76, 941-952. (00-11).

The TLW was one of 12 study sites selected to test whether remote sensing can be used to determine stand-level forest condition. The Bioindicators of Forest Condition Project (BFCP) seeks to develop a forest condition rating system to classify forest stand condition from healthy to stressed using the Compact Airborne Spectrographic Imager (CASI) with validation by traditional on-ground forest evaluation. The TLW Harvesting Impacts Project was the study site for which the influence of structural changes on spectral response was examined. The highest levels of variability were in shelterwood sections compared with the clearcut and control plots.

Sampson, P.H., P.J. Zarco-Tejada, G.H. Mohammed, J.R. Miller and T.L. Noland. 2003. Hyperspectral remote sensing of forest condition: estimating chlorophyll content in tolerant hardwoods. Forest Science, 49, 381-391. (03-08).

CASI was used over the TLW forest harvesting site in July 1998 to test remote sensing as a means of identifying stress effects in forests. CASI proved effective in mapping chlorophyll content as an indicator of forest physiological strain. Seasonal changes for a range of sites were also measured.

Sampson, P.H., P.M. Treitz and G.H. Mohammed. 2001. Remote sensing of forest condition in tolerant hardwoods: an examination of spatial scale, structure and function. Can. J. Remote Sensing. 27, 232-426. (01-06).

Using remote sensing, vegetation structure and physiological condition of the forest at the TLW following the TLW Harvesting Impact Project were examined. Three different methods of harvesting were compared: selection, shelterwood and clearcut. CASI acquired data at three altitudes, and results showed relationships between canopy opening and spectral indices.

Sanford, S. E., I.F. Creed, C.L. Tague, F.D. Beall and J.M. Buttle. 2007. Scale-dependence of natural variability of flow regimes in a forested landscape. Water Resources Research 43 W08414, doi:10.1029/2006WR0052998. (07-09).

This research determined relationships between natural variability in the flow regime and basin scale. A hydrologic model was used to characterize natural flow regimes of basins in the TLW using the range of variability approach. A 30-year simulated flow record was used to calculate natural variability. Flow variability under wetter conditions was similar across all basins, regardless of scale. Flow variability under drier conditions was scale-dependent, as smaller basins were more variable than larger basins. Indices describing near-stream riparian areas within a basin, median basin residence time and basin curvature were significantly related to flow variability under drier conditions. These findings present a potential management template for establishing reference conditions of basin disturbance.

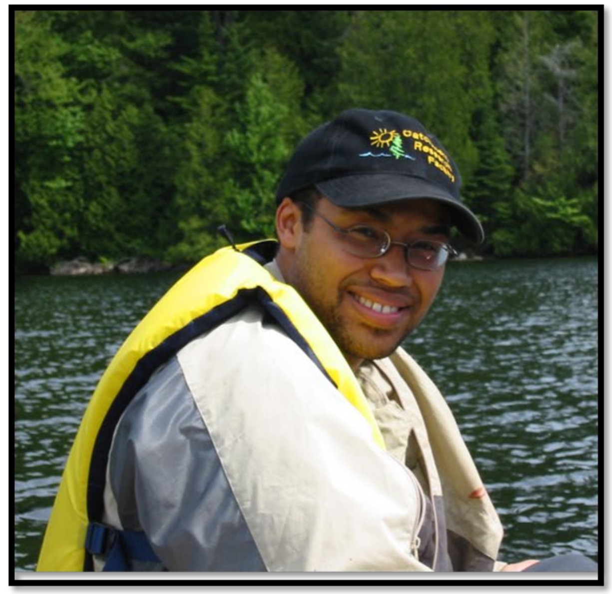
Todd, K.W., F. Csillag and P.M. Atkinson. 2003. Three-dimensional mapping of light transmittance and foliage distribution using LIDAR. Can. J. Remote Sensing, 29, 544- 555. (03-09).

LiDAR measurements of light transmittance and foliage disturbance in the TLW suggest that remote sensing can be a useful tool for evaluating spatial and temporal changes in forest structure.

Treitz, P.M. and B. St-Onge. 2002. Three-dimensional analysis of forest structure and terrain using LIDAR technology. GEOIDE Project #50 Final Report, GEOIDE Business Centre, Université Laval, Laval, QC, 27pp, (+3 Appendices). (02-02)

Project objective was to develop methods and algorithms for collecting, processing and analysing LiDAR data to derive forest structural and terrain information. A high resolution LiDAR-derived DEM of the TLW was acquired that out-performed other data sources. The LiDAR DEM was used with air photos to produce three-dimensional information on the forest canopy.

INTERNAL REPORTS AND THESES



Internal Reports publications represent unpublished reports produced for a more general scientific audience. During the initial years of the TLW Environment and Climate Change Canada – National Water Research Institute produced a series of reports to provide an overview of the physical, chemical and biological characteristics of the watershed. Theses publications represent university MSc and PhD student outputs from research conducted at the TLW in collaboration with Government of Canada partners.

REPORTS AND PUBLICATIONS

Barrie, L.A., H.A. Wiebe and K. Anlauf. 1984. Canadian Air and Precipitation Monitoring Network (APN): 1982. Atmos. Environ. Serv. Rep., ARQB-84-005-T, 9 p. (+9 Appendices). (84-17).

Report summarizes daily air concentrations and wet-only precipitation data for stations in the APN for the 1982 calendar year. TLW data are found in Appendix 2 (labelled "Algoma").

Bendell, B.E., D.K. McNicol and R.K. Ross. 1983. Effects of acidic precipitation on waterfowl populations in northern Ontario. II. Fish community associations in small lakes in the Ranger Lake area, their relationships to chemical and physiographical variables, and their implications for waterfowl productivity. Canadian Wildlife Service Ontario Region, LRTAP program. 56p, 3 Appendices, May 1983. (83-26).

Thirty-seven *lakes in the Ranger Lake area (near the TLW in Algoma) were sampled and categorized by chemical, physiographical and biological variables in a continuing study on the effects of aquatic acidification on waterfowl. In choosing breeding grounds some birds preferred lakes with abundant and diverse fish populations, while the choice of others was independent of fish abundance. The chemical processes at work in the lakes are poorly understood, but ionic composition and metal concentrations probably influence fish community structure, which in turn has implications for breeding success.*

Bendell, B.E. and D.K. McNicol. 1982. Effects of acidic precipitation on waterfowl populations in northern Ontario. I. Relationships between macroinvertebrate and fish faunas in small headwater lakes in the Ranger Lake area. Canadian Wildlife Service Ontario Region, LRTAP program. 48p, 2 Appendices, October 1982. (82-16).

Trophic relationships in ten lakes in the Ranger Lake area (south of the TLW in Algoma) were examined to study the effects of acidification on the availability and abundance of waterfowl food. The focus is upon the relationships between macroinvertebrates and fish, and has implications for waterfowl reproductive success. The abundance and diversity of macroinvertebrates was higher in lakes without fish, thus as acid-sensitive fish disappear the selection of wetlands for breeding will change.

Bobba, A.G. and D.C.L. Lam. 1984. Application of linearly distributed surface runoff model for watershed acidification problems. Turkey Lakes Watershed Unpublished Report No. 84-07, 17p. (84-07).

Report presents the development and preliminary application of a hydrological model in which the different hydrological components of the model are arranged so that they may be related easily to other physical and chemical processes. The model assumptions are also discussed. It is shown to successfully reconstruct the hydrograph for several of the TLW sub-basins using meteorological data as the essential input.

Booty, W.G. 1983. Watershed acidification model and the soil acid neutralization capacity concept. Ph.D. Thesis, Dept. of Geology, McMaster University, Hamilton, Ontario, 194 p. (83-12).

Report presents computer simulation model for predicting movement of water and chemical constituents through a watershed. The model uses a measured ANC for the soils in the watershed and has been applied to the Batchawana Lake basin. Along with flows, the model predicts lakewater pH, snowpack and snowmelt chemistry and stream water pH. Acidification rate was primarily controlled by soil infiltration rates, soil depth, and ANC.

Braun, G.L. 2006. Specificity of substrate control on carbon dioxide flux from soils along a forest toposequence. MSc. Thesis, Department of Biology, University of Western Ontario, London. 114pp, 7 Appendices. (06-05).

The relationship between topography, soil CO_2 flux, soil organic matter and dissolved organic matter (DOM) was determined along a forested hillslope at the TLW. DOM quantity was found to be the key soil property controlling topographically variable CO_2 flux. The relationship between DOM and CO_2 was affected by hydrologic flow, with periods of high flow resulting in transport and lower DOM availability for microbial decomposition.

Callcott, D. 1999. Predicting late-winter oxygen profiles in temperate lakes. MSc Thesis, Faculty of Arts and Science, Trent University, Peterborough, Ontario. 131 p., 30 Appendices. (99-05).

The TLW was one of five study areas for which a model was developed to predict late-winter oxygen profiles in temperate lakes. Data from all groups were used to evaluate annual variation on oxygen budgets. A morphometric variable, strata volume:sediment surface area had the largest influence on these budgets. The model underestimated the oxygen available during winters when temperatures were higher than normal and when new accumulation was lower than average. Results of the study support the continued use of inductive models in limnological studies.

Canadian Forest Service Senior Management Committee. 1999. Turkey Lakes Watershed Field Tour, Sault Ste. Marie, Ontario, September 28-30, 1999. 37p. (99-02).

A field guide to the TLW, with descriptions of its physical, chemical and biological characteristics. Also included are synopses of the impact of atmospheric deposition of acidifying substances.

Casson, N.J. 2008. Rain induced bursts of denitrification activity account for differences in dissolved nitrogen export from forested catchments. MSc. Thesis, Department of Biology, University of Western Ontario, London. 67pp, 2 Appendices. (08-11).

This study sought to explain the discrepancy in dissolved N stream export between C35 and C38 at the TLW in terms of greater gaseous N export from more prevalent wet soils in C38. Minimal N_2O efflux was observed on days without rain. However, on days with rain, N_2O efflux was observed, with a linear increase in the rate of N_2O efflux from wet soils per millimetre of rain. Intensive monitoring of the wetland soil profile suggested that rain delivers water to the surface layers of the wetland creating an oxygen poor environment where accumulated NO_3 is transformed to N_2O then N_2. This study suggests that rain can produce substantial bursts of N_2O and N_2 from forest soils and that failure to account for gaseous N export may lead to an underestimation of N export from forested catchments.

Chan, C.-H., D.J. Williams, M.A. Neilson, B. Harrison and M.L. Archer. 2003. Spatial and temporal trends in the concentrations of selected organochlorine pesticides (OCs) and polynuclear aromatic hydrocarbons (PAHs) in Great Lakes Basin precipitation, 19 (03-10).

Organochlorine pesticides and polynuclear aromatic hydrocarbons from nine precipitation stations in the Great Lakes Basin, including the TLW are reported. Summary concentration statistics were reported for 1995 - 1999. Variation of the volume-weighted means ranged between 9 and 90%. Both north-south and within-lake basin differences in spatial concentration distribution were observed. HCHs have declined in the past 10 years while OCs showed seasonal concentration patterns.

Collins, R.H., R.J. Love, J.R.M. Kelso, J.H. Lipsit and J.E. Moore. 1983. Phytoplankton production, as estimated by the 14C technique, and populations contributing to production 1980/81 in the Turkey Lakes Watershed. Can. Tech. Rep. Fish. and Aquat. Sci. (83-01).

Phytoplankton production was estimated for the ice-free seasons of 1980 and 1981 in each of the lakes in the TLW. Production was observed to increase downstream. Species contributing to production were identified. Highest summer production generally followed the shift of Cyanophyte species.

Cowell, D.W. and G.M. Wickware. 1983. Preliminary analyses of soil chemical and physical properties, Turkey Lakes Watershed, Algoma, Ontario. Turkey Lakes Watershed Unpublished Report No. 83-08, 25 pp. (83-08).

Report provides data and interpretation for soil and morphological analyses of ten upland sampling sites in TLW. Soil profiles have been classified according to the Canadian System. Podzolization is well advanced in all the soils (C horizons occur at 80 cm or deeper) and is attributed to the high moisture holding capacity of the loamy soils and relatively high rainfall. Sulphate adsorption is not considered significant.

Craig, D., L.M. Johnston and D.J. Bottomley. 1983. Acid precipitation and groundwater: an overview of potential problems in eastern Canada. Turkey Lakes Watershed Unpublished Report No. 83-22, 12 p. (83-22).

Report presents a discussion of the problem of groundwater acidification in Scandinavia and compares it to what is currently being observed in specific areas of northern Ontario, including the TLW, Muskoka-Haliburton, and Chalk River.

Craig, D. and L.M. Johnston. 1983. Turkey Lakes groundwater study: aquifer materials and hydrogeological instrumentation. Turkey Lakes Watershed Unpublished Report No. 83-21, 20p. (83-21).

Report presents a summary and description of the aquifer materials and hydrogeological instrumentation that has been installed in the TLW.

Creed, I.F. 1998. Topographic regulation of nitrate-N export from catchments within an old-growth sugar maple forest in the Turkey Lakes Watershed, central Ontario, Canada. PhD Thesis, Department of Geography, University of Toronto, 168 p. (98-09).

The TLW was used as a test region to examine variations in N export behaviour as a means of assessing N saturation in catchments. NO_3-N is the dominant N species, and export was seen to be regulated by a flushing mechanism related to topography. Results of modelling indicated that topography may be more important than landscape or other regional controls in influencing NO_3-N export behaviour.

Daoust, K. 2017. Relative influence of landform, hydrology, and stream habitat on benthic macroinvertebrate communities in a managed northern hardwood forest. MSc thesis, Department of Environmental Sciences, University of Guelph, Ontario. 119pp., Appendix. (17-03).

By using a combination of field measurements and modelling (landscape, hydrological, chemical, and habitat variables) of the Lower Batchawana Watershed, catchment size and stream flow rise rate had the largest influence on benthic macroinvertebrate (BMI) community structure, while forest harvest had no measurable effect.

Delorme, L.D. 1984. Preliminary summary: analyses of inferred pH determinations using fossil diatoms from the lakes of the Algoma calibrated watershed. Turkey Lakes Watershed Unpublished Report No. 84-09, 18 p. (84-09).

Text (with figures) of presentation given at the Royal Society Review of the federal LRTAP research program. Fossil diatoms were used to infer the pH history of lakes in TLW. Results were variable from lake to lake, even basin to basin within a lake. Trends in inferred pH were to lower values in more recent times in most cases. The preliminary nature of the interpretation was stressed.

Delorme, L.D. 1985. Specific gravity determinations of sediments on nine cores from the Turkey Lakes Calibrated Watershed. Nat. Wat. Res. Inst. Tech. Note AED-85-1. Burlington, Ontario, 14p. (85-01).

Report specifies methodology and presents data summaries of specific gravity determinations for nine sediment cores from the TLW. These are the same cores used to infer historical pH changes from diatom analyses.

Dermott, R.M. 1984. The benthic fauna in the lakes of the Turkey Lakes Watershed. Turkey Lakes Watershed Unpublished Report No. 84-04, 15 pp. (+ Tables and Figures). (84-04).

Report presents results of an examination of the benthic fauna in each lake of the TLW. Although there was a slight reduction in the number of taxa present in the lake of lowest pH (e.g. Batchawana Lake), there was little overall relation between fauna abundance or biomass and lake pH or alkalinity. High littoral biomass in Batchawana Lake is related to a lack of fish predation.

Edwards, T.W.D. and S.K. Frape. 1985. Studies of natural gases and trace metals in the sediments of Little Turkey Lake, Algoma District, Ontario. Unpublished Manuscript, U. of Waterloo, Waterloo, Ont. 36p. (85-15).

Profiles of a sediment core from Little Turkey Lake show links between local trace metals and methane abundance and isotopic composition. Bacterial consumption of methane appears to occur at depth in the sediments. Mobilities of Zn, Pb, Fe, Mn and Ni seem to be enhanced by the gas activity. These observations have implications for differentiating between natural and anthropogenic fluxes to lake sediment layers and the overlying aquatic environment.

Eimers, M.C. 2002. Sources and control of sulphur export in Precambrian Shield catchments in south-central Ontario. PhD thesis, Dept. Of Biology, Waterloo University, Waterloo, Ontario. 229pp. (02-03).

While the thesis focuses on Plastic Lake in Haliburton Ontario, samples of upland and wetland soil from sub-basin 50 in the TLW were included in laboratory experiments to determine the effect of drying/re-wetting and increased temperature on SO_4 release (Chapter 5). Organic (sphagnum) soils showed a three- to four-fold increase in mobile SO_4 following drying/re-wetting. Temperature had a relatively lesser influence on SO_4 release. Mineral soils that contain a relatively larger pool of total S are not as responsive to changes in moisture.

Elliott, H. 1985. Geophysical survey to determine overburden thickness in selected areas within the Turkey Lakes Basin, Algoma District, Ont. Nat. Hydrol. Res. Inst. Unpublished Rept. Series, 4 pp. (+ Figures). (85-09).

Report summarizes results from extensive seismic studies in the TLW including presentation of several cross-sections. Overburden thickness is generally < 2 m; however, there are a few areas with large till thicknesses (up to 65 m) that correspond to infilled bedrock channels developed along faults. Almost all surficial deposits are silt-grain size or greater.

Enanga, E.M. 2014. Topographic controls on N_2O and N_2 efflux in a temperate forest. PhD. Thesis, Department of Biology, University of Western Ontario, London. 127pp, Appendix. (14-05).

Topographic influences on soil temperature, moisture, reduction-oxidation (redox) potential, DOC, and nitrate conditions, which in turn influence N_2O release, were investigated at the TLW. More N_2O was released during the summer from the inner (IW) and outer (OW) wetland positions than from lowland and upland topographic positions. Significant positive relationships between N_2O efflux and precipitation events in both the IW and OW were observed. Substantial biogeochemical activities were observed during the non-growing season under a snow-pack, including denitrification. Adding N_2 and N_2O fluxes to catchment N export not only reduced the discrepancy in N export observed among catchments but also between N inputs and outputs.

Fairweather, T.A. 2007. Tracking the alternative fates of nitrogen in forested catchments. MSc. Thesis, Department of Biology, University of Western Ontario, London. 70pp, 2 Appendices. (07-10).

N_2O efflux to the atmosphere and N export to streams (nitrate, ammonium, DON, and N_2O) were measured during the 2006-2007 non-growing season (November- April) in upland (C35) and wetland (C38) catchments at the TLW. Gaseous N_2O efflux did not differ between upland soils in the two catchments or between upland and wetland soils in the catchment with the wetland. While concentrations of dissolved N_2O discharged to surface waters were higher in the wetland catchment than in the upland catchment, when dissolved N_2O fluxes were included in N export estimates, this did not account for the difference in N export between the two catchments.

Federal/Provincial Research and Monitoring Coordinating Committee. 1990. The 1990 Canadian long-range transport of air pollutants and acid deposition assessment report, Part 4: Aquatic Effects, 151 pp. (90-06).

A major assessment report. The effects of acid rain on Canadian aquatic systems have been monitored since 1980. Results of the survey which include TLW are assessed.

Harper, N.S. 1982. Data Report: Pollen analyses of sediments from Turkey Lakes cores, Algoma Calibrated watershed, Ontario. National Water Research Institute Report, Aquatic Ecology Division, 46p. (82-07).

Report contains absolute pollen frequencies of Acer, Ambrosia, Pinus, and Quercus in nine lake sediment cores collected from all the lakes in the TLW. Methodology is outlined.

Jeffries D.S., R.G. Semkin, R. Neureuther and M.D. Jones. 1983. Data Report: Major ion composition of lakes in the Turkey Lakes Watershed (January 1980-May 1982). Turkey Lakes Watershed Unpublished Report No. 83-11, 9 pp. (+ 5 Tables). (83-11).

Major ion data for the main sampling stations in Batchawana (North and South), Wishart, Little Turkey and Turkey Lakes (stations L1 to L5, respectively) are presented for the period January 1980 to May 1981. Information specific to the collection of lake samples and computer storage of the data is also provided.

Jeffries, D.S. (ed.). 1983. Study Progress Report for 1982. Turkey Lakes Watershed Unpublished Report No. 83-06, 38 pp. (83-06).

Report is a compilation of 22 individual progress reports covering work done in 1982. Atmospheric, aquatic, terrestrial, biological, and modelling components of the study are all covered.

Jeffries, D.S. 1983. Lake evaporation and energy budgets in the Turkey Lakes Watershed (1980-81). Turkey Lakes Watershed Unpublished Report No. 83-04, 57 pp. (83-04).

A summary is presented of the meteorological and lake temperature data required to calculate an energy budget and lake evaporation for each of the five lake basins in the TLW for 1980 and 1981. The evaporation estimated by this means is compared to other estimates from evaporation pan measurements (Hydrological Atlas) and Morton's WEVAP model. The magnitude and variation of the components of the energy budgets are discussed. Data compilation and budget calculation methodologies are also presented.

Jeffries, D.S. and R.G. Semkin. 1983. Changes in snowpack, stream, and lake chemistry during snowmelt in the Turkey Lakes Watershed. VDI-Berichte 500: 377-386. (83-10).

This report examines the effect of snowmelt on stream chemistry at station S1 and Batchawana Lake (south) for 1981 and 1982. The meteorological conditions leading to snowmelt are present along with variations in the ionic composition of the snowpack, and stream and lakewaters. Interaction of meltwaters with the soils in suggested to be the major factor controlling the observed variations in chemistry.

Jeffries, D.S., R.G. Semkin and R. Neureuther. 1984. Data Report: Lake outflow hydrology (1980-1983). Turkey Lakes Watershed Unpublished Report No. 84-01, 30 p. (84-01).

Report presents a data summary of daily water flows measured at six NWRI stream gauging stations in TLW. Plots of corresponding meteorological conditions and hydrographs are also included. High unit discharges or runoff ranging from 731 to 1221 mm yr^{-1} *were determined, which leads to relatively short water renewal times for the lakes (from 0.15 year for Wishart Lake to 1.3 years for Batchawana North).*

Jeffries, D.S. and R.G. Semkin. 1983. Data Report: Major ion composition of lake outflows and major streams in the Turkey Lakes Watershed (January 1980-May 1982). Turkey Lakes Watershed Unpublished Report No. 83-05, 30 pp. (83-05).

Major ion data for stream stations S0 to S5 for the period January 1980 to May 1982 are presented. Sampling, analytical, data storage and editing methods are briefly outlined. Charge balance and theoretical conductivity calculations are also provided.

Jeffries, D.S. and R. Semkin. 1982. Basin description and information pertinent to mass balance studies of the Turkey Lakes Watershed. Turkey Lakes Watershed Unpublished Report No. 82-01, 34 p. (82-01)

Report includes a general description of the TLW (geology, geomorphology, forest type, lake characteristics) and provides information on sampling locations, data being collected, data storage, and preliminary water budget calculations.

Jensen, M.J., J.B. Robinson and N.K. Kaushik. 1982. Effects of acid precipitation on microbial activities and populations in streams in the Algoma Area, Ontario. Turkey Lakes Watershed Unpublished Report No. 82-05, 88p. (82-05).

Report presents results (data and interpretation) of studies on the microbial populations and their activities in streams in the TLW. Organisms capable of conversion of S and N forms were emphasized. A literature survey on the effects of acidic precipitation on microbial populations is also included. Both field (leaf decomposition) and laboratory (reconstituted column) experiments are discussed. (see 88-24).

Johnston, L.M. and D. Craig. 1987. Status report: Ground water studies in the acid rain program. Nat. Hydrol. Res. Inst. Contribution No. 87-022, 20p. (87-05).

The current knowledge concerning groundwater studies in the acid rain program (including the TLW) is summarized in 13 points. Further work is required to understand the mechanisms of groundwater acidification on both the large and small scale, to document/confirm trends, and to determine the spatial extent of acidification.

Johnston, L.M. and D. Craig. 1987. Turkey Lakes Watershed Study: hydrogeological instrumentation and aquifer materials (updated 1986). Nat. Hydrol. Res. Inst. Unpubl. Rep., Contribution No. 87-004, 6 pp. (+ Figures and Tables). (88-28).

Report presents data and evaluation of the geochemistry of till samples collected during drilling of the 57 wells at the TLW. Till ANC (expressed as weight % CaCO3) increases with depth from 0.3% (1 m) to 1.4% (7 m). Average till ANC varies from 0.6-1.3% among the five sub-basins. Results from the analysis of inorganic and organic carbon, S, and x-ray diffraction of the silt-clay fraction are also presented.

Klassen, R.A. and W.W. Shilts. 1980. Subbottom profiling of lakes of the Canadian Shield. *In*: Current Research, Part A, Geological Survey of Canada, Paper 82-1A, 375- 384. (82-08).

Subbottom profiling of the sediments in Turkey Lake and Little Turkey Lake (and 11 others in eastern Ontario and Quebec) using an acoustic profiler is reported. Profiles showed that many lake bottoms are filled with more than 25 m of lake glacial sediment, which is generally covered in turn by up to 5 m of modern gyttja-like lake sediment.

Kusmirski, R.T. and D.W. Cowell. 1983. Mineralogy of subsoil samples, Turkey Lakes Watershed, Ontario. Turkey Lakes Watershed Unpublished Report No. 83-09, 30 pp. (83-09).

Report presents data and interpretation of the mineralogy of 20 subsoil and gravel pit samples collected within or near the TLW. The parent bedrock from which these unconsolidated deposits were derived is also inferred. The samples were dominated by material that is mineralogically similar to felsic igneous rocks rather than the mafic rock underlying most of the watershed. It is suggested that the material was transported glacially into the TLW from areas to the north and northeast.

Lin, Jing. 2005. Spatial and temporal modelling of water acidity in Turkey Lakes Watershed. MSc thesis, McMaster University, Hamilton, Ontario. 74p. (05-05).

A set of data from the TLW collected between 1980 and 1987 was chosen for use in a statistical model describing variability, seasonal cycles and trends of acidity in that region. During this period steps were taken by the Canadian government to reduce sulphur dioxide emissions by half, and the US government amended the Clean Air Act in 1990 to reduce SO_2 emissions, thus contributing to a downward trend in SO_4 concentration in the lakes and a slight increase in pH.

Lindsay, J.B. 2004. Coping with topographic depressions in digital terrain analysis. PhD. Thesis, Department of Geography, University of Western Ontario, London. 125pp, 2 Appendices. (04-11).

A fine-resolution DEM was used to delineate wetlands within 12 catchments at the TLW. Wetland metrics as predictors of runoff variation were superior to catchment area and mean slope, two common basin metrics. During wet periods, catchments containing extensive wetlands were marked by a significant decrease in maximum peak discharge and increase in duration of flow. During mesic and dry periods, catchments containing extensive wetlands were marked by an increase in rise and recession times of peak discharge events and the duration of flows.

Liu, W. 2012. Spatiotemporal modeling of the impacts of forest harvesting, climate change and topography on stream nitrates in a forested watershed. PhD Thesis, Geography, Queen's University. (12-07).

This dissertation is an empirical modeling investigation of the impact of forest harvesting, climate change and topography on stream nitrate fluxes in the TLW. Impact of forest harvesting intensity on stream water nitrate fluxes was modeled using three different approaches, including developing transfer function noise models that related different variables, and introducing geographically weighted regression to model spatial and temporal relationships. Results showed a new phenomenon not reported in previous studies: clustered wave-up and wave-downs of stream nitrate increases caused by clearcut and selection cut at the monthly scale; significant responses of stream nitrate fluxes to wet nitrogen deposition in all catchments at the monthly scale between 1982 and 2003; and significant spatial and seasonal variability of relationships between topography and stream nitrate fluxes across space and over time.

McNicol, D.K. and R.K. Ross. 1982. Effects of acidic precipitation on waterfowl populations in northern Ontario. Canadian Wildlife Service Ontario Region Progress Report, 1980-81 LRTAP program. 44pp, 4 Appendices February 1982. (82-15).

Two areas, Algoma and Ranger Lake are discussed in this report. The Algoma component, which includes the TLW, is designed to establish baseline information on waterfowl breeding and distribution density, so that future effects of acidification can be monitored. The Ranger Lake section (slightly south of the TLW) examines habitat parameters relating to reproductive success in waterfowl and the effects of acid precipitation on that success. Results indicate that headwater systems in Algoma are becoming acidified and this could have adverse effects on waterfowl reproduction.

McNicol, D.K. and S. Laframboise. 1984. Effects of acidic precipitation on waterfowl populations in northern Ontario. III. Assessment of age class and condition indices among non-game fish species collected in headwater lakes in the Ranger Lake area, in relation to lake acidification and fish community structure. Canadian Wildlife Service Ontario Region, LRTAP program. 53p. (84-18)

As in CWS reports I and II, (82-16 and 83-26), lakes in the Ranger Lake area (near the TLW in Algoma) were sampled as part of a study on the effects of acid precipitation on waterfowl. In this report, the age structure and condition indices of minnow species are summarized and the correlation with environmental variables is considered. The occurrence of most species seems unrelated to chemical parameters. Controlled laboratory experiments are recommended because of the high number of variables affecting growth rates and pH/metal effects on fish.

Mengistu, S.G. 2012. Topographic influences on trends and cycles in nutrient export from forested catchments on the Precambrian shield. PhD. Thesis, Department of Geology and Environmental Science, University of Western Ontario, London. 162pp, Appendix. (12-06).

This dissertation explored topographic controls on spatial and temporal patterns in water yield and nutrient (carbon, nitrogen and phosphorus) export from forested headwater catchments at the TLW. Topographic metrics representing hydrologic storage potential explained the majority of the observed spatial variation in DOC, DON, and total dissolved phosphorus export. For temporal variation, catchments with low hydrologic loading potential were generally more sensitive to trends and cycles for water and nutrient export. Despite many similarities in these headwater catchments, topography influenced the absolute and relative magnitude of hydrological and biogeochemical export from these catchments, which will have implications on the productivity and biodiversity of downstream aquatic systems.

Monteith, S.S. 2003. Hydrologic response to clearcutting in a hardwood forest during snowmelt. MSc. Thesis, Watershed Ecosystems Program, Trent University, Peterborough. 120pp. (03-12).

Event/pre-event water partitioning, water residence times and stormflow pathways were examined in a paired basin comparison of C32 (uncut) and C31 (clearcut) at the TLW during the 2001 snowmelt, four years after harvest. C31 had larger daily event water contributions to streamflow and peak discharge. There were no differences in groundwater residence times of the basins. Comparison of pre- and post-harvest K/Si ratios in input water, groundwater and streamflow in C31 indicate that near-surface water fluxes have become more pronounced following clearcutting. Topographic properties did not consistently exhibit strong controls on groundwater characteristics.

Morris, J.R. 1982. Benthological studies in the Turkey Lakes (Algoma). Turkey Lakes Watershed Unpublished Report No. 82-06, 21p. (82-06).

Presents results and discussion of studies on lake sediment cores from TLW. Data included profiles of pH, Cu, Ni, Pb, Zn, Al, Mn, and Ca. The distribution and abundance patterns of benthic invertebrates was also assessed.

Morrison, I.K., N.W. Foster and J.A. Nicolson. 1980. Acid precipitation and forest ecosystems. Great Lakes Forest Research Centre Leaflet, 4 pp, March 1980. (82-14).

Report summarizes causes of acid precipitation and effects on forest soils, namely leaching of basin cations, changes in nutrient availability, and alteration of microbial decomposition. Report is essentially a public information sheet.

Murray, C.D. 2003. Snow accumulation, melt and infiltration on forested and clearcut slopes, Turkey Lakes Watershed, central Ontario. MSc thesis, Trent University, Peterborough, Ontario. 78pp. (03-01).

Factors affecting water inputs to a mature hardwood maple stand at the TLW were compared with an adjacent clearcut. Daily melt in the clearcut was greater and more variable than in the forest. Near-surface soil water in the clearcut often reached saturation, while this was not the case in the forested catchment. These factors combine to promote downslope diversion of event water in the clearcut, which has implications for the receiving streams and lakes.

Nihlgård, B., J. Cerny, H. Hultberg, D. Jeffries, A. Jenkins, T. Paces and G. Söderman. 1992. Evaluation of integrated monitoring in terrestrial reference areas of Europe and North America, The pilot program 1989-1991. Environment Data Centre Report, National Board of Waters and the Environment, Helsinki 1992. 60 p. (92-11).

Report evaluates the international monitoring of the effects of long-range transboundary air pollutants on ecosystems. Canadian data are from the TLW, and many useful comparisons with European conditions are made. It was concluded that international integrated monitoring should be continued, to provide a data-base which can predict future trends and determine critical loads in ecosystems.

Pridoehl, F. 2009. Fine root dynamics for three distinct northern Ontario forests: a comparison of approaches used to estimate fine root biomass, productivity, and turnover. MScF thesis, Faculty of Forestry and the Forest Environment, Lakehead University, Thunder Bay, Ontario. 72pp. 1 Appendix. (09-07).

This study conducted for three distinct northern temperate forest/stand types (i.e., northern hardwoods – sugar maple in TLW; northern coniferous – jack pine in Nimitz; and boreal mixedwood – aspen, spruce, balsam fir in Groundhog River) determined that there was a significant difference in fine root standard root length (SRL) between northern temperate tree species and diameter classes. Angiosperms tended to have significantly higher average SRLs compared to gymnosperms. Tolerant, late successional species had higher SRLs compared to their intolerant, early successional counterparts. As diameter class increased, SRLs dropped, suggesting that development of species- and diameter class-specific SRLs should provide better estimates of fine root biomass and productivity, leading to a better understanding of temperate forest C dynamics. A more thorough examination of fine root dynamics is required in order to ensure wider scientific acceptance of broad-based models and their ability to predict impacts of forest management activities or climate change.

Rams, A.P. 2008. Shifts in the magnitude and partitioning of atmospheric versus aquatic carbon export in response to changing climatic conditions. MSc. Thesis, Department of Biology, University of Western Ontario, London. 64pp, 4 Appendices. (08-12).

The aim of this thesis was to determine whether changes in meteorological conditions have caused changes in the magnitude and partitioning of atmospheric vs aquatic C export from C38 at the TLW during the growing seasons from 2003 to 2007. Soil organic carbon pools, the sorption capacity, and the potential saturation of the sorption capacity by dissolved forms of C along an upland-wetland-stream transect were determined. Soil water samples and soil surface CO_2 efflux were collected on the same transect. Stream water samples were collected along with continuous monitoring of water table depth and catchment discharge. Total C export during the growing season increased over the five years of sampling, with greater increases observed in atmospheric losses of C as compared to aquatic losses in the form of DOC.

Rao, S.S., L. Bhaskar and A.A. Jurkovic. 1982. Microbiological studies of some watersheds receiving acid precipitation in Canada. National Water Research Institute Report, Analytical Methods Division, 93p. (82-04).

Report presents results (data and interpretation) of studies on microbial populations and their activities in lake waters and sediments in the TLW and Kejimkujik Watershed, N.S. Field monitoring and laboratory fermenter experiments are both reported. Bacterial activity was found to be depressed in acid stressed lakes.

Ro, C., R. Vet, D. Ord and A. Holloway. 1998. National Atmospheric Chemistry Data Base (NATChen) 1994 Annual Report: Acid precipitation in eastern North America; Atmos. Environ. Service. (98-01).

Same as 95-13 and 95-14, but covering the 1994 calendar year.

Ro, C., R.Vet, D. Ord and A. Holloway. 1995. National Atmospheric Chemistry Data Base (NATChen) 1993 Annual Report: Acid precipitation in eastern North America; Atmos. Environ. Service. (95-14).

Same as 95-13, but covering the 1993 calendar year.

Sanford, S.E. 2005. Scale-dependence of natural variability of stream flow parameters in a forested drainage basin on the boreal shield. MSc. Thesis, Department of Geography (Environmental Sciences), University of Western Ontario, London. 101pp, 4 Appendices. (05-16).

A distributed hydrologic model was used to characterize the natural flow regime of nested basins including the TLW within tributaries of the Batchawana River. The median and interannual variability, defined as the S80 (90thpercentile - 10th percentile) / median), of the magnitude, timing, frequency, duration, and rate of change of flows characterized the natural flow regime. Below the representative elementary area, the relief ratio, the proportion of the basin above a threshold in Wetness Index, and the drainage density, were significantly related to the S80 of many flow parameters. This research demonstrates the scale-dependence of natural variability of flows, against which impacts of disturbance on flows throughout a drainage basin may be measured.

Semkin, R.G., and D.S. Jeffries. 1983. Rock chemistry in the Turkey Lakes Watershed. Turkey Lakes Watershed Unpublished Report No. 83-03, 9 pp. (83-03).

Major and trace element content for 14 rock samples from TLW is reported. Most of the bedrock was determined to be tholeiitic basalt that has undergone regional metamorphism. Minor occurrences of sulphide mineralization were observed which was reflected in elevated Pb, Zn, and Hg content.

Senar, O.E. 2018. PhD Thesis: Causes and consequences of soil carbon mobilization and lake brownification in northern forested landscapes. Western University. (18-03).

This dissertation investigated the causes of soil carbon destabilization and consequences of the mobilized soil carbon to lake food webs in catchment 38 in TLW. Carbon export increased as temperatures increased. Changes in hydrologic connectivity interacted with topography to modulate the timing, magnitude, and fate of soil carbon export. Increased temperatures led to changes in hydrologic disconnectivity that favoured export of soil carbon from carbon-rich wetlands to the atmosphere. However, extreme precipitation events saturated the soils and increased the frequency of periods of hydrologic connectivity from the catchment to the drainage network that led to higher export of carbon to streams, rivers and lakes. Increased carbon content in lakes resulted in lower light availability and larger nutrient pools in lakes. Brownification of clear oligotrophic lakes increased pelagic primary productivity, but favoured cyanobacteria that could adapt to the browner conditions. Changes in biomass and composition of phytoplankton communities altered the carbon transfer and efficiency of lake food webs.

Spoelstra, J. 2004. Nitrate sources and cycling at the Turkey Lakes Watershed: a stable isotope approach. PhD Thesis, Dept. of Earth Sciences, University of Waterloo, Waterloo, Ontario. 180pp. (04-02).

A dual nitrate isotope technique was developed and used at the TLW to trace nitrate sources and cycling in the watershed before and after harvesting. The method was found to be effective especially when combined with d15N analysis of ammonium, soil organic matter and vegetation.

Strachan, W.M.J and H. Huneault. 1983. Evaluation of an organic automated rain sampler. Inland Waters Directorate Tech. Bull. No. 128, 5 p. (82-02).

Report gives results of an evaluation of a new wet-only collector designed to sample persistent organic chemicals in rain. Details of design and manufacture are included. Data from a TLW sampling site was used in the evaluation.

VanLoon, G.W., G.K. Rutherford and A.B. Stewart. 1983. The degeneration effects of acid precipitation on two important eastern Canadian forest soils. Final Report, DSS Contract ISU80-00350, 336 p. (83-15).

Report presents preliminary information on the effect of "watering" reconstituted soil profiles and field plots with simulated rainfall; pHs = 5.7, 3.5, and 2.0. Cation leaching, loss of organic matter, effect on sulphur and nitrogen cycles, etc., are discussed, as well as the differing results from the laboratory vs field experiments. Soils from both the TLW and the Montmorency Forest (Quebec) were studied.

Webster, K.L. 2007. Topographic controls on carbon dioxide efflux from forest soils. PhD. Thesis, Department of Biology and Environmental Science, University of Western Ontario, London. 129pp, 2 Appendices. (07-11).

Heterogeneity in topographic features at the TLW were defined using a fuzzy classification scheme and stochastic depression analysis. These features became the fundamental unit for describing patterns in soil carbon pools and, monitoring and modelling its atmospheric fate in C38. The distribution of soil carbon along hillslopes differed. Rs was higher in the ecotone than in upland or wetland portions of the catchment. A model that included soil temperature and soil moisture explained 57% of the variance in Rs. Inclusion of the soil carbon C:N explained an additional 15% of the variance. Combining this empirical relationship with the area of features provided catchment-aggregated effluxes of Rs.

Webster, K.L. and P.W. Hazlett. 2015. Long-term ecological research at the Turkey Lakes Watershed: 35th anniversary of interdisciplinary, cooperative research, program booklet and workshop summary. Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, Information Report GLC-X-13, 25pp. (15-04).

This information report provides background material and outputs from a TLW 35th anniversary workshop held at the Great Lakes Forestry Centre in Sault Ste. Marie on November 19-20, 2014. The report includes a participant list, workshop program and abstracts from the workshop presentations. Workshop outcomes from a moderated discussion of the science and policy connections directing long-term science at TLW with federal and provincial government, industry and academia representative are also provided.

Wickware, G.M. and D.W. Cowell. 1983. Forest site classification of the Turkey Lakes Watershed, Algoma District, Ontario. Turkey Lakes Watershed Unpublished Report No.83-14, 33 p. + Appendices. (83-14).

Report presents classification of forest sites in the TLW into 17 major vegetation types and nine major soil types. Subsequent ordination of the types suggested that complex environmental gradients were present related to elevation, slope position, soil moisture, texture, and nutrients. Soil classification considered variables such as texture, thickness, and type of both mineral and organic horizons as well as various chemical properties.

Yeung, A.C.Y. 2019. Assessing and managing the stability of stream detrital dynamics under forest disturbances. PhD Thesis, Department of Forestry, University of British Columbia, Vancouver. 237pp, 4 Appendices. (19-03).

Multiple stability components of terrestrial-derived particulate organic matter (POM) availability and breakdowns in small, temperate streams under forest harvesting were quantified. Empirical and process-based modelling studies were based in the Malcolm Knapp Research Forest, coastal British Columbia. Field studies also included mixed hardwood forests in Turkey Lakes Watershed and in the boreal mixedwoods of the White River Watershed in central Ontario. Interannual hydrologic variations poorly explained litter breakdown, so recalibrated reference conditions to allow more robust bioassessments. Resilience of litter breakdown to forest harvesting was likely greater in streams affected by thinning than those affected by clear-cutting with or without riparian buffers. Logging induced changes in litterfall were more influential than peak discharge and stream temperature alterations in regulating POM quantity. Results indicated that riparian vegetation, through litterfall and shading, importantly controlled the stability of stream POM dynamics.

Zhang, J. 2008. Long-term patterns of dissolved organic carbon in boreal lakes. MSc. Thesis, Department of Biology, University of Saskatchewan, Saskatoon. 94pp, Appendix. (08-05).

Regional and global variables in relation to DOC dynamics were analyzed at 5 sites in 55 lakes, including the TLW. Among key variables that best explained the variation in long-term DOC patterns were total solar radiation and precipitation, although not at the TLW site. A general model was developed to compare the response of DOC to regional variables, but since the TLW had no variables in common with the other sites, it was excluded. Nova Scotia was found to dominate the model in strength of response to changes of environmental variables, while Dorset and ELA had only weak contributions to the general model.

HARVESTING IMPACTS PROJECT




In 1997, a harvesting impacts project was built around a field experiment comparing clearcut, shelterwood, and single-tree selection harvest systems to an uncut control (Figure 12). Impacts on long-term soil productivity, stand function, diversity of plant and animal life, and hydrological and other on- and off-site impacts were measured. The selection cut was applied in catchment 33 (24 ha), two-cut shelterwood system applied in catchment 34 (68 ha), and clearcut in catchment 31 (4.5 ha). Catchment 32 (6.7 ha) was maintained as a control. Replicate harvesting occurred in the area just north of the Turkey Lakes Watershed boundary (Figure 11). Publications listed in this section are a subset of those already listed in some of the previous sections, but summarized here based on their relevance to forest harvesting impacts.

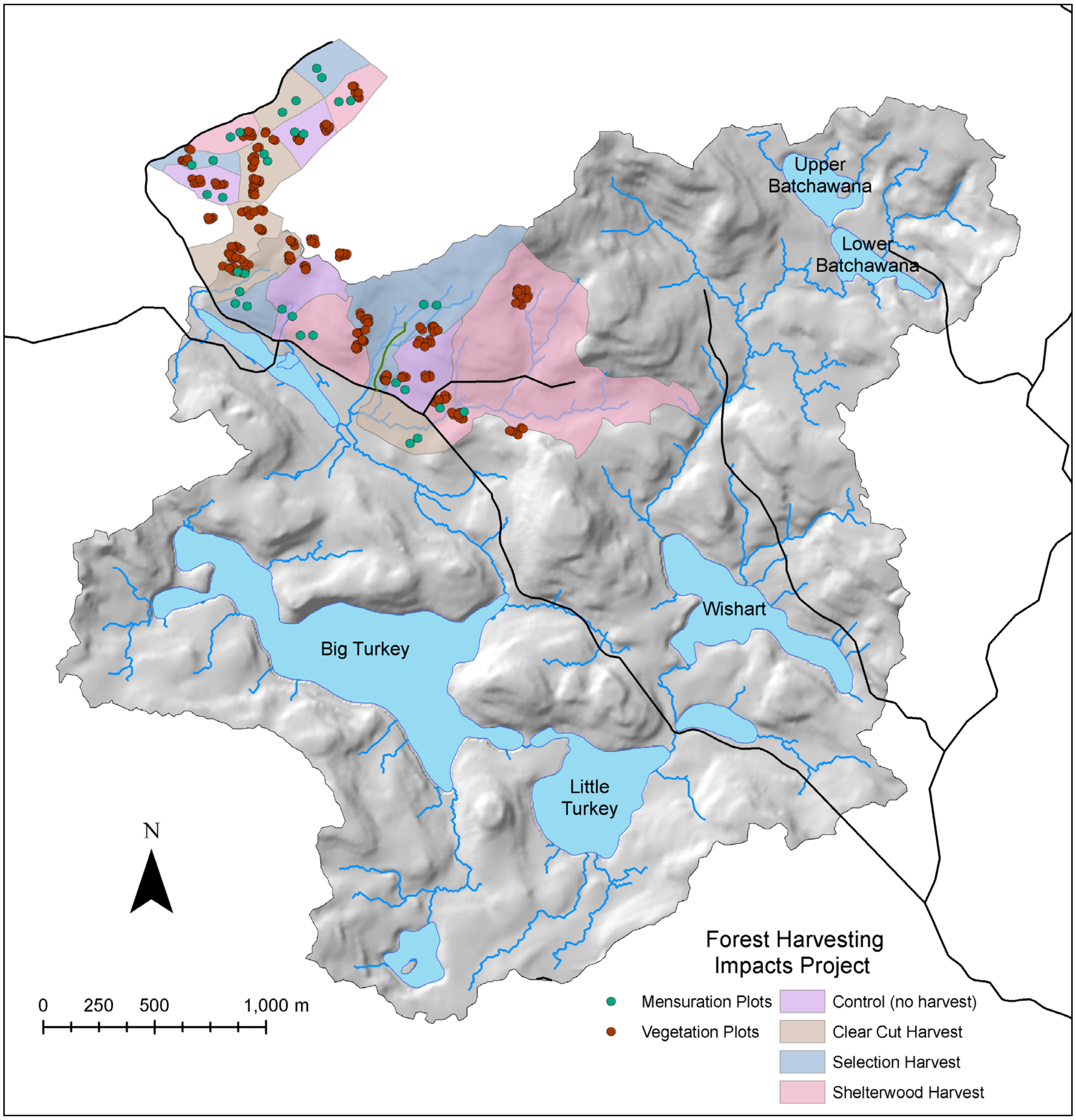


Figure 11. Forest Harvesting Impacts Project illustrating clearcut, shelterwood, and selection cut areas within and outside (replicate study) the TLW.

PUBLICATIONS

Bhatti, J.S. and N.W. Foster. 1996. Computer model predicts diminished productivity of tolerant hardwood forest following full-tree harvesting. Technical Note No. 92, Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, Ontario. 4p. (96-07).

> *This note describes a model, ForSVA (Forest Soil Vegetation Atmospheric Model) that incorporates knowledge of ecosystem processes to predict the effects of various harvesting scenarios on an undisturbed tolerant hardwood forest. The model has been calibrated and validated at the TLW, using 10 years of field data. It demonstrates that full-tree clear-cutting is a less sustainable practice than stem-only cutting. The impacts of harvesting on vegetation, nutrient cycles and water quality of the forest of the TLW are being investigated.*

Buttle, J.M., Beall, F.D., Webster, K.L., Hazlett, P.W., Creed, I.F., Semkin, R.G., Jeffries, D.S. 2018. Hydrologic response to recovery from differing silvicultural systems in a deciduous forest landscape with seasonal snow cover**.** Journal of Hydrology doi: 10.1016/j.jhydrol.2018.01.006 (18-02).

> *Results from a 31-year examination of hydrological response to and recovery from alternative harvesting strategies in a deciduous forest landscape with seasonal snow cover in the TLW. A quantitative means of assessing hydrologic recovery to harvesting was also developed. Clearcutting resulted in increased water year (WY) runoff and increased runoff in all seasons, with greatest relative increases in summer. Direct runoff and baseflow from treatment catchments generally increased after harvesting, although annual peak streamflow did not. Largest WY runoff, seasonal and direct runoff, and baseflow increases occurred in the selection harvest catchment, likely as a result of interception of hillslope runoff by a forest access road and redirection to the stream channel. Hydrologic recovery appeared to begin towards the end of the 31 years, but was incomplete for all harvesting strategies 15 years after harvesting. Harvesting enhance the relative importance of surface and near-surface water pathways on catchment slopes for all treatments, with the clearcut catchment showing most pronounced and prolonged response.*

Buttle, J.M., I.F. Creed, and J.W. Pomeroy. 2000. Advances in Canadian forest hydrology, 1995-1998. Hydrol. Process., 14, 1551-1578. (00-12).

> *The TLW is included in a review of recent progress in understanding hydrological processes in forest landscapes across Canada. A model used by Creed et al. (TOPMODEL) describes flow processes in the TLW basin and postulates episodic N flushing leading to large stream N export. The harvesting project at TLW is listed with ten other forests as a site for monitoring potential impacts due to forest disturbance.*

Buttle, J.M., P.W. Hazlett, C.D. Murray, I.F. Creed, D.S. Jeffries, and R. Semkin. 2001. Prediction of groundwater characteristics in forested and harvested basins during spring snowmelt using a topographic index. Hydrological Processes 15: 3389-3407. (01-04).

> *Piezometric surface elevations were monitored during snowmelt in 2 sub-basins in the TLW, (one mature hardwood and one clearcut,) during the spring of 2000 to test a hypothesized link between groundwater characteristics and topographic indices. A relationship was not confirmed but the potential to use groundwater residence time to evaluate the effects of forest harvesting was discussed. d18O values were measured for input water and groundwater to establish groundwater residence times.*

Buttle, J.M., Webster, K.L., Hazlett, P.W., Jeffries, D.S. 2018. Quickflow response to forest harvesting and recovery in a northern hardwood forest landscape. Hydrological Processes 33 (1): 47-65. (18-01).

Hydrologic response to forest harvesting was studied by evaluating catchment quickflow (QF, water delivered rapidly to the stream channel), a metric of high-flow events controlling a catchment's solute and sediment export. A 31-year examination of QF delivery from treatment (clearcut, selection, and shelterwood harvest) and control catchments in a deciduous forest landscape in TLW was conducted. Prior to harvesting, there was no significant increase in QF with P (precipitation) below a threshold P of 35-46mm; however, there was a significant QF vs P relationship below this threshold for all treatments postharvest. Clearcutting increased the number of QF events for the entire postharvest period and the first 9-year postharvest compared to the other treatments; nevertheless, evidence for inter treatment differences in total QF depth delivered from catchments during the growing season was inconclusive.

Caputo, J., C.M. Beier, P.M. Groffman, D.A. Burns, F.D. Beall, P.W. Hazlett and T.E. Yorks. 2016. Effects of harvesting forest biomass on water and climate regulation services: a synthesis of long-term ecosystem experiments in eastern North America. Ecosystems 19: 271-283, doi: 10.1007/s10021-015-9928-z. (16-01).

New methods assessing trade-offs between biomass harvestings and ecosystem services and their change over time were applied to long- term experimental post-harvest data from the TLW and nine other northern hardwood forest watersheds. Near-term trade-offs were observed between biomass harvesting and the ecosystem services of nutrition pollution remediation and greenhouse gas regulation. Both these ecosystem services recovered with forest vegetation regeneration. Biomass harvesting had relatively nominal and transient impacts on other ecosystem services.

Daoust, K. 2017. Relative influence of landform, hydrology, and stream habitat on benthic macroinvertebrate communities in a managed northern hardwood forest. MSc thesis, Department of Environmental Sciences, University of Guelph, Ontario. 119pp., Appendix. (17-03).

By using a combination of field measurements and modelling (landscape, hydrological, chemical, and habitat variables) of the Lower Batchawana Watershed, catchment size and stream flow rise rate have the largest influence on benthic macroinvertebrate (BMI) community structure , while forest harvest had no measurable effect.

Daoust, K., Kreutzweiser, D.P., Guo, J., Creed, I.F., and P.K. Sibley. 2019. Climate-influenced catchment hydrology overrides forest management effects on stream benthic macroinvertebrates in a northern hardwood forest. Forest Ecology and Management 452 (2019) 117540. (19-02).

Field measurements in the Lower Batchawana Watershed and modelling were used to derive a comprehensive suite of physical, chemical, and biological variables to develop explanatory relationships between these variables and benthic macroinvertebrate community composition of headwater streams in managed forests. The variables related to hydrological patterns and processes (i.e. flow variability; conductivity) were most strongly associated with benthic macroinvertebrate community structure. Selection-based forest harvesting had no measurable adverse effects on benthic macroinvertebrate communities. This study helped to better define the relationships between physical, chemical and biological indicators of aquatic ecosystem function, providing information required to make effective monitoring and management decisions aimed at ensuring sustainability of forest-based aquatic ecosystem services, particularly in the face of a changing climate.

Fleming, R.L. and K.A. Baldwin. 2008. Effects of harvest intensity and aspect on a boreal transition tolerant hardwood forest. I. Initial postharvest understory composition. Canadian Journal of Forest Research 38 (4), 685-697, doi:10.1139/X07-198. (08-06).

Disturbance effects on plant communities largely reflect the degree of overstory removal, soil disturbance, and attendant vegetation destruction. Partial and complete canopy removal and soil disturbance were assessed for their post-harvest impact on vascular plant cover, community responses, indicator species and diversity on north or south facing plots at the TLW 3-years after harvest. Community composition and diversity were primarily related to soil disturbance and aspect related radiation exposure. Canopy opening did not have major influences on its own. Logging-related soil disturbance thus seems to be the predominant silviculture factor (over canopy opening) affecting understory community response and diversity. Prominent aspect related changes suggest that responses will be site and species specific.

Foster, N.W., F.D. Beall and D.P. Kreutzweiser. 2005. The role of forests in regulating water: The Turkey Lakes Watershed case study. The Forestry Chronicle 81,142-148. (05-10).

The TLW is cited as an example of a long-term integrated study of an undisturbed ecosystem, invaluable in aiding decisions regarding future management of forested catchments. The chemistry and biology of atmosphere, forests, soils, streams and lakes have been monitored for more than 20 years, and results include such findings as continued acidification of surface waters following the reduction of S emissions, and an improvement of water quality when partial forest cutting is used instead of clearcutting. Information from this study can contribute to an international dialogue on watershed and forest management decisions.

Jeffries, D.S., and N.W. Foster. 2001. The Turkey Lakes Watershed Study - milestones and prospects. Ecosystems 4, 501-502. (00-05).

A short summary of the TLW Study prepared as an introduction for the special volume published in Ecosystems.

Kreutzweiser, D.P., and S.S. Capell. 2001. Fine sediment deposition in streams after selective forest harvesting without riparian buffers. Can. J. For. Res. 31: 2134-2142. (01-05).

Selective harvesting was carried out in the forest of the Turkey Lakes Watershed in 1997. This paper looks at the resulting fine sediment accumulation in the streams. Significant post-harvest increases in inorganic sediment bedloads were detected, but a greater increase was observed at a road-disturbance site where no harvesting was done. The current 30-m buffer in the riparian zone may not be necessary to prevent increased sediment loading to streams if care is taken to keep machinery and trees out of the stream channel while harvesting.

Kreutzweiser, D.P., S.S. Capell, and F.D. Beall. 2004. Effects of selective forest harvesting on organic matter inputs and accumulation in headwater streams. Northern Journal of Applied Forestry 21, 19-30. (04-04).

Time trend analyses were used to examine headwater stream organic matter inputs and accumulations in the TLW following selective harvesting. It was found that a harvesting intensity of 89% basal area removal resulted in a reduction of organic matter and accumulation in streams, but no significant reductions occurred for a 42% basal area removal. Harvesting impacts are reduced by retention of streamside trees and avoidance of felling into the streams.

Kreutzweiser, D.P., S.S.Capell, and K.P. Good. 2004. Stream invertebrate communities as indicators of logging disturbance in northern hardwood forests of Ontario. In: G.J. Scrimgeour, G. Eisler, B. McCulloch, U. Silins and M. Monita, (eds.) Forest Land-Fish Conference II - Ecosystem Stewardship Through Collaboration, pp165-166. Proc. Forest-Land-Fish Conf. II, April 26-28, 2004, Edmonton, Alberta. (04-05).

The effects on aquatic insect communities of different logging intensities was examined 2 years before and 3 years after harvesting. At 29% basal area removal no changes were observed, at 42% removal small changes occurred, whereas at the high-intensity disturbance sites (89% removal) larger and more distinct changes in insect community structure were observed. This high-intensity logging is above normal harvesting rates. If the riparian code that prohibits tree removal within 3 m of stream edges is observed, harmful effects of harvesting are minimal.

Laporte, M.F., L.C. Duchesne, and I.K. Morrison. 2003. Effect of clearcutting, selection cutting, shelterwood cutting and microsites on soil surface CO_2 efflux in a tolerant hardwood ecosystem of northern Ontario. Forest Ecology and Management 174, 565-575. (03-07).

In 1998 a flow-through portable infared CO_2 gas analyzer was used in a section of the TLW in which harvesting impacts were being studied to examine the effects of selection cutting, shelterwood cutting and microsites on soil surface CO_2 efflux (SSCE). Selection and shelterwood cutting caused decreasing SSCE while clearcutting effects were less than for other treatments but more than for the control. SSCE was higher on undisturbed microsites, and demonstrated the importance of microsite distribution in treated areas.

Leach, J. A., Buttle, J. M., Webster, K. L., Hazlett, P. W., and Jeffries, D. S. (2020). Travel times for snowmelt-dominated headwater catchments: Influences of wetlands and forest harvesting, and linkages to stream water quality. *Hydrological Processes*, *34*(10), 2154-2175. (20-01).

Catchment travel times were estimated for the TLW headwater catchments. Results show that mean travel times can be variable for small geographic areas and are related to catchment characteristics, in particular flowpath length and wetland cover. In addition, forest harvesting appeared to decrease mean travel times. Estimated mean travel times had complex relationships with water quality patterns. Results suggest that biogeochemical processes, particularly those present in wetlands, may have a greater influence on water quality than catchment travel times.

Liu, W. 2012. Spatiotemporal modeling of the impacts of forest harvesting, climate change and topography on stream nitrates in a forested watershed. PhD Thesis, Geography, Queen's University. (12-07).

This dissertation is an empirical modeling investigation of the impact of forest harvesting, climate change and topography on stream nitrate fluxes in the TLW. Impact of forest harvesting intensity on stream water nitrate fluxes was modeled using three different approaches including developing transfer function noise models that related different variables, and introducing geographically weighted regression to model spatial and temporal relationships. Results showed a new phenomenon not reported in previous studies: clustered wave-up and wave-downs of stream nitrate increases caused by clearcut and selection cut at the monthly scale; significant responses of stream nitrate fluxes to wet nitrogen deposition in all catchments at the monthly scale between 1982 and 2003, and; significant spatial and seasonal variability of relationships between topography and stream nitrate fluxes across space and over time.

Moayeri, M., F-R. Meng, P.A. Arp, and N.W. Foster. 2001. Evaluating critical soil acidification loads and exceedances for a deciduous forest at Turkey Lakes, Ontario. Ecosystems 4, 555-567. (00-03).

Critical soil acidification rates determined at the TLW using steady-state mass balance modelling were found to be high (900 to 1400 eq ha^{-1} y^{-1} depending on the forest harvesting regime). As a consequence, critical load exceedance is low. Weathering of TLW soils provides a buffer against acid inputs and natural acidification. The TLW appears to be near or at N saturation.

Monteith, S.S. 2003. Hydrologic response to clearcutting in a hardwood forest during snowmelt. MSc. Thesis, Watershed Ecosystems Program, Trent University, Peterborough. 120pp. (03-12).

Event/pre-event water partitioning, water residence times and stormflow pathways were examined in a paired basin comparison of C32 (uncut) and C31 (clearcut) at the TLW during the 2001 snowmelt, four years after harvest. C31 had larger daily event water contributions to streamflow and peak discharge. There were no differences in groundwater residence times of the basins. Comparison of pre- and post-harvest K/Si ratios in input water, groundwater and streamflow in C31 indicate that near-surface water fluxes have become more pronounced following clearcutting. Topographic properties did not consistently exhibit strong controls on groundwater characteristics.

Monteith, S.S., J.M. Buttle, P.W. Hazlett, F.D. Beall, R.G. Semkin and D.S. Jeffries. 2006. Paired-basin comparison of hydrological response in harvested and undisturbed hardwood forests during snowmelt in central Ontario: I. Streamflow, groundwater and flowpath behaviour. Hydrol. Process. 20, 1095-1116. (06-03).

In a paired-basin study at the TLW, impacts of forest harvesting on groundwater hydrology were examined. Topographic indices were evaluated but inconsistently explained variations between the two basins. Harvesting appears to have increased melt rates and thus the volume of stream runoff via surface and near-surface pathways.

Monteith, S.S., J.M. Buttle, P.W. Hazlett, F.D. Beall, R.G. Semkin and D.S. Jeffries. 2006. Paired-basin comparison of hydrological response in harvested and undisturbed hardwood forests during snowmelt in central Ontario: II. Streamflow sources and groundwater residence times. Hydrol. Process. 20, 1117-1136. (06-04).

In a paired-basin study at the TLW, event-water flux and contribution to peak streamflow during snowmelt was greater in a harvested basin 4 years after harvesting, possibly reflecting increased daily melt rates following harvesting. Both isotopic (d18O) and geochemical (chloride) tracers gave comparable hydrograph separation results (hence the latter is a conservative tracer at the TLW). Groundwater residence times did not vary with depth between basins. Spatial variations such as conductivity and till thickness are also important in understanding groundwater behaviour after harvesting.

Morrison, I.K., D.A. Cameron, N.W. Foster, and A. Groot. 1999. Forest research at the Turkey Lakes Watershed. The Forestry Chronicle 75, 395-399. (99-01).

The Turkey Lakes Watershed was chosen in 1979 for an interdisciplinary study of the impact on forests, lakes and streams of air pollutants deposited through long-range transport. A 20 year data base has been compiled. Throughout the years the site has also been used for several other studies, including participation in the IFS (1986-1989) and ARNEWS biomonitoring (ongoing), a harvesting impacts study (initiated 1997), and recently the ECOLEAP project to test terrain and climate models and relate them to species distribution, abundance and productivity.

Murray, C.D. and J.M. Buttle. 2003. Impacts of clearcut harvesting on snow accumulation and melt in a northern hardwood forest. J. Hydrol. 271: 197-212. (03-02).

Snow depth and melt at a clearcut were compared to that at an undisturbed maple stand at the TLW. Daily melt was higher in the clearcut, but south-facing sites melted faster than north-facing sites in both cases. More meltwater is delivered from clearcut sites to the soil surface and receiving waters, and at a greater rate than that from the undisturbed forested stands.

Murray, C.D. and J.M. Buttle. 2005. Infiltration and soil water mixing on forested and harvested slopes during spring snowmelt, Turkey Lakes Watershed, central Ontario. Journal of Hydrology 306, 1-20. (05-02).

A combined hydrometric and isotopic tracer approach was used on a slope at the TLW to examine the effect of harvesting on water infiltration and storage in the soil profile. Pre-melt and daily water inputs were measured during the 2000 and 2001 snowmelts. Total water input was greater to the harvested soil surface relative to a forest site. Harvesting on slopes is seen to promote increased subsurface flow and overland flow during snowmelt.

Murphy, P.N.C., M. Castonguay, J. Ogilvie, M. Nasr, P. Hazlett, J. Bhatti and P.A. Arp. 2009. A geospatial and temporal framework for modeling gaseous N and other N losses from forest soils and basins, with application to the Turkey Lakes Watershed Project, in Ontario, Canada. For. Ecol. Manage. 258, 2304-2317. (09-04).

A digital elevation, hydrological modeling approach is applied to the TLW soils and basins to quantify the pre- and post-harvest N emissions and other N losses. The calibrated model suggests that nitrification and denitrification induced by harvesting are strongest during the first post-harvest year but drop to background levels in 4-5 years. Further studies are needed to determine whether increased N input due to harvesting leads to N immobilization in mineral soils.

Sampson, P.H., G.H. Mohammed, P.J. Zarco-Tejada, J.R. Miller, T.L. Noland D. Irving, P.M. Treitz, S.J. Colombo, and J. Freemantle. 2000. The Bioindicators of Forest Condition Project: a physiological, remote sensing approach. The Forestry Chronicle 76, 941-952. (00-11).

The TLW was one of 12 study sites selected to test whether remote sensing can be used to determine stand-level forest condition. The BFCP project seeks to develop a forest condition rating system to classify forest stand condition from healthy to stressed using CASI with validation by traditional on-ground forest evaluation. The TLW Harvesting Impacts Project was the study site for which the influence of structural changes on spectral response was examined. The highest levels of variability were in shelterwood sections compared with the clearcut and control plots. The 1999 TLW Workshop.

Sampson, P.H., P.M. Treitz, and G.H. Mohammed. 2001. Remote sensing of forest condition in tolerant hardwoods: an examination of spatial scale, structure and function. Can. J. Remote Sensing. 27, 232-426. (01-06).

Using remote sensing, vegetation structure and physiological condition of the forest at the TLW following the TLW Harvesting Impact Project were examined. Three different methods of harvesting were compared - selection, shelterwood and clearcut. CASI acquired data at 3 altitudes, and results showed relationships between canopy opening and spectral indices.

Sampson, P.H., P.J. Zarco-Tejada, G.H. Mohammed, J.R. Miller, and T.L. Noland. 2003. Hyperspectral remote sensing of forest condition: estimating chlorophyll content in tolerant hardwoods. Forest Science, 49, 381-391. (03-08).

CASI was used over the TLW forest harvesting site in July 1998 to test remote sensing as a means of identifying stress effects in forests. CASI proved effective in mapping chlorophyll content as an indicator of forest physiological strain. Seasonal changes for a range of sites were also measured.

Spoelstra, J. 2004. Nitrate sources and cycling at the Turkey Lakes Watershed: a stable isotope approach. PhD Thesis, Dept. of Earth Sciences, University of Waterloo, Waterloo, Ontario. 180pp. (04-02).

A dual nitrate isotope technique was developed and used at the TLW to trace nitrate sources and cycling in the watershed before and after harvesting. The method was found to be effective especially when combined with d15N analysis of ammonium, soil organic matter and vegetation.

Spoelstra, J., S.L. Schiff, R.G. Semkin, D.S. Jeffries, R.J. Elgood. 2010. Nitrate attenuation in a small temperate wetland following forest harvest. Forest Ecology and Management 259, 2333-2341, doi: 10.1016/j.foreco.2010.03.006. (10-02).

A wetland in the TLW watershed (catchment 31) was the focus of a nitrate attenuation study utilizing stable isotope techniques. Analysis of d18O, d15N demonstrated that concentrations of nitrate were significantly lower in outflow than in inflow to the wetland, and nitrate removal is even complete in some areas. Forest harvesting effects on aquatic systems could thus be reduced if small wetlands are preserved in the watershed.

Yeung, A.C.Y. 2019. Assessing and managing the stability of stream detrital dynamics under forest disturbances. PhD Thesis, Department of Forestry, University of British Columbia, Vancouver. 237pp, 4 Appendices. (19-03).

Multiple stability components of terrestrial-derived POM availability and breakdowns in small, temperate streams under forest harvesting were quantified. Empirical and process-based modelling studies were based in the Malcolm Knapp Research Forest, coastal British Columbia. Field studies also included mixed hardwood forests in the TLW and in the boreal mixedwoods of the White River Watershed in central Ontario. Interannual hydrologic variations poorly explained litter breakdown, so reference conditions were recalibrated to allow more robust bioassessments. Resilience of litter breakdown to forest harvesting was likely greater in streams affected by thinning than those affected by clear-cutting with or without riparian buffers. Logging-induced changes in litterfall were more influential than peak discharge and stream temperature alterations in regulating POM quantity. Results indicated that riparian vegetation, through litterfall and shading, importantly controlled the stability of stream POM dynamics.

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