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Pilot Report: Measurement of Floodplain Value for Downstream Flood Reduction

FOR THE NATURE CONSERVANCY

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Pilot Report: Measurement of Floodplain Value for Downstream Flood Reduction

Introduction

This report details a pilot study on the water storage/flood resiliency value of lands upstream of urban/suburban centers under riverine dominated flooding. The goal is to develop a process that can be applied to other areas in the Southeast US.

This study's intent is to quantify the ability of the floodplain to reduce flooding and assign a potential dollar value to those benefits. The technique uses a GIS based-model approach as opposed to a hydraulic model. The GIS approach provides the ability to expand the use to other areas without complex modeling requirements. The approach assumes that the flood plain will provide (1) passive flood storage of ponding above the land surface, (2) active storage from soil saturation (filling pores) above the shallow groundwater table, and (3) that those waters reduce the flow of the river at the population center under study.

The basic approach uses the flow during Florence as a real-world example of a 1% or above riverine dominated flood (not flash flooding) and how the system reacts to this water input. The empirical data have been used in conjunction with previously developed Northcoast (TNC) flood products to define relationships and algorithms that describe the flood/discharge aspects of the Conway pilot study area.

While time can be an important and dynamic aspect in flood storage and in the active removal of water, the technique has assumed that the character of the river system will respond to floods accordingly. The speed of water (approximately 1 m/sec at high flows) is set by the slope of the river, so barring a dam break type of flood the speed at which the surrounding low-lying areas are flooded is considered a constant. Thus, a simplified treatment of time and flood extents – based on approximately a 0.5 m/day increase in gage levels recorded during Hurricane Florence – was employed to keep volume calculations within the bounds of this initial study.

Pilot Area Extents

The pilot area is northeast of Conway along the Waccamaw River, Kingston Lake River and Maple Swamp River (Figure 1). The general location was discussed with TNC prior; the specific extent is a combined area of approximately 65 square miles (41,000 acres). There are three river gages in the study area: Crabtree Swamp, Waccamaw Above Conway, and Waccamaw at Conway Marina.

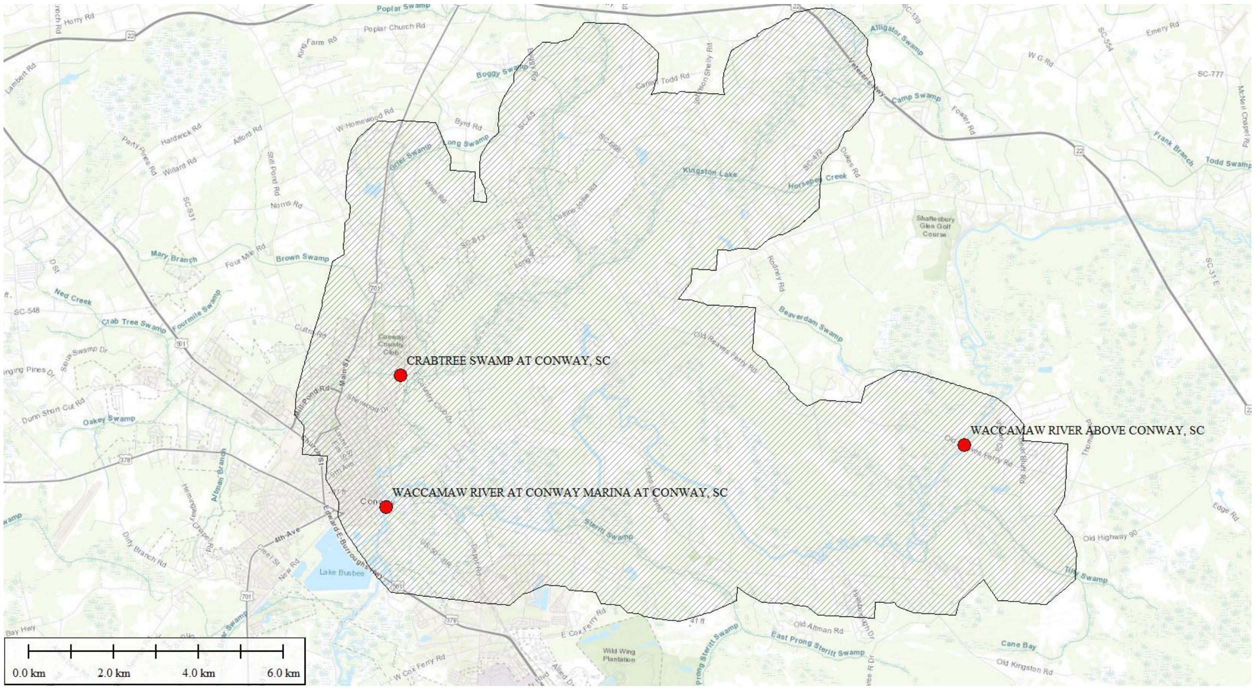

Figure 1. AOI for study

Methods/Background

Much of the work in this report has its roots in an earlier report on Hurricane Florence flooding in Georgetown County[1]. The earlier report highlighted the effects of tides on flow from riverine flooding just downstream of the present AOI. In addition to the gage info used in the early report, the present report also employs a number of GIS datasets to define/describe the hydraulic regime and the infrastructure present.

Data Collection

The first part of the project concentrated on data collection. During the early planning more data sets were collected than ultimately used as early work was to include evapotranspiration. Evapotranspiration was dropped when the volumes of water removal were initially analyzed. Only about 1% of the total water volume would have changed from evapotranspiration during the weeklong period of flooding.

Spatial Data

Spatial data was used as the primary 'analysis' information and included linked coefficients for the active storage parameters. Spatial (GIS) layers sourced from other projects or groups include:

1) Topography – Northcoast lidar-derived DEM
2) Theoretical Water Surfaces - Northcoast Risk Extents, Flooding Depths, and Flood Depth standard deviations
3) USDA Soil data
4) Land cover – NOAA Beta 10 m C-CAP[2]

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[1] William, Thomas M., Daniel Hitchcock, Bo Song, and Thomas O Halloran; 2019. Hurricane Florence flooding in Georgetown County: A qualitative explanation of the interaction of estuary and tidal river.

[2] https://inport.nmfs.noaa.gov/inport/item/57099

5) Wetland Potential Layer – NOAA C-CAP[3]
6) Structure locations – From Microsoft[4]

Coefficients

1) Active storage coefficients – Porosity values for soils from literature[5]

In-situ Data

In-situ data was extremely important; it was used to develop algorithms describing the relationships between flow/volumes and measured water surface heights at each gage and between them. In-situ data consists of:

1) River stage data from Hurricane Florence[6]
2) High water marks from Hurricane Florence[7]

Data from these layers has been used as-is and also to create derived products. The derived products were combined to create master 'flood resiliency value layers' (see Results).

Analysis

The process used to define the value of the floodplains consists of the following steps:

1. Determine river flow vs. elevations relationships
2. Calculate the volume of water on the floodplain – including passive and active storage
3. Determine river elevation vs. water volume relationships
4. Calculate flood levels without storage
5. Determine building damage difference between with and without storage flooding
6. Assign and map yearly floodplain values

River flow and Elevation

There are three gages in the AOI with the most important being the Conway gage. The Conway gage was used as the metric of flooding, the others – Waccamaw River Above Conway and Crab Tree Swamp – were used to complete the inputs to the Conway area (Table 1). Any additional input not captured by these gages was attributed to Kingston River and Maple Swamp. The measured values[1] were very similar to trends of the projected[8] Northcoast derived water surfaces, as were the high water marks[6]. This allowed for the use of previously created flood layers (Northcoast project) to define the water levels in the AOI for all flooding levels since the data was consistent with the data from the earlier study as well as the values from the USGS flood viewer (high water marks). This is an important step of the process as it forms a link between flooding extents and depths on the floodplain in relationship to flow volumes. For example, based on the Northcoast 2017 water surfaces, Hurricane Florence flooding (Figure 2) was about a 200 year event (0.5% yearly).

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[3] https://inport.nmfs.noaa.gov/inport/item/48357

[4] https://github.com/microsoft/USBuildingFootprints

[5] Al-Aboodi, Ali H., Ahmed Al Kadhimi, and Majeed Al-Tai, 2013 Mathematical Model Of Groundwater Flow In Teeb Area, Missan Province, South Of Iraq. Kufa Journal of Engineering (K.J.E) V 5, n 1.

[6] https://nwis.waterdata.usgs.gov/nwis/uv?site_no=02110704

[7] https://stn.wim.usgs.gov/FEV/#FlorenceSep2018

[8] Original Northcoast water surfaces did not include the height of Hurricane Florence flooding; an additional surface was added (100 year increased by 0.5 m) to achieve this beyond 100 year level.

Table 1. Flow balances during peak Hurricane Florence flooding used in modeling river elevations

Gage	**Stage (m, NAVD88)**	**Flow (m/sec)**	**Flow (cfs)**	**Flow/day (cu. m)**
Conway	4.60	1,465	48,796	126,605,963
Above Conway	5.40	1193	39,721	103,060,684
Crabtree	5.70	53	1,768	4,586,371
Kingston River/Maple Swamp		219	7,307	18,958,907

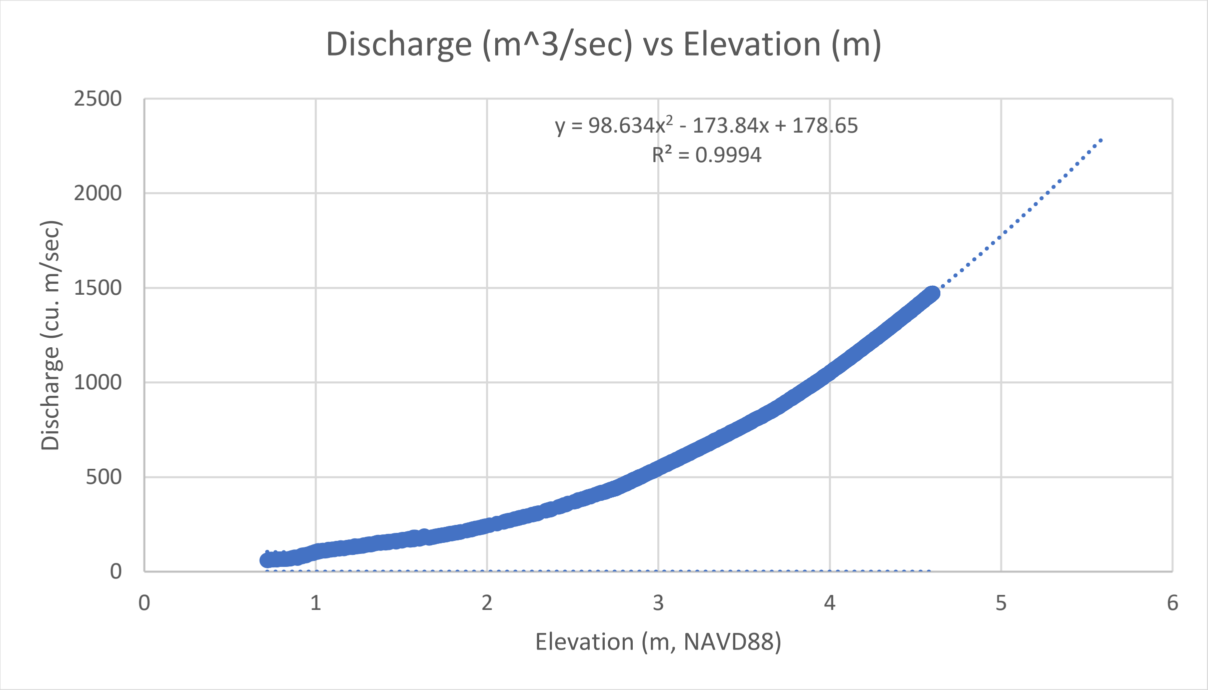


Figure 2. Discharge at Conway gage during rising limb of Florence.

Calculate Floodplain Storage Values

As this project moved forward, it became clear that from a functional damage perspective Passive and Active storage function similarly. They both work to decrease the peak flood elevation, which in this study is being used to measure damage.

The storage values (m^3) are being calculated using the flooding depths defined in the Northcoast study at ten ½ meter intervals. Each of these are associated with a gage elevation at Conway (Table 2). The primary result from this analysis is the calculation of storage increase from each stage, which is roughly equal to one day of flow during Florence (Figure 3). The storage increase is assumed to be equal to the amount of water that would have been added to the flow going through the Conway gage for that level of flood (Figure 2). An important assumption at this point, which will be discussed and addressed in the following sections, is that the loss of floodplains – and resulting water level increases – are not amortized upstream beyond the study area. This 'simplistic' system is flawed, as the increase in water levels would be translated upstream (to maintain a constant water surface slope) and increased flooding would occur outside of the study site (e.g., northeast of the gage Above Conway) and act to decrease the flood levels to a certain degree at Conway.

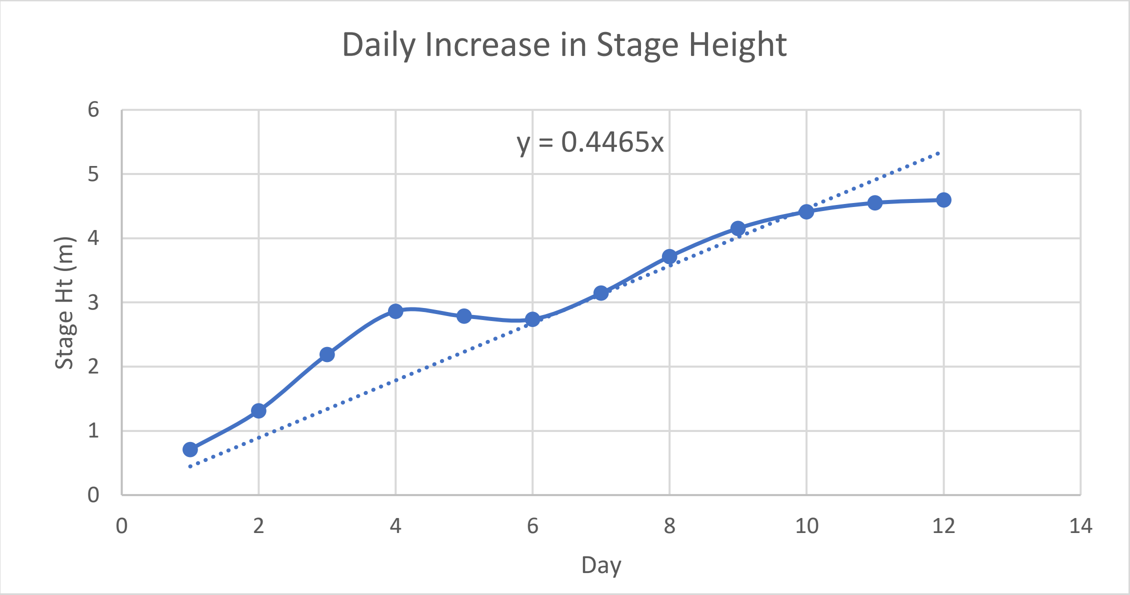


Figure 3. Average increase in gage elevation per day at Conway during Hurricane Florence

Passive Storage

Passive storage was calculated using the water surfaces (10) to define the volume of water on the land surface (Figure 4) at the respective flood elevation (e.g., Table 3). The area was broken into two basins for accounting purposes but is not a necessity for this analysis.

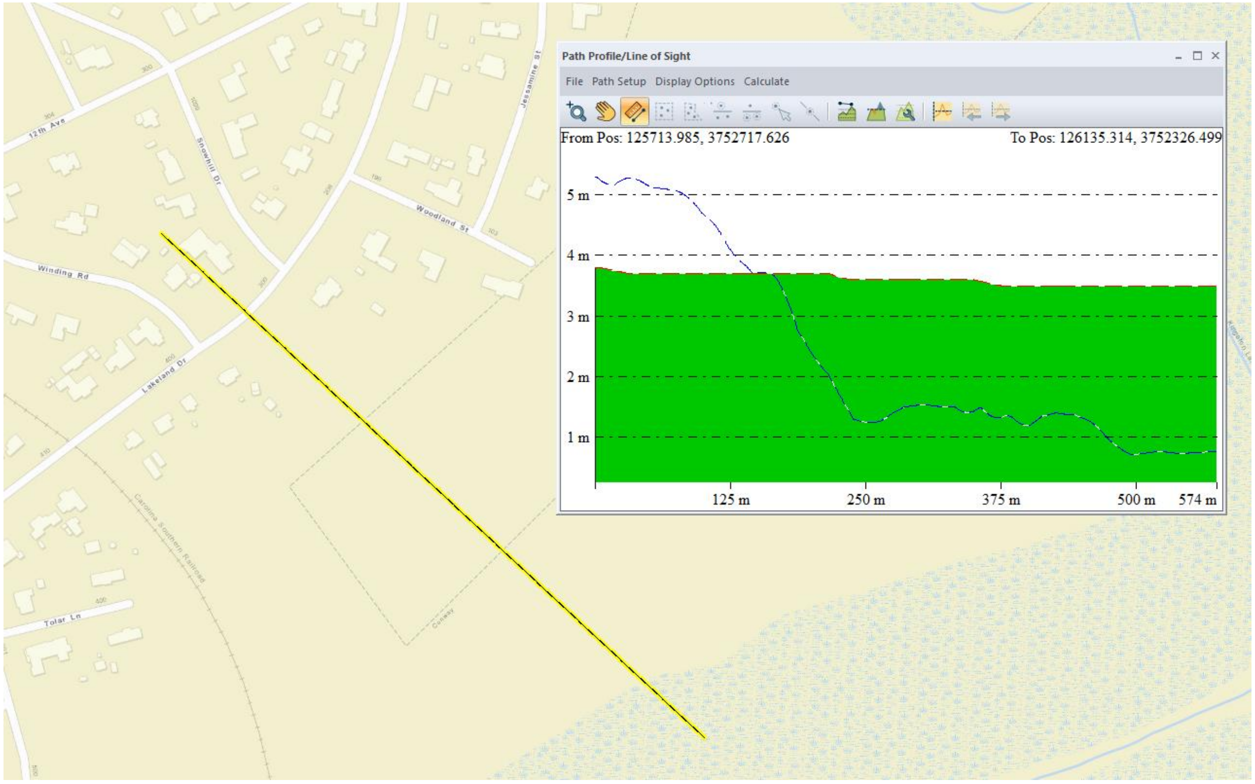


Figure 4. Example profile showing the water surface (green) and the land surface (dashed blue line). The volume between them was calculated across the AOI.

Active Storage

The active storage component was a bit more difficult to calculate as the water table and porosity (soil) varied throughout the AOI. The water table, an important factor in the volume of open pore space, was estimated using the wetland potential layer from NOAA and the soil types were used to estimate the porosity of the sediments.

The NOAA wetland potential layer provides a ranking for areas based on a 1 to 10 (low to high) wetland potential. They were binned into three groups with ‘high’, ‘medium’, and ‘low’ values. These areas were used to define the depth from the land surface to the water-table. For this, it was estimated that the system was ‘dry’ for the analysis such that there was no ponding water in wetlands (not in a flood condition). In that regard, areas with ‘high’ wetland potential were assumed to have a water-table of 1.5 ft below the surface, for ‘medium’ areas 2.5 ft, and for ‘low’ areas 3.0 ft. Using these offsets and the DEM, a water table surface was estimated (Figure 5). This was the first step in determining the Active Storage.

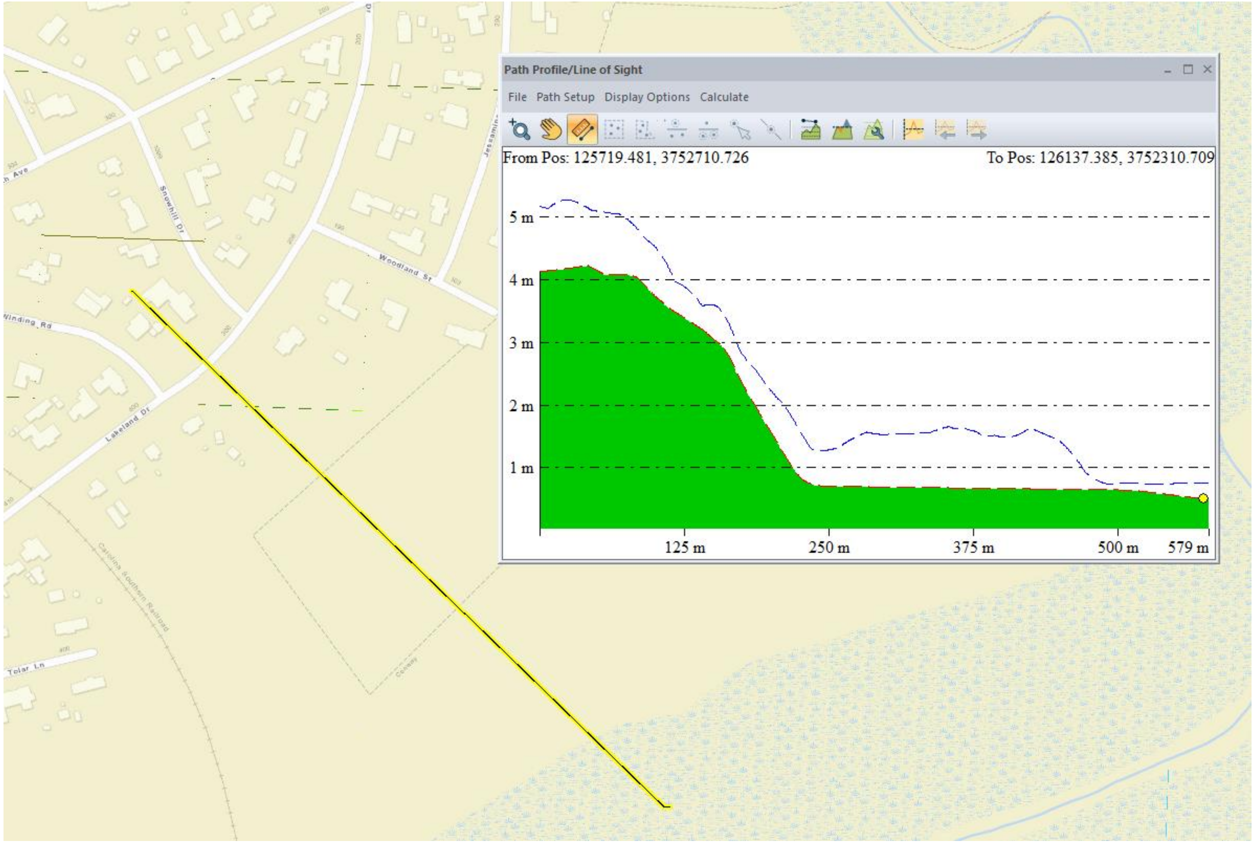
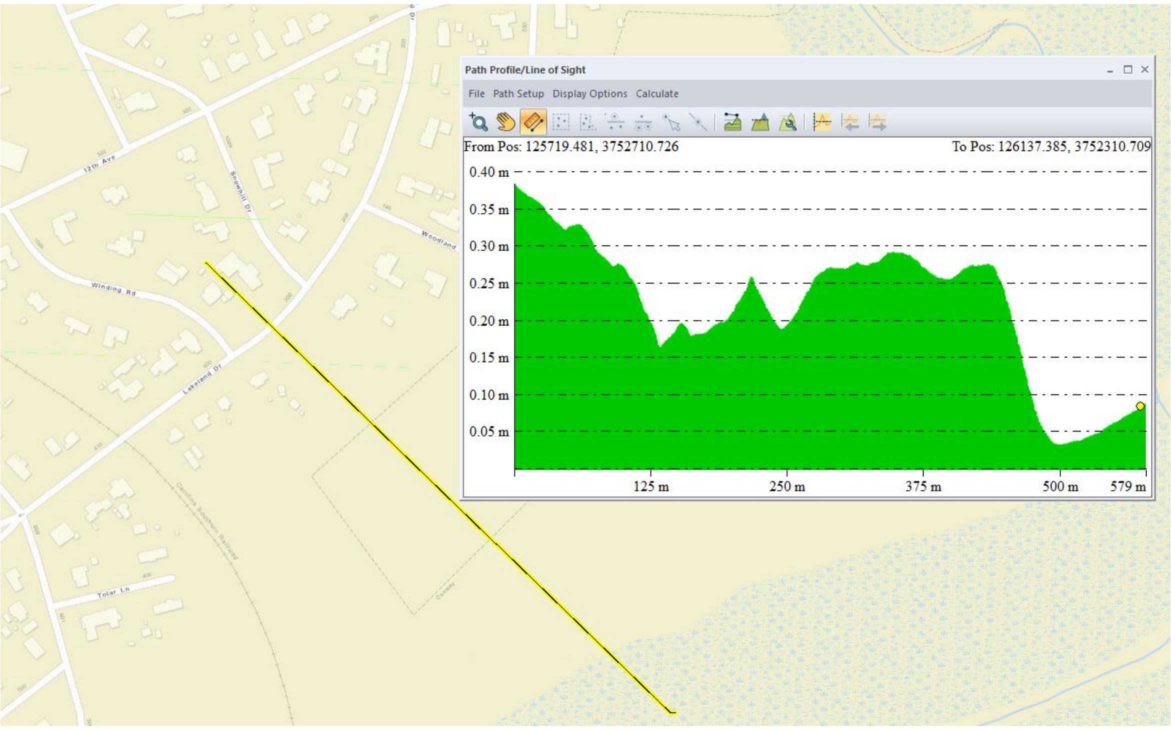


Figure 5. Water table (green) and land surface (dashed blue line) in the same area as Figure 4.

The second step was to estimate the pore space ratio in the ‘dry’ soil to calculate the volume of water that could be held in the surface soils above the water-table. This was done using the USDA soil maps and the hydrologic soil groups. The effective porosity was mapped and the volume surface generated in the first step was multiplied by the effective porosity resulting in the volume of available space for groundwater infiltration. Each area inundated during the 10 flood levels were then defined to calculate the bounds for each level, e.g., the area of L3 was subtracted from L4 to define the extents of L4. (Active Storage listed in Table 3).

Table 2. Soil porosity for different groups[5]

Soil Type	Porosity	Effective Porosity	Residual Water Content
Hydrologic Soil Group: A	0.437	0.417	0.020
Hydrologic Soil Group: B	0.463	0.434	0.027
Hydrologic Soil Group: C	0.398	0.330	0.068
Hydrologic Soil Group: D	0.475	0.385	0.090



From Pos: 125719.481, 3752710.726

To Pos: 126137.385, 3752310.709

Figure 6. The effective height of open soil along the same profile that can be multiplied by area to find volume.

Initial Modeling

With the amortized aspect being addressed in the next sections, the important aspect at this point is to define the floodplain and the area flooded for a certain level. For example, if the gage level was at 3 m, the flow would be about 500 m^3/sec (Figure 2) or about 43,200,000 cubic m/day (500 m^3/day x 86,400 sec/day). If the storage component was not there at this level (3 m) there would be about an additional 25,000,000 cubic m to add to it (Table 3) – this would then be about 68,000,000 cubic m/day or about 780 m^3/sec which would be around a 3.5 m gage height (Figure 7). Thus, the floodplain at this interval is helping to decrease flood levels by about 0.5 meters (before amortization).

Table 3. Passive and Active storage (cu. Meters) in AOI based on gage elevation (M, NAVD88) at Conway. Storage increase was calculated based on total + active – the previous totals.

Elevation @ Conway	Stage	Waccamaw	Crabtree/Grier Swamps	Total	Active	Storage Increase
0.2	0	325,414	616,271	941,685	0	941,685
0.7	1	5,796,076	1,695,933	7,492,009	3,238,634	9,788,958
1.2	2	11,138,396	3,649,934	14,788,330	2,903,008	10,199,329
1.7	3	19,960,942	6,589,422	26,550,364	2,771,571	14,533,605
2.2	4	33,180,677	10,814,788	43,995,465	2,974,530	20,419,631
2.7	5	49,740,398	16,850,148	66,590,546	1,708,925	24,304,006
3.2	6	67,702,906	24,477,053	92,179,959	1,059,839	26,649,252
3.7	7	86,300,201	33,756,919	120,057,120	1,624,932	29,502,093
4.2	8	105,196,670	44,652,603	149,849,273	1,999,141	31,791,294
4.7	9	124,342,937	56,523,198	180,866,135	2,486,333	33,503,195

In practice, the relationship developed from the continuous data (Figure 2; thousands of readings) was applied to the chosen 10 stages to determine the 'without floodplain' discharge. The 'without' elevation is then calculated using the empirical equation (Figure 7) developed from the Conway data. It is important to note that there would be an additional level of floodplain inundation above and beyond what was initially calculated as a result of the increase in flow depths (i.e., the floodplain would increase in size where available to do so from increased water levels). This additional flooding outside of the base floodplain calculation (Table 3) was not calculated as it was, instead, used as the measure of damage – the dependent variable.

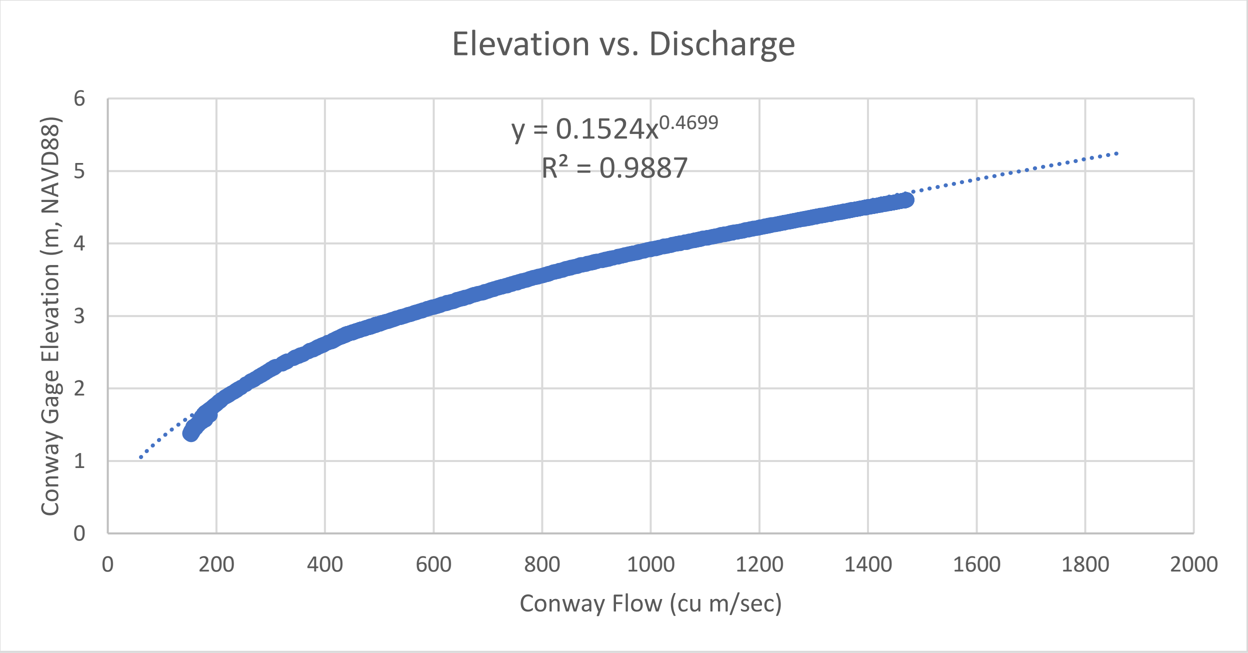


Figure 7. Development of equation to calculate flood elevation (meters) from flow values (m^3/sec).

The resulting relationship between the discreet measurements when flow was calculated with and without floodplains is shown in Figure 8. The equation was applied to the Northcoast water surfaces (GIS layers) in the Conway AOI to define new flood elevations outside of the floodplain (e.g., downtown Conway).

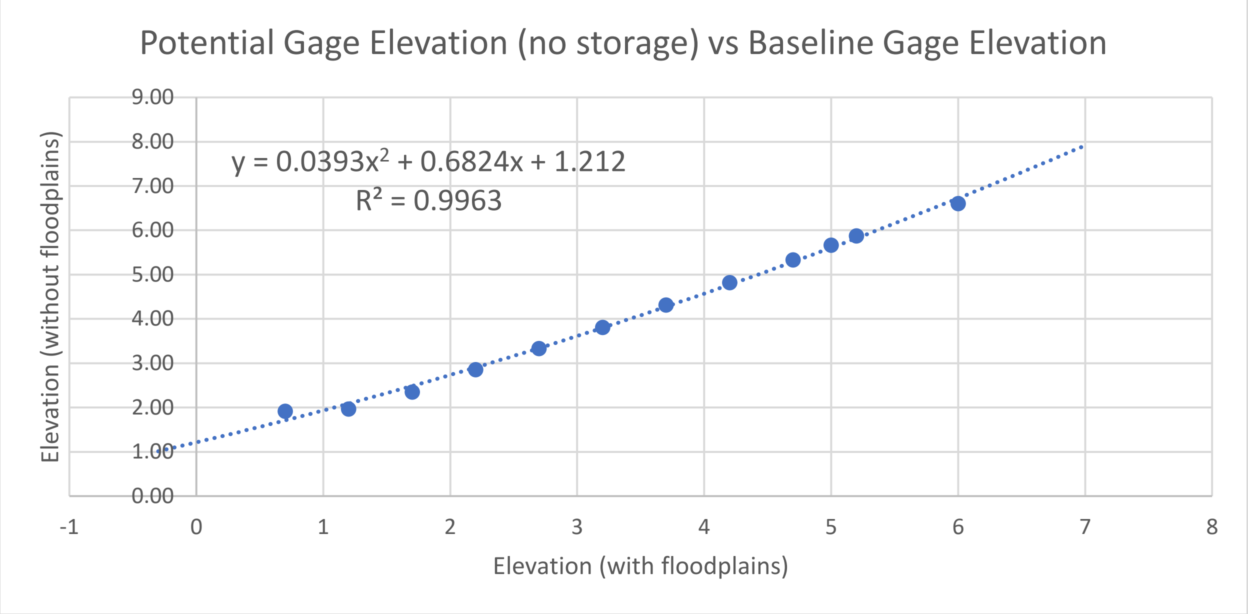


Figure 8. First approximation of the modeled water elevation at Conway with and without floodplains.

Tides

There was some discussion of tides and the ability to incorporate them into the analysis in areas where they are significant; at Conway they are considered a very minor aspect. Based on the process undertaken to understand the system it may be possible to incorporate tides using them as an Active Storage factor (in essence the ocean replaces the shallow groundwater – on a daily or sub-daily basis) but in the other direction, i.e., an increase in floodplains. In this case the daily totals would probably be looked at as ½ day or tidal cycle time. The storage potential is one way to look at the tides, another is to look at the relationships between gages, which is discussed below with regards to accounting for upstream flooding.

Calculate Flood Levels without Storage

The important step in the previous work was to define how much of an increase in flow would occur at Conway if the floodplains were not available. And in the simple case presented that flow was tied to a gage elevation in Conway (Marina). Although the increase in water volume must be offset by the river system, the more correct model would account for an increased level of flooding upstream, outside of the study system, which given the pilot studies limits is an unknown. The upstream flooding increases due to the rise in water elevation would 'amortize' the flooding in Conway by increasing the storage outside the AOI. This studies limitation, not documenting the floodplains outside of the AOI, is likely in cases where defining the entire watershed's character becomes an impediment to the specific question. The process described in this section is a first approximation to account for the unknown nature of the floodplains upstream.

The approximation is based on the assumption that the water levels at Conway during major river flooding are driven largely by the Waccamaw River. There are other inputs, such as Crabtree Swamp, Kingston Lake, and Grier Swamp, but as their name implies they are more of local drainage inputs. They are important in local flashy flooding conditions, but less so in large regional flood conditions where the Waccamaw caries water from 1,000's of square miles of drainage. If local source water is the primary concern the 'Simple' analysis (Figure 8) would be more appropriate to use.

So, instead of directly using the flow vs. elevation relationships at Conway a second step was included that used the flow values (with floodplains) at Conway and calculated the elevation at the gage Above Conway (Figure 9 and 10) at Old Reaves Ferry Road (Figure 1). The modeled equation can then be used to define the elevation above Conway for any flow values at Conway.

This is not a straight comparison, timing plays a role in this to some degree; it takes about 6 hours for a the water to flow from the gage above Conway to the gage at Conway (about 23 km at 1 m/sec). For example, the water elevation at the gage above Conway at 11 am was compared to the flow at Conway at 5 pm. In addition, there are local input and timing aspects to be considered. The flow at Conway is not always tied to the flow above Conway (Figure 9), so it was important to select data that is representative of the regional flooding aspect being studied (Figure 10). Of course there always going to be event-specific factors, but the desire here is to model the system in the most overall representative way, e.g., 'an average response'.

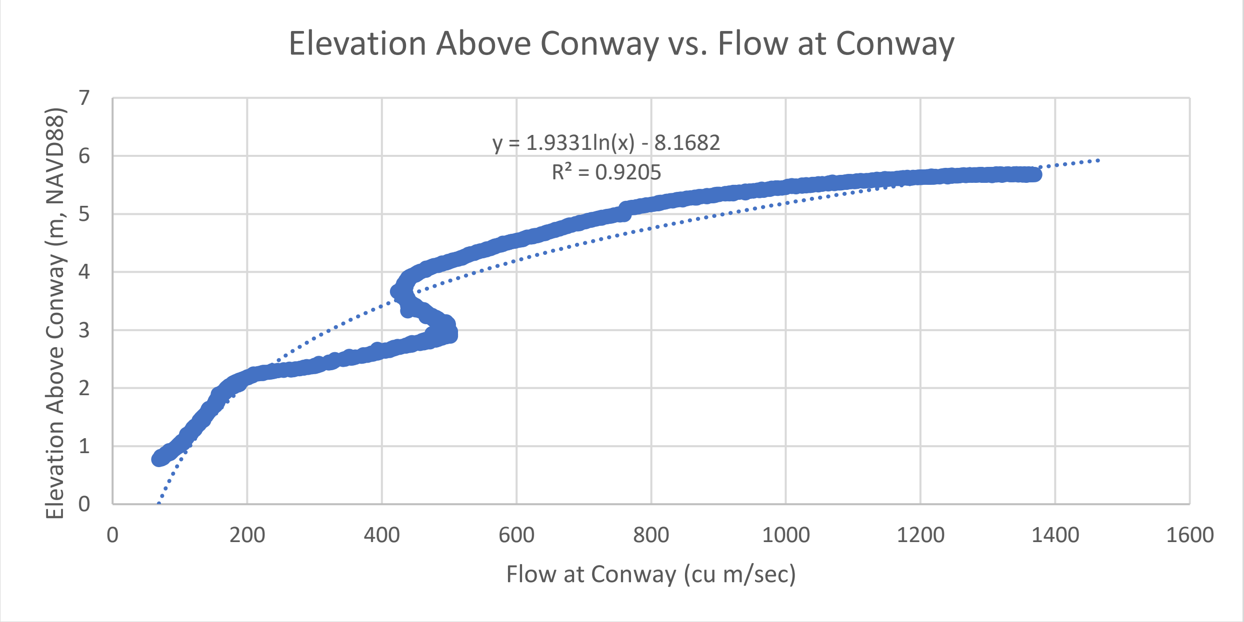


Figure 9. Flow during full rising limb of Conway gage in relationship to the elevation at the gage above Conway with a 6 hour time delay. There is clearly a period of time when local inputs were primary at Conway (i.e., not correlated to the gage above Conway) that are not represented above Conway.

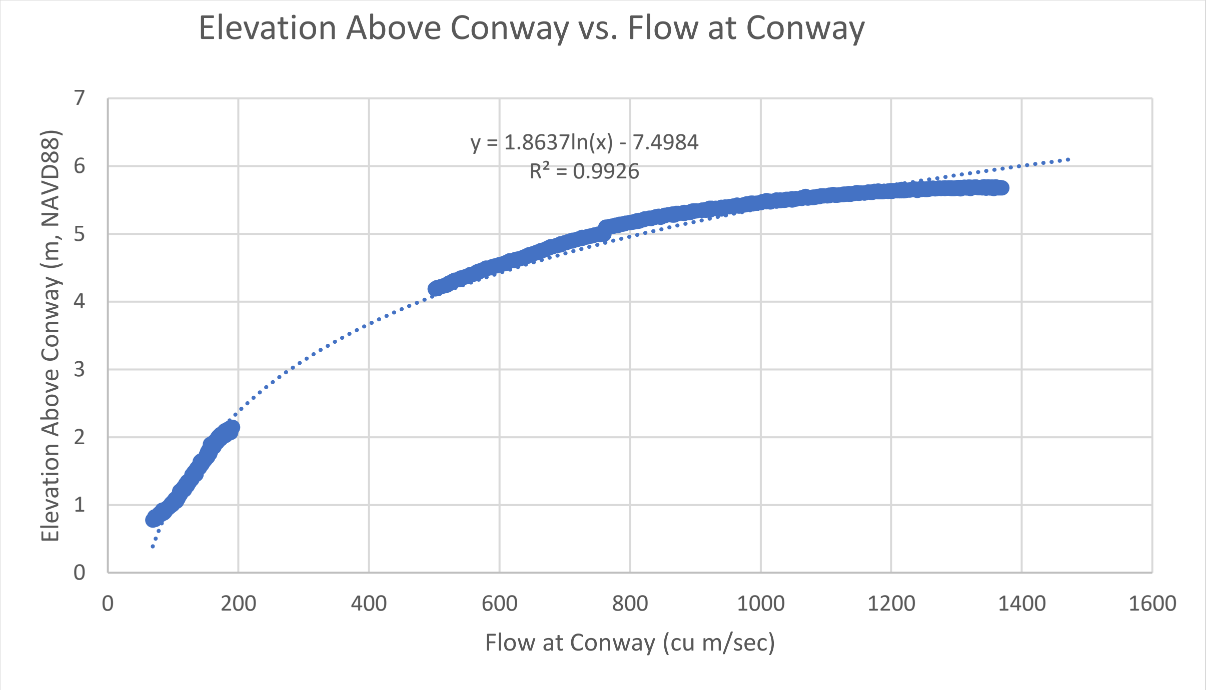


Figure 10. Selected data to define the relationship between Water Elevation above Conway and flow during Hurricane Florence at Conway with a 6 hour difference in sample times.

Once the gage elevation above Conway was defined mathematically, the second step was to relate that to Conway. The gage elevation at Conway was calculated from the relationship of gages above Conway and at Conway during Hurricane Florence (Figure 11). Again, representative data were being used, the same data was used for both Figure 10 and 11. This relationship mimics the existing steady state river slope during large floods, e.g., at an elevation above Conway of 3 meters there was about a 1 m slope to the Conway gage (Figure 11).

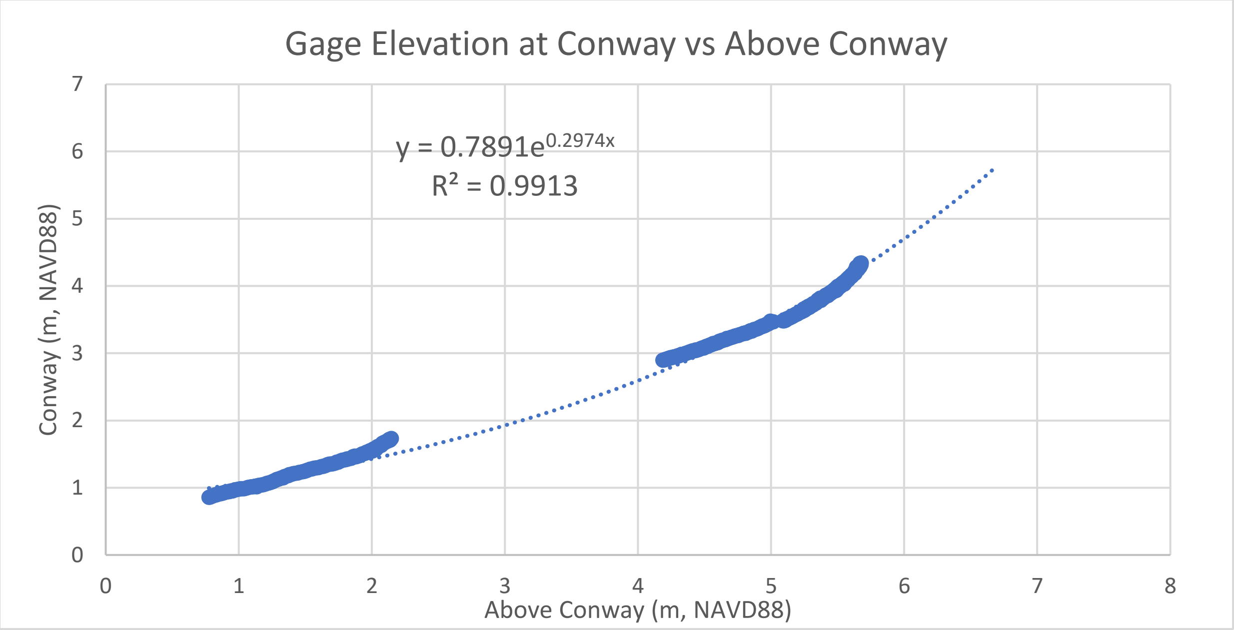


Figure 11. Gage relationship from Hurricane Florence

Using both of these equations (as opposed to the single one for the 'simple' case) the approximated modeled result (Figure 12) is about 1 ft (0.17 to 0.40 m depending on flood stage) below the simple case. This value, although not tested, appears to be consistent with the fact that, in this case, about 82% of the flow was from the Waccamaw. If it was 100% the decrease may have been slightly larger, as the water elevation above Conway would have been higher as compared to Conway (marina) since all the flooding would be coming from the Waccamaw. This highlights the fact that the modeled result (Figure 12) is reflective of a general situation whereby flooding has local and regional inputs. Again, all flood events are unique to some degree and this should be considered when looking at the final results. Additionally, the increased flooding upstream is another real outcome and cost of the theoretical loss of floodplains in the AOI. The cost of this flooding, however, is not being considered in this study.

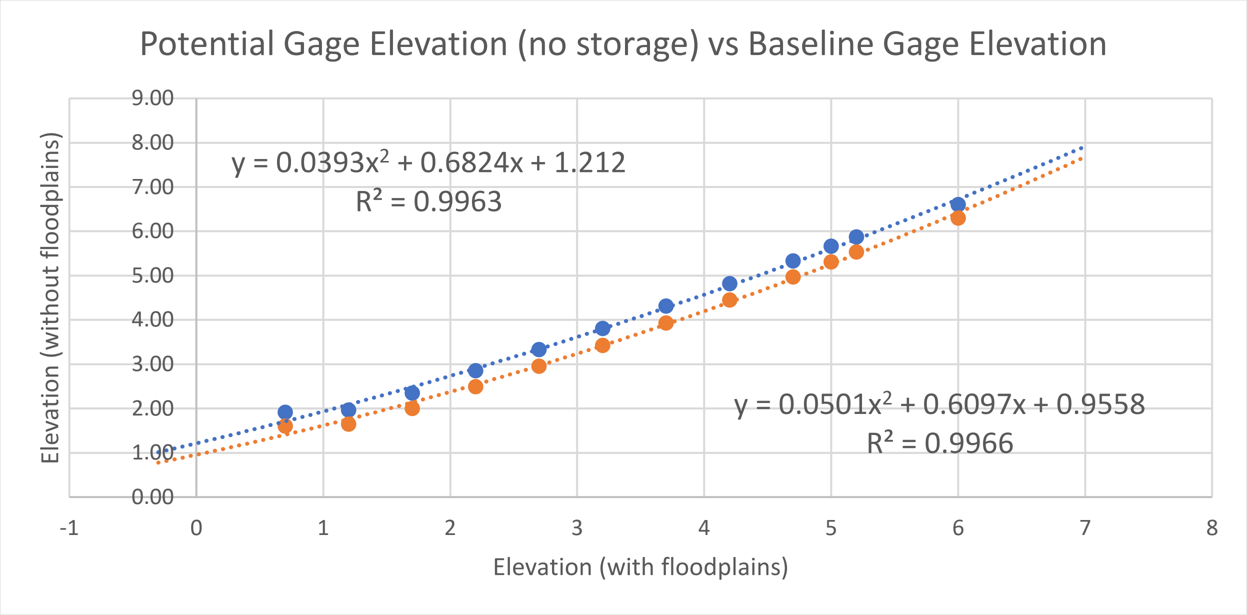


Figure 12. Approximated modeled result (Orange Line) of the with and without flooding conditions. The blue line is the simple case with no upstream flooding as in Figure 8.

In general, this is a relatively easy case since there is only one primary forcing pathway in the AOI – the Waccamaw - the other rivers/swamps are assumed to be flooded from Conway upwards (i.e., they are not primary in forcing the flood). If multiple primary forcing pathways are present, such as Georgetown where multiple regional rivers are present, a 3 point problem solution (commonly used in groundwater solutions) may be required and run for multiple scenarios.

Determine Flood Damage and Costs

Flood damage is being analyzed using the maximum inundation at any specific flood level, an instantaneous calculation of damage. The length of time a structure or road is inundated at a certain level is not considered. This is not to say that the time of inundation is not important or has a cost associated with it, especially for public roads and utilities; however, that would require a level of cost accounting that, at present, is beyond this study's scope. For this study, the storage benefit is being assessed based on the inundation costs associated only with structure flooding levels.

The structures for the AOI (Figure 13) were compared with the multiple 'with' and 'without' floodplain flood elevations (NAVD88) based on the approximated modeled results. For local flood results the 'simple' elevations could be used – and would represent higher values. The approximated results are more conservative.

The data for each structure has both a location and a size (sq. meters). The accuracy of the layer is not perfect (slight registration differences aside), there are some instances of structures missing, differences in area, and also structures where no houses presently exist (Figure 14). That being said, the data is being used as is; it represents a commonly available source that is both conservative (more houses present than omitted) and can be used throughout the US.

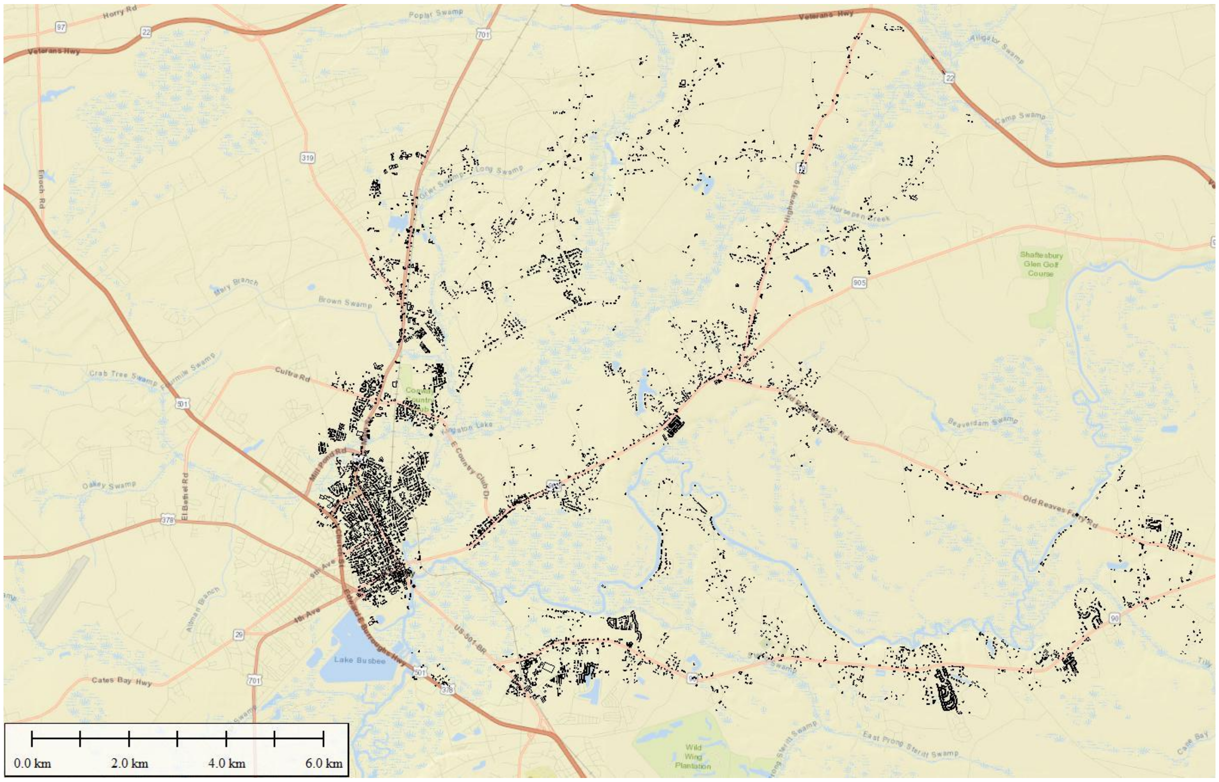


Figure 13. Structures (7,255) in the AOI used to assign costs

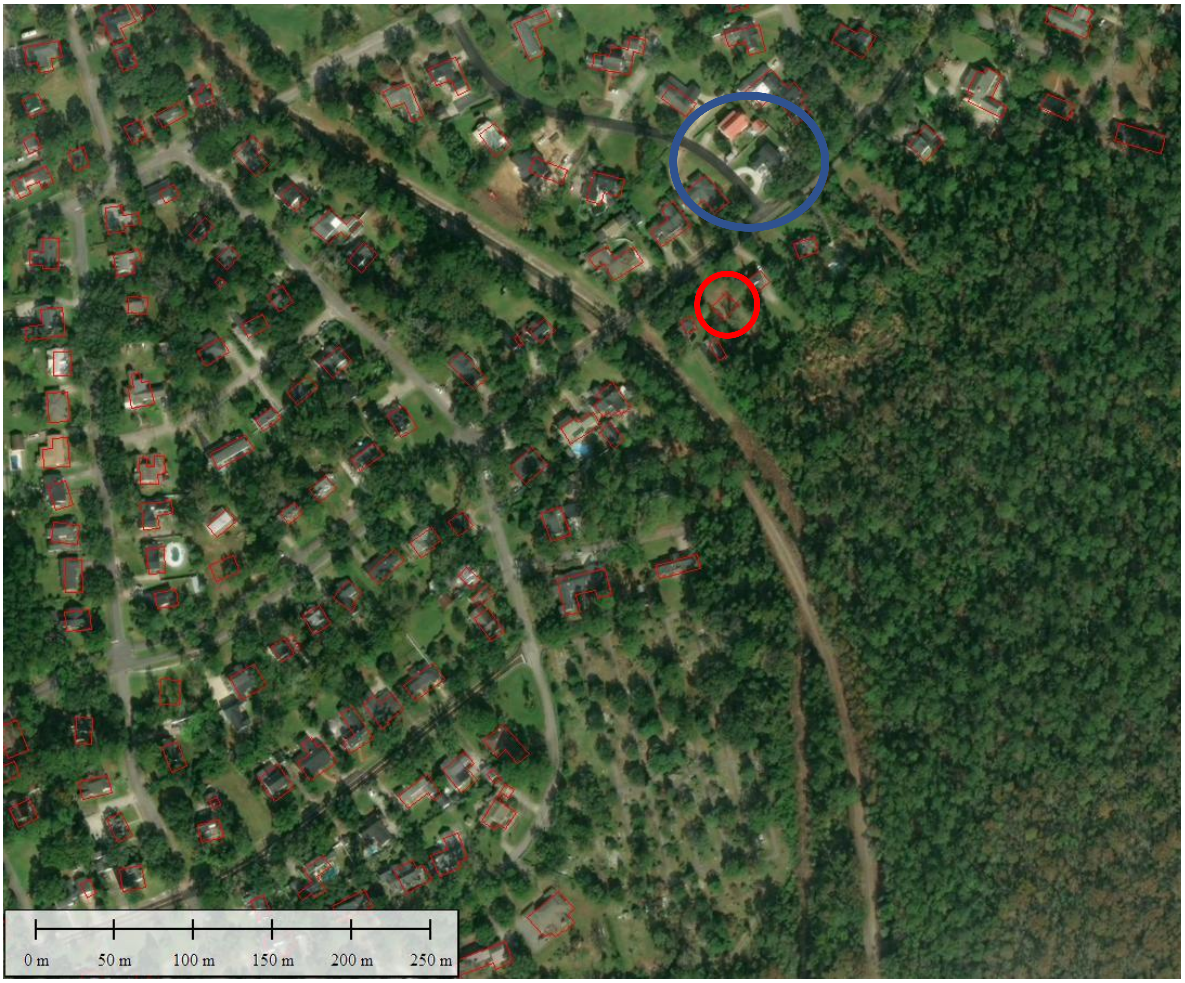


Figure 14. Structures (red) in relation to existing; there are some instances of omission (blue oval) and false inclusion (red oval), with omission being the primary issue.

Damage costs were taken from the FEMA site to estimate flood damage from different levels of inundation within a structure[9]. A single story 1,000 sq. ft residential house was chosen to define the costs/per interior area (in this case sq. m; Figure 15). There are other databases to use and/or work from, but given the limited information on structure types it was assumed that all were residential structures and that the FEMA information are the best for this setting.

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[9] https://www.floodsmart.gov/costOfFlooding/index.html

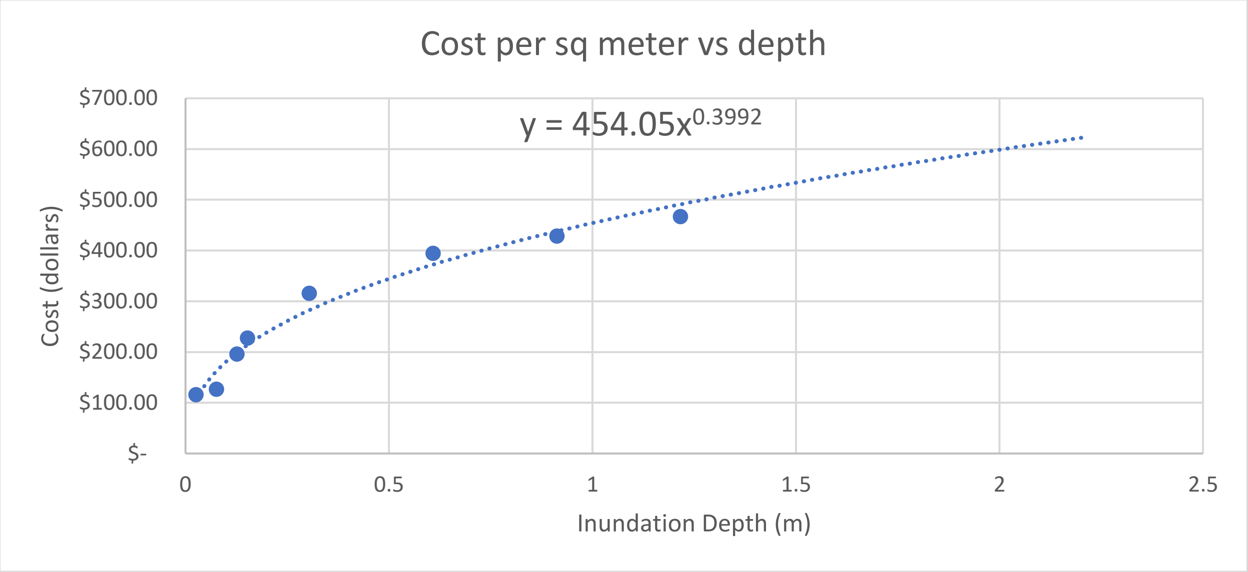


Figure 15. Costs per sq. m for different inundation depths within the structure from FEMA data.

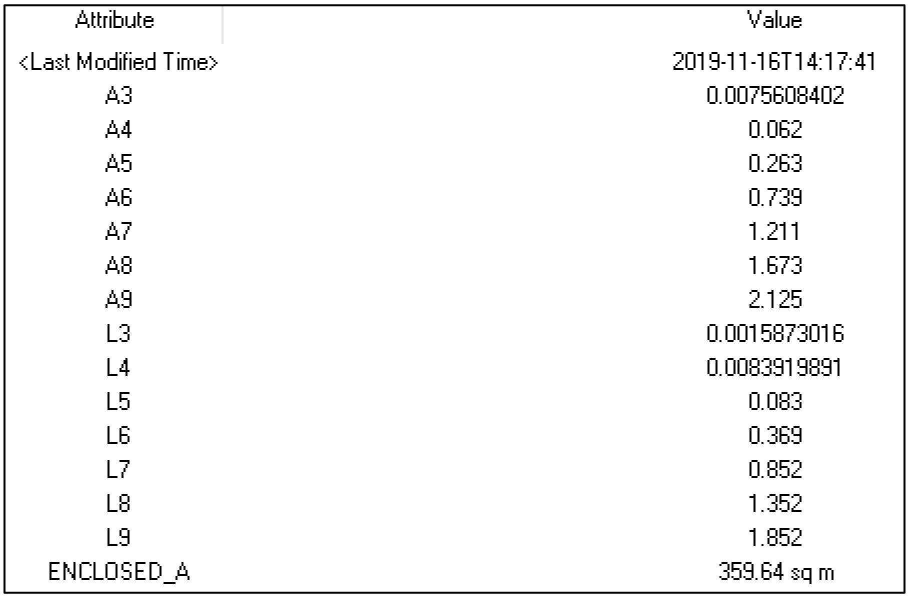
A separate assumption is that each structure is raised to some degree above the land surface. Since no 'first floor' elevations exist for the structure data used in this study, it was assumed that all structures were raised 0.5 m above the land surface and that garages are also assumed to have the same damage costs as interior areas.

For each structure the depth of water at the location was measured for the baseline (with floodplains) modeled level (L values; Table 4) and approximated (without floodplains) modeled level (A values; Table 4). The lowest 3 levels of flooding (Table 3) were not measured since very few structures were at those elevations. The increase in flood costs were calculated based on the depth-costs of the approximated level minus depth costs of the baseline level using inundation depths, enclosed area of structure, and cost vs. depth equation (Figure 15; Table 4). The following equation was used, with the values for each structure, to set the minimum elevation at 0.5 meters and calculate the costs accrued by flooding.

ENCLOSED_A*((454.04*(Max (***A3***,0.5)-0.5)^0.3992) - (454.04*(Max (***L3***,0.5)-0.5)^0.3992))

Where ***Ax*** is the approximate flooding depth in the structure for level x; ***Lx*** is the baseline flooding depth in the structure for level x; and ***ENCLOSED_A*** is the size of the structure in square meters. The cost equation was taken from Figure 15.

Table 4. Inundation depth attributes for structures from simple case; note the A values are slightly larger than the L values due to the loss of floodplains.



Attribute	Value
<Last Modified Time>	2019-11-16T14:17:41
A3	0.0075608402
A4	0.062
A5	0.263
A6	0.739
A7	1.211
A8	1.673
A9	2.125
L3	0.0015873016
L4	0.0083919891
L5	0.083
L6	0.369
L7	0.852
L8	1.352
L9	1.852
ENCLOSED_A	359.64 sq m

The end result is an accounting of the additional costs for each Level of flood. So a flood level of 5 without floodplains would increase total loss by almost 6 million dollars, whereas a flood at level 9 (e.g., Hurricane Florence) would increase total costs by about 8 million dollars. Note that the differences don't always increase with flood levels as the cost curve is not linear. Once a certain level of structure flooding has occurred the costs do not continue to increase as sharply. For example, a level 7 flood would have a greater cost increase than a level 8 flood over baseline, which is in part due to the cost curve and possibly the location (elevation) of the higher structures. Having noted this, the important aspect is that, without exception, there is a cost increase in all flood levels with loss of floodplains.

Table 5. Example flood cost increases from approximate case in the AOI for different flood levels without floodplains.

Level	**Additional Costs**
L3	$1,369,559
L4	$3,974,663
L5	$5,969,452
L6	$8,135,949
L7	$8,469,293
L8	$7,844,802
L9	$8,063,568

Assign and Map Yearly Cost Savings

The next step is to assign yearly cost benefits to each level's floodplain area. It is not a straight calculation – such that each level (tied to % yearly chance) of inundation will have a different value of storage benefit from the same floodplains as the area and additional costs change. As an example, the same flood plains flooded during small flooding events (e.g., L4) will have a specific cost-benefit/area (e.g., $100/acre) for that level that may be different than the cost-benefit/area (e.g., $30/acre) during higher flood levels (e.g., L7). An important aspect for defining the total value of an acre of floodplain is that each level be tied to the yearly chance of reoccurrence. For example, the yearly cost of an L3 flood is higher than the yearly cost of an L7 flood, even though the additional cost is lower, because it happens almost every year. This can then be tied back to potential future changes (climate change) – so yearly benefits (as defined by the risk %) would be higher (e.g., the 2% risk becomes the 5% risk) in 25 years given the assumption that water levels will generally rise from increased storm voracity and to some degree in this area sea level rise.

Assign Yearly Cost Savings

To put everything in one cost category the additional costs can be multiplied by the chances of that flood level occurring in a year to provide costs/year. To do this requires a level of information about the flood frequency at the gage(s). Since this data was calculated during the Northcoast project, it was used in this study, but can also be done using the gage information. Each level at the Conway gage was given a yearly risk using the Northcoast mean yearly flood level and the standard deviation. A z-score was determined for each:

$$Zscore = \frac{Level - Mean\ yearly}{Std\ Deviation}$$

The Z score was calculated, converted to a percentage, and subtracted from 100. This produces a risk % per year for each Level. The incremental costs were then multiplied by the risk fraction to determine the cost per year. This was done for the present and also for 2035 (Table 6) for comparison.

Table 6. Risk values for each level of flooding at present and in 2035 for baseline flooding (with floodplains).

Surface	% Yearly Risk (present)	% Yearly Risk 2035
L3	80	87
L4	55	66
L5	30	39
L6	10	15
L7	2	5
L8	1	1
L9	0.05	0.05

Once the yearly incremental yearly costs have been calculated (Table 6) they can be divided by the total storage (including Passive and Active storage) for that level of flood to define the cost per floodplain volume per year (Table 7). These values were used to populate the GIS layers for spatial analysis.

Table 7. Cost calculations from approximated flood analysis; simple flood analysis would have larger costs due to increased depths at each level

Level	**Additional Costs**	**2017 Yearly Cost**	**2035 Yearly Cost**	**Total Storage**	**2017 value (yr$/m3)**	**2035 value (yr$/m3)**
L3	$1,369,559	$1,095,647	$1,191,516	29,321,935	0.037	0.041
L4	$3,974,663	$2,186,065	$2,623,278	46,969,995	0.047	0.056
L5	$5,969,452	$1,790,836	$2,328,086	68,299,471	0.026	0.034
L6	$8,135,949	$813,595	$1,220,392	93,239,798	0.009	0.013
L7	$8,469,293	$169,386	$423,465	121,682,052	0.001	0.003
L8	$7,844,802	$78,448	$78,448	151,848,414	0.001	0.001
L9	$8,063,568	$4,032	$4,032	183,352,468	0.00002	0.00002

The total value of the floodplains in the AOI on a yearly basis can be derived by summing the yearly costs. At present the value of the AOI floodplains was calculated to be $6,138,008; in 2035 the costs may be $7,869,217 or about a 28% increase.

Mapping Floodplain Storage Values

One-acre parcels form the basis for the calculations; they cover the approximate floodplain extents using the Northcoast layer for the 1% level (figure 16). Within each parcel the volume of the water held within and on the land surface (combined Passive and Active Storage) were calculated for each level using the average depth from Total storage depth surfaces (Figure 17) created during the initial steps of the project and size of the parcel (Table 8).

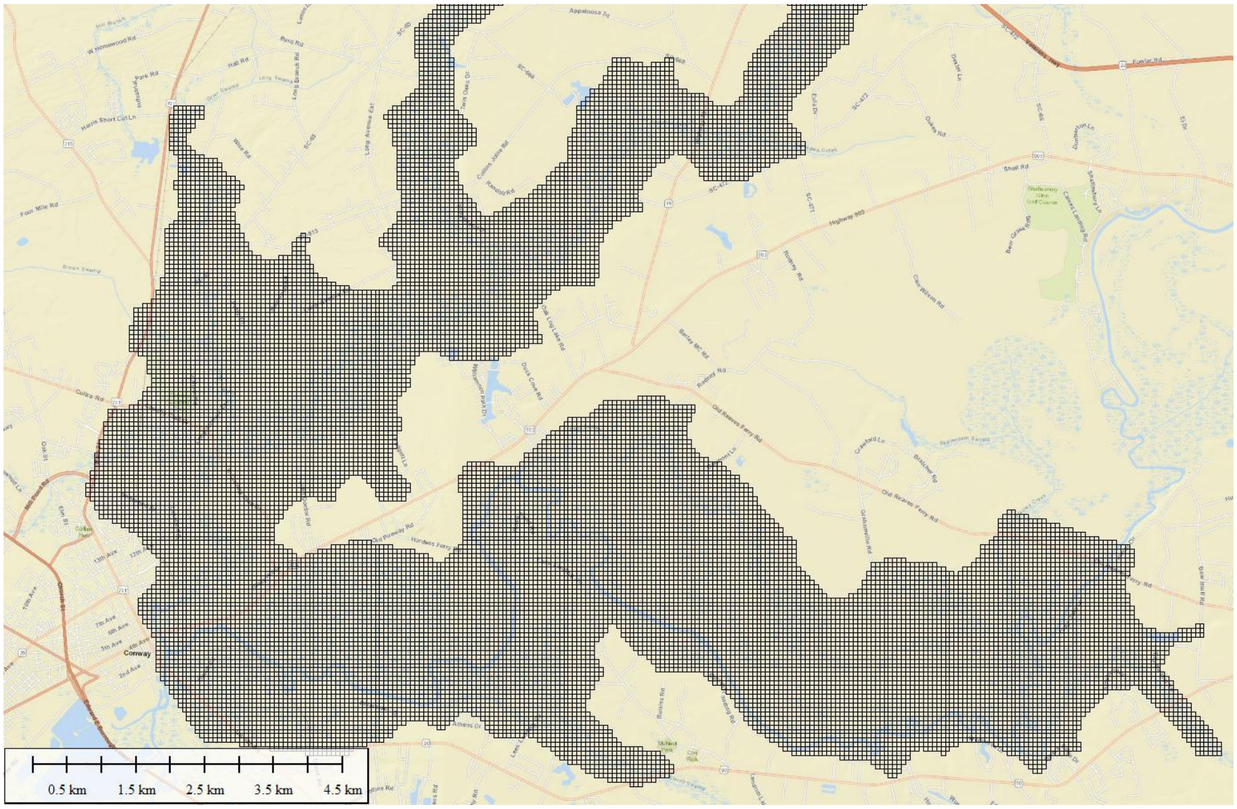


Figure 16. One acre parcels for floodplain value calculations

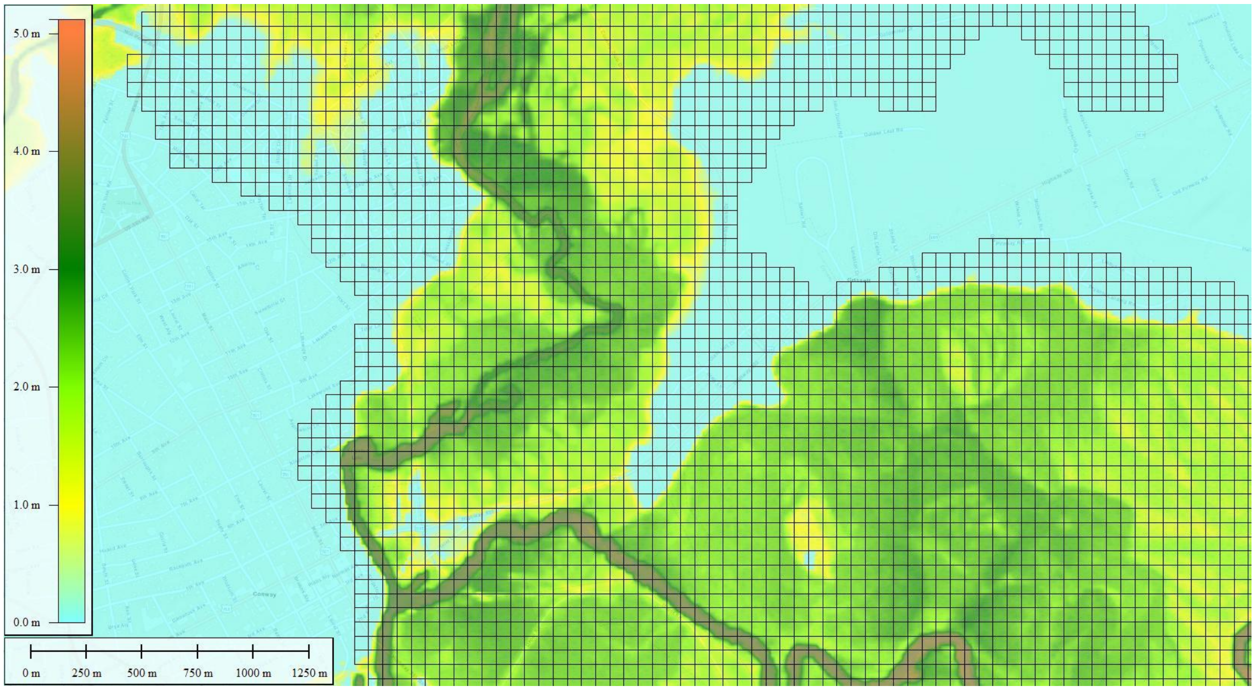
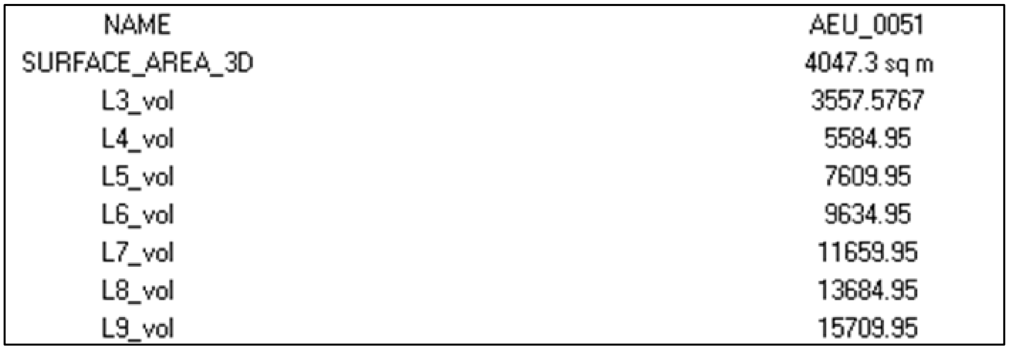


Figure 17. Example of L5 total storage depths from simple case in a portion of AOI

Table 8. Calculated volumes from simple case for each level in parcels



NAME	AEU_0051
SURFACE_AREA_3D	4047.3 sq m
L3_vol	3557.5767
L4_vol	5584.95
L5_vol	7609.95
L6_vol	9634.95
L7_vol	11659.95
L8_vol	13684.95
L9_vol	15709.95

Once the volumes in each level were calculated the value of the 1 acre parcel in terms of flood costs could be calculated using the volumes in each level multiplied by the yearly value (yr$/M^3; Table 7) of each level. Each yearly value for seven levels were summed to provide a total yearly value for the 1 acre parcel using the equation below:

$$Value = (L3\_VOL * 0.037) + (L4\_VOL * 0.047) + (L5\_VOL * 0.026) + (L6\_VOL * 0.009) + (L7\_VOL * 0.001) + (L8\_VOL * 0.001) + (L9\_VOL * 0.00002)$$

The acre parcels can then be used as is or to define a floodplain value surface as needed for future analysis. Areas can be defined in a GIS and the cost attributes calculated for any portion of the floodplains. One of the most notable results are that rivers have the highest damage reducing floodplain values, which may sound contrary but in this analysis makes sense since they store the greatest amount of water volume.

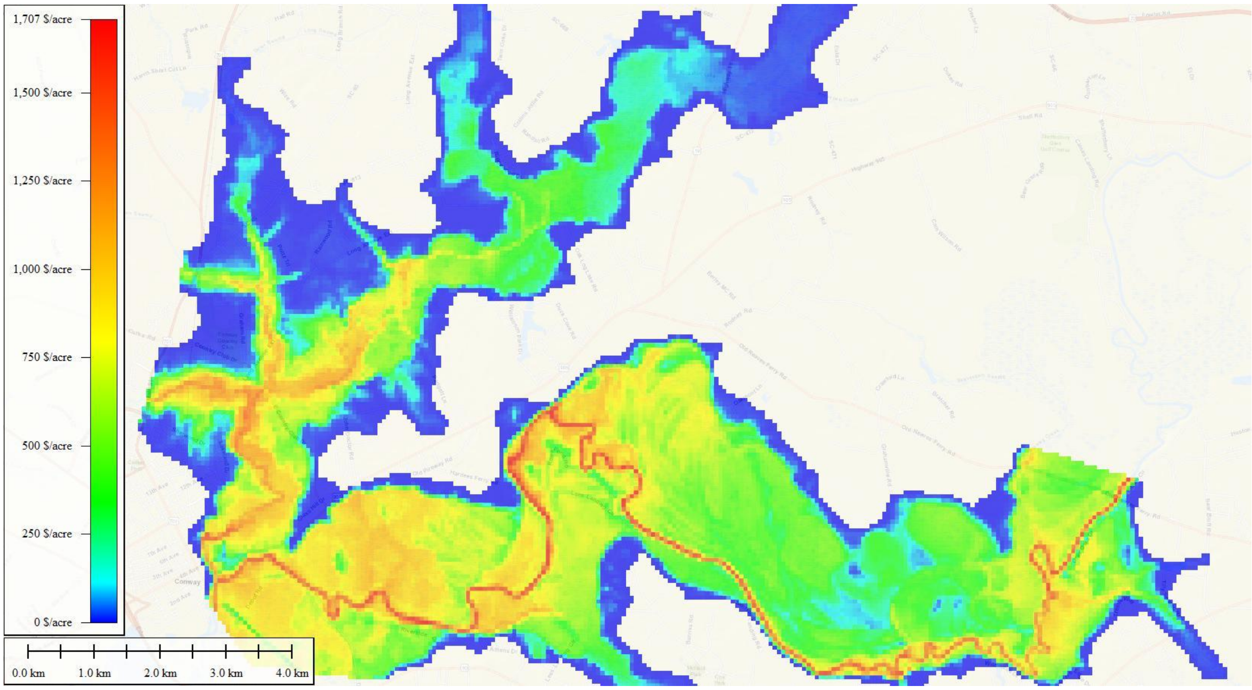


Figure 18. Example floodplain value surface from simple case.

Results

The results are contained within the type of output highlighted in Figure 18. There is a slight difference in the area of acre boxes vs. the total AOI area of floodplains, which does not change the inherent values, but the sum of the 1-acre results (total of 1-acre boxes) is a bit less than the total values calculated from Table 7. The 1-acre boxes comprise an area of about 19,400 acres with a summed values of $5,215,573 per year. The average flood-damage-reducing value per/acre is about $270 per year. In 2035 the projected value of the same area is $6,696,117 or about $345 per acre/per year.

The outputs (which will be delivered to TNC) are represented in Figures 19 and 20. They can be used in several ways – the simplest is to draw an area that is of interest, query the acre boxes, and sum them (Figure 21).

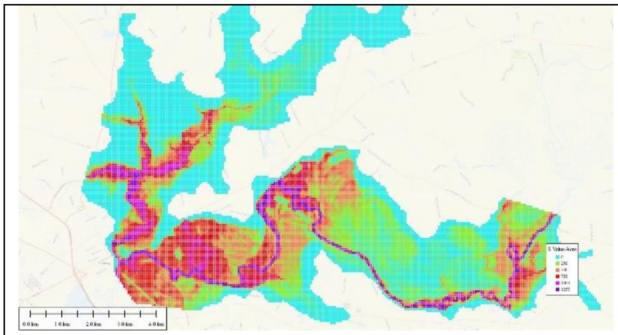


Figure 19. Vector results - present

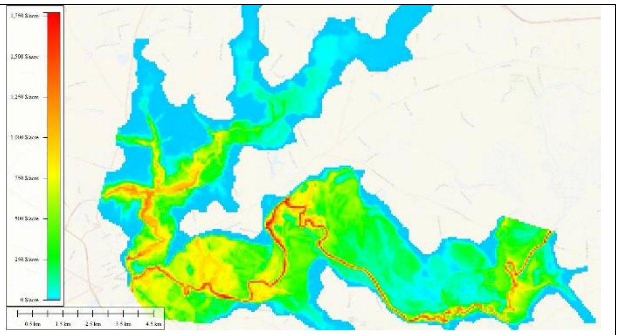


Figure 20. Raster results - present

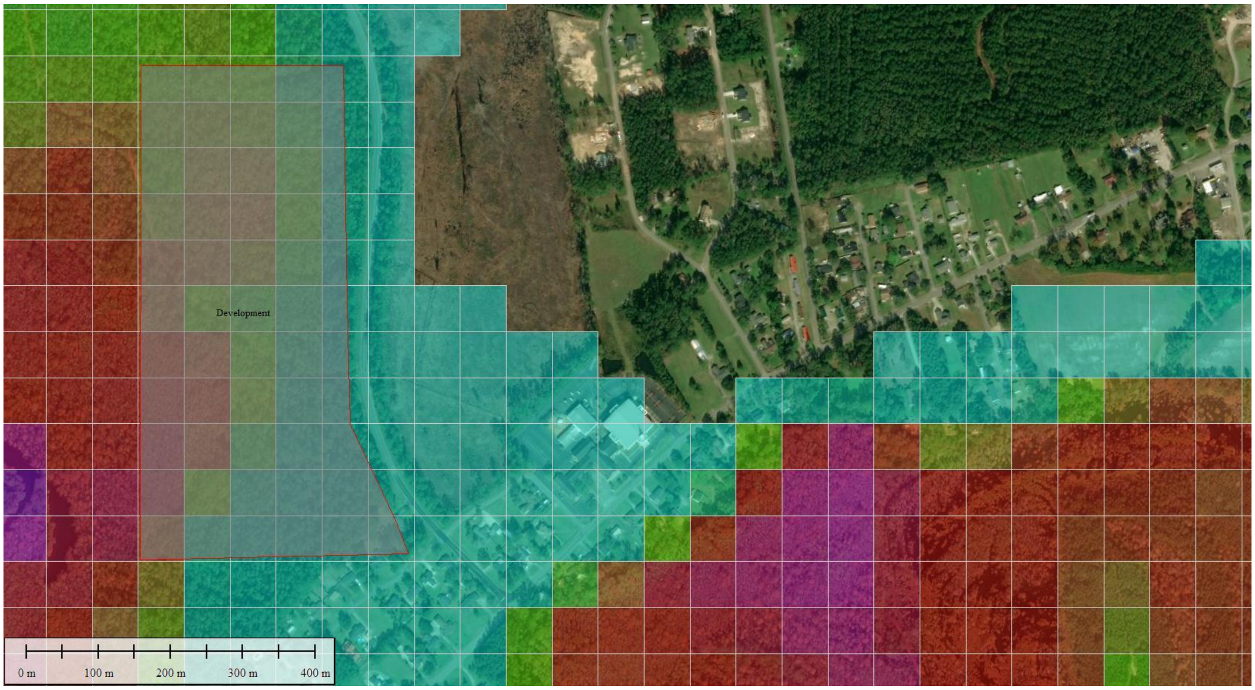


Figure 21. Example use; assuming the development would preclude flooding in the area, the total lost value of floodplains per year is $14,570.

Using the raster data, the same calculation can be done (and is a bit more exact); it simply requires calculating the mean value/acre for the development and then multiplying it by the total acres of the development. The raster data also allows for comparisons of the present and 2035 projections, which can be helpful in determining the areas that may at present not have a high value, but could in the future (Figure 22).

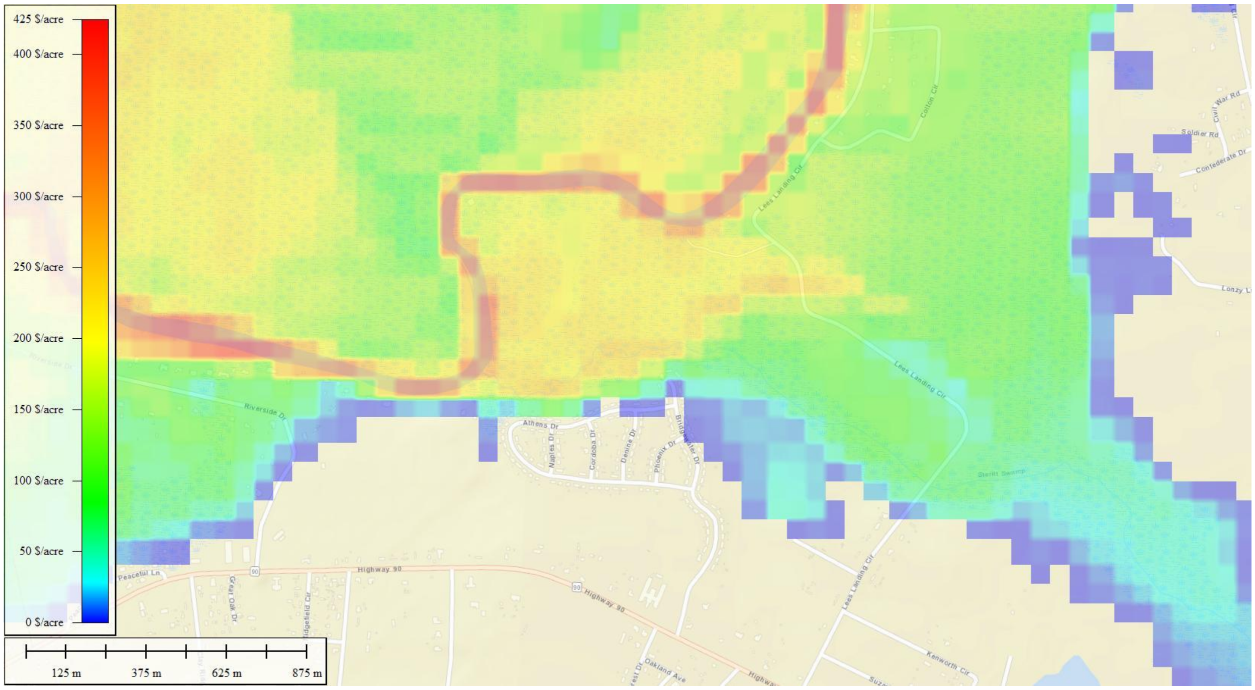


Figure 22. Difference between present and future floodplain values.

Using a similar technique to the example of the development, but with raster data, the land cover values were calculated in the study area (Table 9). The results highlight the value of the wetland habitats in the study area.

Table 9. Land cover statistics in the acre-box extents

Land Cover	**Value**	**Area (acre)**	**Value/acre**
Scrub/shrub	$21,429	242.7	$88
Palustrine scrub/shrub	$96,029	593.5	$162
Palustrine forest	$3,562,126	9940.2	$358
Palustrine emergent wetland	$69,434	380.1	$183
Water	$427,200	470.3	$908
Mixed forest	$693,883	4828.3	$144
Developed	$64,520	717.1	$90
Grassland	$105,335	1465.3	$72
Bare land	$21,017	433.2	$49
Unconsolidated shore	$5,827	31.7	$184

Finally, in a holistic sense the relationship between elevation, flood levels, and values can be estimated to calculate values outside of the specific acre-box area (Figure 23). The Northcoast elevation and 99-year flood surface were used in relationship to the results in this study. The elevation was subtracted from the water surface to define how far above or below the flood-plain each acre-box is. This value was then plotted vs the $ value. This relationship is an estimate, but can be broadly applied in areas above Conway on the Waccamaw or in areas in Crab-tree swamp that were not completely in the study area.

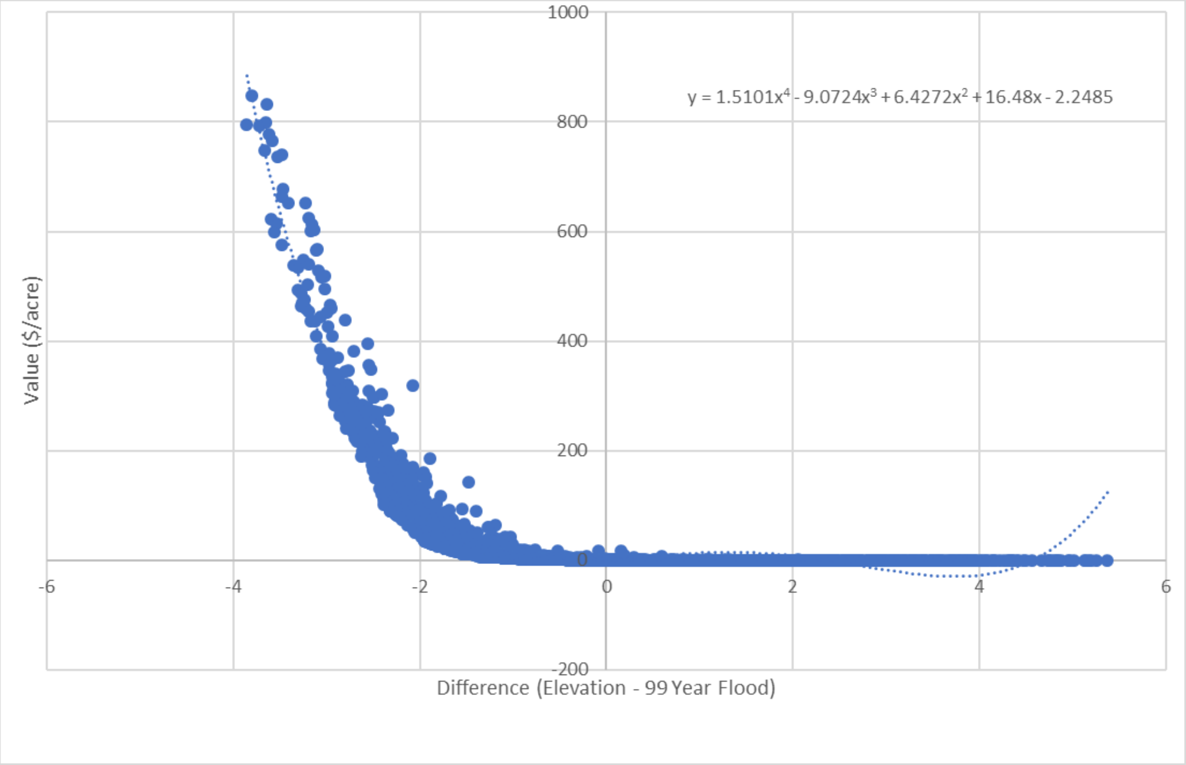


Figure 23. General relationship between the primary variables and the value outcome; values must be between +3 and -4 meters from the flood level.