

Chapter 1

Historical Roots of Forest Hydrology and Biogeochemistry

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1.1 Introduction

The scientific disciplines of forest hydrology and forest biogeochemistry have contributed greatly to our understanding of the natural world even though they are relatively young disciplines. In this chapter, the historical origins, developments, and major advancements of these disciplines will be presented. The Hubbard Brook Ecosystem Study (HBES) will serve as a case study to illustrate the development, integration, and new research directions of these disciplines. Finally, this chapter on the historical roots and evolution of forest hydrology and biogeochemistry sets the stage for the remaining chapters of this volume by providing a conceptual framework in which most hydrological and biogeochemical work is conducted. Excellent reviews on forest hydrology and biogeochemistry are given by Sopper and Lull (1967), Bormann and Likens (1979), Lee (1980), Waring and Schlesinger (1985), Likens and Bormann (1995), Schlesinger (1997), Ice and Stednick (2004a), de la Cretaz and Barten (2007), NRC (2008), and DeWalle (2011).

1.2 The Early Foundations of the Influence of Forests on Water

1.2.1 Pre-Twentieth Century

Kittredge (1948), Zon (1912), and Colman (1953) provide the earliest historical perspectives of “forest influences,” which Kittredge describes as “including all effects resulting from the presence of forest or brush upon climate, soil water, runoff, stream flow, floods, erosion, and soil productivity.” However, the earliest accounts of interactions between forests and water were probably those of Vitruvius (ca. 27–17 BCE) when he recognized that forests played an important role in evaporation. He postulated that in mountainous regions, the loss of water due to evaporation was limited because forests reduced the sun’s rays from reaching the surface (Biswas 1970). About 100 years later, Pliny the Elder in *Natural History* (77–79 CE) observed,

“it frequently happens that in spots where forests have been felled, springs of water make their appearance, the supply of which was previously expended in the nutriment of the trees. . . Very often too, after removing the wood which has covered an elevated spot and so served to attract and consume the rains, devastating torrents are formed by the concentration of the waters” (Bostock and Riley 1855).

As Andréassian (2004) notes, Pliny’s observations highlight the major concerns of forest cover on water and climate (namely streams and precipitation). These and other observations of forest influences led Medieval and Renaissance governments to establish protection forests (Kittredge 1948). In France, King Philippe Auguste issued a decree in 1219 “of the Waters and Forests” that recognized the close relation between water and forests in forest management (Andréassian 2004). During the mid-nineteenth century in France and Switzerland, debates on the effects of forest clearing emerged partly from recent torrent and avalanche activity that had occurred in the Alps, which formed the beginning of the scientific study on the influence of forests on water (Kittredge 1948). Andréassian (2004) describes several French watershed studies that occurred during this period (Belgrand 1854; Jeandel et al. 1862; Matthieu 1878), which are among the earliest studies to report on measurements of forest influences on hydrology and climate.

Despite the experiences in Europe, national recognition in the USA concerning the role of forests in protecting watersheds did not occur until the late nineteenth century, which essentially ushered in a wave of research on forests and water. During the mid to late nineteenth century, there was much speculation on the role that forests played in climate. The accepted wisdom was that deforestation had caused significant macroscale climate changes, especially higher temperatures and lower precipitation; however, much of that was dismissed when climatic data became available showing that only at the microsite did forests have effects on climate variation (Thompson 1980).

Interests in forest influences in the USA began when conservationists such as George P. Marsh became alarmed by the rate of forest clearing and suggested, after reviewing European findings and observations in the Alps, that forest removal had devastating effects on streamflow (Marsh 1864). The publishing of Marsh’s *Man and Nature* followed by several reports on forest influences (e.g., Watson 1865; Hough 1878), eventually led to the 1891 Forest Preservation Act and 1897 Organic Act. These important pieces of legislation both described forest reserves, but the latter also provided a blueprint for their management and for the “purpose of securing favorable conditions of water flows.” As Kittredge (1948) noted, the period from 1877 to 1912 might be called the “period of propaganda,” when numerous writings and debates occurred concerning issues of forest influences on climate and floods. The importance of forests on flood control was generally accepted by foresters, but it had been challenged by prominent engineers such as Chittenden (1909) of the US Army Corps of Engineers and the Chief of the Weather Bureau, W.L. Moore (1910). With little scientific evidence to resolve the controversy, Raphael Zon, the Chief of Silvics with the USDA Forest Service, proposed the creation of the first experiment stations on the national forests and established the first forest and streamflow experiment at Wagon Wheel Gap, Colorado in 1909.

This study and others (e.g., in New Hampshire, see Federer 1969) helped ensure the passage of the Weeks Act in 1911 that provided “for the protection of watersheds of navigable streams” and the purchase of 9.3 million ha of land for national forests in eastern United States. The following year, Zon (1912) issued a seminal report to Congress on “Forests and water in the light of scientific investigation,” which summarized evidence for the influence of forests on floods. This report would become the authoritative reference on the topic for the next several decades.

1.2.2 Early Twentieth Century: Watershed Studies

Disasters in the Alps during the early to mid-nineteenth century when forests were being cleared for pasture land prompted the Swiss to develop the first true watershed study in 1900, in the Emme Valley Emmenthal region (Engler 1919). The study was designed to evaluate the effects of forests on streamflow through comparison of the hydrological response to precipitation of two 0.6 km² watersheds, the Sperbelgraben (97% forested) and the Rappengraben (69% pasture and 31% forest) (Colman 1953). However, results from the Emmenthal study were largely qualitative and conclusions were suspect since the watersheds were not first compared under similar forest cover conditions (Bates and Henry 1928), i.e., the experimental design was faulty (Penman 1959; Whitehead and Robinson 1993).

In 1909, the USDA Forest Service began to plan a purposeful experiment on the Rio Grande National Forest, near Wagon Wheel Gap, Colorado with two contiguous watersheds that were similar in topography and forest cover. Observations were made on meteorological characteristics and streamflow under these similar conditions. Then, forest cover was removed from one of the watersheds and measurements continued as before, until the effects of the forest removal had been determined (Bates and Henry 1928). Wagon Wheel Gap was the first true paired-watershed study, which allowed for direct comparison of the timing and amount of streamflow and amount of erosion before and after removal of the forest. The experiment showed that forest removal increased annual water yield compared to the reference watershed, but the increase in water yield lessened over time as vegetation reestablished with essentially no effect after 7 years. This study would set the stage for the development of the paired-watershed approach (Wilm 1944; Hewlett and Pienaar 1973) all across the USA (Fig. 1.1). Although experimental watersheds have been criticized for their lack of representativeness, expense, and difficulty in interpreting results (Hewlett et al. 1969; Ward 1971; Whitehead and Robinson 1993), they have been instrumental to an understanding of forest hydrology.

In 1936, the Omnibus Flood Control Act gave the USDA Forest Service responsibility for flood-control surveys of forested watersheds to determine measures required for retarding runoff and preventing soil erosion and sedimentation (Hornbeck and Kochenderfer 2004). Increased flooding (e.g., Mississippi River in 1927) and concerns over the role of forest harvesting in the next two decades, spawned new USDA Forest Service watershed research at the San Dimas

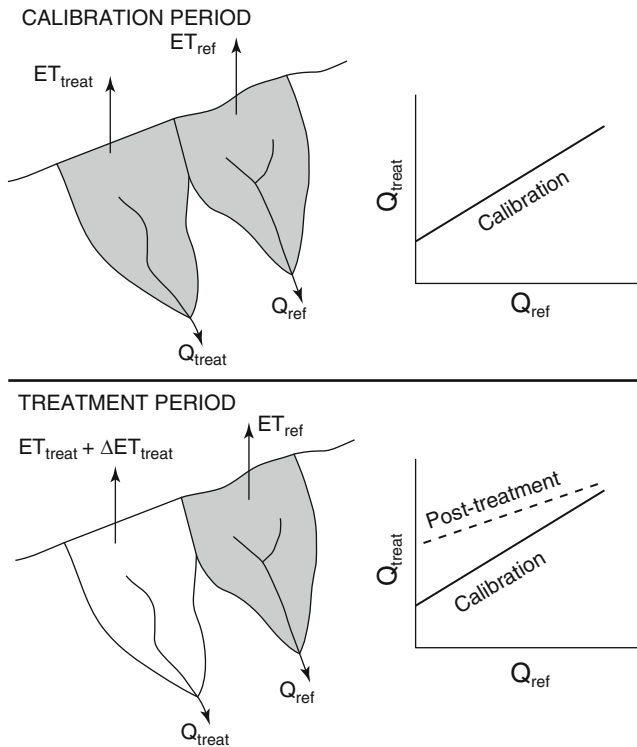


Fig. 1.1 An example of the paired-watershed approach to determine the effect of forest removal on evapotranspiration and water yield (adapted from Hewlett 1982). One watershed is manipulated (treatment, *no shading*) after an initial calibration period of where meteorological and hydrological variables observed to establish a relationship between the two watersheds. Using regression analysis or another statistical approach, differences between the treatment and reference can be established

Experimental Forest in southern California and the Coweeta Hydrologic Laboratory in western North Carolina. Although watershed studies were developed throughout the world, most were located in the USA and included some of the most noteworthy early contributions to forest hydrology (McCulloch and Robinson 1993).

1.2.3 Recognition of a New Discipline: Forest Hydrology

In his book on “forest influences,” Kittredge (1948) may be one of the first to use the term “forest hydrology” to describe a new discipline focused on water-related phenomena that are influenced by forest cover. New curricula at universities were developing to provide professional foresters with hydrologic training to deal with watershed management problems (Wilm 1957). In the decades following, there was a proliferation of forest hydrology research and the establishment of numerous experimental watersheds. Many of these experimental watersheds

are now well known (e.g., Fernow, Hubbard Brook, H.J. Andrews); however, of the 150 experimental watersheds that existed by the 1960s in the USA (Anderson et al. 1976), many have since been discontinued. The discipline of forest hydrology was well established by 1965 when the *International Symposium on Forest Hydrology* was held at the Pennsylvania State University (Sopper and Lull 1967). This symposium captured the discipline in reports of findings from studies on the influences of forest cover on water yield, peakflows, and sediment from all over the world. Proceedings from this symposium are one of the most important collections of papers in forest hydrology (Courtney 1981), and at the time, sparked renewed interest in forest hydrology, launching more process-oriented research on how water cycles within forests. Water quality, however, was not given much consideration at the symposium, with the exception of matters related to sediment (McCulloch and Robinson 1993).

1.2.4 The Influence of Forests on Floods and Water Yield: A Summary of Paired-Watershed Results

Initially, experimental watersheds and the paired-watershed approach were primarily used to evaluate the effects of forest management practices on the timing and magnitude of streamflow and sediment load. Many of these studies were used to develop best management practices that are still in use today (e.g., Kochenderfer 1970). The subject of forest management and its influence on flooding has been a recurring scientific, social, and political theme since the mid-nineteenth century (e.g., Eisenbies et al. 2007). Experiments beginning with Wagon Wheel Gap showed that with 100% forest removal, impacts on flooding appear to be minor if soil disturbance is minimized. Generally, complete forest removal increases peakflow and stormflow volume, although results are highly variable and depend on the severity of soil disturbance, storm size, antecedent moisture condition, and precipitation type (Bates and Henry 1928; Hewlett and Hibbert 1961; Lull and Reinhart 1967; Harr and McCorison 1979; Troendle and King 1985). Given that many scientific and legal arguments regarding forests and flooding continue today (e.g., Mortimer and Visser 2004; Alila et al. 2009), we have much to learn from historical studies and could benefit from objectively re-evaluating historical datasets (DeWalle 2003; Ice and Stednick 2004b).

Following initial concerns of flooding and forest cover change, interest began to develop in manipulating forest cover to augment water yields from forested watersheds (Ponce 1983). Thus, the paired-watershed experiments were used to address a different set of questions such as: could streamflow be increased during dry periods? Or could snowpacks be managed to increase streamflow during the summer months? Changes in forest composition, structure, or density that reduce evapotranspiration rates generally increase water yield from watersheds. Paired-watershed studies showed that annual water yield can increase between 15 and 500 mm with forest removal, although these changes are often short lived

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