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wildland WATERS

IN THIS ISSUE

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Watersheds

When most of us think of our national forests, we think of recreational experiences, wildlife, or timber harvests. In this issue, science writer Mary Carr introduces us to another role–that of forests as "living laboratories."

Located in protected settings across the country, the USDA Forest Service experimental forests are key sources of long-term water information. Research conducted in watersheds on these experimental forests has yielded important, and sometimes, surprising scientific insight. This issue provides the history of these living laboratories and thoughts on their future.

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Karen Solari at ksolari@fs.fed.us.

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The following contributors to this article may be contacted for additional information:
Doug Ryan at dryan01@fs.fed.us.
Jim Hornbeck at jhornbeck@fs.fed.us

Living Laboratories

Small Watersheds in Experimental Forests Play a Big Role in Science, Management, and Policymaking

Tucked away in quiet valleys on national forests across the country are a series of small streams that have a big role to play in the protection and management of our water and forest resources. Located within Forest Service experimental forests, these inconspicuous streams and the watersheds that feed them have served for decades as living laboratories, providing unparalleled opportunities for the study of forest ecosystems. The work here has generated pivotal information about basic ecological processes and how management of landscapes can affect the streams that flow through them. Studies of these small watersheds have enhanced our basic scientific understanding, produced research that is directly useful to land managers, and supplied critical information used to form public policy.

How did this group of otherwise ordinary watersheds come to render such extraordinary service? What influences are they likely to have on important decisions that may affect our water in the future? This is the story of the dedicated, long-term research on small watersheds that has come to hold a prominent place in the world of science, management, and policymaking.

A Grand Experiment

In the early 1900s, intense public and scientific interest was focused on the effects of forest management and forestry practices on streams—including floods, low flows, water yield, and erosion. Apart from general observations and intuition, however, there was little scientific information to answer many important environmental questions related to

What's a watershed?

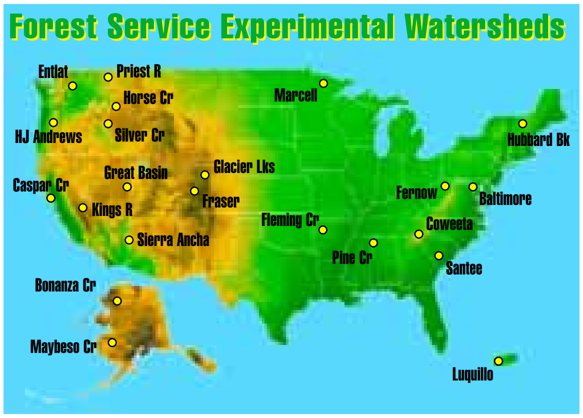
"Watershed" has several meanings, including a specific technical meaning in the field of hydrology. For our purposes here, a watershed is an area of land that drains into a river, river system, or other body of water. A watershed captures precipitation, filters and stores water, and influences where and how water moves. A watershed can be large or small, and smaller watersheds join together in a network to become larger watersheds. Any activity that affects water quality, quantity, or movement at one location can change the characteristics of the watershed at locations downstream.

water. For example, there was a general feeling that removing forests made both floods and droughts worse, but there were few concrete measurements to test this assumption.

Early watershed research was driven by disastrous events, such as the widespread floods along the Mississippi River in the 1880s and 1890s, and by the continuing controversy over whether floods could be controlled by land treatments in the headwaters of large rivers. In 1897, to address these concerns, Congress established forest reserves and set securing "favorable conditions of water flows" in the Nation's headwaters as one of their primary purposes. In 1905, Congress established a new agency, the Forest Service, under the Department of Agriculture. The agency was created to manage the reserves, renamed national forests. The original purpose of these lands, protecting water, was retained. In 1910, Henry S. Graves, the agency's second Chief, established Wagon Wheel Gap experimental watershed on the Rio Grande National Forest in Colorado for the specific purpose of scientifically studying the effects of forest management on water.

The system of experimental watersheds expanded over time to the current total of 24, located across the country in areas specifically set aside for this purpose. These experimental watersheds are equipped with instruments that measure the physical and chemical characteristics of the water that flows through them, enabling them to conduct long-term research.

Ranging in size from 10 to about 200 acres, the experimental forest watersheds are home to experiments for a variety of investigations related to land uses and water, often with a regional focus: acid rain in New England, flooding and geomorphological change in the Pacific Northwest, fire in the Sierras, and nitrogen and carbon loading in the Southeast. These two dozen sites have become the primary windows into the hidden world of nutrient and water movement through forests, above and below ground, across a range of geographic settings.



Windows on a Hidden World

The studies of small watersheds have proven to be valuable and versatile. Water is an integral and integrating factor in numerous natural processes as it flows through an ecosystem. By monitoring water, scientists can measure the net effect of many fundamental ecosystem processes and components that otherwise would remain hidden from easy view. The movement of groundwater, for example, or the mechanics of nutrient cycling, acidity, vegetation changes, and natural disturbance are among the critical scientific details that are needed for making informed forest management and public policy decisions. These decisions may include:

- Determining the effects of logging or grazing on water quality.
- Establishing fire management policies.
- Preventing or responding to insect and disease disturbances.
- Monitoring nutrient and carbon balances that may affect global climate and vegetation change.

In It for the Long Term

Some of these studies have been continued

for more than 60 years

One key to the value of these small-watershed studies is their long-term perspective, rare in the world of research. Some of these studies have been continued for more than 60 years, enabling scientists to detect subtle changes in the forest ecosystem over time. Significant advances have been made in fundamental scientific fields as a result of insights gained from long-term research at these outdoor laboratories.

"A long-term focus on undisturbed watersheds gives us the opportunity to better understand the effects of both human and natural disturbance as it permeates through forest ecosystems," observes Jim Hornbeck, research forester at the Hubbard Brook

We are not alone

"Forest Service experimental forests are among the oldest and most continuous sources of small-watershed studies in the country. However, many scientists at other agencies and universities also conduct small-watershed research. These researchers often work closely with or at Forest Service experimental forests, which frequently act as magnets for scientists from around the country and the world. The H.J. Andrews Experimental Forest in western Oregon, for example, annually hosts faculty and students from 10 to 30 universities in the United States. While other agencies such as the U.S. Geological Survey, Environmental Protection Agency, Department of Energy, and Agricultural Research Service also conduct small-watershed studies, their research focus is not primarily on effects of forest management.

Experimental Forest in New Hampshire. "Besides hydrology, the long-term record provides an understanding of baseline conditions, flooding, and background chemistry, and we can then watch everything from nutrient loss and erosion, to sediment yields after logging, to atmospheric deposition."

The implications of such advances have not been lost on public and private land managers who have found abundant practical use for the information derived from long-term scientific work at experimental watersheds.

At Fernow Experimental Forest, near Parsons, WV, for example, long-term records begun in the 1930s have provided ongoing management guidance. In one instance, studies found that significant impacts on water could be traced to sediment that had eroded and washed into streams from places where the soil surface had been disturbed by road construction on steep slopes or near stream courses. Scientists then worked with managers to develop and test guidelines and techniques to reduce road erosion and protect streamside areas.

"We've discovered that if you build your roads right, sediment and runoff are not a problem," explains Beth Adams, research project manager, "so our numbers contribute to the design of Best Management Practices." Those practices, aimed to ensure management activities have the least negative impact on ecosystem function, are in turn used by public and private land and resource managers.

Small Is Beautiful (and Useful)

Because analysis of large land areas over long time periods cannot be done experimentally, small-watershed studies have an important role to play

Other key features that add to the value of these watersheds as research laboratories relate directly to their small size. The cost of building and running the instruments to make precise measurements can be kept within modest budgets that agencies like the Forest Service can afford. Small watersheds can more easily be kept within one ownership over long periods of time, and the land use treatments that they receive can be more carefully controlled. Consequently, they are better suited for studying cause-and-effect relationships between land use practices and water quantity, quality, and natural processes.

Small-watershed studies are sometimes criticized because they focus on hundreds of acres rather than millions of acres. Managers and decisionmakers are increasingly faced with issues that require solutions at larger spatial scales and over longer time periods. Plans and practices that could once be adequately considered at a local level and for a few years must now be analyzed and planned for in the context of large regions, such as whole river basins, and for decades at a time. For example, national forest planners recently undertook the "Southern Appalachian Highlands Assessment" to examine natural resource management problems stretching across mountain forests in seven Southeastern States.

Because analysis of large land areas over long time periods cannot be done experimentally, small-watershed studies have an important role to play. Experiments at these large scales would be too costly and would affect too many people's lives and property to be remotely possible. Rather, for large areas analysts use models of cause and effect to evaluate land management options and their outcomes for values such as water quality. Small watersheds are the best place to scientifically study the cause-and-effect relationships that are the basis of these models, and the accuracy of these large-scale analyses depends critically on how well the models incorporate knowledge that small watersheds can provide.

A shift in focus: paired watershed studies over time

Traditionally, manipulations in paired watershed studies were selected to simulate potential management actions such as timber harvesting or forest fertilization. Some recent studies have begun to focus accumulated data on restoring ecosystems. At the H.J. Andrews Experimental Forest in Oregon (now the third largest Forest Service research complex in the country), a team effort began in 1955 to use paired sets of small watersheds to examine effects of forest management on streamflow and water quality. Today, several of these watersheds and their decades-long records are subjects of new studies involving networks of watersheds, called "ecological hydrology."

Controlling the Setting: How Watersheds Are Studied

The relatively controlled environment of small watersheds is ideal for studies of physical and biological interactions. A common approach to small-watershed studies requires a minimum of two, or paired, watersheds—one for control and one for treatment. The control watershed accounts for year-to-year or seasonal climate variations. The management practices in the control watershed remain the same throughout the study, with the most common practice for controls being no management at all (that is, let nature run its course). Management of the treatment watershed is deliberately changed at some point during the study; for example, timber may be harvested or fertilizer applied. Then both control and treated watersheds are studied for an extended period of time to see how their response differs. The basic premise is that the control will show changes that would have occurred even in the absence of the treatment, so that any differences between treatment and control will have been caused by the treatment alone.

Adapting to Change: A Crystal Ball?

Over time, the small-watershed studies conducted at experimental forests have undergone changes in priorities, scope, scale, and application. These shifts reflect the evolution of forest management concerns, societal issues, intellectual interest, and technology. While the first studies on experimental forest watersheds were specifically meant to support a small number of management interests, such as increasing water yield from the forest, today much of the small-watershed work undertaken at experimental forests emphasizes fundamental principles and processes that can be used to answer questions that relate to a wide variety of management problems.

The changes in priorities and focus happened gradually and encompassed an ever-widening scale of application, as exemplified in a history of the H.J. Andrews Experimental Forest. By the 1970s, basic studies had matured from specific water flow measurements to holistic ecosystem functions, such as nutrient cycling and energy flow. In the 1980s, that emphasis tilted toward potential applications and implications for "ecosystem management." By the 1990s, the scale of interest had broadened to landscape-scale studies and testing of ecosystem management methods. In the 21st century, the need to answer critical questions that address planet-wide issues and concerns about global climate change and forest sustainability is providing the impetus for continuing research at the small-watershed level.

These long-term, small-watershed studies sometimes seem to anticipate the need for central pieces of information that can be used to address all sorts of issues, years, even decades, later. It's not that these scientists have a crystal ball to see into the future—although researchers do try to project out a decade or two regarding what they think the questions will be and what data will be needed in the future. Rather, it's the fundamental nature of this research that provides vital and

Adaptive management in action

Changes in research priorities at experimental forests embody the approach of "adaptive management," where policy and management decisions are improved as a result of what is learned through research and monitoring. Throughout the Forest Service, policy changes on topics such as coarse woody debris in streams or yarding slash from timber harvest units can be attributed to small-watershed research at experimental forests that provided new information about past practices. For example, at Caspar Creek experimental watersheds in California, it was established that the increases in water yield so desired by early managers could not be achieved without undesirable ecological and social consequences. As a result of this research, forest managers changed the practices they applied to the land. In recent years, Caspar Creek has increased its number of experimental small watersheds due to a demand for information on clean water and the challenge of dealing with regulations on private lands.

By the 1970s, basic studies had matured from specific water flow measurements to holistic ecosystem functions

Who'll stop the rain?

In a stunning example of basic small-watershed research being used to address an emerging large-scale problem, the nutrient cycling and energy flow studies at Hubbard Brook Experimental Forest in New Hampshire led to the first recognition and definition of "acid rain."

Having studied daily stream and precipitation chemistry for years, scientists at the small research forest first documented acidified precipitation in the 1970s.

"Essentially we 'discovered' acid rain through our watershed studies here," explained Hubbard Brook's Jim Hornbeck, "based on collections begun in the early 1960s, and thus we were able to raise the alarm."

When observations similar to those initially done at Hubbard Brook were repeated across the country, acid rain was found to be common in most places east of the Mississippi. The cause was traced to regionally elevated air pollution.

Acid deposition and its damaging effects on fish, wildlife, vegetation, and human-built structures became an intensive and far-reaching policy issue of the 1970s and 1980s. Eventually, in response to public concern about acid rain, Congress legislated stricter air pollution controls in the Clean Air Amendments of 1990. The small-watershed research at Hubbard Brook changed the way we look at and deal with pollution, power, and policy.

credible data needed by managers and policymakers confronted by emerging trends and issues. Years of information stockpiled in the knowledge bank can be re-sorted and re-analyzed, with new perspectives and urgency, to answer previously unimagined questions at a variety of scales from local to global.

Far from the glare of the media and political spotlights, long-term baseline records such as those from the small experimental forest watersheds provide a lens through which to view naturally occurring events over time.

According to Julia Jones, Professor of Geosciences at Oregon State University (OSU), in Corvallis, OR, "existing long-term records from small watersheds have already enriched our 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."

The small-watershed research at Hubbard Brook changed the way we look at and deal with pollution, power, and policy.

Jones is among a growing number of OSU scientists collaborating on small-watershed research at the H.J. Andrews Experimental Forest. She and others believe there is enormous potential for general ecosystem insights from comparisons among multiple, diverse small-watershed experiment sites over time, particularly if an interactive network of long-term studies can be sustained.

"The time dimension of these studies is crucial for credible studies of hydrologic processes as they affect and are affected by forest management," adds Fred Swanson, geologist with the Pacific Northwest Research Station, and ecosystem team leader at the Andrews Forest. "Long-term perspectives are now more widely recognized as essential to understanding complex forest systems and watersheds."

"When viewed long-term, what we call catastrophic events—flood, wildfire, landslides, and windthrow—become natural disturbances, with vital positive functions in the ecosystem," Swanson explains. "Being able to track them with an ever-growing database gives us enormous potential for understanding things like the dominant hydrologic processes and controlling factors, using both field experiments and quantitative modeling."

Interestingly, the crystal ball activated by small-watershed research can also enable managers to see into the past to gain new perspective on old issues. Recent observation at the Caspar Creek experimental watersheds, for example, suggests that a 25-year-old logging operation is now sending a second pulse of sediment into the stream as abandoned roads begin to fail. Such an insight may have been impossible without long-term studies.

Living Laboratories for the Future

Reaching back through the past 60 years of research on small watersheds in experimental forests is helping to resolve many of today's issues about water and land uses. Today's research will be able to contribute to solving the water resource problems of tomorrow, if these types of studies continue to be appreciated and supported. Several features point toward the continued value of small-scale watershed studies.

New methods for observing watersheds are emerging that hold promise for improving answers to managers' long-standing questions. For example, naturally occurring isotopes can be used to trace water and, in some cases, chemicals such as nitrogen as they move through watersheds. The sensitivity and range of this technique have increased dramatically in recent years, giving scientists a powerful tool to unravel complicated flow paths through watersheds that were impossible to achieve until recently. In another example, small, inexpensive, and wireless instruments can now gather many kinds of field data for extended periods of time without human tending; especially valuable in remote areas, such instruments are already in use at Luquillo Experimental Forest in Puerto Rico and Bonanza Creek in Alaska.

New techniques are also evolving for analyzing large collections of watersheds. One such technique for tracking changes in streamflow annually and over decades of vegetation development following cutting and other disturbances is the result of the pioneering efforts at the H.J. Andrews Experimental Forest by Julia Jones, OSU, and Fred Swanson, Pacific Northwest Research Station. Their technique will greatly increase science's predictive power by enabling scientists to draw conclusions from a wide network of watershed studies rather than from one or a few at a time, as was the case in the past. This work is an important component of the emerging field of "eco-hydrology."

The shifting attention of the public, the news media, and the Congress will lead to regular adjustments in priorities for managing landscapes and watersheds across the Nation

To provide grist for such new techniques, scientists at Forest Service experimental watersheds are making their long-term stream flow data accessible on the World Wide Web at http://www.fsl.orst.edu/climhy/hydrodb/. The site has an innovative search engine called a "Web Harvester," which links 23 long-term studies from across the United States and has the potential to answer questions of scientific and practical importance. The network of watershed studies will also provide a portal to other networks such as the National Science Foundation's Long Term Ecological Research Network and the national network of Forest Health Monitoring Plots.

Finally, new issues will continue to emerge, and the need for information by land managers and policymakers about interactions between land and water will continue to change, as it has for the past 60 years. The shifting attention of the public, the news media, and the Congress will lead to regular adjustments in priorities for managing landscapes and watersheds across the Nation. New management and policies will raise new questions that long-term data from small-watershed studies can help answer. ∎

Key Issues

- Many parts of the country benefit from the clean and reliable water that flows from forested watersheds.

- Forested watersheds provide many benefits including:
  - Sources of safe drinking water.
  - Critical habitat for many fish and other aquatic riparian species.
  - Waters for many uses including agriculture, industry, and recreation.

- Natural processes and human activities often interact to affect benefits from forested watersheds, for example:
  - Floods and droughts.
  - Vegetation management including fire, grazing, and logging.
  - Recreation, urban development, and air pollution

- Understanding these complex interactions requires long-term studies in small watersheds where cause and effect relationships can be determined.

Land Management Implications

- To sustain benefits of forest watersheds, managers and policymakers need a scientific understanding of how natural processes and management interact to affect watershed benefits.

- To manage landscapes to protect watersheds, managers and policy makers use basic information from the Forest Service long-term studies of small watersheds.

- To assess and plan management activities at large spatial scales and long time periods, mangers use models that include cause-and-effect relationships. Many of the relationships that underlie these models were derived from data gathered in long-term, small watershed studies.

- As managers respond to evolving uses of land and water by the public, they will need the critical information provided by small watershed studies. ▮

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