POTENTIAL FOR REDUCED INFILTRATION AND RECHARGE ON A LOCAL SCALE FOLLOWING COVER TYPE CONVERSIONS IN THE SOUTHEASTERN COASTAL PLAIN

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Abstract. Conversion of mixed hardwoods to stands of pine has been shown to reduce water yield as stream flow in watersheds of Piedmont and mountainous physiographic provinces. Decreases in yeild have been attributed to documented increases in interception by pines. Transpiration by pines during periods of dormancy in deciduous hardwoods has been identified as another possible factor in decreased yields. Additional factors that may contribute to cover-related reductions in local water budgets in the Southeastern Coastal Plain (SCP) include low topographic gradients with highly permeable surface horizons, species-specific increases in transpiration rates, and increased stand densities of planted pines. Influences on wetlands in the SCP due to local scale reductions in infiltration and recharge have not been considered during cover-type conversions. Some depressional wetlands in areas converted to planted pines in the SCP have exhibited drainage-related stress responses in the absence of surface drainagage features. Research is needed in the SCP to evaluate the potential impact of local scale reductions in infiltration and recharge on depressional wetlands.

INTRODUCTION

Previous research has shown that rainfall is intercepted to varying degrees as it passes through tree canopies (Burch *et al.* 1987, Helvey 1967, Helvey and Patric 1964, Helvey and Patric 1965, Helvey and Patric 1966, Hoover 1953, Kimmins 1973, Parker 1983, Rogerson 1967, Swank 1968, Swank and Miner 1968, Swank *et al.* 1972). Rainfall intercepted by the canopy returns to the atmosphere as evaporation and is not available for infiltration and recharge. Rainfall that penetrates the canopy is classified as either "throughfall" or "stemflow", and can be significantly less than the gross rainfall (incident precipitation (Parker 1983)). Helvey and Patric (1965) and Hoover (1953) define terms involved in this process as follows:

Gross rainfall (P) is rainfall per storm, measured in the open or above the vegetative canopy.

Canopy interception loss (C) is rainfall retained on standing vegetation and evaporated without dripping off or running down the stems.

Throughfall (T) is that portion of the gross rainfall which reaches the litter directly through spaces in the vegetative canopy and as drip from leaves, twigs, and stems.

Stemflow (S) is that portion of the gross rainfall which is caught on the canopy and reaches the litter or mineral soil by running down the stems.

Net rainfall (N) is the total rain reaching the ground beneath a plant canopy (throughfall plus stemflow, as defined by Hoover 1953).

$$C = P - (T + S) \quad (1)$$

In a review of studies conducted throughout the eastern United States (east of the 100th meridian), Helvey and Patric (1965) found strong correlations between rainfall interception and canopy type, with stands of conifers intercepting more precipitation than stands composed primarily of mixed hardwoods. A subsequent review by Swank *et al.* (1972) concluded that annual interception losses for mature loblolly and shortleaf pine were 7.6 to 10.2 cm greater than for mature mixed hardwoods, with "even young stands of pines intercepting more rainfall than do mature (oak-hickory) hardwoods" (Swank 1968). Most of these studies reference "hardwoods" and "conifers" as the categories of comparison. However, based on those authors' discussions of the species evaluated and their conclusions that some portion of the observed responses may be attributed to the absence of leaves in the winter for hardwood species, it is assumed that the authors were inferring comparisons between stands of evergreen conifers and mixed deciduous hardwoods. The distinction is important because extensive stands of deciduous conifers and some stands of evergreen hardwoods occur throughout the Southeastern Coastal Plain (SCP) physiographic province, where limited research of this nature has been reported in the literature.

Spatial and Temporal Variations

Depth of precipitation increases with altitude in areas having similar meteorological conditions. Season, type of storm, and the orientation (i.e., aspect), width, and exposure of the topographic barrier (i.e., slope) are additional factors which may influence precipitation (Dunne and Leopold 1978). No seasonal differences were found in net rainfall in a study of rainfall interception in Union, South Carolina (Piedmont physiographic province) conducted from May 1950 through March 1951 (Hoover 1953). However, only young loblolly pine trees (*Pinus taeda*) were evaluated in that study. Variation in throughfall under similar-aged loblolly pines in a small-scale study in Athens, Georgia also was low, compared with variation under mature loblolly pines (>30 yrs.) and deciduous hardwoods (Bacchus, Adrienne Edwards and Roger Baldwin, unpub. data). Furthermore, a pine canopy is relatively constant throughout the year, unlike canopies of deciduous trees that are leafless during the fall and winter. Therefore, net rainfall would be expected to increase in the winter under stands of deciduous trees. This prediction was supported in a later study by Helvey and Patric (1966), using data summarized from more than 50 study sites throughout the eastern United States. The relative variance in throughfall under hardwoods during the period of peak canopy cover (i.e., summer) was found to exceed that of pines during all seasons, but the coefficient of variation for gross annual rainfall was less than that for throughfall under any condition. As an example of the magnitude of difference in throughfall between species, Burch *et al.* (1987) found interception losses under a forested canopy comprised of four species of *Eucalyptus* was less than 2% of gross rainfall. The interception loss associated with stands of pines described above and below is 6 to 10 times greater than this value, exemplifying the magnitude of difference that may occur based on species composition.

The individual components of net rainfall may vary seasonally, even if total net rainfall does not vary seasonally. For example, summer thunderstorms generally are convective, characterized by high-intensity, short-duration precipitation over limited areas. This type of storm should be more conducive to relatively higher throughfall than frontal systems prompted by warm air masses which move into areas of colder air in the winter and result in gentle, widespread precipitation (Brooks *et al.* 1991). If the responses of stemflow varied from the responses of throughfall for these types of storms, then the resulting net rainfall could be equivalent for different types of storm events, while the individual components of net precipitation varied. Helvey and Patric (1965) note that investigators often disregard stemflow because it is small compared to gross rainfall; but that stemflow is highly variable between storms and between species. Inclusion of stemflow allows more accurate estimation of the total amount of rainfall intercepted. The study of a 10 year-old stand of loblolly pine by Hoover (1953) in Union, South Carolina recorded relatively small increases in the amount of net precipitation reaching the ground under trees when stemflow was included.

Finally, throughfall has been determined to vary with age in stands of pine. In Hoover's study, approximately 12 to 16% of precipitation was lost to interception under a 10 year-old stand of loblolly pine. Swank *et al.* (1972) evaluated interception loss in loblolly pines of 5, 10, 20 and 30 years of age in the Piedmont physiographic province of South Carolina. In this study throughfall was greatest - "85% of gross precipitation for a 1-inch storm" - in the oldest stand of pine evaluated, followed by 80% for the youngest stand, 77% for the 20 year-old stand, and 73% for the 10 year-old stand. The greatest amount of interception associated with 10 to 20 year-old stands is attributed to increasing biomass of foliage, which reaches a maximum at approximately 20 years for loblolly pine, but may vary based on stocking and site quality (Switzer *et al.* 1968). The low levels of interception associated with the oldest stand in the study by Swank *et al.* is attributed to canopy and stand thinning that occur with age. Consequently, interception by post-maturity stands was similar to interception by young stands which had not achieved canopy closure.

Influence of Experimental Design

With respect to experimental design considerations, Dunne and Leopold (1978) note that sparse rain gauge networks tend to underestimate maximum amounts and intensities and can result in gross underestimation of rainfall characteristics required for water budget planning. Furthermore, they note that long-term rain gauges commonly are located in open areas and would not be representative of rainfall in densely forested areas where interception must be considered. They recommended supplementing networks of standard gauges with tube gauges or tin cans which can be read after each storm. Trough gages between 1.2 and 30.5 m long have been used to decrease variance, but troughs are subject to splash effects (Helvey and Patric 1965). Stuart (1962) provides evidence that the number of gages is more important than the kind of gage used. Helvey and Patric (1966) recommended cylindrical collectors for estimating rainfall, but suggested that gauges be moved periodically to new random locations. Kimmins (1973) provided additional support for relocating collectors during the period of study. However, Kimmins was quantifying chemical parameters of throughfall which exhibit considerably greater heterogeneity than the volume of throughfall. Frequent relocation of collectors to truly random (vs. haphazard) locations in a densely vegetated stand, such as those which may occur in the SCP would be extremely labor-intensive and could result in excessive disruption of groundcover and subcanopy vegetation. Therefore, although frequent random relocation of collection devices may be satisfactory for a planted stand of pines with an open understory, this approach does not appear to be well-suited to some natural stands in the SCP, particularly when minimal disruption of vegetation in the study site is desired.

Objectives

The objectives of this paper are to: 1) provide a general background of reported reductions in water available for infiltration due to interception by various forest cover types; 2) identify some additional factors that may contribute to cover-related reductions in local water budgets in the SCP; 3) suggest possible ramifications for reductions in local water budgets; and 4) encourage additional research in forested community types in the SCP where factors influencing the local water budget have been inadequately described.

DISCUSSION

Watershed management has included the periodic harvest of stands of evergreen conifers to increase water yield for managed basins. Results of numerous studies have documented increased water yield following clear-cut harvesting of forested stands from uplands (Hill 1961, Hoyt and Troxell 1932, Johnson and Meginnis 1960). For silvicultural activities where evergreen conifers (e.g., loblolly pines) are propagated in areas previously supporting natural stands of mixed hardwoods (e.g., oak-hickory), the reverse may occur. Swank *et al.* (1972) conclude that it is reasonable to expect that stream flow and groundwater supplies will be reduced following cover-type conversion to pine. They also note that "transpiration losses are probably greater for pines before and during leafing out of hardwoods; therefore, differences in evaporation between these two cover types may be much greater than those indicated by interception data alone".

In contradiction to findings of watershed studies described above, Crawford *et al.* (1993) reported decreases in water table levels following logging of forested wetlands in southern Alabama (SCP physiographic province) during a study designed to evaluate water quality characteristics associated with deforestation. Other recent studies in the SCP (Odum 1986, Riekerk 1993) also suggest that stands of upland species of evergreen conifers may impose a greater demand on local water budgets than natural stands of forested wetlands surrounded by natural stands of upland vegetation. Such a response could be possible if natural forested stands had conservative transpiration rates and reduced evaporative losses under the canopy by maintaining low temperatures and buffering air movement below the canopy. Following removal of the canopy, evaporative losses could exceed previous losses via transpiration, due to higher surface temperatures and increased air movement.

The studies cited above did not address how species-specific differences in transpiration rates might influence local water budgets as changes in cover type are made. For example baldcypress in flood plains were reported to transpire at a rate of 1.89 $m^3/m^2 \cdot yr.$, while pondcypress were reported to transpire at a rate of only 1.12 $m^3/m^2 \cdot yr.$ The most conservative rate of transpiration for cypress, 0.34 $m^3/m^2 \cdot yr.$, was reported for dwarf cypress (Odum 1986). Cypress (*Taxodium* spp.) grow relatively slowly, particularly when compared with other species of conifers such as loblolly pine. Within the genus of *Taxodium*, baldcypress generally grow more rapidly that pondcypress and dwarf cypress, with dwarf cypress growing most slowly under natural conditions, based on evaluations of growth rings. Rapid transpiration has been correlated with rapid growth. In addition to differences in transpiration observed between species, transpiration rates may vary within a species during different stages of growth, although factors other than growth also affect transpiration rates. For example, as commercial stands of pines in the SCP mature (~20 to 25 years), transpiration rates may slow as growth rates slow. Under this scenario, short rotations of commercial stands of pines (~20 to 25 years) for products such as pulp wood could maximize periods of high interception and high transpiration, ultimately leading to significant reductions in local water budgets.

A third factor that may contribute to a reduction in water available for infiltration and recharge is stand density (Prebble and Stirk 1980). For example, longleaf pine stands (*Pinus palustris*) in the SCP are characteristically open (Figure 1). Commercial stands of pine (e.g., slash and loblolly), which have replaced much of the historic longleaf stands in the SCP, are considerably more dense (Figure 2). Greater interception, and less infiltration and recharge would be expected to occur for commercial stands of pine than for natural stands of longleaf pine or mixed hardwoods.

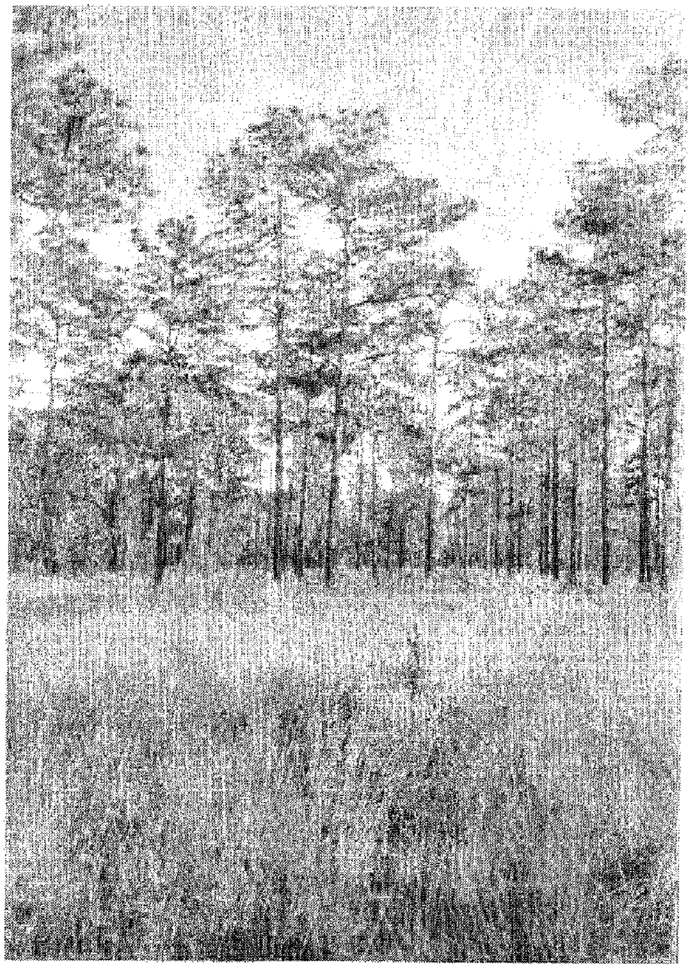

Figure 1. Typical longleaf pine (*Pinus palustris*) - wire grass (*Aristida stricta*) stand in the SCP.

Figure 2. Young stand of commercial pine in the SCP.

Historically, the SCP was characterized by expansive stands of longleaf pine and mixed hardwoods, with interspersed depressional wetlands. Many of the natural forested uplands have been converted to commercial stands of pine (e.g., loblolly and slash). Some depressional wetlands, now surrounded by commercial stands of pine, are exhibiting signs of drainage and stress in the absence of surface drainage features such as ditches (Bacchus unpub. data for Florida, Georgia and South Carolina). Reductions in annual water budgets due to interception by loblolly pine stands were determined to exceed interception losses estimated for hardwood stands in other studies by approximately 10.2 cm (Swank *et al.* 1972). For trees of similar size, transpiration per tree may be higher for pines because of greater total leaf area (Kramer and Kozlowski 1960). Documented reductions in available water due to interception, in addition to potential losses which may result from increased transpiration and highly permeable SCP soils that provide less impediment to water movement, could account for observed adverse responses in depressional wetlands.

In 1972, Swank *et al.* concluded that "any forest management practice that increases evapotranspiration and thereby lowers the amount of water available for streamflow and groundwater supplies may have important consequences." Comprehensive assessments of how factors associated with cover-type conversion (e.g., interception, transpiration, stand density) influence local water budgets of depressional wetlands in the SCP are warranted. Information of this nature could be used to develop guidelines for buffer zones around susceptible wetlands.

SUMMARY AND RECOMMENDATIONS

Studies of interception have been conducted primarily in physiographic provinces other than the SCP and direct knowlege of interception responses associated with natural forested stands in the SCP is limited. The SCP is characterized by low topographic gradients, highly permeable surface horizons and depressional wetlands dispersed throughout extensive, sparsely forested flatwoods (stands of evergreen conifers) with water tables close to the surface under natural conditions. Cypress are dominant components of some SCP forest types. Cypress are deciduous conifers which not only are leafless during the winter months, but can conserve water by abscising their leaves when availability of water is limited.

These conditions differ from conditions in the Piedmont and mountainous physiographic provinces where most interception studies were conducted, and which are characterized by dense stands of evergreen conifers with wetlands confined to narrow riparian bands at the base of relatively steep slopes. Additionally, many studies do not provide quantitative data on the extent of cover of the tree canopies or relative densities of the stands that were evaluated, further limiting application of those findings to different types of forested stands.

Extensive areas of natural flatwoods, mixed hardwood uplands and forested wetlands in the SCP have been and are being converted to commercial stands of pines (e.g., pine plantations) without adequate knowledge of potential short and long-term impacts of such action on the local hydrology and remaining wetlands. Previous studies have shown that dense stands of evergreen conifers (e.g., pines) can reduce the annual water budget by more than 10 cm by intercepting 6 to 10 times more precipitation than forests comprised of other canopy species. Additional research is warranted in the SCP to evaluate the potential for local reductions of water available for infiltration and recharge following conversion of naturally vegetated areas to commercial stands of pines. Local water table response should be evaluated in areas where natural upland and wetland vegetation in the SCP are replaced by commercial species of pines that may decrease available water via higher stand densities and higher rates of transpiration, in addition to increasing interception.

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