WATERSHED ECOSYSTEM RESEARCH FOR PARKS AND EQUIVALENT RESERVES

U. S. GEOLOGICAL SURVEY - MIDCONTINENT ECOLOGICAL SCIENCE CENTER
NATIONAL PARK SERVICE
AND
COLORADO STATE UNIVERSITY

1999 ANNUAL REPORT

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GEOLOGICAL SURVEY

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July 12, 2000

Memorandum

To: Douglas K. Morris, Superintendent of Shenandoah National Park

From: Ray Herrmann

Subject: 1999 Annual Report

Enclosed for your information is the 1999 Annual Report of the Watershed Ecosystem Research and Monitoring Program. It catalogs our activities during 1999 and reflects the current focus of each site. Of note is our shift towards domination by global issues, required by budget considerations and the downsizing required by continued budget reductions. I hope this information is useful to you and your staff.

We thank you for your interest and your past and current support. I hope that ongoing cooperation will continue to support NPS resources management.

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WATERSHED ECOSYSTEM STUDIES

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SUMMARY

Maintaining support for long-term studies is particularly difficult; however, at various times survival of the program has depended upon keeping high peer credibility, and demonstrating local importance, regional applicability and national policy relevance. We have accomplished this by preserving and, when required, enforcing a network philosophy that encourages inter-site linkages and cooperation. We have depended upon the continuing active support of Park resources managers and researchers, both in the study Parks and elsewhere; the understanding and assistance of the Park superintendents; and occasionally when needed, the direct intervention of the Director of the National Park Service. In short, success has relyed upon keeping all levels of Park management and science administration informed while relying on the long-term commitment, skill, dedication and leadership of each site principal investigator. Support for these activities, although much reduced, has been and continues to be provided by the National Park Service and the Biological Resources Division of the U.S. Geological Survey, formerly the National Biological Service. Important contributions are also due to cooperators from the National Atmospheric Deposition Program, the Water Resources Division of the U.S. Geological Survey, the State of California, and the National Acid Precipitation Assessment Program. Finally, I wish to emphasize again our accumulated knowledge about, and current understanding of, Park watersheds has been made possible by the long-term commitment of the many site investigators that continues despite severe budget reductions of recent years.

INTRODUCTION

Lands under the stewardship of the Department of Interior (DOI) are being subjected to a large number of local, regional, and perhaps global-scale disturbances. The public lands have a unique set of mandates and rules regulating their use and conservation. These lands also contain many different ecosystems. For at least 15 years, we have known that major threats to even the remotest of these lands occur from sources external to their boundary. Chief among these threats are air pollution, water pollution, and incompatible conterminous land use. Typically, stress from these sources is subtle, chronic, and changes over long time periods. Traditionally, concern over threats to the integrity of ecosystems and their components on the public lands has focused on sources of stress originating within the boundaries of such lands. Questions regarding the effect of threats have focused primarily on selected components, most often highly visible animal or plant species. This emphasis was often dictated by focused public concern or specific mandates designed to protect selected species. Threats originating within the boundaries of the public lands may be corrected through changing management actions. We now recognize, however, many activities threatening the resources of the public lands originate outside their boundaries. While emphasis on selected ecosystem components can, in some instances, detect stress, this approach is frequently limited in its ability to detect incipient stress and evaluate the full magnitude of effects.

Land managers and scientists have recognized for decades a holistic, long-term research approach was necessary to evaluate forest or ecosystem health and understand the structure and function of land units.

Mitigation of threats to the public lands, especially threats such as air pollution originating outside public land boundaries, will take many years or decades. Mitigation strategies will increasingly impact more constituencies requiring, as a minimum, formidable scientific databases for support. These factors require a significant amount of research coupled with inventory and monitoring to 1) maximize the probability incipient change in response to stress will be detected, 2) that its magnitude will be quantified, and 3) the source of stress, whether human or non-human, will be separable and quantifiable.

The value of long-term, ecosystem-level perspectives is widely recognized, though poorly funded and supported, for understanding ecosystem structure, function, and response to stress. USGS-BRD and NPS watershed research sites now have the potential to comprise important long-term reference points and can provide a unique opportunity against which to measure and assess ecological health. In the past, research, inventory, and monitoring have been handled separately.

PROGRAM DESCRIPTION AND BACKGROUND

During 1980 to 1982, the U.S. National Park Service (NPS) embarked on a program of long-term watershed research and monitoring. The purpose was to understand how "natural" watersheds function as ecosystems, and how the changing chemical environment, in response to atmospheric inputs of acidifying materials, was altering them. Sites were chosen from the U.S. Biosphere Reserves, and included sites with high and low atmospheric deposition. During the initial two years, a core set of monitoring variables were identified including climate, deposition, hydrology, environmental chemistry, vegetation, and soils. Today eleven sites are included in the National Park (NP) watershed network (Table 1).

A number of site networks exist directly addressing the need for long-term, ecosystem level research strategies, including the U.S. Department of Agriculture Forest Service Experimental Forests, the National Science Foundation's Long-Term Ecological Research (LTER) program and the USGS-BRD Watershed Research Program. The original 1980 design of the USGS-BRD Watershed Research Program, formerly the NBS Watershed Research Program and the NPS Watershed Studies Research Program, drew on many sources: interagency discussions, ideas from U.S. Man and the Biosphere Program, the National Science Foundation's Long-Term Ecological Research Program, the National Acid Precipitation Assessment Program, and the US/USSR Bilateral on Biosphere Reserves.

Activities were designed to focus on the watershed and the ecosystems represented therein. The watershed approach has been, until recently, an often overlooked tool for research and monitoring of natural systems. Quantifying the flux of essential mineral nutrients from living to non-living ecosystem components on protected reserves, and making comparisons to other disturbed lands, can assess ecosystem health and integrity. By 1982, the NPS had established its small network of watershed ecosystem studies in three National Parks to examine the effect of atmospheric contaminant inputs on otherwise protected areas. The study sites were chosen from the fourteen NPS Biosphere Reserves existing at the time and selected to be biogeographically representative of ecosystems in relatively remote areas (Table 2, Figure 1). The sites, Sequoia-Kings Canyon, Rocky Mountain, and Isle Royale NP's, represented mature ecosystems receiving varying levels of contaminant inputs. Two years later this network was expanded to a fourth primary site with a watershed ecosystem study site in Olympic NP.

The sites have a number of important common attributes including: long-term protected status, a core area (undisturbed watershed), research hypotheses and experimental designs for detection of ecosystem change and understanding the mechanisms of change, basic inventory information, research and/or monitoring capabilities, monitoring techniques that will not change unless they can be calibrated to new techniques, sampling protocols fitting within the time frame of known physical and biologic events, and standardized protocols for data collection, sample storage, sample archival, and data management.

During 1991-1995, the watershed level research and monitoring activities contributed to the accumulation of important baseline information on deposition, meteorology, hydrology, ecosystem functioning, and biology. Because NPS watershed research was conducted within the context of NAPAP and the government-wide Global Climate Change (GCC) Program, our results were and are being enhanced by these related research activities. In some cases, important information on biological diversity and biogeochemical processes have been obtained. Activities have ranged from needs identification, to reconnaissance or synoptic analyses, to long-term monitoring and to long term ecosystem research. Eleven National Park Service administered areas have implemented some watershed ecosystem research: Big Bend NP (BIBE), Crater Lake NP (CRLA), Denali NP (DENA), Glacier NP (GLAC), Great Smoky Mountains NP (GRSM), Isle Royale NP (ISRO), Noatak National Preserve (NOAT), Olympic NP (OLYM), Rocky Mountain NP (ROMO), Sequoia and Kings Canyon NP's (SEKI), and Shenandoah NP (SHEN). Five sites [ISRO, OLYM, NOAT, ROMO, and Sequoia NP (SEQI)] received funding from the Watershed Research Program. SHEN and GRSM were part of the NPS I&M Program, as were DENA and Everglades NP (EVER). A substantial lake studies program at CRLA was included in the NPS GCC Program. New watershed sites included in the NPS GCC Program were EVER, GLAC, Organ Pipe Cactus National Monument (ORPI), Wrangel St.-Elias National Preserve (WRST) and Buffalo Wild and Scenic River/Ozarks National Scenic River (BUFF/OZAR). Cooperative U.S./Russia watershed research began in the Caucasus Biosphere Reserve and continued at Hubbard Brook. Numerous publications were written, submitted or published during this period based on watershed results from NOAT, OLYM, ISRO, SEQI, and ROMO.

During 1996 to 1999, as budgets were reduced, six sites (BIBE, ISRO, OLYM, NOAT, ROMO, and SEKI) continued to receive funding from the NBS/USGS Watershed Research Program. SHEN and GRSM are still included in the NPS Inventory and Monitoring (I&M) Program along with DENA (all have been evaluated recently by NBS/NPS teams). BIBE, GRSM, ISRO, OLYM, and NOAT became part of the USGS Global Change Progam. The limnology program at CRLA is again included in the NPS Global Climate Change Program, as is the Lake McDonald, Flathead River Watershed at GLAC. Discussions regarding the potential for new watershed sites were curtailed.

Today the four original sites and SHEN, where watershed studies began in 1979, have more than seventeen years of comprehensive watershed ecosystem inventory, monitoring and research data, and a series of publications on ecosystem function and structure, and to some extent, management of park resources. Other N.P. sites have shorter or discontinuous watershed ecosystem records: BIBE, DENA, GLAC, GRSM, and NOAT. Six sites are now part of the NPS/USGS Global Climate Change Program: ROMO, ISRO, OLYM, SEQI, GLAC, and CRLA. Three watershed sites are included in the NPS/USGS Inventory and Monitoring Program: SHEN, GRSM, and DENA. Sites range from the hot Chihuahuan Desert in the Southwest, to the moist boreal forests of Michigan, to eastern deciduous forests of Virginia, Tennessee and North Carolina, to the alpine of California and Colorado, and to the Alaskan taiga-tundra (Table 2). It is important to note the Watershed Program has over the years absorbed a number of budget cuts and until the end of 1999 we have maintained critical site activities. However, at the close of FY 1999, because of USGS budget restrictions amounting to over 28% of the remaining operational budget (Figure 2), SEQI was eliminated from the program.

Each year this summary annual report summarizes accomplishments, major research results, publications, and research plans for the following fiscal year. Current watershed citations through 1999 number over 870 including journals, proceedings, books, government technical reports, and other peer reviewed and technical abstracts and posters.

RESEARCH GOALS, OBJECTIVES, AND DESIGN

The goals of the Watershed Research Program are to 1) provide a basic understanding of selected aquatic and terrestrial ecosystems structure and function, and 2) generate timely scientific input that assist in developing mitigation strategies and addressing major threats to the ecological integrity of the public lands. To help accomplish these goals, a network of watershed ecosystem study sites was established, and with time, a core long-term monitoring data set was developed for study of selected ecosystem processes and provided for updated synthesis of the status of ecosystem knowledge for legally-protected public lands.

From 1980-1982, a core set of variables to be monitored was finalized, and sampling and database protocols were established (Table 3). Since inception, the program has required sites to provide data on atmospheric inputs, ecosystem condition, system response to atmospheric inputs, and stream outputs. Each site must also establish data collection techniques that can be accurately repeated, identify relevant questions or hypotheses, identify anticipated changes and where they are expected to occur, and develop an experimental design for detection of ecosystem change and understanding the mechanisms of change.

The quality assurance/quality control strategy established for ecosystem-level monitoring and study in remote sites, where few baseline data exist, remains critical as experimental manipulation in these legally-protected, undisturbed sites is not possible and data once lost are lost forever. Quality assurance and consistency of procedures were viewed as particularly important since study repetition would not normally be possible in these ecosystems. The following data quality objectives continue to serve to guide our overall and site designs for sample and data handling: (1) obtain data that are of consistent quality with known levels of accuracy and precision; (2) equip all monitoring sites with equivalent instrumentation and ensure uniform collection procedures; (3) use consistent formats in field and laboratory data reporting and in transferring data to computer files; (4) provide for maximum integration of field and laboratory data directly into computer formats to minimize manual data entry or re-entry; (5) maximize automated data handling techniques to ensure quick transfer of raw field and laboratory data into quality assurance analyses for early detection of procedural or analytical difficulties; and, (6) use existing collection and analyses protocols, such as from the National Atmospheric Deposition Program (NADP) and National Acid Precipitation Assessment Program (NAPAP), whenever possible, to maximize comparison possibilities.

The program emphasizes understanding the watershed hydrologic cycle and mass balance, and building an information base sufficient to test a number of hypotheses regarding biogeochemical change and ecosystem function. The following objectives, common among sites, guide research and monitoring activities: 1) generate timely scientific input to assist in developing mitigation strategies to address major threats to the ecological integrity of the public lands; 2) establish watershed response to stress and report on its significance to the managers of park/reserve resources; 3) develop watershed sites as part of a national and possibly international system of long-term background sites to establish a climatic, hydrological, ecological, and biogeochemical baseline against which national and global trends can be measured; 4) design and implement example procedures and protocols to identify, collect, organize, analyze, and synthesize selected watershed data and interpret the current status and trends; and, 5) establish baseline conditions for watershed processes against which change in the hydrologic cycle can be evaluated.

Cooperation

Inter-agency and inter-institutional cooperative efforts at both national and international levels solidify and build new relationships for achieving site specific research and expand capabilities of USGS watershed researchers. The current USGS research involves cooperation between the USGS-BRD, NPS, and a number of USGS programs [Water Energy and Biogeochemical Budgets (WEBB), Hydrologic Benchmark Network, and National Stream Quality Accounting Network (NASQAN) programs]; expands the number of representative preserved biome study sites; and provides continuing information to other regional studies such as wetlands, NAQUA, or assessment of changing conditions in "Priority Ecosystems." These sites are linked through interagency agreements and cooperative research with similar programs and sites managed by other bureaus, agencies, or routine discussions with personnel from institutions such as the Long-Term Ecological Research Program of the NSF, the ecosystem and watershed studies programs of the USFS (Hubbard Brook, Coweeta, and Fraser Experimental Forests), the U.S. Man and the Biosphere Program, and the biogeographic regional sites of the U.S. Global Climate Change Program, and will be linked with the USFS ecosystem studies initiative.

Program ties remain to NAPAP, a decade-long program for the 1980's, which has been re-authorized. Also, major government and international funding agencies are considering the development and continuation of programs to assess a broad range of impacts to the environment including aspects of both the chemical (acid precipitation and air pollution) and physical (temperature and precipitation). Programs proposed or ongoing include the EPA's Environmental Monitoring and Assessment Program (EMAP) and Temporally Integrated Monitoring of Ecosystems (TIME); the International Council of Scientific Unions' (ICSU's) International Geosphere Biosphere Program (IGBP), and the U.S. interagency Committee on Earth and Environmental Sciences (CEES) Global Climate Change Program; the USGS Hydrologic Benchmark Network and National Stream Quality Accounting Network; and, the global climate change programs of the USFS, BLM, NASA, and the interagency Fresh Water Initiative. An expanded program for U.S. parks or wilderness (wild) lands is important, owing to their long-term legally protected nature, likely sensitivity of many areas to environmental impacts, and existing data bases and site support that can be made available. The USGS Watershed Program budget cuts have curtailed international cooperative efforts and have greatly reduced national cooperative efforts (Figure 2).

CONCLUSIONS/THE FUTURE

Long-term watershed studies within the U.S. parks have greatly expanded our knowledge of the response of natural systems to stress, sources, and types of both wet and dry deposition, bedrock weathering rates and weathering mechanisms, soil characteristics and buffering mechanisms, terrestrial nutrient cycles, and alpine and sub-alpine surface water chemistry, biology, and hydrology. Seasonal variations in precipitation chemistry have also been evaluated as to their effect on small watershed ecosystems. Other investigations include quantification of the increase in atmospheric loading with elevation, how vegetation affects the quality and quantity of precipitation, the influence of soils on streamwater quality, the quantification of biogeochemical cycling of specific nutrients (e.g, carbon, nitrogen and sulfur) and their relationship to watershed processes, and snowpack quality. Meteorologic, microclimatic, and hydrologic data now available on USGS/NPS watersheds are used in conjunction with data from ecosystem process studies in the same watersheds to determine whether predicted climate-driven responses may occur.

After 17 years of integrated biogeochemical data collection and analyses from N.P. watersheds we are now able to draw a few management and policy conclusions, suggest a number of testable hypotheses and provide some resources management alternatives or ramifications. We began with an expectation a number of processes would occur in an analogous manner across ecosystems and we could assess the similarities by understanding the natural variability of ecosystems (watersheds) both temporally and spacially. Our analyses identified characteristic carbon (C), nitrogen (N), and sulfur (S) signatures for study sites, and provided knowledge about the functional aspects of biogeochemical processes in natural ecosystems. We generated scientific input to assist in developing mitigation strategies to address threats to the ecological integrity of the public lands, specifically protected lands such as the N.P.'s. Our better understanding of the structure and function of ecosystems, their ecotones, and their response to global change results from collection of long-term monitoring and biogeochemical cycling data. Specifically over the next 5 years we will apply our accumulated knowledge to seek to: 1) quantify long-term change in hydrologic, nutrient, and C budgets on a gradient of watershed ecosystem biota; 2) monitor long-term trends in soil N status; 3) examine spatial and temporal change in subsurface soil water chemistry and flow to quantify N export and response to change in soil temperature and moisture; 4) examine how changes in soil N availability alters forest floor and soil production of dissolved organic carbon (DOC) and dissolved organic nitrogen (DON); 5) quantify change in labile C and N compounds from root exudates, fine root production, and microbial biomass in response to soil temperature and N availability; 6) evaluate long-term trends in forest floor and soil microbial activity, soil microbial biomass and functional diversity, and provide biological parameters for measuring ecosystem stability and response to disturbance; 7) assess spatial and temporal patterns in decomposition rates as decomposition of plant litter is a key ecosystem process linking the below-ground microbial component with primary ecosystem production; 8) assess impact of changes in forest structure alone and in combination with environmental changes (atmospheric inputs, global climate) on the function of watersheds (biogeochemistry and nutrient retention); and, in this way we will continue to 9) provide management and policy recommendations concerning human impacts on Park watersheds.

General findings are also emerging. First, the watershed ecosystem-level data base provides the context for developing hypotheses on ecosystem structure and function. Second, many of the "index" biological and chemical species used to detect human-induced change have considerable annual natural variation. Separating anthropogenic from natural change in ecosystem structure and function requires detecting statistically significant trends against what can be very "noisy" baseline conditions. Third, ecosystem studies permit analysis of processes operating between and among biotic and abiotic components. There is increasing evidence that understanding the magnitude of variation within such processes can provide an earlier indication of environmental change and trends attributable to human-induced stress. Fourth, the watershed ecosystem concept permits assessment of the full magnitude of impact which can serve as a stronger basis for possible mitigation. Fifth, to be effective, studies at the watershed ecosystem level need to be truly inter-disciplinary and integrated in design.

Watershed ecosystem research results are also having direct input to government policy development regarding acid precipitation, air quality protection, global change, freshwater research and watershed ecosystem management. The USGS program also directly supports Park and wilderness managers in assessing resource integrity and in responding to resource threats. Park watershed research sites now comprise important long-term reference points and provide a unique opportunity against which to measure and assess ecological health, test hypotheses relative to human contributions to long-term ecological change within protected watersheds, and support a holistic concept of watershed management.

Important background information has been observed on the nature of ecological change in representative relatively undisturbed watersheds containing mature or "naturally" successional protected ecosystems. These nationally and internationally significant sites have been minimally impacted by direct anthropogenic change (i.e. mining or logging). Indirect changes occurring in these study ecosystems are often related to global climate change, long-range transport of air pollutants, or disruption of natural biodiversity. The program in addressing these issues has provided regular information to land managers regarding the nature and health of watersheds and of the natural resources they contain.

Figure 1. Map of Watershed Research sites.

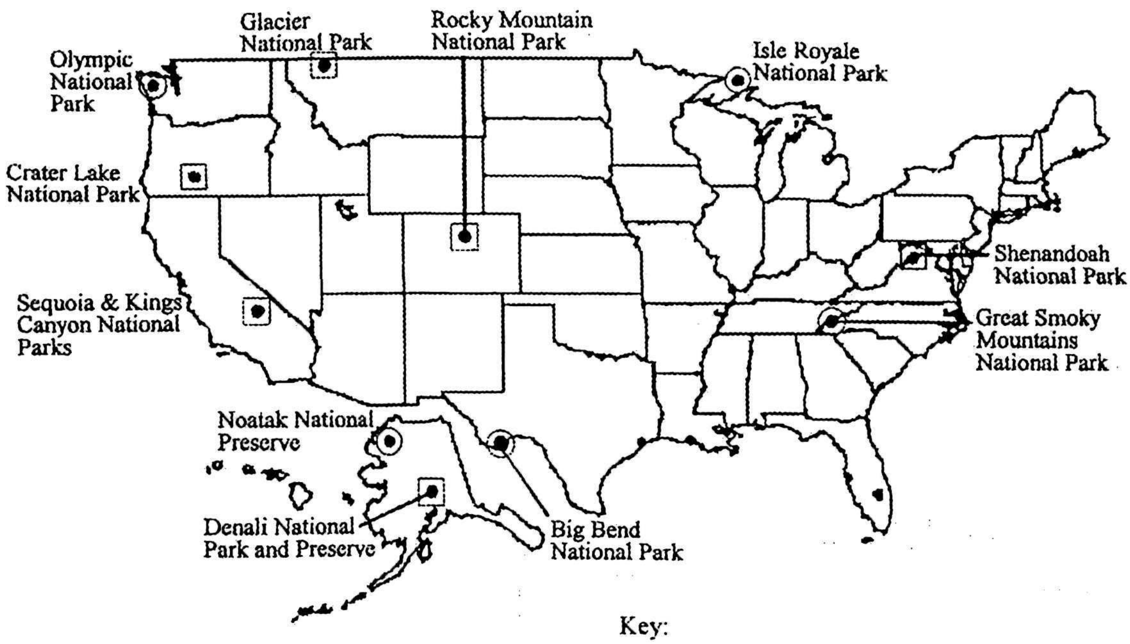

Figure 2. Operational budget for Watershed Research, 1982-2000.

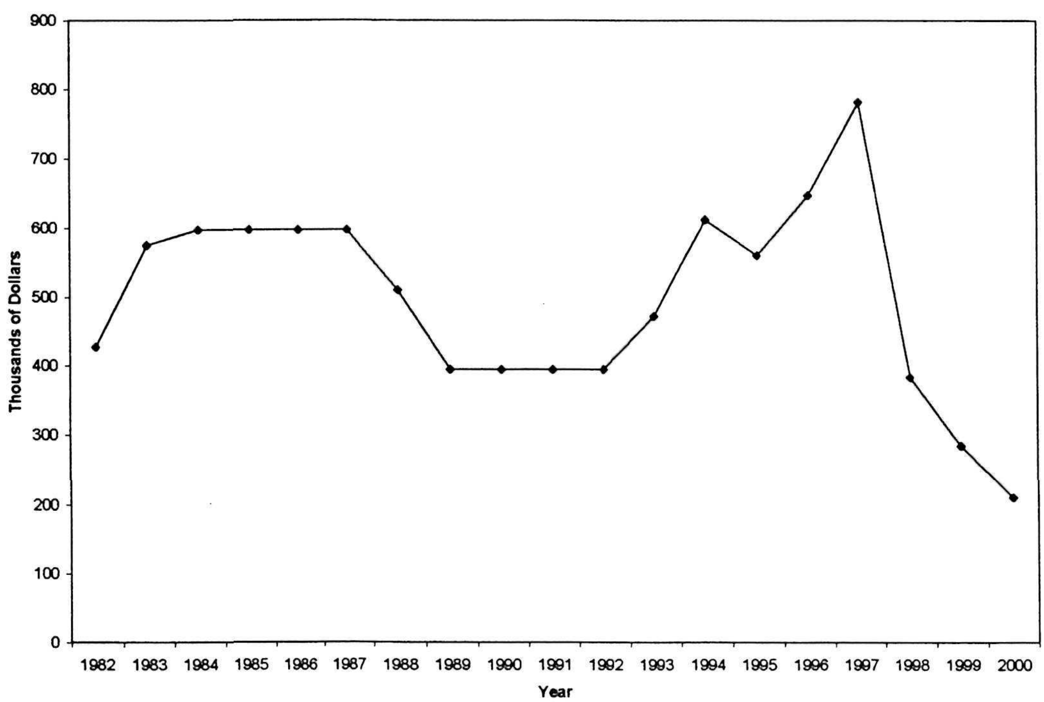

Table 1. Research parks for the USGS[1] Small Watersheds Program (See Figure 1 for site locations).

SITE	P.I.s	Active Agencies and Institutions
1. Noatak Preserve, AK	D. Binkley R. Stottlemyer	NPS[2], USGS, Colorado State University, University of Alaska
2. Denali National Park, AK	D. Binkley R. Stottlemyer	NPS, USGS, Colorado State University, University of Alaska
3. Olympic National Park, WA	R. Edmonds	NPS, University of Washington
4. Crater Lake National Park, OR	G. Larson	NPS, Oregon State University
5. Sequoia/Kings Canyon National Park, CA	D. Graber	NPS, USGS, University of California, California Air Resources Board
6. Glacier National Park, MT	D. Fagre	NPS, University of Montana
7. Rocky Mountain National Park, CO	J. Baron	NPS, USGS, Colorado State University
8. Big Bend National Park, TX	J. Zak K. Urbancyzk	NPS, Texas Tech University, Sul Ross State University
9. Great Smoky Mountains National Park, TN/NC	H. Van Miegroet	NPS, Oak Ridge Labs, Utah State University
10. Shenandoah National Park, VA	R. Webb T. Blount	NPS, University of Virginia
11. Isle Royale National Park, MI	R. Stottlemyer	NPS, USGS, Michigan Technological University

[1]United States Geological Survey
[2]National Park Service

Table 2. Comparative U.S. National Park Watershed Research Sites.

Watershed Site Name	Lat. Long. (N) (W)	Elev. m	Water-shed & Park Size, ha	Area Type	Temp. Jan. & July °C	Humid, %	Precip. cm	Wind m/s	Norm. Ann. Pan Evap.	T. Sol. Radtn. kcal/ cm2/yr	Frost Free Period da	Soils	Geology	Vegetation
Noland Divide, Great Smoky Mountains NP, TN & NC	35 43' 83 20'	256- 2025	17.4 & 207,500	humid eastern forest	4 & 24	70	150	3.5	114	125	180	mixed mt. complexes, podzols	sandstone of quartz & potassic feldspar	SE spruce-fir, Appalachian oak forest, N. hardwood
Pine Canyon, Big Bend NP, TX	29 15' 103 15'	540- 2350	7,800 & 286,600	Pon. for. desert grass. ripar.	11 & 24	53	15- 38	3.5- 4.4	216	173	245	floodplain silt, gravelly desert, mountain humus	volc. bedrock, Quat. alluv., intr. igneous, limestone	Pond. pine, pinyon, oak, fir, juniper, Sotol grassland, bush, desert scrub
Crater Lake, Crater Lake NP, OR	42 56' 122 07'	1800- 2500	6,700 & 74,151	mar. mt. ocean for.- tundra	-1 & 18	40-60	168	7.5- 8.0			130	soil devel. from volc. mat., bacite, andesite, basalt, talus	igneous, collapsed volc. 6800 yrs ago	mt. hemlock, subalpine & noble fir, pine, Eng. spruce
Rock Creek, Denali NP & Preserve, AK	63 44' 149 00'	625- 1737	770 & 2.4 mill.	mt. con. for. taiga tund.	-21 & 15	70	41	5.6- 8.0	19	82	65	permafrost, dry tundra & moss mat., glacier rubble	metam. Paleo. & Meso. volc. & sedim. rock, uplift, granite	tundra sp., moss, spruce, birch, Populus sp., willow, sedge, cottongrass
Fraser Exp. Forest, CO: Deadhorse Cr. St. Louis Cr. Fool Creek Lexen Creek	39 54' 105 53'	2800- 3800	9,328 278 827 297 124	alpine-subalp. for.- mead.	-11 & 13	60	74	2.6- 3.5	127	160	<20	gravel. sandy loam, alluv., weath. amorph. Si & carbonates	gneiss, schist, sedimentary sandstone	aspen, willow, lodgepole pine, Eng. spruce, subalpine fir
Lake McDonald, Glacier NP, MT	51 45' 117 35'	972- 3185	15,000 & 410,000	subalp.- alp. for. -mead. steppe	-6 & 18	41- 70	122	2.6- 3.5	102	125	60	soil devel. from volc., argillite, limestone & dolomite	Precam. sedim. Cretaceous intrusive & extr. ign. & metam.	Pond. & lodgepole pine, w. hemlock, w. redcedar, Douglas-fir
Calumet, Upper Peninsula, MI	47 48' 88 15'	190- 375	175 & 215,740	Grt. Lks. spruce- fir for.	-9 & 16	75	81	5.3- 6.2	89	121	141	alkaline glacial till & old beach deposits	Precam. meta. Portage Lake Volc., basalt & andesite	sugar maple, white birch
Legion Lake, Pictured Rocks National Lakeshore, MI	47 48' 88 15'	72 & 277	215,740	Grt. Lks. spruce- fir for. lake	-9 & 16	75	81	5.3- 6.2	89	121	141	acidic loamy sand, glacial outwash sand	Cambrian & Ordovician sandstone	sugar maple, yellow birch, beech, pine, hemlock
Isle Royale NP, MI: Sumner Lake Wallace Lake	47 48' 88 15'	184- 425	215,740 175 150	Grt. Lks. spruce- fir for. lake	-9 & 16	75	81	5.3- 6.2	89	121	141	reworked post-glacial beachline & sand deposits	metam. ophitic flood basalts, alk. glac. till, limestone	aspen, white birch, white spruce

Table 2. (Cont.) U.S. National Park Watershed Research Sites.

Watershed Site Name	Lat. Long. N & W	Elev. m	Water-shed & Park Size, ha	Area Type	Temp. Jan. & July C	Humid. %	Precip. cm	Wind m/s	Norm. Ann. Pan Evap.	T. Sol. Radtn. kcal/ cm2/yr	Frost Free Period da	Soils	Geology	Vegetation
Asik, Noatak National Arctic Range, AK	67 58' 162 15'	0-1679	360 & 3.0 mill.	tundra, taiga-tun. subarc. mts.	-22 & 11	75	41	5.6-7.5	nd	65	<60	basalt & volc. alluvial & mar. sediment, volc. ash & loess	Paleozoic sedimentary & metamorphic	tussock & shrub, cottongrass, alder, birch, spruce, willow, Populus sp.
West Twin Creek, Olympic NP, WA	47 54' 123 00'	240-800	58 & 362,850	temper. old-growth rain for.	4 & 16	>80	350	2.6	76	110	180	soils devel. from uplifted marine deposits & sandstone	Late-Cret. & Ceno. sedim. & igneous, Pleist. glac. gran. till	fir, hemlock, redcedar, spruce, oxalis, fern & moss sp.
Hoh Lake, Olympic NP, WA	47 54' 123 00'	1250-1525	125 & 362,850	temper. old-growth rain for.	-2.5 & 15	>80	350-500	2.6	76	110	180	soils devel. from uplifted marine deposits & sandstone	Late-Cret. & Ceno. sedim. & igneous, Pleist. glac. gran. till	mt. hemlock, Pac. silver fir, AK yellow cedar, rhododendron sp.
Loch Vale, Rocky Mountain NP, CO	40 20' 105 40'	2300-4010	660 & 106,160	talus outcrop subalp.-alp. for.	-13 & 9	60	102	11.7	127	132	47	soil devel. on moraine & talus or bog & alluvial orig.	Precambrian granite, gneiss, schist	low herb., dwarf-shrubs, lichens, fir, spruce, pine, sedges
Emerald Lake, Sequoia/Kings Canyon NP, CA	36 52' 118 39'	3000	136 & 342,754	sub-alpine cirque	-1 & 29	20-30	70-300	3.5-4.4	330	170	150	soil devel. from fine granitic gravel & sand	Miocene & Plio. uplift of Sierra Nev. batholith, glacial carving	pine, fir, mt. hemlock
Elk Creek, Sequoia/Kings Canyon NP, CA	36 52' 118 39'	750	10.0 & 342,754	chap-arral foothill	-1 & 29	20-30	66	3.5-4.4	330	170	150	soil devel. from fine granitic gravel & sand	Miocene & Plio. uplift of Sierra Nev. batholith, glacial carving	chamise syst. with short-lived shrubs & herb. cover
Log Meadow, Sequoia/Kings Canyon NP, CA	36 52' 118 39'	2100	62.9 & 342,754	montane mixed conif. forest	-1 & 29	20-30	100	3.5-4.4	330	170	150	soil devel. from fine granitic gravel & sand	Miocene & Plio. uplift of Sierra Nev. batholith, glacial carving	white fir, Pond. & sugar pine, giant sequoia, incense-cedar
Shenandoah NP, VA: Deep Run Wht. Oak Run	38 30' 78 30'	162-1220	79,510 306 515	hot cont. mts. for.-alp. mead.	3 & 18	66	100	6.4-7.0		118	175-199	soil devel. from basalt, granite, metam. shale & sandstone	ancient granite & metamorph. volcanic formations	oak, hickory, locust, pine, ash, basswood, chestnut

Table 3. Core Data Collection Elements for NPS Watershed Studies

Field To Be Measured	Data Collected	Frequency
Precipitation (chemistry)	Deposition chemistry	Weekly
	Wet	Weekly
	Snow	Monthly
	Dry	
	Bulk collections	Weekly
	Trace metals	
Climate	Windspeed and direction, humidity (or equivalent), temperature, incident solar radiation, precipitation amount	Continuous on site
Vegetation	Permanent plots	Resurvey 1-5 years
Soils	Plots in a manner consistent with vegetation analysis	Remeasure 5 years
Hydrology and aquatic studies	Temperature	Weekly (for 1 year)
	Chemistry (major cations and anions)	Seasonal/event
	Stream discharge	Continuous
	Lake stage (inflow-outflow measurements as needed for mass balance)	Continuous
	Ground water mass balance (inputs/outputs)	One time-seasonal
	Ground water (chemistry characterization)	5 years
	Characterize aquatic system and establish baseline of indicator species	5 years
Paleolimnology	Sediment cores (diatom and heavy metals analysis)	One time
	Pollen analysis (if poss.)	One time

After Herrmann and Stottlemyer 1991.

1999 Site Highlights

PINE CANYON WATERSHED PROGRAM: UNDERSTANDING THE EFFECTS OF CLIMATE CHANGE ON THE STRUCTURE AND FUNCTIONING OF ARID ECOSYSTEMS AT BIG BEND NATIONAL PARK

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OVERVIEW

The Pine Canyon Watershed Program at Big Bend National Park represents the only long-term monitoring and watershed program in the Chihuahuan Desert along the U.S.-Mexican border examining both abiotic and biotic contributions to watershed dynamics, and has an extensive gradient component. For the past four years we have been collecting and monitoring a suite of biological, environmental, geological and hydrological parameters to evaluate the impacts of large-scale climate and anthropogenic effects on soil parameters, microbial processes and biodiversity, and hydrologic components of this important region. Recent particulate matter monitoring efforts by the Texas Natural Resources Conservation Commission at Big Bend National Park emphasizes the growing significance of the impact of air pollution on the National Park. The soil nitrogen [N, as extractable nitrate (NO_3^-) and ammonium (NH_4^+)] and ground water chemistry data collected along the Pine Canyon Watershed provides the only assessment available to interpret the impacts of anthropogenic inputs to these Chihuahuan Desert ecosystems.

While much of the publicity over loss of global biodiversity and efforts to enumerate biodiversity has focused on tropical systems, evidence continues to build emphasizing the need to expand efforts into arid and semi-arid regions. Arid and semi-arid lands currently occupy about 40% of the planet's surface. Our work at Big Bend provides the venue to develop an understanding of the landscape-level dimensions of microbial diversity within an arid land context while evaluating potential impacts of human impacts and climate change effects on the critical links between nutrient recycling and plant growth.

The Pine Canyon Watershed Program was initiated during the summer of 1995 and is the newest addition to the Watershed Ecosystem Studies of National Parks and Equivalent Reserves. The Pine Canyon Watershed covers approximately 7,800 ha and extends about 19 km in an easterly direction from the central Chisos Mountains. Permanent monitoring sites have been established in the five vegetation zones along the watershed: 1) Lost Mine - Mexican pinyon pine (*Pinus cembroides*)/live oak (*Quercus* spp.) high elevation forests (2103 m), 2) closed-canopy oak (*Quercus emoryi, Q. gravesii*)-juniper (*Juniperus coahuilensis*) association in upper Pine Canyon (1829 m), 3) Sotol (*Dasylirion leiophyllum*)-grassland (1533 m), 4) Creosotebush (*Larrea tridentata*) association at Chilicotal Springs (904 m) and Rice Tanks (956 m), and 5) Lowland Chihuahuan Desert scrub at the Glenn Springs location (791 m). We have added one additional precipitation site, referred to as the Pour-off (1841 m) site in a location in the upper part of Pine Canyon between the Lost Mine and Sotol-grassland primary meteorological (met) stations.

Specific Objectives for 1999

1. Continue collecting weather data from the three primary and three secondary locations along the watershed.
2. Continue monitoring soil and litter temperatures from five locations along the watershed.

3. Obtain subsurface and surface water chemistry data from Chilicotal Springs, Glenn Springs, and Reynold's Well.
4. Continue developing a mass flow model of ground water movement for the Pine Canyon Watershed.
5. Continue evaluatinglong-term patterns in microbial biomass and bacterial functional diversity along the watershed in response to soil moisture, soil temperatures, and soil N dynamics.
6. Continue discerning long-term patterns in soil N dynamics.
7. Continue assessing decomposition dynamics and fungal functional diversity associated with plant litter along the watershed.
8. Initiate surveying of fungal functional diversity and species occurrences of soil fungi along the watershed.
9. Begin collecting continuous soil moisture measurements within the five vegetation zones along the watershed.

GENERAL HIGHLIGHTS

Meteorology

We continue to monitor atmospheric parameters at three primary met stations along the Pine Canyon Watershed at Big Bend National Park: Lost Mine, Sotol-grassland, and Chilicotal Springs. Wind speed and direction, temperature, relative humidity, solar radiation, barometric pressure, and precipitation are recorded at each of these sites on an hourly basis. Precipitation is collected in NADP-style samplers at both the Lost Mine and Chilicotal stations. The two secondary sites, Rice Tanks and Glenn Springs, were added in 1997 to measure precipitation as well as at the Pour-off site.

Rainfall. Rainfall totals for 1999 through October are: Lost Mine - 392 mm, Pour-off - NA, Sotol-grassland - 157 mm, Rice Tanks - 213 mm, Chilicotal Springs - 820 mm, and Glenn Springs - 199 mm. The highest total rainfall amounts for 1997 through 1999 have occurred at the Chilicotal site. The largest daily and monthly rainfall along the watershed has also occurred at this site. For February 1999, 640 mm of rainfall was recorded at the Chilicotal site compared with 1.7 mm at Glenn Springs, 0.3 mm at Rice Tanks, 0.3 mm at Sotol-grasslands, and 1.3 mm at the Lost Mine location.

Air Temperature (1996-1998). Air temperature at 1 meter above the ground has been recorded at five sites since 1996. The highest monthly average maximum air temperatures occurred at the Rice Tanks and Glenn Springs locations. These sites can approach a monthly average of 36° C. The least variation in average maximum air temperatures for 1996 to 1998 was observed for the lowest site on the watershed, Glenn Springs. The lowest maximum monthly average air temperature is found at the Lost Mine site, the top of the watershed. The lowest monthly average air temperature occurs at the Lost Mine and Sotol-grassland sites.

Soil Temperatures (1996-1998). Maximum monthly average soil temperatures at 15 cm were on average 2° C higher for all locations in 1998 compared with 1997. The highest soil temperatures for 1998 were recorded at the Rice Tanks (28° C) and Glenn Springs (28° C) locations. Sotol-grasslands (23° C) was intermediate between the forested sites (Closed Canopy, 17° C) and Lost Mine (15° C). The Closed Canopy Forest in the upper portion of Pine Canyon had the least difference between average monthly maximum soil temperatures and average monthly minimum temperatures (1.1° C), while the largest difference in monthly maximum and minimum temperatures (6° C) was detected at the Rice Tanks location.

Ground and Surface Water

We have an hourly record of basic groundwater chemistry and level at the Reynold's Well site (1573 m) dating back to October, 1996. Discharge at Chilicotal Springs (853 m) has been measured since the summer of 1997. Surface and groundwater grab samples are collected at monthly intervals from Reynold's Well, Chilicotal Springs, and Glenn Springs.

The continuous water level data recorded at Reynold's Well since 1996 reveal a repeating pattern of water table recession during periods of no precipitation, followed by rapid rises in response to local precipitation in the Chisos Mountains. Significant precipitation in the summer of 1999 recharged the system to the highest water levels yet seen during this study (a water table of 1558 m elevation). Since then the water table has declined significantly to a level lower than that recorded at the same time of year for the previous two years.

Water Chemistry

This section describes the general features of the water chemistry for precipitation collected at the Chilicotal Springs met station, surface water collected at the Pour-off location, groundwater collected at Reynold's Well, and spring water samples from Chilicotal and Glenn Springs. Our aim is to describe the basic chemical signatures observed at each site. This knowledge is necessary to evaluate temporal variations, possibly the result of anthropogenic effects. A general observation is the absolute concentrations of the waters increases in the same order as the sites are listed above. As expected, the precipitation values are the most dilute, followed by the water, sampled at the Pine Canyon Pour-off (elevation 1841 m). These samples were taken while the creek in upper Pine Canyon was flowing, indicating recent precipitation. The Reynold's Well data represent groundwater in coarse alluvium immediately below the Pour-off (elevation 1573 m). Chilicotal Springs is located in the lower end of the Pine Canyon watershed while the Glenn Springs site is found 6.4 km south of the Chilicotal location. There exists an inverse relationship between total dissolved solids in the groundwater and elevation.

The basic water chemistry variations can best be explained by a model of increasing degrees of inorganic water/rock chemical reaction (mineral weathering) with the net result being an increase in total dissolved solids with decreasing elevation. Superimposed upon this is the possible influence of variable atmospheric input, cation exchange reactions, and evaporation-induced concentration/precipitation. With this general model in mind, we can initially rank the sites with regard to their absolute concentrations. This can be done in a variety of ways and we choose to use chloride (Cl^-) concentrations as an indicator of chemical "maturity". Average Cl^- values for each group include 0.3 mg/L for the precipitation at Chilicotal, 3.2 mg/L for the Pour-off samples, 3.0 mg/L for Reynold's Well, 11 mg/L for Chilicotal Springs, and 14 mg/L for Glenn Springs. In this discussion, we also include a comparison to data from springs in the nearby Big Bend Ranch State Park (BBRSP). The BBRSP is geologically similar to the Upper Pine Canyon area (the aquifers are located in Tertiary volcanic rock), but it supports a small herd of Longhorn cattle, and can be used to evaluate the effects of livestock on groundwater chemistry.

Utilizing plots of major cation/anions vs. Cl^- concentrations, we are able to discriminate between the different sites. At the scale range necessary to include all data, precipitation plots near the origin, with the Reynold's Well and Pour-off data shifted to slightly higher concentrations of most elements. Water at these two sites has clearly had a shorter residence time in the aquifer system than the water from the lower elevation sites. Beyond this, there tends to be a wide scatter that requires an evaluation of the chemical controls on the water chemistry in the other areas.

For Chilicotal and Glenn Springs, calcium (Ca^{2+}) and magnesium (Mg^{2+}) both increase in a similar fashion with Cl^-. The data tend to plot in the general region defined by the mature springs in the BBRSP. However, the behavior of sodium (Na^+) with respect to Cl^- distinctly separates Chilicotal and Glenn Springs from those in the BBRSP. Sodium values are higher for both. The potassium (K^+) values for Chilicotal are equal to or lower than the Reynold's Well and Pour-off values while the K^+ for the Glenn Springs water plots in the higher (expected) region defined by the BBRSP.

This chemical variation can be related primarily to inorganic water/rock interactions. As describe above, the waters at the Pour-off and Reynold's Well are within an eroded caldera structure. The intermittent Pour-off is fed by a fractured rhyolitic igneous aquifer, while Reynold's Well is located in alluvium derived of the same material. The waters at Chilicotal and Glenn Springs have geologic influences that are more diverse than at the other sites. At Chilicotal, the water emerges from a contact between Quaternary Alluvium and a clay/silt sedimentary unit (Javelina Formation). At Glenn Springs, the water emerges immediately below an igneous intrusion, at a contact with another clay/silt sedimentary unit (Chisos Formation). The waters at the BBRSP are from shallow igneous aquifers strictly located in silicic igneous lava flows and breccias, similar to the Pour-off and Reynold's Well sites in Pine Canyon.

A comparison of Na^+/Ca^{2+} proves effective for describing the chemical differences in the waters that can best be explained by water/rock interaction. The Pour-off, Reynold's Well, and BBRSP samples follow a similar trend of constant Na^+/Cl^- with increasing Na^+, a trend we can refer to as the "igneous" trend. The basic chemical variation along this trend is from weathering of volcanic rock and/or evaporative concentration. Diverging from this trend are the Chilicotal and Glenn Springs data—each reaching higher Na^+/Cl^- values. The main difference is geologic—these samples are reacting with an older sedimentary aquifer with the potential for further (and different) rock weathering and the possibility of cation exchange in clay minerals.

Nitrogen data for the Pine Canyon area revealed the groundwater generally has NH_4^+ and NO_3^- concentrations at or below atmospheric input. Precipitation averages are 0.85 mg/L NO_3^- and 0.24 mg/L NH_4^+. Averages for water at the Pour-off are lower than those in Pine Canyon, possibly indicating a biological control on the N loss from the soil. The Reynold's Well data show a consistent enrichment in NO_3^- (1.85 mg/L average), but are still less enriched in NH_4^+ (0.14 mg/L) than the precipitation. The Chilicotal and Glenn Springs values are also less than precipitation (all below detection), excluding one anomalous value at Chilicotal Springs (5.97 mg/L).

Geology

Our ongoing geologic mapping of the Pine Canyon area supports our previous assessment of the basic geologic controls on water flow in the area. The Pine Canyon drainage begins in a semicircular caldera structure. The upper end of the drainage area (Lost Mine area) is located in caldera fill facies of the South Rim Formation. Lithologies include rhyolite and silicic welded pyroclastic material. This fractured bedrock aquifer system supports intermittent surface flow in upper Pine Canyon only for brief periods after precipitation events. When flowing, water in upper Pine Canyon plunges over the Pour-off below which the water immediately enters a coarse alluvial aquifer. This is the primary aquifer of the area. We have been able to document the dynamic nature of this aquifer at our Reynold's Well site by recording the water level changes directly associated with recent precipitation. This alluvial aquifer is composed of fragments of the same caldera fill material comprising the Lost Mine area. Therefore, any rock/water chemical controls will be similar.

Pine Canyon and GIS

Our GIS database for the Pine Canyon area continues to grow. We have all sites located as a single theme in ArcView. We also have the geologic data from Maxwell and others (1967, the only comprehensive geologic map Big Bend National Park) as another theme. Additionally, we have hand-digitized the geologic map of Ogley (1978) using 7.5 minute digital raster graphics (DRG) as a base, and have created another theme including our own interpretation of the geology (also using the DRG base). For visualization purposes, we have created three-dimensional (3D) digital models using USGS digital elevation model (DEM) data. The next step is to create the 3D elevation models for all geologic layers in the immediate Pine Canyon area, for use in MODFLOW (3D groundwater modeling software). This is accomplished by extracting the surface topography from existing DEM data, then creating our own subsurface layers based upon our growing geologic knowledge of the caldera structure and the alluvial package that progrades away from the high Chisos. This model will include the alluvium, the caldera fill material, the precaldera lithologies (Chisos, Canoe, Javelina, and Aguja Formations), and intrusions.

Soil and Microbial Parameters

Microbial Biomass. The Closed Canopy Oak Forest in the upper portion of Pine Canyon continues to have the highest microbial biomass of any location along the watershed. In addition, this site has the largest variation in microbial biomass compared with the other four locations. The next highest site is Lost Mine, followed by Sotol-grassland, Glenn Springs (Chihuahuan Desert scrub) and Rice Tanks. There was a 50% decline in microbial biomass between August 1998 and January 1999 at the Closed Canopy Oak Forest site due to drought. In the three previous years, microbial biomass at the Oak Forest site has been the highest in January, but not at the start of 1999. There have been no significant changes in microbial biomass in either January or August for Lost Mine and Sotol-grassland since the January 1997 collection. Microbial biomass in soil from Rice Tanks and Glenn Springs has declined significantly since August 1997. The decline at these sites can be attributed to the drought impacting the region since the early part of 1995 with drought severity increasing during 1997 through 1999.

Bacterial Functional Diversity. Bacterial functional diversity, defined as the total activity (optical density) and substrate richness [number of carbon (C) compounds used out of 95 in the BIOLOG microtiter plate-incubation system], has consistently been the highest for the Closed Canopy Oak Forest in upper Pine Canyon. Bacterial functional diversity has been steadily increasing at this location since January 1997 with the highest recorded value detected in August 1999. The drought appears to have initially reduced bacterial functional diversity as measured by either total activity or substrate richness. However, this microbial parameter has continued to increase at the location from January 1997 onward. These results are in contrast to the other forested location, Lost Mine, which has shown a decline in bacterial functional diversity since January 1997. Similarly, the Sotol-grassland site also experienced an initial decline in functional diversity at the beginning of the drought, but has recovered to levels detected during January 1996, the start of the study. Since January 1998, there have been no significant differences in microbial functional diversity between the grassland and high elevation forested locations. Since the onset of the drought, the low desert sites at Rice Tanks and Glenn Springs have declined in functional diversity to the point where bacterial functional diversity is almost non-existent in soils from these locations.

Fungal Functional Diversity and Decomposition Dynamics. Fungal functional diversity is being assessed within each of the five vegetation zones along the Pine Canyon Watershed by following fungal development on decomposing litter of *Agave lechuguilla* and by assessing fungi associated with soil organic matter collected within the five vegetation zones. As with bacterial functional diversity, fungal functional diversity is expressed as the total activity (total optical density) associated with 95 different C compounds contained on a microtiter plates (FungiLog), and substrate richness (number of compounds out of 95) supporting fungal growth.

Two years of evaluation of fungal functional diversity associated with decomposing leaves of *A. lechuguilla* has been completed. Tagged and previously weighed material has been collected every six months since initial placement in June 1997. At each collection, fungal functional diversity, fungal species occurrences, mass loss, N concentration, C chemistry, and respiratory activity have been assessed.

During the first six months after placement, the initial loss in mass is between 12 and 18 %. The highest initial mass loss occurred in the Closed Canopy Oak Forest. Mass loss did not differ significantly within any location for the next year (December 1997 to December 1998). The lack of decomposition was in response to drought conditions. Between December 1998 and June 1999, the material in the Oak Forest lost an additional 15% mass, while material at the other locations lost only 5%. There were no significant differences in total mass lost between the Lost Mine, Sotol-grassland, Rice Tanks, and Glenn Springs locations. The lack of rainfall and low litter layer at these locations during 1998 and early part of 1999 were not conducive for extensive decomposition to occur.

Total activity (optical density from the Fungilog plates) was highest one year after field placement of material and declined during year two at the forest locations (Oak Forest and Lost Mine sites). Total activity for material placed at the Sotol-grassland site declined from December 1997 through December 1998. There has been an increase in total activity between December 1998 and June 1999. The pattern reflects the impact of the drought on fungal activity at this location. Total activity for material placed at the Rice Tanks site increased initially and has plateaued for the remainder of the decomposition period. At the Glenn Springs site, total activity declined significantly between December 1998 and June 1999. After two years of decomposition, functional diversity of fungi as measured by total activity and substrate richness is not significantly different among locations except for the low desert site. It is unclear why fungal functional diversity would be substantially lower for the Glenn Springs (Chihuahuan Desert Scrub) location as compared to the Rice Tanks site (Creosotebush). These data suggest other abiotic factors may be affecting fungal functional diversity at the Glenn Springs location that are not present at the other sites. We are examining NO_3^- concentration effects at the Glenn Springs location as one factor with a possible negative impact on functional diversity. This location does contain the highest NO_3^- values of any site along the watershed. The highest NO_3^- amounts of any location in the watershed during the last four years were observed in August 1998 samples (20 mg/kg soil) at Glenn Springs.

Patterns of fungal functional diversity appear to be significantly impacted also by differences in moisture among the locations. As decomposition proceeds, fungal functional diversity of the *Agave lechugilla* litter declined within each of the five vegetation zones, though not at the same rate. The Oak Forest site with the highest decomposition exhibited the decline first. The data suggest rates of decomposition are related to the functional diversity of fungal species associated with the particular material. Moisture differences among the five vegetation zones along the Pine Canyon Watershed account in part for observed patterns in decomposition and fungal functional diversity. We are continuing to analyze the C chemistry and N concentrations for the litter from the various collection periods at this time.

Soil fungal assemblages from the high elevation oak-pine forest at the Lost Mine site, the Closed Canopy Oak Forest in the upper portion of Pine Canyon, and the Sotol-grasslands exhibited the highest fungal functional diversity (total activity and substrate richness) for samples collected in August 1999. There was no significant differences in fungal functional diversity among these locations. Likewise, there was no significant differences in fungal functional diversity between the low desert locations along the watershed. One aspect of functional diversity, substrate richness, was found to be negatively correlated with average annual low temperature. High diurnal variation combined with high summer soil temperatures, and low moisture availability limits the functional diversity of fungi in the low elevation plant assemblages along the watershed.

Soil Nitrogen Dynamics. The highest average soil NO_3^- level for 1999 (14 mg/kg of soil) was detected at the Sotol-grassland location in August 1999. Previously, the highest NO_3^- levels were observed at the Glenn Springs site. As was observed during 1998, across all sites NO_3^- levels increased from January to August. There was a substantial decrease in extractable NO_3^- in soils from all locations between August 1998 and January 1999. The decrease could be attributed to plant uptake during this period as plants responded to the late summer rains in 1998 that occurred after a lengthy drought period. The lowest levels of NO_3^- continue to be measured at the Lost Mine site.

Soil NH_4^+ levels continue to be highest for the Closed Canopy Oak Forest (17 mg/kg soil) in upper Pine Canyon. There has been, however, a steady decline in soil NH_4^+ levels during 1999 at this site from high values measured in August 1998. The Sotol-grassland location had the second highest level of NH_4^+

(13 mg/kg soil), which has been increasing at the site since January 1998. The increase in NH_4^+ levels in the grassland may account for the higher levels of NO_3^- detected at this site in August 1999 as the NH_4^+ undergoes nitrification to NO_3^-. The lowest level of NH_4^+ was measured in soils from the Glenn Springs location (2.6 mg/kg soil).

pH. The highest average pH values along the watershed are found at the Glenn Springs and Rice Tanks locations (8.5). There has been no significant change in soil pH at these sites since August 1996. Soil pH at the remaining sites does show long-term changes since measurements were initiated in January 1996. At the Closed Canopy Oak Forest site, soil pH has gradually increased from 7.27 in January 1997 to 7.76 in August 1999. Beginning in January 1998, a seasonal change is evident in samples from Lost Mine and Sotol-grassland. Soil pH tends to be lower for August samples and higher in January samples at the Lost Mine and Sotol-grassland locations. Soils are becoming more acidic at these two locations since initial measurements were made in January 1996. The lowest average soil pH value along the watershed (6.08) is found at the Sotol-grassland site. The high level of NO_3^- detected in this site's over the last two years may be contributing to the decline in soil pH in the grassland.

Soil Organic Matter. Percentage soil C estimates (loss on ignition) have varied little at the Glenn Springs (4.2% in Jan. and 5.25% in Aug.), Rice Tanks (2.2% in Jan. and 3.0% in Aug.), and Sotol-grasslands (6.5% in Jan. and 7.5% in Aug.) during 1999. These values were also very similar to measurements made during 1996 and 1997. In contrast, there have been significant yearly differences in soil organic C in the forested locations, which have substantially higher amounts of soil organic C than the grassland and low desert locations. The highest concentrations of soil organic C occur in the Closed Canopy Oak Forest site in upper Pine Canyon. The highest level of soil organic C to date was measured in August 1998 (24.4%) from the Oak Forest soils. Soil organic C declined in the Oak Forest from August 1998 to January 1999 (15.8%) and subsequently increased between January and August 1999 (20.9%). The organic C levels from the Lost Mine site were 12.3% in January and 12% in August. Seasonal changes in soil organic C levels are the result of differences in decomposition rates and loss of CO_2 from microbial activities and rates of inputs from primary production. The steady state of soil organic C in the grassland and low desert sites is indicative of systems unresponsive to drought conditions.

Soil Moisture. Four equitensiometer probes, (EQ2 manufactured by Delta-T Devices) were installed at the Lost Mine, Sotol-grasslands, Rice Tanks, and Glenn Springs locations in October, 1999 at 10 cm soil depth. The probes measure soil matric potential every half-hour and the data are stored on Campbell XR10 data loggers at each location. Since installation in October the sites have received no rainfall. Current soil matric potential is between -3 and -5 MPa.

<u>Microbial and Soil Parameter Synthesis</u>

Canonical Correspondence Analysis (CCA) is an ordination technique summarizing the variation in multiple response variables (e.g., bacterial functional diversity) in a few dimensions (i.e., canonical axes) while simultaneously assessing the relationships of the response variables to environmental parameters. We have undertaken a preliminary analysis of bacterial functional diversity from the Pine Canyon Watershed at Big Bend using CCA to evaluate the utility of this approach to examine the relationships among microbial functional diversity and soil and climatological parameters. Not unexpectedly, our initial analysis of bacterial functional diversity along the watershed indicated all soil parameters (i.e., NO_3^-, NH_4^+, pH, soil moisture and soil organic C) account for some part of the variation in functional diversity. However, certain parameters account for more of the variation than others. In particular, bacterial functional diversity in the Closed Canopy-Oak Forest is positively associated with all measured soil parameters except soil NO_3^- levels. At the low elevation Chihuahuan Desert Scrub site, Glenn Springs, there was a positive relationship between bacterial functional diversity and NO_3^- only. All other parameters were negatively associated with bacterial functional diversity. At the Lost Mine and Sotol-grassland sites, no one parameter accounted for a larger proportion of the variation than the others, while at the Rice Tanks site, which is a creosotebush system, bacterial functional diversity was more positively associated with soil NO_3^- levels and pH. These data are preliminary, but indicate the complex interactions between microbial and soil biotic parameters occurring along the watershed. Efforts have begun to examine seasonal changes in the relationships functional diversity and soil and abiotic parameters as they occur along the watershed and their role in N loss.

MANAGEMENT IMPLICATIONS

The Pine Canyon aquifer passes through a topographic gap at Hayes Ridge (the margin of the caldera structure) where it coalesces with a larger alluvial fan system prograding away from the Chisos Mountains to the east and southeast. The Chilicotal Springs site appears where erosion has cut into this aquifer; therefore, the water is apparently perched on a relatively impermeable siltstone/shale/clay lithology of the Javelina Formation (Cretaceous). The Glenn Springs site is located at a lower elevation than Chilicotal Springs, where a complex set of geologic controls allows for groundwater to appear immediately down-gradient from an igneous intrusion, at the contact between the intrusion and the Aguja Formation (another Cretaceous siltstone/shale/clay lithology). The difference in basic groundwater chemistries between Chilicotal and Glenn Springs reflects the different geologic controls affecting water flow between the two areas.

Our rainfall data suggest the Chilicotal location receives rainfall from a different pattern of storms than occurs for the remainder of the watershed. It is possible the weather systems moving east-northeast out of Mexico affect this site, while the remainder of the watershed is impacted by storms moving from the west or southwest across the National Park. We have begun an analysis of wind directions to investigate the differences in storm tracks for the various locations along the watershed.

All groundwater values for NO_3^- and NH_4^+ from Pine Canyon are low when compared to the Big Bend Ranch State Park (BBRSP) data. At the BBRSP, NH_4^+ values range up to 5.88 mg/L, and NO_3^- values range up to 9.6 mg/L. We suspect these variations are related to the ranching activities in the BBRSP. A survey of existing NADP precipitation data from the nearby K-Bar site shows seasonal variations with highs in the spring and summer (up to 2mg/L NO_3^- and 1mg/L NH_4^+). A regression through this long-term data set also reveals a very slight trend of increasing NO_3^- and NH_4^+ with time.

The microbial components occurring within the each of the vegetation zones found along the Pine Canyon watershed do not respond to drought and changes in soil nutrient levels in a similar manner. Therefore, while all vegetation zones are characterized as Chihuahuan Desert, the microbes in each vegetation zone have specific responses to moisture, temperature, and nutrient availability limiting the ability of the larger systems to process C and energy. The drought has had its greatest microbial impact on the low desert sites, Glenn Springs (Chihuahuan Desert Scrub), Rice Tanks (creosotebush) and the Sotol-grasslands. The forested sites seem to have been buffered from substantial changes in microbial activities that might be drought-induced in the other sites. The cooler soil temperatures of the forested sites appear to compensate for the lower moisture inputs as compared with the dual negative impacts of low soil moisture and higher temperatures common in the low desert locations. If the drought continues, the grassland sites are in danger of beginning the downward spiral of desertification leading to a shrub-dominated system.

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 FY 1999 for the following study sites: 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 (NOAT), 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 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.

SITE DESCRIPTIONS

Northern Michigan

ISRO Wallace Lake Watershed. The Wallace (150 ha) and Sumner Lake (180 ha) watersheds are located toward the northeast end of Isle Royale National Park, Michigan. Watershed vegetation is dominated by aspen (*Populus tremuloides* Michaux), white birch (*Betula papyrifera* Marsh), and white spruce (*Picea glauca* [Moench] A. Voss). The bedrock is metamorphosed ophitic flood basalts covered by scattered alkaline glacial till originally derived from limestone bedrock immediately south of James Bay. The soils are primarily Alfic Haplorthods, sandy to coarse loamy, mixed, frigid, and are between 3000 to 5000-years old. Parent materials are sands and beachline deposits laid down during the post-glacial Lake Nipissing stage and reworked during the post-Lake Duluth stage.

Calumet Watershed. The study area is a small (<175 ha), first-order watershed vegetated by 55-65 yr old sugar maple (*Acer saccharum*) and white birch (*Betula papyrifera*) near Calumet in Michigan's Upper Peninsula. Unlike most catchments in the region, wetlands are not a major component which simplifies site study. The watershed has a northwest aspect and uniform slope varying in elevation from about 190-375 m above mean sea level. The bedrock is Precambrian metamorphic Portage Lake Volcanics (andesite and basalt). The soils (Typic Haplorthods) are alkaline glacial till and old beach deposits with a varying depth of 2-5 m with an almost impervious soil layer (Ortstein) at 1.0-1.3 m depth.

Fraser Experimental Forest

The Experimental Forest is 137 km west of Denver, CO, and west of the Continental Divide. There are four primary watersheds: Lexen Creek (124 ha), gauged since 1957; the treated Deadhorse Creek watershed (278 ha), gauged since 1957 and calibrated with Lexen Creek; Fool Creek (297 ha), gauged since 1942 and treated (strip cuts) in 1955; and East St. Louis (827 ha), gauged since late 1930's and calibrated with Fool Creek. Watershed elevations vary from about 2800 to 3800 m. Various sub-basins within these watershed are also gauged with some manipulation in studies tied to the watershed level: North Fork (subalpine) and Upper Deadhorse (alpine, subalpine) sub-basins; Upper Fool Creek (alpine); two alpine sub-basins in upper

East St. Louis; and, upper Lexen Creek (alpine). The long-term mean annual precipitation at Forest Headquarters (2725 m) is 58 cm. Annual precipitation over the entire forest averages 74 cm. About 70% falls as snow. Sharp increases in snowpack water equivalent (SWE) occur with elevation. Gneiss and schist parent material underlie most catchments. The east aspect Deadhorse and Lexen Creeks' bedrock includes some remnants of sedimentary sandstone at upper elevations. Resistant bedrock and the extensive glaciation of the area account for the rugged terrain and low inherent soil fertility. Soils are dominated by gravelly sandy loams with alluvial soils near the streams. The soils are mostly Inceptisols with surface soil cation exchange capacities (CEC) averaging about 20 mmolc 100/gr and pH ($CaCl_2$) ranging from 4.5 to 6.1.

About 20% of the Experimental Forest is alpine meadow which generally occurs >3350 m elevation. This fraction is the same as for the entire central Rocky Mountain region. The lower and mid-elevation subalpine forest is dominated by lodgepole pine (*Pinus contorta* Dougl.). Upper elevations are generally vegetated by Engelmann spruce (*Picea engelmannii* Parry) - subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.).

Alaska National Parks

The Agashashok River watershed (Asik, 360 ha), and specifically a tributary (the Fishgut watershed), is situated along the treeline ecotone at the northern extent of the boreal biome, 0-1700 m in elevation. The site is above the Arctic Circle in the Noatak National Preserve (3 million ha), NW of the Kobuk N.P. and 80 km NE of Kotzebue, Northwest Alaska. It is mostly tundra, but the taiga-tundra treeline prevails along much of the east-west axis of the Preserve. About 40% of the watershed is vegetated by white spruce (*Picea glauca*), with an understory of willow (*Salix* spp.), horsetails (*Equisetum arvense* L.), and blueberry (*Vaccinium uliginosum* L.). The other major vegetation type is tussock tundra dominated by cotton-grass (*Eriophorum vaginatum* L.), birch (*Betula nana* L.), and bearberry (*Arctostaphylos rubra*).

Glacier Bay is in the Panhandle of Alaska. It is a pristine, highly productive estuarine area. The park (2.4 million ha) has been the site of classical studies in primary and secondary succession along a chronosequence driven primarily by deglaciation. Much of the park is snowfields and glaciers, but a major fraction of its low elevation area is forested by coastal conifers. Lake Clark National Park and Preserve (2.5 million ha) is located southwest of Anchorage. The only practical access is by plane though some boat access is possible as is road access to the southern boundary of the park. Tundra is prevalent, though major portions are in taiga. The park's major lake is Lake Clark, but there are six additional large lakes. The park is a major contributor to the water supply for the largest salmon drainage in the state. Denali National Park (2.4 million ha) is located north of Anchorage in the Alaska Range. Most of the area is tundra though the southern boundary and very eastern boundary is forested with white spruce as the dominant canopy species. The geology in this area of uplift is complex.

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". This FY, we will continue routine monitoring of this watershed, and no new research questions will be addressed. For procedures used in this study, see previous publications on this site.

Wallace Lake Watershed. This year we will continue the routine watershed monitoring and recently approved research on global change (GC). Our overall research objective is to combine the long-term boreal watershed monitoring and research with studies of change in soil and soil water chemistry and root- mycorrhizae chemistry and biomass to understand the mechanisms regulating ecosystem carbon (C) and inorganic nitrogen (N) availability and their response to GC. Factors affecting the quantity of below-ground C influence the soil biota regulating ecosystem N availability and in turn ecosystem production and biodiversity. The primary 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 also 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, incorporates 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. An intensive study of processes by which GC and increased N availability alter DOC and DON production will use split plots. 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 can predict watershed DOC and DON export and compare results to actual fluxes.

Fraser Experimental Forest
This FY we will continue the monitoring of surface water chemistry in nine gauged watersheds located in both alpine and subalpine watersheds. The preparation of a monograph in FY 2000 will begin, summarizing the long-term biogeochemical studies in the Forest. A series of short-term studies will be completed to fill database gaps. However, no new longer-term studies are planned at present unless outstanding research proposals are funded. An emphasis this year will also be publication of completed research datasets.

Alaskan National Parks
This year we will continue the recently funded global change research in the Asik Watershed, Noatak National Preserve. The objectives and methodology of 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 will initiate some 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.

1999 RESEARCH HIGHLIGHTS

Michigan Sites
By the end of FY 99, we completed 17 yrs of precipitation and streamwater chemistry on the two ISRO watersheds, 20 yrs of intensive precipitation, snowpack, snowmelt, and streamwater chemistry at the Calumet watershed, 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 university and government libraries, and many individual scientists. A few copies are still available on request. The book summarizes 15 years (1982-1996) of research and is the only long-term ecosystem biogeochemistry study in the southern boreal biome of North America. This year we also summarized and published long-term studies on the relation of climate to the N cycle. In addition we completed an 18-month 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 long-term trends in forest floor N and C availability with global change (temperature, moisture, precipitation quality).

Calumet Watershed: This year we continue the routine monitoring of the watershed. We also analyzed an intensive data set focusing 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 calcium (Ca^{2+}), ammonium (NH_4^+), nitrate (NO_3^-), and sulfate (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 chloride (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, and 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 carbonate (HCO_3^-) concentrations. At peak streamflow, dilution accounted for >90% of the decline in acid neutralizing capacity (ANC). Increases in 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 desoption is the only process with the capacity to quickly provide sufficient SO_4^{2-} to offset a large streamwater concentration decline from dilute snowmelt. The watershed retained >99% 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 6 primary watersheds. In addition, we have on average 13 yrs of streamwater chemistry for 4 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 and the change in snowpack precipitation with elevation, and summarized a ten-year study of the effect of clearcutting on subsurface flow chemistry and budgets. Our research on disturbed sites led to numerous requests to address likely impacts from clearcutting 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 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 in the Asik watershed, NOAT, Alaska.

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

<u>Alaskan National Parks</u>
Asik Watershed: This year we continued monitoring basic watershed processes. In anticipation some Global Change Research Program funding would become available, we established 50 (10m x 10m) vegetation plots throughout most of the watershed. The plots were located to compare the effects of vegetation, N 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 at the USGS-USFS lab in the Ft. Collins, CO. 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 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 NOAT 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 NOAT has been increasing 0.4° C yr^{-1}, a finding consistent with other monitoring of interior Alaska. Most of the annual temperature increase occurs in May, likely to extend the limited Arctic growing season.

MANAGEMENT APPLICATIONS

The mission statement for the U.S. Geological Survey clearly emphasizes scientific expertise and research objectivity. Overall research priorities focus on complex national environmental issues requiring considerable scientific input. Most of the above research is not directly related to a management issue specific to the site where the study was conducted. While a case can be made for addressing a local issue in some instances, it would be misleading to base the above research on a site-specific issue. Rather, the funding for all the above studies originated at the national level of the NPS or USFS to meet potential national level issues. These issues are 1) the effect of atmospheric contaminant inputs on the structure and function of ecosystems, 2) the potential effects of climate change on ecosystem nutrient cycling, and 3) the development of understanding of the structure and functioning of northern (boreal, taiga, alpine/subalpine) ecosystems.

For the Michigan sites, research results from this study have some public land management and policy ramifications especially for this region. First, precipitation SO_4^{2-} concentrations are in decline, but NO_3^- concentrations appear unchanged while NH_4^+ concentrations are generally increasing. Atmospheric deposition of these ions over the last decade has been little changed except for SO_4^{2-}. The reason is the generally significant decline in precipitation amount that has offset changes in ion concentration and therefore deposition. Change in annual precipitation amount can considerably alter precipitation chemistry and deposition.

Second, streamwater concentrations of C_B and HCO_3^- have been increasing during the last 10-15 years, SO_4^{2-} has declined or remained constant, and inorganic nitrogen (NO_3^- and NH_4^+) has remained steady. The change in C_B and HCO_3^- concentrations, ions derived mostly from geological weathering, is due to a decline in runoff coupled with an increase in ecosystem temperature. The absence of a widespread reduction in streamwater SO_4^{2-} concentration we attribute to the attenuation of streamwater runoff which raises ion concentration. The lack of trends in streamwater NO_3^- and NH_4^+ concentrations we ascribe to the nonexistence of trends in precipitation inputs, and the offsetting effects of increased N mineralization in warmer soils coupled with increased microbial retention.

Third, it is quite clear that climate change, regardless of its cause, is the major driving force in altering soil and streamwater chemistry. Very modest increases (2°C) in soil temperatures on Isle Royale can significantly increase soil inorganic N pools. Seasonal snowmelt appears to remove much of this over-winter and early spring soil N pool. Coupled with the low seasonal biological uptake, the removed N exits via streamwater. To what degree increased soil N mineralization to inorganic N (the form necessary for biological uptake) from higher temperature is offset by increased soil microbial and above ground biological uptake is not yet quantified. Our results suggest, as with atmospheric N inputs, the ecosystem will retain the increased available N that will initially go into soil microbial biomass then above ground biomass. This will change below and above ground biodiversity. In sum, for this region and especially Isle Royale, it does not seem feasible to assess potential effects of change in atmospheric deposition chemistry without detailed knowledge of ecosystem response to climate change.

An emerging question concerns the potential of present atmospheric inputs of inorganic N to lead to "nitrogen saturation", or where NO_3^- movement in forest soils or NO_3^- released into streamwater exceeds inputs. While our datasets suggest surface water chemistry changes are not reflecting precipitation inputs, inorganic N inputs are a problem because they are increasing and the ecosystems are retaining N inputs. It is likely this sequestering of inorganic N is having an effect on ecosystem biodiversity because some organisms can more efficiently utilize this input than others.

LONG-TERM ECOLOGICAL RESEARCH IN LOCH VALE WATERSHED, ROCKY MOUNTAIN NATIONAL PARK

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INTRODUCTION/HISTORY

Loch Vale Watershed (660 ha) is a northeast facing glacial basin in Rocky Mountain National Park, located about 80 km NW of Denver, CO. Loch Vale Watershed's (LVWS) western border is the Continental Divide, at 4010 m. More than 80% of the basin surface consists of bedrock outcrop and active talus slopes. The bedrock of LVWS consists of various Precambrian granites, gneisses, and schists. The basin floor is divided into distinct alpine and subalpine elevational terraces. Sky Pond and Glass Lake are located below Taylor Glacier in the southern alpine basin, and Andrews Tarn rests at the base of Andrews Glacier in the northern alpine basin. Most of the vegetation in the alpine areas of LVWS consists of low herbaceous, dwarf-shrubs, and lichens. Several permanent snowfields and an active rock glacier are also present in the upper reaches of LVWS. The two alpine basins merge into a lower subalpine valley floor at the confluence of Andrews Creek and Icy Brook. The lower terrace has old-growth subalpine fir (*Abies lasiocarpa*)/ Englemann spruce (*Picea engelmannii*) forest. Streams, wetlands, and ponds are also found in this subalpine portion of LVWS.

Loch Vale Watershed was chosen as the site for a long-term biogeochemical study in 1981. Of 42 lakes surveyed throughout Rocky Mountain National Park, Andrews Tarn, Sky Pond, Glass Lake, and the Loch had the lowest summertime alkalinities, making these lakes more susceptible to acidification than those with higher acid neutralizing capacity (ANC). Another reason for choosing LVWS was for its variety of landscape form. As previously mentioned, there are alpine and subalpine lakes, wetlands, tundra, talus slopes, exposed bedrock, spruce/fir forest, and soils of differing degrees of depth and development. LVWS has a single surface water outlet at 3108 m, which facilitates direct measurement of yearly hydrologic outputs. LVWS is remote, yet accessible throughout the year.

Weekly sampling of LVWS surface waters began in 1982. A remote area weather station (RAWS) and a stream gage were installed in 1983. Weekly precipitation sampling began in 1983. All sampling sites have been nearly continuous in operation since their installation. Several agencies and universities have been measuring different data variables at Loch Vale over the time period including National Park Service; U.S. Geological Survey; U.S. Forest Service; U.S. Bureau of Reclamation; National Science Foundation; National Atmospheric Deposition Program; Water, Energy, and Biogeochemical Budgets (WEBB) Program; UNESCO's Man and the Biosphere Program; Colorado State University; and University of Colorado.

Our primary objective is to gain understanding of biogeochemical processes in order to be able to differentiate natural variability from human-caused disturbance. Through monitoring, experiments, and modeling, we study changes in ecosystems and climate that may be affected by increasing urban, agricultural, and industrial activity. Current research in Loch Vale has three themes: 1) long-term trends in climate and biogeochemical fluxes, 2) ecosystem/atmospheric responses to nitrogen (N) deposition, and 3) effects of global change on mountain ecosystems. The presence and quantity of sulfate (SO_4^{2-}) and nitrate (NO_3^-) are of concern when considering acidification processes in LVWS. Depositional increases of these anions or a decrease in ANC can signal an acidification sequence in which the ability of an environment to neutralize acid decreases. One effect of decreasing pH is the release of aluminum that can be extremely toxic to aquatic organisms.

1999 was a productive year for the Loch Vale Watershed Project (LVWS). As usual, significant progress was made toward our program objectives of research, communicating with managers, and education. Regular field sampling continued this year in LVWS. Weekly trips to Loch Vale have consisted of maintaining the stream gage at the outlet of the Loch, routine sampling of stream and lake waters for chemical and biological properties, and participation in the National Atmospheric Deposition Program's (NADP) precipitation monitoring network. A second stilling well was added to the flume at the Loch outlet, and a new stream recorder will be installed at the onset of flow during spring 2000. Failing operational function forced us to dismantle what had been the primary weather station in Loch Vale since 1983. Meteorological parameters will now be estimated with a newer met station maintained by the USGS WRD. The WRD station is located 30 m from the site of the old one. An estimated 360 kg of trash and surplus equipment was eliminated from Loch Vale using 8 Park Service mules. Additional surplus equipment will be removed winter 1999 via sled.

We streamlined some laboratory procedures, replaced old pH and conductivity meters with new ones, and developed methods for analysis of dissolved organic nitrogen (DON) and silica (SiO_2). We also entered an agreement with the Hach Company, who loaned us several meters for use in the field and laboratory. In return, we reported to Hach on the accuracy and usability of these prototype models including the need for clearly written instruction mauals, and simplified start-up and and calibration procedures.

The LVWS Methods Manual is under revision. An updated completed version will be available early in 2000. A comprehensive quality assurance report for all data collected from 1995 to 1998 was completed, showing the chemical and quantity estimates of surface and precipitation water are of high quality and valid for all potential uses. Quality assurance measures of meteorological data are performed by the USGS WRD (USGS Open-File report, under review).

We answered eight data requests in 1999, mostly from collaborators. Development of the LVWS website continued. The URL for the site is http://www.nrel.colostate.edu/PROGRAMS/LTER/LVWS/LVWS.html. A link between the website and our Oracle database will be connected early in 2000.

RESEARCH PROGRESS

<u>LVWS and Fraser Experimental Forest Nitrogen Fertilization Study</u> (Eric Allstott, Jill Baron)
We completed our fourth and final year of this study comparing forest plots in the USFS Fraser Experimental Forest which are limited by N with plots in LVWS which are not N-limited. Fertilization in Fraser has had very little impact. In LVWS, effects of fertilization on vegetative groundcover, soil properties, microbial activity, and soil water resemble the classic symptoms of N saturation.

<u>Regional Forest Response to Nitrogen Deposition</u> (Heather Rueth, Jill Baron)
The current level of N deposition (3-5 kg N ha^{-1} yr^{-1}) along Colorado's Front Range is altering forest biogeochemistry. Efforts are underway to determine what east/west side differences can be partially attributed to discordant physical characteristics rather than solely differences in N deposition. A manuscript on Englemann spruce N cycling in north-central Colorado was submitted to Forest Ecology and Management.

<u>Nitrogen flux at Embryo Pond</u> (Kate Muldoon, Jill Baron)
This research will attempt to differentiate biogeochemical processes controling fluxes of N to Embryo Pond through wetland soils, forest soils, and talus slopes. Quantification of hydrologic flowpaths, microbial N transformations, and the use of N isotopic tracers will be used as tools to separate N deposition from terrestrial processes. Hydrometric and hydrochemical instrumentation of the area

surrounding Embryo Pond was conducted during the 1999 field season. Sampling will commence at the onset of the 2000 field season.

Controls on Nitrogen Flux in LVWS (Don Campbell, Jill Baron, Kathy Tonnessen, Paul Brooks, Paul Schuster)
High-altitude watersheds along the Front Range of Colorado show symptoms of advanced stages of N saturation, despite having lower rates of atmospheric deposition of N than other regions where watersheds retain N. Annual N export increased in years with greater input of N, but more than half of the additional N was retained in the watershed, indicating portions of the ecosystem may be N-limited. Other results suggest the export of N from LVWS is caused by a combination of direct flushing of N from atmospheric deposition and release of N from ecosystem biogeochemical processes (N-cycling). Sensitivity of alpine ecosystems in the western United States to atmospheric deposition of N is a function of landscape heterogeneity, hydrologic flowpaths, and climatic extremes that limit primary productivity and microbial activity, which in turn control retention and release of N.

Vegetational Mapping in Loch Vale (Geneva Chong, Mohammed Kalkhan, Jill Baron, Thomas Stohlgren)
Three Modified-Whittaker plots were established within the Loch Vale watershed: (1) high elevation meadow below Sky Pond, (2) riparian area below Timber Falls, and (3) rock field below Andrews Tarn. Plots were randomly located by vegetation type on a vegetation map created from 1:15840 color air photos. Areas surrounding Embryo Pond and Mystery Pond were surveyed for rare plants and any others not previously encountered. No plants listed as rare or endangered were located during sampling. Approximately 73 species were identified at the Sky Pond plot (all plots are 20 m x 50 m), 78 species in the Timber Falls plot, and 39 species in the Andrews Tarn plot. Surveys indicated some minor, yet necessary corrections to the vegetation classification map.

Patterns in Mountain Lake Biology: An Exploration of Dominant Environmental Gradients (Brenda Moraska, Koren Nydick)
CCA analysis of 22 Front Range lakes sampled in 1998 showed no invertebrate biological response to lake N concentrations.

Biomonitoring and Nutrient Limitation Experiments in LVWS (Koren Nydick, Brenda Moraska)
From June-September, three subalpine lakes in LVWS were surveyed weekly or biweekly. Samples were collected for water chemistry analysis: amonium (NH_4^+), NO_3^-, SiO_2, pH, conductivity, and temperature; and biological analysis: zooplankton, phytoplankton, benthic invertebrates, and chlorophyll *a*. Chemical and biological analyses are in progress. Bioassays revealed lake algae are not limited solely by N but are sometimes co-limited by phosphorus (P) and N.

Snow Studies (Sarah Clements, Kelly Elder)
The goal of this research was to identify spatial and temporal patterns in snow chemistry and how they related to the timing of distribution and melt, and to determine if snow chemistry controls observed differences in stream chemistry between the Icy Brook and Andrews Creek sub-basins. Statistical analyses of snow depth and density measurements indicate there are significant differences between the Andrews Creek and Icy Brook sub-basins. Ionic elution from the snowpack during melt seems to be influenced by snow depth, aspect, and location, and also by discrete snow and rain events during sampling period. A delay in ionic elution may account for observed differences in stream chemistry between the sub-basins. Timing and magnitude of peak ionic concentrations in Icy Brook and Andrews Creek stream water was influenced by chemical mass, solar radiation, topography, and snow water equivalence (SWE) respective to each sub-basin.

Spatial and Temporal Variations in Stream-Water Chemistry (David W. Clow, Andres Torizzo, Mark Dornblaser)
Streamwater chemistry and discharge were measured bimonthly at 12 sites in 2 adjacent alpine/subalpine basins in Rocky Mountain National Park, Colorado during the summer and fall of 1999. Preliminary data indicate discharge increased by an order of magnitude from the highest to the lowest elevation sites. Concentrations of weathering products (base cations, alkalinity, silica) increased as basin size increased and elevation decreased. These variations in streamwater chemistry might be due to greater contact time between water and geologic materials, better-developed soils, and/or warmer temperatures in the subalpine zone compared to the alpine zone. During the summer and fall, concentrations of weathering products followed an inverse pattern with discharge. These temporal trends are probably due to snowmelt dilution of weathering products generated in the alpine/subalpine soils, coupled with flushing of solutes accumulated in the shallow subsurface zone during the winter.

Trace Metal Redox (Alan Shiller)
Several years of weekly data have been collected on the stream concentrations of a number of dissolved trace elements in LVWS. Results show significant seasonal concentration variability for a number of trace elements. In general, this variability results from the seasonal snow cover and its effects on runoff, flush of soils, the redox state, and residence time of lake waters. Comparison with dissolved trace element variability in the lower Mississippi River shows similar patterns for some elements (e.g., manganese and molybdenum) and different for others (e.g., uranium). However, the manganese data suggest similar seasonal concentration variations in these two systems do not necessarily result from the same processes. A detailed study of alkali metal ratios would have the promise of separating seasonal vegetative effects from seasonal weathering effects. To address these questions soil water, spring, and vegetation samples are being collected.

Research Experience for Undergraduates Program
Algal Biomass Following Snowmelt in LVWS (Mary Fitzgerald, Seth Gates, Koren Nydick). The goal of this project was to document changes in algal biomass during the period of snowmelt, and analyze environmental factors effecting algal growth patterns. These factors include NO_3^- concentration, zooplankton abundance, and water temperature. Results indicate although the three lakes sampled were in close proximity, the amount of algae present in each was determined by different factors. As hypothesized, there was an inverse relationship between the amount of chlorophyll *a* and NO_3^- concentration in Embryo Pond. This shows N efflux from snow was consumed by phytoplankton. However, in Mystery Pond NO_3^- levels are undetectable and the presence of abundant macrophyte and epiphytic algae growth suggest a large portion of the primary productivity may not be due to phytoplankton. An abundance of zooplankton grazers may be responsible for controlling the population of phytoplankton. Furthermore, Mystery Pond did not experience a noticeable nutrient pulse following snowmelt. Despite the availability of NO_3^- in the Loch, phytoplankton growth is limited. Bioassays indicate P limitation is an important controlling factor.

Zooplankton assemblages in LVWS (Andrew Ramey, Brenda Moraska, Koren Nydick, Brett Johnson). This project examined the zooplankton communities of Embryo Pond, the Loch, and Mystery Pond. The zooplankton community of Embryo Pond was dominated by copepods, and contained two genera of Cladocerans (*Daphnia* and *Chydorinae*). The zooplankton community of the Loch consisted mostly of rotifer genera (*Asplanchna, Keratella, Monostyla, Notholca,* and *Polyarthra*). Only immature copepods (copepod nauplii) were identified in the Loch, suggesting predation of larger mature copepods by fish. The zooplankton community of Mystery Pond was dominated by rotifers (genus *Keratella*). Copepods were abundant with nauplii and mature copepods. Daphnia species of Cladocera were also identified in Mystery Pond.

COMMUNICATING WITH MANAGERS

We presented findings summaries, and introductory materials to a number of federal land managers and policy makers. These managers, departments, and meetings included the NPS Water Resources Division, the Superintendent of Rocky Mountain National Park, the National Park Service Air Quality Division, the Southwest Wyoming Environmental Task Environmental Force, the Colorado Air Pollution Control Division, the USGS Water Resources Division Research Council, the USDA Forest Service Air Managers, the USDA Forest Service air managers and rangers of Pike and San Isabel National Forests, Bill Brown and Pat Shea (DOI), Eric Heilman and Marti Morgan (staff members for Senator Wayne Allard), and the United States Congress.

EDUCATION

In addition to the project's excellent graduate students (Heather Rueth, Koren Nydick, Brenda Moraska, Kathryn Muldoon, Hee-Seung Koo, Sarah Clements, and Ben Balk), we had a great field season with four students (Mary Fitzgerald, Seth Gates, Andrew Ramey, and Seth Martin) participating in the Research Experience for Undergraduates program. One very positive aspect of our project is every student and technician has the chance to interact with all new and ongoing studies in LVWS. Another strong point of the project is the set of bi-weekly meetings held each semester. In these meetings, time is allotted for general discussion of all related questions and issues, as well as for discussion of relevant readings assigned by staff or a graduate student. Other educational activities have included giving lectures at CSU, and leading field trips and seminars for different organizations.

ECOSYSTEM AND WATERSHED STUDIES IN OLYMPIC NATIONAL PARK

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INTRODUCTION

Long-term watershed studies implemented by the NPS in collaboration with U.S. Geological Survey (USGS)-MESC are expanding our knowledge about the response of natural systems to stress; the sources of stress; climate, biota and soils interactions; aquatic and terrestrial biogeochemical cycles, especially nitrogen (N) and sulfur (S); and, surface water chemistry, biology, and hydrology. Olympic National Park provides an excellent location for gathering valuable baseline data from a pollution-free site for evaluation of the effects of anthropogenic atmospheric inputs and global change on ecosystems as well as the influence of forest management. However, with current estimates predicting increases in global atmospheric nitrogen (especially over Asia, air that has been shown to reach the Pacific Northwest) it is imperative to maintain long-term monitoring, as well as investigate the role of N in the undisturbed ecosystem preempting large changes in inputs. In 1984 we initiated a long-term small watershed research program in West Twin Creek Watershed (WTC), Hoh River Valley, Olympic National Park, Washington, a temperate old-growth forest. This program involves basic monitoring of precipitation, throughfall, stemflow, soil solution, and stream chemistry and hydrology. We have also determined vegetation dynamics, ecosystem biomass and productivity, annual litterfall rates, litter decomposition rates, and monitored tree health, growth and mortality and microclimate in the watershed. For several years we also conducted studies at Hoh Lake, a high elevation site in the Hoh River Valley, and determined lake chemistry, litterfall rates, and tree growth and mortality.

Human activities such as fossil fuel use and crop fertilization have led to high atmospheric N deposition in the eastern U.S. Unlike sulfate (SO_4^{2-}), which has been decreasing in deposition recently, long-term trend analysis of NADP sites across the country reveal eastern sites are seeing no relief in N deposition. Nitric acid in deposition, like sulfuric acid, can result in acidification of forest soils and stream waters that can be slow to recover even as pollution inputs decrease. Increased N inputs to temperate forest in the eastern U.S. have, in some cases, resulted in increased N export in stream waters. Increased transport of N to rivers and coastal areas has resulted in increased acidity of streams and lakes and eutrophication of estuary waters contributing to the decline of marine fisheries. An understanding of the structure and function of forested ecosystems, their ecotones, and their response to global change will result from our analyses of the N-cycle in watersheds having long-term monitoring and biogeochemical cycling data.

The basic monitoring program continued at WTC in 1999. Precipitation and stream chemistry data have been collected from 1984-1999 and hydrology and microclimate data are also available for the same time period. Highlights of this year are 1) a report to date of the riparian vegetation influence on stream food webs, and 2) an analysis of litterfall in the permanent plots from July 1985 to October 1987.

STUDY SITES

The 58 ha WTC is located in the Hoh River Valley on the western side of Olympic National Park, 32 km from the Pacific Ocean. Elevations in the watershed range from 180 to 850 m. The watershed is steep and slopes range from 33-80%. Mean January and July air temperatures are 4 and 16°C, respectively at the Hoh Ranger Station. Soil temperatures do not fall below 0°C and rarely exceed 20°C. Annual rainfall averages 3500 mm and is strongly seasonal with most falling from October to May. Snow rarely falls in the lower elevations, but a weak snow pack may develop above 700 m from December to March. Bedrock and soils are deposits from marine origin and classified as coarse-loamy mixed mesic Typic

Dystrochrepts or medial mesic Andic Dystrochrepts because of a degree of volcanic ash, and forest floor depth ranges from 2 to 10 cm. The sites are characterized by frequent windthrow and soil mixing. The watershed encompasses two vegetation zones: the lower watershed is in the western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) zone, and the upper watershed is in the Pacific silver fir (*Abies amabilis* (Dougl.) Forb.) zone. Common tree species in the watershed are Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western hemlock, western redcedar (*Thuja plicata* Don.), Sitka spruce (*Picea sitchensis* (Bong.) Carr), and Pacific silver fir. The forest is uneven-aged with oldest trees more than 600 years.

Lindner Creek watershed is located just out side the park adjacent to the WTC. It has similar geology and climate as WTC. It is approximately 200 ha in size and spans 200-730 m in elevation.

OBJECTIVES

The Long-Term Objectives of the Study

1. Establish a long-term monitoring site in a pristine environment and collect data for precipitation chemistry and elemental cycling.
2. Obtain baseline information regarding the structure and function of terrestrial and aquatic components in the WTC to determine the influence of plant, soil and stream components on the chemistry of solutions flowing through the ecosystems.

The Specific Objectives for 1999

1. Continue monitoring precipitation, throughfall, and stream chemistry and hydrology in the 58 ha WTC, Hoh River Valley, Olympic National Park.
2. Collect litterfall on two of the six permanent sampling plots in WTC; one in the upper watershed and one in the lower.
3. Collect air, soil, and stream temperature, soil moisture and PAR data at the weir in lower WTC using the computerized weather station.
4. Collect air and soil temperature in the East Twin Creek Watershed using a computerized weather station.
5. Maintain the database containing precipitation, throughfall, stemflow and stream chemistry, hydrology, and microclimate data.
6. Collect the eighth year samples from a long-term (10 year) decomposition study involving leaf and needle and wood litter from Long-Term Ecological Research (LTER) sites from lower East Twin Creek Watershed in the Research Natural area in October 1999. This study is a national decomposition study to examine factors influencing decomposition processes in a variety of ecosystem types.
7. Calculate input/output budgets for nitrogen (N) from 1984 to 1999.
8. Monitor litterfall inputs, stream perophyton, insects, and vertebrates in WTC and Lindner Creek to compare red alder versus conifer dominated riparian vegetation influence on stream food webs.
9. Write and submit a number of research papers.

METHODS

Intensive study will be conducted in the dominant forest vegetation of WTC. We will measure vegetation biomass and litterfall chemistry (a continuation of our ongoing long-term study). We will continually monitor air and soil temperature, soil moisture, wind speed and direction, PAR and precipitation amounts using a Campbell Scientific datalogger (already in place). Soil water will be sampled using tension lysimeters and analyzed for DOC and DON in transects near the weir. Net N mineralization rates (using resin bags) will be monitored at all sites throughout the 5-year period using established methods. Where needed, piezometers from the stream along two aspects will be installed. Soil water flow direction and quality will be monitored on these gradients. Forest floor and soil bacterial and fungal functional diversity will be used to assess below-ground biological relations with soil organic matter, temperature, and moisture. Field measurements of carbon dioxide (CO_2) efflux will serve as an index of below-ground respiration during the study. Efflux will be measured 3-4 times a year using a static chamber 24-hour incubation and an adsorbent.

PAST YEAR ACTIVITIES AND HIGHLIGHTS

Alder versus Conifers in the Riparian Zone

Introduction. Red alder (*Alnus rubra* Bong.) is a pioneer species invading sites following disturbances such as clearcutting and fire. Red alder is also a nitrogen-fixer and can be a significant short-term and long-term source of this essential element to terrestrial and aquatic ecosystems. Inorganic nitrogen (N) is higher in groundwater underneath a canopy dominated by alder compared to a canopy dominated by old-growth conifers. Symbiotic fixation by red alder is hypothesized to be the primary source of N to forested watersheds in the Oregon coast range. Standing stocks of chlorophyll *a* were up to seven times higher in back channels on the Queets River, WA receiving the upwelling from alder-dominated floodplains. Allochthonous inputs into Alaskan streams with red alder were higher than inputs from old-growth coniferous forests in one short-term study. However, in most of the studies mentioned, there was no link made between nutrient chemistry and energy flow in the two forest types and consumer organisms.

Although red alder is potentially an important component of the nutrient capital of Pacific Northwest streams, its presence may have other economic and ecological consequences. Riparian stands of alder may limit establishment of commercially important conifers. Furthermore, red alder provides woody debris less resistant to high flows and decays faster in streams than larger, more resistant conifers. Other studies have shown that large woody debris is important to providing habitat for resident and anadromous fish. Clearly, red alder can affect terrestrial and ecosystem processes in significant ways. There is, however, relatively little information on the influence of red alder on stream ecosystems. To make informed decisions on how to "best" manage riparian areas, managers require quantitative data describing the connections between riparian vegetation, stream nutrient dynamics, energy flow, and aquatic food webs. Our study takes an ecosystem-level approach with the objective of establishing connections between stream structure and function and types of riparian vegetation.

Methods. In this study, we are in the process of linking detailed studies on nutrient dynamics and energy flow to stream food webs. Based on our conceptual view of how riparian ecosystems operate, we have designated 7 compartments to focus our research efforts: (1) leaf litter dynamics and elemental chemistry of carbon (C), phosphorus (P), and N; (2) groundwater-stream connections and groundwater nutrient chemistry; (3) stream water nutrient chemistry; (4) stream seston quantity and quality; (5) stream periphyton dynamics and elemental chemistry; (6) stream insect dynamics and elemental chemistry and (7) stream vertebrate abundance, biomass, and elemental dynamics. A brief description of methods used to measure each compartment can be found in "Ecosystem and Watershed Studies in Olympic National Park: 1999 Annual Report." All activities, except vertebrate surveys (twice a year), are measured in both years and on a monthly basis. We also monitor stream temperature, photosynthetically active radiation, and discharge at both sites.

Results to Date. The amount of total leaf litter was higher in Lindner than in WTC throughout the sampling. The average percent N content of leaf litter was also higher at Lindner Creek (2.4±0.35) than at WTC (0.8±0.1) for the sampling dates 11/2/99 -12/15/99. The C:N was 20.4 and 66.1 for Lindner and WTC litter respectively.

Stream water chemistry in Lindner Creek was less concentrated in cations and sulfate (SO_4^{2-}) than in WTC; however pH, nitrate (NO_3^-), ammonium (NH_4^+), and phosphate (PO_4^{3-}) were not different. This is similar to what was found in comparing WTC to Rock and Tower Creeks, watersheds located immediately east of Lindner. Nitrate values ranged from <0.04 to 0.18 mg/l for WTC, and 0.05-0.25 mg/l for Lindner Creek.

Periphyton biomass on tiles was higher in Lindner Creek than WTC from May through July of 1999. However, August 1999 has higher values in WTC (0.10 mg cm^{-2}, compared to <0.01 mg cm^{-2} for Lindner Creek). Invertebrates on the tiles were frequently not different between the two streams. There was a trend for more invertebrates on Lindner Creek tiles than on WTC tiles.

Litterfall and Nutrient Returns to the Forest Floor in an Old-Growth Forest Watershed in the Hoh River Valley, Olympic National Park, Washington

Introduction. Forest litter production is studied because of its relationship to forest productivity, nutrient cycling and the decomposition of forest floor organic matter. It is also an indicator of pollution and changes in litter production with time may reflect global change.

Litter production and nutrient returns to the forest floor have been studied in western North America in low elevation Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and red alder (*Alnus rubra* Bong.) stands, and high elevation Pacific silver stands (*Abies amabilis* (Dougl.)Forb.). However, few litterfall studies have been conducted in western hemlock (*Tsuga heterophylla* (Raf.) Sarg) dominated forests, especially in coastal old-growth temperate rainforests. Litterfall patterns are strongly influenced by climatic factors and the stormy conditions common in near coastal environments may strongly influence litterfall.

The objectives of this study were to determine: (1) seasonal and annual litterfall by component (green and senescent needles, twigs and small branches, reproductive tissues, and mosses and lichens), (2) litterfall rates in different community types, and (3) nutrient returns in litterfall in a small old-growth temperate rainforest watershed in the Hoh River valley of Washington.

Methods. For methods in greater detail than presented here, please see "Ecosystem and Watershed Studies in Olympic National Park: 1999 Annual Report."

Litterfall collection and analysis: The study was initiated in July, 1985 with collections in October, 1985, January, April, July, and October 1986 and January, May and August 1987. Seven litterfall traps were placed randomly in each of six 0.1 ha circular permanent plots in WTC. In the laboratory, samples were separated into litterfall components; senescent (brown) and green needles, woody - twigs, bark and small branches, reproductive structures (male and female flowers and cones, cone bracts, strobili, seeds and scales), and miscellaneous which included lichens and mosses. Sorted litter was oven-dried and weighed. Mass was expressed as kg per ha per time period or year.

Basal area: Tree basal areas in each of the 0.1 ha circular permanent sampling plots were determined in 1985 by measuring tree diameters at breast height.

Litter nutrients: Litter components were analyzed for concentrations of N, P, sodium (Na^+), calcium (Ca^{+2}), potassium (K^+), magnesium (Mg^{+2}), and manganese (Mn). Litterfall nutrient returns were calculated on a kg per ha basis by multiplying nutrient concentrations by litter mass by season or year.

Results and Discussion. *Litterfall amounts:* Total annual litterfall in the whole watershed was 4019 kg/ha in 1985-1986 and 3027 kg/ha in 1986-1987 and averaged 3523 kg/ha. Litterfall was less in 1986-1987 than in 1985-1986 and a similar year to year variability was reported in old-growth stands in the Oregon Cascades. Annual litterfall was higher in the upper watershed (3,994 kg/ha) than the lower watershed (3052 kg/ha). The same trend was found in old-growth stands in the Oregon Cascades. Total annual litterfall is predicted to be approximately 4000 kg/ha at 48°N latitude and our litterfall is similar. In the central Oregon Cascades at elevations 430 to 670 m, an average total litterfall of 4263 kg/ha was documented in an old-growth watershed dominated by Douglas-fir.

Litter production in the lower watershed is similar to that reported for lowland Douglas-fir stands ranging in age from 30 to 160 years in western Washington. A large amount of variability (300-6,600 kg ha^{-1} yr^{-1}) was noted, depending on stand age and site productivity. Few litterfall data are available for higher elevation Pacific silver stands. Total litterfall of 3000-3020 kg ha^{-1} yr^{-1} was reported for a Pacific silver stands in the Washington Cascades, which are slightly lower values than we found in the upper WTC. However, the stands in the Cascades were at higher elevation with a thick snowpack typically lasting from November to June. At our site snow in the upper watershed lasts for only a few weeks.

Total annual litterfall in old-growth stands in the Oregon Cascades at elevations 457 to 1311 m was calculated in the range 4,530-6,916 kg/ha. These litterfall values are higher than we found. This could be due to the fact that litterfall increases as latitude decreases and the Oregon sites are at lower latitudes.

In old-growth ecosystems total litterfall tends to increase with stand age because of an increase in woody litterfall. On the other hand needle litterfall tends to stay relatively constant after canopy closure and it has been suggested that it should stabilize between 2000 and 3000 kg ha^{-1} yr^{-1}. In old-growth stands in the Oregon Cascades needle litterfall ranged from 2,002 to 3,741 kg ha^{-1} yr^{-1} and in another study in the same region found it to average 1737 kg ha^{-1} yr^{-1}. We calculated needle litterfall average equivalent to 2164 kg ha^{-1} yr^{-1} in the upper watershed and in the lower watershed 2145 kg ha^{-1} yr^{-1}. In the Oregon Cascade studies needle litterfall averaged about 43 and 47% of total litterfall. We found that needle litterfall averaged 62.8% of total litterfall (55.9% in the upper watershed and 69.7% in the lower watershed) which is similar to that found in the Washington Cascades (64-70%) and to that found in the Oregon Cascades if hardwood leaves are included (60.5%). We had no hardwood leaves in our litterfall.

Winter storms are relatively common on the Washington coast. Therefore, we considered green needles may be an important source of litterfall in the period from October to April. Green needle input averaged 63.2 kg ha^{-1} yr^{-1} over the two year period and the percent of annual needle litterfall in green needles was 3%. In the Oregon Cascades where wind speeds are lower only 10 kg/ha was green needles or 0.3% of total needle litterfall. However, even 3% is not a great contribution.

In one study, leaf material contributes 60-76% of total litterfall, while woody litter contributes 12-15% and other material contributes 12-15%. These proportions are very similar to what we found; needles, woody litter and other material averaged 68, 14.1, and 17.1%, respectively. Of the 17.1% contributed by other materials 13.5% was reproductive and lichens were 3.6%. Lichens contributed more in the Oregon Cascades (10.6%), while reproductive was 11.6% and woody material was 17.3%.

Seasonality of litterfall: Highest needle litterfall rates occurred in fall in old-growth stands in the Oregon Cascades although highest total litterfall rates were in winter due to contributions from woody and reproductive litter. We found that the highest needle and total litterfall was in the July to October period in the lower watershed. In the upper watershed the highest needle litterfall was in fall while highest total litterfall was in the winter, similar to the pattern found in the Oregon Cascades.

Litterfall in relation to plant community type: Litterfall varied considerably by plant community type. Highest litterfall was in plot 4 in the *Tsuga heterophylla-Oxalis oregana* community type in the upper watershed (4932 kg ha^{-1} yr^{-1}) while the lowest was in plot 2 *Tsuga heterophylla/Polystichum munitum-Oxalis oregana* community on a north facing slope in the lower watershed (2907 kg ha^{-1} yr^{-1}).

Considerable variability in litterfall by community type was noted in a small watershed in the Oregon Cascades. Interestingly the lowest litterfall in a *Pseudotsuga-Castanopsis* community type on a north slope. Moisture and temperature tend to control productivity and this is reflected in litterfall.

Relationships between litterfall and tree basal area: It has been suggested tree basal area is closely related to leaf litterfall in the different world climatic zones. A strong relationship between leaf litterfall and live stem basal area was found in a cool temperate *Nothofagus* rainforest in Tasmania. We plotted total litter and needle litterfall against total stem basal area and found no significant relationships. However, when total needle litterfall was plotted against hemlock basal area a significant relationship was observed ($y = 54.203x + 1293.9$, where x is basal area and y is annual litterfall; $r^2=0.90$, $n=6$, $p<0.05$). The relationship was also significant when total needle litterfall was plotted against hemlock basal area ($y = 16.572x + 1594.3$; $r^2=0.74$, $n=6$, $p<0.05$). This would suggest hemlock was the greatest contributor to needle litterfall in WTC.

Nutrient concentrations in litterfall: Senescent needles had average N concentrations of 0.62 and 0.72% in the lower and upper watersheds, respectively. Slightly lower N concentrations (0.5 percent) in litter were found in old-growth stands in the Central Oregon Cascades studies. There is considerable variation in N concentrations throughout the year with lowest concentrations in October samples, and a similar pattern was noted with lowest N concentrations in the fall in the Oregon Cascades. Nitrogen concentrations in green needles were higher with average concentrations >1%. Lichens also tended to have high N concentrations while twigs had the lowest.

In the lower watershed concentrations of N in litter followed this sequence: lichens>green needles> reproductive>senescent needles>twigs. In the upper watershed the sequence was similar although lichens and green needles were reversed. Similar concentrations for lichens, cones and twigs were found in the Oregon Cascades.

In the lower watershed concentrations of Ca>K>P>Mg>Mn>Na in all substrates, except for needles and twigs where the Mg>P. Lowest concentrations are in twigs and highest in green needles. In the Oregon Cascades a similar sequence was noted and this sequence also generally occurs in the upper watershed, although K and green needles is greater than Ca in the lower watershed.

Nutrient amounts returned in litterfall: Large quantities of nutrients are returned to the forest floor in litterfall each year. Amounts of nutrients returned in each litter component varies considerably and there is also seasonal variation. Calcium is returned to the forest floor in the highest amounts, ranging from 20 to 30 kg ha^{-1} yr^{-1}. This is only about half the amount returned in litter in the Oregon Cascades, but similar to the amounts returned in Douglas-fir stands in western Washington. Annual returns of N range from 17 to 34 kg/ha with slightly higher returns in the upper than lower watershed. This is similar to the annual returns reported in Oregon (27 kg/ha) and in Washington (21 kg/ha). Total N entering the ecosystem in precipitation during the same period was 4.8 kg ha^{-1} yr^{-1}. We had expected N returns in green needles might be significant at this near coastal site, but only 0.6 kg ha^{-1} yr^{-1} was returned in green needles compared to more than 11 kg ha^{-1} yr^{-1} in senescent needles. Reproductive structures, and twigs and branches returned a considerable of N, but N returns in lichens was small (1-2 kg ha^{-1} yr^{-1}).

Returns of other elements in litterfall were much smaller than those for Ca and N; K (2.4-5.0 kg ha^{-1} yr^{-1}), P (1.7-4.1 kg ha^{-1} yr^{-1}), Mg (0.0-1.1 kg ha^{-1} yr^{-1}), Mn (0.0-1.2 kg ha^{-1} yr^{-1}), and Na (0.0-0.8 kg ha^{-1} yr^{-1}). Annual returns of 8.1, 4.7 and 1.1 kg/ha for K, P, and Mg, respectively were reported in Oregon while in Washington annual returns of 7.3, 3.1, 3.6, and 7.2 kg/ha for K, P, Mg and Mn, respectively were recorded.

KEY FINDINGS TO DATE

The key findings presented here represent our current understanding of the health, structure, and functioning of two small temperate old-growth watersheds (WTC and Hoh Lake) in a "clean" environment with little anthropogenic disturbance. The primary study watershed, WTC, is extremely variable in topography, soils, and vegetation, typical of many small first-order watersheds in the Western Olympic Mountains. Hoh Lake watershed is at higher elevation and temperatures are cooler and annual precipitation higher (380-500 cm) than WTC with most falling as snow. Windthrow is the major disturbance and root-wad mounds are common. Disease is also common, contributing to wind damage, and trees with extensive heart rot may break off above the ground. Some trees have died standing, perhaps from root diseases, creating snags. Insects, particularly bark beetles, also contribute to disturbance. Fire, however, is not common and intervals between major fires are hundreds of years.

Vegetation Patterns

In the WTC there are two major vegetation zones: the western hemlock zone at the base and a transition to the Pacific silver fir zone at the top, and the distribution is attributed to slope steepness. A third vegetation zone also occurs on the river terraces between the weir and the Hoh River; the Sitka spruce (*Picea sitchensis*) zone. Dominant tree species in the watershed are western hemlock, Pacific silver fir, Douglas-fir, and western redcedar. Hardwoods are not common, but big leaf maple (*Acer macrophyllum*) and red alder (*Alnus rubra*) occur in disturbed areas or along the stream. The forest is unevenaged and the oldest tree on the watershed was a Douglas-fir at 635 years. Maximum tree height was greater than 90 m and maximum dbh was 310 cm.

Growth and Mortality Patterns

Typically old-growth forests are thought to be very stable. However, the vegetation in WTC is extremely variable and dynamic. Most of the watershed forest is in the late old-growth gap dynamics phase where the structure consists of large old trees, huge quantities of coarse woody debris composed of snags and large logs, and multiple canopy layers. Mortality is common and the canopy is deteriorating and uneven. There are locations in the upper watershed, however, that appear to be in the stem exclusion phase where the canopy is dense and there is no understory.

In the lower watershed the forest probably originated after a fire about 635 years ago, since this is the age of the oldest Douglas-fir. Douglas-fir ranged in age from 237 to 635 years, western redcedar from 123 to 600 years, western hemlock from 71 to 262 years and Pacific silver fir from 98 to 248 years. Western hemlock and Pacific silver fir are shade tolerant species and typically dominate the later successional stages in these forests.

Clearly, these ecosystems are dominated by large trees creating very high ecosystem biomass values. One community type at WTC (*Tsuga heterophylla/Gaultheria shallon*) had extremely high total ecosystem biomass (1772 Mg/ha). However, there was a large amount of variability in total biomass within watersheds. Ecosystem biomass is composed mostly of living trees and CWD. Understory plants do not contribute greatly to ecosystem biomass. Belowground stores, including the forest floor, mineral soil and roots, comprise a great contribution to total ecosystem biomass.

Litterfall Dymanics

Annual litterfall amounts varied from year to year but were in the range of other reports from old-growth stands. The highest litterfall occurred in the July to October sampling interval. Although there was no relationships found between total stem area and litterfall we did find a significant correlation between total annual litterfall and western hemlock basal area as well as needle litterfall and western hemlock basal area. This suggests western hemlock is the greatest contributor to litterfall in WTC. Calcium and N are the two major nutrients returned in litterfall to the forest floor.

Hydrology in the West Twin Creek Watershed

Small watershed studies enable calculation of annual evapotranspiration from annual precipitation and runoff over a weir at the base of the watershed, assuming the geologic base is watertight. In WTC annual precipitation varied twofold over the study period from a low of 267 cm to 493 cm. Fog occurs in the watershed, but no estimates of the contribution to precipitation were made. A large proportion of the water falling left the watershed via the stream. Percent discharge ranged from 54 to 94 of precipitation over the 12-year period. Evapotranspiration was relatively low in this environment and represented only 6 to 46% of precipitation. Trees were rarely under water stress in the watershed and evaporanspiration only exceeded precipitation in July and August. There was a slight increase in evapotranspiration with a decrease in precipitation. Vegetation, however, did influence the hydrologic cycle. As monthly precipitation increased throughfall increased. During large storms stemflow was commonly observed. Vegetation cover also strongly influenced the hydrograph shape. The old-growth forest on this watershed moderated peak discharge reducing the impact of storms. Forest removal in this high rainfall environment would be expected to change the shape of the hydrograph, likely resulting in sharper peaks and overall higher discharge levels than in uncut watersheds.

Precipitation Chemistry along a Gradient from Coast to Inland

Oceanic influences on precipitation near the Pacific Coast of the Olympic Peninsula were evident in the present study. The main solutes in precipitation in the Hoh Valley were sea salt ions with Cl^- and Na^+ being the dominant anion and cation, respectively. Concentrations of sea salt ions in bulk deposition were significantly correlated with each other. Also, sea salt ion concentrations were the strongest correlates with electrical conductivity suggesting the relative importance in the overall chemistry of atmospheric deposition. The amount and concentration of excess SO_4^{-2} and its negative correlation with precipitation depth are indicative of the importance of marine influences other than sea salt by the production and emission of DMS from the ocean and its role as the principal CCN in marine dominated regions.

Seasonal patterns of rainfall were apparent with a rainy season extending from November to April. Most of the chemical constituents of bulk deposition had lower deposition rates in the summer and higher in winter, similar to the seasonal pattern of rainfall. Excess Ca^{2+}, K^+, TKN, TPN, NH_4^+, and PO_4^{3-} had no apparent seasonal patterns.

The chemistry of bulk deposition was found to change across a relatively short distance inland from the ocean. Electrical conductivity and concentrations of H^+, Cl^-, SO_4^{2-}, Mg^{2+}, Na^+, and excess Ca^{2+} were significantly higher nearer the coast. Concentrations of the remaining chemical constituents also tended to be higher near the coast, but those differences were not significant. The greatest change in chemistry occurred between 4 and 13 km from the ocean. Annual rainfall increased between those same sites, but was constant over the remainder of the transect to a distance extending to 41 km inland.

Annual deposition of H^+, excess SO_4^{2-}, and precipitation were greater at the site furthest inland. Deposition of Cl^-, NO_3^-, K^+, Mg^{2+}, Na^+, and excess Ca^{2+} were higher near the ocean than inland. Calcium and SO_4^{2-} of sea salt origin (total minus excess) decreased further inland along the transect.

Solution Chemistry in the West Twin Creek Watershed

The biogeochemistry of WTC Watershed was examined including: (1) concentrations of major cations and anions and dissolved organic C (DOC) in precipitation, throughfall, stemflow, soil solution and the stream, (2) nutrient input/output budgets, and (3) nutrient retention mechanisms in the watershed. Stemflow was more acidic (pH 4.0-4.5) than throughfall (pH 5.1) and precipitation (pH 5.4). Organic acids were important contributors to acidity in throughfall and stemflow and tree species influenced pH. Soil solution pH averaged 6.2 at 40 cm depth. Stream pH was higher (7.6). Sodium (54.3 μeq/L) and

Cl^- (57.6 μeq/L) were the dominant ions in precipitation reflecting the close proximity to the ocean. Throughfall and stemflow were generally enriched in cations, especially K^+. Cation concentrations in soil solutions were generally less than those in stemflow. Ion concentrations increased in the stream. Dominant ions were Ca^{2+} (759.7 μeq/L), Na^+ (174.4 μeq/L), HCO_3^- (592.0 μeq/L), and SO_4^{2-} (331.5 μeq/L) with seasonal peaks in the fall. Bedrock weathering strongly influenced stream chemistry. Highest average NO_3^- concentrations were in the stream (5.2 μeq/L) with seasonal peaks in the fall and lowest concentrations in the growing season. Nitrogen losses were similar to inputs; annual inputs were 4.8 kg/ha (not including fixation) and stream losses were 7.1 kg/ha. Despite the age and successional status of the forest plant uptake is an important N retention mechanism in this watershed.

Unusual pathways of N cycling were examined. Total annual export from annual fleshy fungi on logs was found to be 18.3 g/ha or 0.4 g/log. Although this appears to be a small amount it is a fair proportion of the initial N in logs. Between 1-3% of this initial N may be transported out of logs via sporocarps at a time when N mmobilization is expected to occur. Potassium and P also occurred in high concentrations in fruiting bodies on logs.

Long-Term Trends in Precipitation and Stream Chemistry

Up until October of 1993, there appeared to be little evidence to suggest long-term patterns of bulk precipitation concentrations for most of this study's analytes. Increases in NO_3^-, SO_4^{2-}, H^+, and K^+ occurred in precipitation and throughfall starting in 1993. The average annual NO_3^- concentrations in precipitation increased from 1.8 μeq L^{-1} before 1993 to 8.4 μeq L^{-1} from 1993 to 1997, while the pH averaged 5.3 and 4.8 respectively. This change in precipitation chemistry may be due to increased pollution in the Asia outflow, air masses known to reach the West Coast of North America.

Stream chemistry also showed increases in N, H^+, and K^+ from 1993-1997. Sulfate had a slight increase along with other major cations. Annual stream NO_3^- concentrations increased from 5.3 μeq L^{-1} to 9.8 μeq L^{-1}, with loss of the strong seasonal pattern. Nitrogen inputs and outputs were also calculated. Stream pH reached as low as 4.3 with an annual average of 6.9 from 1993-1997 compared to 7.3 before 1993. The increase of NO_3^-, K^+, and H^+ concentrations in the stream suggest this old-growth forest is susceptible to soil acidification and N leaching, important factors in forest and stream health.

Carbon Dioxide Evolution from Soil and Coarse Woody Debris

Carbon dioxide evolution rates for downed logs (coarse woody debris) and the forest floor were measured using the soda lime trap method. Respiration rates were depressed in late July and August compared to fall and spring due to the summer drought characteristic of the Pacific Northwest. Large diameter western hemlock logs in decay class 1-2 had higher respiration rates than small diameter logs, whereas large diameter decay class 3 western hemlock logs had lower respiration rates than small diameter logs.

Litter Decomposition

Decomposition rates and nutrient dynamics (for N, P, K^+, Ca^{2+}, Mg^{2+}, Mn, and Na^+) were determined for green western hemlock (*Tsuga heterophylla*) and Pacific silver fir (*Abies amabilis*) needles in WTC. The influence of temperature and substrate chemistry on decomposition was determined. Temperature was the dominant factor controlling differences in decomposition rate in the first year with the fastest decomposition at an elevation of 260 m (lower watershed) and slowest decomposition at 725 m (upper watershed). After 12 months mass loss was averaged 36.4% in the lower watershed and 28.0% in the upper watershed. There was no significant difference in decomposition rates between species. Substrate chemistry, i.e., the lignin/N ratio, became a more important factor than temperature as decomposition proceeded. After 37 months mass loss for western hemlock needles averaged 60.8% and 50.3% for Pacific silver fir with no difference by watershed location. After 61 months both substrates appear to be approaching similar substrate chemistry and decomposition rates, and there were no signficant differences by species or location. Decomposition constants (k values) after 61 months were 0.26 and 0.20 per year for western hemlock needles in the lower and upper watershed, respectively, and 0.22 and 0.19 per year for Pacific silver fir needles in the lower and upper watershed, respectively. The species tend to be immobilizing and releasing N at different rates with Pacific silver needles act as a more immobilizing substrate than western hemlock needles.

EXPECTED ACCOMPLISHMENTS AND DELIVERABLES

The hydrology, precipitation and stream chemistry and microclimate monitoring proceeded as expected in the WTC in 1999. It is anticipated this basic monitoring program will continue in 2000 along with vegetation and decomposition studies. The following tasks will be undertaken in 2000-2001:

1. Write and submit scientific papers.
2. Monitor precipitation, throughfall and stream chemistry in the 58 ha WTC, Hoh River Valley, Olympic National Park.
3. Collect litterfall on 2 of the 6 permanent sampling plots; one in the upper watershed and one in the lower.
4. Collect microclimate data in WTC and East Twin Creek watersheds.
5. Maintain the database containing precipitation, throughfall, stemflow, and stream chemistry, hydrology and microclimate data.
6. Collect litter samples in East Twin Creek Watershed in October 1999 from a long-term (10 year) decomposition study involving leaf and needle and wood litter. This study is being conducted at Long-term Ecological Research (LTER) and other sites across the U.S. It is examining factors influencing decomposition processes in a variety of ecosystem types including grasslands, woodlands, and forests.

MANAGEMENT IMPLICATIONS

The WTC and Hoh Lake Watersheds in Olympic National Park are located in one of the most pristine environments in the contiguous United States. The forests in these watersheds are healthy and show normal patterns of tree growth and mortality. However, long-term monitoring of precipitation and stream chemistry have revealed an increase of inputs of H^+, SO_4^{2-}, and NO_3^- from fall of 1993 through 1996. Although there does not seem to be a continuing trend upward and the increase was not at levels seen in the eastern United States and Europe, it is a dramatic change from the baseline seen in the previous nine years. We suspect some of this pollution is coming from Asian air masses reaching the West Coast of the U.S. This study demonstrates that issues such as fossil fuel burning and agricultural use of N compounds are global problems.

WATERSHED RESEARCH, SEQUOIA AND KINGS CANYON NATIONAL PARKS

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Lead Technician: Andi Head

INTRODUCTION

The Sequoia and Kings Canyon watershed program is a long-term cooperative study of anthropogenic effects on Sierran ecosystems. The SEKI program was designed to collect a set of core baseline measurements on surface water chemistry, vegetation dynamics, precipitation inputs, meteorology, and soil mapping. In the beginning, the SEKI program focused exclusively on sites along an elevational gradient in the Middle Fork drainage of the Kaweah River. This work was initiated to evaluate the consequences of fire on watersheds at two scales: small (~100 ha) and large (~20,000 ha). The literature is lacking in carefully designed studies analyzing fire effects on watershed processes, and when found, these studies are initiated after fire burned a watershed and lack of pre-burn data. Much of what we know about fire effects on Sierran watersheds is derived from a 1990 pilot watershed study conducted in Log Meadow (Giant Forest), in which biogeochemical processes were compared in paired watersheds before and after fire. In 1990, the Tharp's watershed was burned as a pilot study to determine the effects of fire on biogeochemical and hydrologic processes in a mixed-conifer forest, and the Log watershed (49.8 ha) served as the control site.

The striking chemical response of the Tharp's watershed in Giant Forest to fire led to incorporation of further watershed studies in the East Fork of the Kaweah River as an element of the "Mineral King Risk Reduction Project." This experimental effort to reduce fuels and restore typical ecological function to an entire landscape provides a valuable opportunity to measure the physical, chemical, and biotic effects of landscape-scale burning on streams, and on the river systems they feed. For example, fire-induced variations in stream chemistry and sediment loading can have significant impacts on fisheries and reservoirs, respectively. Alterations in forest structure can change hydrodynamics, thus significantly affecting the efficiency of water-storage and release systems. As the Departments of Agriculture and Interior have ordered increases in the area of wildland burned each year, the research in Sequoia and Kings Canyon National Parks will provide for sound implementation of ecosystem management throughout the semi-arid West. Coinciding with the start of the Mineral King Risk Reduction Project in 1995, the SEKI watershed program expanded its efforts to determine the effects of fire on stream chemistry and hydrology. Two first order watershed sites were established in the East Fork drainage and sampling was initiated in the East Fork at Lookout Point. Continued monitoring in the East Fork will allow evaluation of recovery rates of affected parameters such as nitrogen (N) and sulfur (S) constituents, pH, and alkalinity. Additionally, results from the aquatic biota survey will enhance our understanding of the impacts of prescribed fire on the structure of macro-invertebrate communities in the Sierra. While pre-fire surveys of aquatic invertebrate communities provide a baseline for monitoring and developing a catalog of information on the Parks' biological resources, post-fire long-term research will track the response and recovery time of communities to fire, while further enriching our understanding of biological diversity along structural and temporal axes.

The present goal of the watershed program is to build upon our long-term research base to understand the interacting effects of fire and fire exclusion, air pollution and climatic change on key ecosystem elements and processes in Sierran watersheds. In recent years the program has been plagued by budget cuts, so much of this year was spent writing proposals to augment current funding.

This report presents results from ongoing work conducted in both the Middle Fork and East Fork. Results from the analysis of post-fire hydrologic and forest structure changes observed Tharp's Creek following the 1990 burn are presented. Comparisons in runoff are made between a manipulated and control catchment for a sixteen year period (pre-burn n=7, post-burn n=9). Annual precipitation totals and the influence of antecedent moisture conditions on stream discharge are discussed. Reference forest stand data are also presented to document changes in post-fire forest structure and are related to observed changes in post-fire hydrologic responses. The discussion of Mineral King includes the results of the 1999 large woody debris survey, annual runoff coefficients for the study catchments, and annual volume-weighted mean (VWM) solute concentrations. Previous reports and publications summarize the effects of fire on biogeochemistry in the Tharp's catchment following the 1990 prescribed fire and the seasonal variation in pre-burn stream chemistry in the East Fork study sites.

STUDY SITES

Watershed research is conducted in Middle Fork Kaweah and the East Fork Kaweah, large adjacent drainages (Figure 3). The East Fork Kaweah is a diverse 20,000 ha basin comprised of first- to third-order subcatchments. Vegetation in both drainage areas is diverse, ranging from chaparral and hardwood forests at the lower elevations to mixed-conifer and giant sequoia (*Sequoiadendron giganteum*) forests at mid elevations. Alpine vegetation is found above 3,100 m.

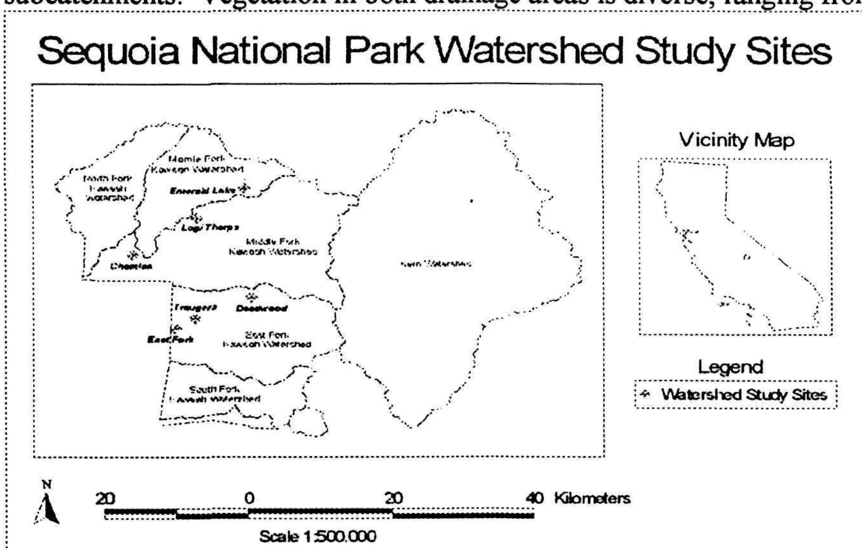

Figure 3. Location of watershed study sites.

Middle Fork

The Middle Fork study sites were part of a larger program established in 1982 to study atmospheric deposition along an elevational gradient in the Middle Fork Kaweah River drainage in Sequoia National Park. Selected areas were located in low elevation chaparral and mid elevation mixed-conifer forest communities.

Log Meadow is dominated by white fir (*Abies concolor*) and giant sequoia (*Sequoiadendron giganteum*). Precipitation averages 100 cm annually, with half falling as snow during the winter months. **Tharp's Creek** (13.1 ha) has a southeast aspect and ranges in elevation from 2067 – 2397 m. **Log Creek** (49.8 ha) has a northwest aspect and ranges in elevation from 2067 – 2255 m. These creeks are sampled as paired first- and second-order watersheds.

East Fork

The East Fork is sampled at Lookout Point (4,200 m) as a representative of downstream accumulation from a large-scale watershed. In addition two first order watersheds are sampled as representatives of the different vegetation types found in the East Fork drainage.

Trauger's Creek (106 ha) is in a transition zone between the lower mixed-conifer zone and the upper chaparral-hardwood zone. The dominant species is canyon live oak (*Quercus chrysolepis*). Average annual precipitation based on available records is 92 cm. Elevation ranges from 1390 m to 1970 m and aspect is south facing.

Deadwood Creek (100 ha) is characterized by white fir (*Abies concolor*), red fir (*Abies magnifica*), giant sequoia (*Sequoiadendron giganteum*), and incense cedar (*Calocedrus decurrens*). Annual average precipitation based on available records is 136 cm. Elevation ranges from 1985 m to 2660 m and aspect is south facing.

METHODS

The watershed approach requires many key aspects of the hydrological and biogeochemical cycles be measured and sampled, understanding fully the variability in watershed processes. The Sequoia watershed program has used a holistic approach by establishing co-occurring sites to measure meteorology, stream discharge, and hydrochemistry.

Meteorology

Meteorological data were collected at established sites in the Middle Fork and East Fork watersheds. These stations were co-located with primary study sites, providing more accurate climatic data for the individual study sites and whole watersheds than could be obtained by a single station within a watershed. Meteorological stations were managed by several federal agencies including: USGS/BRD, NPS, NOAA, and the U.S. Army Corps of Engineers. Most stations measured precipitation, temperature, relative humidity, wind speed and direction, and solar radiation.

Precipitation Chemistry

Precipitation depth and chemistry samples were collected weekly in accordance with National Atmospheric Deposition Program (NADP) protocols in Aerochem Metrics Model 201 samplers located at Lower Kaweah in the Giant Forest area and at Ash Mountain. Belfort rain gauges were located at each site. Samples were shipped to California Air Resources Board (CARB) and NADP labs for chemical analysis. Deposition chemistry was used to determine mass balances for solutes entering Sierran catchments supplying information for understanding fire, air pollution, and climatic change.

Hydrology

The study catchments were equipped with Stevens type A/F records and Omni Data loggers and/or chart recorders to record hourly discharge. The Middle Fork sites were fitted with weirs that provided direct stage-discharge relationships, which were established by USGS/WRD. Discharge data for the East Fork was obtained from Southern California Edison Power Company, which maintains several gauging stations in the southern Sierra. Stage-discharge relationships were developed for Trauger's and Deadwood Creeks using dilution methods.

Hydrochemistry

Stream samples were collected weekly throughout the year. Additional samples were collected during periods of high flow (storm events and snowmelt runoff). This sampling frequency allowed us to examine both inter- and intra-annual variation. Samples were collected and processed according to established protocols. Samples were filtered at the Ash Mountain Water Lab (AMWL) and shipped to the Biogeochemistry Laboratory at the Rocky Mountain Station Experiment Station in Fort Collins, Colorado, for analysis of base cations, ammonium (NH_4^+), nitrate (NO_3^-), sulfate (SO_4^{2+}), and phosphate (PO_4^{3-}). Alkalinity, pH and conductivity were measured at the AMWL.

Stream Morphology

A large woody debris (LWD) survey was conducted and measurements were compared with LWD measurements made by Chan in 1996 to determine the effects of the January 1997 flood. We thought this event would decrease the total volume of woody debris in the creeks. The 1999 woody debris survey also included photo points and stream mapping for post-burn study.

RESULTS AND DISCUSSION

Tharp's Creek Post-Burn Runoff Analysis

Pre- and post-burn stream discharge was analyzed for data collected between 1983 and 1999 in Tharp's Creek and Log Creek, and runoff coefficients were calculated for each catchment. Runoff was expressed as (1) a coefficient of annual precipitation using the equation:

$$RC = \frac{[Q\ (m^3) \div a\ (m^2)] \times 1000\ (mm)}{ppt\ (mm)}$$

where RC = runoff coefficient, Q = total annual discharge, a = area of catchment, and ppt = total annual precipitation. Total annual values were given by water year (October 1 - September 30); and (2) as the runoff ratio of Tharp's:Log. During the analysis, the importance of antecedent precipitation patterns became apparent in explaining runoff totals for any given year. Thus, a discussion of pre- and post-burn runoff responses during wet and dry years is also presented.

Runoff Patterns. Average runoff coefficients increased 325% and 139% in post-burn dry and wet years, respectively, in Tharp's catchment. In Log catchment, average runoff coefficient decreased by 20% in the post-burn wet years. The decrease is a likely response to the seven-year drought. In the post-burn years, annual runoff in Tharp's Cr. has increased steadily. In 1998 the runoff ratio exceeded 1.0, and was 1.32 in 1999, the fourth driest year of the study period. By comparison, in 1985 – a drought year, preceded by a four-year wet period, the runoff ratio was 0.43. This increased runoff has led to a major shift in the post-fire runoff relationship between the two catchments (Figure 4).

Prior to the burn, base-flow discharge contributed the least to the annual runoff in Tharp's Creek, and the creek was dry for much of the summer and fall. In 1990 after four consecutive years of moderate to severe drought, the creek was dry for a record 299 days. Following the 1990 prescribed burn the number of "no flow" days has decreased steadily (Figure 5). In the post-burn years, the contribution of base-flow increased corresponding to an increase in the number of flow days in the summer months. Tharp's Cr. was dry for a record low of 28 days in 1999 despite moderate drought conditions.

Post-fire Changes in Forest Structure. The paired watershed analysis revealed in post-fire years the burned and control catchments both had an increase in annual runoff, and much of the increase can be explained by an increase precipitation. However, there was a greater response from the Tharp's catchment than Log Creek watershed. The results of a companion study on forest mortality and recruitment in these catchments between 1986 to 1995 provide a unique opportunity to correlate post-fire changes in forest structure as a means of explaining some of the observed increases in annual runoff.

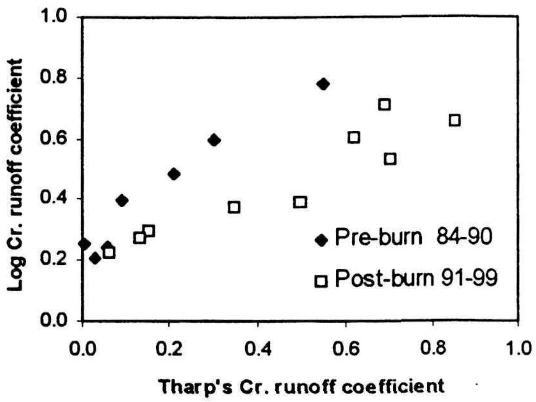

Figure 4. Increases in Tharp's Cr. runoff following the 1990 burn resulted in a dramatic shift in the runoff relationship between Tharp's and Log Creeks.

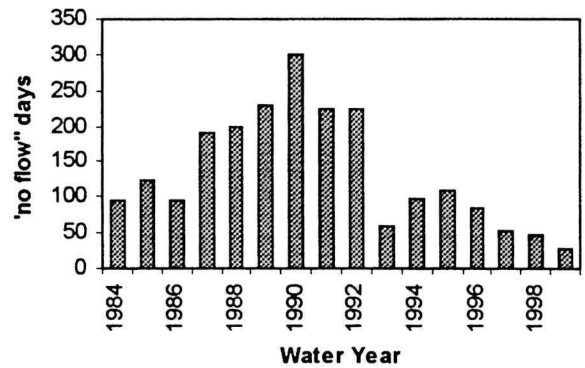

Figure 5. Decreases in the number of "no flow" days for Tharp's Cr. Following the 1990 burn.

In the pre-burn years mean annual mortality for all tree species and size classes was <1% in both catchments. In the post-burn period (1991-1995) annual mortality increased slightly to 1.4% in Log Cr. catchment, whereas Tharp's Cr. catchment had an annual mortality of 17.2%. Sharp increases in mortality rates were observed in Tharp's catchment following the 1990 prescribed burn and rates remain elevated 8 years after the burn. The highest mortality in Tharp's catchment occurred in 1992 and 1993. The increase in mortality in Log Cr. catchment was attributed to drought stress, which reduced tolerance to pathogens and insect outbreaks. Tree mortality in Tharp's catchment was significantly correlated with fire-caused crown scorch, which resulted in a 75% decrease of the trees ≤50 cm dbh (diameter at breast height) and a 25% decrease of trees >50 cm dbh. Although the highest morality averages occurred in the subcanopy class (28%), dominate and co-dominate trees had average mortality rates of 7% a year from 1991-1995. In 1997, mortality rates for the dominate and co-dominate size classes were 1.45% and 4.23% and 0.0% and 1.89% in Tharp's and Log catchments, respectively.

Management Implications. Interception measurements were not collected during either study, but results from the forest study strongly suggest the observed tree mortality in the large size classes resulted in a decrease in interception and evapo-transpiration losses in Tharp's catchment. Studies in other locations have documented shown that these losses can be substantial, ranging from 15 to 30% annually. In the post-burn years, source contributions from snow-melt and base-flow in Tharp's Creek were 10 to 15% greater than in pre-burn years.

The overall mortality rate in Tharp's catchment between 1996 and 1998 was 3.9%, which was more than twice the rate of 1.5% observed in Log catchment. Increased runoff coefficients in Tharp's catchment suggest the continued mortality is contributing to the additional annual runoff. The continued trend of elevated mortality eight years following the prescribed fire indicates severe fire behavior can have a prolonged effect of forest structure and hydrologic response.

Results of this analysis reveal the effects of fire on the hydrologic response of a small mixed-conifer catchment are a complex interaction of biological and physical factors. Paired watersheds and long-term precipitation data are necessary to understand the variation in hydrologic before and after fire. The benefits of companion studies such as the forest mortality study are clearly seen here where detailed information on the changes in forest structure following a prescribed fire provided the information necessary to explain the continued increase in Tharp's catchment annual runoff. The results of this analysis also suggest the need for long-term monitoring in catchments where fire intensity is severe.

Mineral King Pre-Burn Analysis

Runoff Coefficients. Annual runoff coefficients were calculated for each catchment for water years 1996–1999 using the above equation. The East Fork coefficient values were under estimated due to the lack of data for the alpine area of the catchment. Trauger's Creek had the highest values overall for the pre-burn period for the four-year period. Runoff in the small catchments did not seem to be affected by the low precipitation totals for WY 1999. Runoff coefficients are expected to increase in the initial years following the application of fire. Much of the burning in the Mineral King Project has been light to moderate in intensity, and thus, we expect increases in runoff will be slight and short-term. Significant changes in East Fork runoff are not expected due to the patchy nature of burning within the watershed and the time span of the burns.

Stream Chemistry. Annual volume-weighted mean (VWM) solute concentrations show little inter-annual variability for most anions (H^+, SO_4^{2-}), base cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) and nutrients (PO_4^{3-}) with standard error (SE) values ranging from 0.00 to 0.10. Higher SE values were observed for NH_4^+, and NO_3^-, both having variable concentrations. The Mineral King catchments appear to be N-limited as annual VWM NH_4^+ concentrations were significantly less than PO_4^{3+} concentrations, 0.1 to 0.3 μEq and 0.4 to 1.8 μEq, respectively. Phosphate VWM concentrations were highest in Deadwood Cr. Sulfate contributed the highest acid anion VWM concentration in all catchments (Figure 6). High concentrations in the East Fork were correlated with mineral springs in the upper canyon. Nitrate and H^+ accounted for <2.0 μEq in any of the study catchments. These concentrations were contra-indicated by atmospheric deposition patterns where average NO_3^- concentrations were 25% greater than SO_4^{2-} concentrations as reported by NADP. The study sites appeared to be well buffered with alkalinity concentrations >500 μEq. Slightly lower alkalinity concentrations were observed in the East Fork, which may be due in part to higher SO_4^{2-} concentrations. The dominant cation order was Ca^{2+}>Na^+>Mg^{2+}>K^+ (Figure 7), which is typical of Sierran systems with metamorphic terrain and granitic geology. Sodium and calcium were reversed in Trauger's Cr., which also had higher Cl^- concentrations. This may have been influenced by marine onshore air-flow during the winter, when most of the rain falls.

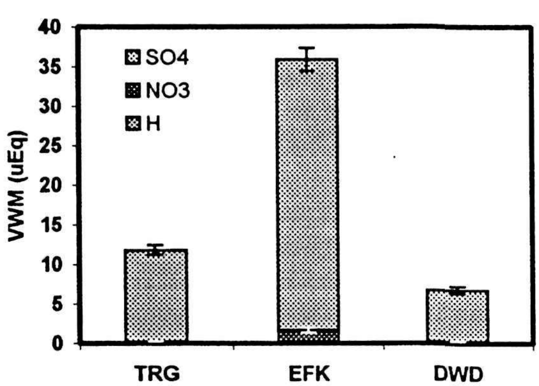

Figure 6. Sulfate is the dominant acid anion. Phosphate and ammonium concentrations are low, 0.1-1.8 uEq, for all watersheds.

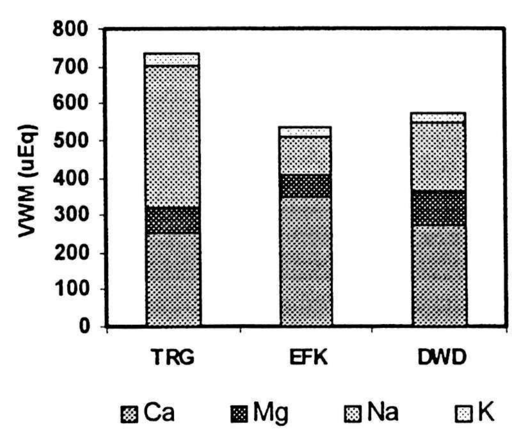

Figure 7. Calcium and sodium are the dominant base cations. Concentrations did not vary significantly from year to year.

Large Woody Debris. The LWD survey indicated most of the downed wood is suspended across the creeks and extending onto the stream bank; <10% of the woody volume was within the bankfull zone - stage height during the 2-year flood. This finding was consistent with results from similar-sized catchments in the Northwest.

In 1996 Chan conducted a LWD survey as part of an aquatic invertebrate study. Starting from the road, he walked up stream and measured the first 50 pieces of wood meeting standards for minimum length and diameter. He traveled 114m and 111m in Deadwood and Trauger's Creeks, respectively, to measure 50 pieces of downed wood. Assuming cylindrical shapes the following equation was used:

$$Volume = \frac{\pi(D_1^2 + D_2^2)L}{8}$$

We followed this protocol in Trauger's (1998) and Deadwood (1999a) to compare results following the January 1997 flood, which was rated as a 35-40 year event by the California Water Resources Department. Comparisons with the 1996 survey showed a substantial decrease in total volume, and an increase in bankfull width (Table 4), suggesting the 1997 flood waters eroded stream banks and removed much of the wood measured in the lower 100 m of Trauger's and Deadwood Creeks.

Table 4. Results of Large Woody Debris surveys comparing pre- and post-flood volumes and randomized versus non-random surveys.

	Bankfull	Dist.	Dia.	Length	Vol/dist	TotVol
DWD			Avg.	Avg.		
1996	1.28	114	0.32	2.34	0.17	19.36
1999a	1.26	111	0.17	1.46	0.01	0.64
1999b	1.33	100*	0.28	4.86	0.02	2.08
TRG						
1996	0.69	111	0.22	3.23	0.11	12.26
1998	1.22	167	0.17	2.22	0.02	3.84
1999b	1.06	200*	0.15	3.60	<0.01	0.69

* sum of 50 m random surveys in each creek.
All measurement in meters, volume in m^3

As the creeks were surveyed, it became apparent the slope influences how wood is positioned in the creeks. In the lower portion of the creeks the gradient is lower, increasing the potential for woody debris accumulation within the bankfull area. To account for this we randomized 50m surveys (1999b) for an accurate representation of the entire stream. Results of the 1999b surveys were mixed. In Trauger's Cr. where is upper 2/3 of the creek is very steep (slopes range from 20% – 35%), the total volume of woody debris was only 0.69 m^3, lower than the 1996 and 1998 results. In Deadwood Creek, where slopes are less steep overall and more varied throughout the short stretch of stream (≈ 400 m) as compared to Trauger Creek, the results showed an increase in total volume over the 1999a survey, but were still significantly lower than the 1996 results. The increased volume related to a number of large downed trees located in the upper 50m survey, where the slope was less than 10%. The results of the randomized survey suggest the accuracy of the total volumes of LWD is increased and the slope effects on woody debris accumulation are visible.

Management Implications. Approximately half of the Deadwood catchment and a much smaller portion of the Trauger's catchment were burned in late 1999. Increased PO_4^{3-} and conductivity values were observed almost immediately in Deadwood Creek. We have not observed changes in stream chemistry in the East Fork, despite burning. It is possible the effects of mosaic burning over time in large drainage areas does not alter the seasonal fluctuation in stream solute concentrations. Every effort should be made to continue the sampling through the burn and post-burn phase of the MKRRP. These watershed results are extremely valuable in understanding the variation in watershed response to fire. As observed in Tharp's catchment, precipitation patterns can strongly influence post-burn watershed response to fire. The Mineral King pre-burn data were collected during a period of wet years, completely opposite the dry years that dominated the pre-burn data collection in Tharp's catchment. This shift pre-burn in precipitation patterns will likely influence the magnitude and duration of the fire effects in the East Fork sites.

We are fortunate to have a long-term data base on stream chemistry, hydrology and meteorology from the Log Meadow catchments. These data allow us to understand how long-term anthropogenic influences affect watershed function and help us to explicate the effects of short-term disturbance such as fire. We should continue to expand this knowledge base by funding studies such as the Mineral King project.

1999 ACCOMPLISHMENTS

- Conducted Large Woody Debris survey in Trauger's and Deadwood Creeks, and compared results with 1996 pre-flood survey.

- Submitted paper entitled "Hydrologic Response of a Forested Catchment before and after Fire" to American Water Resources Association conference: Water Resources in Extreme Environments. Paper will be presented at the May 2000 meeting in Anchorage, AK.

Submitted three proposals to state and federal agencies to continue long-term stream and precipitation sampling with an emphasis on fire effects, and study specific fire effects on sediment transport and storage, and hillslope erosion in small (<100 ha) forested catchments in various stages of fire reintroduction. None of the proposals were funded.

2000 PLANS

The budget for watershed research will be zeroed for FY2000 and all monitoring will be discontinued. A three-phase plan is underway to end the program. In Phase I sampling will cease at all Middle Fork sites as of February 2000. Sampling will continue in the East Fork through April 2000 to capture the winter/snowmelt runoff period in the recently burned watersheds. Final chemistry analysis will be performed for all remaining stream and precipitation samples. In Phase II equipment will be removed from the field, including all data loggers and meteorological stations. During Phase III equipment will be inventoried and stored, all data sets will be updated and reviewed, and all metadata will be completed.

Plans are also underway to complete a draft synthesis of the watershed program. This document will summarize all research and monitoring in the Middle Fork (1984-1998), and will include an overview of fire effects in the Tharp's catchment, and trends analysis on the long-term stream chemistry and hydrology data sets.

BIOGEOCHEMICAL RESEARCH AT THE NOLAND DIVIDE WATERSHED, GREAT SMOKY MOUNTAINS NATIONAL PARK, TENNESSEE/NORTH CAROLINA

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STUDY SITE: NOLAND DIVIDE WATERSHED

Intensive biogeochemical research in the spruce (*Picea rubens* Sarg.)-fir (*Abies fraseri* [Pursh.] Poir.) zone began with the establishment of the Integrated Forest Study (IFS) in the vicinity of Clingman's Dome, NC. In 1991, stream gauging and water quality monitoring was initiated in the Noland Divide Watershed (NDW), a 17.4 ha watershed located between 1675 m and 1920 m near the IFS Spruce-Tower site. Mean air temperature at 1740 m elevation varies from -1 to -3°C in February to +17°C in August. Mean average precipitation is 200 cm, approximately 10% deposited as snow. Snow cover is typically present for 50 days per year and the frost-free period extends from May through September. The watershed is underlain by Thunderhead Sandstone of the Great Smoky Group (Upper Protozoic). Soils in the NDW were recently classified as Inceptisols with a predominantly loamy texture. They are relatively shallow, with a depth to the bedrock often <50 cm, and have a high coarse fragment content. They are characterized by a thick O and A horizons with high organic matter content, low soil pH, and high levels of extractable nitrate-nitrogen (NO_3^--N). The carbon/nitrogen (C/N) values of the soils in the nearby IFS spruce-fir plots ranged between 7-14.

STUDY OBJECTIVES

Long-Term Research Objectives

1. Assure continued stream water monitoring at NDW and establish a long-term stream discharge and water chemistry data record for the watershed.
2. Establish and maintain a central database at the University of Tennessee (UT) with information from projects and monitoring activities at or in the vicinity of the NDW or from monitoring activities in the Great Smoky Mountains National Park (GRSM) relevant to the NDW and/or elucidate biogeochemical processes in the high-elevation spruce-fir forests.
3. Collect baseline meteorological data for the NDW for comparison with other climate stations within GRSM.
4. Characterize the hydrology and hydrologic flowpaths within the NDW.
5. Determine overstory demographics in the spruce-fir forest.
6. Assess spatial variability in soil properties, forest dynamics, and nutrient cycling patterns within the NDW and assess their role in stream water quality.
7. Assure integration and coordination among the different research projects conducted at the NWD to: (a) maintain the integrity of the NDW as a longterm research facility, and (b) optimize its role in providing biogeochemical and climatic data.

Specific Objectives for FY 1999

1. Continue stream water sampling and chemical analysis at the NDW (stream water, lysimeter water, wet deposition, throughfall).
2. Collect standard climatic data at the climate station established on the IFS Tower near the NDW including: precipitation amounts and intensities, wind speed and direction, relative humidity, air temperature, and solar radiation.

3. Calculate spatial variation in overstory nitrogen (N) uptake based on 50 permanent vegetation plots.
4. Perform soil chemical analysis on soil samples taken in 50 permanent plots in NDW and characterize spatial variation in soil properties.
5. Establish site water balance at NDW and identify source areas for discharge water and hydrologic flow paths.

PROGRESS AND RESULTS

Solution Sampling

Streamwater discharge measurements and solution sampling for chemical analysis has proceeded on its routine weekly/biweekly schedule. Due to quality assurance-quality control concerns regarding the past chemical analysis of the samples (especially cation measurements), updated stream water and soil solution chemistry data will not become available until later in 2000. It is not expected this will necessitate a re-evaluation of the conclusions drawn earlier, notably that (1) nitrate (NO_3^-) is the major anion in stream water; (2) Acid Neutralizing Capacity (ANC) is low and circum-zero (negative to slightly positive); (3) ANC depressions are driven by strong acid anion peaks, e.g., sulfate (SO_4^{2-}) and NO_3^-; (3) pH has remained fairly stable but slightly acid (pH range of 4.1-6.4); (4) hydrochemistry is different between the NE and SW streamlet, suggesting different biogeochemical and hydrological dynamics.

Climate Station

The weather station was installed on the IFS Tower in close proximity to the NDW in August 1998. Climate data, including precipitation, wind speed and direction, solar radiation, air temperature, and relative humidity, have been recorded at 15-minute intervals and hourly and daily averages calculated, with some missing date in November and December 1998. In close proximity to the climate station, Campbell model 107 temperature probes and a Campbell CS615 water content reflectometers were installed in the soil in the A and B horizons, and soil moisture and temperature have been recorded every 15 min during the same period. This information supports the hydrology task, ongoing hydrological and biogeochemical modeling, and will provide a baseline record for local climate at NDW.

Spatial Variability in Overstory N Uptake

The N uptake and retention by the overstory vegetation will be calculated from above-ground biomass increment, nutrient content of the biomass components, estimated belowground nutrient increment, and nutrient return to the soil via litterfall and net throughfall. Reinventory of the 50 plots was completed in Fall 1998. Biomass increment over a 5-year period (1993-1998) typically involves allometric relations with tree diameter (DBH) and tree height. The DBH-height relationships were developed for Fraser fir (*Abies fraseri* (Pursh) Poir.), red spruce (*Picea rubens* Sarg.), and yellow birch (*Betula lutea* Michx. f.) in Virginia's Black Mountains. As DBH-height relationships may be different in the Great Smoky Mountains we measured height on a sub-sample of 30 trees per species, selected randomly within the different size classes and proportional to the DBH frequency distribution within NDW for each species. Tree height was derived from clinometer readings, using calculation methods for sloped terrain. For all three species (fir, spruce, and birch), we found that for a given DBH, tree height was shorter in the Smoky Mountains than in the Black Mountains. Using these refined DBH-height relationships will allow us to estimate the biomass for these stands, as use of the Black Mountain allometrics may overestimate biomass increment, and could result in inflated uptake values.

Since it was impossible to sample all 50 plots for litterfall return and overstory biomass chemistry we selected a subset of 12 plots stratified by leaf area index (LAI) and elevation. Plots were classified into 4 LAI classes (Class 1: 3.44-6.57 $m^2 m^{-2}$; Class 2: 6.58-9.71 $m^2 m^{-2}$; Class 3: 9.72-12.85 $m^2 m^{-2}$; and Class 4: 12.86-16.00 $m^2 m^{-2}$) and 3 elevation bands (low: 1710 to 1770 m; medium: 1800 to 1830 m; and high 1860 to 1920 m). One plot was randomly selected within each of these 12 categories, and potential overstory sample trees identified in close proximity to each plot corner. From this pool of candidates stratified by elevation, 5 sampling trees per species and per elevation band were randomly selected (45 overstory trees total), and the following tissue samples were collected: bole wood, dead and live branches, bark, old and current foliage. Samples have been dried and are currently being processed for chemical analysis.

In each of the 12 plots, stratified by LAI and elevation, 4 litter traps were located 3 m from each corner stake, and litter was collected over a one-year period (Sept. 1998-Aug. 1999), monthly in the fall (Sept., Oct., Nov.) and spring (Feb., Mar., Apr.), bimonthly in summer (Jun., Aug.), and once over the winter. Litter was dried at 65°C and weighed within 48 hours of collection; separated it into 4 categories (needles, foliage, bark and twig, other); and composited by type, by plot, and into two collection periods: Fall (Sept.-Dec.) when most litterfall occurs, and the remainder of the year (Jan.-Aug.). Composite samples were ground and are currently being analyzed for N content. The average annual litterfall biomass for the period September 1998-August 1999 was 3400 kg ha^{-1}, which is within the range of values observed for the spruce-fir forest during the IFS (1770-4040 kg ha^{-1} yr^{-1}). Around 40% occurred as conifer needles and about 20% as hardwood foliage. There was no significant change in litterfall biomass with elevation, but there was a significant decline in the relative contribution of hardwood foliage (from 33 % to 5%), reflecting a change in species composition with elevation (lower abundance of yellow birch). To estimate the litterfall biomass and N return in the remaining plots, we will use the LAI and biomass relationship. There was a general increase in litterfall biomass with LAI, but regression analysis showed a weak ($r^2 = 0.30$), albeit statistically significant ($p=0.07$) relationship. The strength of the relationship could be affected by species composition differences between LAI classes, which needs to be further explored. Litterfall collection at the 12 plots will continue into the next project.

Spatial Variability in Soil Characteristics

Soil samples were taken in 4 sampling points in 50 permanent plots thoughout the NDW (between 1700 and 1950 m), separated into an O and A horizon (0-15 cm) and 10-cm sections in the mineral soil (15-25 cm; 25-35 cm; 35-45 cm, and +45 cm). A earlier soil survey in the NDW indicated the average soil depth for the entire watershed was less than 50 cm. The shallowness of the soils In NDW was also confirmed during the hydrological task and by this sampling. Only 9 out of the 50 plots could be sampled past 45-cm depth, and less than half past 35-cm soil depth. This, in conjunction with the fractured bedrock, is expected to have an influence of water storage and flow routing. All mineral soils are overlain by an O horizon 6-7 cm thick.

The pH has been determined on all soils, and samples are currently being analyzed for Leco C and N analysis. Further chemical analysis will proceed into the next year. All pH's (1:1 water to soil slurry) were in the acid range (pH: 3.1-4.5), and corresponded well with values reported earlier for the nearby spruce Tower plot studied as part of the IFS. Averaged across all plots and elevations, the pH of the O horizon (pH=3.6) was somewhat higher than the upper A-horizon (pH=3.4), but subsequently pH steadily increased with increasing soil depth to an average of pH=4.3 around 45-50 cm depth. There was also a strong elevational gradient, especially in the upper part of the soil profile. Highest pH's were consistently observed in the lower part of the watershed; lowest in the upper part (above 1830 m). The pH decreased gradually with elevation in the O-horizon from 3.9 at 1740 m to 3.4 above 1830 m; in the upper A horizon from 3.6 at 1740 m to 3.3 above 1830 m; and between 15-25 cm soil depth from 3.9 at 1700 m to 3.6 above 1830 m. Below 25-cm soil depth, the elevation effect on soil pH was less consistent and no longer statistically significant. We expect base saturation to follow similar trends with soil depth and elevation.

Even though we know the NDW as a whole system is at stage 2 of N saturation, we are attempting to identify areas acting as stronger or weaker N sources or even sinks for N. Soil N status can be characterized by several static and dynamics indicators including: total and extractable inorganic N in the soil, C/N ratio, relative proportion of available inorganic N in NO_3^- form, net N mineralization, net nitrification and inorganic N leaching. Total N and C/N ratio is currently being determined on the soil samples taken to a depth of 45 cm in 1998. In addition, extractable inorganic N and N dynamics for the upper soil (0-15 cm) were measured in summer 1998 and 1999 by *in situ* incubations at 4 locations per plot (resin core technique, approx. 70 days). N leaching losses during summer (Jun.-Sept.) were estimated using exchange resins placed in the soil. Analytical results from the 1998 field season are currently available; chemical analysis of the 1999 field season are still in progress.

All measures of N status showed significant spatial variation within the NDW, but were not well correlated. Extractable inorganic N concentrations varied 10-to 20-fold across the watershed, ranging between 10-94 ug/g in O and 1.5-33 ug/g in A horizon, without a strong correlation between both indices. Contrary to expectation, NO_3^- -N did not dominate inorganic N but accounted for only 19% of inorganic N in O horizon (range: 3-44%) and 33% in A horizon (range: 5-82%). In both horizons there was only a weak, negative correlation between extractable inorganic N concentration and the relative proportion in NO_3^--N form. The average N mineralization rate for NDW during summer 1998 was 32 kg/ha over 70 days (range: 11-64 kg/ha), 85% of which was net nitrification (range: 6-46 kg/ha). This measurement period (70 days) represents approximately 40% of the annual N transformation rates, an estimated 80 kg/ha (range 28-160 kg/ha) was released annually in the soil via net N mineralization, of which approximately 85% was transformed into mobile NO_3^-. This is well in excess of atmospheric N input estimates for the area (28 kg ha^{-1} yr^{-1}). These findings suggest N saturation is not only due to high atmospheric N deposition rates, but also internal N sources within the watershed, especially since the turnover of stored organic N may be sensitive to changes in climatic conditions.

<u>Watershed Hydrology and Hydrologic Flowpaths</u>
Watershed hydology and hydrologic flowpath analysis was separated into three subareas: establishment of a water balance for NDW, watershed delineation, and estimation of soil hydrologic properties across NDW.

Water balance. Estimation of a water balance is based on an account of all inflows (i.e., rainfall), outflows (i.e., stream runoff and evapotranspiration), and storage (i.e., soil moisture) of water in the basin. Streamflow and precipitation data from 1991 to present were requested from the NDW database at UT. In addition, rainfall at Clingman's Dome were obtained from the NPS. Since reliable estimates of the annual water balance requires as a minimum streamflow and precipitation data for a given period, such estimate was only possible for 1993, 1994, and 1995 from the existing data sets. Small gaps in the record (less than 5% of the annual record) were filled using average values for the month in which the gaps occurred. Rainfall and streamflow data show a range of annual streamflow of 150 to 300 cm, with annual precipitation of 230 to 430 cm. Assuming storage changes become negligible over a relatively long period (i.e., a year or more), the resulting estimated annual evapotranspiration NDW is between approximately 80 and 130 cm. This is consistent with mean annual class A pan evaporation estimates for this region, which give a range of 65 to 115 cm annual evaporation based on a pan coefficient ranging from 0.7 to 0.9. It should be noted that length equivalent streamflow calculations are based on an estimate of watershed area that is subject to further refinement.

In an effort to better characterize the short-term water balance (periods of less than one year) for the NDW, continuously monitoring soil moisture probes were installed at three sites in the watershed for the period of approximately May-October 1999. In addition, 83 sites were established during the same period for biweekly soil moisture mapping measurements using a portable probe. As the streamflow and precipitation data for the corresponding time period are incomplete at present, this part of the task is in progress.

Watershed delineation. The second area of emphasis in characterizing the hydrologic response of the NDW involves the delineation of the watershed boundaries. A 10 m digital elevation map of the area was obtained from the USGS website. In addition, a 5 m digital elevation map of area surrounding the watershed was interpolated with available survey information (Autocad files). A set of contributing area algorithms developed by Dr. David Tarboton (Utah State University) were implemented in an Arcview environment to distinguish the watershed boundaries. The same set of algorithms was applied to further distinguish between the subbasins contributing to the SW and NE streamlets. These calculations resulted in a basin area of 15.23 ha for the NE watershed and 2.92 ha for the SW basin (total basin area: 18.15 ha). These estimates are also subject to further refinement.

Soil hydrological characteristics. In summer 1999, we estimated spatially distributed soil hydrologic properties (such as saturated hydraulic conductivity, porosity, and soil depth) across NDW using the existing framework of 50 plots. These values will be used to interpolate maps of each variable for the NDW, and subsequently as parameters for a spatially distributed hydrologic modeling approach. Porosity values in the table are subject to change based on new estimates of soil mineral density.

Highlights from Networked Sites

GLOBAL CHANGE IMPACTS ON HYDROLOGIC AND BIOTIC INTEGRITY IN NORTHERN ROCKY MOUNTAIN STREAM-WETLAND ECOSYSTEMS

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INTRODUCTION

The focus of this past year's research was to continue our monitoring of essential discharge, water chemistry, and biotic data of the ecologically diverse watershed of Lake MacDonald (2870 ha) in Glacier National Park. We continued to examine the relative roles of geology/geomorphology and climatically-driven variation in hydrology and temperature regimes as over-arching driving mechanisms of biodiversity and ecosystem complexity.

Current velocity, substratum size, fluid dynamics, seston quantity and quality, and thermal regimes have been suggested as major abiotic gradients affecting the distribution and abundance of lotic macroinvertebrates. Changes in thermal regimes associated with discontinuities in a river system resulting from river regulation have been implicated as the primary mechanism influencing the distribution of hydropsychid caddisflies. The distribution of plants and animals has been hypothesized as the consequence of energy balances (i.e., gains vs. losses) across multiple environmental gradients. Since environmental gradients operate at different spatial and temporal scales, the distribution and abundance of organisms appear at distinct spatial and temporal scales. For example, well-defined spatial distributions are readily apparent in plant communities along elevation and moisture gradients.

The purpose of this research was a continuation of our efforts to examine the effects of hydrologic and thermal change in alpine and subalpine streams and associated wetlands in McDonald Creek watershed. During the past seven years we have contributed significantly to the ecological understanding of the stream continuum along the elevation gradient of this drainage. The foundation of this understanding includes detailed hydrologic and thermal monitoring, repeated measures of nutrient concentrations and carbon (C) dynamics, and the distribution and abundance of stream fauna. We conducted a detailed spatial analysis of current velocity, substratum size, sestonic C and nitrogen (N), thermal regimes, and changing abundance of dominant species of the macroinvertebrate community along a mountain stream gradient. Macroinvertebrate distribution and abundance is highly correlated with specific stream elevation and thermal characteristics.

METHODS

McDonald Creek is a fourth order stream draining ~ 400 km^2 of Glacier National Park along the west slope of the Continental Divide. St. Mary's Basin is smaller with a drainage area within the park about half that of the McDonald Basin. Maximum elevation along the Continental Divide between the basins is 2912 m. Lake McDonald, a glacial lake on the valley floor near the McDonald Basin terminus, is at an elevation of 961 m. We monitored discharge, temperature and water chemistry at each of the hydrologic monitoring sites in the McDonald Basin.

To determine the relationships between the distribution and abundance of macroinvertebrates and various abiotic stream gradients, data was collected at 8 sampling sites located sequentially along the 1500 m elevation and 36 km longitudinal stream gradient of McDonald Creek. Benthic samples were collected monthly during summer and fall and once during early spring after ice out, but prior to snowmelt runoff. Abundance of mayflies, stoneflies, and caddisflies at each site was summarized from the annual means of the monthly quantitative collections. Samples were made using the modified kick-net procedure specifically designed for large cobble substratum. We also collected seasonal seston samples that were analyzed for C and N content. Current velocity and substratum size were determined at each of the sampling locations. Small, computerized thermograph recorders were installed near the thalweg at each sample site to collect hourly temperature data over the annual hydrographic cycle.

RESULTS

Temperatures increased significantly along the elevation and longitudinal stream gradient as a function of annual degree-days ($p<0.01$; $r^2 = .96$), maximum summer temperature ($p<0.01$; $r^2 = .92$), and mean summer temperature ($p<0.01$; $r^2 = .91$). In contrast, sestonic C and N concentrations as well as current velocity and substratum size were highly variable between sites and were not correlated with either stream elevation or the longitudinal gradient.

The macroinvertebrates displayed distinct trends in abundance and limits to their range along the stream gradient. Among the mayflies, stoneflies and caddisflies, 27 species occurred abundantly at one or more of the sampling sites. Some species occurred most frequently in the headwater sites. Other species achieved maximum abundance among central reach sites while other species occurred most commonly, and some exclusively, at the lowest, downstream sites. Further analyses of these abundance data revealed most species occurred within well-defined, normal-shaped, Gaussian density patterns. Among these mountain stream macroinvertebrates, the well-defined distribution patterns along the elevation and longitudinal gradient were highly recognizable. Species achieved maximum abundance within central reaches of their range.

A predictable species replacement along the stream gradient occurred commonly among similar taxonomic and functional groups. For example, three species of the mayfly genus *Epeorus* occurred abundantly among different sites along the stream length of McDonald Creek. *E. grandis* were found in the highest densities at the most headwater sites, *E. deceptivus* had the greatest numbers at the central reach sites, while *E. longimanus* had the highest populations at the three most downstream sites. Among the predaceous stoneflies, counts of *Setvena bradleyi* were largest at the most upstream sites while the highest numbers of individuals of *Doroneuria theodora* were located at the lower sites. Patterns of species replacement were perhaps most clearly seen among the net-spinning, hydropsychid caddisflies, in which *Parapsyche elsis* occurred most abundantly at upstream sites and was replaced in dominance by *Arctopsyche grandis* at the most downstream sites.

DISCUSSION

There were two major questions in this study: 1) was the distribution and abundance patterns among similar species and across taxonomic groups were distinguishable and predictable? and, 2) were there any environmental gradients other than stream size or elevation that could account for species specific distribution patterns? Indeed, macroinvertebrate distributions demonstrated patterns of abundance consistent for species distributed across a spatially predictable environmental gradient. Current velocity, substratum size, and the quantity and quality of trophic resources have all been suggested as mechanisms controlling landscape-level distribution and abundance patterns of stream invertebrates. However, we found only temperature, expressed as annual degree-days and maximum and mean summer temperatures as the variables occurring as corollary gradients.

Species with distinctly different rates of energy losses or gains across an environmental gradient will respond with different energy efficiencies. In the central region of a species' distribution, energy efficiencies across gradients are maximized; however, at the extreme ends of the distribution, energy inefficiencies are limiting. In this study, temperature is the primary environmental gradient along a predictable spatial gradient, namely stream size and elevation. For example, we observed *Parapsyche elsis* in upstream reaches, whereas *Arctopsyche grandis*, which is functionally almost identical to *P. elsis*, was the dominant net-spinning caddisfly in downstream reaches. Although we observed these species distributed spatially either in upstream or downstream segments, these species are responding to thermally-mediated spatial distributions and species-specific controls of metabolism. This relationship, demonstrated for these species, can be applied among all macroinvertebrate species such that distribution and abundance patterns along the elevation and longitudinal stream gradient can largely be attributed to species-specific bioenergetics under the spatial control of a predictable thermal gradient.

In conclusion, the lack of a significant longitudinal gradient in flow velocity, substratum and seston and the highly significant thermal gradient support the hypotheses regarding a bioenergetic model structuring present distribution and abundance patterns of stream macroinvertebrates. Regardless of the specific bioenergetic mechanisms producing distribution and abundance patterns, this study underscores the value of macroinvertebrates as ideal indicators of thermal modification that may be associated with change in land-use, riparian vegetation, or climate change.

PARK RESEARCH AND INTENSIVE MONITORING OF ECOSYSTEMS NETWORK: PRIMENet (formerly, Demonstration Intensive Site Project - DISPro)

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INTRODUCTION

In September 1996 the National Park Service (NPS) and the Environmental Protection Agency (EPA) signed an interagency agreement to cooperate on a program of long-term monitoring of environmental stressors (air pollution) in park units, and research stress effects on ecosystems. Fourteen parks are included in the Park Research and Intensive Monitoring of Ecosystems Network (PRIMENet). These parks are representative of major ecosystem types and were chosen because of their status as Class 1 air quality parks.

The NPS is supporting air quality monitoring, including ozone, wet and dry deposition, visibility, and meteorology in the site parks. In addition to the air and water monitoring by NPS, the EPA has added UV-B monitors to determine changes in irradiance that may be affecting human health and ecosystem processes.

The two major contributors to this long-term research and monitoring program are the NPS' Natural Resource Program Center and the EPA's Office of Research and Development. At PRIMENet sites we are cooperating with researchers from other organizations, including the USGS-Biological Research Division, USDA-Forest Service, National Oceanic and Atmospheric Administration (NOAA), and universities, to conduct research relating the effects of atmospheric stressors with ecosystem responses. We are also working with NOAA and USDA to develop quality assurance methods and compare UV instrument results.

PROGRAM STATUS

As of the end on 1999, UV-B monitors and a full complement of air monitors were operating in all 14 selected NPS units (Table 5). This cooperative monitoring program is being complemented by process-level ecological research into the effects of UV on arid-land terrestrial processes and amphibian populations. The annual PRIMENet meeting of park staff, researchers, and EPA liaisons was held in November 1999 in Sequoia National Park. Participants reviewed monitoring and research results with a focus on the amphibian/UV project in six PRIMENet parks. This effort will be complemented in FY 2000 by expanded work on amphibian monitoring and inventories in PRIMENet parks sponsored by the NPS Inventory and Monitoring Program and the USGS National Amphibian Monitoring Program.

Air Quality Monitoring

Fourteen parks are included in PRIMENet: Acadia (ACAD), Big Bend (BIBE), Canyonlands (CANY), Everglades (EVER), Denali (DENA), Glacier (GLAC), Great Smoky Mountains (GRSM), Hawaii Volcanoes (HAVO), Olympic (OLYM), Rocky Mountain (ROMO), Sequoia-Kings Canyon (SEKI), Shenandoah (SHEN), Theodore Roosevelt (THRO), and Virgin Islands (VIIS) National Parks (Table 5). At these sites the NPS is sponsoring air quality monitoring, including ozone, wet and dry deposition, visibility, and meteorology.

Table 5. List of monitoring activity at PRIMENet sites.

National Park	Visibility	Ozone	Sulfur Dioxide	Meteor. Sensors	Wet Deposit.	Dry Deposit.
Big Bend	X	X		X	X	X
Great Smoky Mts.	X	X	X	X	X	X
Olympic		X	X	X	X	X
Rocky Mountain	X	X		X	X	X
Sequoia-Kings Can.	X	X		X	X	X
Denali	X	X		X	X	X
Glacier	X	X		X	X	X
Shenandoah	X	X	X	X	X	X
Acadia	X	X		X	X	X
Canyonlands	X	X		X	X	X
Everglades	X	X		X	X	X
Hawaii Volcanoes	X		X	X	X	
Theodore Roosevelt		X		X	X	X
Virgin Island		X		X	X	X

UV-B Monitoring

Each of the fourteen PRIMENet sites will be equipped with a Brewer spectrophotometer, an instrument designed to measure different wavelenths of light, with a focus on the ultraviolet spectra (UV-B radiation is in the 300-320 nm range of light). These instruments actively track the sun to monitor the variation in solar irradiance and record other data, such as total column ozone and optical density. These data are then used to calculate the dose of UV on the earth's surface. Because of the influence of sun angle, clouds, and other forms of air pollution, the seasonal variation in UV-B detected is large. Therefore, long-term monitoring is needed to detect trends in the incidence of UV-B.

The fourteen NPS sites complement an urban Brewer network of eight U.S. cities. These monitoring devices have also been deployed by Canada and countries on other continents, for a global assessment of the status of the stratospheric ozone layer.

RESEARCH PROJECTS

PRIMENet research projects are designed to investigate the effects of environmental stressors on natural ecosystems. These projects are funded for 1999 and 2000, and results are expected in early 2001. Six of the projects were chosen by a competitive RFA process and the other projects include "in-kind" projects by EPA. The Ultraviolet Radiation/Amphibian Populations Study is a two-year effort to investigate the UV dose in amphibian habitats in six PRIMENet parks: ACAD, GRSM, ROMO, GLAC, OLYM, and SEKI. In three of these parks (OLYM, GLAC, and SEKI) research will focus on pond-dwelling amphibians.

Other PRIMENet-supported research currently inderway includes: 1) below ground ecosystem function: merging long-term climate monitoring with soil, root and foodweb dynamics to understand mechanisms regulating C and N transformations in OLYM; 2) using the inter-relationships of stable isotopes in natural abundance as indicators of environmental stress and ecosystem vitality at BIBE, GLAC, and SEKI; 3) atmospheric deposition in mountainous terrain: scaling up to the landscape at ACAD and GRSM; 4) nitrogen (N) deposition and UV-B stressor impacts in CANY as affected by climatic pulse events; 5) inferring regional patterns and responses in N and mercury biogeochemistry using two sets of gauged paired-watersheds in ACAD; 6) relationships between N deposition and ozone injury to ponderosa pine in SEKI; 7) risk assessment of natural and anthropogenic stressor effects in OLYM; 8) anthropogenic chemical contaminant levels at National Park Index Sites; and 9) standardized monitoring methods for amphibians and associations in time and space between amphibian abundance and environmental stressors in BIBE and SHEN.

THE SHENANDOAH WATERSHED

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Shenandoah National Park (SHEN), located along the crest of the Blue Ridge, is the headwaters for three separate river drainages. Information on the chemical composition of stream waters draining SHEN is obtained through the Shenandoah Watershed Study (SWAS), a research and monitoring program conducted since 1979 in cooperation with the Department of Environmental Sciences at the University of Virginia. The distribution of sampling sites provides geographic coverage and representation of geologic and other landscape factors determining spatial variation in stream water composition within SHEN. The SWAS program objectives are to: (1) improve understanding of the processes governing hydro-biogeochemical conditions in the forested mountain watersheds of SHEN and the central Appalachian region; and (2) detect and assess hydro-biogeochemical change occurring in these relatively pristine systems. The priorities of the SWAS program have been concerned with factors most directly affecting the composition of stream waters. Among these are atmospheric deposition, insect infestation, and forest regeneration. Through the effort to detect, understand, and assess stream water change associated with these and other causative factors, the SWAS program has developed a framework of hydro-biogeochemical information supporting a broad range of ecosystem investigation. SWAS data collection in SHEN includes the following measurements: precipitation quantity and chemical composition (2 sites), stream water chemical composition (14 sites), and stream water discharge (5 sites). Detailed information concerning analysis instrumentation, materials, procedures, and quality assurance criteria used by the SWAS program are listed on the website (wsrv.clas.virginia.edu/~swasftp). A regional context for these data and associated findings is provided through separately funded sampling and analysis of 55 additional streams in the surrounding mountainous region.

Acidic deposition associated with atmospheric emissions may be the most serious threat to ecosystem integrity in SHEN watersheds. Although implementation of the 1990 Clean Air Act Amendments (CAAA) is likely to reduce the impact of acidic deposition on surface water resources in many regions of the United States, certain areas, including the central Appalachian region, remain at risk. The susceptibility of surface waters in SHEN and the western Virginian mountain region has been documented. Evidence for past and ongoing impacts on fish in SHEN includes a strong correlation between community diversity and acid-base chemistry in streams, as well as acidity-related reproductive failure of brook trout (*Salvelinus fontinalis*) observed during in-stream bioassay experiments. A recent analysis suggests deposition reductions provided by the CAAA are unlikely to protect streams in SHEN and western Virginia from further acidification and biological impairment.

Despite the bleak prognosis for SHEN streams, reductions in atmospheric deposition of sulfur, a principal agent of stream acidification, have been observed in the central Appalachian Mountains. The SWAS monitoring program provides a basis for evaluating the benefits of these reductions for SHEN streams and watersheds. To date, trend analyses have been performed for key acid-base constituents using quarterly sample data obtained during the 10-year period of 1988-1997 for 60 streams in western Virginia, including 12 streams in SHEN. Site-specific trend tests were performed using the non-parametric Seasonal Kendall test (SKT) modified to account for serial dependence and estimates of trend slopes were made.

Table 6 provides a summary of trend directions for concentrations of sulfate (SO_4^{2-}) and acid neutralizing capacity (ANC) for all the Virginia streams and the subset of SHEN streams. The mean slopes for trends in SO_4^{2-} and ANC for 60 western Virginia streams are -0.21 and -0.68, respectively. For 12 SHEN streams, the mean slope trend for SO_4^{2-} is -0.67 and ANC is -0.43. In brief, the preliminary analysis of trends indicates that although concentrations of SO_4^{2-} (the acid anion derived through oxidation of sulfur) have declined in many streams there is little evidence for decreasing acidification. This finding is generally consistent with trends in acid-base chemistry reported for acid-sensitive surface waters in other regions of the country. Possible explanations for the lack of recovery, despite decreasing concentrations of SO_4^{2-}, include reduced availability of base cations in watershed soils or in atmospheric deposition. Another possibility, especially in SHEN, is the effect of forest defoliation by larvae of the gypsy moth. Increasing concentrations of nitrate (another acid anion) and decreased ANC following severe defoliation has been observed in one SHEN watershed.

Trend assessment will continue in 2000, with analysis conducted to account for effects of both the gypsy moth infestation and variation in stream discharge. Efforts to infer regional trends will involve examination of trend homogeneity among subpopulations of streams defined by watershed bedrock. The results of this assessment will provide resource managers with an objective basis for evaluating stream water response to changing levels of atmospheric deposition.

Table 6. Summary of trend directions for sulfate (SO_4^{2-}) acid neutralizing capacity (ANC), 1988-1997.

	Virginia Streams (n = 60)	
	No. of general trends	*No. of significant[1] trends*
SO_4^{2-}		
(-) direction	33	8
(+) direction	27	4
ANC		
(-) direction	53	18
(+) direction	7	0

	SHEN Streams (n = 12)	
	No. of general trends	*No. of significant[1] trends*
SO_4^{2-}		
(-) direction	10	5
(+) direction	2	0
ANC		
(-) direction	10	0
(+) direction	2	0

[1] Significant at $p<0.1$

CRATER LAKE NATIONAL PARK LIMNOLOGICAL STUDIES

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STUDY AREA

The lake covers the floor of the Mt. Mazama caldera, formed about 6,800 years ago. The lake has a surface area of 53.2 km^2, a maximum depth of 589 m, and a mean depth of 325 m. Steep caldera walls surround the lake, resulting in a ratio of lake area to watershed area (flat map) of about 3.6. A secondary intracaldera volcanic cone forms Wizard Island, the largest island in the lake. Surface inflow is restricted to more than 40 intracaldera springs and small streams. There is no surface outlet.

LIMNOLOGY OVERVIEW

Crater Lake occupies the collapsed caldera of volcanic Mount Mazama in Crater Lake National Park, Oregon. The watershed area is 67 km^2. Crater Lake is the deepest lake (589m) in the United States and the seventh deepest lake in the world. The water column mixes to a depth of about 200 m in winter and spring from wind energy, but becomes thermally stratified in summer and early fall. The metalimnion extends to a depth of about 80 m; thus, most of the water column is a cold hypolimnion. Secchi disk clarity measurements typically are in the upper-20 to lower-30 m range in the summer and early fall. Concentrations of nutrients are low, although conductivity is relatively high owing to the inflow of hydrothermal fluids. Total chlorophyll is low in concentration, but typically maximal at a depth of 120 m during periods of thermal stratification. Primary production is also low, with the maximum levels occurring between the depth of 40-80 m. Phytoplankton and zooplankton taxa partition the water column to a depth of 200 m in the summer and early fall. Water level, clarity, concentrations of total chlorophyll, primary production, and abundances of zooplankton and introduced kokanee salmon (*Oncorhyncus nerka*) exhibit long-term fluctuations. Based primary on a recent ten-year study of the lake, the lake is considered to be pristine, except for the consequences of fish introductions. Funding from the National Park Service will ensure long-term limnological monitoring of the lake.

OBJECTIVES

The program can be summarized in three broad objectives. First, baseline data will be collected to characterize the limnological conditions of the lake. Second, lake structure and organization will be defined in order to develop reliable relationships among physical, chemical, and biological components of the ecosystem. Third, lake conditions will be evaluated for change. If change is detected, special studies will be initiated to determine the amount of change, the possible causes, and consequences. If the changes are determined to be anthropogenically driven, appropriate mitigation measures will be recommended.

Although the three broad objectives are useful for general discussion and program direction, project selection requires the initial development of conceptual models. The first model illustrates the general components and the broad relationships between components within the ecosystem, such as the interrelationships among climatological, terrestrial, anthropogenic perturbations, and lake characteristics. The focus of the second model is the within-lake aspects of the ecosystem, which is the only part of the caldera ecosystem.

Research History
Aquatic studies at Crater Lake from 1896 to the mid-1950s consisted mostly of short-term evaluations of physical, chemical, and biological features. Although these studies were fragmentary in nature, several characteristics were defined: the lake was ultraoligotrophic (nutrient poor), exceptionally deep (589 m), and extremely clear. Studies undertaken from 1959 to 1969 were more detailed than the earlier studies and provided additional information on morphometry, optical properties, sediments, fluctuations of the water level, water budget, and general limnological characteristics, as well as the initial documentation of chlorophyll concentrations, primary production, phytoplankton, and zooplankton. These studies reaffirmed the ultraoligotrophic status of the lake. Results from studies conducted from 1978 to 1981 indicated a possible decline in lake clarity and possible changes in the species composition and vertical distribution of the phytoplankton community. Verification of these changes was not possible because little historic information existed, and sampling techniques and methods varied over time. Nonetheless, the suggestion of possible changes in the lake led to a Congressionally mandated, 10-year monitoring and research program, beginning in the fall of 1982, to investigate the overall water quality of Crater Lake.

The goals of the 10-year monitoring and research program were to 1) develop a reliable quantitative limnological database for future comparison; 2) develop an understanding of the physical, chemical, and biological features of the lake; and 3) establish a long-term monitoring program to examine the characteristics of the lake through time. If changes in the lake condition were detected, studies were to be designed to identify the causes, and mitigation measures were to be recommended.

At the end of the 10-year study, researchers concluded Crater Lake was a complex and dynamic system with considerable seasonal and annual variability. The only change caused by human activities specifically identified or separated from those caused by natural phenomena was the introduction of fish between 1888 and 1941. This affected the food web in the lake. Although the possibility of long-term changes in the lake could not be dismissed, researchers regarded such changes to be too subtle for detection over a time scale represented by the data.

The 10-year study documented many of the components and processes important to lake clarity and the lake system as a whole. Long-term change could not be fully evaluated because very little historical data were available to compare with the detailed database assembled during the 10-year study. This situation underscored the need for a long-term monitoring program to evaluate future change against the benchmark set in the 10-year study. Implementation of the proposed long-term monitoring program at Crater Lake required additional funding. Such funding was available starting in the 1994 field season. The sampling program in 1994 followed the protocols established during the 10-year study, except trace element samples were collected only in August. Spring samples were collected to continue monitoring for changing levels of nitrate after the rim sewage facility was disconnected in 1990 and to assess any possible contamination from construction activities at Rim Village.

CURRENT INVESTIGATIONS

The field season was completed as planned, and the lake was sampled in July, August, and September. The study included water quality (temperature, pH, alkalinity, conductivity, and dissolved oxygen), nutrients (phosphorus and nitrogen species), optical properties (Secchi disk, photometer, and turbidity), chlorophyll, primary production, phytoplankton (species, abundances, and biomass), zooplankton (species, abundances, and biomass), and fish (species and abundances).

Secchi disk clarity measurements ranged from 24.1m in August to 36.6m in July. Water quality and nutrient concentrations were consistent with results obtained since 1982. Chlorophyll concentrations were low relative to data collected between 1984 and 1991. Phytoplankton densities were also low relative to those between 1988 and 1996. Zooplankton densities were low and comparable to samples collected in 1993.

Preliminary results from the study continues to illustrate the lake is complex, dynamic, and unproductive. There are no signs of long-term changes of any variable. The monitoring program emphasizes the interrelationships among environmental, terrestrial, and aquatic components of the lake system. Future work will continue to focus on an ecosystem approach and the development of additional conceptual models. The task of integrating the lake's water column based on our conceptual box models has begun. A major effort was initiated to develop a data management program for the backlog of data collected since 1982. Our goal is to assemble the lake monitoring data into a database.

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