PNW
Pacific Northwest Research Station

# Science FINDINGS

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INSIDE



*"Science affects the way we think together."*
Lewis Thomas

# WINDOWS INTO THE FOREST: EXTENDING LONG-TERM SMALL-WATERSHED RESEARCH

*"When we try to pick out anything by itself, we find it hitched to everything in the universe."*

—John Muir

Scattered across the United States in a variety of mountain locations are several dozen small experimental watersheds, whose every hydrologic move and change informs a dynamic database. These watersheds have been watched by the U.S. Forest Service for at least two decades, and some of them for more than five decades.

Their gauges open the window to information on the peak flows of floods and the mere trickles of droughts, on nutrient cycling and acidity, on effects of fire and rain. They capture stories from the water that reflect vegetation change, water quality and quantity, climate change, natural disturbance, and the whole set of questions that drives the challenges of forest management.

The several dozen sites provide crucial views across a range of geographic settings covering various forest types and snowcover regions. Ranging in size from 5 to about 100 hectares, these small watersheds are home to experiments designed initially to discover whether it was possible to preserve or improve water yield from the forest. Subsequently they have contributed to investigations of grazing and fodder issues, burn/no-burn policies, insect and disease disturbances, and how logging treatments affect nutrient and carbon balances.

As forest management attention has shifted to revegetation, the effects of thinning, and forest health and watershed recovery issues, the small watersheds have continued to yield streams of long-term information to feed the new questions. And now, new statistical, experimental, and data dissemination approaches to the data offer yet deeper insights.

Credit: Al Levno

*Gauging stations in very small watersheds allow scientists to track streamflow processes through time in a tightly controlled data-capture environment.*

Existing long-term records from small watersheds have already enriched knowledge of fundamental processes, and yet they contain a wealth of untapped information about hydrologic and biogeochemical responses to climate change, natural disturbance, and human activities, over a wide range of climate, geophysical, and vegetation settings.

## IN SUMMARY

*Interactions among forests, forestry, and water remain a critical aspect of Forest Service land stewardship. Small, experimental watershed studies managed by Forest Service Research and Development have a long history of advancing science and management and have resulted in a rich collection of long-term data.*

*Early work addressed effects of forestry practices in particular forest types and hydrologic regimes. Revegetation of experimentally treated watersheds and new questions and tools of science and management are leading to new uses of the long-term records for science, management, and education at local to regional and broader scales.*

*Critical contemporary issues include how vegetation controls the magnitude and pace of a watershed's response to natural disturbances and management activities. New approaches for both statistical analysis and public access to long-term data from 35 Forest Service and other ecological sites nationally will foster further innovation. This Science Finding concerns new lessons about the increasing value of these long-term studies and about new ways to make the data publicly available.*

Scientists now believe there is enormous potential for general ecosystem insights from comparisons among multiple, diverse small-watershed experiment sites.

Fred Swanson, a research geologist, and Don Henshaw, an information technology specialist, with the PNW Research Station in Corvallis, OR, are collaborating with Julia Jones. Jones is a professor of geosciences at Oregon State University. Swanson oversees conduct of the long-term watershed studies, Henshaw provides information management to facilitate local and global use of the data from Forest Service sites, and Jones has developed innovative ways to use these data to learn about hydrology. This interdisciplinary collaboration has required working across institutional lines and in the context of the Long-Term Ecological Research program sponsored by the National Science Foundation and Forest Service Research and Development.

## KEY FINDINGS

- Interregional comparisons of the magnitude of initial hydrologic response to forest disturbance and the rate of recovery over the following decades reveal major variation among forest types and hydrologic regimes.
- Experimental watersheds differ in peak flow and low flow response to forest cutting and regrowth, depending on effects of snow hydrology and dominant species of riparian and upland vegetation established after disturbance.
- New Web technologies are useful for dynamic data harvest, assembly, and public access to climate and hydrology data from small, experimental watershed studies, and they facilitate research by providing a common interface to multisite data. The system allows greater productivity and reuse of long-term data and encourages the resurrection of legacy data sets through improved documentation and online access.

## SMALL IS POWERFUL

Many of the small watersheds were selected in Experimental Forests and Ranges, areas set aside on Forest Service land to provide opportunities for research on forests undergoing active management.

"What they offer now is an intensive and unprecedented focus on water in forests by inter-institutional, interdisciplinary teams," Swanson says. "Experimental forests have traditionally provided the meeting ground for collaborations among universities, management agencies, and Forest Service Research to address precisely these kinds of questions. And now, making the data publicly available expands the science opportunities not only across the country, but also around the world."

What is the unique value of data from these very small watersheds?

"The small watershed streamflow data are more useful than data from large watersheds for 'causal inference,' in other words interpreting the causes of changes in streamflow," Jones explains. "This is because their locations in headwaters make it physically feasible to install a gauge (flume) that captures all the outflow, with no leaks. Measuring streamflow from large basins generally involves gauging at sites along a river that is continuously changing, thus requiring resurveys on a regular basis."

In addition, she says, their smaller size makes it easier to understand how streamflow responds to vegetation change and precipitation, both rain and snow. This allows researchers to "close the water budget" to get precipitation, discharge, and evapotranspiration to add up. Furthermore, a number of them were "paired" watersheds, with like features selected to allow for comparative studies between "treated" and control watersheds.

"When used in paired-basin experiments, small basins have additional research strengths," Jones notes. "Often the entire basin is treated; in other words, there is a single 'cause' or treatment imposed on the whole area. Further, the relationship between treatment and control can be established prior to introducing a treatment."

Swanson adds that when viewed long-term, our so-called catastrophic events—flood, wildfire, landslides, and windthrow—appear as natural disturbances, with vital, positive functions in the ecosystem.

### *Purpose of PNW Science Findings*

To provide scientific information to people who make and influence decisions about managing land.

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## THE EXPERIMENTAL CHALLENGE

Paired-basin studies provide a continuous—and continuously changing—record of vegetation and climate, and their interdependent effects on streamflow. Interpreting this record is a challenge. Scientists employ retrospective, modelling, and process study approaches, each with its strengths and shortcomings. The initial focus of small watershed studies was on local implications of individual experiments, but there is great promise for wider lessons. And yet until recently, according to Jones, the hydrologic implications of such studies have been examined largely for individual experiments, or in reviews combining results from studies using disparate and sometimes incompatible methods.

New statistical approaches are enabling researchers to dig deeper into the existing data for their significance in a number of ways. According to Jones, "old" and "new" (post-1990) studies of paired-basin experiments differ in a number of important respects: how the treated/control relationship and the treatment effect were initially defined statistically; the time-basis of data used; the periods of record; and the number of sites examined.

To take examples from the latter three categories, in "old" studies, the data were either annual streamflow (sum of flows for a year), or peak discharges selected by visual examination of the charts. In "new" studies, the data were daily average discharges, aggregated by season as well as for the whole year. "Bigger, higher-resolution data sets can be analyzed today because records are longer, in digital form, and computers have more power for managing large data sets, and because so many data sets have now been collected in one place," says Jones.

Next, in "old" studies, the period of record included the pretreatment period (typically ranged from 5 to 10 years), and one posttreatment period (typically ranged from 5 to 10 years). In "new" studies, the period of record includes the same pretreatment period, but multiple 5-year posttreatment periods (posttreatment periods from 10 to 45 years). Quantifying and comparing streamflow responses at multiple time scales allows researchers to consider storm events, seasons, and decadal climate variability and vegetation change.

And finally, "old" studies typically examined data from only one treated/control pair. New studies have reanalyzed original data from two to 14 treated/control pairs, and as many as 28 control basins using a common analysis. In other words, multiple basins may be used as controls for a given treated basin, and the responses may be compared without concern for confounding effects of differences in analytical methods.

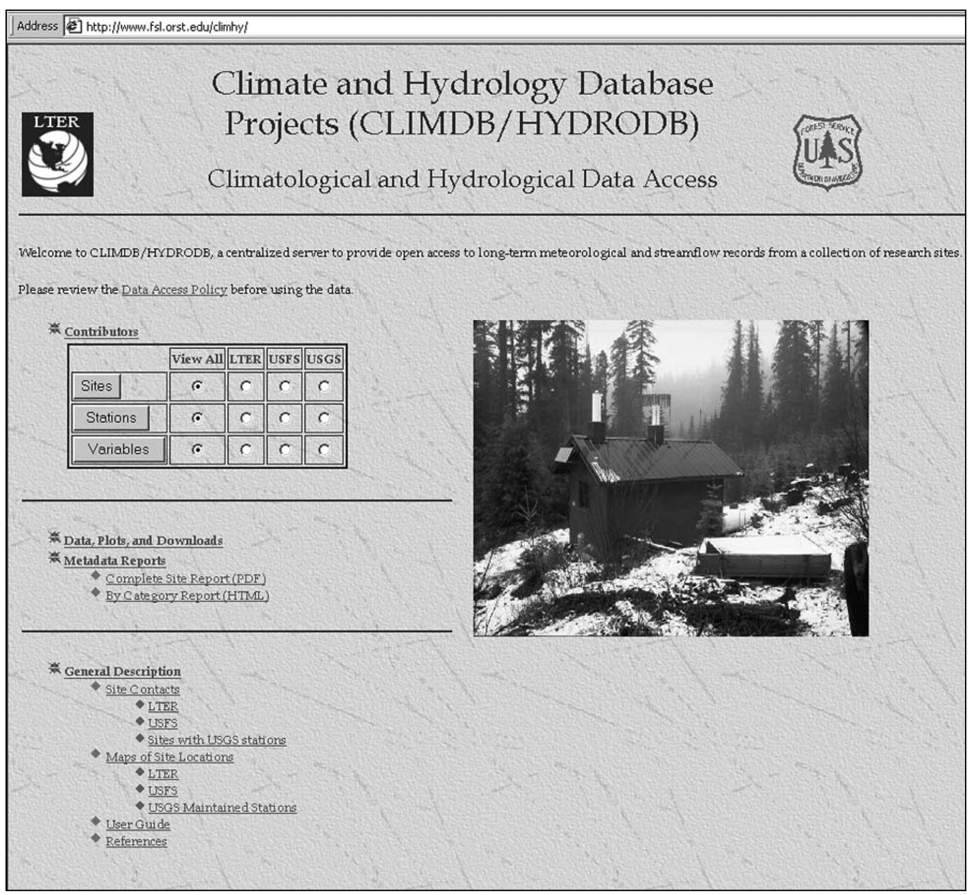
"Research directions are changing to draw inferences from a larger sample of basins, instead of trying to generalize from one treated/control basin pair," Jones explains. "Also, research is attempting to understand how streamflow changes over multiple, changing time periods after treatment, associated with forest succession and climate change, rather than thinking in terms of a black vs. white, treated vs. control situation."

## DYNAMIC DATA

The new statistical techniques and experimental approaches certainly enable more indepth analysis, in what is coming to be known as the field of ecohydrology. More comprehensive approaches to the data aid interactions between hydrologists, stream ecologists, and ecophysiologists. "This multi-time-scale view of differences in streamflow between old and young forests sets a basis for researchers to ask questions about how changes in flow regime affect stream ecosystem processes, such as nutrient cycling and regulation of water temperature. These new depictions of vegetation effects on streamflow will also include analysis of effects on aquatic communities of fish, invertebrates, and plants," Swanson says.

But a factor that is encouraging new investigations just as strongly, he emphasizes, is the availability of data on the internet, and new data-harvesting tools, such as ClimDB and HydroDB. These are Web-based, multisite databases featuring small-watershed streamflow and associated meteorological data and metadata for a network of Forest Service experimental forests and related research sites.

"The general premise of this 'Web harvester' system is to allow individual sites local control to maintain climate and streamflow data in local information systems while also providing for the data to be routinely 'harvested' into a central site database, permitting public access through a common Web interface," explains Henshaw. "Common distribution summary reports, downloadable daily data, and interactive graphical display capabilities are available for all sites." He notes that this project originally included only climate data, but has proven extensible to streamflow and other hydrology data, and may eventually be expanded to include stream chemistry data. The project also captures U.S. Geological Survey stream gauging data directly into HydroDB.




*HydroDB and ClimDB provide a digital home for long-term small-watershed data accessible to scientists all over the world. The Web address is http://www.fsl.orst.edu/climhy/.*

## FRAMING THE QUESTIONS

Around the country there have been different regional focuses for small watershed studies through time, after they all started with a hydrology focus: acid deposition dominated in New England, flooding and geomorphological change in the Pacific Northwest, and fire in the Sierras and Rockies.

With new techniques and broader access to data, challenging new hypotheses are emerging about the coupling of vegetation and climate to hydrology. Studies of global climate change suggest that forests tend toward optimal use of resources such as moisture; thus it is proposed that forest structure and composition develop during succession to reduce stress on plants. Other recent studies indicate that as streamflow responds to changes in temperature and rainfall, there are concurrent changes in vegetation cover and species composition.

"The time is ripe for hydrologists and ecologists to draw more, and broader inferences about the role of seasons and succession from paired-basin, forest-removal experiments," Swanson says. "For example, interregional comparisons of the magnitude of initial hydrologic response to forest disturbance and the rate of recovery over the following decades reveal major variation among forest types and hydrologic regimes."

Jones cites a variety of compelling current (and in some cases very old) research questions emerging from the small-watershed data: Do peak discharge responses to forest removal and roads scale up to large basins? Do peak discharges respond similarly to forest removal and roads across a range of small basins in the Pacific Northwest? How variable is precipitation and streamflow at daily, seasonal, and annual time scales in regions as diverse as the Pacific Northwest, Georgia, New Hampshire, and Puerto Rico? (These are the locations of H.J. Andrews, Coweeta, Hubbard Brook, and Luquillo Experimental Forests, respectively.)

## ATMOSPHERE-SNOWPACK-SOIL INTERACTIONS

A recent study by Jones investigated more than 900 basin-years of record—over 750,000 observations—at 14 treated/control basin pairs where forest removal and regrowth experiments were underway between 1930 and 2002. Hypotheses concerning both seasonal and successional effects were developed and tested at sites in six experimental forests, three in the Pacific Northwest. Northwest sites had conifer forests (Douglas-fir, western hemlock, mixed-conifer, redwood) up to 500 years old and dry summers. Eastern sites had deciduous forest (northern hardwoods, oak-hickory) less than 100 years old and wet summers. The northernmost sites (Andrews and Hubbard Brook) had seasonal snowpacks. Mean annual precipitation ranged from 1000 to 2000 mm across all sites.

The most recent disturbances involved wildfire and logging in conifer sites, and hurricanes and logging on deciduous sites.

"Each site consisted of one or more paired-watershed experiments in which 100 percent of forest cover had been harvested, and an unharvested control basin exists," Jones explains. "Because of differing disturbance histories, 90- to 450-year-old forests were removed in the conifer sites, but 12- to 56-year-old forests were removed at the deciduous sites. The age of most harvested forest ranged from 30 to 125 years."

In 10 cases, forest harvest occurred in a single year. Basin size ranged from 9 to 96 hectares, with most between 20 and 50 hectares. Streamflow and climate records span periods ranging from 17 to 63 years; post-treatment records ranged from 11 to over 40 years. Data included mean daily streamflow, precipitation, minimum and maximum temperature, and snowpack.

## DECIDUOUS/CONIFER VARIATIONS

Regional comparisons of the size of initial hydrologic response to forest disturbance, and the rate of recovery over the following decades, reveal major variations among forest types and water regimes, Swanson says. These differences in part reflect how vegetation controls hydrologic processes, such as via seasonal and successional changes in leaf area in deciduous versus conifer vegetation.

Changes in forest canopy interactions with the snowpack over the course of succession possibly explain long-term changes in snowmelt runoff, Jones notes. Seasonal snowpack volume, of course, depends upon the balance of additions and losses, and thus affects spring snowmelt.

"When deciduous forest canopies are removed, the cold snowpacks are exposed to winter sunlight, and the usually dense regenerating stands may intercept more snow, reducing snowpack volume," Jones says. "The result is that the first decade after removal of deciduous canopies, snowmelt occurred earlier and streamflow was reduced, compared with 40- to 60-year-old forests. After two or three decades of forest regeneration, this effect was reversed."

By contrast, removal of conifer canopies decreases snow interception and also exposes warm snowpacks to warm, wet winds, which melts them faster, she says. Thus, in the first decade after removal of conifer canopies, snowmelt occurred earlier and streamflow was increased during the snowmelt period compared with 125- to 500-year-old forests. Again, a reversal occurred two or three decades after regeneration.

Also, conifers are adapted to use water throughout the year, as long as soil moisture and temperatures are not limiting, whereas transpiration in deciduous trees is limited to periods when leaves are present, Swanson explains. In some western Oregon watersheds, for example, enhanced runoff in the

**WRITER'S PROFILE**

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fall and spring may affect species and watershed processes sensitive to flow conditions at those times.

One other notable implication is suggested by studies of low flows. In western conifer forests, dense riparian alder stands may draw down summer low flows, possibly restricting summer aquatic habitat. Thus the establishment of conifers in riparian zones, also attractive for recruitment of woody debris, could help limit depletion of summer flows because of the lower water demands of conifers, suggests Swanson.

The study suggests that removal of old conifer forests had a larger absolute effect on streamflow than removal of young deciduous forests.

"As forest succession proceeds over 50, 100, or 500 years, many factors may increase the ability of a forest community to capture and store water," Jones explains. "These factors include the increasing age of individual trees, changes in water use by new species succeeding in the overstory and understory, altered intercepting capacity, or development of a canopy epiphyte community."

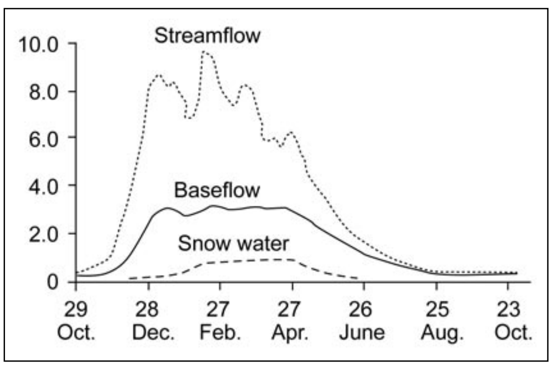
In times of tightening budgets, the value of the long-term gauging of small watersheds has come under scrutiny, but to researchers learning just how much knowledge can be gleaned from the data, they represent the crown jewels of forest monitoring. After all, at issue are magnitudes of flood flows and protection of life, property, and ecosystems; low flows and aquatic habitat; and water yield for human consumption. The data have additional value in examining compatibilities between watershed functions and wood production.

## LAND MANAGEMENT IMPLICATIONS

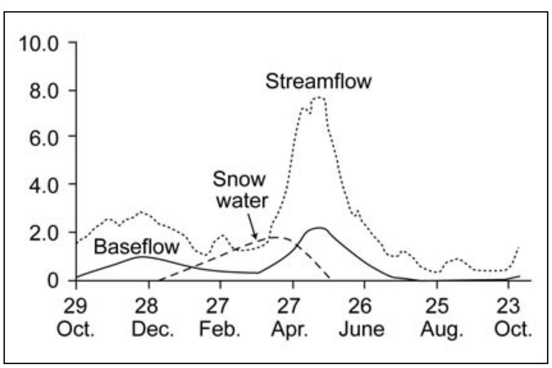
- New techniques to analyze the size and trajectory of response to vegetation disturbance by forest harvest, thinning, forest regrowth, and roads allow us to consider specific vegetation effects on hydrologic processes, rather than simply extrapolating from one area to another, based on gross interpretation of treatment effects.
- Studies of low flows suggest that dense riparian alder stands may draw down summer low flows, possibly restricting summer aquatic habitat. In such cases, establishment of conifers in riparian zones may benefit aquatic habitat in the long term.
- Long-term streamflow data from small watersheds, both treated and control watersheds, are a valuable resource to forest managers conducting watershed analyses, analyses for forest planning, assessments of management impacts on floods, and education and training programs in hydrology and watershed science.

## Hydrology of the sites

*H.J. Andrews Experimental Forest, Oregon*




*Hubbard Brook Experimental Forest, New Hampshire*




*Very different systems can be compared by using the long-term stream databases. The H.J. Andrews watersheds (top) are dominated by conifer forests, with some snow, and the hydrograph shows no strong spring runoff. The Hubbard Brook watershed (bottom) is dominated by younger deciduous hardwoods, with significant snowpack, reflected in the strong spring runoff showing up in the hydrograph. The comparison can address the roles of snow, deciduousness, and seasonal stream flow. The vertical axis is water in millimeters.*

*"Nature cannot be ordered about, except by obeying her."*

—Francis Bacon (1561–1626)

## FOR FURTHER READING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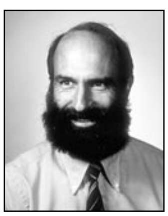

Fred Swanson, a research geologist with the PNW Research Station, has been studying landslides, fire, and other disturbance processes in western Oregon for more than 30 years. Swanson is a leader of the National Science Foundation sponsored Long-Term Ecological Research Program at the H.J. Andrews Experimental Forest in Oregon. He also is a leader of the Cascade Center of Ecosystem Management, a research management partnership involving Forest Service Research, the Willamette National Forest, and Oregon State University.

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Don Henshaw is an information technology specialist with the Ecosystem Processes Program of the PNW Research Station. He also directs information management activities for the Andrews Experimental Forest Long-Term Ecological Research (LTER) Program and the cooperatively supported Forest Science Data Bank (FSDB). He is currently serving on the national LTER executive committee for information management and the LTER advisory committee for development of a network-wide information system. Current emphasis is in ecoinformatics—exploring and adapting new technological solutions for the facilitation of ecological research and development of cross-site databases.

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