

Ground Water and Small Research Basins: An Historical Perspective

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Scientists have been studying hydrological processes within a watershed context for hundreds of years. Throughout much of that history, little attention was paid to the significance of ground water; in nearly all early studies, ground water was never considered. In many recent studies, ground water fluxes are assumed to be insignificantly small. The following is a brief history of the evolution of watershed studies, including the recent increase in interest regarding the influence of ground water on the hydrology and geochemistry of research watersheds.

In 1580, Bernard Palissy, a Frenchman born in poverty and a self-taught observer, boldly challenged the philosophy of educated Roman citizens. He concluded from his observations that rain supplies springs (Palissy 1580). This was perhaps the first published evidence that ground water originates from precipitation. In the late 1600s, two other Frenchmen actually measured a crude water balance for the Seine River in Burgundy (Pierre Perault) and Paris (Edmé Mariotté). A third (Edmund Halley) measured evaporation from seawater. Their conclusions were that evaporation from the sea is enough to equal falling rain and that falling rain is enough to supply the combined discharge of streams and springs. Mariotté's work, published posthumously in 1684, defended Palissy's infiltration theory and maintained that water derived from rain and snow penetrates into the pores of the earth, percolates downward to rock, and then laterally in amounts sufficient to supply springs. He further observed that spring flow increases or decreases in wet and dry periods, respectively, and perennial springs are supplied from larger underground reservoirs.

Even though Palissy's explanation of ground water had existed for 337 years, the importance of ground water to streamflow still was not fully appreciated in the early 1900s, when statements such as this were promulgated:

" . . . [I]t becomes apparent that the aggregate amount of deep seepage, in so far as abstractions or additions to the flow of streams is concerned, is inconsequential . . . " (Meyer 1928). This conclusion was reached based on laboratory measurements rather than field studies. During the early 1900s, ground water flow data were largely limited to laboratory measurements of flow in media with various pore sizes.

In 1912, Raphael Zon (first director of the Lake States Forest Experiment Station in St. Paul, Minnesota) published a world literature review considering the relation of forests to water supply. Zon's paper was published as a U.S. Senate document, but was not widely available until 1927, well after World War I. The relationship of forests to erosion, temperature inside the forest stand, climate, and snowmelt was accurate; however, one conclusion suggesting forests regulate the flow of water to springs was largely false. The evidence cited was the lowering of the water table 13.8 feet in the midwestern United States (an average from more than 9000 wells) during the previous 80 years since European settlement began. The drawdown, however, was actually caused by wholesale conversion of central hardwood forests to agriculture and associated installation of extensive land-drainage systems (Verry 1986).

In 1953, Professor E.A. Colman at Berkeley summarized how vegetation affects water yield. He reviewed a few of the first small watershed experiments to use paired watersheds. In this approach, two watersheds similar in size and geology, and usually adjacent, are measured for precipitation and streamflow during a calibration period. After a five- to 15-year calibration, an equation is developed to predict streamflow on the "treatment" watershed (usually a tree harvesting treatment) from the "control" watershed streamflow where mature forests remain. The excess of streamflow on the treatment watershed above that predicted from the control is assigned to the treatment effect (tree harvesting), and the predicted treatment watershed streamflow to variation in precipitation. The first paired watershed experiment in the world began in 1911 at Wagon Wheel Gap, Colorado (Bates and Henry 1928). Bates and Henry harvested aspen in 1918, after collecting seven years of calibration data to predict the flow of the

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treated watershed from the control watershed; however, neither the work at Wagon Wheel Gap nor Colman's text reported the impact of vegetation change on ground water yield.

The discipline of forest hydrology crystallized with the International Symposium on Forest Hydrology (1965) at Penn State University (Sopper and Lull 1967). At this symposium, A.R. Hibbert (1967) presented a seminal paper titled "Forest Treatment Effects on Water Yield" summarizing the results of paired watershed experiments where one of the paired basins is harvested of trees. Results of watershed reforestation were also reported. The data proved mature forests reduce annual streamflow. The small research watersheds included in Hibbert's summary were the U.S. Forest Service experiments at: Wagon Wheel Gap, Fraser, and Meeker, Colorado; Coweeta, North Carolina; Fernow, West Virginia; H.J. Andrews, Oregon; San Dimas, California; and the Sierra Ancha Experimental Forest in Arizona. Reforestation experiments included work in USGS watersheds in central New York, Agriculture Research Service watersheds in Coshocton, Ohio, TVA's Pine Tree Branch and White Hollow in Tennessee, and Syracuse University's Sacandaga River in the Adirondacks, New York. However, none of these studies reported impacts to ground water. Penman (1963) had listed and discussed (without an analysis of the combined data) many of the same experiments along with others in Japan, Europe, and Africa.

The Penn State symposium also marked the end of the exclusion of ground water from small watershed studies. Of 78 papers presented at the symposium, five considered changes in measured water yield as ground water recharge or discharge. Analyses of well records were used to explain ground water recharge and discharge in Michigan's sandy outwash plains (Urie 1967), the peatlands of northern Minnesota (Bay 1967), the peatlands of Finland (Heikurainen 1967), the Mediterranean hills of Israel (Shachori et al. 1967), and the high-water table beech forests in Denmark (Holstener-Jorgensen 1967).

Urie's analysis of forested ground water basins benefited greatly from a series of ground water studies in the late 1950s and early 1960s. These included the analysis of Meyboom (1961) of streamflow hydrographs to estimate ground water discharge, Meyboom's ground water system model (1962) for the Canadian prairie pothole region, and Toth's theory (1962) and analysis (1963) of ground water motion in small drainage basins in Alberta, opening the era of ground water modeling.

The first application of an electric analog model to a small research watershed in the United States was in 1967 at the U.S. Forest Service, Marcell Experimental Forest in north-central Minnesota. Streamflow emanating from a forested fen wetland in watershed No. 3 was 10 times greater than its surface watershed could possibly produce from rain alone. The ground watershed was 10 times larger than the surface watershed (Sander 1971)!

Since the late 1960s, small research watersheds have been used to define nutrient cycling (Likens et al. 1970, 1977; Swank and Crossley 1988; Verry and Urban 1992; Urban et al. 1995). Even today, the direct accounting of water and nutrients flowing to deep seepage is rarely

accomplished even though broader comprehensive treatments of nutrient cycling now often include the ground water portion (Rankama and Sahama 1950; Stumm and Morgan 1970; Moore and Bellamy 1974; Bowen 1979; Fortesque 1979).

We have taken giant steps in our understanding of the ground water system in watersheds in the last century. Surely, no one today would accept Meyer's (1928) conclusion that ground water below the stream level has little to do with regulating flow in the stream; however, the fact that ground water is important to studies of nutrient flux is not sufficiently recognized. Many evaluations of water yield change in response to vegetation change, or of nutrient cycles, have assumed the stream gauge represented all the water in the watershed.

Watersheds in virtually all paired-watershed studies are selected on the assumption that foundation walls holding the weir or flume are deep enough to cut off seepage beneath the stream gauge. It is assumed the stream gauges are sealed to a confining layer and that all seepage into the watershed overburden exits through the stream at the gauge. In 1963, however, Penman stated that deep seepage (ground water passing beneath the streambed, beneath the surface water control structure, and out of the watershed) "... is frequently ignored altogether in catchment studies in the quiet hope that it is, in fact, zero." We suspect, rather than zero, it is a significant component of many small watershed studies, which is unfortunately overlooked in evaluations of water and nutrient budgets. In 1982, Bosch and Hewlett completed a second summary of tree harvesting impacts on water yield for 61 watersheds (paired with a control watershed) ranging from 1 to 694 ha. They also reported on abandoned farm watersheds replanted to trees and on tree regrowth following fire- or insect-caused tree mortality on 33 basins ranging from 26 to 197,400 ha. None of the experiments considered recharge to ground water. Verry (2003) shows that in a compilation of 32 watersheds, seven of the investigators were fully justified in their quiet hope that deep seepage was zero, 10 were justified in the statistical sense, and 13 may have quietly hoped ignorance really is bliss.

Few studies have quantified ground water recharge within long-term, experimental watersheds. Recent studies at the Hubbard Brook Experimental Forest in New Hampshire (Tiedeman et al. 1997; Rosenberry and Winter 1993) and at the Marcell Experimental Forest in Minnesota (Nichols and Verry 2001) suggest ground water recharge may be as little as 3 cm/year in fractured granite and schist bedrock (Tiedeman et al. 1997; Rosenberry and Winter 1993) or 3 to 20 cm/year in glacial tills (Nichols and Verry 2001). Pint et al. (2003) indicated that recharge to Allequash Creek, a subwatershed of the Trout Lake experimental watershed in northern Wisconsin, is 25 cm/year in glacial sands. Urie (1967) showed recharge of 25 to 46 cm/year in the deep sands of central Michigan's Udell Experimental Forest. Numerous methods now exist for quantifying ground water recharge (Scanlon et al. 2002), and application of these methods is becoming more common.

The evidence from many recent studies clearly indicates that ground water is an important source of water to streamflow in most watersheds, and loss of water via deep

seepage also is a significant component of flow. The use of well networks and the evaluation of hydrographs of ground water levels, or the use of ground water flow models to estimate deep seepage from small research basins, are highly recommended. Future investigators have many tools with which to account for water and nutrients that move through, and out of, a watershed and have no need to quietly assume that ground water recharge, ground water flow within the watershed, or deep seepage is zero.

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