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FLOOD TOLERANCE IN PLANTS: A STATE-OF-THE-ART REVIEW

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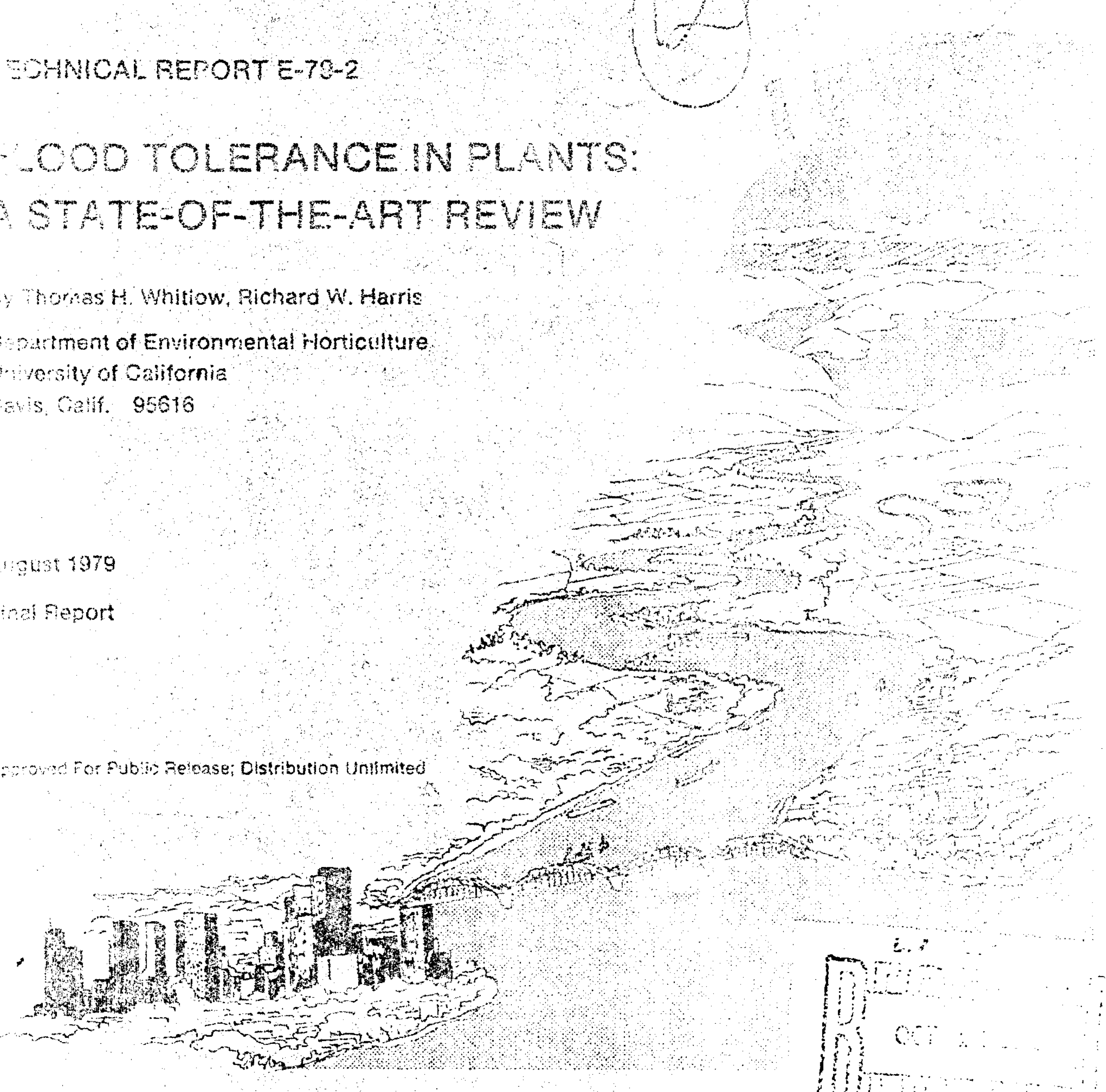

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Both the basic aspects of flood tolerance in plants and the applied aspects of establishing vegetation on reservoir shorelines are discussed through a comprehensive literature review. Flooding imposes complex stresses on many vascular plants, most of which arise from the depletion of oxygen in the flooded soil. Soil anoxia results in conditions that favor reduction reactions and anaerobic metabolism, which lead to the formation of ions in reduced valence states and organic acids and gases in concentrations exceeding those in aerobic soils.

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Changes in pH accompanying soil reduction may also alter nutrient availability. Plants avoid or mitigate these flooding stresses by either transferring oxygen into their roots via anatomical modifications in the shoot and/or by utilizing anaerobic respiration pathways in their roots.

In addition to a plant's ability to withstand soil anaerobiosis, plant age, plant size, flood depth, flood duration, flood timing, substrate composition, wave action, and other factors determine survivorship when plants are flooded. Studies are reviewed that correlate these factors with species tolerances. A detailed summary of research relating directly to reservoir revegetation is provided, and species tolerances are assessed for each of the Army Corps of Engineers Divisions. Techniques for the establishment of vegetation around reservoirs are discussed, as are examples of species mortality prediction and impact assessment.

Additional work is required concerning the integrated plant response to flooding, refined species tolerance assessments, reservoir revegetation techniques, and the selection of species suitable for reservoir environments.

SUMMARY

This report reviews the theoretical and practical aspects of flood tolerance in plants, particularly the native woody species of the contiguous United States. The purpose is to provide a background understanding of phenomena related to flooding and flood tolerance and to summarize practical information pertinent to reservoir revegetation. The report includes a wide variety of information previously unavailable in an assimilated form.

Any depth and duration of flooding impose an extraordinary set of deleterious conditions on most vascular plants. The most elementary differences between well-drained and flooded conditions arise in the soil, and all are directly or indirectly related to the depletion of free oxygen. The near absence of oxygen creates a reducing environment in the soil that favors the activities of anaerobic bacteria. These organisms produce a variety of organic and inorganic byproducts, many of which are present in concentrations toxic to plants. Some of the most physiologically damaging are ethylene, manganese (Mn^{++}), and iron (Fe^{++}). Thus, a plant living under flooded conditions may have to cope with the simultaneous effects of a rooting medium that is both anaerobic and toxic.

Many plants have an ability to survive limited periods of flooding through temporary acclimation processes, but few are genetically adapted to this condition. The causal mechanisms for adaptation are complex and poorly understood. There is reasonable agreement, however, on what is adaptive. For simplicity, adaptations may be regarded as either anatomical or metabolic.

Anatomical adaptations include hollow stems, aerenchyma, lenticels, intercellular air spaces, and other features that facilitate the diffusion of oxygen from the (relatively) oxygen-rich shoot to the oxygen-poor root. The plant may thereby meet its minimal requirements for maintenance energy through aerobic respiration. If oxygen is available to the roots in excess of the respirational demand, it may actually diffuse outward into the soil, creating an oxidized rhizosphere in the

midst of the reduced soil environment. In this instance, the plant has effectively avoided the conditions imposed by flooding.

Metabolic adaptations include the ability to utilize anaerobic pathways for energy production and the removal of certain anaerobic by-products from the roots. Even though these pathways yield far less energy than the more normal aerobic one(s), some plants apparently do grow better under these conditions. Factors involved in this growth probably are an ability to transfer an oxygen debt from the root to the shoot via translocation of reduced compounds, preferential accumulation of nontoxic end products, and even the ability to transfer internal oxygen from the shoot to the root system.

There is strong evidence that many morphological and anatomical modifications are due to changes in concentrations of certain hormone or hormonelike compounds. Experimental research with ethylene, for example, has shown that at high concentrations there is an increase in adventitious rooting in many plants. These are apparently more pervious to oxygen than normal roots and hence would aid the plant during periods of inundation. Ethylene, under "normal" conditions, is known to be involved in leaf abscission and epinasty, but apparently does not function in the same manner under flood conditions.

The external factors of soil anaerobiosis and the production of toxins, and the internal plant adaptations to these, are basic to most flooding situations. There are a variety of additional factors, however, that often assume overriding importance in determining the survival of flooded plants. Such factors include substrate composition, shoreline gradient, wave and current action, flood depth and duration, tolerances of individual species, and ecotypic variation within species. Because these have an immediate, practical bearing on survival, they must be considered in both reservoir planning and impact assessment endeavors.

There are two ways to encourage the development of vegetation in reservoir drawdown zones. During the construction phase of a reservoir, selective clearing below mean pool elevation may be employed to leave flood-tolerant woody species. This technique is of only trivial effectiveness in regions of the country where few species are flood tolerant and the frequency of tolerant plants is low.

Revegetation is the second technique; this is suited to both new and established reservoirs. Generally, the methods of planting are identical to those in common practice in forestry, agriculture, and erosion control. The unique features of drawdown zones often require some special modifications of technique. Barge hydroseeding, air-cushion-craft seed dispersal, and helicopter seeding have been used to good advantage in problem areas. Woody vegetation may be established from bare root, container, or vegetative cutting stock. It is often realistic to overplant since mortality is likely to be high.

Diverse literature concerning experimental and empirical studies of flood tolerance has been collated and analyzed in this report to yield a summary of pertinent research for each of the U. S. Army Corps of Engineers Divisions. A composite rating of plants according to their relative flood tolerances is included for field elements within each Division. Because these ratings are subjective, they are only approximate. Extensive supplemental data are included in the appendices. It is intended that the regional treatments be used as a handbook of selected plants and literature for possible use in reservoir revegetation efforts.

PREFACE

This report was prepared by the University of California at Davis, Department of Environmental Horticulture, for the U. S. Army Engineer Waterways Experiment Station (WES) under Contract No. DACW39-77-M-3423, dated 20 May 1977. This study forms part of the Environmental Water Quality and Operational Studies (EWQOS), Task IIE, Environmental Effects of Fluctuating Reservoir Water Levels. The EWQOS is sponsored by the Office, Chief of Engineers (DAEN-CWO-M), and is assigned to the WES under the purview of the Environmental Laboratory (EL).

The research, a state-of-the-art review of flood tolerance in plants, was conducted by Mr. Thomas H. Whitlow under the general supervision and direction of Dr. Richard W. Harris, both of the Department of Environmental Horticulture, University of California at Davis. This report was written by Mr. Whitlow and Dr. Harris.

The study was under the general WES supervision of Mr. Hollis H. Allen; Dr. Jerry Mahloch, Program Manager, EWQOS; Dr. C. J. Kirby, Chief, Environmental Resources Divison; and Dr. John Harrison, Chief, EL.

The Commanders and Directors of WES during this study were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.856	square metres
feet	0.3048	metres
inches	25.4	millimetres
pounds (mass) per acre	0.000112	kilograms per square metre

FLOOD TOLERANCE IN PLANTS: A STATE-OF-THE-ART REVIEW

PART I: INTRODUCTION

1. This state-of-the-art review is intended to summarize the literature on flood-tolerant plants with an emphasis on temperate woody species. This approach has been adopted first because a comprehensive up-to-date review of flood tolerance in woody plants is lacking, and second, woody plants have not been adequately catalogued and assessed for their potential in reservoir revegetation efforts. Herbaceous species are more adequately covered in the recent literature (Wentz et al. 1974) and have been included in the chapters dealing with basic research. Elsewhere in the text, they are treated in proportion to their representation in the literature pertaining to reservoir maintenance.

2. This review may be approached as two separate, though dependent, sections. The first addresses the conditions imposed by flooding and the resulting physiological, anatomical, and morphological responses occurring in plants. This treatment necessarily covers many areas of basic research in order to convey an understanding of flood tolerance in plants and to highlight the directions of contemporary research in this field.

3. The second section is applied in its emphasis. Included are discussions of factors that may be measured and assessed in the field to aid in impact prediction and facilitate the design and management of artificial bodies of water. An approach to impact assessment that integrates these factors is discussed along with the limitations of current knowledge in this area.

4. Techniques for establishing and maintaining vegetation along the shores of reservoirs and canals are discussed in a general fashion. The limited amount of research in this area is reflected in the small number of plant species and management goals that are described.

5. The status of research with practical applications is

assessed for the ten U. S. Army Corps of Engineers Divisions. Plant-tolerance lists also are provided for each Division. Narrative summaries of research have been deliberately avoided because such treatments are available in several contemporary literature reviews. Instead, research has been summarized on a species-by-species basis for each Corps Division. This summary is included as several appendices. Each is designed to be used as a handbook in conjunction with the tolerance lists provided in the text. This review circumscribes a large body of research on diverse topics. It is hoped that it will serve as a catalyst for future research, both basic and applied, in addition to providing tools for practical problem solving.

6. Scientific and common nomenclature follow the usage of the individual authors in most instances. Where there was reason to suspect that nomenclature was inaccurate, it was reconciled with the binomial used in either <u>Gray's Manual of Botany</u> (Fernald 1970), <u>Manual of Cultivated Plants</u> (Bailey 1949), <u>A California Flora</u> (Munz 1963), or <u>Composite List of Weeds</u> (Weed Soc. of America 1971). Often there are different common names for a single species that enjoy regional popularity. The authors hope that the inclusion of only one common name for each species will not confuse those familiar with a plant by a different common name. The inconsistency of common names makes the use of scientific names imperative for accurate identification. One exception is the use of common names for crop (vegetable) species, which are not applicable to reservoir revegetation.

PART II: THEORETICAL CONSIDERATIONS OF FLOOD TOLERANCE IN PLANTS

Changes in Soils Resulting from Flooding

7. An understanding of flood tolerance in plants is facilitated by knowledge of the changes occurring in soils when they are flooded. The most basic change is the elimination of free oxygen available for chemical and biological processes.

8. Under aerobic conditions, soil microorganisms obtain energy through the breakdown of organic molecules via respiration pathways requiring oxygen (O_2). Flooding a soil drastically reduces the rate of O_2 diffusion into the soil pores and, with aerobic respiration systems intact, soil oxygen is rapidly depleted. Slow diffusion rates prevent the replenishment of O_2 in the soil and the net result is an anaerobic condition. The diffusion coefficients of gases in soil are a function of soil particle geometry and the soil moisture content (Currie 1961). Surface soils are composed of between 35 and 60 percent pore space (Buckman and Brady 1969). These pores are filled with complementary proportions of air and water (Bradford et al. 1934). When a soil is flooded, nearly all the pore space is filled with water and little, if any, is occupied by air. Gill (1970) lists four results of flooding that occur in soils: exclusion of oxygen from roots, carbon dioxide (CO_2) accumulation, production of toxins, and anaerobic conditions around the root. All of these changes are related directly or indirectly to the changes in gas diffusion characteristics resulting from the pores being filled with water instead of air. Oxygen diffuses at a rate 10,000 times slower in water than air (Lemon and Kristensen 1960, Greenwood 1961), and Buckingham (1904) showed that diffusion in soil decreases as the moisture content increases. The difference between oxygen diffusion rates and the demand for oxygen by soil organisms makes it apparent that anaerobic conditions will prevail in soils when they are flooded. Due to activity of microorganisms, most free oxygen in a soil will be exhausted within a few hours of submergence (Ponnamperuma 1972). Soil texture and moisture content will have some effects on the

concentration of oxygen in the soil. Diffusion coefficients for hydrogen gas in a physical model of wet soil were shown to be a function of at least the following five variables: total porosity, crumb porosity, crumb shape, the shape of the particles forming the crumbs, and moisture content of the medium (Currie 1961). Coarse soils, with low organic matter, have relatively high oxygen concentrations in soil solution (Zobell 1946). Generally, however, a sharp drop in oxygen concentration with increasing soil depth is expected in submerged soils.

9. The amount of dissolved oxygen in the water interfacing with a flooded soil will also affect the concentration of oxygen in the soil (Ponnamperuma 1972). Factors such as water movement, depth of flooding, biological activity, and temperature have all been suggested as determinants of oxygen concentrations in these soils (Brink 1954, Hosner 1960). Studies demonstrating the roles of these factors under natural conditions are scarce. Good correlations have been established between low soil oxygen (essentially zero) and stagnant surface water (Armstrong and Boatman 1967). The decrease in available oxygen found in most flooded soils is regarded by many workers as being the most basic cause of flood-induced injury to plants.

10. Veretennikov (1964) observed that calculated values for dissolved oxygen in water were 5 to 11 times higher than the dissolved oxygen in soil water at the same temperature and pressure. He also demonstrated that the oxygen diffusion rate was 0.5 mg/hr/100 cm^2 of surface area in saturated soils. Controlled experiments have been performed to assess the effects of various soil characteristics on oxygen depletion upon flooding. Scott and Evans (1955) provided a notable example of how rapidly oxygen is depleted in saturated soils. Using four air-dried soils they measured changes in oxygen content when the soils were water saturated. Despite differences in organic matter content among the soils, the oxygen depletion curves were very similar. With each of the four soils, oxygen concentration dropped to zero after 6 to 10 hr. They determined that dissolved oxygen decreased to 0.01 of the original value after approximately 75 min. (It should be noted that air drying soils accentuates the rate of oxygen depletion.)

11. Flooding a soil results in a sequential replacement of soil organisms. Obligate aerobic microorganisms rapidly go dormant or die, yielding to facultative and obligate anaerobes (Takeda and Furusaka 1970). The switch to complete anaerobic respiration in the soil occurs at a molar oxygen concentration of 3×10^{-6} (Ponnamperuma 1972). Anaerobes are capable of using compounds other then O_2 as the final electron acceptor. Anaerobic bacteria use NO_3^-, Mn^{+4}, Fe^{+3}, SO_4^{-2}, organic dissimilation products, CO_2, N_2, and H^+ as electron acceptors. These electron acceptors are reduced to lower oxidation or valence states during respiration. Ponnamperuma (1972) discusses the main redox systems operating in submerged soils and chemical equations for each system. A significant corollary of anaerobiosis is the reduction of many compounds found in the soil and the accumulation of reduced products (Gillespie 1920). Ponnamperuma (1972) considers the primary chemical difference between a submerged and well-drained soil to be the reduced state of the submerged soil. Three characteristics are indicative of a reduced state: a gray-green color, low reduction potential, and the reduced forms of a variety of compounds including NO_3^-, SO_4^{-2}, Mn^{+4}, Fe^{+3}, and CO_2 (Ponnamperuma 1972). The sequence of reduction of various compounds in the soil roughly follows the theoretical sequence determined by their reduction potentials. Empirical verification may be found in the observation of the vertical stratification of elements in various redox states in eutrophic lakes and in the succession of aerobic to facultative and obligate anaerobic microorganisms found when a soil is first saturated.

12. The switch to anaerobic pathways is accompanied by a change in metabolic end products as well. Anaerobic and aerobic respiration pathways are similar up to the point where pyruvate is synthesized just prior to entry into the Krebs cycle. Under aerobic conditions, pyruvate is degraded to CO_2 and water via the Krebs cycle. Under anaerobic conditions, pyruvate is degraded to CO_2, ethyl alcohol, organic acids (acetic, formic, propionic, butyric, lactic, valeric, and succinic acid), and organic gases (methane, ethane, propane, n- and isobutane, ethylene, propylene, and butene-1) (Russell 1973, Noggle and Fritz 1976).

One of the first workers to recognize the accumulation of CO_2 in the soil was Clements (1921). Other workers (Bergman 1920, Zimmerman 1930, Childers and White 1942, Yelenosky 1964) ascribed this increase in CO_2 to decomposing organic matter. Of the organic acids formed, the major ones are acetic, formic, propionic, and butyric. These generally peak at 10 to 40 μmoles* per litre within a period of 2 weeks of flooding and then gradually decline. During this period they may reach concentrations toxic to rice, and soil pH may drop below 6.0, but these conditions are unlikely except in soils high in organic matter (Ponnamperuma 1972). Methane (CH_4) is produced by a specialized group of obligate anaerobic bacteria (Ponnamperuma 1972). These are substrate specific and utilize only a small number of organic and inorganic compounds arising from fermentation. The activity of these bacteria results in an almost complete breakdown of the low molecular weight fatty acids and ethanol to carbon dioxide and methane (Stadtman 1967).

13. Soil bacteria utilize a variety of compounds as electron sinks and they may be ordered according to their redox potential (Eh), which reflects the degree of reduction present in a saturated soil. The following tabulation presents such an ordering:

Reaction	Redox Potential, mV, 25°C	
	pH 5.0	pH 7.0
$O_2 + 4H^+ + 4e^- = 2H_2O$	930	820
$NO_3^- + 2H^+ + 2e^- = NO_2^- + H_2O$	530	420
$MnO_2 + 4H^+ + 2e^- = Mn^{+2} + 2H_2O$	640	410
$Fe(OH)_3 + 3H^+ + e^- = Fe^{+2} + 3H_2O$	170	-180
$SO_4^{-2} + 10H^+ + 8e^- = H_2S + 4H_2O$	-70	-220
$CO_2 + H^+ + 8e^- = CH_4 + 2H_2O$	-120	-240
$2H^+ + 2e = H_2$	-295	-413

The higher the redox potential, the more electrons required to bring about a unit reduction in Eh. Because the soil contains a mixture of compounds with different redox potentials, not all compounds will be

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* μmole or micromole = 1 × 10^{-6} moles.

reduced at the same time; NO_3^-, MnO_2, $Fe(OH)_3$, H^+, and SO_4^{-2} can thus exert an inhibitory effect on the complete reduction of a flooded soil. Depending on the mixture of substances in a soil, it is said to be "poised" at a characteristic redox potential (Russell 1973).

14. The advent of reducing conditions in a flooded soil is paralleled by a drop in Eh. Upon submerging an aerobic soil, Eh reaches a minimum within a few days and then gradually increases to a peak. This is followed by an asymptotic decrease to a level characteristic of a specific soil. The presence of readily decomposed organic matter sharpens and hastens the achievement of the first minimum (Ponnamperuma 1955, Yamane and Sato 1968). The initial decrease in Eh is due to the release of reducing substances* that accompanies oxygen depletion before the Mn^{+4} and Fe^{+3} buffering systems are fully activated (Yamane and Sato 1968, Ponnamperuma 1972). The presence of high levels of nitrate postpone the achievement of a negative Eh. This is due to inhibition by nitrite of redox reactions lower on the thermodynamic scale of oxidation-reduction reactions (see preceding tabulation). Low organic matter content or high Mn^{+4} results in a high Eh. This has been shown to occur for as long as 6 months. Temperatures both above and below 25°C also retard a decrease in Eh (Ponnamperuma 1972). Jones and Etherington (1970) found that Eh in waterlogged slack** sands was lower than that of dune sands and ascribed this difference to the higher organic matter content in the slack soils.

15. Accompanying the decrease in Eh is a slight decrease in pH within the first few days of flooding (Ponnamperuma 1972). This is followed by an asymptotic rise to a stable value between 6.7 and 7.2 within a few weeks (Motomura 1962, Ponnamperuma 1965). The net effect of flooding the soil is to increase the pH of an acid soil and decrease the pH of an alkaline soil. In soils high in organic matter and reducible iron, pH stabilizes at 6.5 within a few weeks, while in acid soils with low organic matter or those with iron in an inactive form,

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* A reducing substance is one that donates electrons to another in an oxidation reduction reaction.

** A "slack" is defined by the authors as "the hollows between dunes."

pH stabilizes more gradually at less than 6.5 (Ponnamperuma 1972). The first decrease in pH is caused by an accumulation of CO_2 produced by aerobic bacteria. The following increase in pH is due to the reduction of the soil mainly caused by the formation of ferrous iron (Motomura 1962, Ponnamperuma et al. 1966).

16. McKee (1970) investigated the effects of a sequence of wetting and drying of an acid flatwoods soil from the Gulf Coastal Plain to determine the effects of pH. He found that submergence for 60 consecutive days caused pH to approach neutrality. The Eh decreased approximately 500 mV during this period. Subsequent drying of the soils decreased pH, while submergence decreased the level of exchangeable aluminum, calcium, and magnesium, probably through changes in pH. McKee concluded the changes resulting from submergence could be corrected or remedied only very slowly upon redrying.

17. The equilibria of hydroxide, sulfate, phosphate, and silicate are affected by the pH of the solution. In turn these equilibria control the solubilities of various solids, ion exchange, and the concentration of Al^{+3}, Fe^{+2}, H_2S, and H_2CO_3. The indirect effect of changes in pH, particularly with respect to aluminum and iron, are especially important in rice culture due to the toxicity of these ions. For example, changing from pH 6.5 to 7.5 can change the concentration of Fe^{+2} from 350 to 3.5 ppm. The lower concentration is inadequate while the upper is toxic to rice. Similarly, at a pH of 3.5, the concentration of Al^{+3} on some paddy soils is 69 ppm (toxic to rice) while at a pH of 4.5 it is 1 ppm (nontoxic) (Ponnamperuma 1972). Toxicities of these cations will, of course, very from species to species.

18. It follows that if ion concentrations change, then specific conductance will also change when a soil is flooded. Specific conductance is a function of the balance of chemical reactions that produce or inactivate various ions. Upon flooding, specific conductance of a soil generally reaches a maximum within 4 weeks and is followed by a decrease and gradual stabilization after 16 weeks to a value that is characteristic of the specific soil (Ponnamperuma 1972). Ponnamperuma (1972) attributes the initial increase to the release of Fe^{+2} and Mn^{+2}

from Fe^{+3} and Mn^{+4} hydroxides; the accumulation of NH_4^+, HCO_3^-, and $RCOO^-$; the dissolution of $CaCO_3$ by CO_2 and organic acids; and the displacement of cations from exchange sites on soil colloids.

19. Nitrogen also undergoes a complex series of changes when the soil is flooded. Under aerobic conditions nitrogen occurs as N_2, NO_2^-, and NO_3^-. In the sequence of respiration, nitrogen from organic matter is present as proteins that are broken down to amino acids, which are further broken down to NH_4^+. In the presence of O_2, NH_4^+ could be oxidized to NO_2^- and NO_3^- depending on the Eh, pH, and temperature of the system. Under anaerobic conditions the breakdown process stops at ammonia, which will accumulate under flooded conditions.

20. Ammonification of proteins is accomplished by anaerobic bacteria in flooded soils (Ponnamperuma 1972). The rate is temperature dependent, with high temperatures giving rapid production of ammonia. He also reports that nearly all mineralizable nitrogen in a soil is converted to ammonia within 2 weeks of submergence if the temperature is favorable and if the soil is not strongly acid or deficient in phosphorus. Decomposition of amino acids in anaerobic soil leads to the release of 80 percent of the N present in the amino acids as ammonia within 10 days (Greenwood and Lees 1960).

21. Denitrification is the biochemical reduction of NO_3^- and NO_2^- to N_2O and N_2 gas. In the soil, denitrification results in a loss of nitrogen to the atmosphere. Denitrification occurs only at low oxygen concentrations and is accomplished by bacteria and fungi that function as facultative anaerobes (Skerman and MacRae 1957, Turner and Patrick 1968, Buckman and Brady 1969, Painter 1971, Ponnamperuma 1972, Russell 1973). (These organisms require H^+ to reduce NO_3^- and carbon and ammonia to produce new cells.) Because these raw materials are derived from organic matter, nitrogen loss may be more severe in soils high in decomposable organic matter (Patrick and Wyatt 1964, Ponnamperuma 1972). The presence of organic matter may not always result in greater denitrification. Reddy and Patrick (1975), for example, found that the addition of rice straw immobilized ammonium (NH_4^+), thereby limiting the total N loss.

22. Alternate wetting and drying of the soil has been shown to increase nitrogen losses (Patrick and Wyatt 1964, Reddy and Patrick 1975). This resulted from the creation of an aerobic surface layer during the drying cycle in which NH_4^+ may be biologically oxidized to NO_3^-. This nitrate then diffuses into the anaerobic subsurface soil where denitrification occurs (Patrick and Gotoh 1974).

23. Nitrogen also enters the soil from the atmosphere through the process of nitrogen fixation. Through this process atmospheric N_2 is converted to ammonia. Nitrogen fixation occurs largely through the activities of the blue-green algae and various bacteria. If a flooded soil contains large populations of these organisms, nitrogen fixation can be enhanced.

24. A pronounced increase in the concentration of water-soluble phosphorus (P) is observed when a soil is flooded (Ponnamperuma 1972). In acid soils ($pH < 6.6$) this increase is attributed to the hydrolysis of Fe^{+3} and Al^{+3} phosphates, the release of P from anion exchange sites on clay and hydrous oxides of Fe^{+3} and Al^{+3}, and the reduction of Fe^{+3} to Fe^{+2} with the concomitant release of both bonded and adsorbed P. In alkaline ($pH > 7.3$) soils flooding decreases the pH, thereby increasing the solubility of hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) (Ponnamperuma 1972).

25. Manganic (Mn^{+4}) oxides are converted to manganous (Mn^{+2}) oxides in reducing soils. This is both a biological and chemical process and results in increased concentrations of soluble manganese. Within 3 weeks of flooding, most of the manganese is in the reduced Mn^{+2} form (Ponnamperuma 1972).

26. The reduced iron and manganese formed in flooded soils compete for cation exchange sites on clay minerals. On soils with low cation exchange capacity, Fe^{+2} and Mn^{+2} may displace exchangeable potassium (K^+), resulting in higher K^+ concentrations in the soil solution (IRRI 1963, Jones 1975). Potassium and other basic cations may be displaced in this manner and may be carried away by water movement in the soil. This results in nutrient depletion and acidification of the soil. Brinkman (1977) has described this process in his ferrolysis model of soil formation under a regime of seasonal inundation.

27. According to Ponnamperuma (1972), concentrations of silica in the soil increase slightly after flooding, then gradually decrease to levels lower than before flooding. This phenomenon is thought to be due to the reduction of $Fe^{+3}OH$ sorbing silica and the action of carbon dioxide on aluminum silicates.

28. Ponnamperuma (1972) speculates that the reduction of $Fe(OH)_3$ and $Mn(OH)_4$ should increase the solubility of Co, Cu, and Zn. The increase of pH in acid soils and formation of sulfides should decrease the solubility of these elements. The net result is an increase in the availability of Co, Cu, and Mo, and a decrease in the availability of Zn (Mitchell 1964, Adams and Honeyset 1964, Jenne 1968, IRRI 1970).

29. In summary, flooding of a soil rapidly establishes reducing conditions characterized by an absence of dissolved O_2, reduced forms of cations, elevated concentrations of CO_2, and shifts in Eh and pH that affect both the absolute amounts and availability of nutrients. Additionally, organic acids and gases are produced by soil anaerobes. These changes create a stress environment around the roots that provokes a range of responses in plants inhabiting flooded soils. These responses are addressed in the following section.

Plant Responses to Flooding

30. The consideration of plant responses to flooding is confusing because the responses are numerous and simultaneous. Some are direct, i.e., resulting from external factors arising in the soil and water, while others are indirect, arising from changes in the plant responding to the direct factors. Direct and indirect factors are not usually independent and thus frustrate attempts to identify causal mechanisms. Further, it is often difficult to distinguish an injury from an adaptation. For example, McPherson (1939) reports the death and collapse of root cells in corn (Zea mays) grown in unaerated culture. This apparent injury may have some adaptive value, however, because (a) it decreases the amount of tissue that must be maintained at low oxygen concentrations and (b) the resulting air spaces may enhance the

rate of oxygen diffusion from the shoot to the root (Cannon 1932, Glasstone 1942, Kramer 1951). Lastly, there is surprisingly little verification of injuries caused by specific flood-induced conditions. Much of the early literature must be regarded as anecdotal because experimental design left room for confounding factors. Recent research often fails to consider enough factors simultaneously to arrive at a complete picture of the nature of flood injuries.

31. The discussion thus far has focused on changes in the soil system induced by flooding. The biological and chemical characteristics of flooded soils have a profound influence on higher plants. Table 1 summarizes the conspicuous plant responses to flooding.

32. The historical development of the understanding of flood-induced injury to plants began in the early 1900's with work by a number of European investigators. (No attempt is made to document the complete history of research in this area. The interested reader is directed to Kramer (1951) and Bergman (1959).) Early writers stressed the importance of good soil aeration and attributed injury to low O_2 concentrations in saturated soils. While much of their inductive explanation of observed symptoms has been verified by subsequent research, they were ignorant of mechanisms involving hormones and metabolism. Accordingly, their hypotheses are optimistically simple. More refined hypotheses had to await theoretical and methodological advances in the fields of biochemistry and plant physiology. Indeed, the testing of specific hypotheses on the nature of flood injury is a relatively recent development.

33. A cautionary note is well taken at this point. Research into flood injury and tolerance has been replete with idealistic hypotheses. However, many hypotheses have been substantiated and this has led to a rich diversification of research efforts, sometimes at the expense of integration of ideas. Kramer (1951) recognized the complex nature of flood injury. It is believed that both injury and tolerance are affected by many direct and indirect factors that interact to yield a particular set of plant characteristics. With this caution in mind, the following analysis is presented.

Table 1

Plant Responses to Flooding

Response	Citation
Leaf wilting	Bergman 1920, Heinicke 1932, Marth and Gardener 1939, Curtis 1949, Parker 1949, Shanks and Laurie 1949, Kramer and Jackson 1954, McAlpine 1961, Dickson et al. 1965, Hook 1970
Leaf chlorosis	Heinicke 1932, Marth and Gardener 1939, Shanks and Laurie 1949, Kramer 1951, Bergman 1959, McAlpine 1961, Yelenosky 1964, Wample and Reid 1975
Decreased leaf size	Heinicke 1932, Lindsey et al. 1961
Increased leaf size	Bergman 1920
Leaf thickening	Hook 1968, Hook et al. 1971b
Epinasty of leaf and petiole	Kramer 1951, Jackson 1955, Railton and Reid 1973, Kawase 1974, Wample and Reid 1975
Leaf chlorophyll breakdown	Kawase 1974
Leaf abscission	Parker 1949, Yelenosky 1964, Hook 1968, Hook et al. 1971b
Anthocyanin in leaves	Parker 1949, Hook 1968, 1970
Petiole reorientation	Kramer, 1951
Decreased shoot growth	Bergman 1920, Marth and Gardener 1939, Seeley 1949, McDermott 1954, Hosner 1960, Hook 1968, Kennedy 1970, Harms 1973, Loucks and Keen 1973, Wample and Reid 1975
Stem hypertrophy	Kramer 1951, Hook 1968, Kawase 1974
Decreased internode length	McDermott 1954
Hypertrophied lenticels	Hahn et al. 1920, Zimmerman 1930, Hook 1968

(Continued)

(Sheet 1 of 3)

Table 1 (Continued)

Response	Citation
Spindly shoots	Heinicke 1932
Flower abscission	Oskamp and Batjer 1932
Death of original roots with and without new roots developing close to surface	Bergman 1920, Cannon and Free 1920, Oskamp and Batjer 1932, Kramer 1933, Parker 1949, Seeley 1949, Hunt 1951, Veretennikov 1959 and 1964, Hosner and Boyce 1962, Hook 1968, Hook et al. 1971b
Decreased root growth	Bergman 1920, Cannon and Free 1920, Heinicke 1932, Marth and Gardener 1939, Curtis 1949, Schramm 1950, Williamson 1968
Adventitious rooting	Zimmerman 1930, Kramer 1951, Hall and Smith 1955, Veretennikov 1959, Hosner and Boyce 1962, Yelenosky 1964, Hook 1968, Reid and Crozier 1971, Hook et al. 1971b, Kawase 1974
Production of a larger root system	Bergman 1920
Increased length of lateral roots	Schramm 1950
Decreased number of root hairs	Snow 1904, Weaver and Himmell 1930
Discoloration of roots	Heinicke 1932, Curtis 1949, Schramm 1950
Increased root diameter	Cochran 1972
Decreased nutrient uptake	Yelenosky 1964
Decreased water uptake	Marth and Gardener 1939, Kramer 1951, Williamson and Splinter 1968
Development of aerenchyma	Bryant 1934, Schramm 1950
Poor fruit set	Heinicke 1932
Corky fruit	Heinicke, et al. 1940

(Continued)

(Sheet 2 of 3)

Table 1 (Concluded)

Response	Citation
Fruit abscission	Haas 1936
Decreased transpiration	Livingston and Free 1917, Bergman 1920, Heinicke 1932, Childs 1941, Childers and White 1942, Caughey 1945, Loustalot 1945, Parker 1949, Kramer 1951
Excretion of organic compounds by roots	Grineva 1962

(Sheet 3 of 3)

Direct sources of injury

34. *Low O_2 concentration.* Anaerobic conditions, or anoxia, result from the depletion of available O_2 in the soil through aerobic respiration coupled with a reduction in gaseous diffusion rates.

35. The adverse effects of poor soil aeration on plants have long been hypothesized and demonstrated to varying degrees (Livingston and Free 1917, Bergman 1920, Cannon and Free 1920, Cannon 1925, Beardsley and Cannon 1930, Zimmerman 1930, Heinicke 1932, Haas 1936, Marth and Gardener 1939, Loustalot 1945). Virtually all of the visible symptoms associated with flooding have been ascribed to poor aeration. Soil anaerobiosis is probably the most basic cause of observed flooding injury, although secondary plant responses mediate some symptoms. Bergman (1959) attributed the death of the root system in oxygen-deficient soil to inhibition of respiration, which reduces energy available for maintenance and growth. Kramer (1951) presented a scenario that is a comprehensive model of flood injury. According to Kramer, flooding causes a reduction in water uptake by the root system followed by wilting of shoots and leaves, chlorosis and death of the lowest leaves, epinasty of middle leaves, and adventitious rooting. The rapid production of adventitious roots decreases the degree of injury and facilitates postflooding recovery in some plants. Kramer's model is based on research with tomato, but his observations are consistent with findings for many woody and herbaceous species. Yelenosky (1964), for example, used several tree species and observed decreased transpiration rates, increased leaf water deficits (where leaf water loss exceeds supply), and adventitious rooting. DeWit (1969) found that deoxygenated culture results in decreased polysaccharide contents in barley roots and speculated that the formation of cell walls is inhibited at low oxygen concentrations. This model is useful, too, in that it supports the metabolic and anatomical adaptations that have been demonstrated more recently. Kramer (1951) suggested that accumulation of auxin and the cessation of downward translocation of carbohydrates result in stem hypertrophy and adventitious rooting. Actual mechanisms of response will be discussed later.

36. It should be borne in mind that different plants will

manifest different responses to low oxygen concentrations around the roots. Schramm (1950), for example, found that oats and barley grown in nonaerated solution culture developed longer roots than either the control or the forced aeration treatments. In contrast, tomato and corn had the shortest root systems in the nonaerated culture. Woody species, too, show differing responses to root anoxia. In a comparison of tulip tree (*Liriodendron tulipifera*), sugar maple (*Acer saccharum*), white oak (*Quercus alba*), honey-locust (*Gleditsia triacanthos*), and American elm (*Ulmus americana*), only American elm developed adventitious roots (Yelenosky 1964).

37. *Accumulation of CO_2.* Next to lowered O_2 concentrations, the accumulation of toxic levels of CO_2 around the roots is the most observed and best documented adverse effect of soil saturation. Much of the work has involved varying proportions of CO_2 and O_2 in an effort to determine compensating effects. Knight (1924) found that CO_2 concentrations of up to 15 percent did not affect corn after the soil had been fumigated for 5 days with various concentrations of CO_2. Pure CO_2, however, caused wilting in 2 days. Cannon (1925) concluded that oranges were highly tolerant of CO_2 because some root growth was maintained even when roots were gassed with 21.8 percent CO_2, 1.3 percent O_2, and 76.9 percent N_2 or 75 percent CO_2 and 25 percent O_2. In contrast, Girton (1927) found that root elongation was suppressed with 37 to 55 percent CO_2 even with O_2 concentrations of 17 to 20 percent.

38. Childs (1941) concluded that low O_2 concentration, not CO_2 concentration, had an overriding effect in decreasing transpiration and photosynthesis in apples. Vlamis and Davis (1944) found that passing CO_2 through a nutrient solution in which rice, barley, and tomato were growing caused an immediate cessation of growth with concomitant wilting. Barley was especially susceptible as growth could be stopped with 20 to 30 percent partial pressure of CO_2 even though the remainder of the gas mixture was O_2. Stolwijk and Thiman (1947) identified oats and barley as being more tolerant of CO_2 than pea, bean, sunflower (*Helianthus annuus*), and broadbean. The tolerant plants continued root growth until CO_2 concentration exceeded 6.5 percent, while 1 percent CO_2

was sufficient to retard the latter group. Williamson (1968), too, found that broadbean was sensitive to CO_2, though not particularly sensitive to low O_2 concentration.

39. Harris and Van Bavel (1957) generalized from past research and stated that in the absence of CO_2, O_2 concentration would have to drop below 2 percent for deficiency symptoms to appear. The introduction of CO_2 was found to aggravate the effects of anoxia, but as long as O_2 concentration was greater than 10 percent, CO_2 toxicity could be avoided. They further qualify this generality by adding that the CO_2 concentration cannot be greater than the O_2 concentration. Cessation of elongation by either roots or shoots was the usual criterion for assessing injury. Harris and Van Bavel found that leaf elongation dropped sharply when CO_2 concentration exceeded O_2 concentration. It should be recognized that the authors did not control for other factors that could affect leaf elongation.

40. In addition to reducing plant growth, CO_2 in the soil atmosphere has been shown to result in larger diameter roots and a suppression of root respiration (Shanks and Laurie 1949). Caughey (1945) has shown that transpiration, too, is affected by CO_2 around the roots. Inkberry (*Ilex glabra*), waxmyrtle (*Myrica cerifera*) sweet pepperbush (*Clethra alnifolia*), and white oak (*Quercus alba*) all showed decreases in transpiration by 50 to 70 percent after 1 day of exposure to CO_2-saturated soil.

41. Nutrient uptake also is affected by abnormally high CO_2 concentration around the roots. Vlamis and Davis (1944) were able to demonstrate decreased potassium uptake in barley and tomato but not in rice when plants were grown in 0.005 M KBr solutions saturated with CO_2. In a comprehensive study by Chang and Loomis (1945) with wheat, corn, and rice, bubbling CO_2 through nutrient solutions for 10 min/hr for 36 hr decreased the accumulation of elements in the plant tissues in the order K>N>P>Ca>Mg. More recently, Grable (1966) found that concentration of CO_2 in excess of 20 percent caused chlorosis and decreased ion uptake in corn and soybean.

42. It is apparent from this brief treatment that high CO_2

concentrations, like low O_2 concentrations, affect a variety of plant functions, beginning with respiration on the most basic level, and then directly or indirectly altering nutrient uptake and growth. The actual mechanisms of the various injuries are poorly understood.

43. Production of organic acids. It will be recalled that anaerobic respiration of carbohydrate-rich organic matter results in the production of a variety of fatty and hydroxy acids (Russell 1973) by anaerobic bacteria. While many of these acids are toxic to plants, little work has been done to determine the actual toxic concentration and whether these concentrations are reached under field conditions. Nevertheless, it appears that field concentrations of some organic acids may approach 10^{-2} M for several weeks after flooding (Russell 1973), and this could be sufficient to reduce or stop root growth. Russell (1973), for example, states that butyric acid is toxic in concentrations of 10^{-4} M while acetic acid is toxic in concentrations of 10^{-2} M. Wang et al. (1967) cite the work of Boerner (1956) in which p-coumaric and p-hydroxybenzoic acid suppressed root elongation in rye and wheat, while stimulating root growth in barley. These same workers found that formic, propionic, acetic, and n-valeric acids in nutrient solution depressed top growth in sugar cane in concentrations of 5×10^{-4} N.* Iso- and normal butyric acids were more toxic, depressing growth at 1×10^{-4} N concentrations. Surprisingly, 1×10^{-4} N concentrations of lactic, malic, and succinic acids promoted top growth in sugar cane by up to 71 percent over the controls (Wang et al. 1967). It is apparent that under conditions where soils are high in organic matter, concentrations of organic acids may arise under flooded conditions that affect the growth response of plants.

44. Methane and ethylene. Along with CO_2, methane is a major end product of respiration by obligate anaerobes in the soil after the first few days of flooding (Ponnamperuma 1972, Russell 1973). Methane can continue to be produced for a long period of time by specialized

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* N, or normality, is defined as the number of gram-equivalents of solute dissolved in 1 ℓ of solution. A gram-equivalent is numerically equal to the gram-atomic weight of a compound divided by its valance.

anaerobic bacteria that reduce fatty acids, hydroxy acids, cellulose, ethanol, and CO_2 (Ponnamperuma 1972, Russell 1973). Despite early reports of growth reductions in tomato and barley resulting from methane bubbled around the roots (Vlamis and Davis 1944), recent research has demonstrated the noninjurious nature of methane (Yelenosky 1964).

45. Ethylene is another low molecular weight hydrocarbon produced by bacteria in anaerobic soils. Ethylene can persist due to its low solubility in water. Of all the organic gases produced, only ethylene has a pronounced effect on plant growth. Russell (1973) reports that root growth in tomato, tobacco, barley, and rye was decreased when ethylene in concentration of 1 ppm was supplied to the roots. Measurement of ethylene concentration in poorly drained clay in fields has shown that concentrations can reach and exceed this level for up to 2 months per year (Dowdell et al. 1972). While this may be a significant factor controlling plant growth on some soils, the major influence is probably ethylene produced by the plant under flooded conditions (Kawase 1974). This issue will be discussed in more detail later.

46. Hydrogen sulfide (H_2S). Hydrogen sulfide is produced under anaerobiosis by *Desulphovibrio* bacteria, obligate anaerobes that reduce sulfate compounds to sulfides. The result is the liberation of H_2S, which has a demonstrated toxicity in concentration of 10^{-6} M. Virtually all metabolic functions of the roots are directly or indirectly affected by H_2S, resulting in the death of the root system. Armstrong and Boatman (1967) observed that roots were rotted or stunted in moor grass (*Molinia* sp.) and sedge (*Carex rostrata*) growing in bogs where surface concentrations of H_2S reached 7.5 mg/ℓ. However, they also demonstrated that plants with an ability to oxidize their rhizosphere could form protective sheaths of $Fe_2O_3 \cdot H_2O$ around the roots. Hydrated ferric oxide could react with H_2S to precipitate insoluble FeS. Russell (1973) states that the presence of high concentrations of Fe^{+3} in neutral soils will also eliminate the problem of H_2S. Aomine (1962) demonstrated, too, that the presence of Fe^{+3} in the soil solution indicates an Eh that is too high to permit the reduction of sulfates. Thus H_2S, though

highly toxic to roots, is likely to present a serious problem only in specific cases such as soils that are high in organic matter and deficient in iron.

47. Iron. Ponnamperuma (1972) states that the most important chemical change in flooded soils is the reduction of iron and the corresponding increase in its solubility. Conceivably, Fe^{+2} could reach toxic levels in flooded soils as suggested by Misra (1938). Recent work suggests that concentrations as high as 500 ppm are not toxic to rice (De and Mandal 1957). Ponnamperuma (1965) reports a range of Fe^{+2} between 0.25 and 290 ppm for soils flooded for 50 days. Despite the potentially high concentrations of ferrous iron in flooded soils, toxicity is not generally recognized as a problem except on tropical laterites.*

48. Manganese. Manganese in the reduced manganous (Mn^{+2}) form is another metallic ion produced in submerged soil that can be toxic to plants. According to Ponnamperuma (1972), toxicity to rice does not occur in flooded soils. Jones (1972), however, reports toxicity symptoms in sedge (Carex nigra) and red fescue (Festuca rubra) at 200 ppm. He found concentrations in excess of 1000 ppm in slack sands and suggests that Mn^{+2} could be a factor influencing species distribution.

49. Summary. Flooded soils are characterized by an absence of free oxygen, that is, demonstrate reduced conditions. Plant growth and survival are directly affected by anaerobic conditions and the chemical by-products of anaerobic respiration by soil bacteria. Toxicity has been demonstrated for many of these by-products under specific conditions. Generally, however, low oxygen is the primary limiting factor in flooded soils, and toxic accumulations of ions and organic acids and gases exert a secondary effect. The separation of simultaneous, synergistic effects is extremely difficult.

Adaptive responses to flooding

50. Nature of adaptation. Plants respond directly to the low

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* Personal communication, 3 May 1978, Duane S. Mikkelson, Professor, Dept. of Agronomy and Range Science, University of California, Davis.

oxygen concentrations found in saturated soils and to the reduced compounds arising from anaerobiosis. These responses are most appropriately regarded as injuries, as discussed above.

51. Indirect responses include those hormonal, metabolic, anatomical, and morphological changes occurring in plants when they are flooded. Many of these changes are adaptive in that they convey flood tolerance to plants. As previously suggested, the semantic line between adaptation and injury is fine. The focus of this section is on the mechanisms and adaptive significance of flood-induced changes in plants.

52. In a strict sense, an adaptation arises in response to selective pressures that differentially favor evolutionary trends. Acclimation, on the other hand, refers to an organism's ability to respond to changes in the environment. The plasticity of phenotypic response reflects the degree of specialization a plant has undergone to exploit its environment. With regard to flooding, some plants have become specialists in their ability to tolerate or even require flooded conditions. Others, which are not particularly specialized, are able to undergo acclimation processes that enable them to tolerate flooding. This distinction generally is neglected in the literature. Much of the understanding of flood tolerance has been gained from studying plants that are not adapted to flooding but which can acclimate to flooding if so required. The ability to generalize effectively from basic research to applied situations rests on a recognition of this distinction.

53. Anatomical and morphological responses. Anatomical and morphological adaptations to flooding are the most conspicuous and have received much attention in the literature. The development of new root systems, roots with different characteristics, smaller stems, intercellular air spaces, and other phenomena commonly observed in flooded plants all have one thing in common: they facilitate the conduction of O_2 to the root system to enable the plant to avoid the consequences of anaerobic soil. Evidence supporting this hypothesis has appeared in the literature for some time. Hahn et al. (1920) observed the development of hypertrophied lenticels below the soil surface on conifers growing on wet sites. The connection between lenticels and ray tissue in the

phloem was described by Wetmore (1926) who suggested that this facilitated the aeration of storage tissue. Zimmerman (1930) demonstrated a relationship between oxygen concentration (ca. 1 ppm) and the development of lenticels on submerged willow (*Salix*) cuttings. Apparently, lenticels did not form at O_2 concentrations below 1 ppm, suggesting that the stem could take up O_2 through lenticels only when this threshold was exceeded.

54. A similar relationship between the location of roots in bog plants and aerated strata was observed by Emerson (1921). He classified four types of rooting behavior: (a) plants with root systems horizontal and parallel to the water table, (b) plants with taproots that die at the water table and then produce horizontal laterals, (c) plants with a diffuse system of vertical roots that die at the water table and proliferate into a mat of adventitious roots just above the water, and (d) plants with roots that grow under water.

55. Working with marsh plants of the genera bulrush (*Scirpus*), cattail (*Typha*), reed (*Phragmites*), and cordgrass (*Spartina*), Weaver and Himmell (1930) found that root development was again determined by water level and, assumedly, access to absorbable O_2. Poor aeration resulted in the development of fine, shallow root systems. Interestingly, only *Typha* developed aquatic roots, although the root morphology was similar to the other genera.

56. Cannon (1932) infers that under a favorable temperature and light regime, willow (*Salix*) and sunflower (*Helianthus*) can evolve O_2 photosynthetically that can be translocated from the leaves to the stem and root where it can be used for respiration. He further suggests that the partial pressure of oxygen in the stem may be sufficient to diffuse out of the roots into the substrate. Assuming that this scenario is correct, at least with regard to mechanisms of internal root aeration, then an interconnected system of air channels must be present from leaf to root. Conway (1937) found that in the herbaceous marsh plant, twig rush (*Cladium mariscus*), as much as 6 percent of the stem volume could be filled by air. Through a series of experiments she was able to determine that roots growing in unaerated mud received O_2 from the bases of

dead leaves and living, nongrowing leaves. She found that active meristems have few air spaces, which may account for the absence of an oxygen contribution from growing leaves.

57. Conway (1940) formalized the internal aeration hypothesis and cited the need for experimental verification of the role of aerenchyma, lenticels, and adventitious roots in conveying flood tolerance. McPherson (1939) provides evidence that intercellular air spaces found under anaerobic conditions are an expression of injury, namely the death of cortical cells. Conway poses two questions that lay the foundation for much of the modern investigations in the field. To paraphrase, Conway asks: (a) Do roots of aquatic plants need less oxygen for respiration, or are the oxygen demands met by supplies from the shoot? and (b) Does the aerenchyma form a continuous system and what is the oxygen concentration in the system?

58. Drawing on earlier work, Conway conservatively states that oxygen concentration around the roots must drop below 10 percent before injury becomes apparent (Cannon 1925, Zimmerman 1930). Using *Cladium mariscus*, she found an internal oxygen concentration of 15 percent which exceeds the conservatively high threshold concentration. She notes that though the volume of stem air spaces may be high, Cladium is suffrutescent (having a woody rootstock) and the volume of pore spaces in the rootstock is low. Conway suggests that root aeration in woody genera like willow (*Salix*) and alder (*Alnus*) might be accomplished via a connected system of air spaces in the woody tissue.

59. Most of the important recent research has dealt with gas balance within plants under flooded conditions in an effort to relate anatomical change and metabolism. Much of the work has dealt with nonwoody plants and many of those studies were with vegetable crops. Nevertheless, results of studies of woody plants coincide remarkably well with these studies.

60. Barber et al. (1962) drew from Bryant's (1934) observation that barley grown with its roots in anaerobic medium developed cortical air spaces and attempted to get comparative responses from barley and rice under similar growing conditions. Barley is not typically aquatic,

while rice is. The possibility that both species manifest similar adaptive responses provided an interesting opportunity for experimentation. Barber and his coworkers were unable to induce the formation of air spaces in barley, but were able to derive some important findings nonetheless. After determining the percent air space in the roots of both species, they compared observed O_2 diffusion rates with calculated rates based on the assumption of interconnected intercellular air spaces. The two corresponded quite closely.

61. Soldatenkov and Chirkova (1963) demonstrated that a range of plants over the mesophyte + hygrophyte (sic) continuum were able to supply O_2 from the leaves to roots through intercellular air spaces. Hygrophytes with their shoots in air were able to supply O_2 to their roots (in an anaerobic solution) for an indefinite period of time. Mesophytes under similar conditions were able to maintain their roots for only 7 days.

62. Coult (1964) studied buckbean (*Menyanthes trifoliata*), an aquatic and marsh macrophyte which had up to 60 percent of the rhizome occupied by air spaces. Oxygen diffusion rates across the endodermis were essentially the same as they would have been in an aqueous system while cortical diffusion was one twenty-fifth the diffusion velocity in air. Oxygen replenishment to the roots was via the stele, which is, in part, supplied by the aqueous route through the endodermis. Coult identified this aqueous diffusion as the rate-limiting factor in the process.

63. Teal and Kanwisher (1965) and Greenwood (1967, 1971) have shown that with cordgrass (*Spartina alterniflora*), lettuce (*Lactuca sativa*), and mustard (*Sinapis alba*), O_2 concentrations decrease from leaf to root and that diffusion rates support the theory that "continuous, non-tortuous passages" are present from leaf to roots. Teal and Kanwisher determined the respiratory quotient* for *Spartina* roots and concluded that the O_2 supplied to the roots varied from 0.3 to 2 times the respiratory requirements. Greenwood and Goodman (1971) further

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* Respiratory quotient = CO_2 evolved/O_2 consumed.

demonstrated that O_2 supplied to mustard roots from the shoots decreased with increasing partial pressures of O_2 in the rooting medium, again supporting the hypothesis that gaseous diffusion may account for the supply of oxygen to the roots.

64. A number of workers have found that under experimental flooding conditions plants develop adventitious roots and have demonstrated to varying degrees that the new roots are more porous than the original root system (Emerson 1921, Hook 1968, Luxmore and Stolzy 1969, Yu et al. 1969, Hook et al. 1971, Hook and Brown 1973). Some workers have found that cell walls are thinner (Bryant 1934) and less suberized (Schramm 1950, Hook et al. 1971), while others have shown that flooded plants have the ability to oxidize the medium around their roots (Jensen et al. 1964, Hook 1968, Hook et al. 1971). A caution is well taken to defer the conclusion that adventitious rooting under flooding always serves in an adaptive role. Gill (1975), though not examining root porosity per se, was unable to detect any advantage to the shoot conveyed by adventitious rooting in *Alnus glutinosa,* which is normally considered to be flood tolerant. Gill concluded that adventitious roots affect a large number of plant activities over a prolonged period of time, and how and when the phenomenon is studied determines the conclusions that can be drawn.

65. Though foreshadowed by earlier investigations (Carlson 1938, Sifton 1945, Scholander et al. 1955), the actual role of lenticels in root aeration has only recently been demonstrated. Using species of *Salix* and *Myrica gale,* Armstrong (1968) was able to demonstrate that sealing 3 cm of stem tissue above the waterline effectively stopped oxygen diffusion to the roots. In an extensive investigation of the genus *Nyssa,* Hook (1968) and Hook et al. (1971) showed that stem lenticels, and not leaves, permitted air to diffuse through the stem to the roots. The investigators were able to cause color changes in reduced indigo carmine dye around the roots by switching the shoot environment from N_2 to air. When the stems were coated with paraffin and lanolin prior to exposing the shoot to the N_2> air treatment, only a slight color change was noted. This change occurred in only one replicate and

was attributed to a leak in the stem coating. Using similar techniques, Maronek (1975) found that under anaerobic conditions both red maple (*Acer rubrum*) and sugar maple (*Acer saccharum*) developed swollen lenticels, which facilitated oxidation of the rhizosphere.

66. Hook and Brown (1972) experimented with water tupelo (*Nyssa aquatica*), green ash (*Fraxinus pennsylvanica*), tulip tree (*Liriodendron tulipifera*), cottonwood (*Populus deltoides*), sweetgum (*Liquidambar styraciflua*), and sycamore (*Platanus occidentalis*) to determine the pressure drop required to draw air from the shoot to the root. They found that water tupelo and green ash (both flood tolerant) required a smaller pressure drop than the other species. This increased permeability was linked to intercellular air spaces in cambial ray initials, which were continuous through the phloem and xylem. They speculated that cambial permeability may be an expression of evolutionary strategy. Species adapted to an environment where water is sometimes limiting have an impervious cambium to impede water loss. Species adapted to habitats where oxygen is limiting but water is abundant have cambial air spaces to facilitate gas exchange.

67. A topic deserving brief attention as a special case is the nature and role of pneumatophores, stilt roots, swollen buttresses, and knees in plants. In a recent review article on such morphological features, Jenik (1973) states that the phenomenon is centered in the tropics, where it has been observed in 18 dicot and 3 monocot families. It is always associated with waterlogged soils. He summarizes the functions as providing stability, aiding nutrient uptake, and providing avenues for aeration. Pneumatophores and stilt roots are aerial root-like organs found on mangroves growing in tidal areas of the tropics and subtropics. Both organs are composed of aerenchymatous tissue and are covered with lenticels, strongly suggesting a role in aerating subterranean portions of the root. Scholander and his coworkers (1955) performed field measurements on black mangrove (*Avicennia nitida*, which has pneumatophores) and red mangrove (*Rhizophora mangle*, which has stilt roots) and found that both species do have a direct gas connection between the subterranean and aerial portions of the root. When the

stilt roots and pneumatophores were exposed at low tide, oxygen concentration in the belowground portion of the root systems was maintained at 10 to 18 percent. When pneumatophores were removed from black mangrove, oxygen concentrations in the roots dropped to less than 1 percent within 2 days. Similarly, plugging the lenticels on red mangrove resulted in a rapid decrease in oxygen concentration in the roots.

68. In the swamps of the southeastern United States, swollen buttresses and root knees are found on baldcypress (Taxodium distichum) and water tupelo (Nyssa aquatica). Like pneumatophores and stilt roots, their modified trunks and roots have long been suspected of aiding in root aeration.

69. Penfound (1934) examined the anatomy of Nyssa aquatica and found that the density of the wood increased from knees to buttresses to normal [illegible]k, corresponding to decreasing numbers of parenchyma cells and ring widths. He found little evidence suggesting aerenchyma and therefore discounted the role of buttresses and knees in aeration, though the degree of expression of these features was correlated with depth of flooding. Kurz and Demaree (1934) hypothesized that butt swell in cypress was determined by the interaction of aeration and inundation with swelling resulting from flooding with aerated water. However, the absence of knees in deep water caused them to be skeptical about their role in internal aeration. Whitford (1956) offered the observation that cypress knees were found only in situations where roots were partially inundated and attributed the formation of knees to higher cambial activity on the tops of roots where aeration was presumably better. It would be useful to reexamine the occurrence of knees and trunk buttresses in light of Kawase's recent (1977) findings, which relate rooting of submerged cuttings to ethylene accumulation.

70. The function of cypress knees in aeration was examined by Kramer et al. (1952). They concluded that the knees were permeable and that gas movement to the roots via the knees was possible. That this does, in fact, occur was not demonstrated by Kramer. The rapid growth rate of the meristematic region of the knees was identified as the sink for the absorbed oxygen by Kramer and his coworkers.

71. In brief summary, a wide variety of plants, including domestic crop plants, aquatic macrophytes, and shrubs and trees are capable of producing anatomical and morphological modifications that enhance their ability to withstand flooding. These modifications include intercellular air spaces, aerenchyma, swollen lenticels, adventitious roots, and pneumatophores. All of these facilitate the movement of O_2 to the root system, thereby avoiding anaerobic conditions caused by flooding. The role of knees and buttressed trunks in aeration is questionable but available evidence suggests that it is negligible.

72. Metabolic responses. The ability to regulate and utilize anaerobic pathways in the roots, along with the ability to supply roots with oxygen through appropriate anatomical modifications, enable plants to tolerate flooding (Hook et al. 1971, Crawford 1966, 1972, Hook and Brown 1972, 1973). Respiration would be expected to be a good indicator of changes in the O_2 regime around the roots. Because energy for all active plant functions is derived from respiratory processes, it follows that the onset of anaerobic conditions under flooding would be expressed most basically in changes in respiration. In turn, virtually all plant functions would be influenced by these changes. As early as 1934, Bryant suggested that decreased aeration would lead to decreased respiration, thereby creating an excess of sugars that could then be incorporated into cell walls. In this way he sought to explain the occurrence of thicker cell walls of barley roots in anaerobic culture. A different conclusion from a similar observation was drawn by Van der Heide et al. (1963) who found that barley with roots in a nitrogenated culture had a soluble sugar content more than 100 percent higher and a protein content 4 to 25 percent higher than plants with aerated roots. It is suggested that cell wall formation was inhibited by low O_2 and that the unused sugars show up in the assay.

73. The process of glycolysis is identical in both aerobic and anaerobic metabolism. After glucose is broken down to pyruvic acid, however, its fate is determined by the presence or absence of oxygen. With adequate oxygen, pyruvate is respired aerobically via the Krebs cycle to CO_2 and H_2O. In the absence of oxygen, pyruvate usually is

fermented to ethyl alcohol and carbon dioxide. Alternatively, different pathways are available that convert pyruvate to several simple organic acids instead of ethanol. All anaerobic pathways involve a penalty to the organism in that significantly less energy can be obtained from the partial breakdown of glucose than from complete oxidation via the aerobic pathway. Three lines of inquiry are interwoven in contemporary literature of metabolism in flooded plants. The first deals with the identification of metabolites from anaerobiosis. The second compares relative levels of the metabolites and hypothesizes flood tolerance mechanisms based on general trends observed in plants. In the third, investigators have examined rates of metabolism and enzyme activities in an effort to identify general differences between flood-tolerant and intolerant plants.

74. Dubinina (1961) found that when oxygen-deficient conditions were imposed on the roots of pumpkin, tomato, and willow (*Salix cinerea*), the concentrations of malate, succinate, and pyruvate increased. This indicates that glycolysis and the anaerobic portion of the Krebs cycle were the major metabolic activities and that oxidation was retarded or eliminated. Further, the roots became enriched in amino acids, suggesting a postponement of protein synthesis. Because a wide range of flood tolerances were represented in his study, Dubinina concluded that the phenomena observed were general to all plants.

75. Grineva (1962) found that corn with roots in anaerobic solution culture increased the excretion of glucose and fructose, amino acids, and the organic acids of the Krebs cycle. Grineva notes that the excreted substances are either those not utilized in aerobic respiration or dependent on large energy inputs for further synthesis.

76. Boulter et al. (1963) examined the production of organic acids and ethanol in tissue slices from the rhizome of yellow iris (*Iris pseudacorus*) under various mixtures of O_2, N_2, and CO_2. Though many acids were detected, none accounted for a significant portion of the carbohydrate consumed. Ethanol accounted for only 77 percent of the carbohydrate utilized at 0 percent O_2. These workers concluded that the terminal oxidase must have a high affinity for oxygen (as do the

cytochrome oxidases) to permit such a large percentage of the carbohydrate to be respired aerobically. Armstrong and Gaynard (1976) found that 2.5 percent O_2 was sufficient to maintain unrestricted aerobic respiration, supporting the theory that the system has a high oxygen affinity. Lambers (1976) provides additional supportive evidence of high oxygen affinity of the terminal oxidase in flood-tolerant groundsel (Senecio aquaticus). Recent work by Ye et al. (1977) and Carpenter and Mitchell (1977) has correlated flood tolerance in several woody species with cyanide-resistant respiration. This indicates that an alternative oxidase to the cytochrome system may have a role in flood tolerance.

77. One of the most active workers in the field of vegetation flood tolerance has been Crawford. He studied nonflood-tolerant species in the genus Senecio, and observed that, when subjected to flooding, they showed decreased growth rates, accelerated rates of glycolysis, and accumulated potentially toxic quantities of ethanol (Crawford 1966). In a subsequent article, Crawford (1967) further demonstrated that the activity of the enzyme alcohol dehydrogenase (ADH) was increased in flood-intolerant plants. He pointed out that organic acids could be further broken down and therefore the entire organic acid component should be examined to adequately portray the dynamics of anaerobic respiration. Ethyl alcohol, on the other hand, is not further respired and increased production could be used as an indication of intolerance.

78. Pursuing the enzyme activity idea further, Crawford and McMannon (1968) applied acetaldehyde, an ADH inducer, to a range of tolerant and intolerant plants with varying stem morphologies. It was found that helophytes (flood-tolerant plants) showed less ADH induction from acetaldehyde than nonhelophytes. The fact that this correlates with performance under flooded conditions, regardless of the amount of aerenchyma, suggested that it could be used as a screening method for flood tolerance.

79. More recent work (Wignarajah and Greenway 1976, Wignarajah et al. 1976) has cast some doubt on the usefulness of ADH activity in predicting flood tolerance. ADH activity is a function of oxygen

tension within the roots, which in turn is dependent on root anatomy and morphology. In corn, high ADH activity was found in roots when the surrounding media had an O_2 content between 8 and 13 percent. Thus a flood-tolerant plant with a high proportion of aerenchyma in the stem could conceivably have an ADH level higher than an intolerant species simply because the flood-tolerant species is able to provide more O_2 to the roots. In addition, it has been shown that flood-tolerant species may have lower radial permeability rates than intolerant species (Jensen et al. 1967), which could result in less O_2 and correspondingly higher ADH levels in tolerant species.

80. Wignarajah and Greenway (1976) were able to detect a gradient in ADH activity that increased toward the root apex. This indicates that younger tissues may have intrinsically higher levels of enzyme activity, and sample material for flood-tolerance tests would have to be selected from tissues of equivalent physiological ages.

81. Lambers (1976) has found that the activity of several enzymes increased while respiration decreased in roots under anaerobic conditions. Increased activity of reduced nicotinamide-adenine dinucleotide (NADH)-oxidizing enzymes (nitrate reductase, glutamate dehydrogenase, and lactate dehydrogenase) is proposed as one possible mechanism by which adenosine triphosphate (ATP) for amino acid synthesis may be obtained anaerobically. Lambers draws on an earlier finding (Van der Heide et al. 1963, Dewit 1969) and suggests that ATP levels may also be maintained through the inhibition of cell wall synthesis. Interestingly, the finding that nitrate reductase activities increased in anaerobic roots suggests that sufficient oxygen was transported to the roots to maintain a supply of nitrate in the root zone.

82. Crawford and Tyler (1969) found that the malate to succinate ratio also provided a correlative method for distinguishing tolerant from intolerant plants. In helophytes, the ratio was larger than in nonhelophytes. Other acids provided no consistent patterns which could be used for separating plants into tolerant and intolerant groups. The accumulation of succinate has been associated with tissues damaged by exposure to carbon dioxide or nitrogen atmospheres (Hulme 1956, Bendall

et al. 1960, Wager 1961) while malate accumulation occurs in tissues not irreversibly damaged by anoxia (Henshaw et al. 1962).

83. Crawford and Tyler (1969) have also suggested that the accumulation of malic acid in flooded root systems may not represent a metabolic switch. Rather, malate may be produced to correct the charge imbalance in the cells resulting from the uptake of reduced cations (notably Mn^{+2}). This hypothesis has recently gained support from Keeley* who found that in the genus *Nyssa*, malate accumulation accompanied high rates of ethanol production. Further, the high rate of growth observed in swamp tupelo (*Nyssa sylvatica* var. *biflora*) after 1 year of flooding indicates an energy gain in excess of that attainable via anaerobic production of malate.

84. In summary, the study of plant metabolism under flooding conditions is one that promises to help clarify understanding of flood-tolerance mechanisms and provide expedient methods for screening flood-tolerant plants. It is fair to state that at the present time there is a paucity of generalizable results. The ability to control rates of respiration activity and selectively accumulate nontoxic by-products would undoubtedly be advantageous under flooding. The ability to oxidize the roots via aerenchyma and intercellular air spaces is equally important; however, metabolic studies must be considered to ensure proper interpretation of the results.

85. *The role of plant hormones in flooding responses.* The diversity of morphological responses to flooding has suggested that hormones might play a significant role in flood injury. A plant hormone may be defined as a naturally occurring organic compound that, in small concentrations, modifies physiological processes (Rappaport 1972). These reactions are involved in protein synthesis, cell wall formation, and synthesis of secondary compounds (including hormones) and are manifested in turn by the growth of the plant. Leaf abscission, stem hypertrophy, adventitious rooting, chlorosis, epinasty, decreased

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* Keeley, J. E. 1977. Malic acid accumulation in roots in response to flooding: evidence for a new hypothesis. Unpub. manuscript. Occidental College, L. A. 6 pp.

elongation, and similar morphological changes all implicate hormonal mediation in flooded plants. The synthesis of a particular hormone does not necessarily indicate a plant's ability to withstand flooding; rather, site of synthesis, site of action, and amount of a hormone will determine the nature of the plant's responses. These responses, together with a plant's respiratory and anatomical adaptations, determine the success of a flooded plant. The first suggestion that hormones may act in flood injury came from Jackson (1956). He took issue with the prevalent view that flooding injury was caused by decreased water and nutrient uptake and suggested that injury arose from the inability of the flooded root to supply the shoot with an unknown substance necessary for normal growth.

86. The most popular hormone for study in flooding response is ethylene. The symptoms of ethylene exposure were first elaborated by Crocker et al. (1913) who described a "triple response" in etiolated pea seedlings of (a) decreased rates of stem elongation, (b) increased stem diameter, and (c) stem epinasty. Michener (1938) found that ethylene increased the sensitivity of plants to auxin (indoleacetic acid or IAA) and suggested that the two hormones acted synergistically to produce the triple response.

87. Smith and Restfall (1971) postulated that ethylene in flooded field soils could be a significant factor in determining plant responses to flooding. Concentrations far in excess of the physiological threshold were subsequently found in field studies (Smith and Dowdell 1974), and it was later determined that the ethylene was of microbial origin (Smith 1975).

88. Ethylene also is produced endogenously by flooded plants, though the site of synthesis is debatable. Jackson (1956) and Jackson and Campbell (1975a,b) maintain that the stimulus for ethylene production arises in the root under anaerobiosis and is translocated to the shoot where ethylene is synthesized and its effects are observed. Kawase (1973, 1976, 1977) builds a convincing case for the synthesis of ethylene in both the stem and root. Under normal conditions, endogenous ethylene gas is dissipated to the air before active concentrations are

reached. When a stem or root is flooded, however, ethylene accumulates in the plant tissue because of its low solubility in water. Kawase (1972a, 1972b, 1974, 1976, 1977) has found that ethylene accumulates in stems of crabapple (*Malus robusta*), privet (*Ligustrum obtusifolium*), chrysanthemum (*Chrysanthemum morifolium*), sunflower (*Helianthus annuus*), tomato, radish, and willow (*Salix fragilis*) when portions of the stem are either submerged in water, centrifuged in water, or wrapped in plastic film. In all cases, ethylene accumulation was thought to result from impeded diffusion rather than accelerated production by the tissues. Ethylene also appears to be translocated to portions of the plants not subjected to treatment (Kawase 1977). Both the local accumulation of ethylene and its translocation to other parts of the plant are highly correlated with flooding responses such as leaf epinasty, chlorophyll breakdown, stem hypertrophy, and adventitious rooting (Kawase 1974). The causal link between ethylene and these responses has been almost conclusively established by the finding that plants treated with ethephon (a synthetic compound that releases ethylene) show the same responses as flooded plants (Kawase 1974).

89. Wample (1976) proposes that ethylene, and possibly certain auxins, are responsible for stem hypertrophy and adventitious rooting in flooded sunflower plants. Because these morphological responses were observed on plants growing in aerated solution culture, Wample concluded that these responses are primarily the effect of water around the root and possibly in the intercellular spaces. Epinasty, stunted growth, and chlorosis are attributed to root anoxia. Bradford and Dilley (1978, in press) obtained somewhat contradictory results in their study of tomato. They concluded that root anoxia was the primary cause of accelerated ethylene production in the shoot and did not result from the diffusion of ethylene from root to shoot. They did not detect a concentration gradient of ethylene from root to shoot and therefore discount the root-shoot diffusion hypothesis.

90. The synergistic effects of ethylene and auxin were first discussed by Michener (1938). Though this work does not deal with responses to flooding directly, it is interesting to consider in that

light. Michener concluded that ethylene did not affect the production or transport of auxin, but, in conjunction with low auxin levels, ethylene could produce stem swelling in pea, corn, and oats. The similarity of this response to stem hypertrophy induced by flooding suggested to later workers that other plant growth substances might be responsible for flooding symptoms.

91. Phillips (1964a) found that flooding the roots of sunflower (Helianthus annuus) resulted in leaf epinasty. If the shoot apex was removed, the epinastic response disappeared. Epinasty could be restored by supplying IAA to the cut shoot surface. In further experiments, endogenous IAA content in the shoots of flooded sunflowers was found to exceed the levels in control plants by a factor of 3 to 4 (Phillips 1964b). This increase was attributed to one or more of the following: (a) a cessation of IAA transport to the root, (b) inhibition of oxidation of IAA in the root, or (c) an accumulation of root-synthesized auxin. The effects attributed to accumulated auxin were suppressed stem elongation and the promotion of root initiation.

92. Phillips (1964a) also reports that gibberellic acid (GA) counteracted the IAA-induced leaf epinasty. He speculated that flooding the roots may have stopped GA production by the roots, resulting in an IAA/GA imbalance in the shoot. There is good evidence that both GA and cytokinin are synthesized in plant roots and that lack of root aeration may reduce the levels of these hormones (Jones and Phillips 1966, Burrows and Carr 1969, Reid et al. 1969, Reid and Crozier 1971). Reid and Crozier (1971) have shown that GA levels in the root and the shoot as well as in the xylem sap of tomato decrease after 1 day of root flooding. They attribute the decrease in stem elongation to decreased GA export from the roots, but conclude that other factors probably become limiting after 7 days of flooding.

93. Selman and Sandanam (1972) found that growth of tomato in nonaerated culture solutions was increased by foliar application of GA and benzyladenine (a cytokinin). Gibberellic acid increased dry weight, leaf expansion, and stem elongation while benzyladenine increased leaf thickness, stem diameter, and water content.

94. Burrows and Carr (1969) attributed the breakdown of chlorophyll in leaves of sunflower whose roots were flooded to a reduction in cytokinin export from the roots. Chlorophyll breakdown could be delayed by applying either kinetin (a cytokinin) or sap from unflooded plants to leaves from flooded plants. Railton and Reid (1973) were able to eliminate chlorosis, epinasty, and adventitious rooting in flooded tomato by spraying the leaves with the cytokinin N^6-benzyladenine.

95. It should be apparent from the foregoing discussion that flooding and/or root anoxia disrupts the hormone balance of plants. The synergistic expressions of these hormones on plant metabolism and form are only beginning to be understood, and it is difficult to generalize at this time. Thus far, however, hormone fluctuations do not seem to be good indications of flood tolerance.

96. *The evolution of toxins.* The possibility that toxic byproducts of anaerobic respiration may accumulate in flood-sensitive plants has been introduced in the section on metabolic response. Other sources of toxins are present in some species and are a significant source of injury. Evidence suggests that the evolution of toxins such as cyanide and phenolic compounds is restricted to taxa with the appropriate metabolic intermediates already present in the roots. The ubiquity of the phenomena has not been examined, but warrants study.

97. Rowe and Catlin (1971) established a correlation between the amount of cyanogenic glycoside hydrolized in flooded roots and the relative flood tolerance of peach (*Prunus persica* 'Lovell'), apricot (*Prunus armeniaca* 'Royal'), and plum (*Prunus cerasifera* 'Myrobalan 3 J'). They hypothesized that the cyanogenic glycoside and its hydrolytic enzyme are spatially separated by selectively permeable membranes under normal aerobic conditions. Anaerobiosis decreases the energy available for membrane maintenance, causing the glycoside and the enzyme to come together and cyanide to be released. Free cyanide would then cause further damage in a chain reaction and the trees would be killed.

98. Pursuing further the possibility of autotoxicity under waterlogged conditions, Catlin and his co-workers (1977) conducted a series of experiments on walnut (*Juglans hindsii*, *J. regia*, and

J. hindsii x regia 'Paradox'), and wingnut (Pterocarya steroptera). The same hypothesis of membrane deterioration in root cells was again raised; however, the toxic agents in these species were thought to be phenolic compounds. Released from the vacuole, the phenolics could denature proteins and thereby further inhibit metabolism. Phenolics could also enter the transpiration stream and be translocated to the aerial portions of the plant where further damage could occur.

PART III: SECONDARY FACTORS INVOLVED IN FLOOD TOLERANCE AND PRACTICAL APPLICATIONS

Secondary Factors

99. The factors discussed in Part II--changes in soil chemistry and the direct and indirect responses of plants to these changes--are common to all flood situations. As such, they represent the primary effects of flooding, unconfounded with other variables such as species, age of plant, water depth, turbidity, temperature, wave action, etc. These secondary factors, however, influence plant performance and may be of overriding importance under field conditions. For example, current velocity or wave force may be sufficient to erode soil from the roots and topple even a tree that would tolerate extreme flooding in the absence of water erosion. The combination of secondary factors will be peculiar to each field situation and must be evaluated on a case-by-case basis. The major secondary factors are considered below.

Species and ecotypic variation

100. Probably the most influential factor in determining survival of a plant when flooded is its phenotypic adaptation to flooding. Interspecific differences in flood tolerances are widely recognized and reported (Hall et al. 1946, Yeager 1949, Brink 1954, McDermott 1954, Hall and Smith 1955, Hosner 1958, 1959, 1960, Williston 1959, Hosner and Boyce 1962, Broadfoot 1967, Gill 1970, Pursell 1975, Bedinger 1971, Broadfoot and Williston 1973, Loucks and Keen 1973, Bell and Johnson 1974). Gill (1970) has provided an excellent compilation of species tolerance lists from a number of studies. While different geographic locations and study conditions have resulted in data that are not directly comparable, there is reasonable agreement among different authors on relative species tolerances. Thus, black willow (*Salix nigra*), bald cypress (*Taxodium distichum*), and water tupelo (*Nyssa aquatica*) are generally at the tolerant end of the continuum while loblolly pine (*Pinus taeda*), white oak (*Quercus alba*), and tulip tree (*Liriodendron tulipifera*) are generally intolerant. The lack of

selecting species suitable for reservoir plantings is simplified somewhat by the wealth of related experimental and empirical observations that exists in the literature of forestry and plant ecology.

101. Within a species, ecotypic variation may account for a wide range of flooding tolerances. Some of these may be genuine ecotypic differences with genetic bases, as demonstrated with groundsel (*Senecio vulgaris*) (Crawford 1966), black gum (*Nyssa sylvatica*), and water tupelo (*N. aquatica*) (Hook and Stubbs 1967). In other instances, a species may have become morphologically acclimated to flooding. In these cases any individual of the species may have the potential for being flood tolerant. As pointed out by Hook and Stubbs (1967), such questions are academic when it comes to selecting plant materials for a particular site. They recommend that all propagules be selected from the area where they will be used.

102. *Age of tree.* Tree age is a factor in determining survival during flooding because older, taller trees generally have their leaves above water and may be subjected to relatively less severe conditions than seedlings. Conversely, as Gill (1970) points out, large size also can be a liability because of increased oxygen demand coupled with increased resistance to oxygen diffusion through the stem. Pursell (1975) provides mortality observations consistent with this hypothesis. Despite this obstacle, older trees are generally more flood tolerant than seedlings and saplings of the same species (Broadfoot and Williston 1973). A striking example is provided by Demaree's (1932) study of bald cypress (*Taxodium distichum*), in which seedlings died after 2 weeks of complete submergence. Mature trees, in contrast, are commonly able to survive flooding above the root crown for much of the year.

103. Regarding young plantations, the findings of Kennedy and Krinard (1974) indicate that a year's growth prior to any flooding increases the chances of survival. This is in conflict with the findings of Harris et al. (1975) that trees established for 1 year were no more tolerant than trees planted 2 months prior to flooding.

104. Differential survival has been observed between cuttings and seedlings, with 1-0 outplanted seedlings faring better than current

year cuttings (Maisenhelder and McKnight 1968, Broadfoot and Williston 1973, and Kennedy and Krinard 1974).

105. Regeneration under natural conditions also is affected by flooding. Du Barry (1959) found that among the nine bottomland species tested, germination of hard-coated seeds was enhanced by submersion. Thus, prolonged flooding might be expected to cause changes in species composition through differential germination. Hall and Smith (1955) and Pursell (1975) found that even if seeds germinated after floodwaters receded, reflooding the following season virtually eliminated all reproduction. Broadfoot and Williston (1973) state, however, that seedlings of species that typically leaf out late in the season (e.g., green ash (*Fraxinus pennyslvanica*), water hickory (*Carya aquatica*), and overcup oak (*Quercus lyrata*)) will survive spring floods lasting into July.

106. Noble and Murphy (1975) found that understory vegetation recovered very rapidly after a prolonged flood in Louisiana. However, seedlings of American elm (*Ulmus americana*) apparently were eliminated and species of oak (*Quercus* spp.) suffered significant decreases in cover, according to the 43-day postflood inventory.

107. A secondary factor affecting reproduction is predation by waterfowl attracted to newly flooded forests. Minckler and Jones (1965) and Minckler and McDermott (1960) found that though pin oak acorn production was higher on flooded sites, the seedling population was much smaller than on nonflooded sites. They attributed this to increased waterfowl consumption. As would be the case with differential species survival, preferential predation would be expected to have a long-term effect on species composition in a flooded forest.

Condition of floodwater

108. Aeration of floodwater is another important factor in determining performance under flooding. Hook et al. (1971b) and Harms (1973) have shown experimentally that growth is inhibited more under stagnant conditions than with circulating water and that stagnant water has both lower oxygen concentrations and higher carbon dioxide concentrations than moving water. Broadfoot (1967) observed that O_2 in a shallow impoundment was depleted during dry periods but was replenished by rain. He

attributes good growth to this reoxygenation and suggests that different results might have been obtained in the absence of rain. Similarly, Conner and Day (1976) found that flowing water resulted in higher productivity in swamp forests in Louisiana. Kennedy and Krinard (1974) report that water trapped around trees after floodwaters have receded was not only low in oxygen but was also warm. Demaree (1932), Brink (1954), and Broadfoot and Williston (1973) have reported similar findings. Demaree found that warm water hastened death in seedlings of bald cypress (*Taxodium distichum*), which is typically flood tolerant.

Soil factors

109. The biological and chemical changes occurring in flooded soils have been discussed at length in Part II. It is apparent that soil texture, organic matter content, bulk density, and other variables will influence survival of plants under flooded conditions. With the large variety of soils found in reservoirs and other water management projects around the country, the magnitude and direction of soil effects would have to be evaluated for each site individually.

110. Armstrong and Boatman (1967) have conducted research correlating soil factors with the occurrence of certain British bog plants. Of more immediate relevance, however, is the work of Harms (1973). Using two different swamp soils, he was able to document that soil type had a significant effect on total height, height growth, growth rate, and dry weight of flooded water tupelo. He speculates that the effect is largely nutritional.

111. The role of mycorrhizae (symbiotic associations between fungi and plant roots) in nutrient uptake has gained recent popularity in forestry and agricultural research. While it is reasonable to expect that flooding would influence the formation of mycorrhizae and thus affect tree growth, there is an apparent shortage of published research on this subject. Filer (1975) reports that flooding reduced existing endomycorrhizae and prevented the formation of new ones on sweetgum (*Liquidambar styraciflua*) and green ash (*Fraxinus pennsylvanica*). Ectomycorrhizae were similarly affected on Nuttall's oak (*Quercus nuttallii*), willow oak (*Quercus phellos*), and overcup oak (*Quercus*

lyrata). In both ectomycorrhizae and endomycorrhizae, however, full recovery was observed by the end of the growing season. The long-term influence of changes in mycorrhizal populations resulting from flooding remains to be examined.

Mechanical factors

112. Closely related to soil type and water movement are mechanical factors such as wave action, erosion of soil from around the roots, and silt deposition. Steep banks are known to erode to more gradual grades and shoreline trees can be toppled in the process. Loess soils are particularly susceptible to this phenomena (Peterson 1957). Gill (1974) suggests that age structure of a willow population surrounding a British lake is inversely related to wave power. Wave action in conjunction with abrasion by floating debris can wear off bark on woody vegetation on the downwind shores of water bodies.* Seedlings and saplings would be especially susceptible to mechanical damage.

113. Siltation and tree performance have been examined by several workers (Kennedy 1970, Broadfoot and Williston 1973, Kennedy and Krinard 1974, Noble and Murphy 1975). Cottonwood (*Populus deltoides*) appears to be especially tolerant of siltation around the trunk, since it was uninjured by silt deposits up to 5 ft** deep (Kennedy and Krinard 1974).

114. Broadfoot and Williston (1973) state that cottonwood (*Populus deltoides*), bald cypress (*Taxodium distichum*), tupelo (*Nyssa* spp.), and black willow (*Salix nigra*) can withstand moderate siltation. Along the Pacific coast *Sequoia sempervirens*, the coast redwood, is frequently subjected to siltation and responds by developing another story of roots corresponding to the new soil surface (Stone and Vasey 1968).

115. Texture of the silt deposits can be important in determining injury. Clay deposits crack as they dry, providing access for air to the soil. Sand and silt, conversely, form a noncracking layer over the

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* Personal communication, March 1977, R. W. Harris, Dept. of Environmental Horticulture, Univ. of California, Davis.

** A table of factors for converting U. S. customary units of measurement to metric (SI) can be found on page 9.

soil that may effectively impede O_2 exchange (Broadfoot and Williston 1973).

Hydrologic facto :
timing, duration and depth

116. Timing. The seasonal timing of a flood is of great importance to the survival of woody vegetation. Dormant season flooding usually has no effect on woody plants (Silker 1948, Hall and Smith 1955, McAlpine 1961, Williston 1962, Broadfoot 1967, Burton 1972, Broadfoot and Williston 1973) and may even have a beneficial effect by increasing water available in the soil through the summer (Broadfoot 1967, Burton 1972). Even an intolerant species like the tulip tree (*Liriodendron tulipifera*) can withstand flooding when it is dormant (McAlpine 1961). Conversely, seedlings flooded after leaf flush are very susceptible to damage (McAlpine 1961, Broadfoot and Williston 1973).

117. The time at which a flood occurs during the growing season, along with the duration or period of time (or times) that an area is flooded, can have a signficant impact on the survival of developing vegetation. Huffman (1976) found that flooding was selective on the development of certain bottomland hardwood forest populations. For example, young ironwood (*Carpinus caroliniana*) grew well where flooding was frequent and persisted for 5 days or more at any one time. Conversely, water oak (*Quercus nigra*) seedlings and saplings had little tolerance for this condition. Sweetgum (*Liquidambar styraciflua*) developed best if several floods of 5 days or longer occurred during the second 30-day period of its growing season. Cherrybark oak (*Q. falcata* var. *pagodaefolia*) and blackgum (*Nyssa sylvatica*) did poorly on soils that were flooded for 5 days or more after the first 60 days of the growing season.

118. Duration. Flood duration during the growing season, along with depth, can affect survival of trees. Within any given species, greater injury and lower survival with increasing periods of flooding are reported for both field conditions (Hall et al. 1946, Yeager 1949, Hall and Smith 1955, Williston 1959) and lab conditions (Hosner 1958, 1959, 1960, Hosner and Boyce 1962). Species performances under various

conditions are summarized by region in Appendices A-G. Some generalizations are possible, however. Regarding reservoir shorelines, colonization of shorelines by woody plants appears to be unlikely if flood duration exceeds 40 percent of the growing season. Many natural swamp systems are flooded for 40 percent of the total year, however (Bedinger 1971), and examples of plants surviving inundation for several years are provided by Yeager (1949) and Harris et al. (1975). Although these are isolated cases, the evidence strongly suggests that some woody species could thrive if planted in drawdown zones; these include buttonbush (*Cephalanthus occidentalis*), selected species of willow (*Salix*), oak (*Quercus*), *Eucalyptus*, ash (*Fraxinus*), tupelo (*Nyssa*), and cypress (*Taxodium*).

119. *Depth.* The depth of flooding during the growing season can influence the degree of injury to, or survival of, woody plants. Effective depth on a trunk is a function of tree size as well as water depth. The lower solubility of gases in water, high turbidity, and decreased light intensity are likely to have a detrimental effect on terrestrial vegetation in general if it is inundated completely. Broadfoot and Williston (1973) report that shoot death is common in seedlings of most species if flooding occurs after leaf flush. Under greenhouse conditions, Hosner (1960) demonstrated that seedlings of sycamore (*Platanus occidentalis*), red maple (*Acer rubrum*), Shumard oak (*Quercus shumardii*), sweetgum (*Liquidambar styraciflua*), hackberry (*Celtis occidentalis*), and Spanish oak (*Quercus falcata* var. *pagodaefolia*) all died after 20 days of complete submersion. Seedlings of these same species showed either complete or significantly higher survival when subjected to flooding just to the root collar (Hosner and Boyce 1962). Hall and Smith (1955) found that survival of buttonbush (*Cephalanthus occidentalis*) and black willow (*Salix nigra*) under flood conditions was dependent on whether or not the plants were emergent or completely covered.

120. Leaf abscission is a commonly observed nonlethal injury often associated with flooding of the crown during the growing season (Kennedy and Krinard 1974, Harris et al. 1975). Under stable pool conditions, trunk weakening of young trees below the waterline and

increased trunk diameter above the waterline have also been observed in flooding experiments in California (Harris et al. 1975). This is followed by a bending of the trunk at the water level after the water is drained. Fluctuating water levels probably avoid this problem, as plants tested in field trials subject to seasonal water fluctuation at Folsom Lake, California, showed neither increased stem diameter nor bending at the waterline.

Aquatic Vegetation

121. The establishment and/or control of floating and emergent aquatic vegetation warrants mention even though it is not the primary objective of this work. (The interested reader is directed to Boyd 1971, Lantz 1974, and Wentz et al. 1974, for detailed treatments of aquatic macrophytes.) Infestation of new reservoirs by aquatic vegetation is usually ensured by the fact that endemic species are capable of rapid dispersal into and colonization of new impoundments (Boyd 1971). Once established, these plants may become weeds that interfere with boat traffic and shoreline access and can spread downstream through reservoir releases.

122. The major factors affecting the establishment of aquatic vegetation are water depth, current fluctuation, wave action, temperature, transparency, substrate, and water chemistry (Boyd 1971, Lantz 1974). Lantz concludes that impoundments with suitable characteristics will support aquatic plants despite chemical and water management techniques designed to control vegetation. Management of water level fluctuation to encourage desirable plants is the most effective approach to controlling aquatic plants. Conversely, establishment of aquatic vegetation is encouraged by water management schedules that correspond to the natural life cycles of the plants (Stanley and Hoffman 1974). In conjunction with managing water fluctuation, the introduction of plants that are both competitive with weed species and innocuous to human activities can be a useful approach to aquatic vegetation control (Lantz 1974).

Impact Assessment

123. In predicting the impact of flooding on vegetation, it is difficult to rank factors according to the degree of influence they will exert on survival. Over periods of one growing season or less, species and plant size are probably the most important factors. A mature green ash (*Fraxinus pennsylvanica*), for example, will probably be able to recover from any flood-induced stresses whereas a seedling of the same species or a mature specimen of an intolerant species may succumb. Yeager (1949) has illustrated particularly well, however, that extremes of depth and duration neutralize the advantages of phenotype and age. For example, only 4.2 percent of 661 trees (24 species) sampled above gross pool level died within 4 years of filling the reservoir. In contrast, 45.7 percent of 140 trees (same 24 species) in the mud zone and 93.5 percent of the 569 trees (same 24 species) in the water zone died in the same period. Even species able to tolerate flooding to a considerable depth for a short period died when subjected to saturated soil for 4 years. Water depth, too, seems to matter little if flooding is prolonged. When tree mortality was examined according to five consecutive 10-in. depth increments, Yeager found that in the 1- to 10-in. category, 90.2 percent of 205 trees (16 species) were killed by 4 years of continuous flooding. In the 31- to 40-in. category, 95.1 percent of 41 trees (same 16 species) were dead. Only especially tolerant species like swamp privet (*Forestiera acuminata*) and black willow (*Salix nigra*) were able to withstand the combined effects of prolonged, deep flooding. Yeager also demonstrated that for a wide range of species, 4 years of flooding at different depths was universally lethal in all diameter classes.

124. There are few models available for direct use in assessing the impacts of floods on woody vegetation. It is possible, however, to use empirical studies that document changes in permanently flooded forest communities to provide estimates of mortality and growth over time. Studies by Green (1947), Yeager (1949), Hall and Smith (1955), and Broadfoot (1958) were used to help predict tree mortality resulting

from flood surcharge in the Schell-Osage Wildlife Area (U. S. Army Engineer District, Kansas City 1973). It is difficult to place confidence limits around such predictions because the assumptions made in adapting data gathered on one location to another may not be valid. It should be stressed, however, that the approach is reasonable and may provide quite useful information.

125. Once out of the geographic range of species whose flooding performance has been observed under field conditions, it becomes more difficult to predict the impacts of flooding. Thus, perhaps only three of the Corps' Divisions--the Lower Mississippi Valley, the Ohio River, and the South Atlantic--have sufficient empirical data to permit a formalized, quantitative prediction of the impacts on vegetation. Even in these Divisions, precise predictions are confined to mature trees while predictions of seedling and understory survival must remain on a coarse scale. The importance of further empirical studies to the art of impact prediction cannot be overemphasized, especially in those Divisions lacking detailed field studies.

126. Several examples of approaches to impact assessment are available. Probably the most adequate to date is that prepared by Bell and Johnson (1975) in conjunction with the Springer-Sangamon Environmental Research Program. It is judged most adequate, not because the conceptual model is superior to similar models, but because it incorporates extensive empirical data on species tolerance and occurrence in the immediate locale. These data facilitated the formulation of reasonable assumptions for species performance which, when coupled with stage-frequency data for the proposed project, were used to predict mortality. (It is not known if the project was approved and, if so, how closely predicted loss corresponded to reality.) Lacking local data on species, the next best approach would be to use data collected elsewhere to formulate the model assumptions. Such an approach has been used by the Missouri River Division of the Corps as described above. A good integration of both on site surveys and extrapolation of secondary data is provided by the Wilmington District (1975) to document the effects of the B. Everett Jordan Dam. Because this is an after-the-fact study,

this approach cannot be directly applied to unconstructed projects.

127. Buma and Day (1975) describe a method for monitoring environmental impact downstream from Deer Creek Reservoir southwest of Toronto in Ontario, Canada. The method employs a fairly sophisticated technique to identify and map vegetation cover types using permanent quadrats. The goal of the authors is to document long-term changes in the floodplain vegetation presumably resulting from flood control. Such approaches are useful for calibrating predictive models, but are not in themselves predictive.

Establishment and Maintenance of Vegetation Along Reservoir Shorelines

Introduction

128. Both the design of a clearing schedule to preserve existing vegetation along shorelines of a new reservoir and the revegetation of shorelines of old reservoirs require a detailed knowledge of the substrate, slope and exposure of the shore, water management regime, and plant species available for use. It should be recognized that complete survival will not be achieved since few species are adapted to the drastic stress imposed by wide seasonal or daily water fluctuations. In light of this uncertainty and the cost of revegetating a reservoir, it may be desirable to focus efforts in areas where there is the greatest chance of success or in areas accorded high priority for fish and wildlife habitat or public access. Despite this word of caution, the establishment of vegetation for aesthetics, habitat improvement, timber production, and shoreline stabilization is feasible. Even with the uneven regional coverage summarized in the preceding section, there appear to be plants in most areas of the country suited to virtually any purpose required by a reservoir project.

Approaches to selective cutting prior to new reservoir construction

129. The practice of minimizing the amount of vegetation removed prior to constructing new reservoirs has long been attractive.

Unfortunately, early experiences with tree mortality have led to the routine removal of all woody vegetation below gross pool and often to a surcharge elevation. (Such practices have been standard on Federally licensed power projects, for example.) As documented by Hall et al. (1946) and Silker (1948), especially, it is readily apparent that many tree species are tolerant enough to remain in the upper reaches of littoral and surcharge zones. Certainly in the Mississippi Valley and southeastern U. S. there are a number of species that can be left in the upper reservoir elevations. Whether there would be sufficient cover to meet management goals would depend on the floristic composition of the specific site. At elevations far below gross pool, the chance that any species will survive more than one growing season is greatly diminished. Probably the optimal plan would set a contour below which all trees would be removed. An inventory of tree species and a vegetation map of the area below gross pool, in conjunction with the proposed management regime for the reservoir, would be aids in establishing this contour.

130. Once a reservoir is in operation, periodic pruning and sanitation cuts may be necessary in public use areas. Elsewhere, leaving the inevitable snags can be an asset to waterfowl. It is only realistic to anticipate inadequate regeneration of trees and the eventual decline of woody vegetation subjected to standing water. Thus, artificial revegetation may become necessary even in reservoirs where selective cutting preceded construction.

131. DeBell (1971) conducted a study of stump sprouting of swamp tupelo (*Nyssa sylvatica* var. *biflora*). He found that high stumps (25 in. or more) sprouted vigorously while low stumps did not. This suggests the possibility of leaving high stumps of this species in deep water areas in hopes of establishing fish habitat.

Goals and methods of artificial revegetation

132. There is no conceptual difference between the methods of planting in drawdown zones and practices employed by horticulturists, foresters, wildlife managers, and farmers. Indeed, the methods of propagation and establishment are common to all of these. However,

instead of being faced with a simple goal (pulp production, for example) and a small variety of pedigreed seed or planting stock available commercially, the reservoir manager is faced with an array of non-domesticated plants to fit a variety of needs. Many of these plants are now available from a nursery and will require field collection and propagation if they are to be used. However, a large number of species (especially tree species) are available commercially as seed, bare root, and container stock.

133. The purpose of this section is not to detail specific plants for specific management goals; this is best decided by individual reservoir managers. Neither is it to describe general propagation and planting techniques. Rather, the purpose is to provide examples of revegetation techniques that have been applied to reservoirs.

134. The organizational format of the next few paragraphs treats species and technique as subsidiaries of management goals. The goal most frequently encountered is the improvement of habitat for wildlife and fish.

135. *Wildlife habitat improvement.* The preservation and improvement of wildlife habitat are common goals of reservoir revegetation efforts. Waterfowl are usually the explicit target for improvement work, though overall wildlife diversity and density are enhanced by shoreline vegetation as well.

136. Johnsgard (1956) analyzed the effects of artificially induced water fluctuations on avian populations in natural potholes in Washington state. He found that bird species tended to occupy specific stages in vegetational succession. When the stage was altered, bird species were displaced. This is perhaps self-evident, but the fact that the manipulation of water levels determines the nature of littoral vegetation, which in turn determines waterfowl populations, underscores the need to have a clear wildlife management plan in mind before establishing shoreline vegetation. When waterfowl management has been a primary aim, the common technique has involved planting forage crops during the spring and summer drawdown periods and allowing the plantings to be flooded during fall migration. Millet (*Echinochloa crusgalli* var.

frumentacea) is often prescribed for this purpose (Wilson and Landers 1973) since it is planted from seed, which makes it well suited for vegetating large areas. In the fall, the seed heads provide food for waterfowl. A major drawback is that the crop might need to be reestablished each year, although it may self-seed.

137. Other herbaceous species used by Wilson and Landers to improve waterfowl habitat were big bluestem (*Andropogon gerardii*), yellow nut grass (*Cyperus esculentus*), switchgrass (*Panicum virgatum*), reed canary grass (*Phalaris arundinacea*), pinkweed (*Polygonum pensylvanicum*), and wild rice (*Zizania aquatica*). All of these were apparently sown by hand in the moist shoreline mud as the water receded. By planting in four stages through the month of June, instead of a single planting, favorable seedbed conditions were ensured throughout the entire planting area.

138. A more intensive level of management is described by Barstow (1965). Shallow (18-in.) subimpoundments were created around two Tennessee reservoirs and were planted with a variety of commercial crops (Table 2) using conventional agricultural methods. These subimpoundments were kept dry during the spring and summer and were flooded by the second week of November to coincide with waterfowl migrations. This approach could be adapted to reservoirs with a shallow shoreline gradient where the water management schedule is synchronized with fall

Table 2

Species Planted in Tennessee Subimpoundments

(from Barstow 1965)

Grain Crops	Browse Crops
Corn	Wheat
Buckwheat	Annual rye grass
Milo	Ladino clover
German millet	
Japanese millet	
Browntop millet	

Note: Scientific names were not provided in the original source.

waterfowl migrations. Because the plants used are all annuals, reseeding would also be necessary.

139. *Fish habitat improvement.* The improvement of fish habitat is not necessarily inconsistent with waterfowl habitat improvement, but is different in several respects. First, instead of concentrating on forage, it is largely directed at providing suitable cover for young fish. Submerged shoreline vegetation has been shown to significantly increase growth and survival in bass fry during the first 3 months of life, presumably by harboring food organisms and providing cover from predators (Aggus and Elliott 1975). Because this requires that plants be flooded during the spring and summer, annual terrestrial plants generally are not suitable unless one is willing to replant annually. Either true aquatic macrophytes or flood-tolerant terrestrial perennials are required. Second, plants selected for fish cover often will not produce seed of value to waterfowl. Thus, if both fish and wildlife habitat improvement is desired, different species will have to serve in complementary roles. Finally, whereas waterfowl food can be provided by annual plants that do not need to be flood tolerant, plants providing cover for fish must be able to withstand both flooding and drought and ideally would be self perpetuating.

140. With this prelude, it is discouraging to report that little success has been achieved in attempts to improve fish habitat in reservoirs with fluctuating water levels. A major reason is that fluctuating water levels eliminate perennial aquatic vegetation beneficial to fish (Hestand and Carter 1973, Wilson and Landers 1973, Harris and Eshmeyer 1976). This is caused by the mechanical factors of wave action, the removal of embayments and suitable substrate (Harris and Eshmeyer 1976), and the physiological and reproductive requirements of aquatic plants. However, several promising species and techniques have been identified by the California Department of Fish and Game and the Sacramento District, Corps of Engineers. The California Department of Fish and Game has used willow wattling in the upper reaches of the drawdown zone. The species used is probably *Salix goodingii*, though many species would work equally well. The wattling consists of cigar-shaped bundles

of willow wands 6 to 8 ft long, which are staked and shallowly buried in rows parallel to the slope contour. (A full description of the technique may be found in Leiser et al. 1974.) The stems root and send up new shoots, which create brushy thickets in one season. Once established, *Salix goodingii* is especially flood-tolerant and individual plants have been observed to leaf out after 4 years of continuous flooding in over 50 ft of water. The planting method requires that the reservoir be drawn down and that the plants receive adequate water during the period of establishment. After the first growing season, the plants will probably be able to obtain water from deep roots during summer drawdown.

141. Buttonbush (*Cephalanthus occidentalis*), another shrub with remarkable flood tolerance, has been propagated from cuttings in the drawdown zone of Lake Oroville Pine Flat Reservoir and Millerton Lake, California, by State Fish and Game personnel and the Corps. It roots easily, survives both drought and flooding, and provides good cover for fish.

142. Perhaps the most impressive effort has been conducted by the California Department of Fish and Game using lady's thumb (*Polygonum persicaria*). This plant, when grown under these conditions, is a suffrutescent perennial that develops hollow, floating stems when flooded. It survives under 80 ft of water and has also withstood 2 years of dewatering with no maintenance in a central valley California reservoir. Initial establishment is achieved by inserting sections of stem containing at least one node several inches into the soil. Higher survival could be achieved by propagating in the greenhouse, but adequate results have been obtained using unrooted cuttings. After flooding for one growing season, each plant can be used as a center for establishing a clone. The receding water deposits the floating stems in a pile where they will die back prior to renewed sprouting from the rootstock. If a larger stand is desired, the stems are untangled and spread out around the parent plant. The stems root at the nodes, providing a much enlarged patch of lady's thumb. Lady's thumb may become

a noxious weed, however, and its introduction to new areas should be undertaken with caution.*

143. The effect of these three species (Salix, Cephalanthus, and Polygonum) on fish populations has not been analyzed quantitatively, but visual estimates indicate that fingerling densities are much higher in the vicinity of experimental plantings than in other areas of the reservoirs.

144. It is especially encouraging that these species, and other members of these genera, are widely distributed in North America. They show excellent potential as tools for improving reservoir fisheries and deserve more extensive trial elsewhere in the country.

145. Additional management goals. Management goals that are often given lip service but rarely studied include the maintenance of aesthetics and bank stabilization. The first is not a popular area of study because it is subjective and variable. Under the category of habitat improvement, it is generally assumed that any growing plants are better than none, so the treatment will naturally provide aesthetic benefits. It is obviously an area where research is needed to compare large- and small-scale projects and to balance the choices against public opinion and need. For example, is it preferable to revegetate an entire drawdown zone in an annual grass or to establish a few groves of perennial trees and shrubs in selected locations? Both approaches are possible and the optimum mix will probably be determined on a case-by-case basis.

146. The control of shoreline erosion through the use of vegetation probably will be successful only in areas where erosion is not a serious problem, or where vegetation is used in conjunction with engineering structures, such as revetments. Areas with steep gradients, unstable soil, long wind fetch, and heavy wave action are notorious for destroying vegetation, and the conventional wisdom dictates against spending money to vegetate such sites. In planning new reservoirs, a

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* Personal communication, May 1978, J. Steele, California Department of Fish and Game.

knowledge of the physical site characteristics can be used to shape the shoreline to a stable grade prior to flooding. In this instance, pre-flood plantings would undoubtedly help retain the stable gradient and reduce shoreline erosion.

147. A goal ancillary to both erosion control and fishery improvement is the reduction of turbidity. Keith (1967) describes the use of sorghum planted in the drawdown zone to achieve this end. Reflooding the shoreline vegetation results in the death and decay of the plants. The concomitant electrochemical reactions bring about the flocculation of suspended fine particles.

148. Experimental planting techniques. The planting techniques described thus far may be summarized very succinctly: hand seeding, tractor seeding, and hand dispersal of vegetative propagules. Several unique techniques have been studied by Fowler and Hammer (1976) and are especially attractive for the seeding of large, inaccessible areas. They tested barge hydroseeding, hovercraft seeding, and helicopter seeding to establish Italian ryegrass (*Lolium multiflorum*) around Tennessee Valley Authority reservoirs. The methods were successful for seeding mud flats where even hand seeding would have been difficult. Because Fowler and Hammer's study is both timely and germane, pertinent data are provided in Table 3.

Table 3

A Cost Comparison of Inundation Zone Seeding Techniques

(after Fowler and Hammer 1976)

			Per Acre Production Cost, $				
Seeding Technique	Acres/Day	Crew Size	Equipment	Labor*	Seed**	Fertilizer†	Total
Aquaseeder	90	3	0.10††	1.13	5.00	12.00	18.23
Air cushion vehicle	90	2	0.13††	0.76	5.00	--	5.89
Helicopter	1000	3	0.52‡	0.07	5.00	--	5.59

* Computed at 4.25/hr.
** Ryegrass seeded at 20 lb/acre ($0.25/lb).
† 6-12-12 applied at 200 lb/acre ($0.06/lb).
†† Fuel and maintenance only.
‡ Estimated at 6 hr actual seeding per day ($65/hr plus $130/day).

149. All three methods were used by Hammer and Fowler to establish a temporary cover of vegetation; however, with prudent selection of species and area of application, diverse, self-perpetuating plant communities could be established.

150. Wentz et al. (1974) have compiled an encyclopedic treatment of goals and methods of marsh plant establishment for the Corps of Engineers. The interested reader is directed to their work for details regarding plants adaptable to large-scale seeding operations.

Flood-Tolerant Vegetation in Corps of Engineers Divisions

Introduction

151. The following paragraphs summarize the research pertinent to flood-tolerant vegetation for each of the ten Corps of Engineers Divisions (Figure 1). Included are both applied research into reservoir revegetation and phytosociological research that deals with floodplain vegetation and similar flood-prone areas. The aim is to arrive at a list of species ranked according to their relative flood tolerance for each region. Where appropriate, the lists are extracted from a single source in an effort to preserve the original judgment of the author. In cases where studies were limited to a few species or where the data were not directly interpretable as relative tolerances, composite lists were assembled. Where composite lists are included, supportive data from the original sources are included in the appropriate appendix.

152. In comparing the tolerance lists from the various regions, differences in rank order will be noticed. This is a function of the original data, which incorporate the biases imposed by local site conditions, ecotypic variation, and study design. The inconsistencies are preserved to give a realistic approximation of the range of responses likely to be encountered. It is intended that the regional lists be used to complement each other.

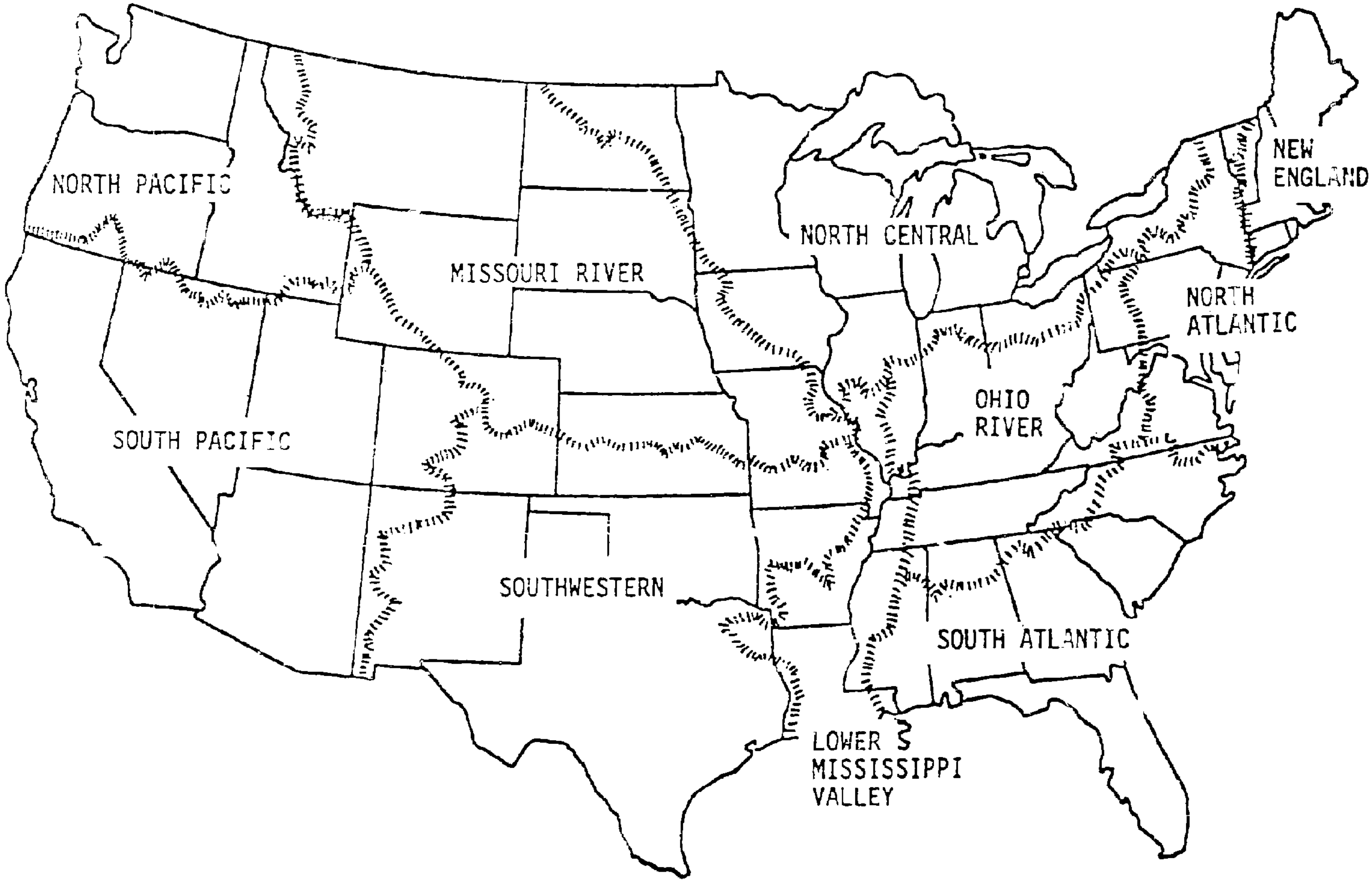

Figure 1. U. S. Army Corps of Engineers Divisions

Lower Mississippi Valley Division

153. The Lower Mississippi Valley Division is fortunate that flood tolerance has long been of interest to foresters and ecologists working with floodplain forests along the Mississippi River. Accordingly, there is extensive literature concerning flood tolerance of trees. The fact that flooding has been a factor exerting selective pressure on plants over evolutionary time has resulted in a number of flood-tolerant native species. In all, 60 species of trees and shrubs have been described in the literature with regard to their ability to endure flooding. Of these, 21 species may be regarded as tolerant or very tolerant of flooding. The relative tolerance of the 60 species is given in Table 4. Though the classification is only relative, the groups may be interpreted as follows:

- a. Very tolerant - able to survive deep, prolonged flooding for more than 1 year.
- b. Tolerant - able to survive deep flooding for one growing season, with significant mortality occurring if flooding is repeated the following year.
- c. Somewhat tolerant - able to survive flooding or saturated soils for 30 consecutive days during the growing season.
- d. Intolerant - unable to survive more than a few days of flooding during the growing season without significant mortality.

154. These ratings are based on the reported performance of mature trees and will obviously vary with changes in the local environments. For a detailed synopsis of research on each species, see Appendix A.

Missouri River Division

155. The Missouri River Division encompasses a large portion of the Great Plains and, not surprisingly, the emphasis in flood tolerance research has been on nonwoody species. However, studies by Peterson (1957), Loucks and Keen (1973), U. S. Army Engineer District, Kansas City (1973), Brunk et al. (1975), and Stanley and Hoffman (1975) have yielded valuable information on a limited number of trees and shrubs.

Table 4

Relative Flood Tolerance, 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's 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)

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* 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 4 (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 4 (Concluded)

Common Name	Scientific Name
	Intolerant††
Ironwood	*Carpinus caroliniana*
Bitternut hickory	*Carya cordiformis*
Shellbark hickory	*C. lacinosa*
Shagbark hickory	*C. ovata*
Mockernut hickory	*C. tomentosa*
Redbud	*Cercis canadensis*
Flowering dogwood	*Cornus florida*
Kentucky coffee tree	*Gymnocladus dioica*
Black walnut	*Juglans nigra*
Red mulberry	*Morus rubra*
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*

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

(Sheet 3 of 3)

Table 5 lists the species by relative flood tolerances. Summaries of research can be found in Appendix B.

156. Several studies warrant special mention as they pertain to establishment and successional dynamics. McGregor and Volle (1950) conducted a study of invading plants in the drained beds of Lake Tonganoxie and Lake Fegan in Kansas. In the first year of exposure, 99 species representing 35 families invaded the lake beds (Table 6 lists these species). Few woody species were found among the colonizers, though isolated individuals of blackjack oak (*Quercus marilandica*), buttonbush (*Cephalanthus occidentalis*), and cottonwood (*Populus deltoides*) were reported. It is impressive that a diverse assemblage of both annual and perennial herbs established itself in 1 year. The possibility of providing seasonal shoreline cover during drawdown periods is a viable option for reservoir managers wanting to mitigate the visual impact of barren shorelines. Stanley and Hoffman (1974, 1975, 1977) provide encouraging results indicating the feasibility of establishing stands of seasonal vegetation by planting seeds and vegetative propagules. Table 7 summarizes the most successful species and planting recommendations resulting from their studies. Stanley and Hoffman also studied the effects of applying a complete fertilizer to plots of natural shoreline vegetation. Fertilizer increased biomass by up to 10 percent and resulted in major changes in species composition (Stanley and Hoffman 1977). The results of their fertilizer trials are summarized in Table 8.

157. Vegetation colonizing drawdown zones may persist for several years if reservoir fluctuation is favorable (Stanley and Hoffman 1977). This corroborates earlier findings that seed from a variety of domesticated herbaceous annuals can germinate after flooding (McKenzie et al. 1949). Table 9 presents these earlier results.

158. The prospects for establishing herbaceous vegetation around reservoirs are good, especially if maintenance efforts are practiced on a yearly basis. The evidence suggests that seeding from boats may be possible in areas where substrate and wave action are favorable.

159. Studies of the dynamics of natural succession have provided

Table 5

Species Tolerance to Flooding, Missouri River Division

Common Name	Scientific Name
	Very Tolerant*
Willow	*Salix* spp.
Bald cypress	*Taxodium distichum*
	Tolerant**
Box elder	*Acer negundo*
Silver maple	*A. saccharinum*
Pecan	*Carya illinoensis*
Green ash	*Fraxinus pennsylvanica*
Sycamore	*Platanus occidentalis*
Cottonwood	*Populus deltoides*
Pin oak	*Quercus palustris*
	Somewhat Tolerant†
Hawthorn	*Crataegus* spp.
Honey locust	*Gleditsia triacanthos*
Swamp white oak	*Quercus bicolor*
Bur oak	*Q. macrocarpa*
American elm	*Ulmus americana*
	Intolerant††
Bitternut hickory	*Carya cordiformis*

(Continued)

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* 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.

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

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

Table 5 (Concluded)

Common Name	Scientific Name
Intolerant†† (Continued)	
Shellbark hickory	C. laciniosa
Hackberry	Celtis occidentalis
Black cherry	Prunus serotina
Snowberry	Symphoricarpos occidentalis

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

Table 6

Plants Colonizing Drained Lake Beds in Kansas

(After McGregor and Volle 1950)

Common Name	Scientific Name
	ACANTHACEAE
Water willow	*Justicia americana*
	AIZOACEAE
Carpetweed	*Mollugo verticillata*
	ALISMACEAE
Water plantain	*Alisma subcordatum*
Duck potato	*Sagittaria latifolia*
	AMARANTHACEAE
Water hemp	*Acnida tamariscina* (= *Amaranthus t.*)
Pigweed	*Amaranthus hybridus*
Pigweed	*Amaranthus retroflexus*
	AMBROSIACEAE
Ragweed	*Ambrosia elatior* (= *A. artemisiifolia*)
Giant ragweed	*A. trifida*
	ANACARDIACEAE
Shining sumac	*Rhus copallina*
	BRASSICACEAE
Bitter cress	*Cardamine parviflora* var. *arenicola*
Peppergrass	*Lepidium densiflorum*
Yellow cress	*Rorippa islandica* var. *hispida*
Yellow cress	*R. sessiliflora*
	CALLITRICHACEAE
Water starwort	*Callitriche heterophylla*
	CAMPANULACEAE
Pale spike lobelia	*Lobelia spicata* var. *leptostachys*
Venus's looking-glass	*Specularia leptocarpa*
Venus's looking-glass	*S. perfoliata*

(Continued)

(Sheet 1 of 5)

Table 6 (Continued)

Common Name	Scientific Name
	CARYOPHYLLACEAE
Sleepy catchfly	*Silene antirrhina*
	CHENOPODIACEAE
Lamb's quarters	*Chenopodium album*
Jerusalem oak	*C. botrys*
Winged pigweed	*Cycloloma atriplicifolia*
	COMPOSITAE
Mayweed	*Anthemis cotula*
Heath aster	*Aster ericoides*
Nodding beggarticks	*Bidens cernua*
Devils beggarticks	*B. frondosa*
Beggarticks	*B. polylepis*
Golden aster	*Chrysopsis pilosa*
Yerba-de-Tajo	*Eclipta alba*
Daisy fleabane	*Erigeron strigosus*
Purple cudweed	*Gnaphalium purpureum*
Sunflower	*Helianthus annuus*
Maximilian sunflower	*H. maximiliani*
Carolina false dandelion	*Pyrrhopappus carolinianus*
	Thelesperma trifidum
	CONVOLVULACEAE
Ivyleaf morning glory	*Ipomoea hederacea*
Morning glory	*I. lacunosa*
	CRASSULACEAE
Ditch stonecrop	*Penthorum sedoides*
	CYPERACEAE
	Bulbostylis capillaris
Spikerush	*Eleocharis obtusa*
	Cyperus acuminatus

(Continued)

(Sheet 2 of 5)

Table 6 (Continued)

Common Name	Scientific Name
	CYPERACEAE (Continued)
Yellow nut grass	*C. esculentus*
Sedge	*Cyperus inflexus*
	FABACEAE
False indigo	*Amorpha fruticosa*
Japanese clover	*Lespedeza striata*
Yellow sweetclover	*Melilotus officinalis*
Wild bean	*Strophostyles helvola*
	FAGACEAE
Blackjack oak	*Quercus marilandica*
	GERANIACEAE
Geranium	*Geranium carolinianum*
	HYPERICACEAE
St. John's wort	*Hypericum mutilum*
	JUNCACEAE
Rush	*Juncus diffusissimus*
Rush	*J. interior*
Rush	*J. marginatus*
Rush	*J. torreyi*
	LAMIACEAE
Bugleweed	*Lycopus americanus*
	LYTHRACEAE
	Ammannia coccinea
	MALVACEAE
Velvet leaf	*Abutilon theophrasti*
Flower-of-an-hour	*Hibiscus trionum*
	NAJADACEAE
Naiad	*Najas guadalupensis*

(Continued)

(Sheet 3 of 5)

Table 6 (Continued)

Common Name	Scientific Name
	ONAGRACEAE
Evening primrose	*Oenothera biennis*
Evening primrose	*Oenothera laciniata*
Sundrops	*O. linifolia*
	OXALIDACEAE
Sorrel	*Oxalis europaea* var. *bushii*
	POACEAE
Ticklegrass	*Agrostis hyemalis*
Brome grass	*Bromus japonicus*
Crab grass	*Digitaria sanguinalis*
Barnyard grass	*Echinochloa crusgalli*
Love grass	*Eragrostis poaeoides*
Junegrass	*Koeleria cristata*
Rice cutgrass	*Leersia oryzoides*
Switchgrass	*Panicum virgatum*
Foxtail	*Setaria glauca*
Corn	*Zea mays*
	PLANTAGINACEAE
Bracted plantain	*Plantago aristata*
Hoary plantain	*P. virginica*
	POLYGONACEAE
Knotweed	*Polygonum aviculare*
Pale smartweed	*P. lapathifolium*
Pennsylvania smartweed	*P. pensylvanicum*
Red sorrel	*Rumex acetosella*
Pale dock	*R. altissimus*
Curly dock	*R. crispus*
	PORTULACACEAE
Common purslane	*Portulaca oleracea*

(Continued)

(Sheet 4 of 5)

Table 6 (Concluded)

Common Name	Scientific Name
	RANUNCULACEAE
Cursed crowfoot	*Ranunculus sceleratus*
	RUBIACEAE
Buttonbush	*Cephalanthus occidentalis*
Buttonweed	*Diodia teres*
	SCROPHULARIACEAE
	Conobea multifida
Toadflax	*Linaria texana*
False pimpernel	*Lindernia anagallidea*
	Bacopa rotundifolia
	Veronica peregrina var. *xalapensis*
	SALICACEAE
Cottonwood	*Populus deltoides*
	SOLANACEAE
Ground cherry	*Physalis virginiana*
Buffalo bur	*Solanum rostratum*
	TYPHACEAE
Cattail	*Typha latifolia*

(Sheet 5 of 5)

Table 7

Species Recommended for Establishment Below the Highest Water Level with an Estimate of the Percent Chance of Success on Each Substrate

(from Stanley and Hoffman 1975)

Species	Planting Recommendation	Substrate		
		Clayey*	Loamy**	Sandy†
GRAMINOIDS				
Reed canary grass (*Phalaris arundinacea*)	Sow seed 1 in. deep, early May-late October	35	85	75
Garrison creeping foxtail (*Alopecurus arundinaceus*)	Sow seed 1 in. deep, early May-late October	25	60	50
Common reed (*Phragmites australis*)	Transplant rootstock, spring	25	60	50
Cattail (*Typha latifolia*)††	Transplant rootstock, spring	25	60	75
Bulrush (*Scirpus validus*)††	Transplant rootstock, spring	25	60	75

(Continued)

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* Clayey substrates in the Missouri River region weather from Pierre Shale, Fort Union Shale, or rarely from Coleharbor glacial till; alluvial deposits derived from these formations also contain considerable clay.

** Loamy substrates in the Missouri River region are commonly soils derived from Coleharbor glacial till or, more rarely, Fort Union formations, Missouri River alluvial deposits, or loess ledges on Missouri River bluffs in the Lake Oahe region.

† Sandy substrates in the Missouri River region may be commonly derived from the Fox Hills Sandstone and occasionally from glacial till, outwash, or alluvial deposits.

†† Closely related species may be equally well adapted.

Table 7 (Concluded)

Species	Planting Recommendation	Substrate		
		Clayey	Loamy	Sandy
GRAMINOIDS (Continued)				
Saltgrass (*Distichlis spicata*)‡	Transplant rootstock, spring	75		
Foxtail barley (*Hordeum jubatum*)‡	Sow seed 1/2 in. deep, early May-late October	50		
Western wheatgrass (*Agropyron smithii*)‡‡	Sow seed 1/2 in. deep, early May-late October	35	60	50
Quackgrass (*Agropyron repens*)‡,‡‡	Sow seed 1/2 in. deep, early May-late October	35	60	50
Kentucky bluegrass (*Poa pratensis*)‡‡	Sow seed 1/2 in. deep, early May-late October	35	60	50
TREE SPECIES				
Cottonwood (*Populus deltoides*)	Transplant seedlings, spring		75	75
Willow (*Salix amygdaloides*)††	Transplant seedlings, spring		75	75
Green ash (*Fraxinus pennsylvanica*)	Transplant seedlings, spring		75	75

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†† Closely related species may be equally well adapted.
‡ This species is not available commercially.
‡‡ This species will not survive extremely long periods of inundation.

Table 8

Response of Shoreline Weeds to Fertilization

(After Stanley and Hoffman 1977)

Common Name	Scientific Name
Strong Positive Response*	
Lambsquarters	*Chenopodium album*
Kochia	*Kochia scoparia*
Positive Response**	
Quackgrass	*Agropyron repens*
Marsh elder	*Iva xanthifolia*
Fowl meadow grass	*Poa palustris*
Knotweed	*Polygonum achoreum*
Bushy knotweed	*P. ramosissimum*
Russian thistle	*Salsola iberica*
Field pennycress	*Thlaspi arvense*
Negative Response†	
Foxtail barley	*Hordeum jubatum*
White sweet clover	*Melilotus alba*
Yellow sweet clover	*M. officinalis*
Curly dock	*Rumex crispus*

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* Species increased in percent cover on at least three of seven test plots.

** Species increased in percent cover on one or two of seven test plots.

† Species decreased in percent cover on one to five of seven test plots.

Table 9

Average Percent Seed Germination Following Flooding

(After McKenzie et al. 1949)

Common Name	Scientific Name	Control	Period of Flooding, days			
			21	42	63	84
Reed canarygrass	*Phalaris arundinacea*	75.0	96.4	87.1	90.3	91.1
Timothy	*Phleum pratense*	70.4	73.6	66.6	54.6	57.0
Smooth brome	*Bromus inermis*	85.5	70.0	50.9	52.1	25.7
Meadow fescue	*Festuca elatior*	91.9	66.6	49.1	31.7	16.9
	Agropyron trachycaulum var. *typicum*	89.1	82.6	76.9	78.4	51.7
Terrell grass	*Elymus virginicus* var. *submuticus*	77.7	48.6	57.1	47.8	38.5
Meadow foxtail	*Alopecurus pratensis*	99.9	38.8	38.6	23.6	16.4
Alsike clover	*Trifolium hybridum*	72.7	61.8	14.4	0	0
Intermediate wheatgrass	*Agropyron intermedium*	97.3	17.7	3.5	0	0
Strawberry-headed clover	*Trifolium fragiferum*	96.5	5.0	3.5	0	0
Medic	*Medicago media*	71.4	53.3	0	0	0
Red clover	*Trifolium pratense*	89.2	2.8	0	0	0
White sweet clover	*Melilotus alba*	37.0	0	0	0	0

some insight to the factors limiting species survival on flood-prone sites. The germination and seedling states are especially vulnerable to environmental perturbations. Around reservoirs and on floodplains these perturbations are most commonly viewed as being related to excess water. Wilson (1970) presents findings that suggest that drought plays a large role in determining which woody species may become established from seed. In a study of floodplain forests in South Dakota, the first stage of woody plants is dominated by willow (Salix spp.). During this stage, the surface soil is characterized as being xeric (dry). Willow stands deteriorate after 15 years and are succeeded by cottonwood (Populus deltoides). Additions of organic material to the soil and shading of the soil create a mesic habitat that favors the invasion of green ash (Fraxinus pennsylvanica), box elder (Acer negundo), and American elm (Ulmus americana). Whether one subscribes to such a strict successional scheme or not, the point is well taken that moisture at the soil surface can be crucial in the establishment of both natural and planted vegetation.

New England Division

160. There is a paucity of flooding research in the New England Division, presumably because flooding is not a conspicuous factor exerting pressure on natural vegetation. This is unfortunate because much of the New England landscape is subject to periodic inundation resulting from spring runoff, heavy rains, and poor soil conditions. Only recently has there been popular recognition of the importance and extent of wetland communities, as witnessed by the passage of protective legislation in several states. Interest in wetland and flood-tolerant vegetation will undoubtedly increase as the demand for practical management of wetlands increases.

161. In the interim, only one study (McKim et al. 1975) has immediate practical application to the matter of revegetating reservoir shorelines. However, two other studies deserve mention: the first is Tattar's very brief 1972 review entitled "Effects of Inundation on Trees", the second is Fairbairn's (1974) dissertation, "Environmental Impact Evaluation in Freshwater Impoundments by Vegetation Analysis of

the Terrestrial Ecosystem." Most of the data in the latter are expressed not by species, but by Raunkiaer Life Form classification (Raunkiaer 1934). Species tolerances cannot be extracted from Fairbairn's treatment.

162. McKim's (1975) study deals specifically with damage to natural vegetation around New England reservoirs resulting from a flood in June and July 1973. Extensive data are provided for Franklin Falls and Ball Mountain reservoirs where floodwaters crested as high as 58 ft over the root crowns of mature trees for 90 hr. The total period of inundation over all depths ranged from 8 to 15 days. The conclusions reached are that silver maple (Acer saccharinum), red oak (Quercus rubra), bigtooth aspen (Populus grandidentata), basswood (Tilia americana), and hornbeam (Carpinus caroliniana) were able to survive the flood. White pine (Pinus strobus), quaking aspen (Populus tremuloides), red spruce (Picea rubens), hemlock (Tsuga canadensis), and birch (Betula spp.) were most sensitive to flooding. Table 10 summarizes the species according to tolerance. Mortality data are elaborated in Appendix C. It is recognized that the tolerance list includes only a limited number of native species for which data exist. Information concerning other natives (or nonnatives suitable for planting) may be found in summaries for the other regions.

North Atlantic Division

163. The North Atlantic Division is sparsely represented in the literature of flood tolerance, but several worthwhile papers provide a solid foundation for assessing differential tolerances among species. Hosner and Leaf (1962) conducted laboratory experiments comparing nutrient absorption and growth of 14 native bottomland hardwood species. Current year seedlings were subjected to 60 days of flooding to the root collar between 27 July and 27 September. Apparently all seedlings survived, suggesting a fairly high tolerance in all species examined. Based on growth and nutrient absorption, the species were ranked according to their relative tolerances (see Table 11). It is interesting to note that performance is not always linked to the ability to produce adventitious roots, but seems rather more closely correlated with the ability to maintain the original root system.

Table 10

Species Tolerance to Flooding, New England Division

Common Name	Scientific Name
Very Tolerant*	
Black willow	*Salix nigra*
Tolerant**	
Red maple	*Acer rubrum*
Silver maple	*A. saccharinum*
Black alder	*Alnus glutinosa*
Slightly Tolerant†	
Red oak	*Quercus rubra*
Bigtooth aspen	*Populus grandidentata*
Basswood	*Tilia americana*
Ironwood	*Carpinus caroliniana*
American elm	*Ulmus americana*
Hop hornbeam	*Ostrya virginiana*
White ash	*Fraxinus americana*

(Continued)

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* 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.

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

Table 10 (Concluded)

Common Name	Scientific Name
Intolerant††	
Sugar maple	*Acer saccharum*
Yellow birch	*Betula alleghaniensis*
Paper birch	*B. papyrifera*
White birch	*B. populifolia*
American beech	*Fagus grandifolia*
Red spruce	*Picea rubens*
White pine	*Pinus strobus*
Quaking aspen	*Populus tremuloides*
Black cherry	*Prunus serotina*
White oak	*Quercus alba*
Chinquapin oak	*Q. muehlenbergii*
Eastern hemlock	*Tsuga canadensis*

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

Table 11

Relative Tolerance of 14 Bottomland Tree Species

(from Hosner and Leaf 1962)

Tolerance	Species		Root Growth	
	Common name	Scientific Name	Nonadventitious	Adventitious
Tolerant*	Green ash	*Fraxinus pennsylvanica*	Nearly normal	Many
	Pumpkin ash	*F. profunda*	Nearly normal	Many
	Black gum	*Nyssa sylvatica*	Normal	None
	Black willow	*Salix nigra*	Normal	Many
Intermediate**	Box elder	*Acer negundo*	Some secondaries died	Many
	Cottonwood	*Populus deltoides*	Lower secondaries died	Many
	Pin oak	*Quercus palustris*	Some secondaries died	Sparse
	Red maple	*Acer rubrum*	Dormant but alive	Many
	Silver maple	*A. saccharinum*	Dormant but alive	Many
	Sycamore	*Platanus occidentalis*	Secondaries died	Many
Intolerant†	American elm	*Ulmus americana*	Secondaries died	Many
	Hackberry	*Celtis occidentalis*	Secondaries died	Sparse
	Sweet gum	*Liquidambar styraciflua*	Secondaries died	None
	Sugarberry	*Celtis laevigata*	Secondaries died	None

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

** Intermediate: able to survive flooding or saturated soils for 30 consecutive days during the growing season.

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

164. White (1973) provides a unique qualitative assessment of the performance of 57 cultivated woody plants in New York subjected to a June 1972 flood by hurricane Agnes. Flooding was of two types: brief, flash floods along streams and deep floods lasting up to 2 weeks around lakes. White's observations are especially valuable because they pertain to species commonly available in the nursery trade which are frequently used in park landscapes. Table 12 summarizes White's observations. Intolerant species are those that were defoliated and showed poor bud set for the 1973 growing season.

165. Bruckner et al. (1973) reported on mortality around the Curwensville Reservoir on the Susquehanna River following several years of surcharge for periods up to 36 days. The study is noteworthy because of its discussion of flood mortality arising secondarily from Fusarium cankers. From a survey of canker damage, the authors concluded that all trees at elevations within 4 vertical feet above the recreation pool and up to 50 percent of the trees at elevations between 4 and 18 vertical feet above pool level will die within 5 years. This type of mortality is not usually noted in field studies of intermittently flooded sites.

166. Dane (1959) studied successional trends in artificial freshwater marshes in New York. His findings may be useful in predicting invasion patterns in shallow water around reservoir shorelines. Table 13 summarizes the major results. It should be pointed out that drawdown may be necessary for successful establishment.

North Central Division

167. Researchers in the North Central Division and adjacent Canada have produced a number of papers pertinent to flood tolerance in vegetation. Of these, seven papers, because of their emphasis and scope, will serve as the basis for discussion.

168. The work of Bell (1974) and Bell and Johnson (1974, 1975) is the most comprehensive. Through detailed, long-term studies of floodplain forest communities in Illinois, species distributions were correlated with flood frequency along the Sangamon River. Table 14 summarizes the flood tolerance of tree species in Illinois as determined by Bell and Johnson (1974). In an effort to present objective criteria

Table 12

Tolerance of Cultivated Species to Flooding During the

1972 Growing Season (from White 1973)

Common Name	Scientific Name
	Tolerant* Shade Trees
Red maple	*Acer rubrum*
Cornelian cherry	*Cornus mas*
White ash	*Fraxinus americana*
Thornless honey locust	*Gleditsia inermis* (= *G. triacanthos* var. *inermis*)
Black walnut	*Juglans nigra*
Dolgo crabapple	*Malus pumila* 'Dolgo'
White mulberry	*Morus alba*
American sycamore	*Platanus occidentalis*
Cottonwood	*Populus deltoides*
White willow	*Salix alba*
Pussy willow	*S. discolor*
European littleleaf linden	*Tilia cordata*
	Tolerant* Evergreens
Red cedar	*Juniperus virginiana*
Pfitzer juniper	*J. chinensis* var. *pfitzeriana*
	Tolerant* Shrubs
Japanese barberry	*Berberis thunbergii*
Gray-stem dogwood	*Cornus paniculata*
Regel privet	*Ligustrum obtusifolium* var. *regelianum*
Arrowwood	*Viburnum dentatum*
Sweet viburnum	*V. lentago*
American cranberry bush	*V. trilobum*

(Continued)

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* Tolerant: 4 to 10 in. of water for 10 days in June of 1972 caused no apparent damage or mortality.

(Sheet 1 of 3)

Table 12 (Continued)

Common Name	Scientific Name
Intolerant** Shade and Ornamental Trees	
Sugar maple	*Acer saccharum*
Norway maple	*A. platanoides*
Paper birch	*Betula papyrifera*
Gray birch	*B. populifolia*
Redbud	*Cercis canadensis*
Yellowwood	*Cladrastis lutea*
White flowering dogwood	*Cornus florida* *C. florida* 'Cloud 9' *C. florida* 'Cherokee Chief'
Red flowering dogwood	*C. florida* var. *rubra*
Washington hawthorn	*Crataegus phaenopyrum*
Lavalle hawthorn	*C. lavallei*
Saucer magnolia	*Magnolia soulangeana*
Apple	*Malus* sp. 'Lodi,' McIntosh,' 'Radiant,' 'Hope,' 'Bechtel,'
Flowering peach	*Prunus persica*
Black cherry	*P. serotina*
Weeping cherry	*P. subhirtella* var. *pendula*
Red oak	*Quercus rubra*
Black locust	*Robinia pseudoacacia*
European mountain ash	*Sorbus aucuparia*
Intolerant** Evergreens	
Norway spruce	*Picea abies*
Colorado spruce	*P. pungens*
Colorado blue spruce	*P. pungens* var. *glauca*
Upright yew	*Taxus cuspidata*

(Continued)

** Intolerant: 4 to 10 in. of water for 10 days in June of 1972 resulted in defoliation or death.

(Sheet 2 of 3)

Table 12 (Concluded)

Common Name	Scientific Name
Intolerant Evergreens (Continued)**	
Spreading yew	*T. cuspidata* var. *expansa*
Hick's yew	*T. media* 'Hicksii'
American arborvitae	*Thuja occidentalis*
Hemlock	*Tsuga canadensis*

** Intolerant: 4 to 10 in. of water for 10 days in June of 1972 resulted in defoliation or death.

(Sheet 3 of 3)

Table 13

Species Capabilities to Invade Freshwater Marshes in New York (After Dane 1959)

Species		Water Depth, cm
Common Name	Scientific Name	
Cattail	*Typha* spp.	66
Bur reed	*Sparganium* sp.	64
Water plantain	*Alisma* sp.	61
Cutgrass	*Leersia* sp.	46
Soft rush	*Juncus effusus*	38
Buttonbush	*Cephalanthus occidentalis*	51
Willow	*Salix* spp.	30-46
Green ash	*Fraxinus pennsylvanica* var. *lanceolata*	30-46
Silver maple	*Acer saccharinum*	<46
American elm	*Ulmus americana*	25-30
Highbush blueberry	*Vaccinium corymbosum*	5-13
Ironwood	*Carpinus caroliniana*	Moist soil
Shagbark hickory	*Carya ovata*	Moist soil
Spiraea	*Spiraea* spp.	38-76
Black alder	*Ilex verticillata*	51
Alder	*Alnus* sp.	<25

Table 14

Flood Tolerance of Illinois Tree Species (After Bell and Johnson 1974)

Common Name	Scientific Name
Tolerant Species*	
Silver maple	*Acer saccharinum*
Eastern cottonwood	*Populus deltoides*
Sycamore	*Platanus occidentalis*
Black willow	*Salix nigra*
Bur oak	*Quercus macrocarpa*
Honey locust	*Gleditsia triacanthos*
Box elder	*Acer negundo*
Red haw	*Crataegus mollis*
Swamp white oak	*Quercus bicolor*
Persimmon	*Diospyros virginiana*
Pin oak	*Quercus palustris*
Somewhat Tolerant Species**	
Red bud	*Cercis canadensis*
Black walnut	*Juglans nigra*
Shingle oak	*Quercus imbricaria*
Shagbark hickory	*Carya ovata*
Hackberry	*Celtis occidentalis*
American elm	*Ulmus americana*
Green ash	*Fraxinus pennsylvanica*

(Continued)

Note: Species are grouped within categories according to increasing tolerance to growing season inundation.

* Tolerant: most individuals survived more than 150 days of inundation.

** Somewhat tolerant: most individuals survived more than 50 days but less than 100 days of flooding.

Table 14 (Continued)

Common Name	Scientific Name
Slightly Tolerant Species†	
Red oak	*Quercus rubra*
White oak	*Quercus alba*
Mockernut hickory	*Carya tomentosa*
Intolerant Species††	
Black oak	*Quercus velutina*
Black cherry	*Prunus serotina*
Sassafras	*Sassafras albidum*

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† Slightly tolerant: some individuals killed by less than 90 days of flood and some individuals survived greater than 150 days inundation.
†† Intolerant: severe effects with less than 50 days of flooding.

for rating species tolerances that would be useful to reservoir operations, Table 15 presents species occurrence as a function of flood frequency. The species in Tables 14 and 15 are not identical, reflecting floristic differences between study areas. While factors other than flood tolerance per se are likely to play a role in determining species distribution, the correlations between species and flood frequency are valuable in assessing probable impacts around new reservoirs. It is also reasonable to use the ranking as a preliminary screening for selecting species to plant around reservoirs. Caution must be employed, however, and the results should not be employed too literally. For example, buttonbush (Cephalanthus occidentalis) is represented by only one individual at a location subject to flooding only 1 percent of the time. Based solely on these data, one might conclude that buttonbush was not particularly flood tolerant. Reports from other regions (see Appendix A) indicate that buttonbush can survive 4 years of constant flooding.

169. Table 16 is extracted from Bell and Johnson (1974, 1975) and expresses tree mortality as a function of flood duration, based on field observations. All species were not represented at all duration classes, but, when compared with the foregoing table, the data provide a good index of probable performance. It is tempting to view Table 15 as a discrete flood-tolerance classification ranging from most tolerant species at the top to least tolerant at the bottom. In actuality, tolerances are best viewed as overlapping. Any single study provides a sample that does not represent the complete tolerance range for a species. Therefore, a different study may generate a different absolute order. The order presented here is only approximate. This is underscored by data provided in Green's (1947) pioneering work in flood tolerance. Observing progressive mortality of trees and shrubs standing in 46 to 133 cm of water in a new reservoir in the upper Mississippi drainage, he compiled the list given in Table 17. Green's data suggest that many of the species covered by Bell and Johnson can survive periods of flooding up to 3 and 4 years.

170. Ahlgren and Hansen (1957) provide rare data on relative flood

Table 15

Maximum Flood Frequency Where Species Were Found (Compiled from Bell 1974 and Bell and Johnson 1975)

Maximum Tolerance, Percent Flood Frequency*	Species Common Name	 Scientific Name
	Trees	
25	Silver maple	*Acer saccharinum*
	Sycamore	*Platanus occidentalis*
20	Green ash	*Fraxinus pennsylvanica*
	Black willow	*Salix nigra*
15	White mulberry	*Morus alba*
	White ash	*Fraxinus americana*
	Honey locust	*Gleditsia triacanthos*
	Hawthorn	*Crataegus mollis*
	Hackberry	*Celtis occidentalis*
	American elm	*Ulmus americana*
10	Cottonwood	*Populus deltoides*
	Bur oak	*Quercus macrocarpa*
	Shingle oak	*Q. imbricaria*
	Black walnut	*Juglans nigra*
	Bitternut hickory	*Carya cordiformis*
	Red bud	*Cercis canadensis*
2	Box elder	*Acer negundo*
	Slippery elm	*Ulmus rubra*
	Shagbark hickory	*Carya ovata*
1	Sassafras	*Sassafras albidum*
	Black cherry	*Prunus serotina*

(Continued)

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* Percent flood frequency = number of days river stages equal or exceed a given elevation divided by the total number of river stage readings.

(Sheet 1 of 4)

Table 15 (Continued)

Maximum Tolerance, Percent Flood Frequency	Species	
	Common Name	Scientific Name
	Trees (Continued)	
0.5	Shellbark hickory	*Carya laciniosa*
	Basswood	*Tilia americana*
	White oak	*Quercus alba*
0.1	Red oak	*Q. rubra*
	Mockernut hickory	*Carya tomentosa*
	Red mulberry	*Morus rubra*
0	Smooth buckeye	*Aesculus glabra*
	Black oak	*Quercus velutina*
	Sugar maple	*Acer saccharum*
	Shrubs and Vines	
20	Bristly greenbrier	*Smilax hispida*
	Poison ivy	*Rhus radicans*
16	Virginia creeper	*Parthenocissus quinquefolia*
	River bank grape	*Vitis riparia*
10	Red stem dogwood	*Cornus stolonifera*
8	Common elder	*Sambucus canadensis*
	Coralberry	*Symphoricarpos orbiculatus*
5	Wahoo	*Euonymus atropurpureus*
	Bladdernut	*Staphylea trifolia*
	Missouri gooseberry	*Ribes missouriense*
2	Grey dogwood	*Cornus racemosa*
1	Buttonbush	*Cephalanthus occidentalis*
0.5	Wild raisin	*Viburnum prunifolium*
0	Sweet viburnum	*V. lentago*
	Hop tree	*Ptelea trifoliata*

(Continued)

(Sheet 2 of 4)

Table 15 (Continued)

Maximum Tolerance, Percent Flood Frequency	Species	
	Common Name	Scientific Name
	Herbs	
20	Nettle	*Urtica gracilis*
	Loosestrife	*Lysimachia ciliata*
	Moneywort	*L. nummularia*
	Wood nettle	*Laportea canadensis*
	Giant ragweed	*Ambrosia trifida*
	Richweed	*Pilea pumila*
	Aster	*Aster simplex*
16	Violet	*Viola papilionacea*
	Gray's sedge	*Carex grayii*
	Swamp buttercup	*Ranunculus septentrionalis*
	Kidneyleaf buttercup	*R. abortivus*
	Honewort	*Cryptotaenia canadensis*
11	Greenbrier	*Smilax ecirrhata*
	Greenbrier	*S. lasioneuron*
8	Spring beauty	*Claytonia virginica*
	Cleavers	*Galium aparine*
	Pale touch-me-not	*Impatiens pallida*
	Sanicle	*Sanicula canadensis*
	Climbing false buckwheat	*Polygonum scandens*
	Phlox	*Phlox divaricata*
	Avens	*Geum vernum*
5	Enchanter's nightshade	*Circaea latifolia*
	Dogtooth violet	*Erythronium albidum*
	Bedstraw	*Galium concinnum*
	Smartweed	*Polygonum virginianum*

(Continued)

(Sheet 3 of 4)

Table 15 (Continued)

Maximum Tolerance, Percent Flood Frequency*	Species	
	Common Name	Scientific Name
	Herbs (Continued)	
5	Trillium	*Trillium recurvatum*
	Violet	*Viola eriocarpa*
3	Dutchman's breeches	*Dicentra cucullaria*
	False spikenard	*Smilacina racemosa*
5	Lopseed	*Phryma leptostachya*
	Elm-leaved goldenrod	*Solidago ulmifolia*
	Yellow parilla	*Menispermum canadense*
	Violet	*Viola sororia*
0	May apple	*Podophyllum peltatum*
	Tick trefoil	*Desmodium glutinosum*
	Agrimony	*Agrimonia gryposepala*

(Sheet 4 of 4)

Table 16

Percent Survival and Maximum Flood Duration Where Species Survived (After Bell and Johnson 1974, 1975)

Species Common Name	Scientific Name	Total Sampled at all Durations*	Maximum Flood Duration, consecutive days	Percent Survival at Maximum Duration
Box elder	*Acer negundo*	6	170-189	100
Silver maple	*A. saccharinum*	39	↓	↓
Honey locust	*Gleditsia triacanthos*	26	↓	↓
Cottonwood	*Populus deltoides*	7	↓	↓
Bur oak	*Quercus macrocarpa*	13	↓	↓
Black willow	*Salix nigra*	1	↓	↓
American elm	*Ulmus americana*	102	↓	↓
Green ash	*Fraxinus pennsylvanica*	115	↓	↓
Shagbark hickory	*Carya ovata*	114	↓	↓
Hawthorn	*Crataegus mollis*	6	150-169	↓
Sycamore	*Platanus occidentalis*	4	150-169	↓
Hackberry	*Celtis occidentalis*	37	150-169	↓
Swamp white oak	*Quercus bicolor*	4	139-149	↓
Persimmon	*Diospyros virginiana*	4	139-149	↓
Red bud	*Cercis canadensis*	13	139-149	50
Pin oak	*Quercus palustris*	4	110-129	100
White oak	*Q. alba*	58	110-129	17
Shingle oak	*Q. imbricaria*	14	90-109	100
Black walnut	*Juglans nigra*	4	90-109	100
Mockernut hickory	*Carya tomentosa*	47	90-109	35
Red oak	*Quercus rubra*	16	70-89	100
Sassafras	*Sassafras albidum*	5	70-89	100
Black oak	*Quercus velutina*	13	30-49	67
Black cherry	*Prunus serotina*	3	30-49	0

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* The original report did not present data for each flood duration.

Table 17

Tolerance of Various Trees and Shrubs to Flooding*

(After Green 1947)

Species	Years Survived	Remarks
Salix fluviatilis Sand-bar willow	2	Mostly dead in first year
Betula nigra River birch	2	Survived well first year
Populus deltoides Cottonwood	2	Survived well first year
Acer saccharinum Silver maple	3	Mostly dead in second year
Ulmus americana American elm	3	Mostly dead in second year
Celtis occidentalis Hackberry	3	Fair growth in second year
Quercus rubra Red oak	3	Scarce in bottoms
Q. macrocarpa Bur oak	3	Mostly dead in second year
Q. bicolor Swamp white oak	3	Fair growth in second year
Q. palustris Pin oak	3	Mostly on higher ground
Alnus sp. Alder	3	Hardy to second year
Fraxinus pennsylvanica Green ash	4	Hardy to second year; fair in third year
Salix nigra Black willow	4	Hardy to third year; all died in fourth year
Ilex decidua Deciduous holly	4+**	Hardy to fourth year
Forestiera acuminata Swamp privet	4+**	Hardy to fourth year
Cephalanthus occidentalis Buttonbush	4+**	Hardy after 4 years
Cornus stolonifera Red-osier dogwood	4+**	Hardy after 7 years

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* In ascending order of flooding tolerance.

** Data inferred from original source; spaces were left blank by Green.

tolerance in conifers. Based on observations of six species flooded by 91 to 122 cm of water for 48 days in May and June, the following decreasing order of tolerance is provided: balsam fir (Abies balsamea), black spruce (Picea mariana), white spruce (Picea glauca), white pine (Pinus strobus), and red pine (Pinus resinosa). All conifer species seemed to be less tolerant than associated hardwoods.

171. Savile (1951) gives a brief treatment of invasion by herbaceous species in a grassland in Ontario that had been denuded by a flood during May through July. Those species that invaded immediately following the flood and the following summer are listed in Table 18.

Table 18

Herbaceous Species Invading After May-July Flood (After Savile 1951)

Common Name	Scientific Name
Kentucky bluegrass	Poa pratensis
Canada bluegrass	P. compressa
Creeping bentgrass	Agrostis palustris
Moneywort	Lysimachia nummularia
Silvery cinquefoil	Potentilla argentea
Mint	Mentha arvensis var. villosa
Common plantain	Plantago major
Common mullein	Verbascum thapsus
Sedge	Carex spp.
Yellow cress	Rorippa islandica var. hispida
Daisy fleabane	Erigeron annuus
Curly dock	Rumex crispus
Common ragweed	Ambrosia artemisiifolia var. elatior

172. The list in Table 18, together with the one in Table 15, provides a source of likely herbaceous species for use in establishing temporary cover in drawdown zones.

173. Harris and Marshall (1963) and Kadlec (1962) have examined

various aspects of water management in freshwater marshes. The general conclusion is that dewatering is necessary for establishment of emergent aquatic plants. In general, 30 cm (1 ft) of water appears to be the upper limit for the maintenance of healthy stands of emergent aquatics. These can withstand lengthy dry periods and would be well suited for wildlife habitat improvement around reservoirs. A composite list of the major species can be found in Table 19.

Table 19

Emergent Aquatic Plants Commonly Found in Northern Marshes (After Kadlec 1962 and Harris and Marshall 1963)

Common Name	Scientific Name
Beggarticks	*Bidens* spp.
Sedge	*Carex atherodes*
Sedge	*C. lacustris*
Sedge	*C. pseudo-cyperus*
Three way sedge	*Dulichium arundinaceum*
Needle spike rush	*Eleocharis acicularis*
Spikerush	*E. palustris*
Rice cutgrass	*Leersia oryzoides*
Pickerelweed	*Pontederia cordata*
Arrowhead	*Sagittaria latifolia*
Hardstem bulrush	*Scirpus acutus*
Woolgrass	*S. cyperinus*
Great bulrush	*S. validus*
Bur reed	*Sparganium chlorocarpum*
Common cattail	*Typha latifolia*
Wild rice	*Zizania aquatica*

North Pacific Division

174. Little research concerning flood tolerance has been conducted on either species or communities of this region. Further, published research pertaining to the region west of the Cascades should not be applied east of the Cascades. Brink (1954) provides a

qualitative appraisal of species performance in response to a June through July flood in British Columbia, but it is impossible to express his observations in a way that relates them to other work. An especially good feature of Brink's report is the inclusion of ornamental species. (See Appendix D for a summary of all species.)

175. Wakefield (1966) analyzed the distribution of riparian vegetation in the Snake River Valley in relation to flood duration. His study is brief but very informative. The data suggest that few species can tolerate more than 50 days of flooding (mostly between January and July) and even fewer species occupy flood-prone areas. A summary of his data is also found in Appendix D.

176. Minore (1968) conducted a greenhouse study to compare flood tolerance among five conifers and one hardwood native to the Pacific Northwest. He found that winter flooding for 4 and 8 weeks had little effect on survival and growth of all species except Douglas-fir (*Pseudotsuga menziesii*). Summer flooding produced variable mortality both within and between species. Survival was closely associated with the formation of adventitious roots. Minore ranks the species as follows:

Rank	Common Name	Scientific Name
Tolerant	Giant cedar	*Thuja plicata*
	Lodgepole pine	*Pinus contorta*
Intermediate	Red alder	*Alnus rubra*
	Sitka spruce	*Picea sitchensis*
Intermediate	Western hemlock	*Tsuga heterophylla*
Intolerant	Douglas-fir	*Pseudotsuga menziesii*

177. Cochran (1972) examined the effects of saturated soil on seedlings of *Pinus ponderosa* and *Pinus contorta* and found that neither species suffered significant mortality even after 1 year of flooding. The author was cautious in restricting his interpretation to "the seed source used" (from populations near Lapine, Oregon, at an elevation of 4500 ft), but the results suggest that both species may have application in vegetating reservoir shorelines just above gross pool.

178. Rumburg and Sawyer (1965) provide the only experimental data

concerning herbaceous vegetation. Varying both depth and duration of controlled floods, they determined that hay yields in simulated wet pasture were greater (though differences were not statistically significant) in all flooded plots in comparison with control plots. Treatments involving flooding in excess of 12.7 cm and 50 days, however, did show decreases in yield over other treatments. The species used in the study are listed in Table 20. The conclusion here is consistent with findings concerning herbaceous, amphibious, and aquatic plants in other regions: namely, that shallow water levels promote growth of emergent vegetation.

Table 20

Flood-Tolerant Wet Meadow Species (After Rumburg and Sawyer 1965)

Common Name	Scientific Name
Sedge	*Carex praegracilis*
Beaked sedge	*C. rostrata*
Salt grass	*Distichlis stricta*
Beardless wildrye	*Elymus triticoides*
Dwarf hesperochiron	*Hesperochiron pumilus*
Foxtail barley	*Hordeum jubatum*
Baltic rush	*Juncus balticus*
Nevada bluegrass	*Poa nevadensis*
Slender cinquefoil	*Potentilla gracilis*

179. Based on the preceding studies, Table 21 ranks the woody species according to their relative flood tolerances.

Ohio River Division

180. No comprehensive studies of comparative flood tolerance in the Ohio Valley have been published according to the literature search made for this review. Several peripheral papers, however, permit the compilation of a partial species list. Hosner and Minckler (1963) examined succession and regeneration in bottomland hardwood forests in southern Illnois. They determined that succession was slower in poorly drained areas and identified buttonbush (*Cephalanthus occidentalis*),

Table 21

Relative Flood Tolerances of Woody Plants, North Pacific Division

Common Name	Scientific Name
Very Tolerant**	
Red-osier dogwood	*Cornus stolonifera*
Narrow leaf willow	*Salix exigua*
Hooker willow*	*S. hookeriana*
Pacific willow	*S. lasiandra*
Tolerant†	
Box elder	*Acer negundo*
Bog laurel*	*Kalmia polifolia*
Labrador tea*	*Ledum groenlandicum*
Lodgepole pine	*Pinus contorta*
Cottonwood	*Populus trichocarpa*
Elder*	*Sambucus callicarpa*
Hardhack*	*Spirea douglasii*
Western red cedar*	*Thuja plicata*
Blueberry*	*Vaccinium uliginosum*
Slightly Tolerant††	
Riverbank mugwort	*Artemesia lindleyana*
Nuttall's dogwood*	*Cornus nuttallii*
Walnut*	*Juglans* spp.
Apple*	*Malus* spp.

(Continued)

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* Species compiled from research conducted in more mesic areas and may not apply to eastern Oregon, Washington, or Idaho.

** 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.

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

Table 21 (Continued)

Common Name	Scientific Name
Slightly Tolerant†† (Continued)	
Sitka spruce	*Picea sitchensis*
Ponderosa pine	*Pinus ponderosa*
Smooth sumac	*Rhus glabra*
Western hemlock	*Tsuga heterophylla*
Intolerant†	
Bigleaf maple	*Acer macrophyllum*
Alder	*Alnus rubra*
Alder	*A. sinuata*
Boxwood	*Buxus sempervirens*
Filbert	*Corylus avellana*
Hazel	*C. rostrata*
Cotoneaster	*Cotoneaster* spp.
Hawthorn	*Crataegus oxyacantha*
Holly	*Ilex aquifolium*
Mock orange	*Philadelphus gordonianus*
Bitter cherry	*Prunus emarginata*
Cherry-laurel	*P. laurocerasus*
Douglas-fir	*Pseudotsuga menziesii*
Wild apple	*Pyrus rivularis*
Cascara	*Rhamnus purshiana*
Blackberry	*Rubus procerus*
Rowan tree	*Sorbus aucuparia*
Lilac	*Syringa vulgaris*

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

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

tupelo (<u>Nyssa aquatica</u>), and bald cypress (<u>Taxodium distichum</u>) as early successional species.

181. Lindsey et al. (1961) conducted a flood depth gradient analysis of two river valleys in Indiana. In Table 22, species reaching maximum importance values in the same flood susceptibility category are grouped together with each group arranged in order of decreasing susceptibility. This closely parallels species flood tolerance observed by workers in other regions and gives a good approximate ranking.

182. Meeks (1969) studied the effects of drawdown on species composition in a freshwater marsh in Ohio. Early drawdowns (March as opposed to June) resulted in a gradual shift to annual weeds while the May drawdown regime yielded the best species mix for ducks. The dominant species identified are listed in Table 23.

<u>South Pacific Division</u>

183. The South Pacific Division is a very diverse geographical area in terms of climate, landform, and zones of floristic affinity. Major climatic discontinuities result from the oceanic influence in California contrasted with the continental influences further inland. Coupled with the latitudinal extent and the influence of the Sierra Nevada, the region defies simple solutions to problems of large-scale vegetation management. The prevailing climate is characterized by low rainfall, and while flash floods do occur, flood tolerance is not a high priority in the adaptive mechanisms of native plants (excepting floodplain vegetation along the major rivers, notably the Sacramento and San Joaquin).

184. As one might expect, there has been little impetus for scientists and land managers to be concerned with research into plant flood tolerance. Ironically, human activities, especially agriculture, have mandated the construction of large reservoirs throughout the region. Because precipitation ~~averages~~ less than 50 cm per year and falls mainly in the winter, reservoir management schedules result in extensive areas of barren shorelines referred to as "bathtub rings" throughout the summer and early fall. Priorities only recently have included vegetating these drawdown zones. Virtually the only studies of flood

Table 22

Species Segregated into Flood Susceptibility Groups, Ranging from Most Tolerant to Least Tolerant*

(After Lindsey et al. 1961)

Common Name	Scientific Name
Buttonbush	*Cephalanthus occidentalis*
Bald cypress	*Taxodium distichum*
Green ash	*Fraxinus lanceolata*
Black willow	*Salix nigra*
Pecan	*Carya illinoensis*
Cottonwood	*Populus deltoides*
Red maple	*Acer rubrum*
Silver maple	*Acer saccharinum*
Pin oak	*Quercus palustris*
Red elm	*Ulmus rubra*
Sycamore	*Platanus occidentalis*
American elm	*Ulmus americana*
Box elder	*Acer negundo*
Black walnut	*Juglans nigra*
Sugarberry	*Celtis laevigata*
Honey locust	*Gleditsia triacanthos*
Kentucky coffee tree	*Gymnocladus dioicus*
Hackberry	*Celtis occidentalis*
Redbud	*Cercis canadensis*
Buckeye	*Aesculus octandra*
Basswood	*Tilia americana*
Black maple	*Acer nigrum*
Bitternut hickory	*Carya cordiformis*
Swamp white oak	*Quercus bicolor*
Rock elm	*Ulmus thomasii*
Red oak	*Quercus rubra*
Shumard oak	*Q. shumardii*

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* Species grouped together have approximately the same flood tolerance.

Table 23

Emergent Plants and Annual Weeds Found in an Ohio Marsh (After Meeks 1969)

Common Name	Scientific Name
Pale smartweed	*Polygonum lapathifolium*
Cattail	*Typha* sp.
Walter's millet	*Echinochloa walteri*
Bur-reed	*Sparganium eurycarpum*
Arrowhead	*Sagittaria latifolia*
Softstem bulrush	*Scirpus validus*
Chufa	*Cyperus* sp.
Needle rush	*Eleocharis acicularis*
Rose mallow	*Hibiscus palustris*
Sow thistle	*Sonchus* sp.
Touch me not	*Impatiens* sp.
Swamp milkweed	*Asclepias incarnata*
Monkey flower	*Mimulus* sp.
Sticktight	*Bidens* sp.
Boneset	*Eupatorum perfoliatum*
Fireweed	*Erechtites hieracifolia*
Rice cut-grass	*Leersia oryzoides*
Bluejoint grass	*Calamagrostis canadensis*
Water lotus	*Nelumbo lutea*

tolerance in the region have come from the University of California (UC), Davis. Notable exceptions are Aldon (1977), Stone and Vasey (1968), and ongoing work by the Sacramento and San Francisco Districts.

185. Since 1969, Harris and Leiser at UC have studied possibilities of establishing vegetation in reservoir drawdown zones. This work has been contracted by the U. S. Bureau of Reclamation, the Corps, and the U. S. Forest Service. The studies have included plantings in operational reservoirs (Harris et al. 1970, Harris et al. 1975), plantings in a 1-acre experimental flood reservoir on the Davis campus (Harris et al. 1975), and observations of species performance after a flood in the Sacramento River delta (Harris et al. 1970). From these studies a species tolerance list has been compiled (Table 24). Supportive data are found in Appendix E. It should be noted that most of the species are not native to California and several are exotic. Continuing research includes screening for flood tolerance a number of species native to the southeastern U. S.

186. Several in-house studies conducted by the State of California Department of Fish and Game and the Corps indicate that three species are especially easy to establish, are drought tolerant, and provide excellent fish habitat during periods of inundation. These are buttonbush (*Cephalanthus occidentalis*), willow (*Salix goodingii*), and lady's thumb (*Polygonum persicaria*). The dual qualities of flood tolerance and drought make the plants ideally suited to California reservoirs. Experiences indicate that drought stress immediately following planting can be a significant mortality factor. All three species are easy to establish vegetatively and all can withstand deep, prolonged flooding. *Polygonum persicaria* (lady's thumb) is especially noteworthy. It is a suffrutescent plant (having a woody rootstock and soft stem) that maintains a shrubby habit during periods of drawdown. It is especially palatable to deer and livestock. When flooded, it produces hollow, floating stems that have been known to emerge through 60 ft of water.* The floating beds apparently provide excellent fish habitat. There is a

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* Personal communication, Dale Mitchell, June 1977. State of California Department of Fish and Game.

Table 24

Species Exhibiting Tolerance to Flooding in California's Central Valley (from Harris et al. 1975)

Common Name	Scientific Name
Considerable Tolerance*	
Tiff green hybrid bermudagrass	*Cynodon dactylon* 'Tiff Green'
Red gum	*Eucalyptus camaldulensis*
London plane tree	*Platanus acerifolia***
Golden weeping willow	*Salix alba* 'Tristis'
Bald cypress	*Taxodium distichum*
Mexican fan palm	*Washingtonia robusta*
Moderate Tolerance†	
Pecan	*Carya illinoensis*
Green ash	*Fraxinus pennsylvanica* var. *lanceolata*
Thornless honey locust	*Gleditsia triacanthos* var. *inermis*
Willow	*Salix* sp.** (Terminus South)††
Willow	*Salix* sp.** (Terminus North)††
Willow	*Salix* sp.** (Folsom)††
Tolerant‡	
Green wattle	*Acacia decurrens*
Silver maple	*Acer saccharinum*
Buttonbush	*Cephalanthus occidentalis***
American sycamore	*Platanus occidentalis*
Balm of Gilead	*Populus candicans*
Carolina poplar	*P.* X. *canadensis*
Fremont poplar	*P. fremontii***
Valley oak	*Quercus lobata***
Corkscrew willow	*Salix matsudana*
Dune willow	*S. piperi***

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* Considerable tolerance: generally able to survive flooding over terminal bud for at least three consecutive months during each of three consecutive years.

** Native or naturalized species.

† Moderate tolerance: generally able to survive flooding over root crown for 100 days during each of three consecutive years.

†† Species nomenclature in parentheses refer to the authors' study locations and are not established varietal names.

‡ Tolerant: at least 70 percent of each species able to survive 100 days of flooding over root crown during each of two consecutive years.

report of Polygonum persicaria becoming a noxious weed in California reservoirs, so introduction of the plant should be approached with caution.*

187. Parnell (1978) reports success in propagating buttonbush from vegetative cuttings and establishing young stands in the Kings River. Field plantings survived the low rainfall years of 1976 and 1977, but it remains to be seen if the plants will survive prolonged inundation.

188. Stone and Vasey (1968) provide an interesting analysis of redwood (Sequoia sempervirens) survival on alluvial flats. Redwoods are able to withstand repeated flooding and siltation by producing adventitious roots with each higher silt layer. The species warrants trial in reservoir situations.

189. Aldon (1977) has examined the ability of three native grasses to withstand flooding in New Mexico. All three species inhabit areas prone to periodic inundation. His results are shown in Table 25. Though all plants displayed decreasing vigor with increased periods of inundation, it is significant that the three species recovered from all treatments.

South Atlantic Division

190. As a geographic region, the South Atlantic states rival the lower Mississippi Valley in the extent of the riverine ecosystem and the number of plants that have evolved to cope with standing water, periodic flooding, and high water tables. It is not surprising, therefore, that much research has been devoted to various aspects of flood tolerance in native plants of the region. Studies on woody species are most numerous, ranging from basic physiology and morphology (Parker 1949, Ford 1972, Hook and Brown 1973) to community ecology (Monk 1966), species growth and development (Hunt 1951, Briscoe 1957, McAlpine 1961, Walker et al. 1961, Bonner 1965, 1966, Kennedy 1970, McMinn and McNab 1971, Briscoe 1972, Mann and Derr 1970, Broadfoot 1973b, Harms 1973), and survival around reservoirs and other situations where water levels are changed

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* Personal communication, James Steele, May 1978. State of California Department of Fish and Game.

Table 25

Average Vigor* of Three Grass Species 1 and 30 Days After Various Inundation Treatments

(After Aldon 1977)

Inundation Treatment days	Alkali sacaton Sporobolus airoides		Desert saltgrass Distichlis stricta		Western wheatgrass Agropyron smithii	
	1 day	30 days	1 day	30 days	1 day	30 days
None	2.83	2.50	1.83ab**	1.67	3.00a	3.00
3	2.67	2.17	2.00a	3.50	2.67ab	2.50
6	[illegible].50	2.50	1.83ab	2.83	3.50a	2.50
12	2.33	2.50	1.50ab	2.50	2.25ab	3.00
24	1.50	2.33	1.00b	2.17	1.75b	2.50

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* Vigor ratings: 1 = poor, 2 = fair, 3 = good, and 4 = very good.

** Column means that have no letters are not different. Column means with the same letters are not significantly different at the $p = 0.05$ level.

artificially (Hall et al. 1946, Silker 1948, Hall and Smith 1955, Klawitter and Young 1965). Similar studies of herbaceous species have been conducted by Gilbert and Chamblee (1965) and Hestand and Carter (1973). This discussion will focus on studies with immediate application.

191. The monumental works of Hall et al. (1946) and of Hall and Smith (1955) are impressive sources of information regarding species tolerances under actual flood conditions in malaria control reservoirs in the Tennessee Valley. By surveying reservoirs over several years, they were able to assess species performance under a range of flooding depths, durations, and repetitions. Table 26 lists woody species by tolerance class. Following the definition of Hall and Smith, "intolerant" refers to those species unable to endure one growing season of flooding to 1 ft; "moderately tolerant" refers to those species succumbing during the second growing season of continuous flooding to 1 ft or more; "tolerant" species are able to withstand two or more successive growing seasons of constant flooding to a depth of 1 ft. Supportive data showing species performance at various flood depths and durations are found in Appendix F.

192. In addition to the observations on woody species, Hall et al. (1946) also provide an extensive list of herbaceous species occurring along the shorelines and littoral zones of southeastern reservoirs. These species, along with their approximate percentage survival after 30 days of flooding, can be found in Table 27.

193. Silker (1948) provides a valuable assessment of the performance of seven species planted in the drawdown and surcharge zones of two Tennessee Valley Authority (TVA) reservoirs during the late 1930's. His assessments are summarized in Table 28.

194. A pertinent paper on the effects of artificial drainage on forest productivity is provided by Klawitter and Young (1965). In a study of growth responses of slash pine (*Pinus elliottii*) to drainage, the authors found that an increase of 20 ft in site index at age 50 was achievable. They used this to argue in favor of wetland improvement for timber production with management goals and economics governing the practicality of site drainage on forest lands. The implication for

Table 26

Approximate Order of Tolerance of Woody Species to Inundation in the Tennessee Valley (Hall et al. 1946)*

Common Name	Scientific Name
	Tolerant**
Silver maple	*Acer saccharinum*
Sweet gum	*Liquidambar styraciflua*
Rattan vine	*Berchemia scandens*
Swamp rose	*Rosa palustris*
Florida vine	*Brunnichia cirrhosa*
Dogbane	*Trachelospermum difforme*
Greenbrier	*Smilax* sp.
Red maple	*Acer rubrum*
Persimmon	*Diospyros virginiana*
Green ash	*Fraxinus lanceolata*
Honey locust	*Gleditsia triacanthos*
Overcup oak	*Quercus lyrata*
Cottonwood	*Populus deltoides*
Water hickory	*Carya aquatica*
Swamp privet	*Forestiera acuminata*
Pepper vine	*Ampelopsis arborea*
Trumpet vine	*Campsis radicans*
Sandbar willow	*Salix interior*
Black willow	*S. nigra*
Buttonbush	*Cephalanthus occidentalis*
Tupelo gum	*Nyssa aquatica*
Bald cypress	*Taxodium distichum*

(Continued)

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* Species within each group are ordered from least tolerant to most tolerant.

** Tolerant: able to survive continuous flooding to a depth of 1 ft or more for up to two growing seasons.

(Sheet 1 of 3)

Table 26 (Continued)

Common Name	Scientific Name
	Moderately Tolerant†
Black alder	*Alnus rugosa*
Indigo bush	*Amorpha fruticosa*
Hispid greenbrier	*Smilax hispida*
Red mulberry	*Morus rubra*
Wild grape	*Vitis* sp.
Cow oak	*Quercus michauxii*
Hackberry	*Celtis laevigata*
Winged elm	*Ulmus alata*
Hawthorn	*Crataegus* sp.
Osage orange	*Maclura pomifera*
Box elder	*Acer negundo*
Loblolly pine	*Pinus taeda*
River birch	*Betula nigra*
Water oak	*Quercus nigra*
American elm	*Ulmus americana*
Sycamore	*Platanus occidentalis*
Deciduous holly	*Ilex decidua*
	Intolerant††
Post oak	*Quercus stellata*
Sugar maple	*Acer saccharum*
White oak	*Quercus alba*
Yellow buckeye	*Aesculus octandra*
Yellow poplar	*Liriodendrom tulipifera*
Prickly ash	*Aralia spinosa*

(Continued)

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† Moderately tolerant: succumb during second growing season of continuous flooding to a depth of 1 ft or more.

†† Intolerant: unable to survive continuous flooding 1 ft deep for one growing season.

(Sheet 2 of 3)

Table 26 (Concluded)

Common Name	Scientific Name
	Intolerant†† (Continued)
American beech	*Fagus grandifolia*
Swamp hickory	*Carya leiodermis*
Black walnut	*Juglans nigra*
Ironwood	*Carpinus caroliniana*
Redbud	*Cercis canadensis*
Red cedar	*Juniperus virginiana*
Scrub pine	*Pinus virginiana*
Shortleaf pine	*P. echincata*
Wild black cherry	*Prunus serotina*
Blackjack oak	*Quercus marilandica*
Basswood	*Tilia* sp.
Southern red oak	*Quercus falcata*
Sourwood	*Oxydendrum arboreum*
Flowering dogwood	*Cornus florida*
Sassafras	*Sassafras albidum*
Black locust	*Robinia pseudoacacia*
Shagbark hickory	*Carya ovata*
Mockernut hickory	*C. tomentosa*
Chestnut oak	*Quercus montana* (= *Q. prinus*)
White ash	*Fraxinus americana*

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†† Intolerant: unable to survive continuous flooding 1 ft deep for one growing season.

Table 27

Effects of 30 Consecutive Days Flooding, Mainly During Month of June, on Littoral Plants with Water Depths of 6 and 12 in.

(After Hall et al. 1946)

Species		Approximate Percentage of Survival	
Common Name	Scientific Name	Water Depth 6 in.	Water Depth 12 in.
Alligator weed	*Alternanthera philoxeroides*	100	100
Common ragweed	*Ambrosia artemisiifolia* var. *elatior*	0	0
Giant ragweed	*A. trifida*	0	0
Purple ammannia	*Ammannia coccinea*	100	50
Broomsedge	*Andropogon virginicus*	25	0
Lake cress	*Armoracia aquatica*	100	100
Aster	*Aster dumosus*	?	0
Aster	*A. ontarionus*	100	?
Aster	*A. pilosus*	0	0
Hop sedge	*Carex lupulina*	100	100
Redroot flatsedge	*Cyperus erythrorhizos*	100	?
Swamp loosestrife	*Decodon verticillatus*	100	100
Water purslane	*Peplis diandra*	100	100
Large crabgrass	*Digitaria sanguinalis*	0	0
Virginia buttonweed	*Diodia virginiana*	100	100
Barnyard grass	*Echinochloa crusgalli*	100	90
Burhead	*E. cordifolius*	100	100
Slender spikerush	*Eleocharis acicularis*	100	100
Blunt spikerush	*E. obtusa*	100	100
Squarestem spikerush	*E. quadrangulata*	100	100
Terrell grass	*Elymus virginicus*	0	0
Love grass	*Eragrostis hypnoides*	?	?
Horseweed	*Erigeron canadensis*	0	0
Lake eupatorium	*Eupatorium serotinum*	10	0
Purplehead sneezeweed	*Helenium nudiflorum*	80	0
Slender-leaved sneezeweed	*H. tenuifolium*	0	0
Indian heliotrope	*Heliotropium indicum*	?	0
Halberd-leaved rose mallow	*Hibiscus militaris*	100	100
Swamp rose mallow	*Hibiscus moscheutos*	100	100
Hydrolea	*Hydrolea quadrivalvis*	100	100
Soft rush	*Juncus effusus*	100	100
Water primrose	*Jussiaea repens*	100	100
Water willow	*Justicia americana*	100	100
Rice cutgrass	*Leersia oryzoides*	100	100
Winged loosestrife	*Lythrum alatum*	100	?
Water milfoil	*Myriophyllum pinnatum*	100	100

(Continued)

Table 27 (Continued)

Species		Approximate Percentage of Survival	
Common Name	Scientific Name	Water Depth 6 in.	Water Depth 12 in.
Lesser naiad	*Najas minor*	100	100
Yellow nelumbo	*Nelumbo lutea*	100	100
Sacred lotus	*N. nucifera*	100	100
Spatterdock	*Nuphar advena*	100	100
Panic grass	*Panicum agrostoides*	100	100
Common pokeweed	*Phytolacca americana*	0	0
Mild smartweed	*Polygonum hydropiperoides*	100	100
Pale smartweed	*P. lapathifolium*	100	100
Pennsylvania smartweed	*P. pensylvanicum*	100	100
Pondweed	*Potamogeton nodosus*	100	100
Curlyleaf pondweed	*Potamogeton crispus*	100	100
Mermaid weed	*Proserpinaca palustris*	100	100
Yellow water buttercup	*Ranunculus flabellaris*	100	100
Liverwort	*Ricciocarpus natans*	100	100
Lizardtail	*Saururus cernuus*	100	100
Woolgrass bulrush	*Scirpus cyperinus*	100	100
Goldenrod	*Solidago altissima*	10	0
American germander	*Teucrium canadense*	100	100
Common cattail	*Typha latifolia*	100	100
Bladderwort	*Utricularia gibba*	100	100
Cocklebur	*Xanthium americanum*	0	0
Giant cutgrass	*Zizaniopsis miliacea*	?	?

Table 28

Species Survival in Plantations Around TVA Reservoirs

(After Silker 1948)

Species		Surcharge Zone*			Upper Drawdown Zone**		
Common Name	Scientific Name	Percent Survival	Plantation Age years	Number of 1/20 acre Plots Sampled	Percent Survival	Plantation Age years	Number of 1/20 acre Plots Sampled
Bald cypress	*Taxodium distichum*	75	5	46	89;96†	12;11	2;13
Water oak	*Quercus nigra*	77	5	22	--††	--	--
Willow oak	*Q. phellos*	77	5	22	--	--	--
Green ash	*Fraxinus pennsylvanica* var. *lanceolata*	90	5	32	--	--	--
Sweet gum	*Liquidambar styraciflua*	72	5	49	--	--	--
Water tupelo	*Nyssa aquatica*	61	5	12	88	12	4
Sycamore	*Plantanus occidentalis*	11	5	6	--	--	--
Southern white					--	--	--
Cedar	*Chamaecyparis thyoides*	37	5	2	58	9	1

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* Surcharge zone: 1 to 15 ft above normal reservoir level.

** Upper drawdown zone: planting sites covered by 1 to 3 ft of water intermittently during growing season.

† Two plantations of different ages were sampled.

†† No data.

stands bordering reservoirs could be that pine site indices could decline in response to elevated water tables. Since such responses are dependent on species, depth to water tables, and soil characteristics, however, it is impossible to make blanket predictions.

195. Table 29 summarizes data illustrating species responses under various water table regimes.

196. It is important to recognize that the similarities between the Lower Mississippi Valley and the South Atlantic Divisions encourage cross-consultation of species lists and research findings.

Southwestern Division

197. There is remarkably good coverage of flood-tolerant vegetation for the Southwestern Division, encompassing woody, grassland, and aquatic plants and using both empirical and experimental approaches. Much of the data was gathered in Oklahoma and experimental confirmation should be obtained for other areas.

198. Studies of flood tolerance in grasses have appeared regularly in the literature (Porterfield 1945, Gamble and Rhoades 1964, Rhoades 1964, 1971). Table 30 summarizes the maximum reported flood durations survived by the various species. Maximum flooding was 183 cm (6 ft).

199. The work of Penfound (1953), though somewhat difficult to interpret, is exemplary in that it covers a large number of woody and herbaceous species found in 32 man-made and natural lakes throughout Oklahoma. Plants are categorized according to their position relative to high and low water levels and, in the case of annual herbs, their season of flowering. Only emergent wetland plants are listed here (Table 31). A complete listing is found in Appendix G.

200. The number of naturally occurring annual herbs found in the drawdown and surcharge zones of the lakes under study is impressive. The fact that such a broad spectrum of species colonized the drawdown zones strongly suggests the possibility of establishing temporary herbaceous cover during the summer. After initial establishment by artificial means, such communities could probably regenerate themselves from year to year.

Table 29

Species Response to Various Water Table Depths

Species		Results	Authority
Common Name	Scientific Name		
Shortleaf pine	*Pinus echinata*	Plants in soil saturated with stagnant water for 12 weeks had poorer growth than alternate flood or moving water treatments	Hunt 1951
Loblolly pine	*P. taeda*		
Pond pine	*P. serotina*		
Slash pine	*P. elliottii*	Best seedling growth occurred with water levels 8.2 to 15.2 cm below soil surface rather than 8.2 to 15.2 cm above soil	Walker et al. 1961
Loblolly pine	*P. taeda*		
Slash pine	*P. elliottii*	Flood-treated seedlings had decreased production of secondary roots and mycorrhizae	McMinn and McNab 1971
Loblolly pine	*P. taeda*	Height growth best on disked and bedded plantings on fine-textured, poorly drained soil	Mann and Derr 1970
Slash pine	*P. elliottii*		
Sycamore	*Platanus occidentalis*	Seedling growth inhibited by 10 to 12 weeks of saturated soil	Bonner 1965
Sweet gum	*Liquidambar styraciflua*		
Nuttall's oak	*Quercus nuttallii*		
Tulip tree	*Liriodendron tulipifera*	Seedlings wilted after 4 days of flooding; 4-yr-old plantation wilted after 6 weeks of surface flooding	McAlpine 1961
Green ash	*Fraxinus pennsylvanica* var. *lanceolata*	Raising of water table to between 46 and 107 cm of soil surface increased radial growth in all species except *Q. alba*	Broadfoot 1973a
Spanish oak	*Quercus falcata* var. *pagodaefolia*		
Cow oak	*Q. michauxii*		
Water oak	*Q. nigra*		
White oak	*Q. alba*		
Willow oak	*Q. phellos*		
Sycamore	*Platanus occidentalis*		
Sweet gum	*Liquidambar styraciflua*		
Longleaf pine	*Pinus australis*		
Cottonwood	*Populus deltoides*	Cottonwood cuttings 25 cm long showed best growth with water table 61 cm below surface; 30.5 cm below surface gave growth equaling drained control	Broadfoot 1973b

Table 30

Maximum Reported Flood Tolerances for Grasses in Oklahoma

(from Rhoades 1964 and 1971, Gamble and Rhoades 1964)

Common Name	Scientific Name	Spring Flood Periods that Species Survived, consecutive days
Bermuda grass	*Cynodon dactylon*	45-90
Buffalo grass	*Buchloe dactyloides*	45-90 (12 months, according to Porterfield 1945)
Knotgrass	*Paspalum distichum*	45-90
Barnyard grass	*Echinochloa crusgalli*	30-60
Virginia wild rye	*Elymus virginicus*	20-45
Beaked panicum	*Panicum anceps*	20-45
Switch grass	*P. virgatum*	15-30
Purpletop	*Tridens flavus*	10-20
Johnson grass	*Sorghum halepense*	10-20
Tall fescue	*Festuca arundinacea*	10-20
Indian grass	*Sorghastrum nutans*	7-14
Big bluestem	*Andropogon gerardi*	7-14
Silver bluestem	*A. saccharoides*	5-10
Little bluestem	*A. scoparius*	3-6
K. R. bluestem	*A. ischaemum*	3-6
Weeping lovegrass	*Eragostis curvula*	3-6

Table 31

Emergent Wetland Species Found in Oklahoma Lakes (from Penfound 1953)

Common Name	Scientific Name
	Herbaceous Plants
Water sedge	*Carex aquatilis*
Rusty sedge	*Cyperus ferruginescens*
Spike rush	*Eleocharis macrostachya*
Barnyard grass	*Echinochloa crus-galli*
Water purslane	*Ludwigia palustris*
Panic grass	*Panicum agrostoides*
Knot grass	*Paspalum distichum*
	Woody Plants
Hazel alder	*Alnus serrulata*
Buttonbush	*Cephalanthus occidentalis*
Sycamore	*Platanus occidentalis*
Cottonwood	*Populus deltoides*
Plains cottonwood	*P. sargentii*
Peachleaf willow	*Salix amygdaloides*
Ditchbank willow	*S. interior*
Black willow	*S. nigra*
French tamarisk	*Tamarix gallica*

201. DeGruchy (1956), Harris (1975), and the U. S. Army Engineer District, Little Rock (1973)* have reported on the performance of trees and shrubs around Oklahoma lakes. Their data, together with those of Penfound (1953), serve as the bases for the tolerance listing found in Table 32.

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* Unpublished report, "High Water Effects on Vegetation at Little Rock District Projects," 8 pp plus exhibits.

Table 32

Relative Flood Tolerance of Woody Plants, Southwestern Division

Common Name	Scientific Name
	Very Tolerant*
Buttonbush	*Cephalanthus occidentalis*
Black willow	*Salix nigra*
Green ash	*Fraxinus pennsylvanica*
	Tolerant**
Box elder	*Acer negundo*
Silver maple	*A. saccharinum*
False indigo	*Amorpha fruticosa*
River birch	*Betula nigra*
Pecan	*Carya illinoensis*
Hackberry	*Celtis occidentalis*
Persimmon	*Diospyros virginiana*
Sweet gum	*Liquidambar styraciflua*
Black gum	*Nyssa sylvatica*
Sycamore	*Platanus occidentalis*
Overcup oak	*Quercus lyrata*
French tamarisk	*Tamarix gallica*
American elm	*Ulmus americana*
	Slightly Tolerant†
Red maple	*Acer rubrum*
Hawthorn	*Crataegus* sp.

(Continued)

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* 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.

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

Table 32 (Concluded)

Common Name	Scientific Name
Slightly Tolerant† (Continued)	
Honey locust	*Gleditsia triacanthos*
Eastern red cedar	*Juniperus virginiana*
Red mulberry	*Morus rubra*
Shortleaf pine	*Pinus echinata*
White oak	*Quercus alba*
Black haw	*Viburnum prunifolium*
Intolerant††	
Bitternut hickory	*Carya* sp. (*cordiformis?*)
Flowering dogwood	*Cornus* sp. (*florida?*)
BlackJack oak	*Quercus marilandica*
Chinquapin oak	*Q. muehlenbergii*
Dwarf chinquapin oak	*Q. prinoides*
Red oak	*Q. rubra*
Post oak	*Q. stellata*
Black oak	*Q. velutina*
Black locust	*Robinia pseudoacacia*

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

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

PART IV: FUTURE RESEARCH

202. Given the nature of flooding phenomena and the myriad ways in which plants respond to flooding, the physiology and ecology of flood tolerance will continue to spawn a diverse research effort. The current vogue of stress physiology and eco-physiology makes the study of flood tolerance in plants very attractive. Research into the mechanisms, sequence, and the energetics of metabolic responses is still needed to determine their adaptive advantages. In addition, the role of hormones in the instigation and mediation of both metabolic and morphological changes is documented but not understood. Research that synthesizes the findings of the hormonal and metabolic schools is vitally needed.

203. At present, it is not possible to develop a model that will predict accurately flood tolerance within a species, much less a general model that encompasses unrelated taxa. Physiological research must expand beyond the traditional "guinea pig" plants before generalities can be drawn. It is extremely difficult to use specific physiological and anatomical characteristics to screen plants for practical applications. Keeley* has outlined a screening experiment that permits an assessment of a plant's potential flood tolerance based on several key adaptive responses. Such an approach is attractive, yet does not incorporate many secondary factors that influence plant survival. Field trials should complement any laboratory screening efforts.

204. From a purely practical viewpoint, there is sufficient research to date to permit a first approximate rating of both native U. S. and introduced plants according to flood tolerance. What is required now, rather than continued screening of large numbers of species, is a detailed evaluation of the performance of previously studied species under a variety of circumstances. The aim should be to produce a refined rating scheme that will focus on regional needs and specific plants to meet those needs. Important in this endeavor will be the description

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* Keeley, J. E., 1977. Plant adaptations to waterlogged soils as indicators of wetland habitats. Unpublished manuscript. Occidental College, L. A. 48 pp.

of ecotypic variation so that cultivars may be selected on the basis of desirable traits. An ideal opportunity is here to join practical concerns with basic research.

205. Concomitant with the research on plant materials is the need to explore planting techniques that will be both successful and economical. Such information will be valuable to the decision-making process.

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GUIDE TO APPENDIX MATERIAL

Appendices A through G summarize the pertinent research on flood tolerance in woody vegetation for several of the ten Army Corps of Engineers Divisions. It is apparent that different authors have used different experimental methods and plant materials and have arrived at results that often are conflicting. This is especially true when relative terms like "tolerant" and "intolerent" are employed. Wherever possible, the original data and adjectives are employed to avoid misinterpretation. It should be recognized that in most instances the knowledge of the ability of plants to withstand is only approximate.

The appendices contain not only recognized flood-tolerant species, but also those species reported in the literature that occur in floodplains, bottomlands, and other flood-prone areas which have been studied with flood tolerance in mind. It is hoped that by being inclusive, clearing practices during reservoir construction may more fully reflect the state of knowledge of the vegetation.

The classification of species according to the region in which the study was conducted is admittedly artificial. Many species have cosmopolitan distributions that violate regional boundaries. Conversely, many species' ranges do not extend over an entire Division. This is especially true in the North Pacific and South Pacific Divisions, both of which encompass vastly different biotic provinces. A knowledge of the local flora will be imperative before selections can be made for specific sites.

It also should be recognized that the lists are undoubtedly incomplete, especially on the species level. Thus, many more species in the genus Salix (willow) than appear in the appendices should be considered flood tolerant. Also, ecotypic variation may be responsible for a species' good or bad performance in a particular study. There is little hard data to lend an idea of the significance of this factor, but evidence suggests that different ecotypes of the same species may exhibit different flood tolerances. Attention should be paid to prevailing conditions under which the species is growing locally when selecting sources of propagules or devising clearing guidelines.

Finally, the diversity of soils, climates, exposures, and drawdown regimes is such that the only reasonable approach to vegetation management is an experimental one. The state of knowledge does not allow accurate prediction of species performance. Each impoundment is its own best source of information and the prudent manager will reccognize the value of his experiences in expanding the scope of understanding. As explained in Part I, scientific and common nomenclature follow the usage of the individual authors in most instances. Where there was reason to suspect that nomenclature was inaccurate, it was reconciled with the binomial used in either Gray's Manual of Botany (Fernald 1970), Manual of Cultivated Plants (Bailey [illegible]9), A California Flora (Munz 1963), or Composite List of Weeds (Weed Society of America 1971).* Often there are different common names for a single species that enjoy regional popularity. The authors hope that the inclusion of only one common name for each species will not confuse those familiar with a plant by a different common name. The inconsistency of common names makes the use of scientific names imperative for accurate identification.

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* See References at end of main text for all sources cited in the appendices.

APPENDIX A:

DATA SUMMARY, LOWER MISSISSIPPI VALLEY DIVISION

Table A1

Data Summary, Lower Mississippi Valley Division

Species	Experimental method	Conditions: Depth cm: Over root crown or as noted	Conditions: Depth cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Acer negundo Box elder	Greenhouse study, current year seedlings 7.6 cm high, 3/pot flooded in July and August	50.8	43.2	2	3	3	No injury	Hosner, 1958
		50.8	43.2	4	3	3	Leaves slightly chlorctic, slow recovery	
		50.8	43.2	8	3	3	Leaves moderately chlorctic, terminal buds died on 2 plants; slow recovery	
		50.8	43.2	16	3	1	Terminal bud on survivor was dead	
		50.8	43.2	32	3	0		
	Greenhouse study, current year seedlings 16.5 cm tall, 5/pot flooded 14 Jul-21 Aug; 60 day recovery period after drainage.	61	-	5	15	15	All recovered rapidly	Hosner, 1960
		61	-	10	15	15	All recovered rapidly	
		61	-	20	15	15	Recovery moderately fast	
		61	-	30	15	14	4 survivors lost terminals; recovery moderately fast	
	Greenhouse study, current seedlings 5/pot, established as natural seed became available; only 60-day data presented.	2.5	-	60	15	15	No significant height difference between treatment and control	Hosner and Boyce, 1962

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Acer negundo Boxelder	Study of tree mortality following the creation of a reservoir behind Alton Dam in southern Illinois. Permanent transects sampled at intervals over a 4-yr period. Sample stratified according to location, land, mud, or water.	land	-	240	20	100%		Yeager 1949
		mud	-	240	0	-		
		water	-	240	0	-		
		land	-	730	20	100%		
		mud	-	730	0	-		
		water	-	730	0	-		
		land	-	1460	20	100%		
		mud	-	1460	0	-		
		water	-	1460	0	-		
	Correlated flood frequency and duration in the lower White River valley, Ark., with forest composition.	-	-	29-40% of time	0	-		Bedinger 1971
		-	-	10-21% of time	5	-		
		-	-	once every 2-8 yrs	0	-		
	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Illinois during 1973 growing season.	-	-	149	6	6	Ranked as tolerant by authors; able to withstand more than 150 days of flooding. Mature trees sampled.	Bell and Johnson 1974
		-	-	189	6	6		

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Acer negundo Boxelder	Sapling survival observed in a hardwood forest along the Mississippi River in La. before and after flooding during the 1973 growing season.	240-480	-	105 (116 max.)	-	-	*A. negundo* comprised 1.2% of understory cover before flood and 1.0% of cover after flood. Saplings generally able to recover.	Noble and Murphy 1975
Acer rubrum Red maple	Greenhouse study, 8-day-old seedlings 5/pot; soil kept saturated.	.64 below root crown	-	1-32	20	20	Growth retarded by all treatments except 4 day.	McDermott 1954
	Greenhouse study; current year seedlings 9.9 cm tall, 5/pot flooded 14 Jul-21 Aug; 60-day recovery period after drainage.	61	-	5	15	15	Recovery rapid.	Hosner 1960
		61	-	10	15	14	Moderately rapid recovery.	
		61	-	20	15	0		
	Greenhouse study; current year seedlings, 5/pot, established as natural seed because available; only 60 day data presented.	2.5 cm	-	60	15	15	No shoot mortality, many adventitious roots; non-adventitious roots went dormant but recovered rapidly; authors rank as intolerant.	Hosner and Boyce 1962

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Acer rubrum Red maple	Controlled field experiment, 8 natural stands in Mississippi Delta flooded Feb-Jul for 4 years to ascertain effect on growth.	90, max.	-	210	3	-	Trees of timber and pole size; 85% radial growth increase over control.	Broadfoot 1957
	Correlated flood frequency and duration in the lower White River valley, Ark., with forest composition.	-	-	29-40% of time	1	-		Bedinger 1971
		-	-	10-21% of time	10	-		
		-	-	once every 2-8 yrs	7	-		
Acer rubrum var. *drummondii* Red maple	Ecological study of a bald cypress-water tupelo swamp site flooded each spring, with soil remaining saturated for duration of year.	15-30	-	90	-	-	Importance value of 3.09, where IV = relative frequency and relative density and relative dominance. Species increases IV after bald cypress are logged.	Connor and Day 1976

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Acer saccharinum Silver maple	Greenhouse study, current year seedlings 7.6 cm high; 3/pot flooded in July and August.	50.8	43.2	2	3	3	Lower wilted; slow recovery.	Hosner 1958
		50.8	43.2	4	3	0	Seedlings had low initial vigor possibly accounting for low survival.	
		50.8	43.2	8	3	0		
		50.8	43.2	16	3	0		
		50.8	43.2	32	3	0		
	Greenhouse study; current year seedlings 3.15 cm tall, 5/pot flooded 14 Jul-21 Aug; 60-day recovery period after drainage.	61	58	5	15	15	Rapid recovery.	Hosner 1960
		61	58	10	15	15	Rapid recovery.	
		61	58	20	15	15	Rapid recovery.	
		61	58	30	15	15	2 lost terminals; rapid recovery.	
	Greenhouse study; current year seedlings, 5/pot established as natural seed became available; only 60 day data presented here.	2.5 cm	-	60	15	15	No shoot mortality; many adventitious roots; non-adventitious roots dormant and alive; ranked as intolerant by authors.	Hosner and Boyce 1962

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions Depth, cm Over root crown or as noted	 Over terminal bud	 Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Acer saccharinum Silver maple	Study of tree mortality following the creation of a reservoir behind Alton Dam in southern Illinois. Permanent transects sampled at intervals over a 4-yr period. Sample grouped according to location: land, mud, or water.	land	-	240	216	98%		Yeager 1949
		mud	-	240	55	100%		
		water	-	240	177	56%		
		land	-	730	216	35%		
		mud	-	730	55	50%		
		water	-	730	177	1%		
		land	-	1460	216	95%	Water depth and dbh* had no effect on 920 day survival (*diameter breast height).	
		mud	-	1460	55	54%		
		water	-	1460	177	0%		
	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Illinois during 1973.	-	-	149	39	39	Data not provided for other durations of flooding. Ranked as tolerant by authors.	Bell and Johnson 1974
Alnus rugosa Hazel Alder	Greenhouse study, 8-day seedlings, 5/pot, soil kept saturated.	.64	-	1-32	20/trt	20	60% mortality in 8 day treatment. NSD among other treatments.	McDermott 1954

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Betula nigra River birch	Study of tree mortality following the creation of a reservoir behind Alton Dam in S. Illinois. Permanent transects sampled at intervals over a 4-yr period. Samples grouped according to location: land, mud, water.	land	-	240	4	100%		Yeager 1949
		mud	-	240	2	100%		
		water	-	240	17	77%		
		land	-	730	4	100%		
		mud	-	730	2	100%		
		water	-	730	17	0%		
		land	-	1460	4	100%		
		mud	-	1460	2	100%		
		water	-	1460	17	0%		
	Greenhouse study, 8-day-old seedlings 5/pot, soil kept saturated.	.64	-	1-32	20	20	All treatments except 1 day caused stunting.	McDermott 1954
Carpinus caroliniana Ironwood	Correlated flood frequency and duration in the lower White River valley, Ark., with forest composition.	-	-	29-40%	1	-		Bedinger 1971
		-	-	10-21%	19	-		
		-	-	once every 2-8 yrs	3	-		

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Carya aquatica Water hickory	Controlled field experiment, 8 natural stands in Miss. Delta flooded Feb-Jul for 4 years to ascertain effect on growth.	90, max	-	210	15		Trees of timber & pole size, 45% radial growth increase over control.	Broadfoot 1967
	Correlated flood frequency and duration in the lower White River valley, Ark., with forest composition.			29-40% of time	120	-		Bedinger 1971
				10-21% of time	70	-		
				once every 2-8 yrs	0	-		
Carya cordiformis Bitternut hickory	Correlated flood frequency and duration in the lower White River valley, Ark., with forest composition.			29-40%	0	-		Bedinger 1971
				10-21% of time	0	-		
				once every 2-8 yrs	9	-		
Carya illinoensis Pecan	Study of tree mortality following the creation of a reservoir behind Alton Dam in S. Illinois. Permanent transects sampled at intervals over a 4-yr pd. Samples grouped according to location: land, mud, water.	land	-	240	46	100%		Yeager 1949
		mud	-	"	2	100%		
		water	-	"	26	77%		

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Carya illinoensis Pecan		land	-	730	46	100%		
		mud	-	730	2	100%		
		water	-	730	26	11%		
		land	-	1460	46	100%		
		mud	-	1460	2	0%		
		water	-	1460	26	0%		
	Report of impacts of 1973 flood during spring & early summer on 1-yr-old plantation in Mississippi.	198 max.	-	60	-	-	Trees had not leafed out when first flooded; maximum water depth occurred on 15 May. Plantation survived flood.	Kennedy and Krinard 1974
	Sapling survival observed in a hardwood forest along the Mississippi River in La. before and after flooding during 1973 growing season.	243-488	-	105	-	-	Saplings were either killed or growth severely retarded.	Noble and Murphy 1975

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Carya laciniosa								
Shellbark hickory	Correlated flood frequency and duration in the lower White River valley, Ark., with forest composition.	-	-	29-40% of time	0	-		Bedinger 1971
				10-21%	0	-		
				once every 2-8 yrs	9			
Carya ovata	Same as above	-	-	29-40%	0	-		Bedinger 1971
Shagbark hickory				10-21% of time	0	-		
				once every 2-8 yrs	38			
	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Illinois during 1973 growing season.	-	-	50	114	100%	Same trees observed throughout study. Authors described as somewhat tolerant.	Bell and Johnson 1974
				109	114	57%		
				149	114	56%		
				139	114	38%		
Carya tomentosa	Correlated flood frequency and duration in the lower White River valley, Ark., with forest composition.	-	-	29-40% of time	0	-		Bedinger 1971
Mockernut hickory				10-21% of time	0	-		
				once every 2-8 yrs	53	-		

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions			No. of plants	No. or % survival	Comments	Authority
		Depth, cm						
		Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted				
Carya tomentosa Mockernut hickory	Study of tree mortality during flood surcharge at Rand Lk. & Lk. Shelbyville in Illinois during 1973 growing season.	-	-	50	47	100%	Ranked as slightly tolerant by authors, able to survive 50-100 days of flooding.	Bell and Johnson 1974
				109	47	35%		
				149	47	0%		
				189	47	0%		
Celtis laevigata Sugarberry	Greenhouse study; current yr seedlings, 15/pot, established as natural seed became available; only 60 day data presented here.	2.5	-	60	15	-	7% shoot mortality, no adventitious roots, all other roots dead except primary.	Hosner and Boyce 1962
	Correlated flood frequency and duration in the lower White River valley, Ark., with forest composition.	-	-	29-40% of time	84	-		Bedinger 1971
				10-21% of time	181	-		
				once every 2-8 yrs	19	-		
Celtis occidentalis Hackberry	Greenhouse study; current year seedlings, 5/pot.	.64	-	38	5	0%	All plants dead in in three wks; no sprouting or signs of recovery.	Hosner 1959

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Celtis occidentalis Hackberry	Greenhouse study; current year seedlings 22 cm tall; 5/pot flooded 14 July-Aug 21; 60-day recovery period after drainage.	61	58	5	15	14	4 lost terminals recovered slowly.	Hosner 1960
		61	58	10	15	1	survivor developed a weak sprout.	
		61	58	20	15	0		
		61	58	30	15	0		
	Greenhouse study; current year seedlings, 5/pot, established as natural seed became available; only 60 day data presented here.	2.5	-	60	15	-	20% shoot dieback after removal from flood tank; sparse adventitious rooting some secondary roots killed.	Hosner and Boyce 1962
	Study of tree mortality following the creation of a reservoir behind Alton Dam in S. Illinois. Permanent transects sampled at intervals over a 4-yr period. Samples grouped according to location: land, mud, water.	land	-	240	45	100%		Yeager 1949
		mud	-	240	3	100%		
		water	-	240	3	66%		
		land	-	730	45	96%		
		mud	-	730	3	66%		
		water	-	730	3	0%		

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Celtis occidentalis Hackberry		land	-	1460	45	93%		Yeager 1949
		mud	-	1460	3	32%		
		water	-	1460	3	0%		
	Controlled field experiment; 8 natural stands in Miss. Delta flooded Feb-Jul for 4 yrs to assess effect on growth.	90, max	-	210	21	-	Trees of timber and pole size; 45% increase in radial growth over controls.	Broadfoot 1967
	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Ill. during 1973 growing season.	-	-	49	37	100%	Note increased mortality as flooding extends into growing season.	Bell and Johnson 1974
				109	37	100%		
				149	37	55%		
				189	37	0%		
Cephalanthus occidentalis Buttonbush	Greenhouse study, current year seedlings, 12.7 cm tall, 5/pot. Flooded 14 Jul-21 Aug. 60-day recovery period after drainage.	61	48	5	15	15	Rapid recovery.	Hosner 1960
		61	48	10	15	15	Rapid recovery.	
		61	48	20	15	15	Rapid recovery.	
		61	48	30	15	15	2 lost terminals; Rapid recovery.	

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions Depth, cm Over root crown or as noted	 Over terminal bud	 Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Cephalanthus occidentalis Buttonbush	Study of tree mortality following the creation of a reservoir behind Alton Dam in S. Ill. Permanent transects sampled at intervals over a 4-yr period. Samples grouped by location: land, mud, water.	land	-	240	0	-		Yeager 1949
		mud	-	240	0	-		
		water	-	240	15	80%		
		land	-	730	0	-		
		mud	-	730	0	-		
		water	-	730	15	47%		
		land	-	1460	0	-		
		mud	-	1460	0	-		
		water	-	1460	15	40%		
	Ecological study of a baldcypress - water tupelo swamp; site flooded each spring, with soil remaining saturated for duration of year.	15 - 30		90			Importance value= 1.71 where IV = relative frequency + relative density + relative dominance. Ranked above Salix nigra at IV= .88.	Conner and Day 1976

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Cercis canadensis Redbud	Study of tree mortality following the creation of a reservoir behind Alton Dam in S. Ill. Permanent transects sampled at intervals over a 4-yr period. Samples grouped by location: land, mud, water.	land	-	240	1	100%		Yeager 1949
		mud	-	240	0	0		
		water	-	240	0	0		
		land	-	730	1	100%		
		mud	-	730	0	0		
		water	-	730	0	0		
		land	-	1460	1	100%		
		mud	-	1460	0	0		
		water	-	1460	0	0		
	Correlated flood frequency and duration in the lower White River valley, Ark., with forest composition.			29-40% of time	0			Bedinger 1971
				10-21% of time	0			
				once every 2-8 yrs	5			

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Cornus florida Flowering dogwood	Study of tree mortality behind Alton Dam in S. Ill. Permanent transects sampled at intervals over a 4-yr period. Samples grouped by location: land, mud, water.	land	-	240	2	100%		Yeager 1949
		mud	-	240	0	-		
		water	-	240	0	-		
		land	-	730	2	100%		
		mud	-	730	0	-		
		water	-	730	0	-		
		land	-	1460	2	100%		
		mud	-	1460	0	-		
		water	-	1460	0	-		
	Correlated flood frequency and duration in the lower White River valley, Ark., with forest composition.	-	-	29-40% of time	0	-		Bedinger 1971
		-	-	10-21% of time	0	-		
		-	-	once every 2-8	8	-		

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Crataegus mollis Hawthorn	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Ill. during 1973 growing season.	-	-	149	6	6		Bell and Johnson 1974
Crataegus spp. Hawthorn	Study of tree mortality upstream from Alton Dam in S. Ill. Permanent transects sampled at intervals over a 4-yr period. Samples grouped by location: land, mud, water.	land	-	240	17	88%	A taxonomically complex genus which undoubtedly displays a range of flood tolerance.	Yeager 1949
		mud	-	240	4	100%		
		water	-	240	16	44%		
		land	-	730	17	88%		
		mud	-	730	4	25%		
		water	-	730	16	19%		
		land	-	1460	17	88%		
		mud	-	1460	4	25%		
		water	-	1460	16	0%		
	Correlated flood frequency and duration in the lower White River valley, Ark., with forest composition.	-	-	29-40% of time	1	-		Bedinger, 1971

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions Depth, cm Over root crown or as noted	 Over terminal bud	 Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Crataegus spp.		-	-	10-21% of time	17	-		Bedinger 1971
Hawthorn		-	-	once every 2-8 yrs	2	-		
Diospyros virginiana Persimmon	Study of tree mortality upstream from Alton Dam in S. Ill. Permanent transects sampled at intervals over a 4-yr period. Samples grouped by location: land, mud, water.	land	-	240	27	96%		Yeager 1949
		mud	-	240	5	100%		
		water	-	240	35	67%		
		land	-	730	27	96%		
		mud	-	730	5	100%		
		water	-	730	35	0%		
		land	-	1460	27	96%		
		mud	-	1460	5	20%		
		water	-	1460	35	0%		

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Diospyros virginiana Persimmon	Controlled field experiment, 8 natural stands in Miss. Delta flooded Feb-Jul for 4 yrs to assess effect on growth.	90, max.	-	210	7	-	10% radial growth increase over control; timber and pole size trees.	Broadfoot 1967
	Observations of tree mortality in Miss. stand flooded for 4 yrs.	<30	-	1460	-	0	All trees died by end of second growing season.	Broadfoot and Williston 1973
	Correlated flood frequency and duration in the lower White River valley, Ark., with forest composition.	-	-	29-40% of time	7	-		Bedinger 1971
		-	-	10-21% of time	44	-		
		-	-	once every 2-8 yrs	5	-		
	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Ill. during 1973 growing season.	-	-	100	5	5		Bell and Johnson 1974

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Forestiera acuminata Water privet	Study of tree mortality upstream from Alton Dam in S. Ill. Permanent transects sampled at intervals over a 4-year period. Samples grouped by location: land, mud, water.	land	-	240	18	100%		Yeager 1949
		mud	-	240	5	100%		
		water	-	240	47	68%		
		land	-	730	18	100%		
		mud	-	730	5	100%		
		water	-	730	47	30%		
		land	-	1460	18	100%	Survivors all found in < 102 cm water; 15% survival after 2555 days.	
		mud	-	1460	5	100%		
		water	-	1460	47	17%		
Fraxinus americana White ash	Study of the mortality upstream from Alton Dam in S. Ill. Permanent transects sampled at intervals over a 4-yr period. Samples grouped by location: land, mud, water.	land	-	240	59	100%		Yeager 1949
		mud	-	240	18	100%		
		water	-	240	31	97%		
		land	-	730	59	100%		
		mud	-	730	18	100%		
		water	-	730	31	31%		
		land	-	1460	59	100%		
		mud	-	1460	18	73%	Survivors in 51 cm water; 7% survival after 2555 days.	
		water	-	1460	31	29%		

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Fraxinus pennsylvanica Green ash	Greenhouse study: current year seedlings, 7.6 cm tall, 3/pot flooded in July and August.	51	43	2	3	3	No effect.	Hosner 1958
		51	43	4	3	3	No effect.	
		51	43	8	3	3	No chlorosis, some loss of lower leaves.	
		51	43	16	3	3	Some wilting after removal from flood.	
		51	43	32	3	0	All died.	
	Greenhouse study; current year seedlings, 5/pot flooded in July and August.	.54	-	38	50	5	Height growth reduced to 21% of controls; secondary roots died and were replaced by a new root system in addition to adventitious rooting; chlorosis observed; plants recovered in 60 days after removal from flood.	Hosner 1959
	Greenhouse study; current year seedlings, 19 cm tall, 5/pot flooded 14 Jul-21 Aug; 60-day recovery period after drainage.	61	-	5	15	15	No effect.	Hosner 1960
		61	-	10	15	14	Rapid recovery.	
		61	-	20	15	14	3 survivors lost terminals; recovered rapidly.	
		61	-	20	15	14	2 survivors lost terminals; recovered slowly.	

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Fraxinus pennsylvanica Green ash	Greenhouse study; current year seedlings, 5/pot established as material seed became available.	2.5	-	60	15	15	No shoot mortality; many adventitious roots, some dead secondary roots but many new tips.	Hosner and Boyce 1962
	Greenhouse study with current year seedlings to determine effects of different moisture regimes on growth.	Soil saturated	-	84	12	12	Out of 4 moisture treatments, plants in saturated soil (the wettest treatment) did best.	Dickson, Hosner, and Hosley 1965
	Controlled field experiment, natural stands in Miss. Delta flooded.	90, max	-	210	9	9	Saplings: 17% growth increase over control.	Broadfoot 1967
					14	14	Poles: 80% growth increase over control.	
					24	24	Timber: 90% growth increase over control.	
	Observations of tree mortality in Miss. stand flooded continuously for 4 yrs.	< 30	-	1460	-	-	Among few species able to survive into fourth growing season	Broadfoot and Williston 1973

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions			No. of plants	No. or % survival	Comments	Authority
		Depth, cm		Duration: consecutive days or as noted				
		Over root crown or as noted	Over terminal bud					
Fraxinus pennsylvanica Green ash	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Ill. during 1973 growing season.	-	-	109	8	8		Bell and Johnson 1974
		-	-	149	68	68		
		-	-	189	82	82		
	Report of impacts of 1973 flood during spring and early summer on 1-, 10-, and 11-yr-old plantations.	76-198	-	60	-	-	1-yr-old plantation not yet leafed out when flooded; emerging leaves were killed but were replaced when flood receeded. Older plantations not affected.	Kennedy and Krinnard 1974
	Sapling survival observed in a hardwood forest along the Miss. River in La. before and after flood during 1973 growing season.	240-480	-	105	-	-	Trees generally able to survive	Noble and Murphy 1975
Gleditsia aquatica Water locust	Study of tree mortality upstream from Alton Dam in S. Ill. Permanent transects sampled at intervals over 4-yr period. Samples grouped by location: land, mud, water.	land	-	240	24	100%		Yeager 1949
		mud	-	240	2	100%		
		water	-	240	25	64%		

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Gleditsia aquatica Water locust		land	-	730	24	96%		Yeager 1949
		mud	-	730	2	100%		
		water	-	730	25	8%		
		land	-	1460	24	96%		
		mud	-	1460	2	0%		
		water	-	1460	25	4%	Survivors in < 25 cm water, 28-38 cm dbh. (dbh=diameter breast height)	
	Correlated flood frequency and duration in the lower White River valley, Ark., with forest composition.	-	-	29-40% of time	83	-		Bedinger 1971
		-	-	10-21% of time	0	-		
		-	-	once every 2-8 yrs	0	-		
Gleditsia triacanthos Honey locust	Controlled field study; 50-yr-old natural stands in Miss. flooded Feb-Jul every year for 4 yrs.	90. max	-	150	5	-	Timber and pole size 53% increase in radial growth over control.	Broadfoot 1967
	Correlated flood frequency and duration in the lower White R. valley, Ark., with forest composition.	-	-	29-40% of time	0	-		Bedinger 1971
		-	-	10-21% of time	4	-		
		-	-	once every 2-8 yrs	0	-		

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Gleditsia triacanthos Honey locust	Study of tree mortality during flood surcharge around Rend Lk. and Lk. Shelbyville in Illinois during 1973 growing season.			109	26	100%		Bell and Johnson 1974
				149	26	100%		
				189	26	100%		
	Study of sapling mortality resulting from March-July flood of Miss. River.	244-488		105			Saplings either killed or growth severely retarded.	Noble and Murphy 1975
Gymnocladus dioicus Kentucky coffee tree	Study of tree mortality upstream from Alton Dam in S. Ill. Permanent transects sampled at intervals over 4-yr period. Samples grouped by location: land, mud, water.	land		240	1	100%		Yeager 1949
		mud		240	0	100%		
		water		240	0	100%		
		land		730	1	100%		
		mud		730	0	100%		
		water		730	0	100%		
		land		1460	1	100%		
		mud		1460	0	100%		
		water		1460	0	100%		

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Ilex decidua Deciduous holly	Correlated flood frequency and duration in the lower White River valley with forest composition.			29-40% of time	0	-		Bedinger 1971
				10-21% of time	3	-		
				and every 2-8 yrs	1	-		
	Study of sapling mortality resulting from March-July flood of Miss. River.	244-488		105	-	-	Saplings generally able to recover.	Noble and Murphy 1975
Ilex opaca American holly	Study of tree mortality upstream from Alton Dam in S. Ill. Permanent transects sampled at intervals over 4-yr period. Samples grouped by location: land, mud, water.	land		240	6	100%		Yeager 1949
		mud		240		100%		
		water		240	3	75%		
		land		730	6	100%		
		mud		730	1	100%		
		water		730	8	0		
		land		1460	6	100		
		mud		1460	1	100		
		water		1460	8	0		

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Juglans nigra Black walnut	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Ill. during 1973 growing season.	-	-	50	4	100%	Ranked as somewhat tolerant by authors, able to survive 90-150 days of flooding. (This is unusually tolerant for *J. nigra*.	Bell and Johnson 1974
				109	4	100%		
				149	4	0		
				189	4	0		
	Report of mortality in 10- and 11-yr-old plantations resulting from flood during 1973 growing season (Apr-Sept).	-	-	180	-	0%	All trees dead.	Kennedy and Krinnard 1974
Liquidambar styraciflua Sweetgum	Greenhouse study, current year seedlings, 7.6 cm tall, 3/pot flooded in July and August.	50.8	43.2	2	3	3	Necrotic leaf margins, rapid recovery.	Hosner 1958
		50.8	43.2	4	3	3	Necrotic leaves, mostly lower; slow recovery.	
		50.8	43.2	8	3	3	Leaf chlorosis, slow recovery.	
		50.8	43.2	16	3	2	Survivors had small dead areas on leaves.	
		50.8	43.2	32	3	0	All dead.	

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Liquidambar styraciflua Sweetgum	Greenhouse study; current year seedlings, 5/pot under conditions similar to other Hosner 1960 trials; no height recorded. 60-day recovery period after drainage.	61	-	5	15	14	4 lost terminals, recovered rapidly.	Hosner 1960
		61	-	10	15	10	Medium recovery.	
		61	-	20	15	0		
		61	-	30	15	0		
	Greenhouse study; current year seedlings, 5/pot, 30 cm tall established as natural seed became available; flooded 27 Jul-27 Sep., Only 60 day data presented here.	2.5	-	60	15	15	No shoot mortality or adventitious roots; secondary roots died while upper laterals grew to surface.	Hosner and Boyce 1962
	Controlled field experiment; natural stands in Miss. Delta flooded Feb-Jul for 4 yrs to assess effect on growth.	90, max	-	210	6	6	Sapling: 82% growth increase over control.	Broadfoot 1967
					37	37	Pole: 77% growth increase over control.	
					25	25	Timber: 86% growth increase over control.	

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions			No. of plants	No. or % survival	Comments	Authority
		Depth, cm						
		Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted				
Liquidambar styraciflua Sweetgum	Correlated flood frequency and duration in the lower White R. valley, Ark., with forest composition.	-	-	29-40% of time	0	-		Bedinger 1971
				10-21% of time	85	-		
				once every 2-8 yrs	76	-		
	Observations of tree mortality in Miss. stand flooded continuously for 4 yrs.	<30	-	1460	-	-	Dead after third year.	Broadfoot and Williston 1973
	Report of impacts of 1973 flood during spring and early summer on 1-, 10-, and 11-yr-old plantations.	198, max	-	58	-	∿ 100%	1-yr-old plantation leafing out when flooded.	Kennedy and Krinnard 1974
		-	-	88	-	0	1-yr-old plantation.	
		-	-	-	-	∿ 100%	10- and 11-yr-old plantations.	
	Sapling survival observed in a hardwood forest along Mississippi River in La. after flood during 1973 growing season.	240-480	-	105 (116 max)	-	-	Many small seedlings and saplings killed.	Noble and Murphy 1975

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Liriodendron tulipifera Tulip tree	Report of impacts of 1973 flood during spring and early summer on plantations of various ages.	198,max	-	30	-	0%	1-yr-old plantation; leaves wilted	Kennedy Krinard 1974
		198,max	-	45	-	0%	1-yr-old plantation; trees killed.	
		213	-	60	-	0%	11-yr-old plantation killed; trees averaged 17 cm diameter breast height (dbh)	
		91	-	60	-	0%	15-yr-old plantation killed; trees averaged 20 cm dbh and 22 m tall.	
Morus rubra Red mulberry	Study of tree mortality upstream from Alton Dam in Ill. over a period of 4 yrs. Samples grouped by location: land, mud, water.	land		240	15	100%	Typically not a swamp species but apparently able to survive some rise in the water table.	Yeager 1949
		mud		240	0	-		
		water		240	0	-		
		land		730	15	100%		
		mud		730	0	-		
		water		730	0	-		
		land		1460	15	100%		
		mud		1460	0	-		
		water		1460	0	-		

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Nyssa aquatica Water tupelo	Controlled field experiment using 10-month-old seedlings averaging 46 cm tall.	8		120	30	100%	52 cm height increase.	Kennedy 1970
				150	30	98%	29 cm height increase.	
				180	30	100%	39 cm height increase.	
		15-25		120	30	92%	27 cm height increase.	
				150	30	100%	30 cm height increase.	
				180	30	95%	17 cm height increase.	
			10-15	120	30	93%	17 cm height increase.	
				150	30	87%	-6 cm height decrease.	
				180	30	32%	-24 cm height decrease.	
		0				95%	Control: 61 cm height increase.	
							Siltation decreased survival to 87% in 15-25 cm flood. Reflooding for 14 days in August reduced survival and caused dieback on survivors.	
	Greenhouse study; current year seedlings grown under 4 different moisture regimes to determine effects on growth.	Soil kept saturated	-	84	12	12	Growth was significantly better under continuous saturation. Growth restricted under moisture equivalent regime.	Dickson, Hosner, and Hosley 1965

(Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Nyssa aquatica Water tupelo	Ecological study of a baldcypress-tupelo swamp in La. Swamp flooded for 90 days every spring with soil remaining saturated for rest of year.	15-30	-	90	-	-	Importance value of 37.58 where IV = relative frequence + relative dominance + relative density. Second only to baldcypress, with IV = 39.20.	Connor and Day 1976
Nyssa sylvatica Black gum	Correlated flood frequency and duration with forest composition in White River valley, Ark.	-	-	29-40% of time	0	-	The genus and species both exhibit a range of flooding tolerances. Provenience is important when selecting planting stock.	Bedinger 1971

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Pinus echinata Shortleaf pine	Observation of planting in a permanent pool and detention pond in Northern Miss. for 3 consecutive growing seasons.	48		105	-	0%	1st winter flood; no survivors in this area.	Williston 1962
		Sat. soil		60	-	-	2nd winter flood didn't lessen survival (sic.).	
		Sat. soil	-	-	-	-	Height growth reduced by 25-50% when roots flooded for winters of 3 consecutive years.	
Pinus taeda Loblolly pine	Same as above.	-	Flooded over terminal to unspecified depth.	180	-	0%		Williston 1962
		Sat. soil	Flooded over terminal to unspecified depth.	120	-	79%	30 days of complete submergence followed by 90 days of root submergence.	
			Flooded over terminal to unspecified depth.	180	-	0%		

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Pinus taeda Loblolly pine	2-yr-old potted plants flooded outside for varying periods of time beginning 3 Jan; stem, foliage, and root parameters measured as well as nutrient level in foliage.	-	-	0	9	9		Burton 1972
		soil sat.	-	49	9	9	49-day treatment gave best performance on all parameters.	
		soil sat.	-	98	9	9		
		soil sat.	-	147	9	9	147-day treatment gave poorest performance. Seedling size class had no apparent effect on performance.	
	Report of impact of 1973 Miss. flood on 15-yr-old plantation; flooded during growing season.	-	-	60	-	100%	Two months of flooding during growing season had no injurious effects.	Kennedy and Krinard 1974
Planera aquatica Water elm	Correlated flood duration and frequency with forest composition in the lower White River valley, Ark.	-	-	29-40% of time	37	-		Bedinger 1971
		-	-	10-21% of time	0	-		
		-	-	once every 2-8 yrs	0	-		

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Platanus occidentalis Sycamore	Greenhouse study; current year seedlings, 11.7 cm tall, 5/pot, flooded 14 Jul-21 Aug 60-day recovery period after drainage.	.64	-	38	5	5	Developed adventitious roots and leaf chlorosis followed by reddening, height growth 13% of controls.	Hosner 1959
	Greenhouse study; current year seedlings, 5/pot, 11.7 cm tall, flooded 2 July - 1 Aug.	61	49	5	15	15	Rapid recovery.	Hosner 1960
		51	49	10	15	15	Medium recovery.	
		61	49	20	15	0	All dead.	
		61	49	30	15	0	All dead.	
	Greenhouse study; current year seedlings, 31 cm tall, 5/pot established as natural seed became available. Flooded 27 Jul-27 Sep. Only 60-day data presented here.	2.5	-	60	15	73%	Many adventitious roots, all secondary and lower primary roots died. Classed as intermediate tolerance by authors.	Hosner and Boyce 1962

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions			No. of plants	No. or % survival	Comments	Authority
		Depth, cm						
		Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted				
Platanus occidentalis Sycamore	Greenhouse study; current year seedlings grown under 4 different moisture regimes to determine effects on growth.	soil kept saturated	-	84	12	12	Best growth achieved in treatment which involved watering to moisture equivalent.	Dickson, Hosner, and Hosley 1965
	17-day-old seedlings kept in pots in saturated soil in early June.	-2.5	-	0-32	20	95%	32-day treatment resulted in slight stunting; rapid recovery.	McDermott 1954
	Study of tree mortality upstream from Alton Dam in S. Ill. Permanent transects sampled at intervals over a 4-yr period Samples grouped by location: land, mud, water.	land		240	6	100%		Yeager 1949
		mud		240	0	-		
		water		240	0	-		
		land		730	6	100%		
		mud		730	0	-		
		water		730	0	-		

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions			No. of plants	No. or % survival	Comments	Authority
		Depth, cm		Duration: consecutive days or as noted				
		Over root crown or as noted	Over terminal bud					
Platanus occidentalis		land		1460	6	100%		Yeager 1949
Sycamore		mud		1460	0	-		
		water		1460	0	-		
	Correlated flood duration and frequency with forest composition in the lower White River valley, Ark.	-	-	29-40% of time	3	-		Bedinger 1971
		-	-	10-21% of time	1	-		
		-	-	once every 2-8 yrs	0	-		Bedinger 1971
	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Ill. during 1973 growing season.	-	-	129	4	100%		Bell and Johnson 1974
		-	-	169	4	100%		

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Platanus occidentalis Sycamore (continued)	Report of mortality in plantations of various ages after 1973 flood.	-	tops emergent	-	-	~ 100%	1 yr old: infected with Anthracnose but recovered when water receded.	Kennedy and Krinard 1974
		-	-	-	-	100%	11-yr-old plantation survived in good condition.	
		-	-	180	-	100%	10- to 11-yr-old plantation flooded March-August; healthy in September.	
		-	-	-	-	100%	Coppice, cut in Jan 73 sprouted when water receded.	
		-	tops covered	-	-	0%	Seedlings planted in January 73 all died.	
Populus deltoides Cottonwood	Greenhouse study; current year seedlings, 7.6 cm tall, 3/pot, flooded July and August.	50.8	43.2	2	3	3	Some leaf necrosis; rapid recovery.	Hosner 1958
		50.8	43.2	4	3	3	Leaf necrosis; rapid recovery.	
		50.8	43.2	8	3	3	Leaf abscission; slow recovery.	
		50.8	43.2	16	3	0	All died.	
		50.8	43.2	32	3	0	All died.	

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
<u>Populus deltoides</u> Cottonwood	Greenhouse study; current year seedlings, 5/pot, flooded July 14-21 Aug, 60-day recovery period after drainage.	.64	-	38	5	5	Original roots died and were replaced by extensive adventitious system. Slight chlorosis; height growth 77% of controls.	Hosner 1959
	Greenhouse study; current year seedlings, 7.11 cm tall, 5/pot, flooded 2 Jul-1 Aug.	61	54	5	15	15	No effect.	Hosner 1950
		61	54	10	15	14	Rapid recovery.	
		61	54	20	15	11	2 survivors lost terminals; slow recovery.	
		61	54	30	15	7	2 lost terminals; slow recovery.	
	Greenhouse study; current year seedlings, 13.4 cm tall, 5/pot, established as natural seed became available. <u>Flooded 27 Jul-27 Sep.</u> Only 60 day data presented here.	2.5	-	60	15	93%	Many adventitious roots; all roots except primary died. Ranked as intermediate tolerance by authors.	Hosner and Boyce 1962

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Populus deltoides Cottonwood	Study of tree mortality upstream from Alton Dam in S. Ill. Permanent transects sampled at intervals over a 4-yr period. Samples grouped by location: land, mud, water.	land	-	240	5	100%		Yeager 1949
		mud	-	240	1	100%		
		water	-	240	9	89%		
		land	-	730	5	100%		
		mud	-	730	1	100%		
		water	-	730	9	0%		
		land	-	1460	5	100%		
		mud	-	1460	1	100%		
		water	-	1460	9	0%		
	Comparison of survival of first year cuttings and seedlings on a low site in a wet year.						Seedlings survive inundation better than cuttings.	Bull and Putnam 1941
	Controlled field experiment; natural strands in Miss. Delta, flooded Feb-Jul for 4 yrs to assess af[illegible] on growth.	90 max.		210	8	8	Timber size; 90% growth increase over controls.	Broadfoot 1967

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions Depth, cm Over root crown or as noted	 Over terminal bud	 Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Populus deltoides Cottonwood	Comparison of survival of seedlings and cuttings on a Miss. site flooded during spring; post-flood cuttings planted for comparison.			±75; 1st season	-	90%	1-0 seedlings, planted in Jan.	Maisenhelder and McKnight 1968
					-	16%	102-cm cuttings, planted in Jan.	
					-	19%	51-cm cuttings, planted in Dec.	
					-	41%	51-cm cuttings, planted in June	
				±75, 2nd season	-	87%	1-0 seedlings, planted in Jan.	
					-	16%	102-cm cuttings, planted in Jan.	
					-	15%	51-cm cuttings, planted in Dec.	
					-	24%	51-cm cuttings, planted in June.	
	Correlated flood duration and frequency with forest composition in the lower White River valley, Ark.	-	-	29-40% of time	1	-		Bedinger 1971
		-	-	10-21% of time	0	-		
		-	-	once every 2-8	0	-		
	Report mortality in various plantations resulting from flood in spring, 1973.	61-183	-	90	- - -	24% 18% 50%	Current year's cuttings.	Kennedy and Krinard 1974
		61-183	-	90	-	100%	1-yr-old cuttings in leaf, with emergent tips.	

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions					Comments	Authority
		Depth, cm						
		Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival		
Populus deltoides Cottonwood		61-183	-	90	-	70%	Stump sprouts on 2-to 3-yr-old rootstock stump 25.4 cm tall.	Kennedy and Krinnard 1974
		61-183	-	90	-	20%	Stump sprouts on 2-to 3-yr-old rootstock, stump level with ground.	
	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Ill. during 1973 growing season.	-	-	149	7	100%	Ranked by authors as tolerant; able to survive more than 150 days of flooding.	Bell and Johnson 1974
		-	-	189	7	100%		
Prunus americana Wild plum	Study of tree mortality upstream from Alton Dam in S. Ill. Permanent transects sampled at intervals over a 4-yr period. Samples grouped by location: land, mud, water.	land	-	240	1	100%	Tolerance to a rise in the water table is impossible to infer from this study, since depth to water table was not studied.	Yeager 1949
		mud	-	240	0	-		
		water	-	240	0	-		
		land	-	730	1	100%		
		mud	-	730	0	-		
		water	-	730	0	-		
		land	-	1460	1	100%		
		mud	-	1460	0	-		
		water	-	1460	0	-		

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Prunus serotina Black cherry	Correlated flood frequency and duration with forest composition in the lower White River valley, Ark.	-	-	29-40% of time	0	-		Bedinger 1971
		-	-	10-21% of time	0	-		
		-	-	every 2-8 yrs	2	-		
	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Ill. during 1973 growing season.	-	-	149	3	0	Ranked as intolerant by authors; severely injured by under 50 days of flooding.	Bell and Johnson 1974
		-	-	189	3	0		
Quercus alba White oak	Correlated flood frequency and duration with forest composition in the lower White River valley, Ark.	-	-	29-40% of time	0	-		Bedinger 1971
		-	-	10-21% of time	0	-		
		-	-	once every 2-8 yrs	27	-		
	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Illinois during 1973 growing season.	-	-	50	58	100%	Ranked as slightly tolerant by authors; surviving 50-100 days of flooding.	Bell and Johnson 1974
		-	-	109	58	54%		
		-	-	149	58	0%		
		-	-	189	58	0%		

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Quercus bicolor Swamp white oak	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Ill. during 1973 growing season.	-	-	49	4	100%	Ranked as tolerant by authors; surviving more than 150 days of inundation.	Bell and Johnson 1974
		-	-	149	4	100%		
	Report of condition of 15-yr-old plantation in Miss. after 2 months flood during 1973 growing season.	-	-	60	-	100%	No apparent damage.	Kennedy and Krinard 1974
Quercus falcata Spanish oak	Greenhouse study; current year seedlings, 5/pot, flooded 14 Jul-21 Aug, 60-day period after drainage.	.64	-	38	5	4	Severe chlorosis; secondary roots died; no adventitious roots. No new leaf or top growth during recovery period. var. pagodaefolia used in this study.	Hosner 1959
	Greenhouse study; current year seedlings, 5/pot, 14 cm tall, flooded 2 Jul-1 Aug.	61	49	5	15	13	Survivors recovered moderately fast.	Hosner 1960
		61	49	10	15	1	Recovery very slow.	
		61	49	20	15	0	All dead.	
		51	49	30	15	0	All dead.	
							var. pagodaefolia used in this study.	

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions				No. of plants	No. or % survival	Comments	Authority
		Depth, cm							
		Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted					
Quercus falcata Spanish oak	Greenhouse study; current year seedlings, 71 cm tall, established as natural seed became available. Flooded 27 Jul-27 Sep. Only 60 day data presented here.	2.5	-	60		15	-	87% shoot dieback. All roots died, no adventitious roots produced.	Hosner and Boyce 1962
	Correlated flood frequency and duration with forest composition in the lower White River valley, Ark.	-	-	29-40% of time		0	-		Bedinger 1971
		-	-	10-21% of time		0	-		
		-	-	once every 2-8 yrs		131	-		
	Report on condition of 1-yr-old plantation in Miss. flooded during 1973 growing season.	-	-	60		-	100%	No apparent damage.	Kennedy and Krinnard 1974
Quercus imbricaria Shingle oak	Study of tree mortality during flood surcharge of Rend Lk. and Lk. Shelbyville in Ill. during 1973 growing season.	-	-	50		14	100%	Ranked as somewhat tolerant by authors, surviving 90-150 days of flooding.	Bell and Johnson 1974
		-	-	109		14	100%		
		-	-	149		14	0%		
		-	-	189		14	0%		

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Quercus lyrata Overcup oak	Controlled field experiment, natural stands in Miss. Delta flooded Feb-Jul for 4 yrs to determine effects on growth.	Max.	-	210	7	-	Timber sized; 20% radial growth increase over control. Genus as a whole benefited very little from flood treatment.	Broadfoot 1967
	Correlated flood frequency and duration with forest composition in the lower White River valley, Ark.	-	-	29-40% of time	209	-		Bedinger 1971
		-	-	10-21% of time	125	-		
		-	-	once every 2-8 yrs	2	-		
Quercus macrocarpa Bur oak	Study of tree mortality upstream from Alton Dam in S. Ill. Permanent transects sampled at intervals over a 4-yr period. Samples grouped by land, mud, water.	land	-	240	3	100%		Yeager 1949
		mud	-	240	0	-		
		water	-	240	5	-		
		land	-	730	3	100%		
		mud	-	730	0	-		
		water	-	730	5	0%		
		land	-	1460	3	100%		
		mud	-	1460	0	-		
		water	-	1460	5	0%		

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Quercus macrocarpa Bur oak	Observations of tree mortality in Miss. stand flooded continuously for 4 yrs.	< 30	-	1460	-	-	Dead after 4th season.	Broadfoot and Williston 1973
	Study of tree mortality during flood surcharge at Rend Lk. & Lk. Shelbyville in Ill. during 1973 growing season.	-	-	189	13	100%	Ranked as tolerant by authors; survived more than 150 days of flooding.	Bell and Johnson 1974
Quercus marilandica Blackjack oak	Correlated flood frequency and duration with forest composition River valley, Ark.	-	-	29-40% of time	0	-	2 individuals found on a site never flooded.	Bedinger 1971
		-	-	10-21% of time	0	-		
		-	-	once every 2-8 yrs	0	-		
Quercus nigra Water oak	Correlated flood frequency and duration with forest composition in the lower White River valley, Ark.	-	-	29-40% of time	0	-		Bedinger 1971
		-	-	10-21% of time	29	-		
		-	-	once every 2-8 yrs	17	-		

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Quercus nigra Water oak	Observations of tree mortality in Miss. stand flooded continuously for 4 yrs.	< 30	-	1460	-	-	Dead after 3rd season.	Broadfoot and Williston 1973
	Report on condition of 1-yr-old plantation in Miss. flooded during 1973 growing season.	-	-	60	-	100%	No apparent injury.	Kennedy and Krinard 1974
Quercus nuttallii Nuttall's oak	Correlated flood frequency and duration with forest composition in the lower White River valley, Ark.	-	-	29-40% of time	16	-		Bedinger 1971
		-	-	10-21% of time	128	-		
		-	-	once every 2-8 yrs	2	-		
	See above: Kennedy and Krinard 1974.	-	-	60	-	100%	No apparent damage.	Kennedy and Krinard 1974

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Quercus palustris Pin oak	Greenhouse study; current year seedlings, 5/pot, flooded 14 July-21 Aug. 60-day recovery period after drainage.	.64	-	38	5	5	Severe chlorosis, no height growth, secondary roots died, no adventitious roots.	Hosner 1959
	Greenhouse study; current year seedlings, 14.7 cm tall, 5/pot, flooded 2 Jul-1 Aug.	61	46.3	5	15	15	Rapid recovery.	Hosner 1960
		61	46.3	10	15	14	Slow recovery.	
		61	46.3	20	15	4	Very slow recovery.	
		61	46.3	30	15	0	All dead.	
	Greenhouse study; current year seedlings, 20.8 cm tall, 5/pot, established as natural seed became available. Flooded 27 Jul-27 Sep. Only 60 day data presented here.	2.5	-	60	15	15	Sparse adventitious rooting, some mortality of secondary roots. Ranked as intermediate tolerance by authors.	Hosner and Boyce 1962

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions Depth, cm Over root crown or as noted	 Over terminal bud	 Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Quercus palustris Pin oak	Greenhouse study; current year seedlings grown under 4 different moisture regimes to determine effects on growth.	soil kept saturated	-	84	12	12	Best growth under moisture equivalent watering regime; saturated soil killed the root system and adventitious roots were virtually nonexistent.	Dickson, Hosner and Hosley 1965
	Study of tree mortality upstream from Alton Dam in S. Illinois. Permanent transects sampled at intervals over a 4-yr period. Samples grouped by location: land, mud, water.	land	-	240	46	96%	Trees in < 76.2 cm water, maximum.	Yeager 1949
		mud	-	240	5	100%		
		water	-	240	28	71%		
		land	-	730	46	80%		
		mud	-	730	5	0%		
		water	-	730	28	0%		
		land	-	1460	46	72%		
		mud	-	1460	5	0%		
		water	-	1460	28	0%		

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Quercus palustris Pin oak	Correlated flood frequency and duration with forest composition in the lower White River valley, Ark.	-	-	29-40% of time	0	-		Bedinger 1971
		-	-	10-21% of time	0	-		
		-	-	once every 2-8 yrs	4	-		
	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Ill. during 1973 growing season.	-	-	109	4	100%	Ranked as tolerant by authors.	Bell and Johnson 1974
Quercus phellos Willow oak	Greenhouse study; current year seedlings, 24.8 cm tall, 5/pot, established as natural seed became available. Flooded 27 Jul-27 Sep. Only 60 day data presented here.	2.5	-	60	15	15	No shoot mortality No adventitious roots.	Hosner and Boyce 1962

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions Depth, cm Over root crown or as noted	 Over terminal bud	 Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Quercus phellos Willow oak	Controlled field experiment, natural stands in Miss. Delta flooded Feb-Jul for 4 yrs to determine effects on growth.	90, max	-	210	20	-	Timber size; 10% radial growth increase over control.	Broadfoot 1967
	Correlated flood frequency and duration with forest composition in the lower White River valley, Ark.	-	-	29-40% of time	0	-		Bedinger 1971
		-	-	10-21% of time	80	-		
		-	-	once every 2-8 yrs	73	-		
	Observations of tree mortality in Miss. stand flooded for 4 yrs.	< 30	-	1460	-	-	Most trees died during 3rd year.	Broadfoot and Williston 1973

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Quercus rubra Red oak	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Ill. during 1973 growing season.	-	-	50	16	100%	Ranked as slightly tolerant by authors; survive 50-100 days of flooding.	Bell and Johnson 1974
Quercus shumardii Shumard oak	Greenhouse study; current year seedlings, 13 cm tall, 5/pot, flooded 2 Jul-1 Aug.	61	48	5	15	15	Only 2 plants grew after flooding.	Hosner 1960
		61	48	10	15	15	Slow recovery.	
		61	48	20	15	0	All dead.	
		61	48	30	15	0	All dead.	
	Greenhouse study; current year seedlings, 21.3 cm tall, 5/pot, established as natural seed became available. Flooded 27 Jul-27 Sep. Only 60 day data presented here.	2.5	-	60	15	15	33.3% shoot mortality no adventitious roots, some dead secondary roots.	Hosner and Boyce 1962

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Quercus shumardii Shumard oak	Correlated flood frequency and duration with forest composition in the lower White River valley, Ark.	-	-	29-40% of time	-	-		Bedinger 1971
		-	-	10-21% of time	0	-		
		-	-	once every 2-8 yrs	9	-		
	Report on condition of several Miss. plantations flooded during 1973 growing season.	76-198	-	75	-	10%	January planting of seedlings.	Kennedy and Krinard 1974
		-	-	75	-	100%		
Quercus [illegible]llata Post oak	Correlated flood frequency and duration with forest composition in the lower White River valley, Ark.	-	-	29-40% of time	0	-	10 individuals found on sites never flooded.	Bedinger 1971
		-	-	10-21% of time	0	-		
		-	-	once every 2-8 yrs	32	-		

(Continued)

Table Al (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Quercus velutina Black oak	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville in Ill. during 1973 growing season.	-	-	50	13	66%	Ranked as intolerant by authors; severe injury from under 50 days of flooding.	Bell and Johnson 1974
		-	-	109	13	0%		
		-	-	149	13	0%		
		-	-	189	13	0%		
Salix nigra Black willow	Greenhouse study; current year seedlings, 7.6 cm tall, 3/pot, flooded in July and August.	50.8	43.2	2	3	3	No effect.	Hosner 1958
		50.8	43.2	4	3	3	Lower leaves abscissed, rapid recovery.	
		50.8	43.2	8	3	3	Lower leaves abscissed, slight chlorosis, rapid recovery.	
		50.8	43.2	16	3	3	Lower leaves abscissed, slight chlorosis, rapid recovery.	
		50.8	43.2	32	3	3	Severe chlorosis, rapid recovery.	
	Greenhouse study: current year seedlings, 8 cm tall, 5/pot, flooded 2 Jul-1 Aug.	61	53	5	15	15	No effect.	Hosner 1960
		61	53	10	15	15	No effect.	
		61	53	20	15	15	Rapid recovery.	
		61	53	30	15	13	3 lost terminals, recovered rapidly.	

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions [illegible] Over root crown or as noted	 Over terminal bud	 Time: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Salix nigra Black willow	Study of tree mortality upstream from Alton Dam in Ill. Permanent transects sampled at intervals over 4-yr period. Samples grouped by location: land, mud, water	land	-	240	0	-		Yeager 1949
		mud	-	240	0	-		
		water	-	240	23	37%		
		land	-	730	0	-		
		mud	-	730	0	-		
		water	-	730	23	61%		
		land	-	1460	0	-		
		mud	-	1460	0	-		
		water	-	1460	23	56%	39% survival in 1946. More than half of the mortality occurred in > 104 cm of water.	
	Study of tree mortality resulting from flood surcharge at Rend Lk. and Lk. Shelbyville, Ill., during 1973 growing season.	-	-	189	1	1		Bell and Johnson 1974

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Salix nigra Black willow	Ecological study of a baldcypress - water tupelo swamp in La.	-	-	-	-	-	Importance value of .88 where IV= relative frequency + relative dominance + relative density.	Connor and Day 1976
Sassafras albidum Sassafras	Study of tree mortality resulting from flood surcharge at Rend Lk. and Lk. Shelbyville, Ill., during 1973 growing season.	-	-	49	5	100%	Ranked as intolerant by authors.	Bell and Johnson 1974
				109	5	100%		
				149	5	0%		
				189	5	0%		
Taxodium distichum Baldcypress	1- to 4-yr-old seedlings 20-30 cm high were submerged in the St. Francis River, Ark., from 26 June-6 Jul.	200		11	30	0		Demaree 1932
		300		11	80	1		
		100		11	80	0		
		2-3		11	80	0		
		2-3		11	80	2		
	Correlated flood frequency and duration with forest composition in the lower White River valley, Ark.	-	-	29-40% of time	117	-		Bedinger 1971
		-	-	10-21% of time	0	-		

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Taxodium distichum Baldcypress		-	-	once every 2-8 yrs	1	-		
	Ecological study of baldcypress - water tupelo swamp in La.	-	-	-	-	-	Importance value= 39.2, where IV= relative frequency + relative density + relative dominance.	Conner and Day 1976
Ulmus alata Winged elm	17-day-old seedlings placed in saturated soil in June.	-2.5		0-32	20	100%	Growth stunted in all treatments except 1 day.	McDermott 1954
	Correlated flood frequency and duration with forest composition in the lower White River valley, Ark.	- - -	- - -	29-40% of time 10-21% of time once every 2-8 yrs	0 13 79	- - -		Bedinger 1971

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions Depth, cm Over root crown or as noted	 Over terminal bud	 Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Ulmus americana American elm	Greenhouse study; current year seedlings, 23 cm tall, 5/pot, flooded 2 Jul-1 Aug.	61	38	5	15	15	14 developed "side branches."	Hosner. 1960
		61	38	10	15	15	7 lost terminals; recovered rapidly.	
		61	38	20	15	4	Survivors lost terminals; sprouted weakly.	
		61	38	30	15	0	All dead.	
	Greenhouse study; current year seedlings, 37 cm tall, 5/pot established as natural seed became available. Flooded 27 Jul-27 Sep. Only 60 day data presented here.	2.5	-	60	15	15	6.7% shoot.	Hosner and Boyce 1962
	Study of tree mortality upstream from Alton Dam, Ill. Permanent transects sampled at intervals over 4-yr period. Samples grouped by location: land, mud, water.	land	-	240	98	99%		Yeager 1949
		mud	-	240	37	100%		
		water	-	240	104	78%		

(Continued)

Table A1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Ulmus americana American elm		land	-	730	98	95%		
		mud	-	730	37	86%		
		water	-	730	104	0%		
		land	-	1460	98	94%		
		mud	-	1460	37	49%		
		water	-	1460	104	0%		
	Correlated flood frequency and duration with forest composition in lower White River valley, Ark.	-	-	29-40% of time	4	-		Bedinger 1971
		-	-	10-21% of time	47	-		
		-	-	once every 2-8 yrs	29	-		
	Observations of tree mortality in Miss. in stand flooded for 4 consecutive years.	< 30	-	1460	-	-	Trees died during second year.	Broadfoot and Williston 1973

(Continued)

Table A1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Ulmus americana American elm	Study of tree mortality during flood surcharge at Rend Lk. and Lk. Shelbyville, Ill., during 1973 growing season.	-	-	49	102	100	Ranked as somewhat tolerant by authors; generally killed by 90-150 days of flooding.	Bell and Johnson 197
		-	-	109	102	98		
		-	-	149	102	77		
		-	-	189	102	91		
	Mortality observed in understory as result of 1973 flood during growing season.	243-488	-	105	-	-	Species was killed or severely retarded by flood.	Noble & Murphy 1975
Ulmus rubra Slippery elm	Study of tree mortality upstream from Alton Dam, Ill. Permanent transects sampled at intervals over 4-yr. period. Samples grouped by location: land, mud, water.	land		240	1	100%		Yeager 1949
		mud			0	-		
		water			0	-		
		land		730	1	100%		
		mud			0	-		
		water			0	-		

(Continued)

Table A7 (Concluded)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Ulmus rubra		land		1460	1	100%		
Slippery elm		mud			0	-		
		water			0	-		

APPENDIX B:

DATA SUMMARY, MISSOURI RIVER DIVISION

Table B1
Data Summary, Missouri River Division

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
<u>Acer negundo</u> Boxelder	Observations of vegetational changes following creation of Harry Strunk Lk., Neb.	30-91					Colonized and thrived on site subject to occasional floods.	Peterson 1957
	Controlled field expt; compared growth & survival of seedlings flooded 1-4 wks in June and July; Kansas	61		28	27	33%		Loucks and Keen 1973
<u>Acer saccharinum</u> Silver maple	Empirical model for tree mortality in the Schell-Osage Wildlife Refuge resulting from surcharge at Harry S. Truman Dam					24%	Based on observed vigor, depth duration predictions, and previous studies of species performance.	U.S. Army Eng. Dist., Kansas City 1973
	See Loucks and Keen 1973 above	61		28	27	90%		Loucks and Keen 1973

(Continued)

Table 31 (Continued)

Species	Experimental method	Conditions Depth, cm Over root crown or as noted	 Over terminal bud	 Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Acer saccharinum Silver maple	Transects sampled around new reservoirs in Iowa & Ill. during 1973 growing season	6^{a*}		119^{b}; 92^{c}	28	100%	a) Elevation above conservation pool, in feet.	Brunk et al. 1975
		5.5^{a}		128; 94	1	100%	b) Total days.	
		4.5^{a}		140; 99	9	11%	c) Days after leafing out.	
		4.0^{a}		148; 106	6	17%		
		3.5^{a}		155; 110	1	100%		
		2^{a}		168^{b}; 112^{c}	3	100%	Data from second reservoir.	
Carya cordiformis Bitternut hickory	See Brunk et al. 1975 above	4^{a*}		148^{b}; 106^{c}	3	0	a, b, & c: see explanation above.	Brunk et al. 1975
Carya illinoensis Pecan	Controlled field experiment compared growth and survival of seedlings flooded 1-4 wks in June and July; Kansas.	61		28	27	75%		Loucks and Keen 1973
	Empirical model for tree mortality in the Schell-Osage Wildlife Refuge resolution from surcharge at Harry S. Truman Dam.					13%	Based on observed vigor, depth duration predictions, and previous studies of species performance.	U.S. Army Eng. Dist., Kansas City 1973

*See comments above for explanation of superscripts.

(Continued)

Table B1 (Continued)

Species	Experimental method	Conditions			No. of plants	No. or % survival	Comments	Authority
		Depth, cm						
		Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted				
Carya laciniosa Shellbark hickory	Transects sampled around new reservoirs in Iowa and Ill. during 1973 growing season	4^{a*}		148^{b}; 106^{c}	8	0	a) Elevation above conservation pool, in feet. b) Total days. c) Days after leafing out.	Brunk et al. 1975
Celtis occidentalis Hackberry	Observations of vegetational changes following creation of Harry Strunk Lk., Neb.						Mature trees killed in 1 yr in flowing seep below dam.	Peterson 1957
	See Brunk et al. 1975 above	4^{a*}		148^{b}; 106^{c}	9	0	a, b, c: see explanation above.	Brunk et al. 1975
Crataegus sp. Hawthorn	See Brunk et al. 1975 above	5.0^{a*}		129^{b}; 83^{c}	1	100%	a, b, c: see explanation above.	Brunk et al. 1975
		2.5		158; 108	2	100%		
		2.0		163; 120	1	0		
		1.0		171; 119	1	0		

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*See Comments above for explanation of superscripts.

(Continued)

Table B1 (Continued)

Species	Experimental method	Conditions Depth, cm Over root crown or as noted	 Over terminal bud	 Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
<u>Fraxinus pennsylvanica</u> Green ash	Transects sampled around new reservoirs in Iowa and Ill. during 1973 growing season.	5.5^{a*}		128^{b}; 94^{c}	1	[illegible]	a) Elevation above conservation pool, in feet. b) Total days. c) Days after leafing out.	Brunk et al. 1975
		4.5		140; 99	1			
		4.2		145; 104	1			
		3.0		161; 114	1	[illegible]		
	Controlled field expt; compared growth and survival of seedlings flooded 1-4 wks in June and July; Kansas.	61		28	27	100%		Loucks and Keen 1973
	Empirical model for tree mortality in the Schell-Osage Wildlife Refuge resulting from surcharge at Harry S. Truman Dam.					15%	Based on observed vigor, depth duration predictions, and previous studies of species performance.	U.S. Army Engineers Dist., Kansas City 1973
<u>Fraxinus pennsylvanica var. lanceolata</u> Green ash	Observations of vegetational changes following creation of Harry Strunk Lk., Neb.						Mature trees killed in 1 yr. in flowing seep below dam.	Peterson 1957

*See Comments above for explanation of superscripts.

(Continued)

Table B1 (Continued)

		Conditions						
		Depth cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Gleditsia triacanthos Honey locust	Transects sampled around new reservoirs in Iowa and Ill. during 1973 growing season.	5^{a*} 3 2 0		129^{b}; 83^{c} 152; 103 163; 112 208; 154	1 1 1 1	1 1 0 0	a) Elevation above conservation pool, in feet. b) Total days. c) Days after leafing out.	Brunk et al. 1975
	Controlled field experiment; compared growth and survival of seedlings flooded 1-4 wks in June and July; Kansas.	61		28	27	65%		Loucks and Keen 1973
Platanus occidentalis Sycamore	See above, Brunk et al. 1975	3^{a*} 2 1.5		152^{b}; 103^{c} 163; 112 168; 116	1 6 1	100% 66% 0	See a, b, c above for explanation.	Brunk et al. 1975
Populus deltoides Cottonwood	Observations of vegetational changes following creation of Harry Strunk Lk., Neb.	30-91		30-90			Colonized and thrived in an area subject to periodic flooding.	Peterson 1957

*See Comments above for explanation of superscripts.

(Continued)

Table B1 (Continued)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Populus deltoides Cottonwood	Controlled field experiment; compared growth and survival of seedlings flooded 1-4 wks in June and July; Kansas.	61		28	27	65%		Loucks and Keen 1973
	Transects sampled around 2 new reservoirs in Iowa and Ill. during 1973 growing season.	6.0^a 4.5		119^b; 92^c 145; 104	8 2	50% 0%	a) Elevation above conservation pool, in feet. b) Total days. c) Days after leafing out.	**Brunk et al. 1975**
Prunus serotina Black cherry	See Brunk et al. 1975 above	4.5^{a*} 3.0 2.5		139^b; 92^c 152; 103 158; 108	1 2 2	0 0 0	a, b, c: see explanation above.	**Brunk et al. 1975**
Quercus bicolor Swamp white oak	Transects sampled around 2 new reservoirs in Iowa and during 1973 growing season.	5^{a*} 4.5 4.2 4.0 3.5		133^b, 96^c 140; 99 145; 104 148;106 155;110	3 6 6 1 5	0% 66% 17% 0% 0%	a) Elevation above conservation pool, in feet. b) Total days. c) Days after leaf out.	**Brunk et al. 1975**

*See Comments above for explanation of superscripts.

(Continued)

Table B1 (Continued)

Species	Experimental method	Conditions Depth, cm Over root crown or as noted	 Over terminal bud	 Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Quercus macrocarpa Bur oak	Controlled field experiment; compared growth and survival of seedlings Flooded 1-4 wks in June and July; Kansas.	61		28	27	55%		Loucks and Keen 1973
Quercus palustris Pin oak	See above, Brunk et al. 1975	5.5[a]*		128[b]; 94[c]	2	50%	a) Elevation above conservation pool, in feet.	Brunk et al. 1975
		5.0		133; 96	4	100%	b) Total days.	
		4.5		140; 99	8	62%	c) Days after leaf out.	
		4.2		145; 104	4	75%		
		4.0		148; 106	35	20%		
		3.5		155; 110	9	11%		
		3.0		161; 114	5	0%		
		5.0		129; 83	3	33%	Second reservoir.	
		4.5		139; 92	3	33%		
		4.0		140; 93	2	0%		
		3.5		146; 98	4	100%		
		3.0		152; 103	7	57%		
		2.5		158; 108	4	75%		
		2.0		163; 112	6	50%		
		1.5		168; 116	9	22%		
		1.0		171; 119	5	20%		
		0.5		192; 139	5	0%		
		0		208; 154	2	0%		
	Empirical model for tree mortality in the Schell-Osage Wildlife Refuge resulting from surcharge at Harry S. Truman Dam.					36%	Based on observed vigor, depth duration predictions and previous studies of species performance.	U.S. Army Eng. Dist., Kansas City 1973

(Continued)

*See Comments above for explanation of superscripts.

Table B1 (Continued)

		Conditions						
		Depth, cm						
Species	Experimental method	Over root crown or as noted	Over terminal bud	Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Salix spp Willow	Observations of vegetational changes following creation of Harry Strunk Lk., Neb.	182		365		100%	Established thicket survived flooding and 91 cm of sedimentation.	Peterson 1957
Symphoricarpos occidentalis Snowberry	See Peterson 1957 above	61		30		100%	Flood occurred during May and June.	Peterson 1957
Taxodium distichum Baldcypress	Controlled field experiment; compared growth and survival of seedlings flooded 1-4 wks. in June and July; Kansas.	61		28	27	100%		Loucks and Keen 1973
Ulmus americana American elm	Observations of vegetational changes following creation of Harry Strunk Lk., Neb.			365		0	Mature trees killed in 1 yr in flowing seep below dam.	Peterson 1957

(Continued)

Table B1 (Concluded)

Species	Experimental method	Conditions: Depth, cm: Over root crown or as noted	Conditions: Depth, cm: Over terminal bud	Conditions: Duration: consecutive days or as noted	No. of plants	No. or % survival	Comments	Authority
Ulmus americana American elm	Transects sampled around 2 new reservoirs in Iowa and Ill. during 1973 growing season.	5^{a*}		129^b; 83^c	3	33%	a) Elevation above conservation pool, in feet. b) Total days. c) Days after leafing out.	Brunk et al 1975
		4.5		139; 92	3	33%		
		4.0		140; 93	2	0%		
		3.5		146; 98	4	100%		
		3.0		152; 103	7	57%		
		2.5		158; 108	4	75%		
		2.0		163; 112	6	50%		
		1.5		168; 116	9	22%		
		1.0		171; 119	5	20%		
		0.5		192; 139	5	0%		
		0		208; 154	2	0%		
		4.5		140; 99	4	0%	Second reservoir.	
		4.0		148; 106	35	20%		
		3.5		155; 110	9	11%		

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*See Comments above for explanation of superscripts.

APPENDIX C:

NEW ENGLAND DIVISION, FLOOD DAMAGE SURVEY

Table C1

October Damage Survey 4-15 Days Flooding to Various Depths in June and July[1]

(compiled from McK[illegible] et al., 1975)

Common Name	Scientific Name	Injury Category[2] a	b	c	d	e	f	Total	% Survival[3]
Red maple	*Acer rubrum*	6	7	-	-	3	7	23	74
Sugar maple	*A. saccharum*	10	6	-	-	5	7	28	64
Silver maple	*A. saccharinum*	6	-	-	-	4	2	12	50
Speckled alder	*Alnus glutinosa*	-	-	-	-	-	-	-	-
Yellow birch	*Betula alleghaniensis*	17	10	-	-	-	1	28	39
Paper birch	*B. papyrifera*	13	-	-	-	1	2	16	19
Grey birch	*B. populifolia*	18	-	1	-	1	4	24	25
Ironwood	*Carpinus caroliniana*	3	-	-	-	2	1	6	50
American beech	*Fagus grandifolia*	7	2	-	-	3	-	12	42
White ash	*Fraxinus americana*	6	-	-	-	3	-	9	33
Hophornbeam	*Ostrya virginiana*	20	1	-	-	1	2	24	17
Red spruce	*Picea rubens*	31	-	-	-	-	-	24	17
White pine	*Pinus strobus*	55	-	1	-	4	41	100	45
Bigtooth aspen	*Populus grandidentata*	-	-	-	-	2	-	2	100
Quaking aspen	*P. tremuloides*	6	-	1	-	7	12	25	76
Black cherry	*Prunus serotina*	1	-	-	-	-	-	1	0
White oak	*Quercus alba*	-	-	1	-	-	1	3	100

(Continued)

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[1] Depth and duration of flood are not provided for each species. High survival may be accounted for in some cases by the fact that a species grows on a terrace above the floodplain and was subjected to very mild stress.

[2] Key to injury: a) devoid of leaves; b) new leaf growth; c) basal sprouts; d) ice damage; e) no damage; f) canopy alive.

[3] % Survival was calculated assuming all individuals in category "a" died while in the remaining categories survived.

Table C1 (Concluded)

October Damage Survey 4-15 Days Flooding to Varius Depths in June and July

(compiled from McKim et al. 1975)

Common Name	Scientific Name	Injury Category a	b	c	d	e	f	Total	% Survival
Chinquapin oak	*Quercus muehlenbergii*	-	-	-	-	-	1	1	1
Red oak	*Q. rubra*	14	4	1	-	11	23	53	74
Black willow	*Salix nigra*	-	-	-	-	4	-	4	100
Basswood	*Tilia americana*	-	-	-	-	6	2	8	100
Hemlock	*Tsuga canadensis*	3	1	-	-	1	4	9	66
American elm	*Ulmus americana*	1	-	-	-	1	-	1	100

APPENDIX D:

NORTH PACIFIC DIVISION

Table D1

Species Survival After June and July Flooding in the Lower Fraser River Valley, British Columbia

(after Brink 1954)

Common Name	Scientific Name
Tolerant Species[1]	
TREES	
Box elder	*Acer negundo*
Walnut	*Juglans* spp.
Apple	*Malus* spp.
Sitka spruce	*Picea sitchensis*
Lodgepole pine	*Pinus contorta*
Cottonwood	*Populus trichocarpa*
Willow	*Salix hookeriana*
Western red cedar	*Thuja plicata*
SHRUBS	
Nuttall's dogwood	*Cornus nuttallii*
Redstem dogwood	*C. stolonifera*
Bog laurel	*Kalmia polifolia*
Labrador tea	*Ledum groenlandicum*
Elder	*Sambucus callicarpa*
Hardhack	*Spiraea douglasii*
Blueberry	*Vaccinium uliginosum*
HERBS AND GRASSES	
Quack grass	*Agryopyron repens*
Bent grass	*Agrostis stolonifera*
Horsetail	*Equisetum arvense*
Manna grass	*Glyceria* spp.
Reed canary grass	*Phalaris arundinacea*
Kentucky bluegrass	*Poa pratensis*
Sheep sorrel	*Rumex acetosella*
Sphagnum moss	*Sphagnum* spp.
White clover	*Trifolium repens*
Intolerant Species[2]	
TREES	
Bigleaf maple	*Acer macrophyllum*
Hawthorn	*Crataegus oxyacantha*
Holly	*Ilex aquifolium*
Douglas fir	*Pseudotsuga menziesii*
Rowan	*Sorbus aucuparia*
Western hemlock	*Tsuga heterophylla*

(Continued)

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[1] Tolerant species: no significant mortality resulting from flooding.
[2] Intolerant species: species not surviving flood.

Table D1 (Concluded)

Common Name	Scientific Name
	SHRUBS
Alder	*Alnus rubra*
Alder	*A. sinuata*
Boxwood	*Buxus sempervirens*
Filbert	*Corylus avellana*
Hazel	*C. rostrata*
Cotoneaster	*Cotoneaster* spp.
Mock orange	*Philadelphus gordonianus*
Cherry	*Prunus emarginata*
Cherry laurel	*P. laurocerasus*
Wild apple	*Pyrus rivularis*
Cascara	*Rhamnus purshiana*
Blackberry	*Rubus procerus*
Lilac	*Syringa vulgaris*
	GRASSES AND HERBS
Orchard grass	*Dactylis glomerata*
Rush	*Juncus effusus*
Perennial rye	*Lolium perenne*
Timothy	*Phleum pratense*

Table D2*

Summary of Data

(from Wakefield, 1966)

Species Common Name	Scientific name	Lowest contour of occurrence (Ft)[1]	Av. max. flood pd. at lowest contour (Days)[2]	Freq. at lowest contour (number) of plants)[3]	Av. freq. at all contours where present (number) of plants[4]	Range of max. flood pd. at contours of max. freq. (Days)[5]
Downy brome	Bromus tectorum	17	84.3	1	14.10	2-17.7
Russian thistle	Salsola kali	17	84.3	2	10.55	3
Redstem filaree	Erodium cicutarium	17	84.3	1	8.56	2-3
Panicled willowweed	Epilobium paniculatum	19	64.1	2	6.89	111.7
Prickly lettuce	Lactuca serriola	20	52.7	2	11.53	0-2
Birdfoot trefoil	Lotus purshiana	20	52.7	2	3.79	10.9-15.1
Tumble mustard	Sisymbrium altissimum	21	44.7	5	10.39	6.1
Greenflower pepperwood	Lepidium densiflorum	21	44.7	1	10.60	2-15.1
Yellowflower pepperwood	L. perfoliatum	21	44.7	1	2.13	15.1
Whitlow grass	Draba verna	22	38.7	2	13.06	0-4.5
Jagged chickweed	Holosteum umbellatum	25	20.1	1	16.29	0-10.9
Mouse ear cress	Arabidopsis thaliana	26	17.7	4	8.6	2
Forget-me-not	Myostis micrantha	26	17.7	2	4.09	3
Common lambquarters	Chenopodium album	26	17.7	1	3.50	6.8

*Interpretation of Table D2: The grass Bromus tectorum was represented at low elevation of 17 ft (column 1) by only one individual (column 3). At this contour the chance exists for plants to be flooded 84 days a year (column 2). With an average frequency of 14.1 (column 4), the species is apparently more common at higher contours. Species most common where maximum flooding is only 17.7 days (column 5). Therefore, while species is found in flood-prone areas, it is more successful on drier sites.

[1] Height above USGS gaging station datum; smaller the number, the closer to the stream.
[2] Calculated from 17-yr record of *max. annual flood duration for each contour.*
[3] Number of plants found in a study plot at a given contour.
[4] Avg. number of plants found in all study plots.
[5] Days of avg. max. flooding at contours where species most common

(Continued)

Table D2 (Continued)

Summary of Data

(from Wakefield, 1966)

Species Common Name	 Scientific Name	Lowest contour of occurrence (Ft)[1]	Av. max. flood pd. at lowest contour (Days)[2]	Freq. at lowest contour (number) of plants)[3]	Av. freq. at all contours where present (number of plants)[4]	Range of max. flood pd. at contours of max. freq. (Days)[5]
Tarweed fiddleneck	Amsinckia lycopsoides	26	17.7	1	2.00	6.8
Annual polemonium	Polemonium micranthum	27	15.1	1	1.00	6.8-15.1
Miner's lettuce	Montia perfoliata	27	15.1	2	1.83	2
Plantain	Plantago patagonica	27	15.1	3	4.56	4.5
Thymeleaf sandwort	Arenaria serpyllifolia	27	15.1	1	3.14	4.5
Henbit	Lamium amplexicaule	28	10.9	1	2.67	4.5
Prostrate knotweed	Polygonum aviculare	28	10.9	1	3.33	6.1
Field pennycress	Thalaspi arvense	31	6.1	1	2.0	6.8
Sandwort	Arenaria pusilla	33	3.0	1	9.83	2.0
Plectritis	Plectritis macrocera	34	4.5	1	1.33	2.0
Popcorn flower	Plagiobothrys tenellus	34	4.5	6	7.20	2.0
Pacific willow	Salix lasiandra	3	135.2	16	12.25	146.3
Sandbar willow	S. exigua	13	135.2	6	7.57	94.9
Sagebrush	Artemisia lindleyana	16	93.9	16	14.33	48.7-52.7
Wheatgrass	Agropyron trachycaulum	19	64.1	1	11.33	32.2-38.7
Eriophyllum	Eriophyllum lantaum	21	44.7	2	8.35	17.7
Gaillardia	Gaillardia aristata	21	44.7	5	3.63	38.7

[1] Height above USGS gaging station datum; smaller the number, the closer to the stream.
[2] Calculated from 17-yr record of max. annual flood duration for each contour.
[3] Number of plants found in a study plot at a given contour.
[4] Avg. number of plants found in all study plots.
[5] Days of avg. max. flooding at contours where species most common.

(Continued)

Table D2 (Concluded)

Summary of Data

(from Wakefield, 1966)

Species Common Name	Scientific Name	Lowest contour of occurrence (Ft)[1]	Av. max. flood pd. at lowest contour (Days)[2]	Freq. at lowest contour (number of plants)[3]	Av. freq. at all contours where present (number of plants)[4]	Range of max. flood pd. at contours of max. freq. (Days)[5]
Canada bluegrass	Poa compressa	21	44.7	1	2.00	32.2
Sand dropseed	Sporobolus cryptandrus	24	20.1	7	4.55	9.3
Chicory	Cichorium intybus	27	15.1	1	2.73	6.1-9.3
Curly dock	Rumex crispus	27	15.1	5	3.0	6.8-15.1
Wheat grass	Agropyron spicatum	27	15.1	2	5.33	9.3
Sneeze weed	Achillea millefolium	28	10.9	1	1.67	2.0
Phacelia	Phacelia heterophylla	30	6.8	3	2.50	3.0
Douglas brodiaea	Brodiaea douglasii	30	6.8	1	1.0	6.8
Buckwheat	Eriogonum proliferum	32	4.5	1	8.57	<2.0
Smooth sumac	Rhus glabra	34	3.0	1	5.20	<2.0
Woodland star	Lithophragma parviflora	34	3.0	3	4.20	2.0
Poverty weed	Iva axillaris	34	3.0	2	2.75	2.0
Rabbit brush	Chrysothamnus nauseosus	36	2.0	1	1.0	2.0
Cholla cactus	Opuntia polyacantha	38	<2.0	4	4.0	2.0

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[1] Height above USGS gaging station datum; smaller the number, the closer to the stream.
[2] Calculated from 17-yr record of max. annual flood duration for each contour.
[3] Number of plants found in a study plot at a given contour.
[4] Avg. number of plants found in all study plots.
[5] Days of avg. max. flooding at contours where species most common.

APPENDIX E:

SOUTH PACIFIC DIVISION

Table E1

Survival and Height of Species Subjected to Flooding in 1972, 1973, and/or 1974 (from Harris et al. 1975)

PLOT SUMMARY
FOLSOM LAKE
SPRING, 1975

◣ N Alive
‡ Alive '73, Dead '74
/ Dead '72, '73
N-Ht. (feet)

ELEVATIONS Above Average Gross Pool

DAYS WATER AT OR ABOVE ELEVATIONS YEAR	+2	0	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22	-24
72	0		34		56		82		102		124		147	
73	0	9	24	34	44	49	55	60	68	86	103	121	144	162
74	0	0	17	53	69	83	102	114	125	134	143	155	171	190

	SPECIES[1]	YEAR PLANTED	+2	0	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22	-24
1.	*Taxodium distichum*	73		◣		/		◣		◣		◣		◣		◣
2.	*Salix* sp. (Terminus South)[2]	74		‡		◣		◣		‡		‡		◣		◣
3.	*Salix alba* 'Tristis'	72	◣		/		◣		◣		◣		/		◣	
4.	*Salix* sp. (Terminus North)	74		/		◣		◣		◣		◣		◣		[illegible]
5.	*Carya illinoensis*	72	/		/		/		◣		/		◣		/	
	Carya illinoensis	73		‡		/		/		/		/		/		/
6.	*Salix* sp. (Folsom)	74		/		◣		◣		/		◣		/		/
7.	*Fraxinus pennsylvanica* var. *lanceolata*	72	◣		◣		◣		◣		/		/		/	
	Fraxinus pennsylvanica var. *lanceolata*	73		◣		/		◣		◣		‡		/		/
8.	*Salix blanda*	73		/		/		◣		◣		‡		/		/
9.	*Salix matsudana*	73		‡		◣		◣		◣		‡		/		/
10.	*Populus x canadensis*	72	/		◣		◣		◣		/		/		/	
11.	*Populus candicans*	72	/		◣		◣		◣		/		/		/	
	Populus candicans	73		◣		◣		‡		/		/		/		/
12.	*Populus fremontii*	72	/		◣		◣		◣		/		/		/	
13.	*Eucalyptus camaldulensis*	73		◣		◣		◣		‡		‡		/		‡
14.	*Gleditsia triacanthos* var. *inermis*	72	◣		◣		/		/		/		/		/	
	Gleditsia triacanthos var. *inermis*	73		◣		◣		◣		‡		/		/		/
15.	*Acer saccharinum*	72	◣		◣		/		/		/		/		/	
	Acer saccharinum	73		◣		◣		/		/		/		/		/
16.	*Platanus occidentalis*	72	◣		◣		‡		/		/		/		/	
	Platanus occidentalis	73		◣		◣		/		/		/		/		/
17.	*Platanus racemosa*	72	◣		◣		‡		/		/		/		/	
	Platanus racemosa	73		◣		/		/		/		/		/		/
18.	*Populus alba*	72	/		◣		/		‡		/		/		/	
	Populus alba	73		◣		/		/		/		/		/		/
19.	*Eucalyptus aggregata*	73		◣		/		/		/		/		/		/
20.	*Eucalyptus cosmophylla*	73		◣		/		/		/		/		/		/
21.	*Salix discolor*	72	/		/		‡		/		/		/		/	
	Salix discolor	73		◣		/		/		/		/		/		/
22.	*Acer negundo*	73		◣		/		/		/		/		/		/

[1] See following page for common names.

[2] Nomenclature in parentheses refer to the authors' collection locations and are not accepted varietal names.

(Continued)

Table E1 (Concluded)

	Common Name	Scientific Name
1.	Baldcypress	*Taxodium distichum*
2.	Willow	*Salix* sp. (Terminus South)
3.	Willow	*S. alba* 'Tristis'
4.	Willow	*S.* sp. (Terminus North)
5.	Pecan	*Carya illinoensis*
6.	Willow	*Salix* sp. (Folsom)
7.	Green ash	*Fraxinus pennsylvanica* var. *lanceolata*
8.	Wisconsin weeping willow	*Salix blanda*
9.	Matsudana willow	*S. matsudana*
10.	Carolina poplar	*Populus X canadensis*
11.	Balm-of-Gilead	*P. canadicans*
12.	Fremont cottonwood	*P. fremontii*
13.	Murray red gum	*Eucalyptus camauldulensis*
14.	Thornless honey locust	*Gleditsia triacanthos* var. *inermis*
15.	Silver maple	*Acer saccharinum*
16.	Sycamore	*Platanus occidentalis*
17.	Sycamore	*Platanus racemosa*
18.	White poplar	*Populus alba*
19.	Eucalyptus	*Eucalyptus aggregata*
20.	Eucalyptus	*E. cosmophylla*
21.	Pussy willow	*Salix discolor*
22.	Boxelder	*Acer negundo*

Table E2

Woody Species Exhibiting Tolerance to Flooding

in the Sacramento-San Joaquin Delta in 1969 and/or 1972

(from Harris et al. 1975)

Common Name	Scientific Name	Sherman Island, 1969[1] # of Plants	Sherman Island, 1969[1] % Survival	Andrus, Brannan Islands, 1972[2] # of Plants	Andrus, Brannan Islands, 1972[2] % Survival
Silver wattle	*Acacia decurrens*	5	100	1	100
Red gum	*Eucalyptus camaldulensis*	25	96	100	90
Sycamore	*Platanus racemosa*	8	50	25	92
Balm-of-Gilead	*Populus candicans*	--	--	13	100
Valley oak	*Quercus lobata*	--	--	9	100
Dune willow	*Salix piperi*	8	100	--	--
Baldcypress	*Taxodium distichum*	--	--	50	80
Mexican fan palm	*Washingtonia robusta*	--	--	51	75

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[1] Plants subjected to 50-150 days of flooding with a maximum depth of 12 ft for 38 days. For more information see "Vegetation Management on Reservoir Recreation Sites", Summary Report, 1966-1971. July 1971. Dept. of Environmental Horticulture, Univ. of Calif., Davis.

[2] Plants subjected to 60-112 days of flooding with a maximum depth of 13 ft for 33 days.

APPENDIX F:

SOUTH ATLANTIC DIVISION

Table F1

Effect of Flooding on Plants, West Sandy Dewatering Project, Tennessee[1]

(after Hall and Smith 1955)

Species	Elev. above MSL (Ft)	Dead line Lowest healthy tree Percent of time flooded during all growing seasons[2]	Elev. above MSL (Ft)	Dead line Lowest sickly tree Percent of time flooded during all growing seasons[2]
Black cherry (*Prunus serotina*)	359.4	0.6	356.4	13.4
Flowering dogwood (*Cornus florida*)	359.0	0.8	356.7	11.6
Hop hornbeam (*Ostrya virginiana*)	358.7	1.8	356.7	11.6
Sassafras (*Sassafras albidum*)	358.5	2.3	357.7	5.6
Beech (*Fagus grandiflora*)	358.2	3.2	355.5	16.1
Yellow-poplar (*Liriodendron tulipifera*)	357.9	4.5	355.5	16.1
American holly (*Ilex opaca*)	357.0	9.7	354.9	17.0
Pawpaw (Asimina triloba)	356.7	11.6	356.7	11.6
Redcedar (*Juniperus virginiana*)	356.3	14.0	353.8	24.4
Black alder (*Alnus rugosa*)	355.9	15.8	353.7	24.6
Shagbark hickories (*Carya* spp.)	355.7	16.0	354.2	22.4
Loblolly pine (*Pinus taeda*)	355.4	16.1	355.4	16.1
Black gum (*Nyssa sylvatica*)	355.0	16.3	354.0	25.3
Water oak (*Quercus nigra*)	355.0	16.3	354.0	23.9
Catalpa (*Catalpa* sp.)	354.7	18.6	354.0	23.9
Pignut hickories (*Carya* spp.)	354.6	19.4	354.5	20.2
Ironwood (*Carpinus carolinana*)	354.1	23.2	353.1	26.1

(Continued)

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[1] Plants listed in order of increasing tolerance to flooding as indicated by the lowest healthy tree observed during the summer of 1952, summer pool elevation = 359.0 ft.

[2] Growing season was considered to be 1 April-1 Oct. Period of record was 1 Sep. 1944-1 Jul. 1952, giving a maximum growing season flood of 1402 days. Elevations based on 10 observations per species.

Table F1 (Concluded)

Species	Elev. above MSL (Ft)	Dead line Lowest healthy tree Percent of time flooded during all growing seasons	Elev. above MSL (Ft)	Dead line Lowest sickly tree Percent of time flooded during all growing seasons
Birch (Betula nigra)	354.1	23.2	350.0	34.5
Sycamore (Platanus occidentalis)	354.0	23.9	351.2	31.2
Winged elm (Ulmus alata)	353.7	24.6	353.6	24.9
American elm (Ulmus americana)	353.7	24.6	348.5	38.8
Hackberry (Celtis sp.)	363.6	24.9	353.6	24.9
Swamp black gum (Nyssa sylvatica var. biflora)	353.1	26.1	353.1	26.1
Cow oak (Quercus michauxii)	352.2	28.6	350.2	34.0
Honey locust (Gleditsia triacanthos)	352.0	29.1	349.8	35.0
Persimmon (Diospyros virginiana)	351.5	30.4	349.3	36.2
Willow oak (Quercus phellos)	351.4	30.6	347.8	41.6
Hawthorn (Crataegus sp.)	351.0	31.7	349.0	36.9
Sweetgum (Liquidambar styraciflua)	350.1	34.3	347.4	43.3
Cottonwood (Populus deltoides)	350.0	34.5	350.0	34.5
Deciduous holly (Ilex decidua)	349.7	35.2	349.0	36.9
Red maple (Acer rubrum var. drummondii)	349.2	36.4	348.0	40.7
Water tupelo (Nyssa aquatica)	348.6	38.4	346.1	53.0
Ash (Fraxinus sp.)	348.6	38.4	347.8	41.6
Pin oak (Quercus palustris)	348.4	39.2	348.1	40.3
Buttonbush (Cephalanthus occidentalis)	348.4	39.2	346.1	53.0
Overcup oak (Quercus lyrata)	348.1	40.3	346.3	51.2
Black willow (Salix nigra)	347.6	42.5	345.7	58.8
Swamp ironwood (Planera aquatica)	347.5	42.9	346.0	53.9

APPENDIX G:

SOUTHWESTERN DIVISION

Table G1

Species Found Around 32 Oklahoma Lakes

(from Penfound, 1953)

Woody Plants

Flood zone (terrestrial, subject to surcharge)

- *Celtis laevigata* (Sugar berry)
- *Diospyros virginiana* (Persimmon)
- *Fraxinus pennsylvanica* var. *subintegerrima* (Green ash)
- *Prunus angustifolia* (Chickasaw plum)
- *Rhus aromatica* var. *serotina* (Fragrant sumac)
- *Smilax bona-nox* (China brier; a very thorny vine not suitable for areas of human use)

Summer pool level (permanent wetland grading into surcharge zone)

- *Alnus serrulata* (Common alder)
- *Cephalanthus occidentalis* (Buttonbush)
- *Platanus occidentalis* (Sycamore)
- *Populus deltoides* (Cottonwood)
- *P. sargentii* (Plains cottonwood)
- *Salix amygdaloides* (Peach leaved willow)
- *S. interior* (Ditchbank willow)
- *S. nigra* (Black willow)
- *Tamarix gallica* (French tamarisk)

Herbaceous Plants

Drift lines (windrows at upper reaches of flood zone)

- *Ambrosia psilostachya* (Western ragweed)
- *Andropogon hallii* (Beardgrass)
- *Cenchrus pauciflorus* (No common name)
- *Helianthus petiolaris* (Prairie sunflower)
- *Lythrum alatum* (Winged loosestrife)
- *Verbena bracteata* (Prostrate vervain)

Flood Zone

Residual (survivors from original grassland)

- *Andropogon virginicus* (Broomsedge)
- *Aster exilis* (Slender aster)
- *Buchloe dactyloides* (Buffalo grass)
- *Coreopsis tinctoria* (Plains coreopsis)
- *Cynodon dactylon* (Bermuda grass)

(Continued)

Table G1 (Continued)

Panicum oligosanthes var. helleri (Heller's panic grass)
P. virgatum (Switchgrass)
Paspalum laeve var. circulare (No common name)
Sporobolus asper (Dropseed)

Flood induced (flood surcharge zone)

Spring and Summer

Amaranthus albus (Tumble pigweed)
Ammannia coccinea (Purple ammannia)
Bacopa rotundifolia (Round leaved water hyssop)
Conobea multifida (No common name)
Cyperus inflexus (Sedge)
Diodia virginiana (Virginia buttonweed)
Eclipta alba (Eclipta)
Eleocharis obtusa (Blunt spikerush)
Fimbristylis autumnalis var. mucronulata (No common name)
Hemicarpha drummondii (No common name)
Lepidium densiflorum (Greenflower pepperwood)
Lindernia dubia (False pimpernel)
Mollugo verticillata (Carpetweed)
Myosurus minimus (Mousetail)
Rorippa obtusa (Yellow cress)
R. sessiliflora (Yellow cress)
Rotala ramosior (Toothcup)
Sida hederacea (Alkalai sida)
Spermacoce glabra (Buttonweed)
Veronica peregrina (Purslane speedwell)

Autumn

Actinea odorata (No common name)
Acnida tamariseina (Water hemp)
Ambrosia psilostachya (Western ragweed)
Aster exilis (Slender aster)
Buchloe dactyloides (Buffalo grass)
Coreopsis tinctoria (Plains coreopsis)
Echinodorus rostratus (Burhead)
Euphorbia marginata (Snow-on-the-mountain)
Conyza canadensis (Horseweed)
Franseria tomentosa (Woollyleaf bursage)
Gutierrezia dracunculoides (Common broomweed)
Juncus torreyi (Torrey's rush)
Lippia cuneifolia (Wedgeleaf frog fruit)
L. lanceolata (Frogfruit)
Oenothera canescens (Western yellow evening primrose)
Panicum virgatum (Switchgrass)
Paspalum distichum (Knotgrass)
Rumex crispus (Curly dock)
Sophora sericea (No common name)
Xanthium italicum (Italian cocklebur)

(Continued)

Table G1 (Concluded)

Summer pool level

- *Carex aquatilis* (Water sedge)
- *Cyperus ferruginescens* (Rusty sedge)
- *Eleocharis macrostachya* (Spikerush)
- *Echinochloa crusgalli* (Barnyard grass)
- *Ludwigia palustris* (Water purslane)
- *Panicum agrostoides* (Panic grass)
- *Paspalum distichum* (Knotgrass)

Recession zone (exposed
area below mean summer pool)

- *Acnida tamariscina* (Water hemp)
- *Aster exilis* (Slender aster)
- *Atriplex argentea* (Silver scale saltbush)
- *Chenopodium incanum* (Hoary goosefoot)
- *Eleocharis macrostachya* (Spikerush)
- *E. quadrangulata* (Square stem spikerush)
- *Conyza canadensis* (Horseweed)
- *Franseria tomentosa* (Wooly leaf bursage)
- *Helianthus ciliaris* (Texas blueweed)
- *Juncus nodatus* (Rush)
- *Justicia americana* (Water willow)
- *Leersia oryzoides* (Rice cutgrass)
- *Monolepis nuttalliana* (Monolepis)
- *Myosurus minimus* (Mousetail)
- *Polygonum coccineum* (Swamp smartweed)
- *P. hydropiperoides* (Mild smartweed)
- *P. lapathifolium* (Pale smartweed)
- *P. persicaria* (Lady's thumb)
- *P. ramosissimum* (Bushy knotweed)
- *Saururus cernuus* (Lizardtail)
- *Scirpus validus* (Softstem bulrush)
- *Sida hederacea* (Alkalai sida)
- *Triticum sp.* (Wheat)
- *Typha domingensis* (Southern cattail)
- *T. latifolia* (Common cattail)
- *Xanthium italicum* (Italian cocklebur)
- *Zizaniopsis miliacea* (Giant cutgrass)

Table G2

Survival of Trees During Flood Surcharge at Two Oklahoma Lakes

(after Harris 1975)

Species		% Alive After 26 April-15 June Flood	
Common Name	Scientific Name	Keystone Lake: max. flood depth = 28.5 ft above gross pool	Oologah Lake: max. flood depth = 21.3 ft above gross pool
Cottonwood	*Populus deltoides*	100	98
Willow	*Salix* sp.	100	100
Green ash	*Fraxinus pennsylvanica* var. *lanceolata*	99	94
Box elder	*Acer negundo*	99	97
Silver maple	*A. saccharinum*	98	--
American elm	*Ulmus americana*	95	66
Sycamore	*Platanus occidentalis*	94	97
Persimmon	*Diospyros virginiana*	93	40
Hackberry	*Celtis occidentalis*	91	61
Red mulberry	*Morus rubra*	66	80
Pecan	*Carya illinoensis*	55	88
Hawthorn	*Crataegus* sp.	69	--
Black haw	*Viburnum prunifolium*	--*	68
Honey locust	*Gleditsia triacanthos*	--	43
Eastern red cedar	*Juniperus virginiana*	45	--
Black oak	*Quercus velutina*	30	43
Blackjack oak	*Q. marilandica*	20	5
Post oak	*Quercus stellata*	6	15
Red oak	*Q. rubra*	3	7
Dwarf chinquapin oak	*Q. prinoides*	--*	10
Chinquapin oak	*Q. muehlenbergii*	1	--
Black locust	*Robinia pseudoacacia*	--	6

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* Species absent or sample too small for evaluation.

Table G3

Relative Tolerance to Flooding, April-July to a Maximum Depth of 23 ft (From U. S. Army Engineer District, Little Rock, 1973*)

Common Name	Scientific Name
Tolerant[1]	
Buttonbush	*Cephalanthus occidentalis*
Persimmon	*Diospyros virginiana*
Sweet gum	*Liquidambar styraciflua*
Sycamore	*Platanus occidentalis*
Black willow	*Salix nigra*
River birch	*Betula nigra*
Black gum	*Nyssa sylvatica*[4]
Overcup oak	*Quercus lyrata*[4]
Moderately Intolerant[2]	
White oak	*Quercus alba*
Post oak	*Q. stellata*
Red oak	*Q. rubra*
Shortleaf pine	*Pinus echinata*
Eastern red cedar	*Juniperus virginiana*
American elm	*Ulmus americana*
Ash	*Fraxinus* sp.
Red mulberry	*Morus rubra*
Intolerant[3]	
Hickory	*Carya* sp.
Red maple	*Acer rubrum*
Dogwood	*Cornus* sp.

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[1] Tolerant: survived complete submergence for several months during growing season.

[2] Moderately intolerant: stressed or killed by complete submergence.

[3] Intolerant: killed by partial submergence.

[4] Too few observed to make adequate assessment.

*Unpublished report, U. S. Army Engineer District, Little Rock, 1973. High water effects on vegetation at Little Rock District projects, 8 pp + exhibits.

(Continued)

Table G4

Observations on Flood Tolerance of Mature Trees in Central Oklahoma (from DeGruchy 1956)

Fraxinus pennsylvanica var. subintegerrima (Green ash)
Plants survived in 30 in. 17 consecutive months

Ulmus americana (American elm)

Flooding from 5 June-1 October 1951

Depth (in.)	Date of leaf abscission (presumed dead)
30	8/5
24	9/14
14	10/1
6	died following spring

Cephalanthus occidentalis (Buttonbush)

Plants survived summer flood to 36 in. for 3 months followed by a 15-month flood to 44 in. the following year.

Amorpha fruticosa (False indigo)

Plants survived 3 months of summer flooding to depths of 48 in.; poor recovery if period is extended.

Tamarix gallica (French tamarisk)

Survived 3 months of summer inundation to a depth of 36 in.; killed by 16 months continuous flooding to 48 in.

Cynodon dactylon (Bermuda grass)

Survived 15 months of continuous inundation to 6 in.; significant mortality when flooded to 12 in. for the same period. Some dormant rhizomes apparently able to survive 15 months of flooding to 18 in.

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.

Whitlow, Thomas H
Flood tolerance in plants: a state-of-the-art review / by Thomas H. Whitlow, Richard W. Harris, Department of Environmental Horticulture, University of California, Davis, California. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.
161, [96] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; E-79-2)
Prepared for Office, Chief of Engineers, U. S. Army, Washington. D. C., under Contract No. DACW39-77-M-3423, Work Unit IIE:1.
Includes bibliographies.
1. Flood tolerance. 2. Plants (Botany). 3. Reservoirs. 4. State-of-the-art studies. 5. Tolerances (Physiology). 6. Vegetation. I. Harris, Richard W., joint author. II. California. University, Davis. Dept. of Environmental Horticulture. III. United States. Army. Corps of Engineers. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; E-79-2.
TA7.W34 no.E-79-2