2003

Blue Planet Prize

Dr. Gene E. Likens (U.S.A.)
President and Director, Institute of Ecosystem Studies

Dr. F. Herbert Bormann (U.S.A.)
Oastler, Professor of Ecosystem Ecology, Emeritus, Yale University

Dr. Vo Quy (Vietnam)
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To the Earth, Our Home:
When did humanity begin to live away from the ground that had nurtured all life in the world apart from other creatures? At the 2003 Awards Ceremony of the Blue Planet Prize of its12th year, opening film expressed the desire that humanity would take a new look at the planet earth, as our home, the place for us to return to.

Dr. Jiro Kondo, chairman of the Presentation Committee explains the rationale for the determination of the year's winners

His Imperial Highness Prince Akishino delivering congratulatory speech

Dr. Hiroyuki Yoshikawa, chairman of the Selection Committee makes a toast at the Congratulatory Party

Their Imperial Highnesses Prince and Princess Akishino at the Awards Ceremony

The prizewinners meet the press

Howard H. Baker Jr., Ambassador of the United States of America to Japan and Vu Dung, Ambassador of Vietnam to Japan, congratulate the laureates

The prizewinners receive their trophies from Chairman Seya

Dr. Gene E. Likens and Dr. F. Herbert Bormann

Dr. Vo Quy

Profile

Dr. Gene E. Likens and Dr. F. Herbert Bormann

Dr. Gene E. Likens
President and Director, Institute of Ecosystem Studies
Dr. F. Herbert Bormann
Oastler, Professor of Ecosystem Ecology, Emeritus, Yale University

Dr. Gene E. Likens
Education and Academic and Professional Activities

1935	Born on January 6 in Pierceton, Indiana, USA
1957	Graduates from Manchester College
1962	Obtains his Ph.D. in Zoology, University of Wisconsin-Madison
1963	Instructor, Department of Biological Sciences, Dartmouth College, and prommoted to Assistant Professor
1969	Associate Professor, Section of Ecology and Systematics, Cornell University
1972-1983	Professor, Section of Ecology and Systematics, Cornell University
1983-1993	Vice President, The New York Botanical Garden
1983-present	President and Director, Institute of Ecosystem Studies
1984-present	Professor of Biology, Yale University
1985-present	Professor, Graduate Field of Ecology, Rutgers University
1981	Elected, National Academy of Sciences
1993	Tyler Prize - (with Dr. F. H. Bormann)
1994	Australia Prize for Science and Technology
2001	National Medal of Science

Dr. F. Herbert Bormann
Education and Academic and Professional Activities

1922	Born on March 24 in New York City, New York, USA
1941	Enters the University of Idaho and mustered out of Navy
1946	Enters Rutgers University and graduates in 1948
1948	Enters Duke University and obtains his Ph.D. in 1952
1952	Assistant Professor, Emory University
1956	Assistant Professor, Dartmouth College
1962	Professor of Botany, Dartmouth College
1966-1992	Oastler Professor of Ecosystem Ecology, Yale University
1992-present	Professor Emeritus and Senior Research Associate, Yale University
1973	Elected to the U. S. National Academy of Sciences

1992 International St. Francis Prize for the Environment.
1993 Tyler Prize. (with Dr. G. E. Likens)

The 40-year Hubbard Brook Ecosystem Study arose from an idea conceived by Dr. Bormann. As a botany professor at Dartmouth College in 1960, he proposed to Dr. Robert S. Pierce (deceased), Project Leader of hydrologic station at the Hubbard Brook Experimental Forest (HBEF) of the U. S. Forest Service in the White Mountain National Forest in New Hampshire, that by measuring streamwater nutrient concentrations it would be possible to estimate nutrient outputs for entire forested watershed-ecosystems. This simple but powerful model allowed the use of small watersheds to quantify the connection between forest ecosystems and the larger biogeochemical cycles of the earth.

Gene E. Likens, who specialized in experimental limnology (the study of lakes and streams) joined the faculty in the Department of Biological Sciences at Dartmouth College in the fall of 1961. Thus, in a wonderful set of serendipitous circumstances, Bormann, a forest ecologist, and Likens, an aquatic ecologist, joined forces.

Dr. Likens invited Dr. Noye M. Johnson (deceased), a geologist, to join in their proposal. In 1963, the National Science Foundation funded their proposal. Thus, The Hubbard Brook Ecosystem Study was initiated.

In the 1960s, Drs. Bormann, Likens, Pierce, and Johnson formed the core of the small group that initiated ecosystem and biogeochemical studies. The Hubbard Brook Ecosystem Study continues to be productive and vibrant to this day.

As of 2003, more than 60 principal researchers have participated along with scores of Ph.D. students, and research at Hubbard Brook has resulted in over 1,200 published articles and six books.

Some of the major contributions of The Hubbard Brook Ecosystem Study to science and to the management of natural resources are as follows.

1. Research from The Hubbard Brook Ecosystem Study offered to the scientific community a new way to evaluate nutrient cycling in whole, intact or manipulated, terrestrial ecosystems.
2. Based on observation, experimentation and the Jabowa computer model, they developed a biomass accumulation curve for the northern hardwood forest. This finding has great implications for estimates of the rates at which forests can remove carbon dioxide from the atmosphere.
3. The HBES has demonstrated that the small watershed technique can be used to evaluate the effects on ecosystems of such factors as air pollution, timber harvesting, ice storms, and climate change.
4. One experiment revealed that deforestation not only resulted in a large increase in stream flow but also in loss of nitrate at rates 40 to 50 times higher than preharvest levels. Long-term study indicated that nearly ten years were required for streams to return to preharvest levels. These findings resulted in a substantial national debate on forest harvesting methods.

5. Discovery of acid rain in North America. The continuous analyses of precipitation since 1963 demonstrated the link between the use of fossil fuels in North America and increased acidification of rain and snow. This discovery prompted the world's first international symposium on acid rain. These data subsequently contributed to the 1990 Clean Air Act Amendments in the United States. Moreover, it made it clear that acid rain leaches calcium from the forest soil. This leaching deprives the soil of nourishment and buffering capacity and causes major damage to forest and aquatic ecosystems.

From the beginning of the HBES, Drs.Likens and Bormann, by a variety of means, seminars, and newspaper and magazine interviews, have tried to make the connection between science and policy clear to the public. To achieve these ends, they joined with others to form The Hubbard Brook Research Foundation which functions to connect science and policy.

Essay

Surprises from Long-term Studies at the Hubbard Brook Experimental Forest, USA

Dr. Gene E. Likens

Introduction

Long-term records of ecological phenomena are rare and very difficult to obtain, but they provide unique insights into how an ecosystem, if not the world, works. As such, these records are a critical component of overall ecological inquiry (Likens 1989a, 1992; Carpenter 1998; Lovett *et al*. 2006). Long-term records are usually developed through monitoring of ecosystem parameters (optimally guided by questions, not mindless collection of data), but statistically-valid records of high quality are difficult to develop and sustain over long periods. Thus, there are relatively few records of long duration and high quality, which have had frequent and careful scrutiny. Indeed, the integrity and application of quality assurance/quality control (QA/QC) protocols are key to the success of long-term studies (see Buso *et al*. 2000; Lovett *et al*. 2006; Hirsch *et al*. 2006). Without high quality QA/QC, long-term records are, for the most part, seriously compromised.

The pioneering efforts at Rothamsted, UK (Lawes Agricultural Trust 1984) and of the United States Weather Service come to mind as exemplary models. In the last 3 decades or so in the United States, there have been attempts to initiate and sustain long-term studies, e.g. Long-Term Research in Environmental Biology (LTREB), Long-Term Ecological Research (LTER), Atmospheric Integrated Research Monitoring Network (AIRMoN), Clean Air Status and Trends Network (CASTNeT). In spite of the documented value of such efforts (Likens 1989a) they are supported by fickle finances, and thus are difficult to maintain.

From a survey of some 100 ecologists involved in long-term research, Strayer *et al*. (1986) found that the survival of long-term research was primarily dependent on the dedication and longevity of one or a few project leaders. Another key ingredient for maintaining long records of high quality is the frequent examination and use of these data, that is, this is the primary way that errors, artifacts, or other problems are discovered, and enthusiasm is sustained. Moreover, it is much easier to resolve a problem in long-term data when it is identified in a timely fashion, while observers and methods are still available for examination. New sensors, modified or new analytical procedures and real-time data can add significantly to long-term data (Hirsch *et al*. 2006), but offsets and glitches generated by new methodology are a common problem in long-term data sets and must be addressed carefully. In the long-term Hubbard Brook Ecosystem Study, we don't replace an analytical method or a procedure with a new one without first overlapping the two for many months or more than a year in order to compare results (Buso *et al*. 2000). Also, many samples are stored for later analysis to help reconcile problems and to enable new questions to be pursued when new technology becomes available (e.g. see Alewell *et al*. 1999). Some requirements for long-term studies are given in Table 1.

Table 1. Requirements for long-term studies. [From Likens 2001b and based in part on Likens 1983 and modified from Likens 2001c].

(1)	Continuous data sets must be constantly updated, scrutinized for errors and rigorously reviewed.
(2)	Methods and procedures should be standardized to the extent possible, and intercalibrated with other organizations or individuals doing similar studies. Calibration of analytical results should be done by comparison against standardized samples.
(3)	Full data sets should be stored in at least TWO separate locations to avoid accidental loss.
(4)	Analytical methods or collection procedures should not be changed without testing fully the effect of the new procedure on the long-term record.
(5)	Methods or procedures developed for one location or study should not be adopted for another area or study without careful testing and justification.
(6)	The best frequency for sampling in a time series should be determined on the basis of questions addressed and from analysis of results. Duration of measurements must be at least as long as the phenomenon being evaluated, or scaled to the frequency of the event being studied.
(7)	Plots and other study sites should be marked and identified permanently. Detailed descriptions of the area and the methodology should be on file in more than one location. Sufficient detail should be provided so that other investigators could reproduce calculations, methods, etc., at some later date.
(8)	Appropriate and adequate controls must be established at the beginning of the study.
(9)	Provision should be made for the long-term storage of samples.

(10) Stability, interest and dedication of responsible individuals, institutions or agencies are critical to success of long-term studies.

(11) Funding should be sustained and reliable.

(12) Long-term data sets should be *used* to answer questions.

Surprises Revealed From Long-Term Data at the Hubbard Brook Experimental Forest

There have been many new insights revealed from the examination of long-term data collected in the Hubbard Brook Valley [43°56'N, 71°45'W] in the White Mountains of New Hampshire, USA. Many of them were surprises to us about how ecosystems function, and were helpful in evaluating the effectiveness of Federal regulations. Currently, many ecological records in the Hubbard Brook Valley extend for 55 years, and the continuous long-term records of precipitation and streamwater chemistry (43 years through May 2006) are the longest in the world. Nevertheless, it could be argued convincingly that these records would be even more valuable if they were twice as long, or more!

Surprises are defined as, something "to come or fall upon suddenly or unexpectedly" or another definition that I like better is, "to strike with wonder and astonishment…, to astound." (Webster's New Universal Unabridged Dictionary, 2nd edition, 1983). The converse is; what did we expect to find from long-term study that we did not find?

Here, I present a few brief examples of the more "astounding" results from the long-term efforts of the Hubbard Brook Ecosystem Study.

Acid Rain

Probably the biggest surprise from our long-term research at the Hubbard Brook Experimental Forest was the discovery that "natural" rain was so acidic. The first sample of rain we collected in July 1963 had a pH of 4.25! At the time we didn't know why the rain was so acid, or what it meant.

As part of our study's protocol, samples of rain and snow were collected and chemically analyzed in an effort to measure all inputs to the watershed-ecosystem at the Hubbard Brook Experimental Forest (Bormann and Likens 1967). It required many years, discussions with colleagues, and samples we collected in other areas of the northeastern U.S. before we understood that our results on rain from the Hubbard Brook Experimental Forest were an unusual phenomenon of great ecological importance (Likens *et al*. 1972; Likens 1989b). Because of the variability associated with weather, air-mass trajectories and diverse pollutant loadings to the atmosphere, it required 18 years of continuous monitoring to determine statistically that the acidity of precipitation at the Hubbard Brook Experimental Forest had increased with time and in response to Federal legislation designed to reduce the emissions of sulfur dioxide (SO_2) to the atmosphere (Fig. 1) (Likens 1989b; Likens *et al*. 2001).

Short and Long-term H+ trends

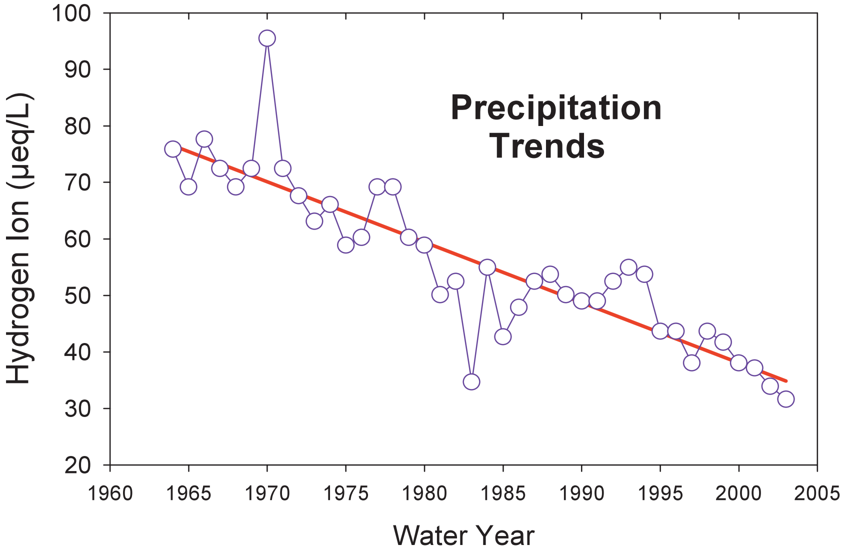

Figure 1. Annual, volume-weighted hydrogen-ion concentration in bulk precipitation at the Hubbard Brook Experimental Forest, New Hampshire. The line represents a linear regression at $p<0.05$ (updated from Likens 1989b).

Our long-term research now has contributed to the understanding of this environmental problem and to the management of it. For example: long-term research at the Hubbard Brook Experimental Forest has shown that: *i.* Changes in emissions of sulfur dioxide, SO_2 (a major precursor to acid rain), as a result of Federal legislation, are strongly correlated with changes in sulfate concentrations in precipitation and stream water at the Hubbard Brook Experimental Forest (Likens *et al*. 2001, 2002, 2005); *ii.* Nitric acid is increasing in importance in precipitation at the Hubbard Brook Experimental Forest and is predicted to be the dominant acid in precipitation within 5 to 10 years without further controls on emissions of SO_2 and NO_x (Likens and Lambert 1998; Likens 2004); *iii*. In sharp contrast to predictions from the decade-long, U.S. National Acid Precipitation Assessment Program calcium and other plant nutrients have been markedly depleted in the soils of the Hubbard Brook Experimental Forest as a result of acid rain inputs (Likens *et al*. 1996, 1998); *iv*. As much as one-half of the pool of exchangeable calcium in the soil has been depleted during the past 50 years by acid rain (Likens *et al*. 1998); and *v*. As a result of these losses in soil buffering, the forest ecosystem is currently much more sensitive to acid rain impacts than previously thought (Likens *et al*. 1996, 1998; Likens 2004).

Depletion of Base Cations from the Soil

We were surprised to learn that acid rain had significantly depleted magnesium, and especially calcium from the soils at the Hubbard Brook Experimental Forest (Likens *et al*. 1996, 1998).

This depletion effectively increased the sensitivity of these soils to continuing inputs of acid from atmospheric deposition by depleting the buffering capacity of the soil. It is estimated that some 850 kg Ca/ha were leached from the soils of the Hubbard Brook Experimental Forest by acid rain between 1940 and 1990 (Likens *et al*. 1996, 1998).

Forest Biomass Accumulation

A truly surprising finding from the long-term studies at the Hubbard Brook Experimental Forest was that the forest stopped accumulating biomass after 1982 (Fig. 2; Likens 2001b; Likens *et al*. 1994, 1996, 1998).

Forest biomass accumulated steeply from 1965 to 1982, but since 1982, accumulation has been flat, possibly even declining slightly (Fig. 2). This surprising result led to a whole-stream manipulation and a major watershed manipulation with a calcium-rich mineral, Wollastonite ($CaSiO_2$), at the Hubbard Brook Experimental Forest in June 1999 and October 1999, respectively (Peters *et al*. 2004; Likens *et al*. 2004).

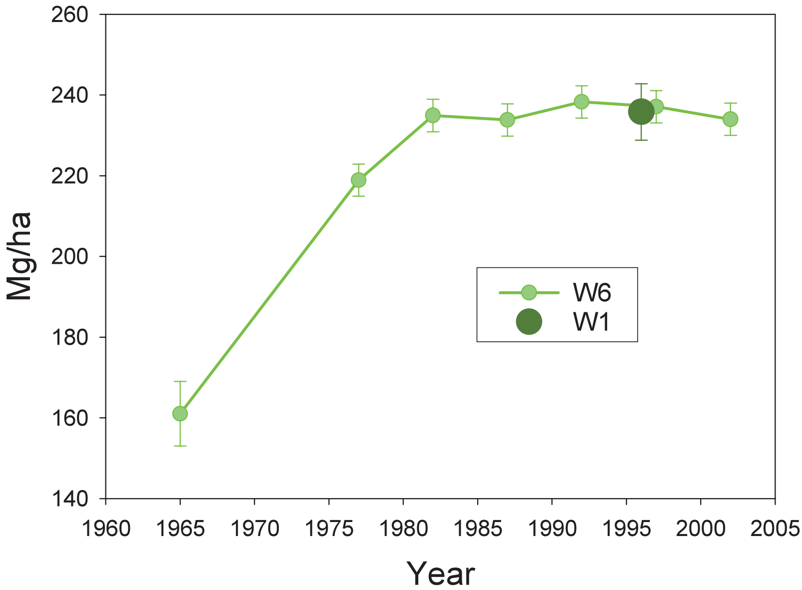

Figure 2. Accumulation of living, aboveground biomass for Watersheds 1 and 6 of the Hubbard Brook Experimental Forest, New Hampshire (based on Whittaker *et al*. 1974; Bormann and Likens 1979; Likens *et al*. 1994; T. G. Siccama, unpublished data; and updated from Likens 2001b). The bar around each point represents the standard error of the mean.

Algal Blooms

Some 40 years ago, careful examination revealed no algae in streams of the south-facing watershed-ecosystems at the Hubbard Brook Experimental Forest. We were surprised by this lack of attached algae, but assumed that it was due to heavy shade from the surrounding forest and low nutrient content of the stream water. In the mid 1980s, Mayer and Likens (1987) found algae in Bear Brook and then Bernhardt and Likens (2004) observed blooms of attached, filamentous algae in headwater streams subsequent to snowmelt and prior to canopy leaf out of the deciduous forest on south-facing watershed-ecosystems. More recently, blooms of attached algae have been observed in the main Hubbard Brook (Fig. 3), a fifth-order stream draining the Hubbard Brook Valley. Possible explanations for this surprising change include thinning of the overstory canopy due to increased tree mortality, which may result in warmer, streamwater temperatures and more light reaching the stream earlier in the spring (Bernhardt *et al*. 2005).

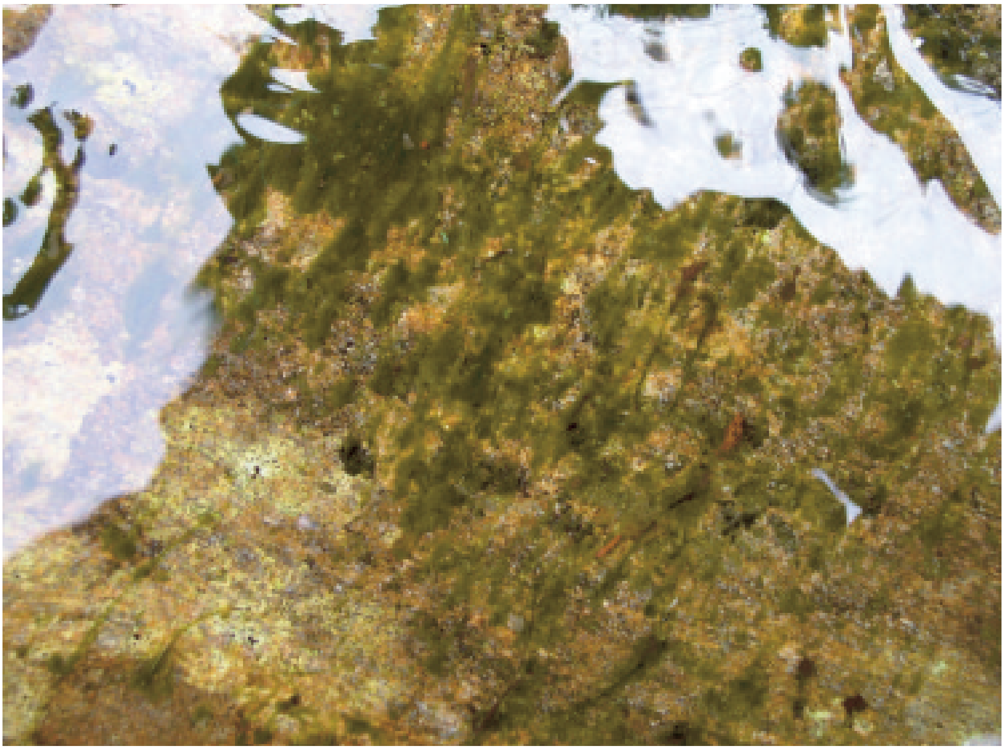

Figure 3. A photo of attached, filamentous algae in Hubbard Brook, a fifth-order river draining the Hubbard Brook Valley, New Hampshire. (Photo by D. C. Buso on 28 April 2006).

Atmospheric Inputs and Watershed Nutrient Retention

Long-term studies revealed the surprising capacity of undisturbed, forested watershed-ecosystems to retain nutrients (e.g. N) critical to forest growth. Following disturbance (e.g. cutting, ice-storm damage, soil frost) large amounts of N may be lost in stream water (Likens *et al*. 1970; Bormann *et al*. 1974; Bormann and Likens 1979; Likens and Bormann 1995; Mitchell *et al*. 1996; Houlton *et al*. 2003; Bernhardt *et al*. 2003). Retention in this case refers to <u>net</u> retention (inputs from atmospheric deposition > losses in stream water).

Surprisingly, and in sharp contrast to predictions (Vitousek and Reiners 1975), NO_3^- levels in stream water at the Hubbard Brook Experimental Forest are currently at their lowest value during our 43-yr record in spite of forest maturation and lack of biomass accumulation (Likens 2004; Bernhardt *et al*. 2005).

Other chemicals are also strongly retained by forested watershed-ecosystems at the Hubbard Brook Experimental Forest including hydrogen ion, chloride and phosphorus (see Likens and Bormann 1995; Likens 2004). Surprisingly, atmospheric deposition provides a major source of these chemicals and others, to the watershed-ecosystems of the Hubbard Brook Experimental Forest.

Significantly, ecologically important inputs of many nutrients in watershed-ecosystems, including base cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+), are derived from atmospheric deposition even though the primary source is weathering of geologic substrates (Likens and Bormann 1995; Likens *et al*. 1994, 1998; Likens 2004; Gorham 1955).

Chloride as a Conservative Ion

Initially, our assumption was that chloride (Cl^-) should be conservative (no long-term storage or "sudden" release from storage pools). However, long-term studies surprisingly revealed that Cl^- is not conservative. For example, losses in stream water significantly increase following disturbance, such as forest cutting, in the Hubbard Brook Valley (Lovett *et al*. 2005). This finding raises important questions about the biogeochemistry of Cl^- and its use as a conservative tracer in experimental manipulations.

Ice Cover on Mirror Lake

Systematic observations on the duration of ice cover on Mirror Lake near the mouth of the Hubbard Brook Valley were begun in the mid 1960s (Fig. 4). Surprisingly, with time the date when the ice cover (ice out) on the lake melted has occurred earlier each April, so that now the duration of ice cover on the lake during the winter is some 20 days less than it was in the mid 1960s (the date for the onset of ice cover each year has remained about the same). This surprising change has been related to global warming (Likens 2000), and has been found in other lakes and rivers throughout the world (Magnuson *et al*. 2000).

What surprises are expected (an oxymoron) in the future? There probably will be many, and a few are listed here:

[*1*] Will depletion of Ca^{2+} and Mg^{2+} from the soil of the Hubbard Brook Experimental Forest decline in response to reduced sulfur loading from the atmosphere and decreased storage of Ca^{2+} and Mg^{2+} in forest biomass?

[*2*] Will the chemistry of the main Hubbard Brook (reflecting a valley-wide response) continue to change or reach a steady-state value as a result of reduced sulfur loading from the atmosphere?

[*3*] Will NO_3^- become the dominant acid anion in precipitation and what will be the ecological ramifications?

[*4*] Will NO_3^- concentrations in stream water increase during the growing season with the cessation of forest biomass accumulation.

High quality, long-term data, accumulated into the future, will be instrumental in addressing these interesting and ecologically-important questions.

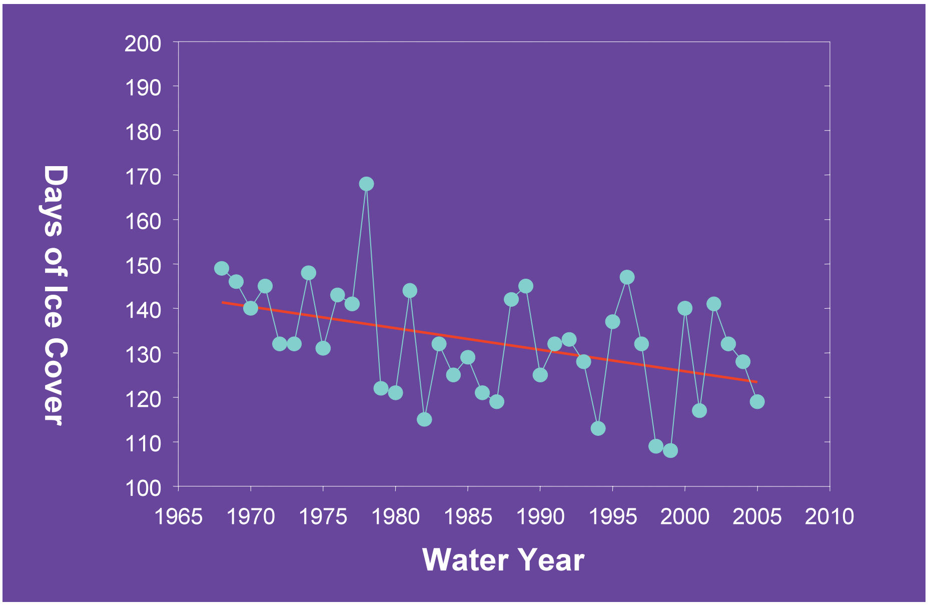

Figure 4. Duration of ice cover from 1967 to 2006 in days on Mirror Lake within the Hubbard Brook Valley. The linear regression has a slope of -0.48 ($r^2 = 0.18$; $p = 0.009$). [Updated from Likens 2000b].

Summary

There are many other "discoveries"/"surprises" from our long-term studies in the Hubbard Brook Experimental Forest, but the examples given here are astonishing to me. Some additional discussion about our long-term results has been presented elsewhere (see, e.g. Likens 2004). Nevertheless the point is clear, long-term data and long-term studies are critical for revealing ecosystem functions that either would be difficult to discover or possibly not revealed from short-term studies.

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Lecture

Environmental Challenges in the 21st Century and Our Respect for Nature

Dr. Gene E. Likens and Dr. F. Herbert Bormann

Introduction

We are deeply honored and proud to have been chosen for the Blue Planet Prize in 2003. This prestigious honor reflecting the Asahi Glass Foundation's goal to "work toward protecting our planet from human-made demise, ensuring that the natural environment continues to exist for tomorrow's generations," is especially meaningful to us after 40 years of research to understand how ecosystems work and how human activities may disrupt their working to society's disadvantage.

From a satellite our Blue Planet looks benign and placid as it hurtles through hostile space. That view is deceiving as our planet's surface is extraordinarily dynamic with constant exchanges between it's atmosphere, hydrosphere, geosphere, and biosphere. It is upon these processes of exchange, mostly directly and indirectly driven by solar energy, that all life depends and through time, evolution adapts life to new conditions as our planet ages and moves toward some ultimate destiny (Figure 1).

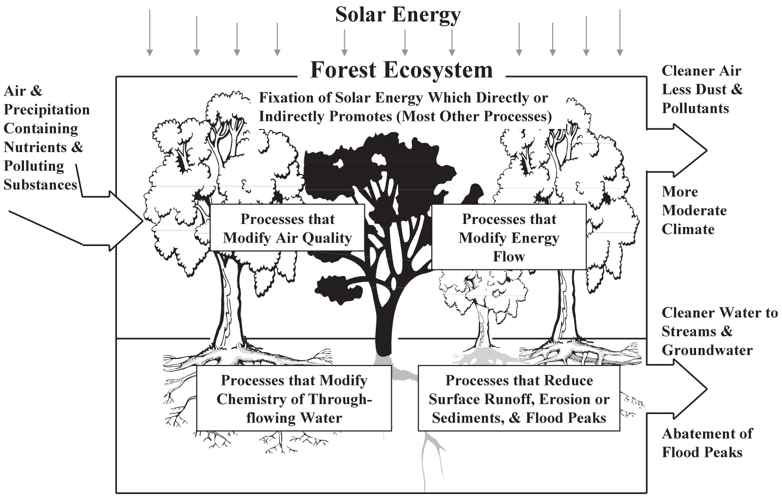

Figure 1. Some uses of solar energy by the forest ecosystem in regulating ecosystem function and biogeochemical cycles. [Modified from Bormann 1985].

As human societies have evolved from hunter-gatherers to space travelers they have become a force of change with a potency equivalent to a major geological event like continental glaciation. As our human numbers and our skills increase and promise to increase even faster in the 21st Century, and as our activities push wild nature more and more into the background, thoughtful persons, scholars, scientists, laymen, business persons, theologians, and poets have begun to question how long this degradation can continue before human societies collapse in the face of some new environment we have created, an environment that may be inimicable to further growth of human societies or at the least, inimicable to the sustenance of human dignity, which all humans seek.

Concepts of limits to growth and sustainable systems are being debated everywhere. To evaluate such ideas, it has become apparent that we need much more information on how the natural systems of the world work! This is an incredibly complex task involving not only science but also economics, social studies and politics with the understanding that answers must be in a systems format where changing one component will reverberate throughout the ecosystem. The widespread public conception that science can provide piecemeal "yes" or "no" answers has little applicability in understanding how the world really works.

Vaclav Havel calls this the "Modern Age," an "Age" with a central tenet of belief in the inevitable dominance of humans over the rest of the world, a belief that the world is a wholly knowable system governed by a finite number of laws that humans can grasp and rationally direct for their own benefit. The goal of science and technology in the "Modern Age" is to find a universal theory of the world, and thus a universal key to unlock it's prosperity. Nature under this paradigm is a commodity to be bought, sold and manipulated with little consideration of effects on naturally-occurring processes that in the end govern how the world works.

The "Modern Age" began with the development of technology to use energy locked in fossil fuels. Energy from fossil fuels freed humans from their sole dependence on solar energy, the way of all previous human history, and opened exciting new areas of activity. This "Age," which many regard as humanity's finest hour, has been marked with an endless succession of human achievements. Science and technology have recorded successes undreamt of in the Eighteen Century. Marvels of human infrastructure are found everywhere in the world, health care and agriculture have made incredible advances, and we are now passing from the industrial revolution to the information revolution. In material terms the quality of life for many people is at its highest level ever.

With this cornucopia of human benefits came the power to alter environmental processes of the Earth in ways menacing to the survival of a great many organisms on the planet. From the narrow perspective of human welfare, we might think of this response as nature's backlash to the "Modern Age." Many fear that today's level of environmental degradation already threatens our human future.

Unlike any previous time in Earth's history one species – humans – has come to monopolize the use and availability of our planet's resources. Humans now number more than 6.3 billion and are expected to reach 8 to 10 billion in the next 50 years or so. Where will this number find adequate and affordable supplies of fresh water, clean air and nourishing food? And, how will the distribution of wealth, natural resources and quality of life play out as humans increase in number, activity and interactions throughout the globe? Questions such as these will drive major environmental challenges in the Twenty-First Century.

Human-accelerated environmental change (Figure 2), such as global climate change, toxification of the biosphere, the spread of infectious disease and alien species, loss of biodiversity, and particularly the all-pervasive land-use changes are serious in themselves, but their interactions and acceleration by human population growth and increased activity of humans represent a daunting challenge for sustainability of all species, including survival of human societies.

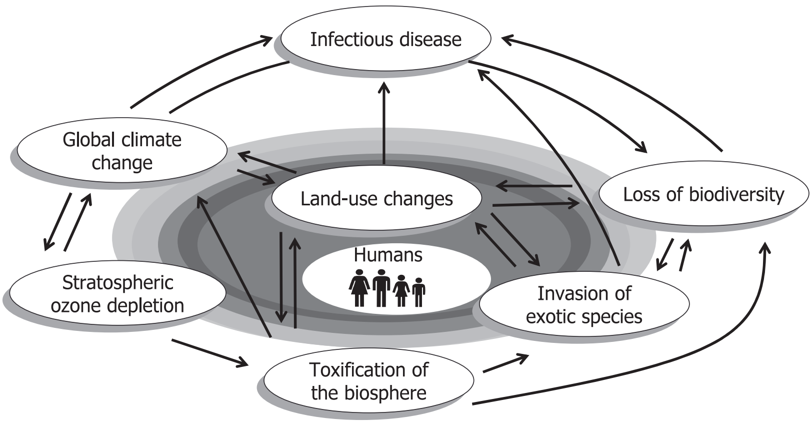

Figure 2. Interactions among the major components of human-accelerated environmental change. [Modified from Likens 1994].

The study of ecosystems as units of nature provides critically important "windows" on ecosystem function and on environmental problems and change. Currently, there is great demand for scientific information at large scales (the whole biosphere, regions and landscapes), as often it is more realistic to apply information gained from large-scale research to widespread environmental problems and management issues.

In 1960, F. Herbert Bormann in a letter to Robert S. Pierce, proposed the use of small watershed-ecosystems for the study of ecosystem functions and the connection of the ecosystem to the atmosphere and hydrosphere. But it was not until Gene E. Likens and Herb Bormann, a plant ecologist, joined their diverse talents that the small watershed technique became a functional reality. Likens, an aquatic ecologist, brought ecosystem research experience, extraordinary energy, and what was to develop into a deep understanding of how a complex multidisciplinary study should be conducted.

Forty years ago, we instituted the small watershed-ecosystem approach to the study of natural landscapes. Our approach allowed direct measurement of the linkage between the atmosphere, the geosphere or watershed-ecosystem, and the hydrosphere. It allowed estimates of how the biosphere influenced these relationships. Answers to important ecological questions about air and water quality, forest growth and sustainability, and ecosystem structure and function in complicated natural landscapes are difficult to obtain. We believed that the watershed-ecosystem approach would provide an important "window" for tackling such problems.

Our initial approach to this conundrum took the form of an analogy. We postulated that we could use the chemistry of stream water draining out of a watershed like the diagnostic approach a physician uses in measuring the chemistry of blood or urine of a human patient. We also needed to determine, simultaneously and quantitatively, all chemical inputs to the watershed-ecosystem (Figure 3). Such input-output measurements allowed calculation of nutrient budgets (mass balances) for the ecosystem. Then, combined with experiments at the watershed scale, and because experimentation is such a powerful tool in science, we were able to address quantitatively, diverse environmental questions at a watershed/landscape scale. Using this watershed approach, we launched the Hubbard Brook Ecosystem Study.

Measurement of inputs to our small, naturally-occurring forest ecosystems (12 to 40 ha in size), provided a measure of how the atmosphere influenced the forest and interlinked stream ecosystems through it's input of rain, snow, particles and gases, and associated chemicals. This feature of our research became of great importance since we quickly realized that the atmosphere was laden with pollutants from distant human activities.

The chemical and hydrological measurement of output waters allowed us to determine how water passing through the watershed-ecosystem was altered by the ecosystem and, in turn altered the ecosystem. Analysis of output water, like analysis of blood and urine in humans, became a measure of the "health" of the ecosystem, providing insights into the basic functions of the ecosystem. Since output water was linked to the local and regional hydrosphere, our output measurements provided a means for evaluating the effects of local ecosystem management on regional systems. Outputs of gases linked to global atmospheric circulation. Collectively, linking the atmosphere, the hydrosphere, the biosphere, and the implications of these linkages to ecosystem management provided a powerful tool for thinking about local, regional, and global planning and development. The value of this approach was stated in our first scientific publication in 1967, e.g.:

"…the rate at which an ion is released by weathering (the breakdown of rock minerals) must equal its rate of net loss from the ecosystem plus its rate of net accumulation in the biota and organic debris." …"Thus, net ionic losses from an undisturbed, relatively stable terrestrial ecosystem are a measure of weathering within the system."

"Acceleration of losses or, more specifically, the disruption of local cycling patterns by the activities of man could reduce existing 'pools' of an element in local ecosystems, restrict productivity, and consequently limit human population."

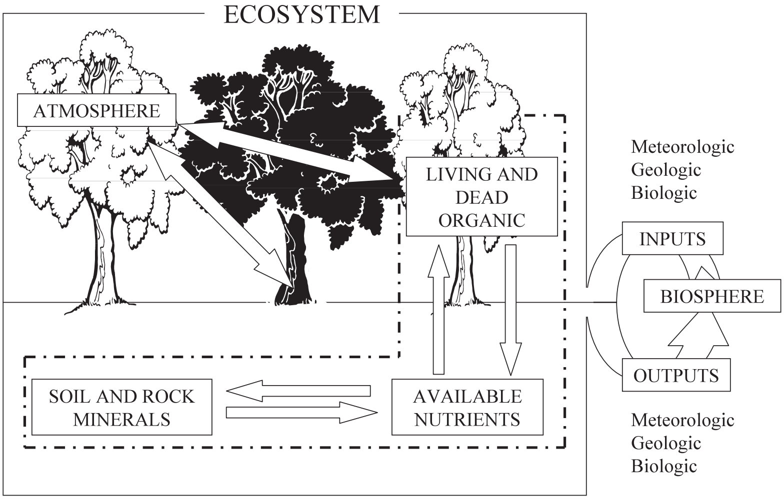

Figure 3. Nutrient relationships in a terrestrial ecosystem. Inputs and outputs to the ecosystem are moved by meteorologic, geologic and biologic vectors (Bormann and Likens 1967; Likens and Bormann 1972). Major sites of accumulation and major exchange pathways within the ecosystem are shown. Nutrients that, because they have no prominent gaseous phase, continually cycle within the boundaries of the ecosystem between the available nutrient, living and dead organic matter and primary and secondary mineral components, tend to form an intra-system cycle. Fluxes across the boundaries of an ecosystem link individual ecosystems with the remainder of the biosphere. [Modified from Bormann and Likens 1967].

Major Findings of the HBES

There have been numerous, extremely interesting, if not surprising discoveries from the long-term research of the Hubbard Brook Ecosystem Study, including:

- Using the small watershed approach and measurement techniques developed for the Hubbard Brook Ecosystem Study, we established quantitative input-output budgets for undisturbed northern hardwood forest ecosystems. Inputs demonstrated means by which the close and far environment could affect internal functions of the undisturbed forest. Outputs from the ecosystem represented inputs for the myriad of near and far ecosystems linked through movement of air and water, and demonstrated how the undisturbed forest ecosystem could affect interconnected aquatic ecosystems and the atmosphere.
- Through an experimental disturbance, clear cutting of the forest, we set in motion an array of ecosystem processes, which revealed ecosystem responses to disturbance, primarily loss of biological regulation of outputs, and with time after disturbance, gradual recovery of biological regulation of outputs. The primary effect of deforestation was a severe reduction in evapotranspiration with a shift in evaporative water, a gaseous loss, to runoff, a liquid loss, and to increased stormflow, a potentially destructive change in hydrology. A major finding was that forest cutting not only had a major effect on hydrology, as expected, but also on microbial activity. Decomposition and especially the process of nitrification were greatly accelerated with great production of hydrogen and nitrate ions that facilitated extreme losses of nutrients in output

waters. Cutting and enforced devegetation also caused an increase of the erodibility of the devegetated system with time. Other natural disturbances such as severe soil freezing or ice storm damage also can increase nitrate loss in stream water from watershed-ecosystems. Our actual and theoretical work on the structure, function, and development of the northern hardwood forest ecosystem resulted in management protocols for forest harvest and long-term forest management.

- "Acid rain" in North America was discovered at the Hubbard Brook Experimental Forest, and was shown to consist of acidified (pH less than 5.2) rain, snow, sleet and hail, fog and cloud water, and direct deposition of acidifying gases and particles. Acid deposition has now been identified as a major environmental problem in widespread areas of the world, including Europe and Asia. Long-term data from the Hubbard Brook Experimental Forest provided important ecosystem understanding about acid deposition, and information that subsequently was useful for development of a political resolution to this major environmental problem. This included information necessary for the passage of the Amendments to the Clean Air Act in 1990, which for the first time in the U.S. focused on regulating the acid rain problem.
- Calcium and other plant nutrients have been markedly leached from the soils of the Hubbard Brook Experimental Forest by acid deposition. As much as one-half of the pool of exchangeable calcium in the soil has been depleted during the past 50 years by acid deposition. As a result of these losses of nutrients and soil buffering capacity, the forest ecosystem in the northeastern U.S. is currently more sensitive to impacts of acid deposition than previously thought.
- Based on observation and computer simulation, we designed a biomass accumulation model for the northern hardwood forest. In contrast to other models of the time our model demonstrated a substantial loss in net biomass following deforestation/clear cutting before net biomass accumulation resumed. We used the model to develop a realistic/theoretical description of the dynamics of disturbance, development and the steady state of the northern hardwood forest ecosystem through time.
- Based on extensive and diverse experimental manipulations, it was learned that stream ecosystems do not function like "Teflon pipes." Instead, they are active sites of nutrient uptake and processing of nutrients and organic matter. Solute pulses added to streams are rapidly attenuated as they move downstream. This attenuation of solute additions is the result of instream retention and processing, thereby reducing overall net losses from the watershed.
- Computer simulation models were developed by our colleagues and applied as important research and predictive tools as part of the Hubbard Brook Ecosystem Study. JABOWA, a forest growth simulator, was the forerunner of many subsequent models. The BROOK model was developed to simulate and study forest hydrology. ALCHEMI, CHESS and PnET-CBC have been important biogeochemical tools in the Hubbard Brook Ecosystem Study and elsewhere.
- The Hubbard Brook Ecosystem Study demonstrated that changes in land-use can have marked environmental effects on interconnected hydrologic ecosystems. A major

interstate highway was constructed through the Mirror Lake watershed within the Hubbard Brook Valley in 1969-1971. Subsequent application of large quantities of salt (NaCl) during winter to melt snow and ice on the roadway resulted in large and continuing increases in salt concentrations in the affected drainage stream and in the lake itself (chloride concentrations currently have increased by 20-fold and 4-fold in the drainage stream and in Mirror Lake, respectively). This quantitative illustration of the environmental effects of road salt on interconnected aquatic ecosystems, seems particularly significant since some 10 million tons of salt are applied to U.S. roads in the winter.

One of the most profound ideas to have come from the long-term measurements at the Hubbard Brook Experimental Forest, especially of experimentally manipulated systems, is that complex legacies play out over very long periods of time. Each disturbance creates a set of conditions or trajectories that impacts the next situation, and thus, the sum total of ecosystem processes is influenced by historical events, each event being overlaid on some previous one. Our long-term ecological and biogeochemical data from the Hubbard Brook Ecosystem Study have been invaluable for unraveling such legacy effects, as well as for providing continuity for examination of critical questions, for identifying extreme events, for generating new research questions, for detecting environmental change, and for providing knowledge needed by decision makers. The long-term ecological and biogeochemical record at the Hubbard Brook Experimental Forest increases in intrinsic value with every year of record added to it. Some examples of our long-term studies include:

— Declines in emissions of lead, associated with the elimination of leaded fuels in the U.S. were correlated with a marked decrease of lead in precipitation and in the forest floor at the Hubbard Brook Experimental Forest. These data helped confirm the efficacy of regulations against the use of leaded gasoline in the U.S.;

— Enigmatically, net accumulation of forest biomass has ceased since 1982 at the Hubbard Brook Experimental Forest. Is this result some complicated effect of acid rain? Failure of the northern hardwood forest ecosystem to grow could have serious implications for the sustainability and harvest of forest landscapes in the northern U.S. This important question is the subject of intense, ongoing investigation.

— Long-term studies of Mirror Lake during winter show that the duration of ice cover is becoming significantly shorter each year. This decrease in ice cover is one clear measure of global climate change.

— Organic debris dams, naturally formed in streams in a forest landscape, play major functional roles in the ecology and biogeochemistry of stream ecosystems. It was found that 100 years or more are required for organic debris dams in headwater streams to reform following their loss due to disturbance from deforestation.

— Initial models of the rate of return to steady-state conditions in forest ecosystems following clear cutting involved measurement of solutes in stream water exiting the watershed-ecosystem. For ions such as nitrate, calcium and potassium, there were large net losses peaking in the second year after cutting. Thereafter, streamwater losses declined as the vegetation recovered and net losses of dissolved chemicals returned to near pre-cutting levels at rates unique to each ion. For the purposes of understanding the ecosystem effects of forest cutting and for planning future forest management strategies, these data were clear and sufficient. Yet, decades after these experimental clear cuts were done within the Hubbard Brook Experimental Forest, subtle to large differences still can be seen in several streamwater solutes, such as calcium. Understanding gained from our long-term element mass-balance analyses suggests that the legacy from the 1965-66 cut was still affecting ecosystem function in 2003!

It is not possible here to describe the major results of numerous other research efforts at the Hubbard Brook Experimental Forest over the years, including the important studies of bird populations and dynamics, studies of the ecology, biogeochemistry and hydrology of stream and lake ecosystems [see www.hubbardbrook.org/research/current/projects/ streams/stream_99.htm], studies of pattern and process in the northern hardwood forest ecosystem, and experimental ecosystem ("Sand Box") studies.

Management of the HBES

Long-term continuity of a complex study, such as the Hubbard Brook Ecosystem Study, involves much more than science alone. Several management features and goals were fundamental to sustaining the productivity and integrity of the Hubbard Brook Ecosystem Study over such a long period (40 years); (1) developing at the outset and continuing to use a conceptual biogeochemical model (Figure 3) for guiding research and ecosystem analysis; (2) nurturing a strong incentive within our team to understand the whole system (the ecosystem) rather than a reductionist approach of focusing exclusively on the components (parts) of the system; (3) integrating results and preparing synthesis volumes as rapidly as possible (see www.hubbardbrook.org/research/pubs/hbrbib.htm); (4) nurturing the concept of long-term studies even though it was often difficult to maintain uninterrupted funding; (5) enticing outstanding, senior colleagues from a variety of disciplines to join our scientific team; (6) maintaining a small, focused and dedicated team of researchers that spent much time in residence, interacting together at the Hubbard Brook Experimental Forest; and (7) developing analytical procedures that were neither changed nor replaced without first overlapping and comparing results from the "long-term method" with those from a proposed new method. This procedure helped to avoid "artifacts" in the long-term data. Any such changes were carefully documented.

We believe that these management approaches to our science were central to the successes we have had. Additional detail on our operating and management philosophy for the Hubbard Brook Ecosystem Study was given in the Prefaces to our first two synthesis volumes:

Likens, G. E., F. H. Bormann, R. S. Pierce, J. S. Eaton and N. M. Johnson. 1977. Biogeochemistry of a Forested Ecosystem. Springer-Verlag New York Inc. 146 pp.

Bormann, F. H. and G. E. Likens. 1979. Pattern and Process in a Forested Ecosystem. Springer-Verlag New York Inc. 253 pp.

Long-Term Studies

Long-term data can be used to evaluate the biogeochemical response to and recovery from disturbance, such as from acid rain, forest cutting, ice storms and from experimental watershed manipulations. Such long-term records are critical for developing biogeochemical trends and for understanding complicated changes in ecosystem structure and function. These qualitative and quantitative records provide hard information for decision makers wrestling with understanding and solving major environmental issues.

Three examples of our long-term studies are presented here in more detail.

Acid Rain

The primary source of acid rain (atmospheric deposition of acidified rain, snow, sleet, hail, cloud and fog water and acidifying gases and particles) is the combustion of fossil fuels, which releases of sulfuric dioxide (SO_2), nitrogen oxides (NOx) and particles to the atmosphere. The SO_2 and NOx may be converted in the atmosphere to sulfuric and nitric acids, and along with the gases themselves and acidifying particles, are eventually returned to the Earth's surface. These inputs acidify some terrestrial and aquatic ecosystems resulting in diverse impacts including the loss of species and accelerated leaching of nutrients, such as calcium. Acid rain is a relatively recent environmental problem, now spread widely around the world and particularly in eastern North America, northwestern Europe and southeastern Asia.

We learned from the very first sample of rain we collected at the Hubbard Brook Experimental Forest in June 1963 that the rain was acid, but it took several years to discover the cause and the nature of its widespread occurrence. Acid rain represents an experiment at a grand scale being imposed by humans on diverse ecosystems around the world.

As combustion of fossil fuels increased in the U.S. following the Industrial Revolution, emissions of SO_2 and NOx increased. Recently, atmospheric emissions of SO_2 and small particles have decreased in the U.S. due to Federal regulation. In contrast, NOx emissions, which are largely unregulated, have increased (Figure 4). Sulfuric acid has been the dominant acid in precipitation at the Hubbard Brook Experimental Forest since 1963, but nitric acid is expected to be the dominant acid in the next decade or so. This change is likely to have significant ecological and biogeochemical consequences on recipient ecosystems.

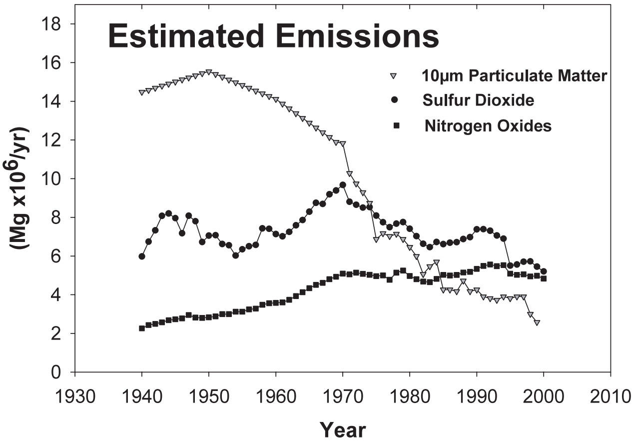

Figure 4. Long-term trends in emissions of sulfur dioxide, nitrogen oxides and particulate matter (10 µm in diameter) from the Hubbard Brook Experimental Forest source area (updated from Butler *et al.* 2001; Likens *et al.* 2001).

Undoubtedly, the amount and mix of emissions will continue to change in the U.S. as a result of changing energy demand and pending federal and state actions. Given the cost and angst involved with this legislation since the mid 1960's, it is important to measure the legislation's impact on atmospheric deposition and on recipient forest and aquatic ecosystems that have now become highly sensitive to these acidic inputs.

The causes, distribution and effects of acid deposition have been aggressively studied and debated in North America for three decades following our publication in 1972, which identified this problem in North America. Federal regulations to control air pollution in the U.S. were significantly strengthened and enlarged in 1970 primarily to reduce particulate emissions, but the Amendments to the Clean Air Act (CAAA) in 1990 were the first national legislative initiative, which focused directly on the problem of acid rain. Significant reductions of SO_2 emissions did not occur until 1995 when implementation of Phase I of the CAAA caused a decline in U.S. emissions equivalent to ~40% of the overall reduction targeted by the CAAA.

An extremely important finding from the long-term data at the Hubbard Brook Experimental Forest was the clarification of the relationship between gaseous emissions (SO_2) and concentrations of sulfate dissolved in precipitation. This contentious issue had dominated the national debate during the 1980's in the absence of long-term data. We found that both precipitation and streamwater concentrations of sulfate are significantly correlated with emissions of SO_2 from the source area upwind of the Hubbard Brook Experimental Forest (Figure 5). Atmospheric deposition of nitrate (another acidifying anion) also is correlated with NOx emissions. Moreover, there is a strong correlation (r^2=0.76) between the decrease in streamwater concentrations of sulfate observed at the Hubbard Brook Experimental Forest and the decrease in base cations (calcium, magnesium, sodium and potassium) concentrations in stream water. This is an important finding as the base cations control the acid-neutralizing capacity or alkalinity of the ecosystems in the Hubbard Brook Experimental Forest.

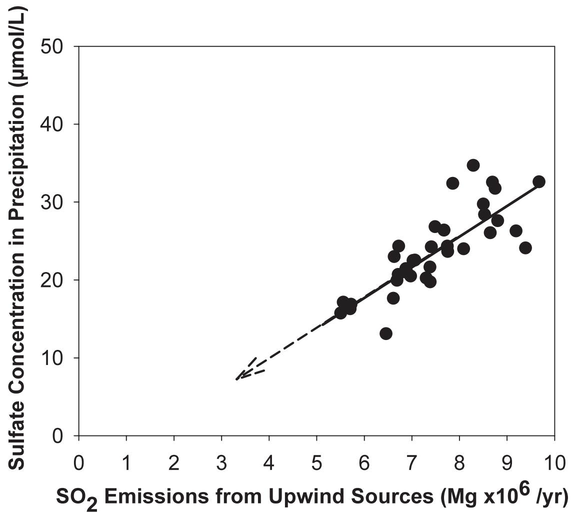

Figure 5. Annual sulfur dioxide (SO_2) emissions vs. sulfate (SO_4^{2-}) concentrations in precipitation at the Hubbard Brook Experimental Forest (updated from Likens *et al*. 2001).

Our long-term research has greatly advanced the knowledge base needed for developing policy and Federal legislation related to air pollution. For example:

- Changes in emissions of sulfur dioxide, SO_2, as a result of Federal legislation, are strongly and linearly correlated with changes in sulfate concentrations in precipitation and stream water at the Hubbard Brook Experimental Forest. Thus, reducing emissions of SO_2 will directly reduce inputs of acidifying sulfate.
- Eighteen years of continuing study were required to verify that the acidity of precipitation had decreased at the Hubbard Brook Experimental Forest (Figure 6). The acidity of precipitation increased from about 90 μeq H^+/liter in the mid 1960's to about 55 μeq H^+/liter in the late 1980's. However, current values are still about 8 times more acid than if the precipitation were not polluted (about 5 μeq H^+/liter).

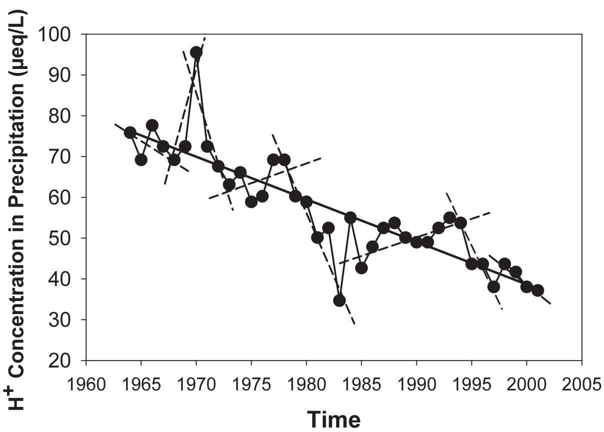

Figure 6. Long-term trends in hydrogen ions in precipitation at the Hubbard Brook Experimental Forest.

- Nitric acid is increasing in importance in precipitation at the Hubbard Brook Experimental Forest and is predicted to be the dominant acid in precipitation by 2010-2015 without further controls on emissions of SO_2 and NO_x.
- Calcium and other plant nutrients have been markedly depleted in the soils of the Hubbard Brook Experimental Forest as a result of acid deposition.
  - — As much as one-half of the pool of exchangeable calcium in the soil has been depleted during the past 50 years by acid deposition. These losses may be affecting the biological productivity of the ecosystem.
  - — As a result of these losses in soil buffering, the forest ecosystem is currently more sensitive to acid deposition impacts than previously thought.

The Hubbard Brook Experimental Forest is an important site for monitoring atmospheric pollutants in the northeastern U.S. because of the long and high-quality record of precipitation chemistry, its location "downwind" of major sources, and lack of local, major sources of pollution.

We have initiated a whole watershed manipulation to test experimentally some of the long-term effects of acid deposition on the ecosystems at the Hubbard Brook Experimental Forest. A natural calcium silicate mineral (Wollastonite) was mined in the Adirondack Mountains of New York State, pulverized, pelletized and then added to a watershed-ecosystem at the Hubbard Brook Experimental Forest by helicopter in 1998. An amount of calcium estimated to have been depleted from the ecosystem during the past 50 years was added in this manipulation. It is planned to study the effect of this experimental manipulation on stream and soil chemistry, tree growth, animal populations, microbial activity and other aspects of ecosystem structure and function over the next 50 years!

Effects of Forest Disturbance, Such as Cutting, on Ecosystem Dynamics at the Watershed Scale

Entire-watershed, experimental manipulations have been a powerful analytical tool of the Hubbard Brook Ecosystem Study. In the words of a colleague, W. Lewis, "Watershed manipulation now is a standard part of the biogeochemist's repertoire, but in the 1960s it must have seemed radically intrusive and perhaps even a bit pushy. . . (Experimental) manipulation, as we now know, vastly accelerates the pace of discovery, and that was one of the secrets of success for what became known as the Hubbard Brook Ecosystem Study". The ability to do such large-scale, experimental manipulations on a long-term basis, with adjacent watersheds for reference, indeed was one of the scientific joys and successes of the Hubbard Brook Ecosystem Study.

We discovered that cutting the forest sets in motion an amazing array of changes in ecosystem processes and interactions with concomitant changes in environmental conditions (Figure 7). Watershed 2 was deforested in 1965-66 – no trees were removed, and the watershed was treated with herbicides during summers of 1966, 1967 and 1968. As a result of this experimental manipulation, microbially-dominated processes: decomposition, mineralization and nitrification, were accelerated; ecosystem processes governing the loss of evaporative water to the air (transpiration) were markedly slowed; streamflow, the process whereby water is removed from the ecosystem was greatly increased as water previously evaporated by the intact forest became liquid water; sunlight energy previously intercepted and partly reflected back the atmosphere now was intercepted by the forest floor where it warmed the soil; concentrations of dissolved substances (nutrients) in the soil solution rose dramatically as a result of increased microbial activity combined with greatly diminished uptake by the trees that had been cut. This set of interactions within the northern hardwood ecosystem, triggered by our experimental clear cut, illustrates the complex nature of ecosystem behavior. This complexity is greatly deepened with the realization that for each research question answered, two or more arise.

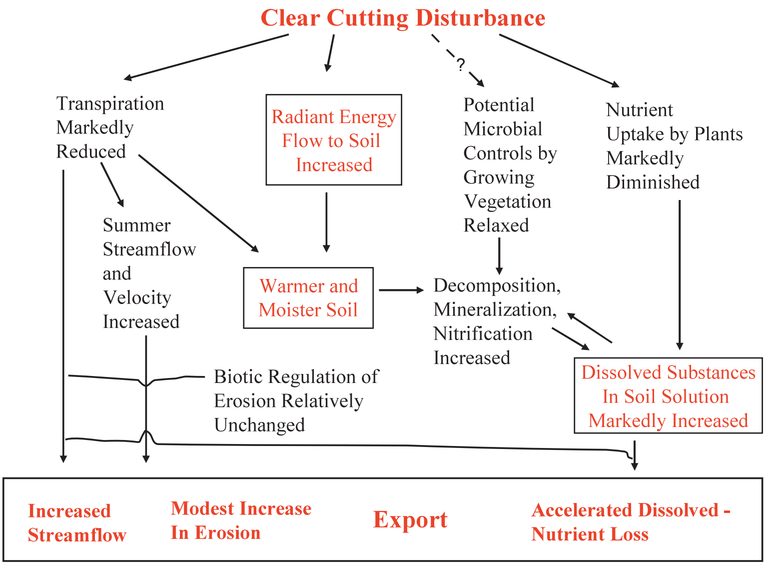

Figure 7. Major hydrologic and biologic responses of the northern hardwood forest ecosystem during the first two years after cutting. The erosion response assumes little damage to the soil during the harvesting process. Responses in double-lined boxes represent marked increases in resource availability within the ecosystem following disturbance. [Modified from Bormann and Likens 1979].

Effect of Climate Change

Currently, one of the most vexing problems in environmental science is how to determine the rate and effect of global climate change. Specifically in our case, is climate changing at the Hubbard Brook Experimental Forest, and if so, what are the impacts of climate change on ecosystem structure and function?

Changes in the heat budget of lakes reflect long-term changes in climate. Because duration of ice cover is a significant component of the annual heat budget of northern Temperate lakes, changes in duration of ice cover can be used as an important measure of changes in climate. Uniquely reliable records of ice IN and ice OUT dates exist for Mirror Lake since 1968. The error of the ice IN date is ± 2 days and for ice OUT date is ± 1 day. Thus, both the length and quality of the record for Mirror Lake are unusual.

The duration of ice cover on Mirror Lake has declined at a significant ($p<0.016$) rate of about 0.5 days per year during the past 36 yr, or currently ice cover exists on the lake for about 19 days less than it did in 1967 (Figure 8). This trend of decreasing ice cover on Mirror Lake is the result of the ice melting earlier (earlier ice OUT dates), which is correlated with increased air temperatures in spring and cloudier spring weather at the Hubbard Brook Valley during this 36-yr period.

The long-term record of ice-cover on Mirror Lake provides an important contribution to the debate on global climate change, and indicates that our region is indeed undergoing warming. Decreasing ice cover has been found on lakes in other regions of the world. An important question now under investigation in the Hubbard Brook Valley is, what are the biological implications of climate change on local aquatic and terrestrial ecosystems?

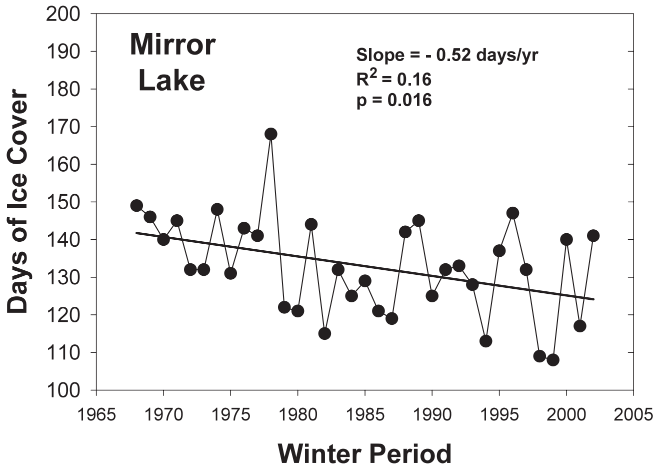

Figure 8. Annual duration of ice cover in days on Mirror Lake since 1967 [updated from Likens 1999]

The Future of the Hubbard Brook Ecosystem Study

It is extremely difficult, if not impossible, to predict the future, particularly in these uncertain times. Nevertheless, the long-term chemical record combined with the long-term hydrologic record and stable research infrastructure provided by the USDA Forest Service at the Hubbard Brook Experimental Forest have served, and are likely to serve well into the future, as a magnet for research and researchers of the Hubbard Brook Ecosystem Study. There is no lack of exciting questions and research opportunities for studies of ecosystem structure and function, and biogeochemistry. Some difficult biogeochemical problems that we have wrestled with for 40 years, will continue well into the future, e.g. dynamics of the N cycle (fixation, denitrification and ecosystem retention); elaboration of the weathering process; impacts of acid deposition, and many new questions that will emerge (Table 1). Dozens of senior scientists, students and technicians conduct research at the Hubbard Brook Experimental Forest every year. It seems likely that they will do so for at least another 40 years, and will be driven by persistent questions that remain vital to science and society, and by new questions that are generated from the long-term data and from the effects of new perturbations imposed on this most remarkable and valuable Valley.

Table 1. Some major challenges for biogeochemical studies in the future [modified from Likens 2003].

1. What are the specific effects and relationships of the increasing size of the human population on the biogeochemical flux and cycling of elements, and the effects of forcing functions often incongruent in space and time?

2. What controls fluxes of N and P to and from natural and human-dominated (cities, agricultural) ecosystems?

3. What is and what controls C sequestration in diverse ecosystems (e.g. forest, ocean, lakes, wetlands) on variable temporal and spatial scales?

4. What controls weathering rates, and what are the fates of the weathered products, including nutrient loss in terrestrial ecosystems?

5. What are the quantitative interrelationships between hydrology, ecology and biogeochemistry?

6. How can a better synoptic understanding of the biogeochemical flux, cycling and interaction of elements among air, land and water (including ocean) systems be achieved?

7. What are the critical linkages and feedbacks among major nutrient and toxic element fluxes and cycles?

Respect for Nature

In every quarter of the globe, in every culture and ethnicity and among many, but by no means all, there is a deep respect for nature (Bormann 2000). This respect, based on beauty and to some degree appreciation of how the natural world works, finds it's expressions in art, literature, architecture, taboo's of all societies.

We believe that our work adds a new and important dimension to the concept of "Respect for Nature." Studies by colleagues and us blossomed with more than a thousand scientific publications during the last four decades and, with that blossoming, our perception of the forest landscape has changed. Today, there is still the beauty and magnificence of the forest landscape, but now there is more. Despite the seeming quiet of the forest, there is a sense of being surrounded by an enormous dynamism: thousands of liters of water and tons of chemicals stream upward through tree trunks, photons of energy are absorbed by leaves and put to work evaporating water through leaves and fixing energy in organic compounds, food manufactured in leaves stream to growing points, insect predators quietly nibble away, rocks are broken down into useable nutrients, microbes disassemble organic compounds and free nutrients for reuse, all species play out their roles in reproduction, the forest ecosystem grudgingly restocks the forest stream with water, the stream ecosystem uses and recycles nutrients and organic matter from the water on its ultimate journey downhill, and a million other things occur simultaneously.

Our concept of beauty changed with the realization that visual beauty can be enhanced or surpassed by unseen corroborative pictures flashing across the screen we call our consciousness. Despite our growing knowledge of the natural world, there is still a vast unknown component to the Earth whose extent and effectiveness is supported every day as this BLUE planet sails through forbidding space. We should *respect, cherish and change with utmost caution* this largely unknown natural world because it works as it does, and we are totally dependent on this "working."

Rather than waging a "war on nature", it is important to incorporate aspects of humility and respect for nature in our daily lives if we are to achieve some measure of sustainability. We must make a major shift in our thinking and in our actions from a consumer society to what J. H. Gibbons calls a "conservator society." Some components of respect for nature include:

- Respect for nature's complexity
- Respect for nature's resilience and fragility
- Respect for nature's changing structure and function
- Respect for what nature does for us every second of the day providing clear air, clean water and clean and nourishing food, and much more.
- Respect for the conservation of nature's great regenerative powers

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