Environmental & Water Quality Operational Studies

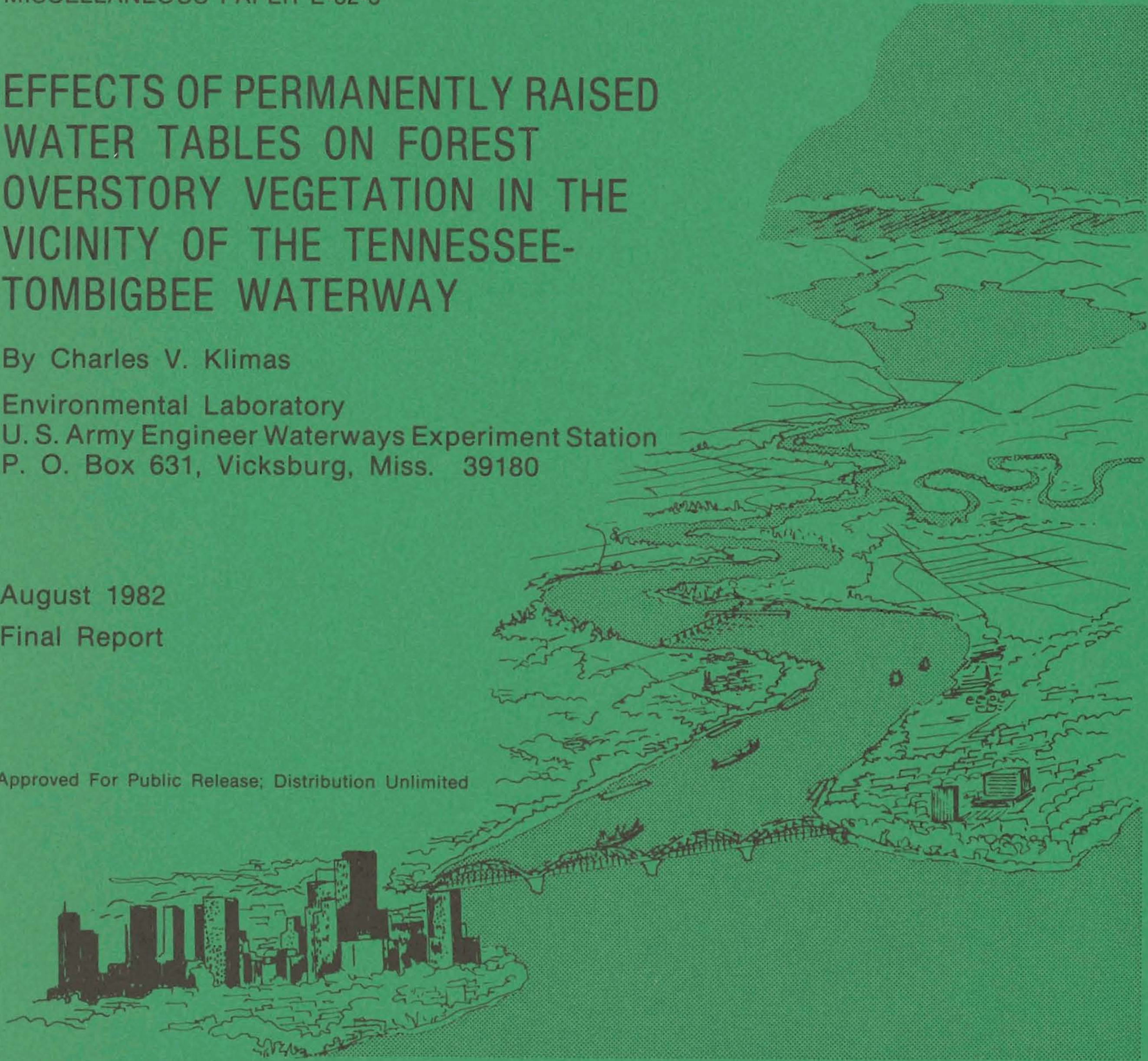
MISCELLANEOUS PAPER E-82-5

EFFECTS OF PERMANENTLY RAISED WATER TABLES ON FOREST OVERSTORY VEGETATION IN THE VICINITY OF THE TENNESSEE-TOMBIGBEE WATERWAY

By Charles V. Klimas

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

August 1982
Final Report



Prepared for U. S. Army Engineer District, Mobile
Mobile, Ala. 36628

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper E-82-5	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (*and Subtitle*) EFFECTS OF PERMANENTLY RAISED WATER TABLES ON FOREST OVERSTORY VEGETATION IN THE VICINITY OF THE TENNESSEE-TOMBIGBEE WATERWAY		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Charles V. Klimas		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Environmental Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Environmental and Water Quality Operational Studies Program
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Engineer District, Mobile P. O. Box 2288 Mobile, Ala. 36628		12. REPORT DATE August 1982 13. NUMBER OF PAGES 31
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)		15. SECURITY CLASS. (*of this report*) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Water tables are expected to rise somewhat in the vicinity of planned impoundments along the Tennessee-Tombigbee Waterway. Where permanent flooding of timber is anticipated, tree mortality is expected and has been accounted for in the project planning process. However, where water table levels will be raised significantly but permanent flooding does not occur, the effects on forests are very unclear. This report identifies factors that may be pertinent in assessing this type of impact. The information presented
(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

20. ABSTRACT (Continued).

here has been drawn from the scientific literature on species flood tolerance and related topics that provide insight on potential water table effects.

This review concentrates on induced mortality and changes in growth rates of mature trees. Raised water tables can detrimentally affect trees primarily by causing oxygen depletion in the root zone. The ability of an individual tree to withstand this type of stress may be related to a variety of factors, including the tree species, rooting depth, soil conditions, and the timing, duration, and frequency of encroachment of the water table into the root zone. In some situations, trees may show improved growth as a result of raised water tables, although this response may be short-lived.

The forest communities likely to be most sensitive to partial root-zone saturation are those typically found on well-drained upland sites. Where such communities are subjected to drastic changes in the root environment, mortality may be widespread and rapid. In contrast, swamp forest communities (cypress-tupelo) are generally much less sensitive to increases in site moisture status, and may be affected primarily with respect to long-term growth and reproduction, or not at all. The complex floodplain forest (bottomland hardwood) communities present the greatest difficulty in predicting potential impacts resulting from raised water tables. Possible effects range from near-complete mortality in areas where permanent surface saturation occurs to no effect or growth rate increases in response to very minor, subsurface water table rises. The complexity of this issue suggests that only very general impact predictions may be possible except in areas where extreme stresses are anticipated.

Preface

The following report was prepared at the request of the U. S. Army Engineer District, Mobile. It was one of several such reports intended to provide that agency with background information to aid in preparation of a Draft Supplemental Environmental Impact Statement for the Tennessee-Tombigbee Waterway, and it was included in that document as Appendix I.

The report is primarily a review of the scientific literature, although it contains several references to field data collected on the waterway by the Mobile District. Despite these occasional site-specific discussions, the report has potential general applicability to Corps of Engineers project areas throughout the southeast, and is being disseminated under the auspices of the Environmental and Water Quality Operational Studies (EWQOS) Program sponsored by the Office, Chief of Engineers (DAEN-CWO-M), and assigned to the U. S. Army Engineer Waterways Experiment Station (WES), Environmental Laboratory (EL).

The report was prepared by Mr. Charles Klimas, Botanist, under the general supervision of Dr. Hanley K. Smith, Chief, Wetland and Terrestrial Habitat Group; Dr. Conrad J. Kirby, Chief, Environmental Resources Division; and Dr. John Harrison, Chief, EL. Dr. Jerome L. Mahloch was Program Manager of EWQOS. Preparation of this and related reports submitted to Mobile District was coordinated by Dr. Thomas D. Wright, Chief, Aquatic Habitat Group. Technical manuscript review was provided by both Mobile District and WES personnel, and editorial review was provided by Ms. Dorothy P. Booth, EL.

The Commander and Director of WES during preparation of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

Klimas, Charles V. 1982. "Effects of Permanently Raised Water Tables on Forest Overstory Vegetation in the Vicinity of the Tennessee-Tombigbee Waterway," Miscellaneous Paper E-82-5, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Contents

EFFECTS OF PERMANENTLY RAISED WATER TABLES ON FOREST OVERSTORY VEGETATION IN THE VICINITY OF THE TENNESSEE-TOMBIGBEE WATERWAY

Introduction

1. This report is intended to provide basic information relevant to assessment of impacts of the Tennessee-Tombigbee Waterway on adjacent forests. The information was taken from published scientific literature pertaining to the effects of raised water tables on forests of the southeastern U. S. in general, since materials provided for this review indicate that most plant communities of the project area are characteristic of the entire region. Literature regarding areas outside the southeast was reviewed in instances where the same species occurred or pertinent ecological principles were illustrated. Studies concerned with flooding and submergence also were used where they provided insight on water table effects.

2. The focus of this review was on mature tree mortality and growth response. Related issues, such as effects on agricultural lands and long-term plant community change, are not discussed in detail, but additional sources of information on these topics are identified. As evidenced below, the literature on induced mortality and growth changes following hydrologic alteration is fragmentary and often somewhat contradictory. It illustrates that a variety of factors may be pertinent in assessing this type of impact, including soils, individual species' characteristics, and pre- and postimpoundment water table levels.

3. Despite the apparent complexity of correctly predicting the impacts to the forest of this type of habitat alteration, certain generalizations can be made. The following review briefly discusses the causes of plant injury resulting from this type of change, and edaphic and hydrologic principles that pertain to this issue. This is followed by a survey of pertinent studies, particularly field observations, and conclusions. Estimated species tolerances and community characteristics

are included that may aid in the assessment process, and a bibliography is provided to give access to species- and site-specific information that may be applicable.

Discussion

Mechanisms of plant mortality

4. Tree mortality induced by raised water tables or increased flooding is generally regarded as a direct result of oxygen depletion in the flooded soil within the root zone (Whitlow and Harris 1979). The symptoms of stress and rate of decline may be quite variable (Kramer 1969), but in general, root death and the inability to form new roots may be viewed as the fundamental source of plant injury resulting from soil saturation (Crawford 1978). The ability of a plant to withstand such anaerobic conditions depends upon its ability to increase oxygen supply to the root system. Although temporary avoidance of severe damage may be accomplished through alteration of metabolic rates and pathways or through oxygen transport from shoot to root system (Teskey and Hinckley 1977), a permanent change in rhizosphere aeration will probably require formation of new secondary and adventitious roots if the plant is to survive. That tree species vary considerably in their susceptibility to this type of injury has long been recognized, and reviews of flood tolerance have been provided by Gill (1970), Loucks (1970), Tattar (1972), Teskey and Hinckley (1977), Whitlow and Harris (1979), and Klimas et al. (1981).

5. Other potential causes of tree mortality following raising of the water table include increased windthrow and the heightened susceptibility to insects and disease commonly noted in stressed plants (Fowells 1965). Saturation of soils that are highly acid or have high sodium content, and increases in surface sedimentation have also been identified as being particularly detrimental (Broadfoot and Williston 1973). The literature available for this review, however, ascribes no particular importance to these effects when compared to the direct effects of maintaining an anaerobic atmosphere in the root zone.

6. The timing, duration, and frequency of water-table-induced anaerobic conditions in the soil will affect species differentially. In general, growing season hydrology is of much greater concern than dormant season effects. Many authors have stated that increased flooding (or saturation) during the dormant season does not appear to have detrimental effects on bottomland forest stands, although there is some evidence (derived from long-term observation of greentree reservoirs) that gradual shifts in species composition may occur (Fredrickson 1979) or that tree vigor may be detrimentally affected (Fredrickson 1979, Rogers 1981). In general, however, tree response to raised water tables will be dependent on water levels during the growing season: when do they rise into the rooting zone and how long do they remain there? Once this is known, tree response must be evaluated by species (Table 1) or by communities (Table 2), the component species of which may tend to respond similarly with respect to flooding or soil saturation.

Identification of the rooting zone

7. The rooting zone will vary with the soil conditions, species, and water regime under which the tree established and grew (Kramer and Kozlowski 1960). Certain species typically are deep-rooted (e.g., yellow poplar) while others tend to have shallow spreading roots (e.g., blackgum) (Byrd 1978). Rooting depth may be greatly affected by soils and moisture conditions, with impervious soil layers or high water tables restricting the downward extension of roots (Hodgkins et al. 1979). Zimmerman and Brown (1971) offered the generalization that the bulk of the root system of most trees growing on medium-textured soils (loams and clay-loams) is within 3 ft of the surface. Broadfoot (1973) assumed a 4-ft rooting zone in loamy soils adjacent to Demopolis Reservoir. Baker and Broadfoot (1979) indicated that some of the most common bottomland species can be moderately successful when established on sites with water tables at 1 to 2 ft below the surface, although best growth is attained with somewhat deeper water tables, and that sites with water tables within a foot of the surface are unsuitable. Since water tables restrict root extension during development of the tree, it can be assumed that these bottomland species can grow successfully with fairly

Table 1

Relative Flood Tolerance of Selected Trees and Shrubs in the Lower Mississippi Valley*

Common Name	Scientific Name
	Very Tolerant**
Water hickory	*Carya aquatica*
Pecan	*C. illinoensis*
Buttonbush	*Cephalanthus occidentalis*
Swamp privet	*Forestiera acuminata*
Green ash	*Fraxinus pennsylvanica*
Water locust	*Gleditsia aquatica*
Deciduous holly	*Ilex decidua*
Water tupelo	*Nyssa aquatica*
Water elm	*Planera aquatica*
Overcup oak	*Quercus lyrata*
Nuttall oak	*Q. nuttallii*
Black willow	*Salix nigra*
Bald cypress	*Taxodium distichum*
	Tolerant†
Red Maple	*Acer rubrum*
Sugarberry	*Celtis laevigata*
Hackberry	*C. occidentalis*
Persimmon	*Diospyros virginiana*
White ash	*Fraxinus americana*
Shingle oak	*Quercus imbricaria*
Pin oak	*Q. palustris*

(Continued)

* Adapted from Whitlow and Harris (1979).

** Very tolerant: able to survive deep, prolonged flooding for more than 1 year.

† Tolerant: Able to survive deep flooding for one growing season, with significant mortality occurring if flooding is repeated the following year.

(Sheet 1 of 3)

Table 1 (Continued)

Common Name	Scientific Name
	Tolerant† (Continued)
Sweetgum	*Liquidambar styraciflua*
Cottonwood	*Populus deltoides*
	Somewhat Tolerant††
Box elder	*Acer negundo*
Silver maple	*A. saccharinum*
Hazel alder	*Alnus rugosa*
River birch	*Betula nigra*
Hawthorn	*Crataegus mollis*
Honey locust	*Gleditsia triacanthos*
American holly	*Ilex opaca*
Black gum	*Nyssa sylvatica*
Sycamore	*Platanus occidentalis*
Swamp white oak	*Quercus bicolor*
Spanish oak	*Q. falcata*
Bur oak	*Q. macrocarpa*
Water oak	*Q. nigra*
Willow oak	*Q. phellos*
Winged elm	*Ulmus alata*
American elm	*U. americana*
Red elm	*U. rubra*

(Continued)

† Tolerant: able to survive deep flooding for one growing season, with significant mortality occurring if flooding is repeated the following year.

†† Somewhat tolerant: able to survive flooding or saturated soils for 30 consecutive days during the growing season.

(Sheet 2 of 3)

Table 1 (Concluded)

Common Name	Scientific Name
	Intolerant‡
Ironwood	*Carpinus caroliniana*
Bitternut hickory	*Carya cordiformis*
Shellbark hickory	*C. laciniosa*
Shagbark hickory	*C. ovata*
Mockernut hickory	*C. tomentosa*
Redbud	*Cercis canadensis*
Flowering dogwood	*Cornus florida*
Kentucky coffee tree	*Gymnocladus dioica*
Black walnut	*Juglans nigra*
Shortleaf pine	*Pinus echinata*
Loblolly pine	*P. taeda*
Wild plum	*Prunus americana*
Black cherry	*P. serotina*
White oak	*Quercus alba*
Blackjack oak	*Q. marilandica*
Red oak	*Q. rubra*
Shumard oak	*Q. shumardii*
Post oak	*Q. stellata*
Black oak	*Q. velutina*
Sassafras	*Sassafras albidum*

‡ Intolerant: unable to survive more than a few days of flooding during the growing season without significant mortality.

(Sheet 3 of 3)

Table 2

General Summary of Major Lower Mississippi Valley Floodplain Aquatic and Forest Plant Types in Relation to Soil-Moisture/Hydrologic Habitat Regimes*

Soil-Moisture/Hydrologic Regime	Aquatic Plant and Forest Types**
	Aquatic Plant Types
I. Permanently saturated or inundated - Soil saturation or inundation by ground or surface water occurs on a permanent basis throughout the growing season of the prevalent vegetation.	Attached-Floating Free-Floating Rooted-Emergent Submerged Plant
	Bottomland Hardwood Forest Types
II. Intermittently exposed - Soil inundation or saturation by surface or groundwater typically exists on a nearly permanent basis throughout the growing season of the prevalent vegetation, except during extreme drought periods.	Bald Cypress (101) Bald Cypress - Water Tupelo (102) Slash Pine - Swamp Tupelo (99) Sweetbay-Swamp Tupelo-Red Maple (104) Water Tupelo (103)
III. Semipermanently inundated or saturated - Soil inundation or saturation by surface or groundwater occurs with detectable intermittent periodicity for a major portion of the growing season of the prevalent vegetation. Typically occurs during the spring and summer months with a frequency ranging from 51 to 100 years per 100 years. The total duration of time for the seasonal event(s) typically exceeds 25 percent of the growing season.	Black Willow (95) Overcup Oak - Water Hickory (96)
IV. Seasonally inundated or saturated - Soil inundation by surface or groundwater typically occurs with detectable intermittent periodicity for 1 to 2 months during the growing season of the prevalent vegetation. Typically occurs up to the beginning of the summer season with a frequency ranging from 51 to 100 years per 100 years. The total duration of time for the seasonal event(s) typically ranges from 12.5 to 25 percent of the growing season.	Cottonwood (63) Laurel Oak - Willow Oak (88 - wet site variation) Live Oak (89 - wet site variation) Slash Pine (84 - wet site variation) Slash Pine - Hardwood (85 - wet site variation) Sweetgum - Nuttall Oak - Willow Oak (92) Sycamore - Pecan - American Elm (94)
V. Temporarily inundated or saturated - Soil inundation or saturation by surface or groundwater typically occurs with detectable intermittent periodicity for short periods during the growing season but not totaling more than one month for the entire growing season of the prevalent vegetation. Typical frequency ranges from 11 to 50 years - 1 to 10 years per 100 years. The total duration of time for the seasonal event(s) typically ranges from 2 to 12.5 percent of the growing season.	Beech - Southern Magnolia (90 - wet site variation) Loblolly Pine (81 - wet site variation) Loblolly Pine - Mixed Hardwood (82 - wet site variation) Swamp Chestnut Oak - Cherrybark Oak (91)

* Adapted from Huffman and Forsythe (1981). Ordering of each group of forest types is based on maximum tolerance levels recurring over an extended period of years to the soil moisture/hydrologic regimes listed. Forest types may therefore be found associated with less frequently inundated habitats; however, these associations are not shown. No attempt is made to order forest types associated within each category due to the high degree of within group variability.

** Aquatic plant types adapted from Sculthorpe, 1967; forest type number, Society of American Foresters, 1975 - see SAF (1975) for nomenclature.

shallow root systems. As a general guide, then, the rooting zone for most trees that establish and grow on bottomland sites with heavy soils and occasional flooding or high water tables might be expected to be largely restricted to the upper 2 ft of the soil. With better drainage or lighter soil texture, rooting depth should increase to the point where well-drained loamy soils support root systems down to 3 to 4 ft below the surface. Even where rooting is deeper than 4 ft, the largest proportion of the root biomass can normally be assumed to be in the upper portion of the soil profile, since aeration is greatest near the surface.

Hydrology and soils

8. For the purpose of this discussion, increases in water table levels will be examined in the following terms:

a. Flooding occurs when the soil is saturated and at least a small portion of the plant stem is below water. This will concern us primarily with respect to seedlings.

b. Saturation is the raising of the water table to the soil surface. In discussions of mature-tree response to increases in moisture, most authors regard the effects of complete saturation as only slightly less damaging than, or equal to, the effects of shallow flooding.

c. Raised water tables are of concern insofar as they enter or influence the rooting zone of existing trees. Where the water table enters the rooting zone, stresses will result as described in paragraphs 4 and 5. However, where the water table approaches but does not invade the rooting zone, damage may be insignificant and in fact, many trees may benefit from the increased availability of capillary water. Capillary flow upward from the water table provides water to tree roots without necessarily imposing anaerobic conditions. Water will move in this manner as much as several feet over a period of weeks in loamy soils, with a lesser rise in compact clays and a more rapid but still smaller rise in sands (Buckman and Brady 1969). This capillary fringe may approach saturation in the area immediately above the water table (Black 1957); thus the anaerobic environment of the water table may be extended slightly.

9. Soil characteristics are of interest here with respect to their effects on water movement, aeration, and rooting. As noted above, soil texture will influence the rate and extent of the rise of capillary

water, and it has a bearing on the availability of water and the aeration status of the soil. In general, the higher the clay content of the soil, the greater the degree of root zone anoxia and indirect effects such as accumulation of toxic materials in the rhizosphere tend to be more acute in heavier soils (Gill 1970). Where soils include an impervious layer (clay pan), the position of the water table may be altered and drainage may be impeded. Heavy soils and clay pans will generally restrict downward root extension, while well-drained soils may promote deep rooting.

Observed responses to altered hydrology

10. Information on species response to this type of impact is primarily of two types. The first concerns laboratory studies of seedlings subjected to various degrees of flooding or saturation. The second is field observations of forest stands subjected to increased flooding or raised water tables, usually due to reservoir construction. Such studies contain almost no quantitative information on water table levels and usually focus on flood depths and durations. In general, however, the tolerance of mature trees to flooding closely parallels the tolerance of seedlings to soil saturation and reflects the relative position of the species on the flood gradient in hydrologically unmodified forests. Therefore, studies of flood tolerance are pertinent here and reflect the relative tolerance of species to increases in groundwater within the root zone, even when actual flooding does not occur.

11. Comprehensive reviews of flood tolerance that include information on southern bottomland species have already been noted in paragraph 4. Many of the publications on which these review articles were based are listed in the attached bibliography, which also includes the literature cited in this report. Rather than detail the many seedling studies reported by these authors, a few generalizations are given below, and specific flood-tolerance limits are incorporated into Tables 1 and 2 and the general community-type discussions given later in this report. For a tabular summary of many of these studies, see Appendix A of Whitlow and Harris (1979).

12. Seedling studies are of interest here in two ways: they give an indication of the relative flood tolerance of mature trees, and they provide clues to the eventual forest cover on sites where existing communities may be expected to suffer mortality or gradual decline. However, these data should be regarded as relative indices of species tolerances, and where authors specify the number of days a seedling survived flooded conditions, this should be taken as an indication of the general range of tolerance rather than an absolute limit, since, as indicated above, numerous soil-site factors may affect a plant's performance in a particular situation. One further aspect of seedling ecology should be noted. Where flooding is sufficient to cause complete submergence of seedlings, detrimental effects are greatly increased. Thus data taken from submergence experiments should not be used to evaluate the effects of raised water tables unless flood heights will also be raised, and where prediction of eventual community composition is attempted.

13. Mortality. Field observations of the effects of reservoir construction illustrate the variable nature and rates of induced mortality to trees, even though most studies were concerned primarily with flooding and water table heights were not reported. Yeager (1949) studied the effects of raised water levels following the completion of Alton Dam in Illinois. Within his study area, the average summer water stage increased by about 3 ft, reducing the highest adjacent elevations to 7 ft above the average summer water surface. Where permanent flooding sufficient to submerge the root collar occurred, mortality in most species was 100 percent in 6 years, and nearly all individuals were dead within 8 years. Many species were completely eliminated within 4 years. Within species, both very young and overmature individuals tended to be least tolerant of flooding. Where the water table was raised to the ground surface, mortality patterns were similar to those observed under flooded conditions but occurred at a much slower rate. Three years after impoundment, only a few species showed significant mortality on the saturated sites. However, after 6 years mortality ranged from 50 to 100 percent for most species studied, although a few

species such as river birch and cottonwood exhibited no significant mortality. The author suggested, however, that premature mortality appeared likely in all species in time. Sites on dry land where water tables were presumed to have risen 3 ft suffered very limited mortality in 6 years, with only 5.3 percent of the entire sample dying during the study. No attempt to measure natural tree mortality or actual water table levels was reported.

14. Hall and Smith (1955) studied tree mortality associated with operation of a malaria-control dewatering project in Tennessee. The project apparently did not function effectively, and prolonged growing season flooding occurred during 4 of the first 7 years of operation. In general, flooding for half or more of the growing season resulted in nearly complete mortality, much of it occurring the year after flooding began. With shorter flooding periods, tree survival increased to the point where most species survived brief periods of root-crown inundation during the growing season. However, four species (dogwood, yellow poplar, hornbeam, and beech) showed sensitivity even to this limited flooding. No information was supplied concerning topography or groundwater levels.

15. Harris (1975) reported on hardwood mortality resulting from one season's flooding on two lakes in northeast Oklahoma. Once again, no water table effects were monitored, but flood mortality was greatest among strictly upland species (e.g., black oak) with lesser effects on species typically found on bottomlands (e.g., box elder). Similar patterns of tree mortality were reported following reservoir impoundments in Iowa and Illinois (Green 1947, Bell and Johnson 1974, Dellinger et al. 1976), Tennessee (Hall et al. 1946), Mississippi (Broadfoot and Williston 1973), and Louisiana (Penfound 1949, Eggler and Moore 1961).

16. In general, the studies cited in paragraphs 13-15 reported greatest mortality in typically upland species and best survival in bald cypress and water tupelo, typically swamp species. Intermediate floodplain species are somewhat less predictable in their response to hydrologic alteration, but in most cases they reflect the tolerance rankings given in Table 1. One possible contributing factor to the observed

variable responses (other than site factors) was identified by Keeley (1979) and McGee et al. (1981). Both of these studies demonstrated that there was considerable variability within species (black gum and cottonwood) in response to changes in moisture regime and showed that the origin of the plant population (e.g., upland vs. bottomland) may account for differential adaptability to stress.

17. Growth effects. It is possible that raised water tables that cause plant injury in some situations may benefit plants in others. Many studies describe increased growth rates in trees after changes in hydrology are effected. Broadfoot (1973) reported greatly increased growth rates (about 50 percent) in a variety of species in the 5 years following impoundment of Demopolis Pool. The water table on the study sites averaged 46 in. below the soil surface (preimpoundment levels unknown), and capillary moisture extended to an average of 15 in. below the ground surface. Broadfoot assumed rooting depth to be about 4 ft and attributed the increased growth to the increase in available moisture. In the same paper he reported similar, but more variable, results for trees adjacent to the Jim Woodruff Reservoir (Lake Seminole) in Florida. Most species showed marked growth rate increases in the 5 years following impoundment when water tables were raised no nearer than 4 ft from the soil surface, bringing capillary water within 30 to 40 in. of the surface. On one site where the water table was raised to 18 in. below the surface, a turkey oak was killed, but radial growth of a longleaf pine on the same site was increased by 113 percent after impoundment. A second longleaf pine showed a 38 percent growth increase with the water table raised to 12 in. below the surface. Another site with a water table at 12 in. below the surface showed sharply reduced growth for green ash, sugarberry, and sweet gum, and only a moderate increase for sycamore. The author attributed the decreased response to deposition of sand on the sites by floodwaters, but it is reasonable to assume that the extremely high water tables may have compounded the detrimental effects of sedimentation.

18. Green (1947) reported highly variable growth responses in the 7 years following impoundment of pools on the upper Mississippi River.

Permanently flooded trees all died within 4 years of impoundment, but normal growth rates continued until death. Broadfoot (1973) noted a similar phenomenon in the dead turkey oak he sampled at Woodruff, which showed increased growth until it died abruptly. Green (1947) found little mortality among trees that were above the 2-ft contour (2 ft above normal pool) during his study, but he noted substantial differences in growth response between trees growing just above the 2-ft contour and those on "high ground." Most trees in both of these groups showed a growth reaction (usually stimulation) in the year of impoundment or the following year. In subsequent years, however, growth patterns developed that illustrate the complexity of this issue. Although American elm and pin oak showed eventual good growth and black willow performed poorly on both sites, other species did not respond consistently. Growth was improved on high ground for silver maple and green ash, but was reduced for these species in the area just above the 2-ft contour. River birch followed an opposite pattern, while cottonwood grew better on the lower area but performed very erratically on high ground. The author suggested that mortality may eventually occur in the species exhibiting reduced growth.

19. Studies concerned with increased dormant-season flooding also noted growth and vigor effects. Early studies of greentree reservoirs and other dormant-season impoundments generally reported improved tree growth (Broadfoot 1958 and 1967, Broadfoot and Williston 1973) and better production of sound fully developed acorns (Minkler and McDermott 1960), which may be an indication of tree vigor. However, more recent studies indicate that long-term tree response may not be so consistently improved as had earlier been thought. Fredrickson (1979) studied a 20-year-old greentree area in southeastern Missouri and found that tree growth had been improved for some species (pin, willow, and overcup oaks), but was reduced for others (red maple, Shumard oak, and sweetgum). Rogers (1981) reported that pin oak growth had not improved and may have been somewhat reduced after 20 years of dormant-season impoundment. McQuilkin and Musbach (1977) found no increase in sound fully developed acorn production on a greentree site after 14 years of data had been

collected; this was in contrast to the increased production reported for the same site after a shorter period of study by Minkler and McDermott (1960).

20. The preceding discussion illustrates that the increases in growth and vigor frequently reported in the period immediately following water table/flooding changes may, in some cases, be transitory and do not preclude eventual water-induced decline or mortality. Although beneficial growth effects appear to have been somewhat overstated in the past, they probably do occur, but are more species- and site-specific than previously thought. In general, however, it is reasonable to assume that where water tables are raised sufficiently to increase the accessibility of capillary water without causing anaerobic conditions in the root zone, tree growth might be expected to improve without eventual mortality. This is especially true of floodplain species, which are more resistant to root injury and can often use more water than is typically available during the growing season (Broadfoot and Williston 1973).

Prediction of tree mortality

21. Several attempts have been made to develop specific investigative techniques or models of tree mortality or community change following impoundment. Buma and Day (1975) presented an example of an inventory and classification technique that they suggested had specific applicability to monitoring of changes resulting from reservoir construction. In essence, however, their system is simply a pre- and post-impoundment sampling and data-synthesis scheme and a variety of similar techniques could be applied to the same purpose.

22. Franz and Bazzaz (1977) developed a simulation model designed to predict the eventual shift in species distributions with respect to modified hydrologic regimes following reservoir impoundment. The model was not concerned with tree mortality, but rather was an attempt to provide a long-range assessment of the effects of a project on the composition and structure of a forest as a whole. The authors acknowledged that much additional research would be required to refine the model but suggested that it is a promising approach.

23. The U. S. Army Engineer District, Kansas City (1973), attempted to predict tree mortality prior to impoundment of Harry S. Truman Reservoir in Missouri. Tree species tolerances were estimated from the literature, and growth rate and canopy position were used to indicate age and vigor. Thus, for each species and flooding intensity, a minimum growth rate and canopy position were assigned. Trees not meeting the minimum requirements were assumed to be subject to flood-induced mortality. Sampling was conducted and percentages calculated to arrive at an estimated percent mortality by species for the project area. As with the two studies described above, no follow-up study was available for review to determine if the prediction process was accurate.

24. Bruckner et al. (1973) attempted to predict eventual tree mortality on an impoundment in Pennsylvania by examining growth effects during the first few years of operation. They sampled residual living trees to determine postimpoundment growth rates and tallied tree diameters, slope, and elevation data for each tree. Linear regression and analysis of variance techniques were employed to examine relationships among the measured variables, but the results were largely inconclusive. The authors found that change in diameter increment could not be used as a measure of decline, nor could flooding duration or percent slope be used to predict changes in diameter increment. These results are consistent with other studies noted above that reported wide variation in growth responses, including increased growth followed by abrupt mortality.

25. Clearly, a variety of factors influence the ability of an individual tree to either withstand or benefit from changes in groundwater regimes. The Aliceville-Gainesville piezometer and cover-type data collected by the U. S. Army Engineer District, Mobile, and supplied for this review should aid considerably in making estimates of eventual tree mortality in those areas, but even these data are unlikely to be adequate for a full and accurate assessment. The piezometer data indicate that preimpoundment water table levels have in some instances been affected by construction activities, and postimpoundment levels often exhibit no particular quantifiable pattern over the short period they

have been monitored. Even where fairly clear patterns are evident, it is uncertain whether this type of data can be reasonably and accurately extrapolated to unmonitored areas. Studies in the Red River area reported by USDA (1977) noted discrepancies between actually measured water tables (piezometer data) and the predicted values, which were derived by extrapolation over large areas. The accuracy of prediction will be lessened with distance from the sampling station, but estimates of tree mortality in such unmonitored areas will be improved by the incorporation of accurate surface topography, soil, and subsurface geologic data that bear on water movement. One additional problem with the existing piezometer data concerns sampling frequency. The plotted data indicate sampling intervals of several months in many cases, while species tolerances are generally expressed in terms of weeks. Thus, while the data may indicate that groundwater enters the root zone on a particular site, they may not be sufficient to determine if the duration of root-zone saturation is likely to be harmful to trees on that site.

26. The project-area cover-type data supplied for this review may also be too generalized to permit rigorous analysis of water table effects, particularly in highly diverse forest types, such as "mixed oak-hickory," which may exhibit a wide range of responses depending on species, microtopography, and other variables discussed below. For example, it may be expected that in certain situations only one species of two or three codominants might be particularly sensitive to the proposed change in groundwater levels. In such a case only detailed stand-specific compositional and structural data would permit accurate estimation. However, such detailed forest sampling would only be justified if there is a high degree of confidence in the accuracy of the hydrologic predictions.

27. It is suggested that the older impoundments in the area, such as Demopolis Pool, might provide suitable models for at least some of the areas in question and allow estimation of tree mortality and community change over time. However, such a comparison would require reasonably similar preimpoundment site conditions including soil and vegetation types and water table depths, accurate records of the

preimpoundment vegetation, and similar postimpoundment hydrologic conditions and forest management. Surveys of the recently impounded Aliceville and Gainesville pools may give an indication of the extent of the most severe and immediate mortality, but are unlikely to reveal the more subtle effects, since these may appear very slowly.

Related issues

28. Community change. Whether or not mortality is evident in affected areas, a certain degree of change in species composition may be expected in time. Bottomland plant communities exhibit fairly restricted distributions with respect to the various soil and flooding/saturation factors discussed (see Table 2). Seedling success in bottomlands may be greatly affected by hydrologic changes, particularly where the frequency, timing, and duration of flooding and surface saturation are altered. In such situations a gradual shift to a wetter cover type may be anticipated. For a more complete discussion of the factors involved in determining eventual community composition, including understory vegetation and wildlife populations, following alteration of flooding regimes, see Klimas et al. (1981).

29. Agricultural lands. Much of the difficulty in assessing impacts to forest land derives from the very gradual response of trees to noncatastrophic change. In contrast, changes in land suitability for row crops and pasture may be manifested more quickly and thus it may be preferable to evaluate these largely on the basis of direct monitoring rather than prediction. This topic is beyond the scope of this review, but the reader is referred to USDA (1977) for an example of this process as conducted in the Red River area in Louisiana. A more theoretical review and source of additional literature on the subject is provided by Williamson and Kriz (1970).

Summary

30. Any significant rise of growing-season water tables into the rooting zone of upland tree species is likely to cause mortality in a short period of time, often within a few years. Only those species

which also are commonly found in bottomlands, such as black gum, persimmon, and sweetgum, are likely to survive such conditions for an extended period. As a general guide, the rooting zone for most species growing in fairly well-drained medium-textured soils is likely to be restricted primarily to the upper 3 to 4 ft of the soil profile. This may vary considerably under different textural or drainage conditions and is related to the age and species of the tree.

31. The wettest forests of the bottomlands (cypress-tupelo) will probably be least sensitive to water-table rises, since these species are well adapted to prolonged flooding. Permanent soil saturation and minor increases in flood heights or durations should not cause immediate mortality, and mature individuals may persist for many years, although large rises in water levels may cause growth reduction or mortality even in these species (Eggler and Moore 1961, Mitsch et al. 1979, Harms et al. 1980). However, the requirements for reproduction of cypress and tupelo are very stringent, and without occasional drying of the soil surface followed by a year without extended seedling submergence, they cannot reproduce (Demaree 1932, Shunk 1939, Johnson 1973). Growth in these species also is related to periodic drying of the substrate (Crawford 1978).

32. The zone between the deep swamps (cypress-tupelo) and the uplands presents the greatest difficulty in predicting tree mortality. These bottomland hardwood species are generally adapted to periodic flooding or saturation and can withstand minor or temporary increases in moisture without serious harm. However, permanent saturation to or above the soil surface can be expected to cause near-total eventual mortality. Gill (1970) made the generalizations that year-round root inundation can be tolerated only in isolated years and that even the most flood-tolerant species need to be unflooded for at least 55 to 60 percent of the growing seaon. He further stated that flooding a site for more than 40 percent of the growing season renders it unsuitable for woody plant establishment. Crawford (1978) suggested that permanent flooding of root systems will cause tree mortality within 3 years in

nearly all cases, and he related this limit to the need to regenerate the younger absorbing roots every 2 years.

33. In situations where water tables are raised into the rooting zone but do not saturate the surface soil, differential mortality may be expected to occur, generally reflecting the relative flood tolerance of the species. The frequency, timing, and duration of the root-zone saturation must be taken into account, and species-specific information on this is available in Table 1 and in numerous seedling studies listed in the attached bibliography. Estimation of the extent of the root zone is difficult, but certain generalizations can be made. Baker and Broadfoot (1979) indicated that some of the most common bottomland species can be moderately successful on sites with water tables at 1 to 2 ft below the surface, while sites with water tables within a foot of the surface are unsuitable. Note, however, that they refer to trees that have established on the site with the water table already at these levels; on sites where the water table is lower, rooting is likely to be deeper and damage may result from raising the water table as demonstrated by Broadfoot et al. (1971) with cottonwood. Examination of Baker and Broadfoot's (1979) evaluation of hardwood sites, taken together with the likelihood of fairly heavy soils and occasional flooding on most bottomlands, suggests it is reasonable to suppose that the bulk of tree roots on such sites would be restricted to the upper 2 ft or so of the soil profile, assuming the water table has not historically occupied this zone. As with upland species, the actual location of the roots may be influenced by a variety of other factors not considered in detail here.

34. In certain situations raised water tables may result in a general increase in tree growth by increasing the availability of capillary water to the roots without causing anaerobic conditions in the rhizosphere. Frequently, however, reported initial surges in tree growth have been followed by a decline in tree vigor or abrupt mortality.

35. To conclude this discussion, the reported review indicated that a variety of factors should be evaluated in order to make a reasonably complete estimate of the extent of tree mortality to be expected in

conjunction with impoundment. The estimated position of the water table relative to the surface elevation over the growing season must be used to assess the duration and extent of root zone saturation, and this must be evaluated in light of the species' documented flood tolerance. Rough estimates of flood tolerance can be obtained from Tables 1 and 2, and refinement may be possible through examination of applicable studies listed in the bibliography. Estimation of rooting zones, capillarity, and other pertinent factors may be aided by the preceding review and additional soils and hydrologic information, as available. Although consideration of these types of data should improve the accuracy of prediction, it should be recognized that the complexity of this issue makes errors inevitable. A balanced integration of the many factors influencing tree survival and growth is difficult; thus truly accurate prediction of effects may be possible only in areas of extreme stress, such as sites where permanent saturation to the soil surface will occur.

Literature Cited and Bibliography

Adams, D. E., and R. C. Anderson. 1980. Species response to a moisture gradient in central Illinois forests. Am. J. Bot. 6:381-392.

Anderson, R. C., and J. White. 1970. A cypress swamp outlier in southern Illinois. Trans. Ill. State Acad. Sci. 63:6-13.

Applequist, M. B. 1959. Longevity of submerged tupelogum and bald-cypress seed. LSU Forestry Note No. 27. Louisiana State Univ., Baton Rouge. 2 pp.

Armstrong, W. 1968. Oxygen diffusion from the roots of woody species. Physiol. Plant. 21:539-543.

Baker, J. B. 1977. Tolerance of planted hardwoods to spring flooding. S. Jour. Applied For. 1:23-25.

Baker, J. B., and W. M. Broadfoot. 1979. A practical field method of site evaluation for commercially important southern hardwoods. U. S. Dep. Agric., For. Serv. South. For. Exp. Stn. Gen. Tech. Rep. SO-26. 51 pp.

Bedinger, M. S. 1971. Forest species as indicators of flooding in the lower White River Valley, Arkansas. Pages C248-C253 in: Geol. Survey Res. U. S. Geol. Sur. Prof. Pap. 750-C.

__________. 1978. Relation between forest species and flooding. Pages 427-435 in: P. E. Greeson, J. R. Clark, and J. E. Clark eds. Wetland Functions and Values: The State of Our Understanding - Proceedings of the National Symposium on Wetlands. Am. Water Resour. Assoc., Minneapolis, Minnesota. 674 pp.

Bell, D. T., and F. L. Johnson. 1974. Flood caused tree mortality around Illinois reservoirs. Trans. Ill. State Acad. Sci. 67:28-37.

Bergman, H. T. 1920. The relation of aeration to the growth and activity of roots and its influence on the excesis of plants in swamps. Ann. Bot. 34:13-33.

__________. 1959. Oxygen deficiency as a cause of disease in plants. Bot. Rev. 25:418-485.

Black, C. A. 1957. Soil-Plant Relationships. Second Edition. J. Wiley and Sons, NY. 792 pp.

Bonner, F. T. 1966. Survival and first year growth of hardwoods planted in saturated soils. USDA For. Serv. South. For. Exp. Sta. Res. Note SO-32. 4 pp.

Boyce, J. S. 1961. Forest Pathology, 3rd ed. McGraw-Hill Book Co., New York. 572 pp.

Braun, E. L. 1950. Deciduous Forests of Eastern North America. Hafner Press, New York. 596 pp.

Briscoe, C. B. 1957. Diameter growth and effects of flooding on certain bottomland forest trees. Ph. D. Dissertation. School of Forestry, Duke Univ. 103 pp.

__________. 1961. Germination of cherrybark and Nuttall oak acorns following flooding. Ecology 42:430-431.

Broadfoot, W. M. 1958. Reaction of hardwood timber to shallow-water impoundments. Miss. Agric. Exp. Stn. Info. Sheet 595. Stoneville.

__________. 1964. Hardwoods respond to irrigation. J. For. 63:579.

__________. 1967. Shallow water impoundment increases soil moisture and growth of hardwoods. Proc. Soil Sci. Soc. Am. 31:562-564.

__________. 1973. Raised water tables affect southern hardwood growth. U. S. Dep. Agric. For. Serv. South. For. Exp. Sta. Res. Note SO-168. 4 pp.

__________. 1973. Water table depth and growth of young cottonwood. U. S. Dep. Agric. For. Serv. South. For. Exp. Sta. Res. Note SO-167. 4 pp.

Broadfoot, W. M., B. G. Blackmon, and J. B. Baker. 1971. Soil management for hardwood production. pgs. 17-29 In: Proc. Symp. on Southeastern Hardwoods, USDA For. Serv., SE State and Private For. 102 pp.

Broadfoot, W. M. and H. L. Williston. 1973. Flooding effects on southern forests. J. For. 71:584-587.

Bruckner, W., T. W. Bowersox, and W. W. Ward. 1973. Response of trees to flooding at the Curwensville Reservoir. Penn. State Univ., Agr. Exp. Sta. Research Briefs 7(2):4-7.

Buckman, H. O. and N. C. Brady. 1969. The Nature and Properties of Soils. 7th ed. The MacMillan Co., New York. 653 pp.

Bull, H., and J. A. Putnam. 1941. First-year survival and height growth of cottonwood plantations at Stoneville, MS. U. S. Dep. Agric., For. Serv. South. For. Exp. Stn. Occas. Pap. 98. 16 pp.

Buma, P. G. and J. C. Day. 1975. Reservoir induced plant community changes: a methodological explanation. J. Env. Mgt. 3:219-250.

Burandt, C. L., Jr., E. S. Nixon, and R. L. Willet. 1977. Woody vegetation of an inland heronry in east Texas. Southwestern Nat. 21:475-486.

Burton, J. 1972. Prolonged flooding inhibits growth of loblolly pine seedings. U. S. Dep. Agric., For. Serv. South. For. Exp. Stn. Res. Note No. 7. 4 pp.

Byrd, N. A. 1978. Some effects of soil moisture on management of forest cover for recreation and aesthetics. pp. 119-124 In: W. E. Balmer (ed.) USDA For. Serv. S. E. State and Private For. Proc. Symp. on Soil Moisture and Site Productivity.

Cannon, W. A. 1925. Physiological features of roots with especial reference to the relation of roots to aeration of the soil. Carnegie Inst. Wash. Publ. 368.

Carter, J. R., Jr. 1978. A floristic study of the Delta National Forest and adjacent areas. M.S. thesis, Mississippi State Univ. Starkville. 79 pp.

Conner, W. H., and J. W. Day, Jr. 1976. Productivity and composition of a bald cypress-water tupelo site and a bottomland hardwood site in a Louisiana swamp. Am. J. Bot. 63:1354-1364.

Conway, V. M. 1940. Aeration and plant growth in wet soils. Bot. Rev. 6:149-163.

Crawford, R. M. M. 1978. Metabolic adaptations to anoxia. pp. 119-136 In: Hook, D. D. and R. M. M. Crawford (eds.). Plant Life in Anaerobic Environments (Draft). Ann Arbor, MI.

Dabel, C. V., and F. P. Day, Jr. 1977. Structural comparisons of four plant communities in the Great Dismal Swamp, Virginia. Bull. Torrey Bot. Club 104:352-360.

Dellinger, G. P., E. L. Brunk, and A. D. Allmon. 1976. Tree mortality caused by flooding at two midwestern reservoirs. Proc. Ann. Conf. S. E. Assoc. Fish and Wildl. Agencies 30:645-648.

Demaree, D. 1932. Submerging experiments with Taxodium. Ecology 13:258-262.

Dickson, R. E., J. F. Hosner, and N. W. Hosley. 1965. The effects of four water regimes upon the growth of four bottomland tree species. For. Sci. 11:299-305.

Eggler, W. A. and W. G. Moore. 1961. The vegetation of Lake Chicot, Louisiana after eighteen years' impoundment. Southwestern Nat. 6:175-183.

Filer, T. H. 1975. Mycorrhizae and soil microflora in a greentree reservoir. For. Sci. 24:36-39.

Ford, H. W. 1972. Eight years of root injury from water table fluctuations. Proc. Fla. State Hort. Soc. 85:64-69.

Fowells, H. A. 1965. Silvics of Forest Trees of the United States. U. S. Dep. Agric., For. Serv. Agric. Handbook No. 271. 762 pp.

Franz, E. H. and F. A. Bazzaz. 1977. Simulation of vegetation response to modified hydrologic regimes: a probabilistic model based on niche differentiation in the floodplain forest. Ecology 58:176-183.

Fredrickson, L. H. 1979. Floral and faunal changes in lowland hardwood forests in Missouri resulting from channelization, drainage, and impoundment. U. S. Dep. Int., Fish and Wildl. Serv./OBS/-78/91. 130 pp.

Gill, C. J. 1970. The flooding tolerance of woody species-a review. For. Abstracts 3:671-688.

Golden, M. S. 1979. Forest vegetation of the lower Alabama piedmont. Ecology 60:770-782.

Grable, A. R. 1966. Soil aeration and plant growth. Adv. in Agro. 18:57-105.

Green, W. E. 1947. Effect of water impoundment on tree mortality and growth. J. For. 45:118-120.

Gunter, G. 1956. Land, water, wildlife, and flood control in the Mississippi Valley. Proc. La. Acad. Sci. 19:5-11.

Hall, T. F., and G. E. Smith. 1955. Effects of flooding on woody plants, West Sandy Dewatering Project, Kentucky Reservoir. J. For. 53:281-285.

Hall, T. F., and W. T. Penfound. 1943. Cypress-gum communities in the Blue Girth Swamp near Selma, Alabama. Ecology 24:208-217.

Hall, T. F., W. T. Penfound, and A. D. Hess. 1946. Water level relationships of plants in the Tennessee Valley with particular reference to malaria control. J. Tenn. Acad. Sci. 21:18-59.

Harms, W. R. 1973. Some effects of soil type and water regime on growth of tupelo seedlings. Ecology 54:188-193.

Harms, W. R., H. T. Schreuder, D. D. Hook, C. L. Brown, and F. W. Shropshire. 1980. The effects of flooding on the swamp forest in Lake Ocklawaha, Florida. Ecology 61:1412-1421.

Harris, M. D. 1975. Effects of initial flooding on forest vegetation at two Oklahoma lakes. J. Soil and Water Cons. 30:294-295.

Hodgkins, E. J., M. S. Golden, and W. F. Miller. 1979. A guide to forest site classification in Alabama-Mississippi. South. Coop. Series No. 210. Auburn Univ., Auburn, AL. 64 pp.

Hook, D. D. 1968. Growth and development of swamp tupelo (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.) under different root environments. Ph.D. Thesis, Univ. of Ga., Athens. 109 pp.

__________. 1973. Root adaptations and relative flood tolerance of five hardwood species. For. Sci. 19:225-229.

__________. 1971. Lenticels and water root development of swamp tupelo under various flooding conditions. Bot. Gaz. 131:217-224.

Hook, D. D., and C. L. Brown. 1972. Permeability of the cambium to air in trees adapted to wet habitats. Bot. Gaz. 133:304-310.

Hook, D. D., C. L. Brown, and P. P. Kormanik. 1971. Inductive flood tolerance in swamp tupelo (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.). Jour. Exp. Bot. 22:78-89.

Hook, D. D, O. G. Langdon, J. Stubbs, and C. L. Brown. 1970. Effect of water regimes on the survival, growth, and morphology of tupelo seedlings. For. Sci. 16:304-311.

Hosner, J. R. 1957. Effects of water upon the seed germination of bottomland trees. For. Sci. 3:67-70.

__________. 1958. The effects of complete inundation upon seedlings of six bottomland tree species. Ecology 39:371-374.

__________. 1959. Survival, root, and shoot growth of six bottomland tree species following flooding. J. For. 57:927-928.

__________. 1960. Relative tolerance to complete inundation of fourteen bottomland tree species. For. Sci. 6:246-251.

Hosner, J. R., and S. G. Boyce. 1962. Tolerance to water saturated soil of various bottomland hardwoods. For. Sci. 8:180-186.

Hosner, J. R., and A. L. Leaf. 1962. The effect of soil saturation upon the dry weight, ash content, and nutrient absorption of various bottomland tree seedlings. Soil Sci. Soc. Am. Proc. 26:401-404.

Hosner, J. R., and L. S. Minkler. 1963. Bottomland hardwood forests of southern Illinois - regeneration and succession. Ecology 44:29-41.

Howard, J. A., and W. T. Penfound. 1942. Vegetational studies in areas of sedimentation in the Bonnet Carre Floodway. Bull. Torrey Bot. Club 69:281-289.

Huffman, R. T. 1980. The relation of flood timing and duration to variation in selected bottomland hardwood communities of southern Arkansas. U. S. Army Engineer Waterways Exp. Stn. Misc. Pap. EL-80-4, Vicksburg, MS. 22 pp.

Huffman, R. T., and S. W. Forsythe. 1981. Bottomland hardwood forest communities and their relation to anaerobic soil conditions. DRAFT. In press. in: J. Clark and J. Benforado, eds. Bottomland Hardwood Workshop. National Wetlands Technical Council, Washington, D. C.

Hunt, F. M. 1951. Effects of flooded soil on growth of pine seedlings. Pl. Physiol. 26:363-368.

Johnson, R. L. 1973. Oak-gum-cypress in the Midsouth. pp. 98-12 in: Silvicultural Systems for the Major Forest Types of the United States. U. S. Dep. Agric. For. Serv., Ag. Handbk. No. 445. 114 pp.

Johnson, F. L., and D. T. Bell. 1976. Plant biomass and net primary production along a flood-frequency gradient in the streamside forest. Castanea 41:156-165.

Keeley, J. E. 1979. Population differentiation along a flood frequency gradient: physiological adaptations to flooding in Nyssa sylvatica. Ecol. Mongr. 49:89-108.

Kennedy, H. E., Jr. 1970. Growth of newly planted tupelo seedlings after flooding and siltation. For. Sci. 16:250-256.

Klimas, C. V., C. O. Martin, and J. W. Teaford. 1981. Impacts of flooding regime modification on wildlife habitats of bottomland hardwood forests in the lower Mississippi Valley. U. S. Army Engineer Waterways Exp. Sta. Tech. Rep., Vicksburg, MS (in press). 140 pp. plus appendix.

Kramer, P. J. 1951. Causes of injuries to plants resulting from flooding of soil. Pl. Physiol. 26:722.

________. 1969. Plant and Soil Water Relationships: A Modern Synthesis. McGraw-Hill Book Co., NY. 482 pp.

Kramer, P. J., and T. T. Kozlowski. 1960. Physiology of Trees. McGraw-Hill Co., NY. 642 pp.

Loucks, W. L. 1970. A review of the literature concerning the effects of inundation upon trees. Kansas State University, Manhattan, KA. Unpub. manuscript. 54 pp.

Loucks, W. L., and R. A. Keen. 1973. Submersion tolerance of selected seedling trees. J. For. 71:496-497.

Maisenhelder, L. C., and J. S. McKnight. 1968. Cottonwood seedlings best for sites subject to flooding. U. S. Dep. Agric., For. Serv. Tree Planters Notes 19:15-16.

McAlpine, R. G. 1959. Flooding kills yellow poplar. Forest Farmer 19:13-14.

McCracken, F. I., and J. D. Solomon. 1980. Insect and disease problems in greentree reservoirs. Page 34 in: Southern Forest Soils Council. Soils and Hardwoods of the Lower Mississippi Valley: Field Tour Guide; Eighth Council Workshop. 50 pp.

McDermott, R. E. 1954. Effects of saturated soil on seedling growth of some bottomland hardwood species. Ecology 35:36-41.

McGee, A. B., M. R. Schmierbach, and F. A. Bazzaz. 1981. Photosynthesis and growth in populations of *Populus deltoides* from contrasting habitats. Amer. Midl. Nat. 105:305-311.

McQuilkin, R. A., and R. A. Musbach. 1977. Pin oak acorn production on greentree reservoirs in southeastern Missouri. J. Wildl. Manage. 41:218-225. (Erratum:J. Wildl. Manage. 41:597).

Minkler, L. S., and R. E. McDermott. 1960. Pin oak acorn production and regeneration as affected by stand density, structure, and flooding. Univ. Missouri Agric. Exp. Stn. Res. Bull. 750. 21 pp.

Minkler, L. S., and D. Janes. 1965. Pin oak acorn production on normal and flooded areas. Univ. of Missouri Agric. Exp. Stn. Res. Bull. 898. 15 pp.

Mitsch, W. J., C. L. Dorge, and J. R. Wiemhoff. 1979. Ecosystem dynamics and a phosphorus budget of an alluvial cypress swamp in southern Illinois. Ecology 60:1116-1124.

Monk, C. D. 1966. An ecological study of hardwood swamps in north central Florida. Ecology 47:649-654.

Montz, G. N. 1978. Flora of baldcypress-tupelo gum swamps in Louisiana. Unpublished manuscript. 14 pp.

Mueller-Dombois, D. 1964. Effect of depth to water table on height growth of tree seedlings in a greenhouse. For. Sci. 10:306-316.

Olson, D. F., Jr., and S. G. Boyce. 1971. Factors affecting acorn production and germination and early growth of seedlings and seedling sprouts. pp. 44-4 in: Oak Symposium Proceedings, U. S. Dep. Agric., For. Serv. Northeastern For. Exp. Stn. 161 pp.

Parker, J. 1950. The effects of flooding on the transpiration and survival of some southeastern forest tree species. Plant Physiol. 25:453-460.

Patrick, W. H., and S. Gotoh. 1974. The role of oxygen in nitrogen loss from flooded soils. Soil Sci. 228:78-81.

Patrick, W. H. Jr., and R. Wyatt. 1964. Soil nitrogen loss as a result of alternate submergence and drying. Soil Sci. Soc. Amer. Proc. 28:647-653.

Penfound, W. T. 1949. Vegetation of Lake Chicot, Louisiana, in relation to wildlife resources. Proc. La. Acad. Sci. 12:47-56.

Petranka, J. W., and R. Holland. 1980. A quantitative analysis of bottomland communities in south-central Oklahoma. Southwestern Nat. 25:207-214.

Ponnamperuma, F. N. 1972. The chemistry of submerged soils. Adv. Agron. 24:29-96.

Putnam, J. A. 1951. Management of bottomland hardwoods. U. S. Dep. Agric., For. Serv. South. For. Exp. Stn. Occasional Pap. 116. 60 pp.

Putnam, J. A., and H. Bull. 1932. The trees of the bottomlands of the Mississippi River, delta region. U. S. Dep. Agric. For. Serv. South. For. Exp. Stn. Occasional Pap. 27. 207 pp.

Putnam, J. A., G. M. Furnival, and J. S. McKnight. 1960. Management and inventory of southern hardwoods. U. S. Dep. Agric. For. Serv. Agric. Handbook 181:3-7.

Robertson, P. A., G. T. Weaver, and J. A. Cavanaugh. 1978. Vegetation and tree species patterns near the northern terminus of the southern floodplain forest. Ecol. Monogr. 48:249-267.

Rogers, R. 1981. Flooding, stand structure, and stand density affect pin oak growth in southeastern Missouri. Submitted to S. Jour. Applied For. 21 pp.

Sculthorpe, C. D. 1967. The Biology of Aquatic Vascular Plants. Edward Arnold Ltd., London. 610 pp.

Shelford, V. E. 1954. Some lower Mississippi Valley floodplain biotic communities: their age and elevation. Ecology 35:126-142.

Shunk, I. V. 1939. Oxygen requirements for germination of seeds of *Nyssa aquatica* - tupelo gum. Science 90:565-566.

Silker, T. H. 1948. Planting of water-tolerant trees along the margins of fluctuating-level reservoirs. Iowa State Coll. J. Sci. 22:431-447.

Society of American Foresters. 1975. Forest cover types of North America, exclusive of Mexico. Soc. Am. For., Washington, D. C. 69 pp.

Sternitzke, H. S. 1976. Impact of changing land use on Delta hardwood forests. J. For. 71:25-27.

Tattar, T. A. 1972. Effects of inundation on trees. USDA For. Serv., N. E. Area State and Priv. For. P-72-4. 6 pp.

Terpening, V. A., L. J. Hunt, D. K. Evans, S. J. Bleiweiss, and R. C. Zoanetti. 1974. A survey of the fauna and flora occurring in the Mississippi River floodplain between St. Louis, Missouri, and Cairo, Illinois. U. S. Army Eng. Waterways Exp. Stn. Contract Rep. 6-74-3. Vicksburg, MS. 391 pp.

Teskey, R. O., and T. M. Hinckley. 1977. Impact of water level changes on woody riparian and wetland communities. 6 volumes. U. S. Fish and Wildlife Service Office of Biological Services 77/58, 77/59, 77/60, 78/87, 78/88, 78/89.

Thieret, J. W. 1971. Quadrat study of a bottomland forest in St. Martin Parish, LA. Castanea 36:174-181.

Thomson, P. M., and R. C. Anderson. 1976. An ecological investigation of the Oakwood Bottoms Greentree Reservoir in Illinois. Pages 45-64 in: J. S. Fralish, G. T. Weaver, and R. C. Schlesinger (eds.) Proc. of the First Central Hardwood Forest Conference, Southern Illinois University, Carbondale, Ill. 484 pp.

U. S. Army Engineer District, Kansas City. 1973. A vegetation mortality study of the Schell-Osage Wildlife Area. Unpublished manuscript. 20 pp. plus appendices.

USDA. 1977. Agricultural observation and groundwater study, Red River Waterways Project-Main Report. Prepared for USAE District, New Orleans by USDA Soil Conservation Service, Alexandria, LA. 39 pp plus appendices.

Walker, L. C., R. L. Green, and J. M. Daniels. 1961. Flooding and drainage effects on slash pine and loblolly pine seedlings. For. Sci. 7:2-15.

Wharton, C. H. 1970. The southern river swamp - a multiple-use environment. Bureau of Business and Economic Research, School of Business Administration. Georgia State Univ., Atlanta. 48 pp.

__________. 1971. Statement before Congress. in: H. S. Reuss (Chairman), Hearings on Stream Channelization, House of Representatives. U. S. Gov't. Printing Office, Washington, D. C., Cong. Rec. 1971:4: 2198-2201.

Whitlow, T. H., and R. Harris. 1979. Flood tolerance in plants: A state-of-the-art review. U. S. Army Eng. Waterways Exp. Stn. TR E-79-2. Vicksburg, MS. 161 pp.

Williamson, R. E., and G. J. Kriz. 1970. Response of agricultural crops to flooding, depth of water table, and soil gaseous composition. Trans. Soc. Agr. Eng. (1970):216-220.

Williston, H. L. 1959. Inundation damage to upland hardwoods. U. S. Dep. Agric. For. Serv. South. For. Exp. Sta. Res. Note 123.

_________. 1962. Pine planting in a water impoundment area. U. S. Dep. Agric., For. Serv. South. For. Exp. Stn. South. For. Note 137.

Yeager, L. E. 1949. Effect of permanent flooding in a river-bottom timber area. Ill. Nat. Hist. Survey Bull. 25:33-65.

Zimmerman, M. H., and C. L. Brown. 1971. Trees: Structure and Function. Springer-Verlag New York, Inc. 336 pp.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Klimas, Charles V.
Effects of permanently raised water tables on forest overstory vegetation in the vicinity of the Tennessee-Tombigbee Waterway / by Charles V. Klimas (Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. ; The Station ; Springfield, Va. ; available from NTIS, 1982.
31 p. ; 27 cm. -- (Miscellaneous paper ; E-82-5)
Cover title.
"August 1982."
Final report.
"Prepared for U.S. Army Engineer District, Mobile."
At head of title: Environmental & Water Quality Operational Studies.
Bibliography: p. 23-31.

1. Forests and forestry. 2. Plants. 3. Tennessee-Tombigbee Waterway. 4. Water table. I. United States.

Klimas, Charles V.
Effects of permanently raised water tables : ... 1982.
(Card 2)

Army. Corps of Engineers. Mobile District. II. Environmental & Water Quality Operational Studies. III. U.S. Army Engineer Waterways Experiment Station. Environmental Laboratory. IV. Title V. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; E-82-5.
TA7.W34m no.E-82-5