Watershed research is, by its nature, a series of case studies and examples. Because weather, hydrography, soil, vegetation, and disturbance patterns all influence hydrologic response, hydrologists and watershed scientists tend to learn and pass on lessons using allegory. When a forest hydrologist says Hewlett and Hibbert, other hydrologists think variable source area. When they discuss the Alsea Watershed Study, the demonstrated effectiveness of riparian buffers to minimize stream temperature changes is understood. The language of forest watersheds is expressed as the collective allegorical lessons from watershed research over the past century. This article provides a brief introduction to that language and history, identifying some of the research watersheds in the United States and their key management-related issues and scientists.

FOREST WATERSHED RESEARCH IN THE UNITED STATES

Concerns about forest management effects on streams go back to the birth of professional forestry in the United States. Public license to harvest timber has always been contingent on acceptable water resource consequences. This is clearly displayed in the first effort to use professional forestry in the United States. In the late 1800s a young German forester named Carl Schenck replaced Gifford Pinchot as the forester of the Biltmore Estate in western North Carolina. Schenk was to continue the effort for George Vanderbilt to manage the estate as a model for the nation. Following Pinchot's plans, Schenck described the construction of a splash dam on Big Creek to transport logs thus:[1]

> *The bed of the creek was freed of protruding rocks and fallen timber and of all sharp bends that would obstruct the passage of logs driven in a splash. Where the creek had low and shallow banks, strong barricades were made along the banks to confine the current to a depth that would float the logs downstream…a second splash dam was constructed…on the North Fork of Big Creek… The waves from the two splash dams were so timed that they met one another at the confluence of the two creeks.*

This transportation system proved to be a problem with logs washing out bridges and streambanks as well as burying farmland adjacent to the river. Schenck, after inspecting Big Creek, concluded: *"Had* [Vanderbilt] *seen the terrible change presented by Big Creek, the devastation in the laurels framing its once paradisiacal banks, the rocks in the creek washed bare of their original mossy patina,*

BY GEORGE G. ICE AND JOHN D. STEDNICK

FOREST HISTORY SOCIETY COLLECTION, PHOTO #309.

Splash Dam on the North Fork of Big Creek on the Biltmore Estate near Asheville, North Carolina (now the Pisgah National Forest). Splash dams on Big Creek were commonly up to 22 feet high, built of cribs made of hemlock logs. Circa 1896. Image from Carl Alwin Schenck's manuscript The Dawn of Private Forestry in America, Recollections of a Forester Covering the Years 1895 to 1914.

he would have been furious, and forestry in Pisgah Forest might have come to a quick death." Later, the Biltmore Estate became the nucleus of the Pisgah National Forest.

EVOLUTION OF WATER RESOURCE RESEARCH

The water issues of Schenck's and Pinchot's day played an important role in the formation of the National Forest system.[2] One of the primary justifications for the legislation that established the National Forests was "*…the protection and enhancement of water supplies, including flood protection.*"[3] Observations that streams draining forested watersheds typically had greater and more constant runoff than streams from watersheds without forests led many to conclude that it was the presence of trees that increased precipitation and runoff. Forests were seen as sponges that soaked up moisture and then released it slowly, minimizing flood events. Research was to show that this was a simplified, and in some cases, incorrect view. Much of the functions provided by forest watersheds were found to result, not directly from the forest vegetation, but from the forest litter and favorable soil conditions created by forest vegetation.[4, 5]

The relation between forests and floods was a matter of debate in those years. As early as 1864, George Marsh argued in *Man and Nature* that forests reduced both the number and volume of floods. One intent of the 1873 Timber Culture Act, to promote tree planting on homesteads, was based on the assumption that forests brought rain.[6]

The role of forests in moderating streamflow was unclear but gained credence enough to be integral to the creation of forest reserves. The 1897 Organic Act cites "securing favorable conditions of water flows" or watershed protection as a primary function of forest reserves. The importance of forests in flood protection was recognized by foresters but not by engineers, who advocated flood control by use of dams and levees.[7] The dispute was not just a scientific one; Pinchot felt the Corps of Engineers' position harmed the conservation cause by undermining one of the key arguments for creating forest reserves.

Because of the need to gain political support for purchase of national forests in the East, the issue was important. The constitutionality of federal purchase of forestland was at stake. The House Judiciary Committee decided that the commerce clause permitted the purchase of watersheds of navigable streams if it could be proved that forests prevented floods.[7]

The job fell to the USDA Forest Service Office of Silvics to counter the view that forests were unimportant to flood control. In 1901 Raphael Zon became head of forest research. To decentralize research, Zon proposed creation of forest experiment stations on the national forests. The first area experiment station was established in 1908 at Fort Valley on the Coconino National Forest in Arizona.[8] Most studies addressed forest-specific issues rather than national priorities. An exception was the Wagon Wheel Gap Watershed Study begun in 1910. (See map for locations of watershed studies described in this article). This study helped ensure the passage of the Weeks Act in 1911 that provided for purchase of 9.3 million ha of land in the eastern United States "for the protection of watersheds of navigable streams."

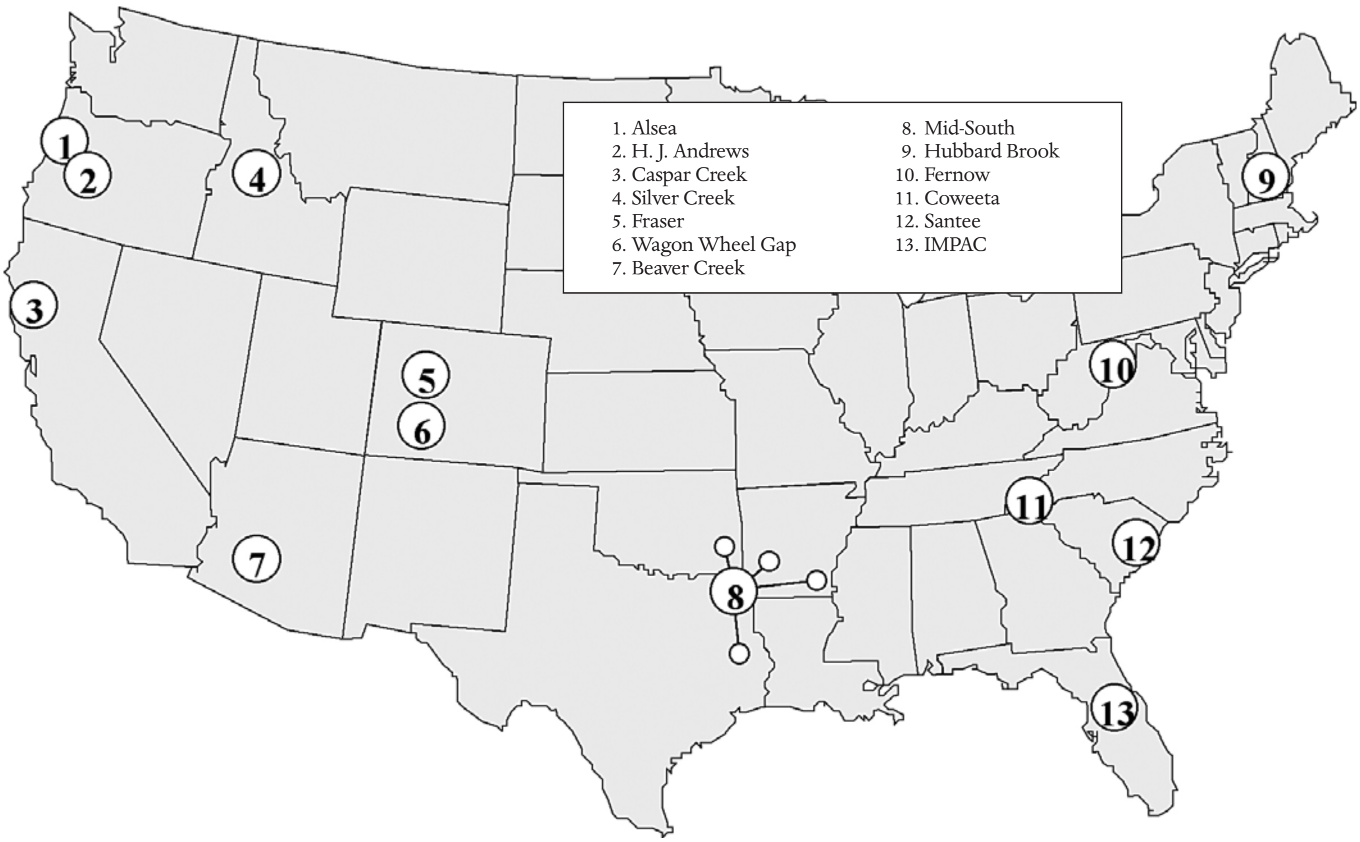
THE FIRST STUDIES: WAGON WHEEL GAP

Prior to the Wagon Wheel Gap project, only one other effort had been made to measure the influence of forests on streamflow. That study was fifteen years of streamflow observation near Emmental, Switzerland.[9] The Emmental watersheds were monitored for streamflows under natural vegetated conditions, with one watershed 97% forested and the other 35% forested. A study contemporary to Wagon Wheel Gap was conducted by the U.S. Geological Survey in 1911 and 1912 in northern New Hampshire, assessing the influence of forest condition on runoff.[4] This study showed that forest cutting and burning reduced infiltration, which produced lower base flow and caused streamflow to increase more rapidly during storms.

Still, most forest hydrologists trace the beginning of the classic watershed studies in the United States to the Wagon Wheel Gap Project in Colorado.[10] In 1909 the USDA Forest Service selected a site on the Rio Grande National Forest near Wagon Wheel Gap, Colorado, for what was to be a very complete study of the effects of forest cover on streamflow and erosion under the conditions of the central Rocky Mountains. Over the 16-year period of the study, lead scientist Carlos Bates continually sought to extend the study's scope but money was lacking. USDA Forest Service research was shifting from empirical observation to experimental testing of hypotheses, but agency funding did not keep pace with research needs.[7] Shortage of funding continues to be a constant theme throughout the history of watershed research in the agency.

The study plan was to observe meteorology and streamflow

Location of major watershed studies in the United States.



for two similar, contiguous watersheds for several years and then to denude (harvest) one of the watersheds of its forest. This would allow a comparison of the time and amount of streamflow, amount of erosion, and the quantity of sediment transported in the stream before and after removal of the forest. The control watershed allowed the researchers to predict what outputs the treated watershed would have been expected to produce before the forest was removed. Since the study plan required detailed meteorological observations, the cooperation of the weather bureau was solicited. Construction of research facilities, living quarters, and instrumentation began June 1, 1910, and was completed by October 22, 1910.

Streamflow measurements were made with concrete dam-weir structures. Forest removal increased annual water yield compared to the control watershed, but the water yield increase became smaller as vegetation reestablished. Researchers felt that the treated watershed had recovered after seven years. They wanted to then use the treatment watershed as the control and harvest the former control watershed but financial support from the Washington office was not obtained. The experiment was terminated on October 1, 1926.

The Wagon Wheel Gap Study set several important standards for subsequent research. Personnel lived on site and were better able to maintain instruments and respond to storm events. Instrumentation included meteorologic and hydrologic stations. Investigations of soils, geology, and vegetation were all part of the study plan. The Wagon Wheel Gap site has been nominated for the National Registry of Historical Places in the United States. A little known fact is that seven people died on site during the study period. The causes ranged from diphtheria to being buried by a snow avalanche.

RESEARCH IN THE SOUTH: COWEETA AND FERNOW

The king and queen of watershed research sites in the South are the Coweeta Hydrologic Laboratory near Franklin, North Carolina, and the Fernow Watersheds in central West Virginia. These watersheds, along with significant watershed research sites in the southern flatwoods and numerous watershed studies throughout the South, have provided important lessons about how to minimize effects on water quality from forest operations.

Coweeta Hydrologic Laboratory

The disastrous Mississippi floods of 1927[11] stimulated research on the role of forests in runoff. One of the first to pursue forest watershed research was Charles Hursh with the USDA Forest Service. His plot research at Bent Creek near Asheville, North Carolina, used infiltrometers to compare runoff from forest and agricultural covers. In 1934 the Coweeta Hydrologic Laboratory in the mountains of North Carolina was established as the first long-term forest hydrologic research facility in the United States.[12] Although more mountainous than much of the Southeast, this research facility and its scientists have contributed greatly to our understanding of forest watershed response to management activities and the development of Best Management Practices (BMPs) for the South.

Early studies at Coweeta focused on how land management affects the hydrologic cycle and included studies on the effects of

FROM C.G. BATES AND A.J. HENRY, FOREST AND STREAMFLOW EXPERIMENT AT WAGON WHEEL GAP, COLORADO. MONTHLY WEATHER REVIEW SUPPLEMENT NO. 30.

Gaging station at Wagon Wheel Gap, Colorado. This was the prototype for later small forest watershed studies in the United States, with a control watershed and calibration period prior to treatment. USDA Weather Bureau photo (1928).

mountain farming, woodland grazing, and unrestricted logging. Additional work addressed comparisons of water resource changes from partial and clearcut harvesting, alternative road designs, and the use of cable logging. One of the earliest studies looked at removing riparian vegetation as a means of increasing water yields.[13] The current mission at Coweeta is to "evaluate, explain, and predict how water, soil, and forest resources respond to management practices, natural disturbances, and the atmospheric environment; and to identify practices that mitigate changes on these watershed resources."[12]

Notable contributions in this region include John Hewlett's and Alden Hibbert's work on runoff pathways and hydrologic processes (including the Variable Source Area Concept that recognizes that the portion of the watershed contributing to runoff expands and contracts with the size of the event)[14] summarized in the standard text, *Principles of Forest Hydrology*;[15] Lloyd Swift's research on road erosion control; and Wayne Swank's work on nutrient cycling and atmospheric inputs.

Fernow Experimental Forest

The Fernow Experimental Forest was established in the central Appalachians in central West Virginia in 1951.[16] In response to a severe drought in the region, the original purpose of the Fernow Experimental Forest was to investigate the opportunity to increase water yields from forest watersheds. Studies at the Fernow showed that water yield did increase after harvesting but recovered rapidly. Research also looked at water quality and how timber harvesting and forest roads can affect sediment in streams. In recent years research has explored the watershed effects of acid precipitation. Stream chemistry data for one undisturbed watershed, dating back to 1969, provide an important benchmark for the region. Notable researchers associated with Fernow are Jim Kochenderfer, J.D. Helvey, and Jim Patric.[17] So the origins of Coweeta and the Fernow represent bookend concerns about flow from forest watersheds; one established to study floods and the other, drought.

These and other mountain research sites in the South provided important lessons about minimizing water resources effects from forest operations. However, the sites were not representative of other important physiographic regions of the South such as the Piedmont and Upper and Lower Coastal Plains. Important contributions to watershed research in the South came from work in flatwoods watersheds at the USDA Forest Service's Santee Experimental Forest and Clemson University's Belle Baruch Hydrologic Institute in South Carolina as well as the Intensive Management Practices Assessment Center (IMPAC) Study in Florida. The Santee Experimental Forest, located on the Atlantic

USDA PHOTO #469668. COURTESY OF SPECIAL COLLECTIONS, D.H. RAMSEY LIBRARY, UNIVERSITY OF NORTH CAROLINA AT ASHEVILLE.

Leroy Jones reading rainfall recorded in a standard rain gage at the weather station at the Coweeta Hydrologic Laboratory Administration Headquarters. Photo taken by Leland J. Prater (September 1952).

PHOTO BY GEORGE ICE, APRIL 1990.

Studies on how to control road erosion were conducted at Coweeta and Fernow. This study of road erosion at Fernow, West Virginia, looks at rolling dip roads as a means of getting water off the road and minimizing erosion.

PHOTO FROM HANS RIEKERK, UNIVERSITY OF FLORIDA, MAY 1978.

At the Bradford Forest in Florida, the Intensive Management Practices Assessment Center (IMPAC) Study addressed runoff and water quality for low-relief watersheds. Special control sections were necessary to gage runoff. In the heat of Florida, refrigerated storage was also used on site to preserve samples.

Coastal Plain flatwoods, deserves special note because the forest experienced extreme wind damage in 1989 from Hurricane Hugo.[18] Although watershed monitoring at the Santee has been discontinuous in recent years, it provides an important database for low topography forest response.

INCREASED WATER FROM FORESTS: FRASER, H. J. ANDREWS, AND BEAVER CREEK WATERSHEDS

During the dust bowl era, watershed concerns spread to the condition of the watershed, potential water quality changes, and management practices that could minimize negative watershed effects. The Soil Conservation District movement, initiated by the Soil Conservation Act of 1935, is representative of this effort to develop practical methods of managing lands to protect watershed functions. Craddock and Hursh wrote "Watersheds and How to Care for Them" in the *1949 Yearbook of Agriculture*.[19] They stated: *"Today, better land-management practices must be inaugurated to restore a more favorable plant cover and soil structure if we wish to maintain land and stream conditions to serve our present and future needs for usable water."* Options were explored where timber cutting could be used to increase available water.[20]

Fraser Experimental Forest

The Fraser Experimental Forest in Colorado was established in 1937 specifically to examine the effects of vegetation manipulation on water storage and yield from subalpine forests (http://www.fs.fed.us/rm/fraser/). The Fraser also serves as one of five principal long-term watershed research sites within the USDA Forest Service system. The first paired watershed study in the Fraser was the Fool Creek experiment, where logging created variously sized openings to look at the effect of opening size on snow pack accumulation and streamflow. Pretreatment monitoring started in 1945, with the adjacent East St. Louis Creek serving as the control watershed. Fool Creek watershed manipulation began in 1955. The watershed gauging program is still active, and East St. Louis Creek remains undisturbed. The Fool Creek study was one of the first to look at the effects of timber harvesting activities on sediment yields. Road and timber harvesting-related erosion was measured by collecting individual grab samples and measuring deposition in a sediment detention basin located at the watershed base.

In 1955 Deadhorse Creek and Lexen Creek were instrumented. These watersheds are used to assess the effects of different silvicultural prescriptions, including patch cuts and overstory thinning on water yield and water quality. Nested watersheds and treatments on different aspects further identify streamflow generation mechanisms in the cold snow zone.

Most early research at the Fraser was oriented toward timber or water production resulting from forest management. Current research addresses links between forests, riparian areas and streams, and to better understand nutrient cycling, snow hydrology and ecosystem carbon storage. Fraser is unique in that it has a relatively long-term record, pristine atmospheric input, and significant areas that have not been impacted by management.

Compared to other sites, water yield increases measured in Fraser Experimental Forest have lasted longer because of slower tree growth. Streamflow monitoring continues at Fraser due to the importance of water resources in the Southwest. Fraser Experimental Forest has a large legacy of forest hydrologists including H. G. Wilm, E. G. Dunford, Dudley Love, Marvin Hoover, Bert Goodell, Burchard Heede, Chuck Leaf, C. A. Troendle, Jim Meiman, and Manuel Martinez.

H. J. Andrews Experimental Forest

The H. J. Andrews Experimental Forest is located 80 km east of Eugene, Oregon, and was established by the USDA Forest Service in 1948.[21] It covers more than 6,000 ha including the entire Lookout Creek Watershed. A number of small experimental

PHOTO BY JOHN STEDNICK, AUGUST 2001.

Fool Creek in Colorado looked at how the size of openings created by harvesting affected runoff. It was also one of the first sites to look at how timber harvesting affected sediment yields.

watersheds have been established within the Experimental Forest and are monitored for discharge, water chemistry, and suspended sediment. Monitoring of discharge in Watersheds 1, 2, and 3 began in 1953; sediment and water chemistry monitoring were added in 1957 and 1962, respectively.[22] These watersheds were used in a paired watershed study of alternative harvesting and road practices. Watershed 2 serves as a control. Watershed 1 was clearcut between 1962 and 1966. Watershed 3 was partially harvested and had road construction. Sediment and nutrient losses increased from clearcut Watershed 1, especially after prescribed burning through the channel. Nutrient and suspended sediment outputs recovered over time but increases in bedload (larger sediment moving along the channel bottom) have persisted.[23] This study showed the importance of protecting the stream channel and adjacent vegetation to minimize changes in water quality. Debris torrents (rapid moving, water-charged landslides in channels) in Watershed 3 during the 1964 and 1996 floods dominate the sediment production observed. In this case poor road construction methods resulted in landslides during major precipitation events. This led to improved road designs that are less likely to fail. Reanalysis of long-term streamflow records from these watersheds has sparked considerable debate among forest hydrologists about our ability to detect changes in peak flow, particularly for extreme events.

Another H. J. Andrews watershed, Watershed 10, also deserves note because it was the focus watershed in Oregon for research as part of the Coniferous Forest Biome research project. Landslide inventories in the H. J. Andrews Experimental Forest, responding to concerns raised by the road failures in Watershed 3, were important in identifying the potential risks of sidecast (material from excavation of road prism pushed downslope without compacting it and used to support part of the road tread) road construction methods. Research at H. J. Andrews also helped to identify the importance of large wood in streams. Many watershed experiments are underway today in this area, including creation of artificial landslides and testing the effects of artificial shade on streams. Watershed monitoring continues on watershed response to disturbance agents such as floods, fire, and windthrow.

Key researchers and topics include Jack Rothacher and his research on the effects of forest management on water quality and streamflow; Ted Dyrness and his research on forest management and fire effects on soil; Richard Fredriksen who studied water quality response to timber harvesting and site preparation; Dennis Harr who studied runoff from snow and rain-on-snow events; and Doug Swanston and Fred Swanson who studied landslide processes in the forest, and with George Lienkamper and Jim Sedell, introduced the study of large wood in streams.

Beaver Creek Watershed

In the Southwest, critical water demands pushed watershed scientists to look at occasionally radical options to increase water supplies, such as removal of streamside vegetation. The Beaver

PHOTO COURTESY OF JIM HORNBECK, USDA FOREST SERVICE.

A series of watershed experiments are shown in this photo of Hubbard Brook, New Hampshire, taken the winter of 1972–1973. In the foreground is a block-clearcutting (performed in 1970). In the middle of the photo is a progressive strip cutting (performed from 1970–1974). To the far right is a watershed that was clearcut with trees left on site (1965–1966) and experimentally treated with herbicides (applications for three years).

Creek Experimental Watershed[24] was established in 1956 to study the influence of vegetation manipulations on water yields from a pinyon-juniper and ponderosa pine forest as well as to evaluate effects of forage and timber production on soil movement. Beaver Creek is located on more than 110,000 ha, 80 km south of Flagstaff, Arizona. Paired watershed studies at Beaver Creek and elsewhere showed that water yields could be increased but that increases were transient, and other factors, such as water quality, needed to be considered. Wildfire, and the potential formation of water repellent soils, is another key concern for the Southwest. Some of the key researchers in this region included Leonard DeBano, who studied the formation of water repellent soils, and Peter Ffolliott and Malchus Baker, who investigated the effects of vegetation manipulation on water yields.

WATER QUALITY: HUBBARD BROOK, CASPAR CREEK, AND THE ALSEA WATERSHEDS

Initial watershed studies examined how different vegetation patterns affected water yield. Interest about how vegetation manipulations and forest management practices affected water quality was also increasing. Watershed-level studies were conducted to look at the effect of forest management practices on nutrient concentrations, suspended sediment, water temperature, dissolved oxygen, and fish habitat.

Hubbard Brook

By the 1950s paired watershed studies were underway in the Hubbard Brook Watershed near Thornton, New Hampshire. One of the first experiments at Hubbard Brook was harvesting trees. Unlike typical commercial forest harvests, the trees were left on site, and the area was repeatedly sprayed with herbicide to prevent vegetation regrowth. Nitrate concentrations increased in surface waters, and there was a concern that forest productivity could not be sustained due to nutrient losses. While this study is not representative of the effects of commercial forest harvesting on water quality, it did contribute to our understanding of nutrient cycling processes in forest watersheds. Publication of these results by Gene Likens, F. Herbert Bormann, Noye Johnson, and others are available in journals such as *Science*,[25] *Ecological Monographs*,[26] and *BioScience*.[27] Because of the concerns raised by this study, subsequent research tested forest management approaches that minimize or eliminate nutrient losses in streamflow from forest watersheds. Some of the management options to reduce nutrient losses include rapid revegetation, minimizing disturbance to the forest floor, and varied harvesting patterns, such as the use of partial harvesting or streamside management zones, that allow for uptake of nutrients by residual vegetation.

Caspar Creek

Caspar Creek is located in coastal northern California. A paired watershed study was initiated in 1961 on the North and South Forks of Caspar Creek.[28] After 5 years of calibration monitoring, roads were built in the South Fork in 1967. The entire South Fork was selectively harvested between 1971 and 1973. The sequencing of management activities allowed researchers to assess road and harvesting impacts on runoff and sediment. After a period of recovery, the Caspar Creek Watershed was reentered, this time with management in the North Fork and with the South Fork (and sub-basins within the North Fork) serving as controls. Begun in the late 1970s, this study used nested small watersheds to assess cumulative effects downstream. Various combinations of harvesting, yarding, site preparation, roads, and streamside management zones were tested in the small watersheds. Sediment samples were collected using pumping samplers and a new sample collection approach known as SALT (Select At List Time).[29] This approach provides an unbiased estimate of the total sediment passing a monitoring station. Additional studies investigated the importance of large hydrologic events, subsurface flow dynamics, bedload movement, low flows, aquatic invertebrate response to harvesting, woody debris recruitment, and water chemistry.

The first Caspar Creek study demonstrated changes in both runoff and water quality as well as rapid hydrologic recovery in coastal watersheds with forest regrowth after harvesting. The second study, which was conducted with the current forest practice regulations, demonstrated that these practices could significantly reduce water quality impacts. The second study also provided more detailed assessments of fine-scale impacts such as runoff flowpaths and interception (deposition of precipitation on foliage). The USDA Forest Service and California Department of Forestry and Fire Protection have recently signed a 100-year agreement to continue watershed research at Caspar Creek. This will allow for a comparison of forest management impacts prior to the state Forest Practice Rules, after adoption of the Rules, and after revisions to the Rules. A recent USDA Forest Service general technical report summarizes the major findings from Caspar Creek.[30] Some key researchers in this area included Raymond Rice, Robert Ziemer, and Elizabeth Keppler (stream-

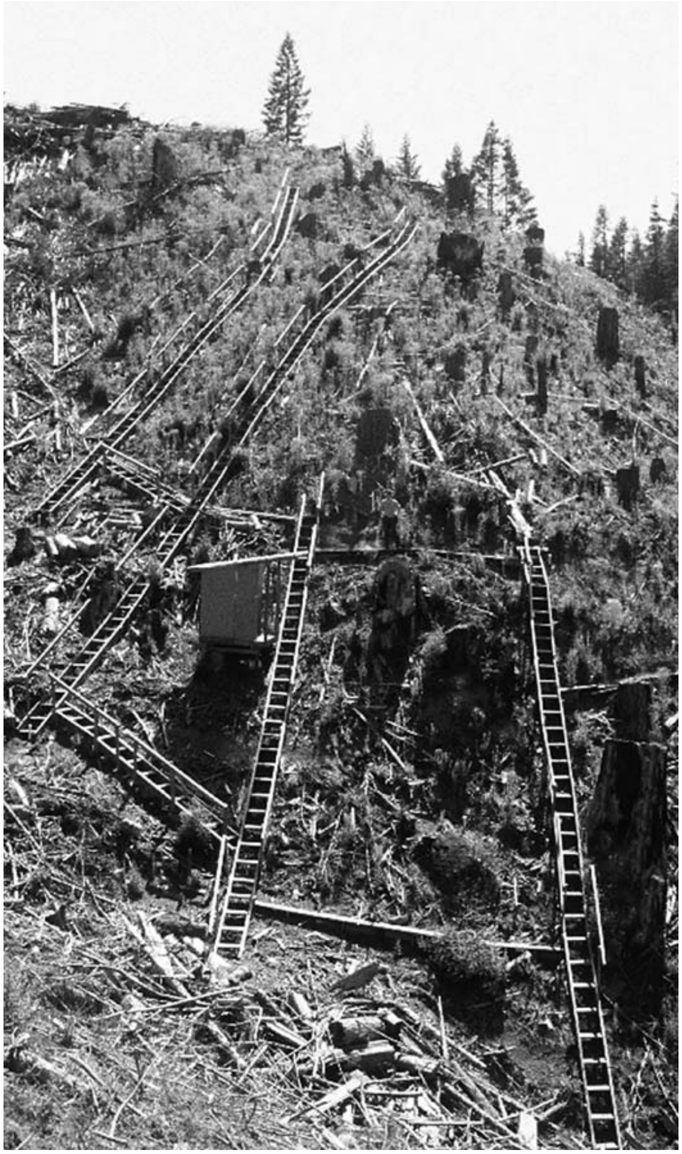


PHOTO COURTESY OF ROBERT ZIEMER, USDA FOREST SERVICE.

Process studies of soil moisture, subsurface flow, and pipeflow at Caspar Creek assisted in understanding effects of logging on streamflow and erosion. Summer 1991.

flow, erosion, and cumulative effects) and Robert Thomas (monitoring methods). Joseph Kittredge[31] and Paul Zinke[32] at nearby University of California, Berkeley, contributed to research on forest influences and forest canopy interception.

Alsea Watershed Study

The Alsea Watershed Study (1958 to 1973) was the first long-term watershed study in the nation to simultaneously consider the effect of timber harvesting on water quantity and quality, fish habitat, and fish populations. Three small watersheds in the Coast Range near Salado, Oregon, were monitored from 1958 through 1973. Flynn Creek served as the control and is designated as a Research Natural Area by the USDA Forest Service. Deer Creek was patchcut with a vegetation buffer along the main channel. Needle Branch was completely clearcut and site prepared by slash burning without a streamside buffer. This study clearly demonstrated the effectiveness of riparian management areas to minimize water quality and fish habitat

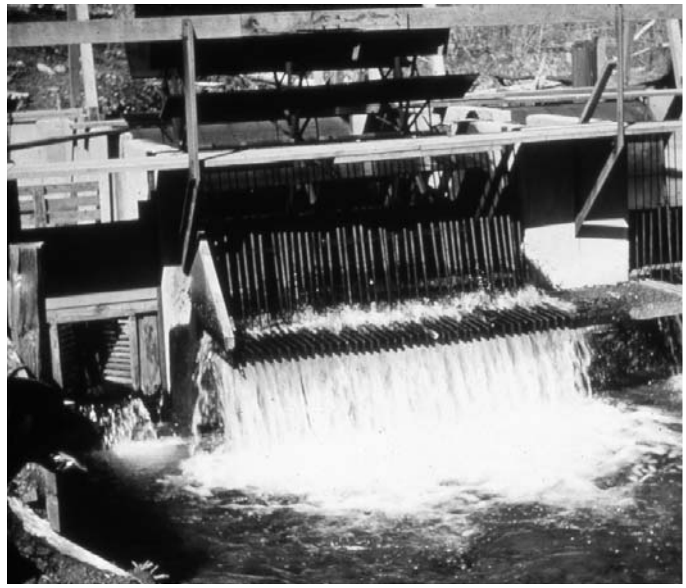


PHOTO COURTESY OF DR. JAMES HALL, OREGON STATE UNIVERSITY, CIRCA 1966.

This fish trap was used during the Alsea Watershed Study in Oregon to measure the effects of forest management on salmon runs.

impacts. Temperature and dissolved oxygen showed especially dramatic response to the retention of riparian vegetation. Some of the key researchers on this project were Don Chapman (research design), Jim Krieger (water quality), Jim Moring and Richard Lantz (physical and biological response), Jim Hall (fisheries response), and George Brown (Brown Equation for temperature). The Brown Equation is a commonly used tool for predicting maximum potential temperature change in streams due to removal of streamside or riparian shade.

The findings from the Alsea Watersheds influenced the development of rules for the first Forest Practices Act in the United States, adopted in 1971 and implemented in 1972. The findings are summarized in many articles[33] and continue to influence forest management decisions today.

The authors of this article reactivated the Alsea Watershed Study (AWS) in 1990 to address long-term hydrologic recovery and to assess cumulative effects of timber harvesting on water and salmon resources. This study will be the subject of a soon-to-be-published book.

BEST MANAGEMENT PRACTICES AND THE MID-SOUTH STUDIES

Passage of the 1972 Federal Water Pollution Control Act Amendment accelerated the need for forest watershed research to assess the effectiveness of alternative forest management practices in protecting water quality. This was particularly true in the South where concerns were raised about the effects of clearcutting and mechanical site preparation on water resources.

To identify Best Management Practices (BMPs) to mitigate water resources changes from harvesting and site preparation, a series of replicated small watershed studies were undertaken in the mid-South, beginning in 1979.[34] Each site had three replicates of each treatment and three control watersheds, and pretreatment monitoring was conducted for a year. Water samples were collected using H-flumes and Coshocton wheels. One site, established by Texas A&M University, was located in east Texas near

Alto in the Upper Coastal Plain. Treatments included harvesting followed by shearing and windrowing, and harvesting followed by roller chopping (six treated watersheds and three controls). Another set of watersheds, established by the University of Arkansas at Monticello was located in Arkansas in the Gulf Coastal Plain and compared clearcutting and selective cutting. A third set, also established by the University of Arkansas at Monticello, was located in the Athens Plateau of Arkansas and compared clearcutting with mechanical and chemical site preparation. This study showed that mechanical site preparation significantly increased sediment and water yield but that these increases were relatively small compared to other land uses and recovered rapidly. Chemical site preparation did not significantly increase sediment losses.

Another set of sites was established in the Ouachita Mountains. Weyerhaeuser Company established six small experimental watersheds in Oklahoma in 1977 and compared clearcut and mechanically site prepared watersheds (including deep ripping to improve percolation of water into the subsoil) with untreated watersheds. In Arkansas the USDA Forest Service and other cooperators tested clearcutting and selective harvesting (six treatments and three controls). As observed in other watershed studies, timber harvesting and mechanical site preparation resulted in increases in sediment but these lasted only one to three years. Changes in stormflow runoff were mixed, with some watersheds showing increases and others experiencing no change. The watersheds with deep ripping seemed to have reduced stormflow runoff the first year. This may have resulted from increased infiltration, increased water storage, and possibly disruption of macropores (large openings in the soil created by roots, animals, etc, that allow for rapid subsurface movement of water). Some of the key researchers for this region included Scott Beasley, Will Blackburn, Ed Lawson, Stan Ursic, Ed Miller, Don Turton, Gray Henderson, and George Coltharp.

CUMULATIVE EFFECTS: SILVER CREEK AND THE SALMON RIVER

Erosion, sediment transport in streams, and downstream cumulative effects have long been a concern in the northern Rocky Mountains. Both surface erosion and mass wasting (landslides) are a concern in this region, with steep, often erosive slopes. Annual surface erosion rates from undisturbed forests are quite low but can be greatly increased with both natural disturbance and fire. Logging practices in the 1950s and 1960s that used short cable systems over a high road density, known as jammer logging, resulted in extensive soil disturbance and erosion. Watershed studies to assess the effects of alternative management practices were conducted at Silver Creek, Idaho, and monitoring continues there today.[35] Silver Creek allowed for controlled studies of alternative harvesting and road practices on runoff and water quality. These intensive small watershed studies were complemented by larger watershed studies such as those focused on the Salmon River. Research by Walt Megahan, Jack King, Jim Clayton, and Ed Burroughs has led to recommendations for road location, construction, and maintenance practices in the region to minimize water resource effects. The development of erosion and sediment delivery models has also been an important part of research application in this region.

PHOTO BY GEORGE ICE, APRIL 1981.

H-flumes and Coshocton wheels like this one at the Oxford, Mississippi, Hydrologic Laboratory were used in the mid-South studies to measure flow and sediment runoff from catchments with different harvesting and site preparation practices. The Coshocton wheel rotates to expose a slot that collects a fixed proportion of the flow coming off the watershed. Dr. Stan Ursic of the Hydrologic Laboratory demonstrates how the wheel works.

CONCLUSION

Over the last century hundreds of forest watersheds have been monitored and used in watershed studies. Despite this impressive list of studies and results, we find that much of the watershed research work was conducted in classic paired watershed experiments 30 to 50 years ago. In the 1960s there were 150 forested experimental watersheds being studied; today, only a handful of these remain active.[36] Since 1970, over 2000 articles have been published on watershed-scale studies. Some researchers question whether watershed studies warrant the expense and whether watershed models can be used to replace physical studies. Yet it is these watershed studies that continue to be used to assess management alternatives as well as calibrate and validate watershed models.

No matter how much forest watershed research is conducted, there will always be questions about the effects of forest management practices on water quantity and quality. Still, the lessons

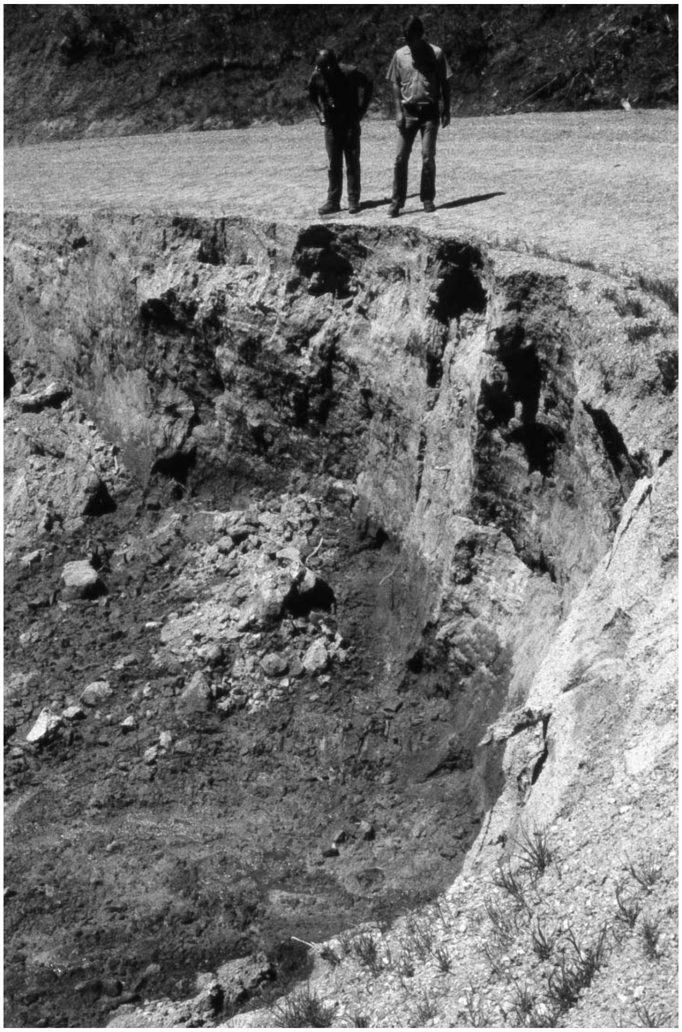


PHOTO BY GEORGE ICE, MAY 1982.

A road-fill failure is inspected at Silver Creek, Idaho. Roads are often a major source of management related sediment losses, and research at Silver Creek identifies road sediment control options.

learned from these historic forest watersheds studies are invaluable. They have contributed to our understanding of hydrological processes and how management activities change those processes. These insights have led to the continued refinement of Best Management Practices (BMPs) and have improved forest management decisions.

The product of this research investment has been dramatic improvements in forest watershed and water quality protection and documentation that good practices help. For example, Williams and colleagues[37] compared water quality impacts for a recent watershed study in the South Carolina Piedmont with an earlier study by Hewlett at the B.F. Grant Memorial Forest in the Georgia Piedmont.[38] In 1979, Hewlett had found that most of the increased sediment loss during his study was the result of roads and channel disturbance. With properly designed and maintained roads, effective streamside management zones, and careful site preparation and planting methods, Hewlett estimated that 90% of the increase in sediment could be avoided. In 1999, Williams et al. monitored sediment and other water quality impacts from timber operations in Piedmont watersheds where BMPs were used. They found small but statistically significant increases in sediment concentrations immediately after harvesting, even with BMPs. Still, the increases were small when compared with those measured by Hewlett. Williams et al. estimated that BMPs reduced first year sediment yield increases tenfold compared to the earlier study, or just about what Hewlett had estimated.

Clearly, given the hundreds of watershed studies, this paper does not begin to completely cover the lessons learned and the watershed researchers who have contributed to our understanding of wildland watershed processes. Other important members of the forest watershed community include E. A. Colman; Henry Anderson, Marvin Hoover, and Kenneth Reinhart; Peter Black; Kenneth Brooks, Peter Ffolliott, Hans Gregersen, and John Thames; and Richard Lee. Many others including Hank Froehlich, Bob Beschta, Mingteh "Mike" Chang, Hans Riekerk,William Sopper, Howard Lull, Carl Settergren, Dave Wooldridge, Sandy Verry, Tom Williams, Dave Rosgen, George Dissmeyer, and Art Eschner, have also contributed. They are listed here as a beginning point for researchers delving into the literature more deeply. Any omission is a matter of space and oversight, not the lack of contributions. □

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For additional information on lessons learned from watershed studies and research, look for A Century of Forest and Wildland Watershed Lessons, edited by George G. Ice and John D. Stednick ISBN 0-939970-88-0, Approx. 300 pp., paperback. Society of American Foresters, Bethesda, MD; www.safnet.org; 301/897-8720.

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