UNIVERSITY OF GEORGIA
Warnell School of Forestry & Natural Resources

Publication WSFNR-22-35C

June 2022

Hurricane Storm Surge & Seawater Damage To Trees

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Hurricanes remain a major disturbance process along the coast. Hurricane winds and rains buffet maritime forests and community trees. Coastal trees and their sites are badly damaged by hurricanes and associated flooding, tornadoes, and storm bands. One component of hurricane damage to trees is the storm surge and saltwater inundation generated by major hurricanes.

Categories

Hurricanes are commonly measured by the Saffir-Simpson Hurricane Scale. This categorization of hurricane energy is based upon sustained wind speed. Note there are many aspects of hurricanes beside sustained wind speed which damage trees and sites, but this wind scale system is the one used for gauging hurricane intensity.

The Saffir-Simpson Hurricane Scale catagorizes hurricane intensity into five (5) separate classes. Category 3-5 storms are considered major hurricanes. Figure 1. Converting the hurricane category sustained wind speed into a frontal pressure (pounds of wind pressure per square foot of exposed tree area) onto a tree can help people appreciate tree wind loads. As each category of hurricane changes, wind loads on trees greatly changes. Remember, as wind speed doubles, wind load force on trees nearly quadruples.

Surge

With increasing sustained wind speeds, hurricanes push on the surface of the ocean. As a hurricane nears shore, or makes land-fall, this mass of water pushed by the storm swells up above the tide and normal sea level. This mass of water is not a noticeable wave or tidal bore, but a quick general surge in water levels. This storm surge can quickly raise water levels and quickly fall again.

Every place along the coast and up coastal rivers can experience storm surges. The landforms, tidal phase, and season of the year (as well as intensity of the hurricane) can all impact the mass, duration, and height of any storm surge. Storm surge height is not directly related to hurricane category, but is related to concentration of energy and water along various coastal landforms and near-coastal water depth and water flow obstructions. Figure 2 provides a general guide to storm surge height which could occur by hurricane category. The most energetic hurricanes move the most water. Figure 3.

Tall Water

Hurricane storm surge can be visualized by the high water marks on trees and buildings. The high water mark in any hurricane will be a combination of storm surge, high tide, and wave height. For example, if a hurricane left a 27 feet tall high water mark or line on a tree, the individual components could be composed of 15 feet storm surge on top of a 2 feet high tide and 10 feet tall waves. The wave action with its energy (speed, frequency, and mass) generate active tree damage by pounding tree structure. Storm surge damage is a rapid rise in water table and flood waters surrounding a tree, bringing water with varying levels of salt levels onto a site.

The force generating a storm surge in a hurricane is composed of wind pushing on ocean water (85% of surge), waves pushing ashore (8% of surge), and low pressure in the hurricane eye (7% of surge). Hurricane forces can cause a water surge, which is not a wall of water but a rapid rise in water levels, within minutes to an hour. As this water rises and moves, internal currents can be rapid and powerful, mimicking currents found in class 3-5 white water rapids.

Storm surge essentially rides over the top of other water levels changes, like tides, flooding, or sea level rise. A water surge can move up coastal rives at 25 miles per hour for hundreds of miles. Surge can be made greater (worse) by inland flooding from rainfall which fills rivers. The complex interactions of potential sea level rise with river flooding events from extreme rainfall events associated with a hurricane and hurricane storm surge can generate large scale tree and forest damage. (Gill & Marcy, 2009)

Historic Surges

To appreciate the size of an impending storm surge which could occur, a brief review of past storm surge events is helpful. Figure 4 shows the storm surge of category 5 hurricane Camille in 1969 Mississippi. The storm surge over a period of 50 hours climbed roughly 25 feet in height. This surge peaked and dissipated all within a 24 period.

Other historic storm surge events are listed in Figure 5 (Pilkey et.al. 2016). Starting with hurricane Sandy in 2012 and ending the survey with hurricane Audrey in 1957, these eight hurricanes had storm surges ranging from 8 feet to 27 feet. All these storm surges devastated coastal trees and forests, and in many cases changed the landscape significantly.

Future Surges

Figure 6 provides the average years between storm surge flood events over roughly 82 years. The time between storm surge severity from historical data ranges from every 7 years for moderate surges to every 81 years for record surges. With continued sea level rise, and projected levels of sea level rise over the next 80 years, storm surge impacts are projected to become more frequent. A two feet rise in sea level generates a major storm surge event almost 16 times more often, and a record storm event 11 times more often.

Wetland Wall

With stable sea levels, wetlands develop along low-lying coastal areas. These wetlands of various plant communities have provided a cushion between storm surges and more developed landscapes. A rule-of-thumb (i.e. general estimate across many conditions) suggests the thickness of wetland vegetation between the beach and the upland slows and reduces storm surge. For every 3 miles of wetlands back from the beach, storm surge can be reduced by 1 foot in height and slowed appreciably.

With wetlands removal, seawater flooding and coastal erosion tolls upon remaining coastal and riverine wetland areas, and their associated protective functions, will be compromised.

Surge Vulnerability

Development and construction has place coastal areas at great risk of storm surge. Population vulnerability to storm surge along the Atlantic coast increased 17% from 1990 – 2008, according to NOAA data. The Georgia coast is cited with more than 118,000 properties with significant storm surge risk (Pilkey et.al. 2016). Expectations over the next decades are for coastal property values to quickly decline over the next 40 years, shorelines to quickly retreat over the next 80 years, and sea level rise to continue to increase for at least the next two centuries (Englander 2014).

An example of vulnerability of the Georgia coast is shown in Figure 7. This map presents potential storm surge areas along the coast from a category 4 hurricane. Some coastal counties are completely within the storm surge area. Also shown is the flooding area in the lower parts of major watersheds from extreme rainfall events form a category 4 storm.

A Little Salty

Storm surge brings with it various levels of salt water, and poor drainage systems can let salt water remain for a period of time over tree root systems. Figure 8 shows various saltwater types based upon the percent of salt. Seawater is roughly 3.5% salt while freshwater is considered to have less than 0.05% dissolved salt. A generic term used often with storm surge is brackish water which contains up to 3% dissolved salt, but can contain as little as 0.05% (freshwater levels) dissolved salt. Drinking water has less than 0.01% dissolved salt.

Seawater is highly damaging to trees and forests. Few trees can handle seawater innundation for any extended period of time. Some people see various species of trees in coastal wetlands and along rivers floodplains. These trees have both freshwater sources, and seawater drainage. They usually grow 1-5 feet above the local water table in a well oxygenated / well drained soil.

Water Water Everywhere

Seawater is ~2.7% heavier that freshwater which allows seawater to move under freshwater flowing over its top. Mixing energy comes from water flow velocity and turbulence. The interface between seawater and freshwater moving back and forth in coastal rivers depends on sea level and tide heights, and level of river flow. Projections of salt water intrusion events (both magnitude and duration) into freshwater intakes for coastal cities are expected to increase by five times (5X) for a one foot sea level rise.

Seawater is ~70 times more salty (more dissolved salts) than freshwater. Seawater has a pH of 7.5 – 8.4, making it more basic and interfering with availability of a number of tree essential elements in soils. Seawater has a water potential roughly 60 times more negative than freshwater. Seawater innundation of tree sites represent a damaging growth environment and a poisonous water resource for almost all trees (subtropical mangroves are an exception). (Hodson & Bryant, 2012; Willey, 2016)

Tree Killer

Seawater or water high in dissolved salts kills trees through damaging roots and changing available soil resource values. As trees continue to take up water, the dissolved salts are left behind at the soil root interface, creating a salt desert layer surrounding tree roots. In a short time roots can no longer generate water potential force to draw water into the tree without damage. A root killing dose of salt water is always a function of the amount of seawater present and the time it is present around the roots (i.e. amount and duration). Fast inundations and quick freshwater rinses greatly reduce saltwater damage to trees.

Seawater Symptoms

Trees show many symptoms when challenged with seawater. Seawater stress includes: tree wilting; less permeable / less effective roots; drought level water potentials even though flooded with water; sodium (Na^{+}) and chlorine (Cl^{-}) ions toxic especially to enzyme functions; sodium and chlorine ions complete with potassium (K^{+}), magnesium (Mg^{++}), and nitrate ions inducing essential element deficiencies; and, huge respiration costs in roots trying to exclude salt. (Hodson & Bryant, 2012; Willey, 2016)

Roots are damaged by seawater, but the tree top portion is also damaged. Seawater stress in trees above the soil include: closing of tree stomates; shut-down of photosynthesis, chlorophyll production, and protein synthesis; increased leaf temperature from lack of transpiration; no elongation growth; leaf margins and older leaves become necrotic; and, eventual death of tissues in progressively larger volumes. (Hodson & Bryant, 2012; Willey, 2016)

Seawater Flooding Treatments

The two greatest treatments for trees after seawater innundation from storm surge is to assure drainage of the site (both surface and sub-surface) and freshwater rinsing (assuring wells and water sources are salt-free). Small amounts of calcium (Ca^{++}) can be of value, but do not add a calcium source which increases the salt content level. Small additions of potassium (K^{+}) and nitrate can be applied if soil aeration has been reestablished. Do not add micro-elements. While trees are recovering from seawater stress, do not root prune, damage the tree or associated soil, or complete greenwood pruning. (Hodson & Bryant, 2012; Willey, 2016)

Conclusions

Hurricane storm surges can bury great trees and soils under a layer of damaging water. Without quick drainage and rinsing of the accumulated salt away with freshwater, tree roots and tree life will be compromised. Storm surge can cause severe injury to large areas of trees and forests. Hurricane storm surge extent and duration should not be underestimated in assessing tree health risks. Coastal landscapes with trees are vulnerable to storm surge damage, as are coastal communities.

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storm category	wind speed mph	mid-point wind pressure* lbs/ft^2	tree impacts
1	74-95	19	branch & tree failures
2	96-110	28	major tree failures
3	111-129	38	large tree failures – leaves gone
4	130-156	54	massive tree blow-downs
5	> 157	> 63	most trees down

(* column is not part of wind scale but added by author)

Figure 1: Saffir-Simpson hurricane wind scale with associated wind load pressures and tree impacts.

storm category	wind speed mph	mid-point wind pressure* lbs/ft^2	storm surge feet
1	74-95	19	4-5
2	96-110	28	6-8
3	111-129	38	9-12
4	130-156	54	13-18
5	> 157	> 63	> 18

(* column is not part of wind scale but added by author)

Figure 2: Saffir-Simpson hurricane wind scale with associated wind load pressure and general storm surge heights in feet.

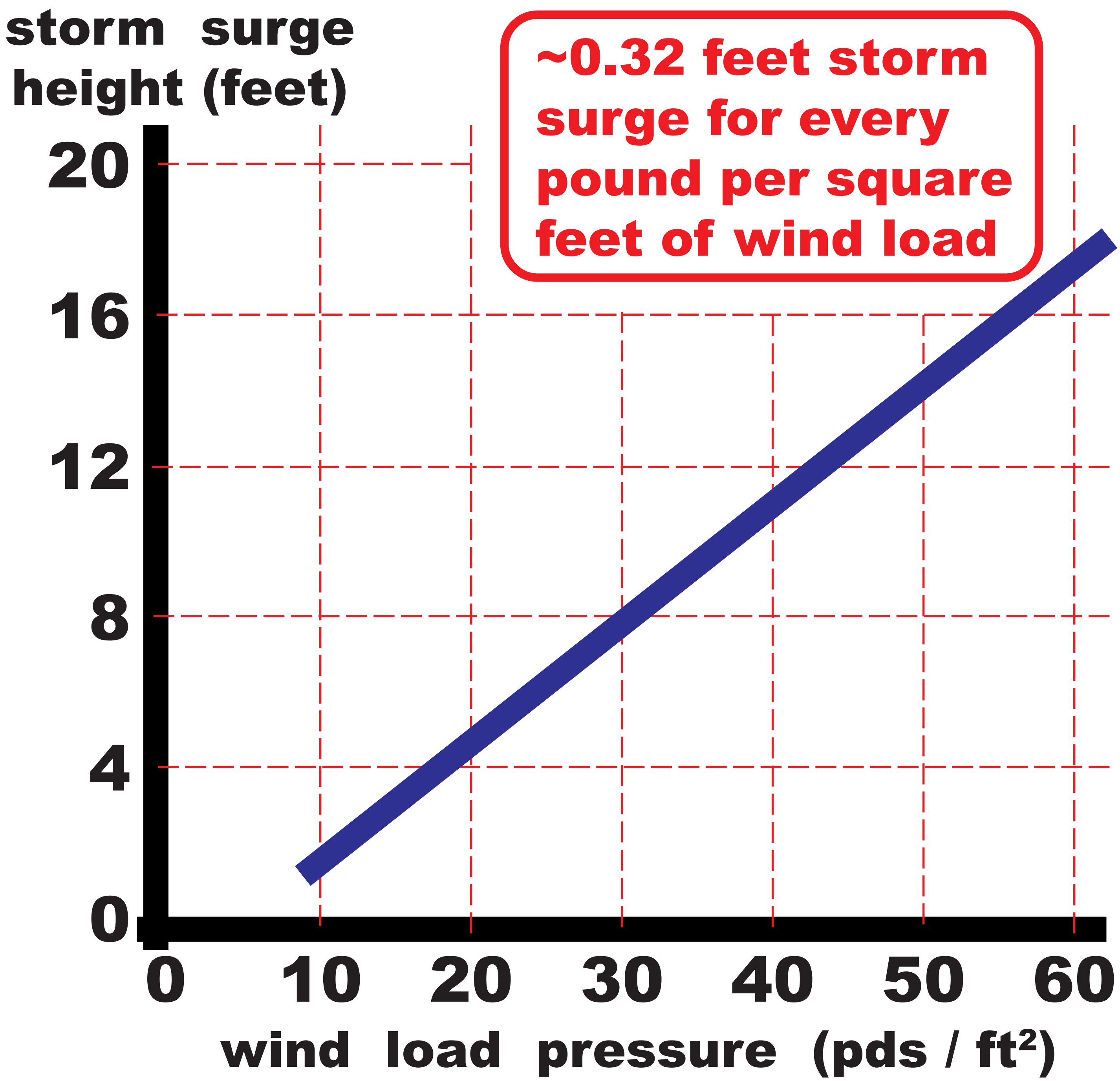

Figure 3: Idealized wind load pressures in pounds per square feet generating storm surge heights in feet.

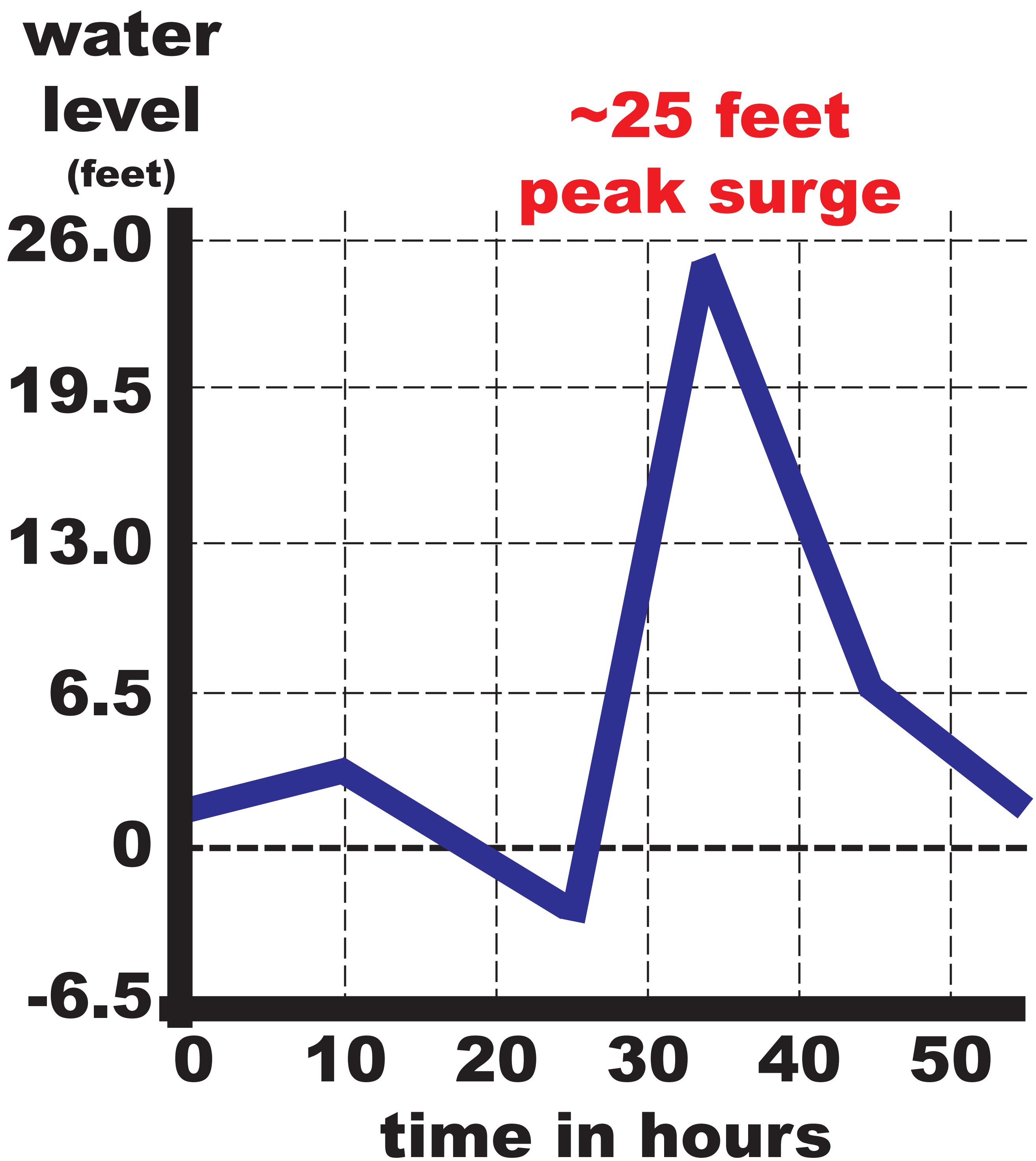

Figure 4: Storm surge associated with Hurricane Camille (cat. 5 -- 1969) in Mississippi. (after Hine et.al. 2016)

Sandy	2012	13 ft
Katrina	2005	27 ft
Dennis	2005	8 ft
Isabel	2003	8 ft
Opal	1995	24 ft
Hugo	1989	20 ft
Camille	1969	24 ft
Audrey	1957	12 ft

Figure 5: Selected hurricane storm surge levels in feet.
(Pilkey et.al. 2016)

Average Years Between Storm Surge Events

severity	historical	2' rise	3' rise
moderate	7 yrs	0.3 yrs	0.1 yrs
major	27	1.7	0.3
record	81	7.3	1.7

Figure 6: Average number of years between storm surge flooding events historically (1927-2009), and number of years between storm surge events projected for two sea level rise changes in the future. (Stiles 2012)

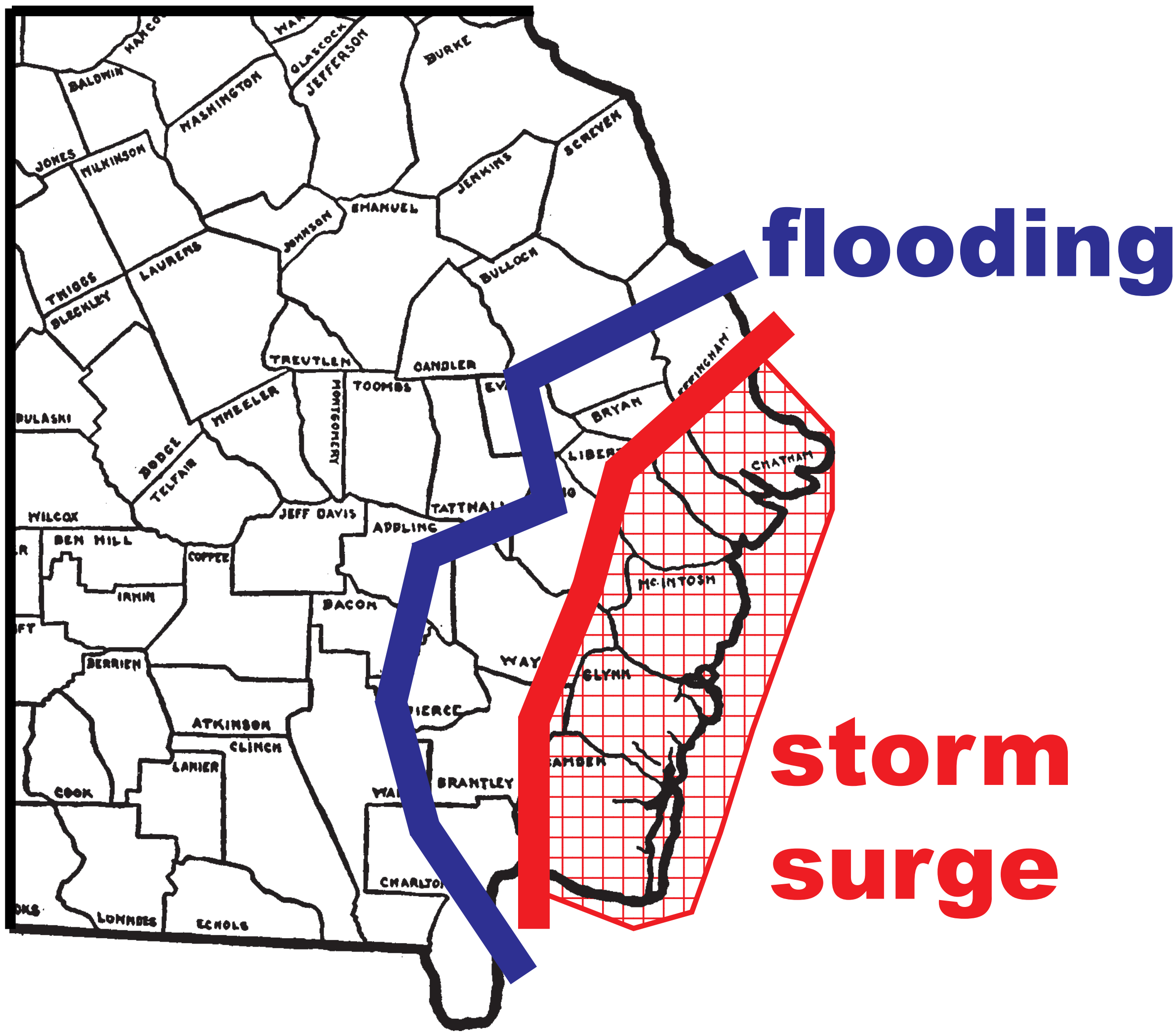

Figure 7: Potential storm surge area (1-10 feet deep) in red, and major flooding area (blue) under a category 4 hurricane along the coast of Georgia. (after GEMA, 2015)

SALTWATER TYPES

water name	salt %
brine	> 5%
saline water	3 - 5%
sea water	3.5%
high salinity	1 - 3.5%
brackish water	.05 - 3%
moderate salinity	.3 - 1%
slight salinity	.1 - .3%
irrigation water	< .2%
fresh water	< .05%
drinking water	< .01%

Figure 8: Gradient of saltwater definitions between brine and drinking water with percent dissolved salts. Note salt content percent between freshwater and seawater.

Citation:

Coder, Kim D. 2022. Hurricane storm surge & seawater damage to trees. Warnell School of Forestry & Natural Resources, University of Georgia, Outreach Publication WSFNR-22-35C. Pp.14.