Flood Damage to Trees

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Introduction

Flood damage to trees develops in three primary ways: 1) acute soil and tree changes because of saturated and inundated soil conditions; 2) flood water physically knocking over trees; and, 3) chronic problems associated with a changing environment and modified tree reactivity.

Most trees and woody shrubs are not adapted well to flooded conditions. There are a range of flood tolerance levels among different species and individuals. There are a number of growth form, anatomy, and physiology changes available in tolerant plants to try and minimize flooding damage and growth constraints.

Major Impacts of Flooding

The major impacts of flooding on the tree and site resources are:

1) Poor Aeration -- Flooding initiates an immediate constraint on oxygen movement from the atmosphere to the respiring surfaces of the tree. As a site floods with water, water moves into and occupies the macro-pores that previously held gas. The tree root interface then does not have a gaseous component. The diffusion rate of oxygen across a water interface is 7,000 times slower than across a gas interface.

Available oxygen is quickly (l-3 hours) used by the respiring roots and the soil microorganisms. The only area where oxygen is available is in the top l/10 of an inch of soil that is in contact with oxygenated water. Lack of oxygen leads to production and accumulation of carbon-dioxide, methane, hydrogen, and nitrogen gas.

2) Soil Structure -- Flooding alters soil structure by allowing soil aggregates to fall apart from reduced cohesion, dissolving of metallic and organic coatings, and dispersing of clay particles.

3) Anaerobic Ecology -- Flooding causes anaerobic organisms to replace aerobic organisms in the soil. Anaerobic organisms are primarily bacteria. These bacteria cause denitrification and reduction of manganese, iron, and sulfur.

4) Reduced Chemical Activity -- Flooding reduces redox potential, increases pH of acid soils, and decreases the breakdown of organic matter. The breakdown or decomposition of organic matter in normal soils helps hold cations and anions, releases essential elements, and prevents leaching of elements. This decomposition process is a rich assemblage of organisms.

In flooded soils, the decomposition of organic matter is by anaerobic bacteria. These organisms are less diverse and much more inefficient at decomposition. Slick, slimy layers of partially decayed organic matter may be present as a result.

In normal soils, decomposition of organic matter yield carbon-dioxide and humus. Carbon-dioxide moves into the atmosphere and components of the humus are bound to clays and oxides of aluminum and iron. This binding process improves soil structure. The nitrogen in the soil that is released as ammonia is converted to nitrate. Sulfur compounds are oxidized to sulfates.

In flooded soils, decomposition of organic matter yield carbon-dioxide, humus, methane and a large number of other materials. The gasses produced included carbon-dioxide, methane, and hydrogen. Other materials, some extremely volatile and some very toxic are produced. Examples of other materials produced by decomposition of organic material under anaerobic conditions include various hydrocarbons, alcohols, carbonyls, fatty acids, phenolic acids, sulfur compounds, acetaldehyde, and cyanogenic compounds. Many of these materials escape as gas bubbles, dissolve in the water, or float to the water surface.

UNIVERSITY OF GEORGIA EXTENSION FOREST RESOURCES PUBLICATION FOR94-61

Flooding effects trees at every stage of their development, from seed germination and flowering to sprouting and vegetative growth. At each life stage, flooding can cause injury, changes in anatomy and growth form, decline, and death.

Seed Problems

Seed germination requires oxygen and water. As the seed takes in water, its respiration increases. Flooding fills the gas exchange pores on the seed and limits oxygen transport. Depending upon the species and duration of flooding, seed viability quickly declines.

For example, baldcypress, water tupelo and black tupelo seeds remain viable for extended period of flooding. These seeds do not germinate under the flood water but when the water recedes. Cottonwood, willow, and sycamore seeds can germinate under water to hasten establishment on new areas caused by flooding. Green ash and boxelder, both wetland species, have seeds that loose vitality quickly after flooding.

Seedling Problems

Flood tolerance of seedlings vary greatly. Coverage of foliage with water is a critical feature to initiating flood damage -- the longer the leaves are under water the worse damage becomes. Seedlings can also be buried by sediment and pushed over or swept away by flood water. Major damage can occur along the young stem and root collar area that permanently damages the tree.

General Tree Problems

Soil anaerobic conditions initiate several symptoms of flood damage including: no growth or internode elongation; poor leaf expansion; limited leaf formation; leaf chlorosis; premature senescence; and, abscission (old leaves first). Leaf abscision can take from two weeks in upland species to eight weeks in wetland species after flooding. Wetland species can be damaged just as badly as upland species by growing season / warm weather flooding.

The usual symptom of a tree to flooding is a decline in growth. It is possible to have trees show in the first year after a flood an apparent increase in diameter growth. This is caused by the bark, phloem tissue, and xylem tissue producing more intercellular spaces and lower density cells. This low density material makes the tree look like it has made a large growth spurt. In some trees this growth pattern may. be a prelude to decline and death.

One growth response of trees to flooding is production of proportionally greater numbers and enlargement of thin-walled cells called parenchyma. These cell types are found in both the xylem and phloem. Resin duct number are also increased in species with these features. Flooding initiates production of low density cells and more intercellular spaces in the xylem, phloem and bark. The stem becomes lower in density to facilitate oxygen transport and removal of toxic materials.

Root Problems

Tree root response to flooding is a reduction of root initiation and growth. Within seven days there is noticeable root growth loss. Many types of root limitations can be seen in normal soils with a shallow water table. Rooting depth is related to water table depth and the lower limits of adequate oxygenation. A shallow water table generates a shallow root system. Roots only growth where soil atmosphere has 5% oxygen.

Flooding causes a loss of extent, reach and health of the roots. Over time, decline, death and decay are the results. Additionally, pathogens such as Phytophthora fungi attack the tree roots. This fungi tolerates low soil oxygens levels and is stimulated by poor host vigor and root membrane leakage. Generally under flooded conditions, the woody roots survive and non-woody roots die. Loss of root mass through attack and decay leave the tree prone to drought damage the following growing period and to windthrow.

Physiology Effects

Flooding effects on the physiology of the tree generically include energy production, root membrane health, and coping with toxic materials in the soil.

Within five hours, photosynthesis is shutdown. Photosynthesis is limited by loss of carbon fixation enzymes, loss of chlorophyll, reduction of leaf area, and leaf abscission. Photosynthesis is an expensive system to maintain and very sensitive to internal and external environmental changes. Once flooding is over, it takes an extended time for photosynthetic activities to return to normal.

Root problems include the poor uptake of macro-essential elements and additional resource loss through leakage from root membranes. Nitrogen is lost in the soil and throughout the tree under flooded conditions. Nitrate in the soil is lost by denitrification to atmospheric nitrogen and through production of nitrogen oxides. At the same time, the roots are not taking-up available nitrogen. Flooding also suppresses mycorrhizae fungi which are strongly aerobic. Poor phosphorus and potassium uptake is an associated problem.

Flooding initiates many growth regulator production changes and effects how they are destroyed once they have carried their message. Auxin, ethylene and abscisic acid concentrations increase in flooded trees while gibberellic acids and cytokinins decrease. The result is **leaf** epinasty, senescence and abscision; stem growth disruption; and, adventitious root production.

Tree Growth Responses

The tree does aerate as much of its tissues as possible. Transport modifications move oxygen more effectively from the air into lenticels and down into the roots where some leaks out to oxidize materials (like iron and manganese ions) which are toxic. The oxygen availability is through lenticel and stomate openings, moving in both wood and bark.

Flooded trees produce larger, more open lenticels which are connected to intercellular spaces and can provide more oxygen transport. Trees also can use vertical air roots to assist with oxygenation. Knees, such as in baldcypress, do not effectively transport oxygen but act as structural supports for anchoring the root system.

Under flooded conditions, trees can start to generate a tissue called aerenchyma, which is thin-wailed cells with large intercellular spaces. This tissue forms by dissolution of cells and separation of cell walls to form a spongy cellular mass. Examples of species capable of producing aerenchyma include loblolly and pond pine.

Flooding also initiates adventitious roots on the submerged stem area. The more flood tolerant the species, the more likely the species will form adventitious roots. Adventitious roots increase the capacity of the tree to uptake materials, oxygenate the rhizosphere, detoxify soil materials, and increase root growth regulators.

Flood Tolerance

Tree flood tolerance depends upon many attributes of the tree, site and flood. The extent and destructiveness of flooding on tree growth depends upon: the time of the year the flooding occurred; water quality and water oxygen content; water depth: air and water temperature; and, tree stage of life, structure and health.

Flooding in the growing ***season*** is worse than dormant season flooding, especially if the air temperature is warm. The higher the temperature, the faster and deeper the oxygen shortage will be felt, and the more the top of the tree will dehydrate. After only two weeks of inundated or saturated conditions the root crown area began to have many problems that can lead to decline and death.

Flooding during warm growing season periods magnify flood damage because of respiration needs and foliage water loss. Stagnant water is usually more damaging than flowing water. Flowing water has turbulent surface mixing and internal flows that move oxygen more effectively to root surfaces than standing water.

As a general rule, broadleaved trees (including baldcyress) tolerate flooding better than conifer species. Middle-aged trees tolerate flooding better than young and old trees. Keeping foliage above the flood waters is critical. Floodwater itself is important. Stagnant water is not as good as flowing water. Flowing water does carry debris and momentum that can physically damage trees.

The role of a tree under flooded conditions is to maintain its glucose supply in all cells that it can and avoid accumulating toxins. Trees can generally be rated on a gradient ranging from flood intolerant to flood tolerant. Table 1 provides a list of selected species in our area and their general flood tolerance.

Tree Toppling

One aspect of flood damage, especially after flash or scouring flood conditions, is the toppling of trees. Trees stand erect against most wind and flood conditions on the basis of tree weight, stiffness of the main trunk, width of the base, amount of fluid dynamics drag, fluid velocity, and fluid mass.

In air, the tree tends to sway back and forth as it *is* loaded and unloaded. The period of the sway is set by the mechanical properties of the tree. The swaying can loosen tree roots from the soil and lead to toppling under light winds in saturated soils. When a tree is under water in a moving flow, there is more constant stress on the tree and no swaying.

A general relation for trees pushed over in a flood is:

Tree Pushed Over by Flood Waters =

+ directly proportional components --
(drag (drag through deformation with increasing **velocity^{1X})**
(height to living crown and center of gravity vs. water level height))
(water velocity)
(weight of water + suspended and floating materials)
(further stress from neighbor toppling)

- inversely proportional components --
(weight of tree)
stifness of trees)
(anchorage of tree (width of base))

A tree stands because of its stiff, heavy, wide-based trunk provides weight and a center of gravity that does not move too far laterally. The relatively low drag in flowing water comes from flexible twigs and branches that bend and deform to provide a smaller area blocking the flow. Trees that growth and respond with a flexible stem utilize many roots holding under tension. As a tree falls over, the force of falling puts addition stress on downstream neighboring trees. A domino effect of tree toppling may then occur.

Long-term Growth Problems

One of the most important long-term growth problems affecting a tree is siltation. Soil fill deposited over the root system could range from zero to six feet (or more) of various textured soil. Soil fill will require a quick root response to the new soil conditions. The trees under these conditions will be generating a new root system in new locations. Some species are not effective in reacting to these kinds of changes and will decline and die.

Another problem after flooding is soil erosion. Some trees will be left without soil covering roots and may not have enough soil around and under its roots to keep it structurally stable. Addition of small amounts of soil fill can help if the roots have not already been allowed to dry out. Toppling of these trees with a wind storm is a distinct possibility.

Tree that are going to be removed as salvage must be gathered quickly if they are dead. Wood quality degradation from drying, fungi infection and insects attacks will quickly cause value loss in these trees. Standing trees that remain alive but are structurally at risk or scheduled for removal should be promptly harvested to minimize value losses. Some dead snags and downed logs may be of benefit to wildlife populations if left on the site.

Over the long-run, tree vigor and structural stability will be questionable on many trees. Because of the growth patterns of some trees, flood damage effects will be present for 2-3 years into the future. Pest problems, because of the massive number of stressed trees in the area will reach peak populations quickly and present a management problem for as many as five years into the future.

Best Management Practices

Activities that can be done immediately, or by the end of the current or most immediate growing season include:

1) Perform an assessment of tree survival and structural hazard conditions. Expect trees to die suddenly, decline and die this year, or decline over the next few years.

2) Use soil testing to determine proper essential element management.

3) Provide phosphorus and potassium fertilization with some dolomitic limestone for calcium and magnesium addition. This application should be repeated in each of the next three years.

4) Add one light dose of nitrogen, approximately 0.5 - 2.0 pounds of nitrogen per 1,000 square feet of open soil surface area. Very small amounts of calcium sulfate can be added to return sulfur to the soil. After this application, do not fertilize with nitrogen again until after full leaf expansion in the next growing season. In each of the next three years, apply 3 pounds of nitrogen per 1,000 square feet of open soil surface area.

5) Do not add micro-elements.

6) Do as little green-wood pruning as possible to conserve tree food supplies. Prune for safety concerns.

7) Beware of fungal and insect attacks on stressed trees and take informed action. Both the trees under attack and the surrounding trees may need therapeutic or preventative treatments.

8) Many things will have washed down-stream in the flood. Most materials will have been extremely diluted. Be cautious with activities in flood damaged areas. Dust, soil, water, and biting insects can provide biohazards and chemical hazards. The micro-topography of the land can also have changed. Beware of new holes in the soil and places where you might fall. Always wash thoroughly after activities in the flood damaged areas.

9) In your clean-up activities, do not change land-use types or perform large-scale soil movement and major water channelization / drainage without contacting your local USDA-Soil Conservation Service (Natural Resources Conservation Service). Additionally, do not modify habitat areas and disrupt individuals of species listed on the federal and state endangered species lists.

10) **Contact the University of Georgia Cooperative Extension Service in your county for further information and up-dates on activities that can protect your resource values.**

TABLE 1: Flood Tolerance of Selected Trees

-- Tolerant --	-- Moderately tolerant --	-- Intolerant --	
Silver maple	Red mulberry	American ash	Shortleaf pine
Sweetgum	Swamp chestnut oak	Chinkapin oak	Virginia pine
Persimmon	Hackberry	Mockemut hickory	Eastern red cedar
Green ash	Winged elm	Shagbark hickory	Eastern redbud
Honeylocust	Hawthorn	Black locust	Black walnut
Overcup oak	Osage orange	sassafras	Swamp hickory
Eastern cottonwood	Boxelder	Flowering dogwood	American beech
Water hickory	Loblolly pine	Sourwood	Tulip poplar
Black willow	River birch	Southern red oak	Yellow buckeye
Tupelo gum	American elm	American basswood	Sugar maple
Bald cypress	Sycamore	Blackjack oak	Post oak
	American holly	Black cherry	