# Hurricane Florence Shows Us a Need For a New Classification System to Categorize Flooding and Damages

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## Abstract

Over the years flooding is usually associated with rivers and streams where flood water has overtopped streambanks.. Other flooding was observer but seldom identified. Wetlands flood when there is heavy rainfall and are referred to as ponding. Water accumulation in lakes sometimes exceeds the lakes capacity, so water accumulates around the lake. Water from rivers and flood plains, along with that from wetlands and lakes eventually reaches estuaries where the accumulation exceeds the banks of the estuary causing flooding. Along the ocean significant waves and storm surge wash over land areas to cause local flooding. The geomorphic expression ( i.e. the topography) associated with all these types of flooding can be placed in USFWS wetland classification (Circular 39, 1979). If we modify the wetland classification to only look at the flood component, the flood classes are: Riverine, Lacustrine, Palustrine Estuarine, and Marine. Historically Riverine flooding has been defined (Reckendorf, 1973) as that floodplain with alluvial land adjacent to a river that can be flooded by the occasional great flood such as the 1% chance event. This would be consistent with FEMA maps based on a base flood with a 1% chance event. Lacustrine flooding would be that which occurs along typical wetland and adjacent flat areas.. Palustrine flooding would be typical of flooding around lakes. Estuarine flooding includes flooded areas around estuaries and lagoons and would include river stage, tidal flooding and storm surge. Marine flooding includes all areas around coastlines that could be flooded by significant waves , storm surge, and associated run-up. The landscape developed during the Holocene to Recent set a geomorphic low topography that has a historical record of flooding. This topography along the North and South Carolina Coast has flooded many times. It is unknown if the duration and depth of flooding of the equivalent areas flooded during hurricanes or tropical storms has increased because of climate change impacts along the North and South Carolina coast. It is known that slower hurricanes can dump more rain in an equivalent area , which is reflected in Hurricane Florence flooding. Hurricane Florence made land fall as a Category 1 hurricane. Inland it changed to a tropical storm, and than to a tropical depression. Florence has changed how we need to look at flooding. The slow movement (2 mph) was a major cause for the Lacustrine and Palustrine flooding, which adds to the Riverine Flooding. The Swansboro Rain Gage recorded 33.89 inches of precipitation for the event compared to 24.86 inches for the Floyd Hurricane. Hurricane Florence caused inland flooding where it has never occurred before. Flood peaks along rivers in North and South Carolina greatly exceeded prior flood peaks ,

# Introduction

Flooding throughout the world has been recognized as a problem for over 100 years. The subject is complex and is described differently depending on the conditions where the flooding occurs. This paper shows a new template to categorize all types of flooding. The focus will be on flooding in the United States of America and include the natural condition of the landscape flooding and the encroachment of infrastructure that has caused natural flooding to increase.

The topography (geomorphology) along rivers and streams, lakes, estuaries, and coastlines has developed over geologic time of Holocene and Recent. The Holocene Period, is basically the last 10,000 years. The Recent period represents the last 2,000 years, but in the later part of the Recent time frame, flooding has been modified and often increased, because of changes in the watershed natural landscape and encroachment into the floodplain.

To reflect the topography for both the natural condition and the modified condition the author proposes a new template. The template proposed is a modification of the US Fish and Wildlife Service system for categorizing wetlands published in Circular 39 (USFWS, 1979). The system divides wetlands into Riverine, Lacustrine, Palustrine, Estuarine, and Marine Classes. Circular 39 does has an important vegetative component of the classification system. The vegetation criteria for that component will be ignored is this classification system designed to represent the aerial extent of flooding by the 1% chance event.

Background information about the conditions that caused Florence hurricane flooding will be presented before a discussion of the new classifications system and their applicability to Florence and in the US. Also discussed will be the evolvement of FEMA.

# Background

## Weather and Rainfall

Tropical Cyclone Florence became Hurricane Florence on September 6, 2018, and was the sixth named hurricanes, and the first major hurricane of the 2018 hurricane season. At one time Florence was classified as a Category 4 hurricane, but slowed to be classified as a Category 1 hurricane (sustained winds of 74 to 95 mph) when it made landfall just south of Wrightsville Beach North Carolina on September 13, 2018 (Wikipedia, Hurricane Florence, October 2, 2018). Within a day it transitioned to a Tropical Storm and then to a Tropical Depression. During the storm bands of the circulation had different intensites of rainfall. Florence slowly drifted inland over a wide area such that tropical force winds occurred out 195 mi. from the hurricane's eye (Rhodan, 2018).

A ridge of high pressure over eastern North America stalled Florence'a forward motion for several days. It moved forward at only 2-3 mph and dumped heavy rainfall from the outer rain bands between September 13th. to 15 th. By September $15^{th}$, the storm had stalled only a few miles from Wilmington NC. A rainfall total near Swansboro NC of 30.58 inches broke the all time record rainfall for a tropical system. The prior record was 24.06 inches during Hurricane Floyd.

A  recent paper from Penn State (Mann, 2018), states that unusual warmth in the Arctic causes jet streams, the rivers of air in the atmosphere that push or pull the weather systems,  to slow down stall or meander in strange ways,  When the undulations of the jet stream lock in place, weather systems can be trapped in place and cause havoc like extreme flooding from long duration storms.. The extremes and unusual jet stream patterns are known as "quasi-resonant amplification".  The paper indicated this effect on the jet stream is increasing because of climate change brought about by the burning of fossil fuels.

On June 8, 2018 the Science Daily  reported that some hurricanes are moving more slowly.   They state that according to a June 6, 2018 article in the Journal Nature a  study has measured translation speed, which measures how quickly a storms moves over an area.  Between 1949 and 2016 tropical cyclone translation speeds declined 10 percent word wide.  In another study James Kossin, a climate scientist with NOAA measured how fast a storm moved over the landscape and found that tropical cyclones were slowing down.  He also states that steering winds are responsible for moving hurricanes along their path, as hurricanes are carried passively by the winds that are sitting in, somewhat like a cork in a stream.  He goes on to state that the steering winds draw power from the temperature differences between tropics and the poles.  However, because of climate change that temperature difference is declining, which weakens the winds and therefore  hurricanes move more slowly.  An article by Doyle Rice  on September 29,2018, that appeared in USA today, reported on a new study of Atlantic Ocean temperatures.  He reported that  the 2017 hurricane season, that included Hurricanes Harvey, Irma, and Maria, was fueled in part by warm ocean water.  In 2017 six major hurricanes  formed which was twice the average.  Sea water in main hurricane development area averaged 0.7 degrees warmer than normal for the entire hurricane season.  Quoting Hiro Murakami, climate scientist and hurricane expert at National Oceanic and Atmospheric Administration (NOAA), " We show that the increase in 2017 major hurricanes was not primarily caused by La Nina conditions in the Pacific Ocean, but mainly by pronounced warm  sea water conditions in the tropical North Atlantic".

## Geology, Soils, Topography, and Trees

North Caroline lies to the north of South Carolina.  They both have a topography characterized by a large coastal plan on the east side. During the Cenozoic Era the ocean covered the lowlands, and subsided repeatedly , creating terraces each time.  Eleven marine terraces can be found in South Carolina representing higher sea levels.  Extensive back barrier marsh deposits occur and some estuarine and delta deposits. These soils would tend to have drainage problems and this along with high water tables means that these  soils and the sandy soils can easily be saturated with high rainfall.  Runoff was responsible for gradually shaping the coastal plain's gradual downward slope,  and rivers cut down to the existing sea level.  Several rivers have their headwaters in North Carolina and than flow through South Carolina at their lower end.

The trees on the North Carolina Coastal plain include Loblolly Pine, Oak,  Red maple, Yellow Popular,  Lealand Cypress, Bedford Pear, and Sassafress.  South Carolina's Coastal Plain trees are mostly Oak, Maple, Pine, Palm,  Bald Cypress, and barkless trees. Spanish Moss tends to accumulate on Oaks and Bald Cypress.

## Hydrology

As Florence moved inland from September 15 to 17, 2018, the heavy rainfall caused widespread flooding inundating cities such as Fayetteville, Smithfield. Lumberton, Durham and Chapel Hill, as major rivers such as the Neuse River, Eno River, Cape Fear River, and Lumber River overtopped their banks. In Fayetteville, NC, the Cape Fear River crested at 61.4 ft some 26 ft. above its normal flood level which is 21 ft. (Rhodan, 2018). A larger area has flooded than was flooded in Hurricane Mathew two years ago. The Neuse River reached a new peak height of 25.8 ft, with a major flood peak being 21 ft. The Cape Fear River near Fayetteville NC had a flood peak of 61.4 ft, which was 25 ft. above flood stage. A larger area flooded from Florence than was flooded in Hurricane Mathew two years prior. Florence is projected to be classified as a 500 to 1000-yr. average recurrence interval event for some rivers in North and South Carolina. Flood stages for riverine areas reached new highs.

## Damages

Hurricane Florence currently (September, 2018) ranks 6$^{th}$, >$38,000 million in damages (Wikipedia, October 1, 2018). It is still too early to get a final total on damages, but current estimates will be much higher if one builds in the loss of commerce because of the flooded roads, especially I-40, I-95, and US Routes 70 and 401, and Sate Highway 76. Their was an extensive flood fight in both NC and SC and there were 42 deaths attributed to Hurricane Florence..

## FIA, FEMA, and Floodplain Zoning.

With the passage of the National flood Insurance Act (FIA) in 1968 the author started to do Flood Insurance Studies in Oregon, starting with a Type 2 study to identify communities that had flood problem. The first field study was a Type 10 Flood Insurance on the Applegate River in Jackson County in Oregon (Reckendorf and Taylor, 1971). That study established a floodway and a flood fringe, and included a economic evaluation of flood damages. The study established at each cross section what was the height of water in the floodway if the cross sections was constricted so that the water in the floodway was increased in increments from 1.0 ft. to 2.5 ft. These results were plotted on curves presented in the report as " Increasing Depth Remaining Width Curves". That report never got beyond the Draft Stage as the Flood Insurance Administration was so anxious to see what a flood insurance study looked like that they accepted the draft report as a final and no further work was done. The constriction analysis was done to determine how much freeboard to add to the base flood to be shown as flood fringe on the maps. The author worked with the SCS national staff and FIA in determining the criteria for a Flood Insurance Study.

The Federal Emergency Management Agency (FEMA) was created in 1978 and 1979 (Wikippedia, 12/22/2018). FEMA made Flood Insurance Rate Maps (FIRM) which show Special Flood Hazard Areas (SFHA) defined as areas inundated by a base flood event having a 1% chance of being equaled or exceeded in any given year, often referred to as 100-year flood zones. The SFHAs are separated into flood zones such as areas flooded by Riverine flooding in 1% chance events, areas of minimal flood hazard outside the SFHA, and areas flooded in the 0.2% chance event. In the early 1980's the author was part of the team that evaluated what should be recommended for the first floor elevation for development above the base flood, and be designated as the flood fringe on floodplain maps. The author's position was that the elevation needed for development should be 2-3 feet of freeboard above the stage determined for the 100-year average recurrence interval event. A few government agencies used the 2-3 feet criteria in their development of the floodplain zoning ordinances. However, for economic reasons, the FIA chose to recommend the one foot above base flood for development for the flood fringe. The author thinks that this was a major mistake by FIA, as it allowed for so little freeboard to accommodate any mistakes in the analysis and did not accommodate the higher flood events that might come in the future because of upstream development that would decrease the time of concentration of flood waters or for climate change.

# Classification System

## Riverine Flooding

Runoff during the Holocene shaped valleys to form a sequence of terraces and floodplains. Former floodplains became terraces as the rivers down-cut during the Holocene. For those streams tributary to the ocean, the rivers cut lower floodplains because their base level was lowered as ocean levels dropped. For streams not influenced by a lowering base level, streams down-cut to form lower floodplains due to high volumes of runoff. Ice and snow remaining from glacial conditions of the Pleistocene and Holocene caused high runoff to initiate down-cutting to form a sequence of terraces and floodplains. The floodplains developed had geomorphic form and features in the landscape.

For this new classification systems to describe flooding for FEMA studies, Riverine floodplain flooding is that alluvial land that can be flooded by the occasional great flood, that has a 1% chance of occurrence in any given year (Reckendorf, 1973). This definition would be consistent with the base flood on Flood Boundary Maps and Floodway Map (FBFM) and mapped on FIRM maps. It would also be applicable to the floodplain zone mapping done by units of government, that show the area flooded by the base flood, plus one foot or higher above the base flood required by the unit of government. Floodplains have been defined otherwise such as by Leopold (1994). He defined floodplain as a level area near a river, constructed by the river in the present climate and overflowed by moderate flow events.

Leopold later described the floodplain in a video on bankfull flow as the first depositional surface along a river and floods with an average recurrence interval of about 1.5 to 2 yrs. (Leopold, 1994). Rosgen (1996) and others call higher floodplains along the river as terraces, defined as former floodplains where downcutting has occurred. Restricting the definition of the floodplain to that overtopped in bankfull flow was very useful in the development of the Rosgen Stream Classification (1996), and for field identification of the first flat depositional surface. However it is not useful when classifying areas flooded by large events such as that which occurs in a 1% chance event. The thousands of square miles of floodplain shown on floodplain boundary maps and floodplain rate maps FIRMs developed under FIA and FEMA for over 50 years, are based on a frequency of flooding in a 1% chance event, so that definition needs to be the working definition of floodplain for floodplain rate mapping.

The author has done floodplain mapping since 1966, on close to a million acres spread throughout OR, AL, WA, and AZ. These studies have been done for flood hazard analysis, flood insurance studies, floodplain zoning maps, comprehensive plans, river basin studies, and for litigation. He has also made numerous flood observations in 20 states. The author has determined that there are extensive intermediate floodplains that occur above the first flat depositional surface floodplain but below the floodplain flooded in the 1% chance event. In OR, this intermediate floodplain is flooded by about the 10% chance event. Above the intermediate floodplain is the high floodplain that in western OR is flooded with a 2% chance of occurring in an given year as well as well as flooding in the 1% chance event. The difference in width is minimal as the 1% chance event is just deeper water, and is higher on the scarp break. In the Oregon, it was established that the floodplain outside scarp break to a terrace was high enough to confine the 500-year average recurrence inter flood, i. e. a 0.2% chance event. The height of the outside scarp between 1% chance event and 0.2% chance event is not consistent across the country. In some states 500-year average recurrence interval flood event would put flood water up on a terrace, where it can spread out for miles.

The geomorphic features used in the authors floodplain mapping, were explained in a paper entitled “Geomorphic Features of Oregon Streams and Floodplains” (Reckendorf, 1969). The methodology used in the mapping was published as “Methods for Identification and Mapping of Flood Plains” (Reckendorf, 1968, and Reckendorf, 1973).

The author’s floodplain mapping has been incorporated into FBFM, FIRM and floodplain zoning ordinances, in several Willamette Valley Counties in Oregon. The author mapped a total of about a half a millions acres of Riverine floodplains in Oregon. He later mapped 231,000 acres of Riverine flooding on nine streams in Alaska, as well as doing studies and floodplain mapping along streams in Washington and Arizona. Extensive mapping has given the author an opportunity to examine flooding in a broad context. He has observed the various types of flooding in this classification system, but there was no comprehensive system for mapping the various types of flooding as the programs developed by the Federal Government primarily focused on Riverine flooding. Today there are millions of acres along Riverine streams that have FBFM, and FIRM maps of the area flooded in the base flood. Boundaries for rate maps are marked “A” for approximate floodplain and “AE” for detailed mapping floodplains

The flood problems along rivers has partly occurred because the infrastructure developed along rivers to facilitate transportation. Once roads developed and needed to cross rivers, people often placed a fill on the floodplain to elevate both the approach and the bridge over the river. The bridge opening was often not large enough to pass large flood flows so backwater occurred. In addition, bridges were often built at the grade of the land which was much lower that that flooded in a 1% chance event. Therefore the cross section at the bridge had limited capacity to pass flood water. To offset the limited capacity the units of government sometimes excavated below the bridge. This excavation tended to start a head-cut that migrated upstream, often undermining the foundation of upstream bridge. To offset the flood damages to infrastructure that was occurring from building roads and railroads that crossed river, engineers started building dams to store flood runoff, and or channelizing the river to try and increase the velocity to pass through the reach. This channelization was only partly successful, as river channels tended to re-meander by down-cutting and widening to return the river to a dynamic equilibrium condition.

With the passage of the National flood Insurance Act (FIA) in 1968 the author started to do Flood Insurance Studies in Oregon, starting with a Type 2 study to identify communities that had flood problem. His first field study was a Type 10 Flood Insurance study on the Applegate River in Jackson County in Oregon (Reckendorf and Taylor, 1971). That study established a floodway and a flood fringe, and included a economic evaluation of flood damages. The study established at each cross section what was the height of water in the floodway if the cross sections was constricted so that the water in the floodway was increased in increments from 1.0 ft. to 2.5 ft. These results were plotted on curves presented in the report as " Increasing Depth Remaining Width Curves". That report never got beyond the Draft Stage as the Flood Insurance Administration was so anxious to see what a flood insurance study looked like that they accepted the draft report as a final and no further work was done. The constriction analysis was done to determine how much freeboard to add to the base flood to be shown as flood fringe on the maps. The author worked with the SCS national staff and FIA in determining the criteria for a Flood Insurance Study.

The author has extensive experience in field flood plain mapping, so he is an authority on the subject, and is well suited to evaluate if our present floodplains as represent on FEMA maps are adequate He has been involved in 15 litigations concerning flood plain boundaries, and the associated streambank erosion. Most of the authors mapping has become part of later studies published by FEMA. The authors floodplain mapping has been incorporated into floodplain zoning ordinances, in several Willamette Valley Counties in Oregon. The author mapped about a half a millions acres of Riverine floodplains in Oregon. He later mapped 231,000 acres of Riverine flooding on nine streams in Alaska, as well as studies along streams in Washington and Arizona.

If any single date can be assigned to the importance of floodplain encroachment in the US it is January 22, 1936. On that date Congress passed the Federal Flood Control Act. The Act recognized that flood problems where national in scope and resulted in national policies which placed primary reliance on flood control structures. to solve the flood problems. Between 1936 and 1998 the Federal Government invested more than seven billion dollars in building dams and doing channelization. However the flood damage was greater in 1966 than it was in 1936 (Reckendorf 1973). In 1965 the Bureau of the Budget appointed a task force on flood control policy. The task force report was printed as House Document 465, entitled "A Unified National Program for Managing Flood Losses", U.S. Congress (1966). The report directed that: (1) all towns with a flood problem be identified; (2) flood plains were to be outlined on aerial photographs; (3) there should be an accelerated program of floodplain mapping and reports by Federal Agencies. With the passage of the Federal Flood Insurance Program in 1968 a local unit of government could request through the U.S. Department of Housing and Urban Development (HUD) Federal Insurance Administration (FIA) that subsidized floodplain insurance be made available, if minimum floodplain management requirements were met by the unit of government (HUD, 1968).

In the decade of the 1990's, with flood damages at an all-time high, and with upward spiraling disaster relief costs that began to strain national budgets, new approaches were attempted to reduce flood damages. The Midwest Flood of 1993 served as a catalyst to recognize the value and benefits of floodplains as natural resources, and pointed the way toward restoration and wise management of these beneficial resources as part of the overall strategy to reduce flood losses. In the wake of the 1993 Midwest Flood, many of the flooded communities began to develop and implement a new strategy of voluntary buyouts and relocation of homes out of the floodplain. Since than, many other communities across the country have followed suit. These actions represent a major change in attitude and approach toward addressing flood problems, with significant benefits to people at risk and taxpayers, as well as not having adverse environmental impacts (Conrad, et. al. 1998).

The prime candidates for voluntary buyouts and relocations are properties that are considered to be “Repetitive Loss Property”. The National Flood Insurance Program (NFIP) defines any insured property that has sustained two or more flood losses in a 10 year period as a “Repetitive Loss Property” (Conrad et. al, 1998). In the time period between 1978 and 1995, the repetitive loss properties only represented two percent of all insured properties, but claimed 40 percent of the NFIP payments. Nearly one out of every ten repetitive loss properties has had cumulative flood insurance claims that exceed the value of the property. (Reckendorf et. al. 2012). In spite of the large investment in flood control, and in flood insurance, flood damages from large floods have continued to rise. In the area flooded by Hurricane Florence it is estimated that less than 3% of the people had flood insurance. To make matters worse, recent floods in the area of NC and SC are estimated to have 500 to 1000-year average recurrence intervals.

In North Carolina, 16 major rivers were out of bank because of Florence. The Coastal Plain topography in both NC and SC, is such that once rivers are out of bank they can flood for miles. Some rivers such as the Cape Fear River and the Neuse River in North Carolina reached all-time highs and long duration flooding did extensive damage to homes, commercial and industrial areas as well as agricultural land and livestock. Power was out for 343,000 people in NC alone. In NC and estimated 1.7 million chickens were killed because of flooding. Crops at harvest such as cotton and peanuts were extensively damaged and an estimated half of the tobacco crop was flood damaged. Some local flood control structures, such as levees, had been installed but many were flanked or overtopped. The City of Lumberton had a protective levee but there was an opening in the levee for the CSX railroad tracks. Flood waters came through the gap as it had earlier in Hurricane Matthew. This is an unresolved conflict between the railroad and local officials as to how to provide some flood protection and keep the railroad operational. The Weather Channel showed a steel railroad bridge over the Lumber River with flood water up on the side of the bridge, creating backwater and accumulated woody debris. Many roads were flooded, such as Highway 76, by the Lumber River. A low area of I-95 in North Carolina, at the exit to Fayettville, flooded closing the interstate in both directions.

## Lacustrine Flooding

Lacustrine flooding is that flooding that occurs on wetlands and adjacent flat land. The soils under wetlands are classified by the Natural Resources Conservation Service (NRCS) as Poorly or Imperfectly Drained. Adjacent well drained soils may not typically pond because of their good drainage but, if the soil is saturated because of long duration rainfall, than well drained soil cannot be readily separated from poorly or imperfectly drained soils. Any soil impediment to drainage can cause water to pond on the surface and can create mapped Lacustrine flooding. FIRM maps show Lacustrine flooding with map symbol AH to represent surface ponding. What is shown as AH is not the equivalent of Riverine flooding in the 1% chance event. One would need a statistical analysis of precipitation gages to determine a 1% chance storm, and that analysis is not being done. The largest data base of Lacustrine flooding areas is that shown by state in the National Wetland Inventory. What is shown as Lacustrine flooding can be used as a first approximation of the extent of Lacustrine flooding in local areas not previously mapped.

However there is no flood frequency associated with the Lacustrine flooding as the maps are only showing that from wetlands and do not show the additional flooding because of obstructions to runoff that road and railroad fills, as well as fills for housing and industrial developments cause. NRCS soil survey maps show poorly and imperfectly drained soils. A map of these soils would also give an approximation of Lacustrine flooding but with no flood frequency.

In the 1970's the State of Alaska was examining sites that might be suitable to relocate the State Capitol from Juneau. The Soil Conservation Service was asked in 1975 to do a study of the area east of Fairbanks, called Delta Junction, as a possible site for the relocation. The author was asked to do the floodplain mapping of the proposed area. He mapped 231,100 acres of Riverine flooding along nine streams. In addition he mapped 135,471 acres which would be classified now as Lacustrine flooding. In this case, the impermeable soils were because of the shallow permafrost that caused to water to pond on the surface every year. No frequency was assigned to the 37% of the area flooded due to Lacustrine flooding.

The author from visual date of NC shown by the Weather Channel in their coverage of Hurricane Florence noted that long before rivers overtopped their streambanks, large areas were flooded a few feet deep. The author interpreted this situation that thousands of acres were Lacustrine flooding, as the area being shown were 6-7 miles to the nearest stream. For the area south of Mechlenbuerg NC in Union Co., it was stated that the area had never flooded before. The area was receiving 2-3 inches per hour of rainfall, and at the time had accumulated 12" of rainfall. The author interpreted this flooding as Lacustrine flooding.

## Palustrine Flooding

Palustrine Flooding would be that area flooded around lakes. The largest data base of Palustrine flooding would be the National Wetlands Inventory. These maps can be used as a first approximation of Palustrine flooding. What is shown would have the same limitations as mentioned for Lacustrine flooding, that no frequency is assigned to the flooding.

In the authors field work in Alaska in 1971 he visited lakes in the vicinity of Point Barrow. These lakes were described to be part of the oriented lakes. The water in the Lakes was almost to the level of the adjacent cotton grass tundra. Snow melt alone would provide standing water around the lakes that could not drain off. The underlying restriction to any infiltration was the permafrost leading to Palustrine flooding.

The Sanford dam breach on boiler Springs Lake in NC, had Palustrine flooding as the reservoir flooded adjacent areas that were not planned as part of its capacity. The Headwater Dam above Creston N. C. also filled to capacity and caused adjacent Palustrine Flooding. During the Weather Channel flood coverage of Florence one location visited was a reporter near Lumberton, N. C. The reporter repeatedly reported that there was no river for 5-6 miles and no overbank flooding. However he noted that there was a lake about a mile away that had filled to capacity and that any water that would have flowed into the lake now spread out on to the adjacent ground. The author has interpreted this situation near Lumberton, NC as Palustrine. Flooding.

## Estuarine Flooding

As with Lacustrine and Palustrine flooding, an approximation of the Estuarine flooding can be obtained by looking at the National Wetland Inventory maps for each state. The estuaries at the mouth of the major rivers in North Carolina and South Carolina had extensive high water for many days. The Little Pee Dee and Lumber Rivers join near Nicholes, SC, which is near the head of the estuary. Nicholes had severe flooding from Hurricane Mathew in SC causing 600 residents to evacuate Only 400 returned to live is this flood prone area.. Some 4-6 feet of floodwaters again inundated Nicholes from Hurricane Florence Estuarine flooding. In general, Estuarine flooding is not separated from Riverine AE, and A on FIRM maps or from Marine flooding V and VE on FIRM maps.

### Marine Flooding

Marine flooding along the coast of North Carolina and South Carolina during Florence occurred during storm surge. In some parts of NC, 20 inches of rain fell on areas of high tides and a storm surge. The expected storm surge at the mouth of the Pee Dee River was 20 ft. Deposition of beach sand inland is an indication of the extent of storm surge. At Surf City, NC, sand deposition from the Florence storm surge was observed several blocks inland. Hurricane Hugo produced 12.5 ft. of storm surge along the South Carolina Coast. On the FIRM maps these areas are mapped as V and VE. An approximation of the extent of Marine flooding can be obtained from the National Wetland Inventory maps. There is a projection of as much as 3 inches of seal level rise along the Carolina coast by 2100, to increase the flood problem. Flooding from Significant Waves has been ignored in flood studies along the Carolinas. In Oregon Significant Waves average 12.8 times average wave height (Komar, 1997).

## Discussion

Hurricane Florence was directly or indirectly responsible for 42 death. One can ask if Hurricane Fluorence flooding was natural flooding that should be expected or was it just an extreme event in a long-term record? In addition was it enhanced by climate change? The ocean temperature was very warm in the tropics where Hurricane Florence originated. Research is needed to establish if the ocean temperatures that generated Florence represent a new condition. A big problem was the slow movement of the hurricane rain bands at 2-3 mph for a long duration over local areas. Some gages reported rainfall of over 60 inches for the event. The high rainfall and lack of drainage ditch capacity and adequate outlets, caused ponding (Laciustrine flooding) that has not in general been documented.

Hurricane Florence is likely to be one of the worst flood disaster in terms of area flooded, that the nation has experienced. Part of this is that some of the flooding was a none traditional type like Lacustrine flooding because the soils in some areas were saturated, the drainage ditches were full and there was no way for water to infiltrate or run off. The capacity of some lakes and reservoirs were maxed out causing Palustrine flooding of surrounding areas. On some NC and SC streams, Riverine flooding occurs with flood stages that only occur in very extreme floods like those with 500 to 1,000 year average recurrence intervals. The Riverine, Lacustrine, and Palustrine flooding eventually reached estuarine causing Estuarine flooding. Where Florence made landfall there was also a storm surge which caused Marine flooding.

The FEMA floodplain maps were not adequate to represent the extent of potential flooding, which made it difficult to understand the extent of the problem from Hurricane Florence   In addition the denial of local people of  the potential flood hazard, and the cost of flood insurance caused   resulted in a low percent of people with flood insurance. Also  the denial of local people to recognize the flood problem caused a need for extensive search and rescue, and the need for over 3,000 people having to reside in shelters in North Carolina,   The Hurricane Florence flood fight and rescue operations were greatly hampered by flooding over roads, and down trees and power lines.   Some of the road flooding was Lacustrine flooding because of inadequate road ditches, and culverts to move the surface ponded water over to drainage outlets that had not yet reached  flood stage.

During Hurricane Florence  a lot of trees were blown down along  roads bringing down power lines in the process. In addition hundreds of trees were blown down along stream banks.  These blown down trees and other Large Woody Debris (LWD) restricted flood runoff and caused backwater effects that increased flooding and its duration.  It is unknown if the trees blown down in Florence were shallow rooted  or deep rooted species.  If the problem was deep rooted trees were blown over because the soils were saturated than those areas needs evaluation for better drainage.  In addition a better evaluation is needed if  trees have been planted in the past to minimize blow down.

The author has mapped about a half a millions acres of  Riverine floodplains in Oregon. He later mapped 231,000 acres of Riverine flooding on nine  streams in Alaska, as well as studies along streams in Washington and Arizona. Most  of the authors  mapping has become part of  later studies published by  FEMA.  The authors floodplain mapping has also been incorporated into several floodplain zoning ordinances, in the Willamette Valley in Oregon.

The author's extensive experience in floodplain mapping leads him to present a new way to discuss and map flooding. These new categories are Riverine, Lacustrine, Palustrine, Estuarine, and Marine.  A better understanding of these other types of flooding, especially Lacustrine flooding, may help us understand how to manage this overall water accumulation.  Lacustrine flooding is more of a drainage problem because of impermeable soils or saturated soils that local drainage districts must deal with in terms of ditch size, vegetation maintenance, and culvert size..  The rainfall caused ponding  has not in general been documented   This may be because Riverine studies are being done using HEC-RAS to only document water surface profiles along river cross sections.

The author believes that to adequately map Lacustrine, Palustrine, Estuarine and Marine flooding one needs high resolution Lydar aerial imagery, and drone flights over these types of flooding events.  However there are Federal Aviation Administration (FAA) restrictions on where drones can fly.  FAA restrictions applied during Florence prevented getting the coverage needed to represent any type of flooding.

We need to take a hard look at the encroachment by development that has changed what would occur as natural flooding to one modified by encroachment.   Often streams are abandoned and put in a straight ditch with no floodplain and with inadequate culverts.

Three  ways to evaluate how to   constrain encroachment  is flood  proofing,  relocation and buyouts.  A part of  flood proofing  is to raise the elevation of structures above the base flood. The author led a study in Washington of a large river basin that had a long history of flooding where these solutions have been used. (Reckendorf et al, 2012).

The Chehalis River and the Skookumchuck River were formed by runoff from the Pudget Glaciation and have been subject to periodic flood flows ever since. The Centralia newspaper has documented reports of 34 flood events from 1887 to 2007 in Lewis County, 27 of which included the Chehalis Basin. USGS stream gages have documented 35 flood events in the Chehalis Basin that cover from 1930 to 2010. With this extensive flood history, how the local have dealt with floods is worthy of consideration. There are no flood control structures, channel works or major dikes to mitigate flood hazards. Since 1993, the Cities of Centralia, and Chehalis in Lewis County worked with individual landowners to reduce flood hazard. This work was done with the support of FEMA, Washington State Emergency Management Division, and the Small Business Administration (SBA) which invested several million dollars to acquire or elevate many flood prone residential structures in Lewis County (FEMA 2008). Between 1994 to 2004 Lewis County, Centralia, and Chehalis combined flood proofed 230 structures, and removed 61 flood prone structures. (Brown and Caldwell, 2008). To determine the effectiveness of this non-structural program, FEMA in 2008 developed a study on residential structures located in Centralia that had been flood proofed. The study focused on 35 structures that were elevated after being flooded in 1996 and 1997. Detailed flood elevation data was obtained on these 35 structures following the December 2007 flood event. The total mitigation cost for the 35 structures was estimated to be $1,906,000. The flood damages prevented from 2007 flood on these 35 structures exceeded the project cost by almost 2 to 1 (FEMA, 2008).

In addition to the projects listed above, since 2006 Lewis County has assisted in raising 105 homes within both the Chehalis and Cowlitz Basins. Also, Lewis County demolished 29 flooded homes after the December 2007 flood on the Chehalis River. Of the homes that were damaged in the December 2007 flood event, 85% were not located in a FEMA map flood zone.

In the Chehalis Basin, Lewis County Conservation District has flood proofed land areas for livestock, called critter pads. The fill is placed above a certain flood elevation for both livestock and equipment. Critter pads have also been used Tillamook County, OR to get livestock and equipment above of expected flood stages.

To offset the flood damages to infrastructure that was occurring throughout the United States engineers started building dams to store flood runoff, and or channelizing the river to try and increase the velocity to pass through the reach. This was only partly successful, as river channels down-cut and widen to return the river to a dynamic equilibrium condition.

We have been trying to solve flood problems for close to 100 years. Unfortunately, the flood problem has become a moving target, because of encroachment, modified watersheds from pavement in the watershed, fires, and clear-cutting. Some possible increase in flooding may be occurring because of climate change that we do not fully understand.

## Conclusion

Scientists can do a better job of preparing maps of potential flooding and the classification suggested in this paper could help in that characterization. The names are Riverine, Lacustrine, Palustrine, Estuarine, and Marine. Some flood types like Riverine have a standard hydraulic procedure when used for FEMA studies. There are no standard procedures for evaluating ponding on flat ground (Lacustrine) or for that around lakes (Palustrine), or estuaries (Estuarine) or for flooding above the beach by tidal surge, storm surge and that from significant waves (Marine). These types of procedures need to be developed. Use of drones for aerial mapping during flood events would greatly help in establishing flood boundaries. In addition updating the land topography with high resolution Lydar would allow updated flood maps to be drawn with good topographic control. The author is unsure if FBFM and FIRM mapping is being done using high resolution Lydar at the resolution being used by the Oregon Consortium. That lydar exceeds the lydar requirements being used by USGS.

Waterway conveyance constraints such as bridges, culverts, floodplain encroachment, and climate change have resulted in flooding being a "moving target" in term of expected area, depth, and duration. Studies are needed to update existing maps of flooding.

There needs to be a statistical analysis of rainfall gages to establish 100 year average recurrence interval events, that cause flooding of Lacustrine, Palustrine , and Estuarine areas.

Flooding and flood damages are likely to increase again in the future so our needs for accurate maps means built in updated studies.

The options to deal with the extensive flood problems involve integrating all of the solutions (flood control, flood proofing, relocation, increasing ditch and culvert capacity, and planting appropriate trees to minimize blow down) in a comprehensive way.

In the uplands, there is a need for an evaluation by U. S. Forest Service and the Bureau of Land Management to find ways to manage forest and rangeland to reduce runoff and erosion. Research could be provided by the Agricultural Research Service.

For all flooding there is a need for another national task force like the one in House Document 465, " A Uniform National Program for Managing Flooding in US " . The same agencies (e.g. USCOE, NRCS, USGS, and TVA) that developed House Document 465 are needed as well as FEMA, SBA, NOAA, NWS USFHA, FAA, USBR as well as representation from soil , water , and atmospheric Professional societies. They need to provide direction to upgrade data collection on precipitation, runoff, and mapping of flooding of all types.

At the state level water resources departments, natural resources departments, departments of transportation, flood control districts, drainage districts as well as soil and water conservation districts need a task force to evaluate what can be done to reduce overall flooding that floods state highways, and that along drainage ditches. Counties and cities need a task force to determine how to reduce flooding along roads from inadequate drainage ditches, and culverts. This should include representation from drainage districts and Soil and Water Conservation Districts. NRCS can help establish areas of poorly and imperfectly drained soils.

There is a need for local arborist and foresters to have a task forces   to evaluate if the correct species to reduce tree throw have been installed in the past and will be replanted in areas of extensive blow down during flood events. This should involve consultation with NRCS on soil differences that can influence tree root systems and the ability to remain upright in high winds.

These various task forces   are needed to establish policy and procedures for reducing storm and flood damage. The approach needs to be that we are in this together and cooperative evaluation is a necessity. The coordination of all these various task forces should be placed under FEMA, which should be responsible for preparing legislation to go to the U. S. Congress for future evaluation and mapping of Riverine, Lacustrine, Palustrine, Estuarine, and Marine flooding.  Block grants to states could be authorized and  set up a program to do the field mapping.

## References


Brown and Caldwell Consulting,  2008.  Lewis County Comprehensive Flood Plain Management Plan.  Prepared for Lewis County, Washington. Seattle, WA.

Conrad, D., McNitt, B., and Stout, M.,  1998.  Higher Ground. A Report of Voluntary Property Buyouts in the Nations Floodplains, A Common Ground Solution Serving People At Risk, Taxpayers, and the Environment. National Wildlife Federation, Chehalis, WA

Cowardin, L. M., Carter, V., Golet, F. C., and LaRoe, E., T.,  1979.  Classification of Wetlands and Deepwater Habitats of the United States. US Department of the Interior, Fish and Wildlife Service, Washington, DC, Jamestown, ND Northern Prairie Wildlife Research Center Home Pate. http:///www.npwrc.usgs.gov/resource/1998/classwet.htm (Version 04DEC98).

FEMA,  2008.  Evaluating Losses Avoided through Hazard Mitigation. City of Centralia, FEMA. Washington, DC

Komar, P.,  1997.  The Pacific Northwest Coast. Duke University Press, Durham, NC

Leopold, L.,  1994.  A Guide to the Field Identification of Bankfull Stages in the Western United States. USDA Forest Service Rocky Mountain Forest and Range Experiment Station, Stream Systems Technology center, CD, (31 minute  Video).

Mann, M.,  2018,  Controlling future summer weather extremes still within our grasp. Penn State. Science Daily, October 31, 2018

Reckendorf, F., Renner, D., Amrine, R., Verd, K., Wilson, N., Stevens, M., and Fenwick, D.,   2012. Chehalis River Basin Studies, Inventory and Evaluation.  Lewis County Conservation District, in Cooperation with USDA, Natural Resources, Conservation Service, and Washington State Conservation Commission.

Reckendorf, F.,  1998,  Use of Geomorphic Surfaces in Floodplain Mapping as Modified by Land Use Changes, and Reflecting the Adequacy of FEMA Mapping and Guidelines, as well as Oregon Land Use Goals. Environmental, Groundwater, and Engineering Geology: Applications from Oregon. Star Publishing. Belmont, CA.

Reckendorf, F, and Styner, W., 1978., Flood Hazard Analyses, Delta Study Area, Alaska. USDA, Soil Conservation Service, Anchorage Alaska

Reckendorf, F., 1973, Techniques for Identifying Floodplains in Oregon. PhD Thesis, Corvallis, Oregon State University. 344 pages, leaves.

Reckendorf, F. and Taylor, P., 1971. Draft, Type 10 Flood Insurance Study, Applegate River Portion of Applegate River in Jackson, CO, OR. Report for Flood Insurance Administration, USDA, SCS, Portland, OR.

Reckendorf, F., 1969, Geomorphic Features of Oregon Streams and Floodplains. American Society of Civil Engineers, Hydraulic Specialty Conference, Logan, Utah. August 20-22, 1969.

Reckendorf, F., 1968. Methods of Identification and Mapping of Floodplains. American Society of Agricultural Engineers, Annual Meeting. June 18-21, 1968.

Rhodan, M., 2018, When the Rivers Rise. Hurricane Florence pounds the Carolina coast, leaving residents at nature's mercy. Time Magazine, pp 32-35.

Rippey, B., 2019. Weatherwatch, Weatherwise Magazine, January/ February 1019. Philadelphia, PA.

Rosgen, D., 1996, Applied River Morphology, A Classification of Natural Rivers. Wildland Hydrology, Pogosa Springs, Colorado.

U.S. Congress, House Committee on Public Works, 1966, "A Unified National Program for Managing the Nations Flood Losses", 89th Congress, Second Session, House Document 465. Washington, D.C.

U.S. Department of Housing and Urban Development, 1968. National Flood Insurance Act of 1968, HUD Washington D. C. 28p.

U.S. Department of Homeland Security, Federal Emergency Management Agency, 2018, FEMA Policy Standards for Flood Risk Analysis and Mapping. Washington, DC.