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Long-term ecological research at the Turkey Lakes Watershed: 35th anniversary of interdisciplinary, cooperative research

Program Booklet and Workshop Summary



**Sault Ste. Marie, ON
2015**

**Natural Resources Canada
Canadian Forest Service
Great Lakes Forestry Centre**

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Long-term ecological research at the Turkey Lakes Watershed: 35th anniversary of interdisciplinary, cooperative research, program booklet and workshop summary.

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Introduction

The Turkey Lakes Watershed (TLW) study was established in 1979 in response to the need to understand the terrestrial and aquatic effects of acid rain in ecosystems. The 10.5 km² area provided a large, relatively undisturbed example of the Great Lakes forest type on the Canadian Shield (see Figure 1), where multidisciplinary studies on the biogeochemical processes of the watershed could be carried out. A founding principle of the TLW study has been inter-agency collaboration and the core federal partnership between Natural Resources Canada, Environment Canada and Fisheries and Oceans Canada has allowed for benefits beyond what could have been achieved working alone. These three federal departments have assumed the central funding responsibility for the study and have cooperated in maintaining the field and laboratory infrastructure needed to develop the consistent, long-term research and monitoring datasets that are its hallmark. Numerous university researchers have also worked at TLW and brought their own resources to the study. The Ontario Ministry of Natural Resources and Forestry bears administrative responsibility for the Crown Land reserve containing the TLW.



Figure 1- Geographic location

The whole-ecosystem investigative approach used within the TLW study was adopted from the outset and has allowed research to evolve and expand from its original (and continuing) acidification focus to include evaluations of the effects of other pollutants or perturbations, e.g., toxic contaminants, forest harvesting, fish habitat modifications, climate change, carbon accounting and indicators of ecosystem integrity. The scientific and support infrastructure and length and breadth of the data record at TLW has been essential for understanding long-term environmental trends. Nearly 400+ research papers and graduate theses have resulted from TLW research, including 3 special issues (Canadian Journal of Fisheries and Aquatic Sciences in 1988, Ecosystems in 2001 and Water, Air and Soil Pollution: Focus in 2002). The watershed has figured prominently in many continent-wide comparison studies to understand fundamental principles common to all watersheds as well the importance of "uniqueness of place". The knowledge gained at TLW has influenced public policy and forest management across the country (e.g., Great Lakes Canadian-Ontario Agreement, Canada-US Air Quality Agreement,

Canada Acid Rain Assessments, Forest Management Guide for Conserving Biodiversity at the Stand and Site Scale).

The TLW is an international icon of interdisciplinary, integrated systems studies. Of the five major calibrated watershed areas in Canada: the Experimental Lakes Area in northwestern Ontario, the Muskoka-Haliburton area in south-central Ontario, Lac Laflamme in southern Quebec, and Kejimikujik in central Nova Scotia, the TLW has the most comprehensive, multi-disciplinary record amongst its peers. Its legacy is the foundational science that has led to the development of policies that ensure sustainability of Canada's forest ecosystems. Results from TLW continue to provide the federal government with science to improve the quality of life for Canadians. As such, research at TLW is well positioned to improve our understanding of emerging environmental issues and cumulative effects, thus upholding Canada's international reputation for environmental stewardship and leadership into the future.

Site Description

TLW is an experimental forest (47°03'00"N and 84°25'00"W) located on the Algoma Highlands on the northern edge of the Great Lakes-St. Lawrence Forest Region, the second largest forest region in Canada that, with the exception of a small gap where the Boreal Forest Region touches the north shore of Lake Superior, extends from southeastern Manitoba to the Gaspé Peninsula.

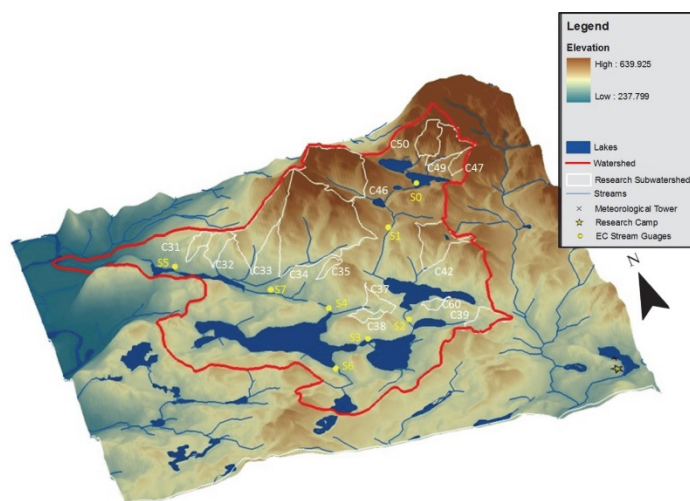


Figure 2 - Watershed terrain



Figure 3 - Upper and Lower Batchawana Lakes

The basin is 10.5 km² and is predominantly situated on metamorphic silicate bedrock (greenstone) overlain by glacial tills. These geological conditions render the basin moderately sensitive to acidic deposition. The TLW has moderately high relief (400 m in elevation from the outlet to the summit of Batchawana Mountain, see Figure 2) and relatively high precipitation (>1200 mm yr⁻¹). The drainage system is composed of many intermittent and perennial first-

order streams draining into and through a chain of four dimictic lakes (Upper and Lower Batchawana, Wishart, Little and Big Turkey Lakes, see Figures 3 and 4) that range in size from 5.8 to 52.0 ha and in mean depth from 2.2 to 12.2 m. There is a chemical gradient in the aquatic system with higher elevation waters being more dilute (lower



Figure 4 - Little Turkey Lake

Ca²⁺ and alkalinity concentrations) than lower elevation waters. The lakes drain into Norberg Creek that ultimately drains in the Batchawana River and thence to Lake Superior.

The climate is continental and is strongly influenced by the proximity of Lake Superior, with mean annual precipitation and temperature of 1189 mm and 4.6°C, respectively, for the period 1980 to 2010. A snowpack persists from late-November or early-December through to late-March or early-April. Peak stream discharge

occurs during snowmelt and again in October to November during autumn storms.

The landscape is controlled by bedrock and contains rugged slopes terminating abruptly in depressions that may be connected or disconnected from the drainage systems, forming topographic features with distinct physical, chemical, and/or biological properties. These include uplands (frequently dry), critical transition zones (intermittently wet) and wetlands (frequently wet). Orthic Ferro-Humic and Humo-Ferric podzolic soils have developed with dispersed pockets of highly humified organic deposits (Ferric Humisols) found in bedrock-controlled depressions and adjacent to streams and lakes.

The watershed is covered by an old-growth (140 years and older), hardwood forest (see Figure 5) that is tolerant to shade and dominated (90%) by a relatively homogenous canopy of sugar maple (*Acer saccharum* Marsh.). Upland overstory associates include white pine (*Pinus strobus* L.), white spruce (*Picea glauca* Moench Voss.), ironwood (*Ostrya virginiana* (Mill.) K. Koch), red oak (*Quercus rubra* L.) and yellow birch



Figure 5 – Forested area typical of the TLW

(*Betula alleghaniensis* Britton). Wetland stands are typically mixtures of black ash (*Fraxinus nigra* Marsh.), eastern white cedar (*Thuja occidentalis* L.), red maple (*Acer rubrum* L.), balsam fir (*Abies balsamea* (L.) Mill.), yellow birch, and tamarack (*Larix laricina* [DuRoi] K. Koch.) (Wickware and Cowell 1985). Stand density (904 stems ha⁻¹), dominant height (20.5 m), diameter at breast height (15.3 cm), and mean basal area (25.1 m² ha⁻¹) are relatively uniform across vegetation types (Jeffries et al. 1988). The sparse understories of upland stands are dominated (more than 95%) by saplings and seedlings of sugar maple with a depauperate herb flora dominated by *Maianthemum racemosum* L. Link, *Streptopus roseus* Michx., *Polygonatum pubescens* ([Wild.] Pursh) and a variety of ferns. The wetland understories are composed of the seedlings and saplings of the overstory trees, various ferns, herbs (e.g., *Caltha palustris* L., *Carex trisperma* Dewey and *Impatiens capensis* Meerb.) and a mix of feather and sphagnum mosses (e.g., *Sphagnum cuspidatum* Ehrh. Ex Hoffm. and *Ptilium crista-castrensis* (Hedw.) De Not.) .

Jeffries, D.S.; Kelso; J.R.M.; Morrison, I.K. 1988. Physical, chemical, and biological characteristics of the Turkey Lakes Watershed, central Ontario, Canada. Canadian Journal of Fisheries and Aquatic Science 45(Suppl. 1): 3-12.

Wickware G.M.; Cowell, D.W. 1985. Forest ecosystem classification of the Turkey Lakes Watershed, Ontario. Environment Canada Lands Directorate. Ecological Classification Series No. 18: 33p.

Long-term ecological research at the Turkey Lakes Watershed: 35th anniversary of interdisciplinary, cooperative research

2014 TLW Science Workshop
Great Lakes Forestry Centre,
1219 Queen St. E., Sault Ste. Marie, ON
November 19-20, 2014

Program

The program will consist of a day and a half of oral presentations, a poster session and a half day panel discussion on future directions and strategic linkages. The focus of oral talks is to provide overview/summary/synthesis of research topics and the focus for the poster session (during breaks and lunch) is to provide detail on short-term, process based studies, student research or other relevant research.

Wednesday November 19, 2014

0830 Welcome and Introductions, David Nanang, Director General, Great Lakes Forestry Centre

1. Trends in atmospheric pollution and climate

0900 **Jason O'Brien** presenting on behalf of **Bob Vet (EC)**, Mike Shaw (EC) – Trends in atmospheric deposition at the TLW and in eastern North America

0930 **Ray Semkin (EC)**, Fred Beall (CFS), – Trends in TLW meteorology (precipitation and temperature) and its influence on recovery from acidification

1000 *Break*

2. Ecosystem response to acidic deposition and a changing climate

1030 **Kara Webster (CFS)**, Irena Creed (UWO) – The fate of soil carbon and nitrogen within the Turkey Lakes Watershed: A “hot” topic

1130 **Paul Hazlett (CFS)**, Fred Beall (CFS), Ray Semkin (EC), Dean Jeffries (EC) – Impacts of environmental factors on elemental cycling and storage at the Turkey Lakes Watershed

1200 *Lunch*

1300 **Dean Jeffries (EC)**, Fred Beall (CFS) – Response of surface water chemistry to declining acidic deposition

3. Impacts of human activities on ecosystem structure and function

- 1400 **Paul Hazlett (CFS)**, Rob Fleming (CFS), Ken Baldwin (CFS), Kara Webster (CFS) – Impacts of a changing climate and harvest intensity on forest growth and composition at the Turkey Lakes Watershed
- 1430 **Fred Beall (CFS)** – Impacts of harvest intensity on water quality and quantity in headwater streams
- 1500 *Break*
- 1530 **Dave Kreutzweiser (CFS)**, Scott Capell (CFS), Kylie Wallace (Laurentian), Alex Potter (Trent), Jim Buttle (Trent), John Gunn (Laurentian) – Harvesting impacts on forest streams: The new stuff we've learned at the Turkey Lakes Watershed
- 1600 **Karen Smokorowski (DFO)**, Bill Gardner (DFO), Tom Pratt (DFO), Evan Timusk (DFO) – A summary of fish and aquatic invertebrate responses to anthropogenic stressors in the Turkey Lakes Watershed
- 1630 *Adjourn*

Thursday November 20, 2014

0815 *Welcome*

4. Cumulative effects of human activities on ecosystem services

- 0830 **Paul Sibley (Guelph)**, Dave Kreutzweiser (CFS), Irena Creed (Western), Jim Buttle (Trent) – Canadian Network of Aquatic Ecosystem Services: Project overview and the role of the TLW.
- 0900 **Jesse Caputo (State University of New York College of Environmental Sciences and Forestry: SUNY-ESF)**, Colin Beier (SUNY-ESF) – Development of a Forest Ecosystem Services Toolkit (FEST) to estimate impacts of forest management on ecosystem services

5. The contribution of TLW to understanding broad scale response to ecosystem stressors

- 1000 **Greg Lawrence (USGS)**, Paul Hazlett (CFS), Rock Ouimet (RNF du Québec), Ivan Fernandez (U Maine), Scott Bailey (USFS) – Long-Term Response of North American Forest Soils to Declining Acidic Deposition

6. Science and policy connections to direct long-term science at TLW

- 1030 *Break*
- 1100 Exploring the drivers: policy, science, and operations – Facilitator: **Guy Smith**, Regional Coordinator and Chief, Knowledge Transfer and Policy, Canadian Wood Fibre Centre
Panel: representing federal and provincial governments, industry, and academia

Canadian Forest Service - **Rory Gilsenan**, Acting Director, Strategic Analysis and Policy Development Division
Environment Canada – **Sandra Weston**, Director, Aquatic Contaminants Research Division
Forest Industry - **Mike Thompson**, Boniferro Mill Works, VP Woodlands
Ontario Ministry of Natural Resources and Forestry - **Joe Churcher**, Supervisor Forest Policy Guide Unit
University - **Jim Buttle**, Professor, Department of Geography, Trent University

Moderator follows press-conference format; pitches following questions to each panelist:

Thinking about TLW and from your perspective,

1. What are the big emerging policy and science needs?
2. How can future research at TLW make a difference?

In turn, each panelist gives their take on question 1, then question 2.

1200 *Lunch*

1330 Moderator facilitates interaction in the room, to build upon what the panelists said

- Questions and comments pertinent to panel theme
- Seek broad participation within the room

1400 Towards a guiding framework: making the science-policy connections

Facilitated small group interactions. 10 minutes to set up in small groups; 45-50 minutes of focussed discussion (max 7 per group)

Tasks for each group:

1. Going forward how can TLW science address the needs identified during the press conference
2. Discuss the main challenges in responding to the needs
3. List solutions to overcome challenges and respond to needs

Facilitator to select top three answers to each question from each group. Large cards stuck to long wall. All other ideas retained on sheets of paper for subsequent use.

1500 *Visit the wall while taking a break*

1530 Short review of top ideas from the wall; supporting comments provided by group participants to enrich the sharing of findings

1600 Wrap up

Abstracts

Topic 1: Trends in atmospheric pollution and climate

Trends in atmospheric deposition at the Turkey Lakes Watershed and in eastern North America

Bob Vet and Mike Shaw

Air Quality Research Division, Environment Canada

The Canadian Air and Precipitation Monitoring Network (CAPMoN) has measured/estimated wet and dry deposition at the Turkey Lakes Watershed (TLW) since the early 1980s. A time series of wet and dry deposition shows that wet and dry deposition fluxes of sulphur and nitrogen at the watershed have decreased considerably in response to major SO₂ and NO_x emission reductions in both Canada and the United States, particularly since 1990. In 1998, a new inferential dry deposition velocity model was adopted by CAPMoN to estimate dry deposition fluxes. From 1998 to 2012, the estimated wet+dry deposition of sulphur decreased 56% from an estimated 9.1 to 4.0 kg S ha⁻¹ a⁻¹. During that period, dry deposition was estimated to account for 30 to 40% of sulphur wet+dry deposition. Similarly, wet+dry deposition of nitrogen (oxidized+reduced) decreased by 40% from 1998 to 2012, from 11.7 to 7.0 kg N ha⁻¹ a⁻¹. Dry deposition was estimated to account for approximately 20 to 30% of nitrogen wet+dry deposition. However, not all nitrogen species are included in these estimates. Long range transboundary transported SO₂ and NO_x emissions from the United States contribute significantly to sulphur and nitrogen deposition at the TLW, as well as to most of eastern Canada. Trends of wet and dry deposition at the TLW are presented and described in the context of North American and global deposition.

Bulk deposition in the Turkey Lakes Watershed and the role of meteorology in the recovery from acidification

Ray Semkin¹ and Fred Beall²

¹National Water Research Institute, Environment Canada

²Canadian Forest Service, Natural Resources Canada

Bulk deposition in the Turkey Lakes Watershed (TLW) is reviewed for the period 1982 to 2012 and compared to results from the CAPMoN (Canadian Air and Precipitation Monitoring Network) wet-only plus dry deposition station. Significant annual decreases in sulphate and nitrate deposition were observed in both networks. Decreasing annual trends in H⁺, total nitrogen and total phosphorus were noted in bulk deposition whereas the sum of base cations showed an increasing trend. Dissolved organic carbon in bulk deposition revealed no significant trend over time. Annual averages of daily mean, maximum and minimum air temperatures are increasing in the TLW at the rate of 0.064°C/yr, 0.080°C/yr and 0.052°C/yr respectively. September and June increases appear to contribute most to the rising annual air temperature. An increasing air temperature results in a longer growing season, a longer ice-free period in the lakes, a reduced snowpack and an increased incidence of zero stream discharges and reduced stream yields. Major fluctuations in temperature and precipitation at the TLW commonly correlate with strong episodes of the El Nino/La Nina Southern Oscillation and have the potential to offset or delay the recovery rate of the watershed from decreasing levels of acidic deposition.

Topic 2: Ecosystem response to acidic deposition and a changing climate

Where does dead stuff go? The fate of soil carbon and nitrogen within the Turkey Lakes Watershed

Kara Webster¹ and Irena Creed²

¹Canadian Forest Service, Natural Resources Canada

²Department of Biology, Western University

Soil is the largest storehouse of carbon (C) and nitrogen (N) within the forest. Dead organic matter that enters the soil pool will decompose over time. Carbon within that dead material can stay in the soil, becoming more refractory over time, or leave the soil. Carbon may exit to streams when mobile forms become soluble and flow out, or be released to the atmosphere when labile forms are converted to carbon dioxide (CO₂) through heterotrophic microbial respiration. Nitrogen within dead matter is mineralized during decomposition, producing bi-products that are either soluble (e.g., NO₃, DON [dissolved organic N]) or volatile (N₂O, N₂). Intensive monitoring within catchments C38 and C35 of the Turkey Lakes Watershed has shown that topography is a key factor to understanding where biogeochemical hotspots of nutrient cycling occur on the landscape. For example, footslopes are areas of high CO₂ production and the outer wetland a zone of high N₂O production. Seasonal changes in precipitation and temperature are also important in understanding shifts in environmental and hydrological conditions that affect C and N fate throughout the year, with spring flush important for NO₃, growing season for CO₂ and N₂O, and autumn storms for DON. Intense rain storms over short periods of time were also shown to have impacts on magnitude of the fluxes out of the catchment. Monitoring over a seven year period has shown considerable inter-annual variability in C and N fates that appear to be strongly linked to average annual air temperatures. Understanding the spatio-temporal controls on C and N fate within forest soils will allow us to make better estimates for GHG (greenhouse gas) accounting and make informed predictions of the implications of a changing climate.

Impacts of environmental factors on elemental cycling and storage at the Turkey Lakes Watershed

Paul Hazlett¹, Fred Beall¹, Ray Semkin² and Dean Jeffries²

¹Canadian Forest Service, Natural Resources Canada

²National Water Research Institute, Environment Canada

This presentation examines two aspects of ecosystem research at the Turkey Lakes Watershed (TLW); soil base cation depletion due to acid rain and the impact of a changing climate on C and N cycling.

Mass balance studies including those at TLW have provided evidence to suggest that soil base cations are being depleted as a result of S and N deposition. In addition, direct soil measurements at several sites in eastern North America have shown decreased pH and exchangeable base cation concentrations when comparing soils sampled over decadal time scales. To assess the impact of acid deposition at TLW, chemical properties of mineral soils sampled from seven permanent sample plots were determined in 1986 and in 2003 and 2005. There were no declines in pH, exchangeable Ca, Mg or K during the sampling period across the watershed. There were various patterns of exchangeable cation change at the plot level. Mineral weathering inputs from a large total base cation pool appeared to provide stability to the exchangeable pool in spite of large leaching losses.

Increasing temperature and changing precipitation patterns have increased drought conditions at the TLW. While mean annual air temperatures at the TLW have increased at a rate of 0.6 °C per decade over the 30 years of the study, there has been significant inter-annual climate variability. Soil temperature and moisture greatly influence the rates of organic matter decomposition and N mineralization in the soil and as a result can influence the concentrations of dissolved organic carbon (DOC) and N in soil and surface waters. DOC, ammonium (NH₄⁺), nitrate (NO₃⁻) and dissolved organic N (DON) concentrations were determined in forest floor and mineral soil percolate, first-order streams, lake and lake outflows from the early 1980s to present. The Palmer Drought Severity Index (PDSI), a water balance index that considers water supply and demand, was used to evaluate climate impacts on catchment biogeochemistry. The PDSI showed limited success in explaining year to year variability in DOC and N concentrations in ecosystem water. As an explanatory tool the PDSI showed most potential for predicting headwater stream concentrations. Summer drought increased annual NO₃⁻ and DON concentrations in stream water while winter drought decreased annual stream NH₄⁺ and increased DON and DOC.

Response of soil and surface water chemistry to declining acidic deposition

Dean Jeffries¹ and Fred Beall²

¹ National Water Research Institute, Environment Canada

² Canadian Forest Service, Natural Resources Canada

Here we present an analysis of surface water chemical trends observed in the Turkey Lakes Watershed (TLW) and the factors that affect them over the period 1983 to 2012. This is accomplished using records of volume-weighted annual average, major element concentrations from two higher elevation streams, two lower elevation streams, the outflow of the headwater lake (Batchawana L.) and the outflow of the lowest elevation lake (Turkey L.). The non-parametric Mann-Kendall test with the Sen's slope estimator was used. There is an elevation-based gradient in base cation and alkalinity concentrations (lower at higher elevations) that overlays the trends, while SO_4^{2-} and NO_3^- concentrations show minor variations related to elevation. Sulphate shows the most consistent and pronounced temporal trend throughout the watershed - a decline that parallels the decline observed in atmospheric deposition. Short-term trend excursions are usually related to the occurrence of wetlands in the basin and climatic variations, particularly drought. There seems to be a recent divergence in SO_4^{2-} responses between higher and lower elevation waters. Calcium declines in headwater streams and Batchawana L. throughout the study period, but it began to increase in Turkey L. around the turn of the millennium. Calcium declines have been the most important chemical compensation for declining SO_4^{2-} . Headwater streams show no trend in alkalinity, whereas the lake outflows have begun to show positive trends in the latter part of the study period, i.e., acidification recovery. There are increasing dissolved organic carbon (DOC) trends in some headwater streams and Batchawana L. outflow, although they may be obscured by climate-influenced variation. Increasing DOC may partially compensate decreasing SO_4^{2-} and reduce the alkalinity response. Trends in other variables are also presented. The TLW lakes fall in the upper half of the critical load distribution observed in the Algoma region. Critical load exceedance has decreased over time, but further reductions in SO_4^{2-} deposition will be needed to meet the goal of the Federal-Provincial Acid Rain Strategy.

Topic 3: Impacts of human activities on ecosystem structure and function

Impacts of a changing climate and harvest intensity on forest growth and composition at the Turkey Lakes Watershed

Paul Hazlett, Rob Fleming, Ken Baldwin and Kara Webster

Canadian Forest Service, Natural Resources Canada

Decreased soil moisture during drought periods has the potential to decrease forest productivity. The Turkey Lakes Watershed (TLW) is located in rugged terrain with well-defined relief, presenting a range of topographic and soil moisture conditions, from drier slope crests and backslopes progressing to wetter footslopes, toeslopes and forested wetlands. Total tree biomass for 23 permanent sample plots (PSPs) was determined over a 30 year period from 1980 to 2010 using species and site specific dbh (diameter at breast height)-biomass regressions. Gross and net periodic biomass increments were calculated for two 15-year periods. The study objective was to assess the impact of increasing temperature and changing precipitation patterns on forest growth across the various landscape positions represented by the PSP network. In addition, topographic indices were calculated including mean upslope flowpath length, specific contributing area and wetness index for each plot location using digital terrain analysis and a 5m LiDAR digital elevation model for the TLW. During the 1980-1995 period there was a positive relationship between five-year gross periodic increment and several topographic indices, indicating greater growth on landform features characterized as “water receiving”. This relationship was not significant during the warmer and drier 1996-2010 period because even though gross growth rates were maintained on “water shedding” plots, growth rates decreased on plots at lower slope positions in the landscape. The impact of changing climate on forest growth was not uniform across this small study area due to inherent differences in plot level drainage and soil moisture.

Tolerant hardwood forests on the boreal shield are often associated with shallow soils. Site nutrient loss due to harvesting removals and nutrient leaching can present a challenge to sustaining forest productivity and maintaining aquatic system integrity. To determine the impact of alternative silvicultural systems on nutrient cycling, harvesting removals, logging residue retention, stand growth and understory vegetation recovery were determined for a harvesting experiment at the TLW. Treatments included shelterwood (even-aged), selection (uneven-aged), diameter limit (all stems > 20 cm dbh harvested) harvests and an unharvested reference. Five years after harvest, gross growth in the shelterwood and selection treatments had recovered to the reference treatment. Nutrient storage in understory vegetation of the diameter limit treatment represented 30-35% of the total stand storage five years after harvest. Pin cherry and yellow birch in-growth between five and ten years post-harvest increased gross growth on the diameter limit treatment. All treatments resulted in higher Ca and N loading to the site (in pushed over trees and slash) than was removed by harvest. Shelterwood and selection harvesting conserved overstory nutrients on site to a greater extent than the diameter limit harvest.

Impacts of harvesting intensity on water quantity and quality in headwater catchments at the Turkey Lakes Watershed

Fred Beall

Canadian Forest Service, Natural Resources Canada

An experiment was installed in 1997 to examine the impacts of different levels of overstory removal on ecosystem processes at the Turkey Lakes Watershed (TLW). A portion of the experiment encompassed five headwater catchments that are part of the headwater monitoring program at TLW. Three different harvesting systems were employed: a diameter limit harvest, where all trees greater than 10 cm dbh (diameter at breast height) were cut and merchantable stems removed, a shelterwood harvest and a selection harvest; while two catchments served as references. The basal area removal was 89%, 38% and 29% in the diameter limit harvest, shelterwood and selection harvests, respectively. Impacts on runoff were generally small and transient. There was a small increase, proportional to the degree of canopy removal, in annual runoff as the result of harvesting. Harvesting tended to increase low and median flows with the greatest effect being observed with the greatest harvesting intensity. However, the effects diminished within 5 to 10 years and, in general, most impacts were within the natural range of variation. Harvesting intensity impacted the export of a few nutrients. Nutrients that were not affected include most base cations, sulphate and dissolved organic carbon (DOC). There were large increases in the export of nitrate and potassium, with minor increases in Ca and ammonium. Fourteen years after harvest, potassium remains elevated in stream water (~2-fold) and nitrate, after increasing dramatically after harvest, is now approximately one half its pre-harvest levels. The results demonstrate that partial harvesting in the Algoma region is not likely to result in more than subtle, short-term effects on water quantity and quality. However, not all parameters have returned to pre-harvest levels 14 years after harvesting (nitrate and potassium) and it is unclear how these effects may accumulate at larger scales.

Harvesting impacts on forest streams: The new stuff we've learned at the Turkey Lakes Watershed

Dave Kreutzweiser¹, Scott Capell¹, Kylie Wallace², Alex Potter³, Jim Buttle³, John Gunn² and Paul Sibley⁴

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Nested within the 35-year research and monitoring period at the Turkey Lakes Watershed, several manipulative studies were conducted to assess the impacts of current or novel forest management practices on headwater streams. In one series, forest areas adjacent to stream reaches were harvested at two operational partial-harvest intensities and at an intentionally high intensity, including riparian (shoreline) areas. The inclusion of riparian harvesting offered a unique opportunity to test the notion that riparian harvesting can emulate natural gap dynamics in shoreline forests to encourage early successional regeneration, while minimizing harmful alterations to adjacent water bodies. Results from sampling 2 years before and 3 years after harvesting indicated that the operational harvest in upland and riparian areas caused little or no measurable change in overhead canopy cover, leaf litter input rates, and fine sediment deposition. The intentional high-intensity harvest significantly reduced canopy cover and litter inputs, and increased fine sediment deposition. In other areas, significant increases in fine sediment deposition were only associated with road building or improvement. Benthic invertebrate communities reflected these changes. We show how these results were and are being used in the development of new shoreline forest management guidelines. A follow-up study was initiated 10 years after harvest to assess longer term effects. By 10 to 12 years after harvest, there was a significant change to riparian forest composition and structure, over-stream canopy cover had redeveloped, and leaf litter input rates were near baseline levels at all sites, including the intensive harvest area. The diversity of leaf litter deposited in streams was significantly higher at the intensive site, but similar to reference at the operational site. Trends in benthic invertebrate community composition at the operational site diverged slightly from pre-harvest and reference conditions between years 1 and 7, while those at the intensive site diverged significantly over the same time frame. Return to pre-harvest conditions was evident by year 11. These changes were driven by responses to open canopy at the intensive site, and to increases in fine particulate organic matter at both operational and intensive sites. Overall, these studies demonstrated that 1) careful riparian harvesting can be conducted to emulate natural shoreline disturbance while minimizing adverse effects in streams, 2) fine sediment delivery to streams is usually a road problem, not a forest harvest problem, and 3) return to pre-harvest conditions was evident even at the high-disturbance site within a decade. Forest harvest impacts studies of this duration are rare. We then describe new studies that extend impact assessments to broader spatial scales at which forest/water linkages and spatially-cumulative impacts are being assessed. All of this contributes to improved, science-based forest management policies and guidelines.

A summary of fish and invertebrate responses to anthropogenic stressors in the Turkey Lakes Watershed, Ontario

Karen Smokorowski, Bill Gardner, Tom Pratt and Evan Timusk.

Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada

Beginning in 1976 with investigations on acidic precipitation effects on freshwater biota, building to the first Canadian Journal of Fisheries and Aquatic Sciences supplement in 1988 and culminating in 2008 with the end of the habitat manipulation experiment, Fisheries and Oceans Canada- Great Lakes Lab for Fisheries and Aquatic Sciences has conducted many aquatic studies in the Turkey Lakes Watershed. Two of these projects will be discussed in detail: the fish contaminants project and the habitat manipulation experiment. For the contaminants in fish project, three species of fishes (Burbot, Brook Trout, and White Sucker) were analyzed for organo-chlorine (OC) and metal based contaminants several times over a 20 year period. Contaminant levels in precipitation, available from Environment Canada, were examined and compared with fish contaminant levels for trends. Generally, OC and metal contaminant levels in fish and precipitation are correlated and have been decreasing since the mid-1990s. For the habitat manipulation experiment, a before after control impact (BACI) design was used. The chosen treatment was to remove wood from 50% of the nearshore areas of three small (< 25 ha) lakes to provide a coarse-scale empirical test of the relationship between fish habitat and productive capacity. The whole fish community in the three treatment lakes and two control lakes was sampled annually between 1998 and 2003, and then again in 2005 and 2008. These data were used to calculate abundance, biomass, production and CPUE (catch per unit effort) before (1998-1999) and after (2000 onward) the treatment. In addition, visual transects were conducted and the locations of observed fish were overlaid on a habitat map. Abundance, biomass and production were highly variable for all lakes which, combined with low statistical power, reduced our ability to detect any changes that may have resulted from the treatment, even with the addition of the long term data (2005 and 2008). Visual surveys, however, indicated a clear, positive relationship between fish abundance and habitat complexity within lakes.

Topic 4: Cumulative effects of human activities on ecosystem services

Canadian Network of Aquatic Ecosystem Services: Project overview and the role of the Turkey Lakes Watershed

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Aquatic ecosystems provide many economic, socio-cultural, and ecological services valued by humans. Many of Canada's resource industries require large amounts of high-quality water but the effect of such demand and use on ecosystem functions and services, especially in regions of Canada that may be particularly vulnerable to climate change, is poorly understood. Knowing how aquatic ecosystem services will respond, or have responded to, varying stressors and their interactions is essential to develop responsible and effective public policies necessary for land use and resource development decisions. The Canadian Network of Aquatic Ecosystem Services (CNAES) is a science-based research program involving a multidisciplinary team from academia, industry, government, and NGOs whose goal is to develop new tools and knowledge for industrial and government managers to assess environmental impacts (or recovery) from current and future resource developments, assess risks and trade-offs to strategically and economically important ecosystem goods and services, and to facilitate informed development, use, and management of Canada's natural resources. To address this goal, the CNAES has developed three major research themes: 1) Coupling the Landscape, Aquatic Ecosystems, Services, and Environmental Change in Canada's North; 2) Healthy Forests, Healthy Aquatic Ecosystems; 3) Quantitative Indicators & Metrics of Ecosystem Services, Health and Function. Specific objectives and research areas in each theme will be discussed during the presentation but emphasis will be placed on the research activities being conducted in the Healthy Forests, Healthy Aquatic Ecosystems theme of the CNAES as it is in this theme area that work at the Turkey Lakes Watershed is, in part, featured. Focusing on headwater streams, the conceptual foundation for research within the Healthy Forests, Healthy Aquatic Ecosystems theme includes characterization and development of physical, chemical and biological indicators of aquatic ecosystem services through monitoring and hypothesis-driven manipulation, assessment of cumulative effects of anthropogenic and natural forest disturbance regimes on ecosystem services, and identifying desired management and policy futures that integrate competing social, economic and aquatic ecosystem services outcomes in changing forest landscapes that maintain aquatic ecosystem services on forest landscapes.

Development of a Forest Ecosystem Services Toolkit (FEST) to estimate impacts of forest management on ecosystem services

Jesse Caputo¹, Colin Beier¹, Fred Beall² and Paul Hazlett²

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The Forest Ecosystem Services Toolkit (FEST) is a collaborative effort to couple long-term ecological data with social information to generate dynamic measures of ecosystem services. In this case study, we assessed the impacts of harvesting biomass for energy feedstocks on a suite of ecosystem services, including flow regulation, water quality regulation, greenhouse gas regulation, and supporting services associated with forest growth. Services were assessed using both social data and long-term ecological data from a number of research sites, including Turkey Lakes Watershed (TLW). In the short-term, trade-offs were apparent between provisioning services and both greenhouse gas regulation and supporting services. In contrast, biomass removals did not strongly impact regulation of water flow or water quality. In the long-term, greenhouse gas regulation and forest growth services recovered in harvested stands as stand vegetation regrew. In fact, there is reason to believe that, over multiple rotations, the cumulative value of the greenhouse gas regulation service in the harvested stands would eventually exceed that in the reference stand. Assumptions regarding human demand for benefits are critical to quantifying ecosystem services. In places where social data regarding beneficiaries is limited, such as TLW, this gap represents an important research opportunity for the future.

Topic 5: The contribution of TLW to understanding broad scale ecosystem services

Long-Term Response of North American forest soils to declining acidic deposition

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Possible effects of acidic deposition on soils have led to the resampling of soils previously sampled in past decades. Some studies have detected changes associated with acidic deposition, such as decreased pH and exchangeable bases, and increased exchangeable Al, whereas other studies did not detect changes. Although nearly all North American soil resampling studies have been conducted during periods when levels of acidic deposition were declining, results suggesting possible recovery are, to our knowledge, limited to a single study of six spruce forests in New England over a 10-year period (Lawrence et al. 2013). To expand the assessment of possible soil recovery, a resampling study has been conducted over eastern Canada and the northeastern U.S. This study includes resampling data from 20 sites (including Turkey Lakes), over a variety of time periods between 1985 and 2010 in ON, QC, NY, VT and ME, plus the six spruce sites, of which three have been sampled for a third time. The study also includes sites with a wide range of acidic deposition, and the Bear Brooks, ME site, which has been annually treated with elevated levels of $(\text{NH}_4)_2\text{SO}_4$ since 1989.

Concentrations of exchangeable Ca showed few changes, but the ratio of base saturation of the O horizon (recent to past) was correlated with the percent reduction in sulfate deposition ($P < 0.05$). Measurements of pH in the O horizon increased at most sites and only decreased in two sites. In the upper B horizon, pH increased at most sites and did not decrease at any sites. Concentrations of exchangeable Al decreased in the O horizon of most sites and decreased at none, but both decreased and increased in the upper B horizon. The ratio of Al in the O horizon (recent to past) was also correlated with the percent reduction in sulfate deposition ($P < 0.05$). Past mobilization of Al leading to the accumulation of Al in the forest floor was previously documented, and now the reversal of this accumulation appears widespread. This change in soil Al has implications for trends in surface water chemistry. In an Adirondack watershed that is included in the soil resampling study, decreases in exchangeable Al in Oe and Oa horizons from 1997 to 2010 totaled 69 kmol for the watershed, a value similar to the 60 kmol of total Al exported from the watershed

over this period. During this same period, pH and DOC concentrations in stream water increased ($p < 0.01$) and SO_4^{2-} concentrations decreased by 60%. Because Al solubility in the forest floor is controlled largely by complexation with organic matter, increased solubility of organic matter from decreasing acidic deposition suggests a mechanism for loss of forest floor Al.

Lawrence, G. B.; Dukett, J.E.; Houck, N.; Snyder, P.; Capone, S.B. 2013. Increases in dissolved organic carbon accelerate loss of toxic Al in Adirondack lakes recovering from acidification. *Environmental Science & Technology* 47:7095-7100.

Panel and Discussion Questions

Science and policy connections to direct long-term science at Turkey Lakes Watershed

Exploring the drivers: policy, science, and operations

Panel: representing federal and provincial governments, industry, and academia

Canadian Forest Service - **Rory Gilsenan**, Acting Director, Strategic Analysis and Policy Development Division

Environment Canada – **Sandra Weston**, Director, Aquatic Contaminants Research Division

Forest Industry - **Mike Thompson**, Boniferro Mill Works, VP Woodlands

Ontario Ministry of Natural Resources and Forestry - **Joe Churcher**, Supervisor Forest Policy Guide Unit

University - **Jim Buttle**, Professor, Department of Geography, Trent University

Moderator follows press-conference format; pitches following questions to each panelist:

Thinking about TLW and from your perspective,

1. *What are the big emerging policy and science needs?*
2. *How can future research at TLW make a difference?*

Facilitated small group interactions. 10 minutes to set up in small groups; 45-50 minutes of focussed discussion (max 7 per group)

Towards a guiding framework: making the science-policy connections

Tasks for each group:

1. *Going forward how can TLW science address the needs identified during the press conference?*
2. *Discuss the main challenges in responding to the needs.*
3. *List solutions to overcome challenges and respond to needs.*

Workshop Outcomes

1. Key messages:

The Turkey Lakes Watershed (TLW)

... is the most **integrated and interdisciplinary** of the long-term ecological research sites in Canada. It has comprehensive on-going measurement records of forest ecosystem, atmospheric, terrestrial, hydrological and aquatic indicators. There is a clear role for the federal government to maintain a site like TLW that cannot be maintained by other research organizations.

... is an excellent example of the application of an **integrated systems approach** incorporating all ecosystem components (soils, vegetation, aquatic) achieved through partnerships among federal, provincial, and academic partners.

... provides a unique opportunity to **study natural and anthropogenic effects at a watershed scale**. This allows for truly ecosystem-based studies, measuring how a particular event, disturbance or experimental manipulation to one part of the ecosystem affects many other components of that same ecosystem, at multiple scales (both in space and time).

... has had **value added projects from universities** that couched their experiments within the long-term context. There is a continuing important role for these partnerships.

... represents long-term investment in one spot and is a sentinel of change common to many other ecosystems. TLW is an **important node in regional research networks** (soil, water, ecosystem services). TLW can serve as a pilot study area to test many scientific concepts and policy-driven hypotheses.

... is regarded as a showcase of long-term ecosystem science by the forest industry in the region. It can be utilized to **respond to sustainable forest management (SFM) questions and criticisms**. This role should be enhanced within federal government.

... is **suited to studying forest change** to changing climate and atmospheric deposition given high rates of temperature changes and emission reductions, and strategic location at the boundary between Great Lakes St. Lawrence and Boreal zones, and long-term sampling of ecosystem properties.

... is ideal for studying **cumulative effects of ecosystem stressors across scales**. Work has shown there are interactions between acid deposition recovery, climate change and forest harvesting on ecosystem properties.

2. Key continuing/emerging policy and science needs:

- *Science-based SFM to show environmental leadership and promote market access.*
- *Science-based prescriptions for operational forest management.*

- *Science to support understanding of what SFM will look like in a changed climate.*
- *Science to support of SFM certification (indicators and thresholds).*
- *Science to understand the effects of increased utilization of woody biomass for bioenergy on ecosystem biogeochemistry.*
- *Science to relate ecosystem function to ecological services.*
- *Science in support of conservation of biological diversity and species at risk.*
- *Science (and tools) to support understanding of the effects of climate and atmospheric deposition change on forest ecosystems and adapting to climate change (thresholds and indicators).*
- *Science to support carbon accounting research and carbon budget modeling.*
- *Science to support water security, both in terms of water quantity and quality.*
- *Science to measure the catchment-scale effects of forest management, natural disturbances, and climatological patterns and trends.*
- *Science to quantify cumulative effects of disturbances.*
- *Science to understand ecosystem recovery from multiple, contemporaneous disturbances.*

3. Challenges to responding to policy and science needs and potential solutions:

Challenge: Defining the role of federal government in long-term ecosystem research.

Solution: There is a clear role and need for the federal government to maintain long-term research for the public good but research must be targeted to current department priorities. Long-term research sites cannot be maintained by other research organizations (e.g., universities, industry) because of different mandates, shorter time frames for research and lack of funding for infrastructure maintenance.

Challenge: Ever changing institutional mandates and priorities.

Solution: Enhanced communication between scientists and management to define core needs, priorities and outcomes. Continue to explore partnerships and networks to share data benefits.

Challenge: Diminishing resources for people, infrastructure, on-going maintenance and research costs.

Solution: Building a framework for federal departmental priorities and create “business-science” models and partnerships to fund those priorities. In addition to federal priorities there is a need to ensure connections to provincial policies and guidelines which provide linkages to forest industry and enable collaborative science. Continue to encourage and develop partnerships with university researchers to maintain and enhance resources.

Challenge: Sharing and archiving data.

Solution: Defining the best approach for data to be accessed and archived. Data can be used to measure the efficacy of existing environmental policies, develop new policies related to current stakeholder priorities, and address new unanticipated issues that will arise in the future.

Challenge: Integrating research programs among partners.

Solution: Renewal of the Turkey Lake Watershed Steering Committee. Ensure program planning among government, academic and industry partners to promote awareness of emerging new science and emerging policy and management priorities and potential collaboration.

Workshop Participants

Last Name	First Name	Affiliation
Arsenault	Christiane	Canadian Forest Service - NCR
Baldwin	Ken	Canadian Forest Service - GLFC
Beall	Fred	Canadian Forest Service - GLFC
Broad	Jamie	Canadian Forest Service - GLFC
Buttle	Jim	Trent University
Capell	Scott	Canadian Forest Service - GLFC
Caputo	Jesse	The State University of New York
Chapman	Kim	Canadian Forest Service - GLFC
Chartrand	Derek	Canadian Forest Service - GLFC
Churcher	Joe	Ontario Ministry of Natural Resources and Forestry
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Diochon	Amanda	Lakehead University
Dominy	Steve	Canadian Forest Service - GLFC
Dutkiewicz	David	University of Guelph
Edwards	Kate	Canadian Forest Service - AFC
Fera	Jeff	Canadian Forest Service - GLFC
Fleming	Rob	Canadian Forest Service - GLFC
Gardner	Bill	Department of Fisheries and Oceans
Gibbs	Sharon	Canadian Forest Service - GLFC
Gilsenan	Rory	Canadian Forest Service - NCR
Good	Kevin	Canadian Forest Service - GLFC
Hawdon	Laura	Canadian Forest Service - GLFC
Hazlett	Paul	Canadian Forest Service - GLFC

Last Name	First Name	Affiliation
Hearn	Brian	Canadian Forest Service - AFC
Hoepting	Mike	Canadian Forest Service – CWFC-GLFC
Jeffries	Dean	Environment Canada
Jones	Trevor	Ontario Ministry of Natural Resources and Forestry
Kreutzweiser	Dave	Canadian Forest Service - GLFC
Lawrence	Greg	The U.S. Geological Survey
Neureuther	Roy	Environment Canada
Newbery	Alison	Canadian Forest Service - GLFC
O'Brien	Jason	Environment Canada
Osborne	Art	Canadian Forest Service - GLFC
Primavera	Mark	Canadian Forest Service - GLFC
Roy	Vincent	Canadian Forest Service - LFC
Schiff	Sherry	University of Waterloo
Shabaga	Jason	University of Toronto
Sibley	Paul	University of Guelph
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Smokorowski	Karen	Department of Fisheries and Oceans
Thibodeau	Marla	Department of Fisheries and Oceans
Thompson	Mike	Boniferro Mill Works
Toole	Dean	Canadian Forest Service – CWFC - AFC
Venier	Lisa	Canadian Forest Service - GLFC
Voelker	Steve	Oregon State/Lake Superior
Vogel	Linda	Canadian Forest Service - GLFC
Webster	Kara	Canadian Forest Service - GLFC
Weldon	Tom	Canadian Forest Service - GLFC
Wilson	Stephanie	Canadian Forest Service - GLFC

