

**LONG-TERM STUDY OF BOREAL
WATERSHED/LAKE ECOSYSTEMS, MICHIGAN; FRASER
EXPERIMENTAL FOREST, CO; AND ALASKA**

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Introduction

This report summarizes research completed during FY99, and outlines research objectives and a study plan for FY 2000. The study sites considered in this research report are the Wallace Lake Watershed, Isle Royale National Park (ISRO), Michigan; the Calumet Watershed, Michigan's Upper Peninsula; watersheds of the U.S. Forest Service Fraser Experimental Forest, Colorado; and the treeline Asik Watershed, Noatak National Preserve, Alaska. The sites are predominantly boreal ecosystems. All are located at major ecotones (northern hardwoods-boreal, subalpine-alpine, taiga-tundra). While the research objectives differ somewhat among sites, the conceptual approach is similar. Much of the work is common among sites, or is planned to be such. The research emphasis has been and continues to be on terrestrial processes. An assessment of the literature suggests for terrestrial ecosystems that the study of processes in an ecosystem context likely will give the earliest statistical indication of incipient change due to stress, and a better quantification of the magnitude of response.

1999 Research Highlights

MICHIGAN SITES

By the end of FY 99, we completed 17 yrs of precipitation and streamwater chemistry on the two Isle Royale National Park (ISRO) watersheds, 20 yrs of intensive precipitation, snowpack, snowmelt, and streamwater chemistry at the Calumet watershed, Michigan's Upper Peninsula, and 13 yrs of intensive forest litter and soil solution monitoring during snowmelt at Calumet.

Wallace Lake Watershed: About 600 copies of our monograph on this site (see 1999 Publications) were distributed to all university and government libraries and to many individual scientists. A few are still available and given out on request. The book summarizes 15 years of research, and is the only longer-term ecosystem biogeochemistry study in the southern boreal biome of North America. This year we also summarized and published the longer-term studies on the relation of climate to the nitrogen cycle (see FY 99 publications below). In addition, we completed an 18 month long forest litter decomposition study. This study was intended to examine litter quality and the interaction of climate variables on decomposition rates. Routine monitoring was continued including monthly and over-winter soil net N mineralization rates under major vegetation types. We are testing this procedure, along with annual and seasonal change in mineral soil and forest floor C:N ratios, as possible monitoring tools to examine longer-term trends in forest floor N and C availability with global change (temperature, moisture, precipitation quality).

Calumet Watershed: This year we continued the routine monitoring in the watershed. We also analyzed an intensive data set which gives more resolution on the importance of watershed subsurface flowpath in inorganic and organic nutrient export. In this analysis, we examined physical, chemical, and biological processes responsible for observed seasonal change in streamwater chemistry based upon intensive study in water year 1997. Soils were unfrozen beneath the snowpack. Small, but steady, snowmelt occurred throughout winter. Uniform cool snowpack temperatures, and late winter increases in precipitation Ca^{2+} , NH_4^+ , NO_3^- , and SO_4^{2-} concentrations and snowpack water equivalent (SWE) resulted in a high snowpack ion content late in the season followed by rapid snowmelt. Cumulative precipitation ion inputs exceeded peak snowpack content except for Ca^{2+} and Cl^- . The increased late winter snowpack Ca^{2+} and Cl^- content likely reflected increased regional use of road salts. Snowmelt ion concentrations were twice snowpack levels. Most snowmelt (90%) entered the forest floor and surface soil. During snowmelt, soil water levels rose rapidly to the surface, concentrations of base cations (C_B) declined, and NO_3^- , NH_4^+ , SO_4^{2-} , and DOC increased. Soil lysimeter C_B concentrations increased with depth, but H^+ , NH_4^+ , and NO_3^- concentrations were <10% snowmelt levels. Linkages between soil water and streamwater ion concentrations were apparent. In shallow soils, rapid lateral movement of meltwater coupled with less amounts of readily weathered C_B material reduced soil water and streamwater C_B and HCO_3^- concentrations. At peak

streamflow, dilution accounted for >90% of the decline in acid neutralization capacity. Increases in streamwater NO_3^- concentration before peak snowmelt and in shallow soil water during snowmelt indicate significant over-winter N mineralization and rapid NO_3^- mobilization by meltwater. The increased DOC concentrations in shallow soil water and streamwater at maximum discharge are additional indicators of high over-winter forest floor and surface soil organic mineralization. Streamwater SO_4^{2-} concentration declined <10% during snowmelt. Soil desorption is the only process with the capacity to quickly provide enough SO_4^{2-} to offset a large streamwater concentration decline from dilute snowmelt. The watershed retained >99% of snowmelt H^+ by soil exchange, and >99% of NH_4^+ and >90% of NO_3^- by soil microbial and above-ground uptake while SO_4^{2-} output exceeded input. Mass balance analyses suggest little relationship of streamwater ion concentration and flux to precipitation or snowmelt inputs. Seasonal change in streamwater chemistry primarily reflected hydrology, over-winter organic mineralization products, snowmelt/soil water movement of readily flushed ions and DOC from shallow soils, and mineral soil weathering when soil water was deep.

FRASER EXPERIMENTAL FOREST

We completed 17 yrs of continuous monitoring of precipitation and streamwater chemistry for the six primary watersheds. In addition, we have on average 13 yrs of streamwater chemistry for four alpine catchments, 13 yrs of comparison data for precipitation chemistry with elevation, 13 yrs of monthly snowpack chemistry along an elevation gradient, 6 yrs of intensive snowpack/snowmelt chemistry along an elevation and aspect gradient, a unique 10 yr data set on change in soil solution chemistry with depth following paired plot clearcutting, and a decade of snowpack chemistry in a separate experiment with paired plots following clearcutting.

This year we continued the basic monitoring of surface water chemistry in nine gauged watersheds, the change in snowpack chemistry with elevation, and summarized our ten-year study of the effect of clear cutting on subsurface flow chemistry and budgets. Our research on disturbed sites led to numerous requests to address likely impacts from clear cutting on surface water quality in National Forests of the Rocky Mountains. We have begun the two-year process of assembling and analyzing the long-term climate and hydrology database to integrate with our biogeochemistry for eventual publication in a monograph. The monograph topics will be similar to our recent book on Isle Royale, but will incorporate data from all nine watersheds, contain considerable more data on long-term change in snowpack and snowpack chemistry, and address the effects of subalpine canopy removal on hydrology and nutrient export from watershed ecosystems.

In fall 1999, we began the intensive (25 plots) seasonal examination of micro-climate, soil process rates, soil nutrient pools, and production and export of soil DOC and DON in response to aspect and elevation in the Lexen Creek watershed. The study design and processes examined are similar to the study underway in the Asik watershed, Noatak National Preserve, Alaska.

Finally, we made some modest but essential upgrades in the cooperative USGS-USFS biogeochemistry laboratory in Ft. Collins, Colorado. Chief among these was improved equipment to help prepare soil, forest floor, and plant tissue samples for analysis, a new laboratory computer, and new laboratory software for converting analog to digital output with improved post-analysis computation options.

ALASKAN NATIONAL PARKS

Asik Watershed: This year we continued monitoring basic watershed processes. In anticipation some global change funding would become available, we established 50, 10m x 10m vegetation plots throughout most of the watershed. The plots were located to compare the effect of vegetation, nitrogen availability, site productivity, and aspect on basic soil processes and the production of inorganic N, DOC, and DON. We collected monthly soil and forest floor samples for extractions and

C:N analyses, placed small dataloggers above and below ground to monitor forest floor and air temperature, routinely monitored soil moisture at all sites, and collected seasonal data on soil/forest floor respiration rates. A subset of instrumented plots were left intact over-winter. These data are currently being analyzed in Ft. Collins. Two additional research proposals were prepared and submitted to obtain additional support for this ongoing watershed ecosystem study.

Finally, we began to combine the long-term climate record for this region with Asik watershed data collected during the last three years to better assess potential relationships between climate change and ecosystem nutrient availability. We also compared climate change during the last five decades for five USGS small watershed research sites including Asik. Among these sites, during the last 50 years the Noatak region has experienced a significant increase in mean annual temperature and the rate of increase is greater than any of the other four sites in the lower 48 contiguous states. In addition, since 1990 the mean annual temperature in the Noatak region has been increasing $0.4^{\circ}\text{C yr}^{-1}$, a finding consistent with other monitoring of interior Alaska. Most of the annual temperature increase occurs in May which is thought likely to extend the limited Arctic growing season.

FY 00 Research Objectives/Hypotheses

MICHIGAN SITES

Calumet Watershed: Current hypotheses: 1) Snowpack accumulation of anthropogenic ions is a significant fraction of annual inputs, but high solute retention until spring melt and peak stream runoff does not occur due to periodic thaws and unfrozen soils; and 2) the pattern of snowmelt, and especially the occurrence of initial small melts, largely determines the snowpack solute pathway to streams and therefore the potential for streamwater solute "pulses". In FY 00, we will continue routine monitoring of this watershed. No new research questions will be addressed. For procedures used in this study, see previous and current publications on Calumet.

Wallace Lake Watershed: This year we will continue the routine watershed monitoring and inventory, and begin the setup for studies on relationships between global change and ecosystem processes. More of the site-specific research is now being done with the intent of examining intersite variation in processes and their response to stimuli as global change. The research emphasis is to combine selected components of past watershed monitoring and research with new studies of change in year-round soil respiration, soil, and soil water chemistry, to better understand mechanisms regulating terrestrial ecosystem carbon (C) and nitrogen (N) availability and export to the aquatic ecosystem. Factors affecting the quantity of below-ground C affect the soil biota which regulate ecosystem N availability and in turn ecosystem production and biodiversity. The specific objectives are to 1) quantify the relation between forest floor and soil temperature, moisture, and N availability with production of dissolved organic carbon (DOC) and dissolved organic nitrogen (DON), 2) quantify below-ground CO_2 efflux, and mycorrhizae and small root production with change in soil temperature, moisture, and N availability, 3) correlate terrestrial DOC and DON production to export in aquatic ecosystems, and 4) use the long-term watershed chemical monitoring datasets with mixing models and piezometer results to determine seasonal change in watershed hydrologic flowpaths - a major factor regulating DOC and DON export to the aquatic ecosystem. This 2-3 year study will first be conducted in the Asik Watershed in the Noatak National Preserve, Alaska, located at the northern extent of the boreal biome. The sampling strategy, nested hierarchical, will incorporate data on vegetation, air and soil temperature, soil moisture, precipitation, and soil water ions, DOC, and DON from a network of small plots in each watershed to develop predictive relations between vegetation, climate, and soil DOC and DON production. Using split plots, we will intensively study processes by which GC and increased N availability alter DOC and DON production. Finally, by merging climate data from an extensive site network in each watershed with vegetation, topographic information (aspect, elevation), chemical and hydrologic results from flow-proportion soil piezometers and

watershed-level mixing models, we will predict watershed DOC and DON export and compare results to actual fluxes.

FRASER EXPERIMENTAL FOREST

This year we will continue the monitoring of surface water chemistry in nine gauged alpine and subalpine watersheds. In addition, we will conduct a series of short term studies initiated in 1999 to fill in database gaps in preparation for starting a monograph summarizing the long-term biogeochemical studies in the Forest. No new longer-term studies are planned at present unless research proposals are funded. An emphasis this year will also be publication of completed research datasets as indicated in the section below, Anticipated Accomplishments in 2000.

ALASKAN NATIONAL PARKS

This year we will implement the recently funded global change research in the Asik Watershed, Noatak National Preserve. The objectives and methodology in this research are the same as described above for Wallace Lake, the paired watershed site. We continue to assist Denali National Park in its monitoring of the Rock Creek watershed, and this year may initiate additional terrestrial process studies at Rock Creek to better explain change in stream water chemical signatures. Support for this research comes from the National Park Service.

Publications in FY 99

Stottlemyer, R. 1999. Glacier Hydrology and Hydrochemistry. M. Sharp, K. S. Richards, and M. Tranter (eds), John Wiley and Sons, Chichester, U.K., 342 pp. J. Hydrol. 219:94-99.

Stottlemyer, R. 1999. Parks and Preserves. In: Encyclopedia of Environmental Science, D. E. Alexander and R. W. Fairbridge, Eds., Kluwer Academic Publishers, London, p. 418-421.

Stottlemyer, R., and K. McLoone. 1999. Stream chemistry in small watersheds, Denali National Park and Preserve, AK. Abstracts of the American Assoc. Advance. Science 50th Arctic Science Conf., Denali National Park and Preserve, Alaska, p. 196.

Stottlemyer, R., and C. Rhoades. 1999. Biogeochemistry of a treeline watershed, Noatak National Preserve. Abstracts of the American Assoc. Advance. Science 50th Arctic Science Conf., Denali National Park and Preserve, Alaska, p. 193.

★ Stottlemyer, R., and D. Toczydowski. 1999. Nitrogen mineralization in a mature boreal forest, Isle Royale, Michigan. J. Environ. Qual. 28(2):709-720.

Stottlemyer, R., and D. Toczydowski. 1999. Seasonal relationships between precipitation, soil, and streamwater nitrogen, Isle Royale, Michigan. J. Soil Sci. Soc. Amer. 63(2):389-398.

Stottlemyer, R., D. Toczydowski, and R. Herrmann. 1998. Biogeochemistry of a mature boreal ecosystem: Isle Royale National Park, Michigan. National Park Service Scient. Monogr. NPS/NRUSGS/NRSM-98/01, U.S. Dept. Interior, Washington, D.C., 116 p.

Stottlemyer, R., and C. A. Troendle. 1999. Biogeochemistry of alpine and subalpine ecosystems, Fraser Experimental Forest, Colorado. Ecol. Soc. Amer. Abstracts, p. 311.

★ Toczydowski, D., and R. Stottlemyer. 1999. Biogeochemistry of a mature boreal ecosystem: Isle Royale National Park, Michigan. Ecol. Soc. Amer. Abstracts, p. 315.

ISO-2130
ISO-2132

Deliverables in FY 00

The following papers should be submitted or published in FY 00.

Herrmann, R., L. Scherbarth, and R. Stottlemyer. 2000. Environmental effects of water use on watersheds in the United States. *J. Amer. Water Resour. Assoc.*

Herrmann, R., R. Stottlemyer, J. C. Zak, R. L. Edmonds, and H. Van Miegroet. 2000. Biogeochemical effects of global change on U. S. National Parks. *J. Amer. Water Resour. Assoc.*

Stottlemyer, R., and B. Cohn. 2000. Merging long-term climate monitoring with soil, root, and foodweb dynamics to understand mechanisms regulating C and N transformations in Olympic National Park: Watershed-level study. *J. Soil Sci. Soc. Amer.*

Stottlemyer, R., and R. Herrmann. 1999. Boreal ecosystem response to atmospheric nitrogen inputs and climate change. In: *Disturbance in Boreal Forest Ecosystems: Human Impacts and Natural Processes*, U.S. Forest Gen. Tech. Rept.

Stottlemyer, R., and K. McLoone. 2000. Stream chemistry in small watersheds, Denali National Park and Preserve, AK. *J. Amer. Water Resour. Assoc.*

Stottlemyer, R., and C. Rhoades. 2000. Biogeochemistry of a treeline watershed, Noatak National Preserve. *J. Environ. Qual.*

Stottlemyer, R., C. Rhoades, D. Toczydlowski, and R. Herrmann. 2000. Comparison of nutrient budgets and mineralization in boreal ecotone watersheds, Alaska and Michigan. *J. Soil Sci. Soc. Amer.*

Stottlemyer, R., and D. Toczydlowski. 1999. Seasonal change in precipitation, snowpack, snowmelt, soil water and streamwater chemistry, northern Michigan. *Hydrol. Process.*

Stottlemyer, R., and D. Toczydlowski. 1999. Seasonal change in precipitation, snowpack, snowmelt, soil water and streamwater chemistry, northern Michigan. In: *Snow Hydrology: The integration of physical and biological systems*, J. P. Hardy, M. R. Albert, and P. Marsh (eds), John Wiley and Sons, Ltd., Chichester.

Stottlemyer, R., and C. A. Troendle. 2000. Effect of subalpine canopy removal on snowpack, soil solution, and nutrient export, Fraser Experimental Forest, CO. *Hydrol. Process.*

Stottlemyer, R., and C. A. Troendle. 2000. Effect of canopy removal on snowpack quantity and quality, Fraser Experimental Forest, Colorado. *J. Hydrol.*

Stottlemyer, R., and C. A. Troendle. 2000. Effect of subalpine canopy removal on snowpack, soil solution, and nutrient export, Fraser Experimental Forest, CO. In: *Snow Hydrology: The integration of physical and biological systems*, J. P. Hardy, M. R. Albert, and P. Marsh (eds), John Wiley and Sons, Ltd., Chichester.

Suarez, F., D. Binkley, M. Kaye, and R. Stottlemyer. 2000. Expansion of forest stands into tundra in the Noatak National Preserve, Northwest Alaska. *Ecoscience*

Presentations at national scientific meetings. One presentation will be made at the AGU fall conference, two presentations at the Ecological Society of America, and several at regional science conferences.