

HYDROLOGY OF WETLAND FOREST WATERSHEDS

by

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The physiography and climate of the lower coastal plain of South Carolina and adjacent states have enabled woodlands there to develop into a humid, subtropical setting where water is a key resource and a knowledge of hydrology is essential for water management. Within this area are millions of acres of swamps, wet flats, bays, and bottomlands or, as they are known collectively, the wetland forests. The unique value of these areas to the State's water and other wildland resources has been overlooked until recent years. Wetland forests were once viewed as a curse to the roadbuilder and logger trying to extract timber. Now they are recognized as a major water, wildlife, timber, and recreational asset to the State.

Let us consider a few other aspects of this watery domain before we delve into its hydrology. It would be unwise to think of these wetlands only in terms of water, because the terrain, water, and vegetation interact strongly. Many trees in the wetland forests, such as tupelo trees, which are highly valued by the veneer and other wood-using industries, literally thrive on a natural abundance of water (2). Oaks, hickories, sweetgum, and other wetland trees provide mast for wildlife, both migratory and native to the wetlands. Needless to say, without an abundance of water in these lower coastal plain wetlands to provide resting and feeding areas needed by waterfowl, a significant ecological dislocation could occur. And finally, many of these wetlands stand ready to supply large quantities of water for industrial, agricultural, and municipal use.

On the other side of the coin, land form, vegetation, and water do not always complement each other in the natural state. One or more may have to be altered by a scientific water or land management practice to enhance the usefulness of wetland forests as resource areas (3).

For example, some bays and pocosins are such poor timber or wildlife producers in their natural state that controlled drainage is needed to achieve a better balance between water, trees, and wildlife. Waterfowl may find some swamps "dry" in the fall. To offset this problem, forest and wildlife managers hold water back with control structures to create better resting and feeding areas. And in addition, clearcutting of a moderately wet pine flat can result in the raising of the average groundwater level to the extent that water control may be necessary to regenerate a new stand of trees.

If water is to be managed on wetlands, regardless of their intended use, a basic knowledge of the hydrology of the area is essential. Without knowing how much, when, where, and why the water behaves the way it does, we are in a poor position to suggest sound water management techniques. Unfortunately, until recent years the needed data have been almost non-existent. In order to prescribe improved water management practices for wetland forests, however, the Southeastern Forest Experiment Station in Charleston began to develop a knowledge base of hydrologic information and understanding in 1964. Some of the highlights of this work are covered in the balance of this paper.

Before we describe the research results of our hydrologic investigations, however, let us examine our concept of the hydrologic cycle on wetland forest watersheds. During this discussion, we will briefly point out: (1) the type of hydrologic information needed to manage water scientifically on wetlands, and (2) the segments of the hydrologic cycle most amenable to management. We have depicted this cycle in a workable, schematic model (fig. 1). On this model are illustrated the key elements in the hydrologic cycle for which information is needed; that is, the characteristics of the media through which water is transported (forest surface, soil mantle, and stream channel) and the processes that transport the water (precipitation, infiltration, overland flow, groundwater seepage, evapotranspiration, and surface runoff). All of these items, whether media or processes, are familiar terms, and the uniqueness they play can best be seen by tracing water through the model.

The sun provides the energy to evaporate water from the rivers, lakes, oceans, and land surface and to carry it into the atmosphere. Air currents move the moisture-laden air over the forest where moisture is released as precipitation when suitable atmospheric conditions occur. If the total amount of precipitation is small and

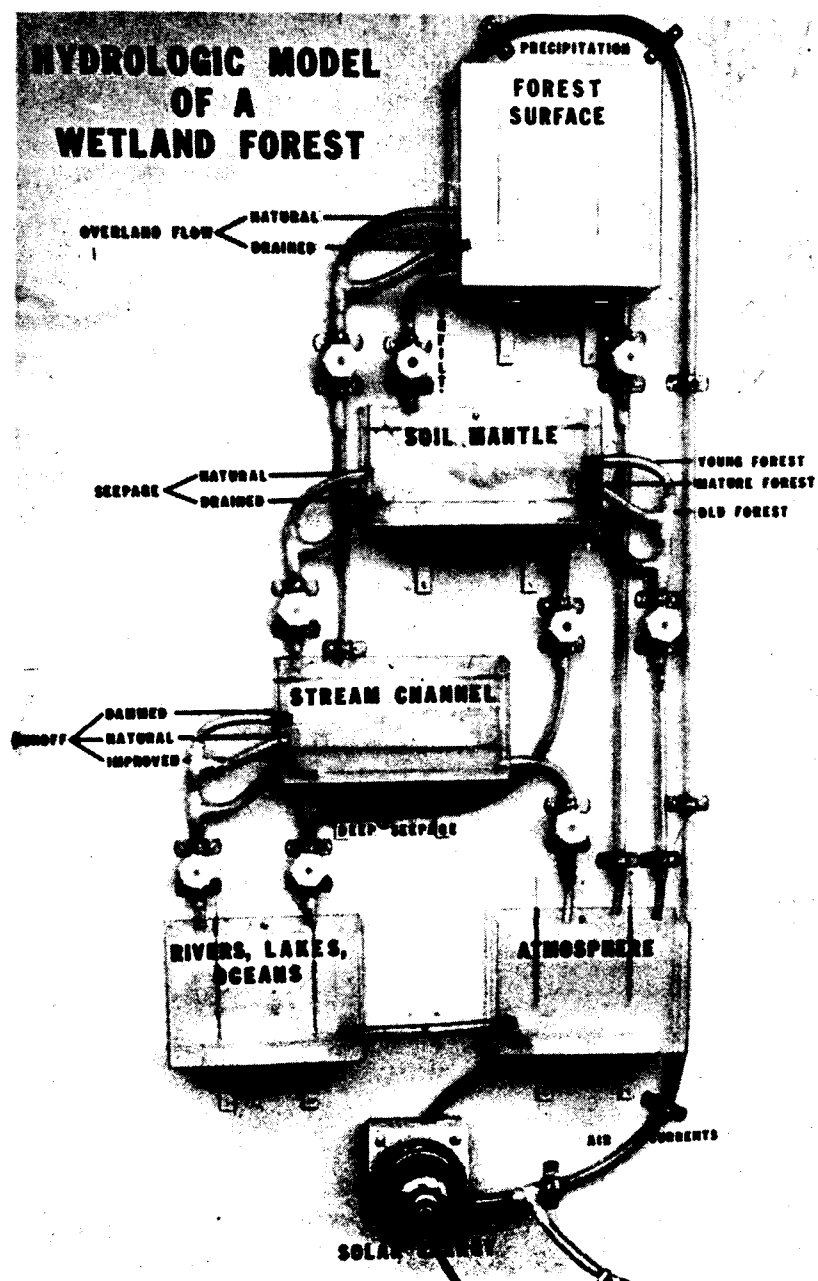


Figure 1.--A workable, schematic model which depicts water cycling through a wetland forest.

the forest surface is dry, as depicted by our model, then most of the moisture is absorbed by, or adheres to, the needles, leaves, and bark and is soon evaporated back into the atmosphere.

More prolonged rainfall quickly exceeds evaporation from the trees and soon moistens the entire forest surface. Thereafter, water begins to infiltrate the soil mantle at a rate dependent upon the physical characteristics of the soil and soil surface. When rainfall intensity exceeds the infiltration rate or the water table is at the soil surface, water begins to accumulate on the surface of the forest. In wet, flat, forested areas with many depressions, a substantial amount of water can accumulate on the surface before overland flow begins. One water management technique, ditching, can be used to reduce the surface storage capacity of wetland forests. As you can see on our model, the tube marked "drained" will carry water away from the forest surface before overland flow will occur under natural conditions.

Water leaves the soil mantle in several ways. In natural wetland areas, water seeps out of the soil into natural stream channels. Ordinarily, the soil must be nearly saturated or, in other words, have a high water table in order for sufficient head to be available to push water through the soil into the stream channel. Ditches that are sufficiently deep will lower the water table in wetland soils by providing a head difference between the water table surface in the soil and the free water level in the ditch.

Water can also leave the soil through deep seepage which will carry water away into deeper aquifers that may exit into large rivers and lakes or off-shore into the sea.

A third way that water leaves wetland soils is through evapotranspiration. Our model depicts evapotranspiration from the soil mantle at three levels. Each level is associated with a different-aged forest. The use of age may be misleading because what we are really trying to depict here is the extensiveness of the root system of each of these forests. At the upper extreme, one should visualize the young forest with a shallow root system and only a small proportion of the total soil volume occupied by roots. At the other extreme, visualize the old forest with deep, penetrating roots which occupy the entire rooting soil volume to a large degree. Thus, without additional rainfall to replenish the moisture in the soil, we would expect the old forest to deplete the total available soil water to a much greater extent than a young, newly-planted forest with a juvenile root system.

Water which flows over the soil or through it will finally enter the stream channel. At that point, the water will then either move rapidly downstream, depending upon the condition of the stream channel, or fill up one pocket and then the next progressively until the entire stream channel is recharged. Our hydrologic model illustrates three levels of water leaving the stream channel. The lower level depicts an improved stream channel where a dragline or a backhoe has recently cleared out the channel, smoothed the grade, and increased capacity. The intermediate level is one more common to the natural stream channel. Windfalls and logging debris frequently block the channel at intervals along its length, forming pools, which are joined by short reaches of fast-moving water. Finally, the upper category of "dammed" illustrates a situation where water is held in the channel for irrigation, flood control, fisheries, or some other purpose. Water also leaves the stream channel by deep seepage into lower aquifers and evapotranspiration from the pools and the vegetation along the channel's length.

Now that we have reviewed conceptually the hydrologic cycle on a wetland forest, let us turn to some of the results of our hydrologic research to date. The results come primarily from a 400-acre watershed located 30 miles north of Charleston on the Santee Experimental Forest, Francis Marion National Forest. This watershed is well stocked with pole-sized and larger loblolly pine (Pinus taeda L.) on the slopes and flats and with swamp hardwoods, mainly swamp tupelo (Nyssa sylvatica var. biflora (Walt.) Sarg.), in the natural runs and lows. The soils range from well-drained to very poorly drained, with the majority in the somewhat poorly to very poorly drained category. Surface elevation ranges from about 20 to 30 feet above m. s. l.

The watershed at the Santee Experimental Forest is a pilot installation for South Carolina and adjacent states. Data collected there cannot be correlated, as yet, with data from the many thousands of acres of similar land in the lower coastal plain because of the lack of replication elsewhere. Thus, only broad generalizations about hydrologic behavior can be made. Nevertheless, records gathered at the Santee have indicated several important hydrologic characteristics that should be of general interest to those involved in managing water from coastal plain wetlands.

We have only scratched the surface of quantifying all phases of the hydrologic cycle. Our results cover two of the output variables in the hydrologic cycle: runoff and evapotranspiration, and one input variable: precipitation. These variables will be discussed in terms of method of measurement, quantitative values, major influencing factors, comparison with data from other areas, and implications for water management.

Precipitation

Precipitation was collected in five standard U. S. Weather Bureau gages in and around the watershed and averaged by the Thiessen method. Reference to precipitation data has been included in the discussions of runoff and evapotranspiration results because rainfall influences the output of these other variables.

Runoff

Surface runoff has been measured and recorded by an AV-3 weir at the outlet of the watershed since January 1964. Discharge stages were recorded on an analog-to-digital water level recorder. Discharge records showed total runoff from our watershed has been quite variable for the period of record, 1964 to 1966, ranging from a low of 16.8 inches in 1965 to a high of 34.2 inches in 1964. However, each of the years had above-average rainfall and the majority of the runoff was confined to individual wet periods during those years. Runoff for the 3 years averaged approximately 38 percent of total precipitation.

Stormflow characteristics of the area may be of more interest than total runoff. Streamflow records reflect the tendency of the watershed on the Santee to release more rainfall than other forested areas in the Southeast. Three years of measurements show that this watershed, on the average, yielded 22 percent of its rainfall as stormflow (8). In contrast, small forested watersheds in the mountains and Piedmont yield, on the average, only 10 percent of their rainfall as stormflow (1).

The greater amount of stormflow from wetlands when compared to that from the Piedmont and mountains may surprise many people. Although the greater slope in the uplands does tend to cause water to

drain off quickly, many of their soils are deep, hold considerable amounts of water, and are seldom saturated to the surface. This ability of the soils to retain water prevents overland flow to stream channels and lessens the volume of stormflow. By contrast, overland flow in wetland forests is quite common because their soils are often saturated to the surface.

Comparison of Santee Experimental Forest storm runoff records with those from three flatwoods watersheds in southern Florida (5) reveals some anomalies even between coastal plain watersheds. The standard for comparison was runoff computed by the Cypress Creek formula^{1/} (5), a drainage formula used by the SCS and other drainage engineers to determine design capacity for drainage canals. Measured peak runoff from the Florida watersheds agreed with that estimated by the Cypress Creek formula, using an average soil storage capacity of 3 inches prior to rainfall. Using this formula and the same assumed storage capacity, we found that during wet to very wet periods the formula underestimated our peak flows by about 60 percent; during dry to average periods, it underestimated by about 25 percent; and during dry to very dry periods, it overestimated from as little as 20 percent to as much as 300 percent.

These comparisons indicate that runoff from wetland watersheds is influenced strongly by the moisture storage capacity of the soil prior to rainfall. Individual storms on our watershed have produced storm runoff amounts that ranged from zero to 70 percent of the total rainfall. The upper limit of 70 percent occurred when the groundwater table was at or near ground surface. In contrast, no flow was recorded with rainstorms as large as 2 inches when the water table was low. A statistical analysis of these interrelationships indicated that although 54 percent of the variability of runoff on a 2-week basis could be accounted for by relating runoff to total precipitation, an additional 26 percent of the variability in runoff could be accounted for by relating runoff to depth to the groundwater table. If computations had been made for individual storms, the results would probably be even more convincing.

^{1/} $Q = CM^{5/6}$

Q = peak 24-hour runoff rate (cfs)

C = degree of protection coefficient

M = drainage area (sq. miles)

Water yield from the watershed has been reasonably large for the years of record. Baseflow, often a measure of water yield, has averaged 16 percent of yearly rainfall (8). In terms of volume, baseflow amounted to an average of 10.2 inches annually. This, however, occurred during years of above-average rainfall and different yields could occur during years with below-average rainfall. The yield of water has not been continuous, however, and seasonal periods of no-flow have occurred each year. The three longest periods of no-flow lasted 26, 40, and 66 days, respectively.

What then are the water management implications based on these preliminary flow data? First, because of the flashy nature of flow from wetland coastal plain watersheds, downstream ditches, culverts, and bridges must be adequate in size to handle large volume peak-flows. Peak-flows can occur which are considerably in excess of values presently predicted for wetland forests of the State. Part of this underestimation of runoff appears to lie in failure to account adequately for storage potential prior to rainfall. A 3-inch average storage potential appears to be too large for our area during wet years. Extreme care must be exercised, therefore, when choosing a runoff prediction method or equation for wetland forests. Preferably, a method should be chosen that includes soil moisture storage as a variable in the equation. Second, flow, even during wet years, is not dependable. If these wetlands are to serve as a source of surface water, then provisions must be made to (1) use groundwater during certain seasons, (2) store water during times of excess for times of shortage, or (3) simply rely on these areas as alternate or supplemental sources of water.

Evapotranspiration

Evapotranspiration (ET) was computed indirectly by balancing the water entering the watershed with that leaving.^{2/} We assumed that subsurface losses or gains were negligible. Over the last several years, these computations have been made on a biweekly basis. Simultaneous measurements of evaporation from a standard U. S. Weather Bureau evaporation pan and estimations of potential evapotranspiration (Thornthwaite method) have also been made.

$$2/ \quad ET = P - RO - \Delta SM$$

ET = evapotranspiration

P = precipitation

RO = runoff

SM = water and soil moisture storage

Annual ET from the watershed averaged a little higher than potential ET: 38.4 inches vs. 36.0 inches. The higher watershed ET was not unreasonable, considering that Thornthwaite's potential ET is not necessarily a maximum for forests because his method was developed to estimate water loss from a low, uniform cover where water is unlimiting. It is conceivable that tall forest stands can transpire more than the calculated potential $\overline{ET}$. Our data compare favorably with the annual average ET of 39.4 inches for two flatwoods watersheds in Florida (6) where rainfall is plentiful and water tables high.

The watershed ET data from the Santee Experimental Forest was checked further by comparing it to evaporation pan data. As expected, average annual open pan evaporation (53.1 inches) was considerably higher than watershed ET, but the ratio of .73 of watershed ET to evaporation pan data compares favorably with a maximum ratio of .78 for Florida (6).

The water management implications of this evapotranspiration data might not be as easily recognizable as those for runoff. The pine forest on the watershed was probably removing water at a very high rate because of its extensive root system. If the trees were removed, the average water table could rise and remain high (7), increasing the probability of severe flooding. Also, controlled drainage might be needed if the water table remained too high and damaged newly-germinated seedlings. On the positive side, more groundwater could be available for baseflow and the length of no-flow periods shortened.

It doesn't take much imagination to see how potentially productive wetland forests are for water, timber, wildlife, and recreation. Moreover, water is invariably linked to any management envisioned for these wetlands (4). In one case, manipulation of the vegetation can influence the amount and timing of streamflow; in another case, control of the surface and groundwater can influence timber production and wildlife. Whatever the case, we cannot neglect the water management of these coastal plain woodlands. Knowledge of the hydrology of wetland forest plays an important part in their management, and in-depth study of their hydrologic processes must continue and be strengthened.

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