westonandsampson.com

672 Marina Drive, Suite 204
Charleston, SC 29492
tel: 843.881.9804

REPORT

March 21, 2018

CITY OF
Charleston
SOUTH CAROLINA

Evaluation of the Church Creek Drainage Reduction Study

EXECUTIVE SUMMARY

Weston & Sampson was selected by the City of Charleston to review current conditions within the Church Creek drainage basin with a goal of determining a strategy to reduce or even prevent flooding. In order to do this, Weston & Sampson performed several tasks, including:

- Conducting public outreach to gain information and to hear concerns from residents in the area
- Develop a Rain on Grid model to evaluate topography and to guide preliminary project development
- Upgrade the hydraulic model to ICPR4 which incorporates one-dimensional and two-dimensional aspects
- Inspect the key elements of the conveyance system
- Provide a review of past recommendations
- Provide recommendations for improvements to prevent flooding
- Provide recommendations for policy considerations to improve and protect drainage assets for the future

Weston & Sampson, along with Team members from DHI Group, Atlantic South Consulting, and NOAA, collected data, reviewed model runs and developed new projects and evaluated past projects. We also inspected most of the main conveyance systems wading in waist deep water through wetland areas following TS Irma to gain a full understanding of how the basin responds to storm events. Flood mitigation measures were developed that included several projects described later in this report and policy considerations and strategies are suggested that support resilience and sustainability efforts associated with drainage. Those projects include Tidal Surge Protection, Southwest Basin Conveyance Improvements, Northeast Basin Improvements, Hickory Farms Overland Flow Diversion, Church Creek Stormwater Pump Station, Channel Conveyance and Modifications to the Lake Dotterer Outfall System. ICPR4 Model runs based on simulated build-out conditions have indicated that the most effective improvements include increasing storage considerably in the areas North of Village Green along with the construction of a stormwater pump station with tidal surge protection. These three projects should be considered with a high priority in order to realize the most improvement in drainage conditions and to prevent flooding within the basin. Detailed descriptions of the overall effort along with cost opinions are included as a part of this report.

PROJECT BACKGROUND

Weston & Sampson was selected by the City of Charleston to evaluate the Church Creek Drainage Basin to identify improvements associated with drainage related assets and to recommend policy strategies to help protect basin capacity, reduce flood levels and improve flood control in the basin. Several areas in the Church Creek basin have experienced flooding on many occasions in the past involving significant rain events, significant tidal events or both simultaneously. The overall scope of work was outlined in an RFQ issued by the City as a solicitation in January of 2017. The overall Scope was very straightforward and included the following elements with a goal of reducing the risk of flooding and property damage due to flooding in the basin:

1. Review Past Stormwater Analysis
2. Provide Recommendations for Additional Standards, policies & physical infrastructure Improvements that could be implemented to reduce the risk of flooding and property damage

Weston & Sampson developed an approach to the project that included the following tasks:

- Data Collection & review of the history of the basin & perform field inspections of key conveyance elements
- Review the performance of past structural improvements
- Review the accuracy, condition and performance of the hydraulic model
- Upgrade the hydraulic model to ICPR4
- Confirm the calibration of the upgraded hydraulic model
- Review recently proposed improvements
- Review Performance of recent Improvements
- Provide recommendations for additional required improvements to prevent future flooding

Weston & Sampson proposed to complete the tasks listed above with an emphasis placed on actual field conditions and performance.

DATA COLLECTION

Weston & Sampson field crews performed inspections of the main conveyance system assets. This inspection included two teams of two engineers walking all the main conveyance channels from the salt marsh on Church Creek up to areas located North of the currently developed property (Village Green & Grand Oaks). Two-man crews utilized iPads with data collection applications to record dimensions, condition and photographs of key drainage assets. Several model revisions resulted from a review of the data collected during this exercise. A list of those revisions is included in a memo from Pete Singhofen which is included in Appendix B. An aerial inspection was performed on the church Creek channel located in the salt marsh of the Ashley River. This enabled the project team to gain insight into the overall operation and physical capacity of the outfall channel near the Ashley River. The Church Creek Channel extends beyond Village Green and branches of Church Creek and other channels extend to the West beyond the Charleston County landfill. Additional key channels extend to the West & East from the Church Creek Channel into Shadowmoss, Hickory Farms and Hickory Hill Subdivisions. Visual inspections of channels and drainage structures were performed and key drainage assets were also surveyed using Trimble GPS equipment. Invert elevations and structure dimensions at key locations were also verified during the data collection effort. Collected data was then compared to existing model input data. Revisions were made where the inspection revealed that changes had occurred and the revised input data was then used to populate the new ICPR4 hydraulic model. A summary of revised input data is provided in the model discussion section.

Weston & Sampson Crews were also able to perform field observations during and following Tropical Storm Irma. This information provided very useful visual and water surface elevation survey data to aid in model calibration and provided evidence of overall basin response to tidal surge and significant rainfall. Observations during this event also provided valuable insight concerning overall basin performance. This event also provided real time evidence associated with many culverts and helped to identify locations with significant head loss during high water events within the basin. Downstream areas outside of the basin but containing outfalls from the basin were also observed during and after TS Irma.

Plans were also collected from SCDOT associated with the Bees Ferry Road Widening project. Culverts shown in the plans were verified in the ICPR4 model.

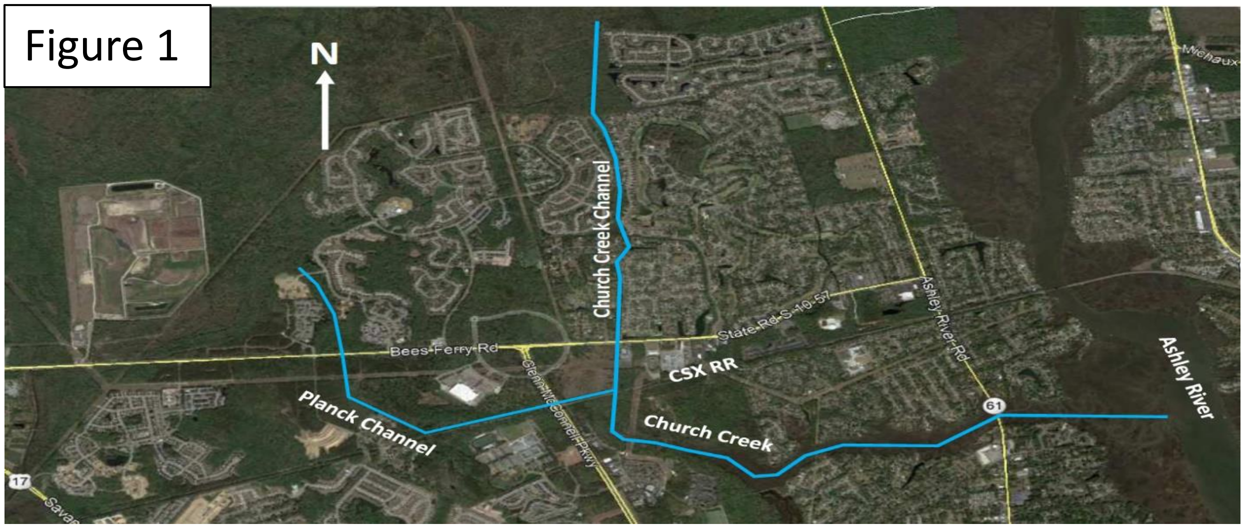
The City of Charleston also recently installed two tide gages which are located on Bees Ferry Road at Church Creek (Maxwell) and at the culvert on Bees Ferry Road located 6000 feet Southwest of Church Creek (Planck). These two tide gages provide very good data associated with water surface elevation, tide and rainfall that was useful in model calibration.

PUBLIC OUTREACH

Weston & Sampson, in conjunction with the City and ASCS, conducted public outreach efforts by organizing together with the City staff, attending and presenting at 14 Public Meetings, culminating with a large meeting held at the Citadel Mall, which was attended by over 200 residents. In addition, Weston & Sampson received over 100 comments from citizens who mainly reside within the Church Creek Drainage Basin. These comments were mostly focused along areas adjacent to the saltmarsh and the main conveyance system of Church Creek and its tributary canals. Several visits to residents were also performed to view areas of concern. This information was incorporated into the conceptual alternatives to help address flooding concerns where possible.

REVIEW EXISTING CONDITIONS AND PAST STUDY RECOMMENDATIONS

In December of 2001, a report was submitted to the City which evaluated several alternatives to improve drainage in the basin. Two of the alternatives were recommended for implementation. Those two included installing a new channel along Bees Ferry Road from Dove Haven Court to Shadowmoss Parkway and a new culvert under the CSX railroad labeled as Alternative 2C in that report. The second included adding three Culverts under the CSX railroad in the Church Creek channel.



PAST STRUCTURAL IMPROVEMENTS

Recent structural improvements in the basin have been made to improve overall drainage performance. These improvements were primarily associated with the main conveyance system. This conveyance system includes the Church Creek Channel and the tributary to this channel referred to as the Planck Channel Shown on Figure 2 below. Church Creek has existed likely for centuries The Creek is part of the salt marsh of the Ashley River up to approximately the location that it crosses the CSX railroad on the South side or Bees Ferry Road. The creek and adjacent wetland areas extend approximately 5 miles to the Northwest beyond the CSX railroad. Portions of Church Creek upstream of the CSX railroad have become channelized over time mainly as a result of mining and timbering practices.

The drainage basin for the Church Creek Channel extends from Bees Ferry Road to the North for approximately four miles. This channel drains a very large area that has little elevation change throughout. Flows in developed areas of the basin are collected in systems of pipes and ponds that were installed as development occurred over the years and conveyed to the main channels either directly or via wetland areas. In the undeveloped areas mainly to the North of the basin, stormwater is collected via a network of small channels that have been constructed over time as a result of mining and timbering land uses. Under significant rain events, this flow concentration exceeds the capacity of the Church Creek Channel which results in the development of rising water along the main conveyance areas. This impacts outfalls from many of the stormwater ponds and tends to slow down drainage in many parts of the basin.

In 1997, the City along with SCDOT and Charleston County, installed three new 72” steel culvert pipes in the Church Creek Channel under the CSX railroad. While this improvement added significant capacity to that crossing at high water levels, the full benefit was likely not realized based on the capacity of the downstream areas of the Church Creek Saltwater channel.

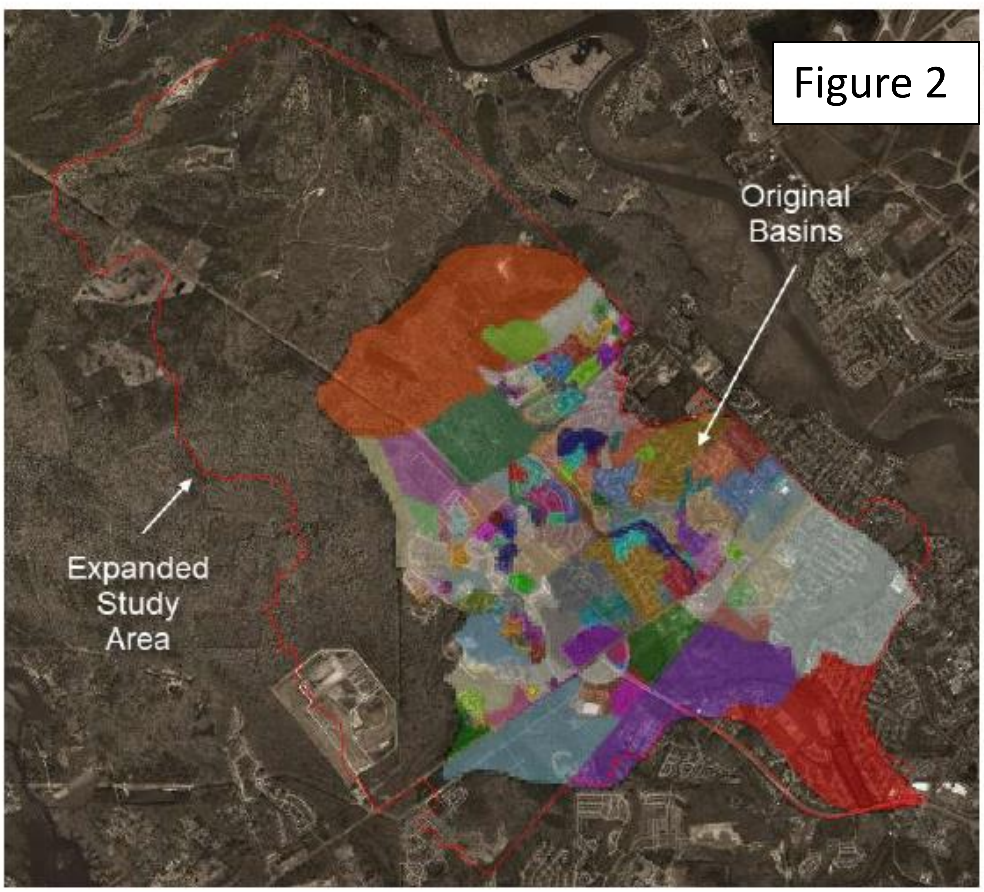
In 2007, a project was constructed by the City that included a new channel and outfall to Church Creek along with new culverts under Bees Ferry Road and the CSX Railroad. The ICPR4 model shows that this project will become much more effective if water levels in the salt marsh portions Church Creek can be lowered by reducing the overall flow that the Church Creek salt marsh area receives.

Other recent improvements in 2010 have included additional storage adjacent to Middleboro within the basin, and a new 12’ x 4’ box culvert from the Bridgepoint point pond to the main outfall channel. Both of these improvements are also affected by the capacity of the Church Creek channel which results in high water levels and delayed basin recovery. Improvements to the water levels in that section of Church Creek based on flow diversions out of the lower basin will result in better performance of the previously mentioned structural improvements which discharge to the Church Creek Channel.

Other past recommendations include modification of storage requirements associated with land development. While this strategy is suitable for future development, it is not aggressive enough to correct the current flooding conditions that take place during severe events. This strategy may help to improve basin performance but should be carefully monitored to identify impacts of stormwater release timing as improvements are made and conditions change. Ideally, storage facilities should be evaluated to ensure that releases are timed in conjunction with current and future conditions at the discharge location.

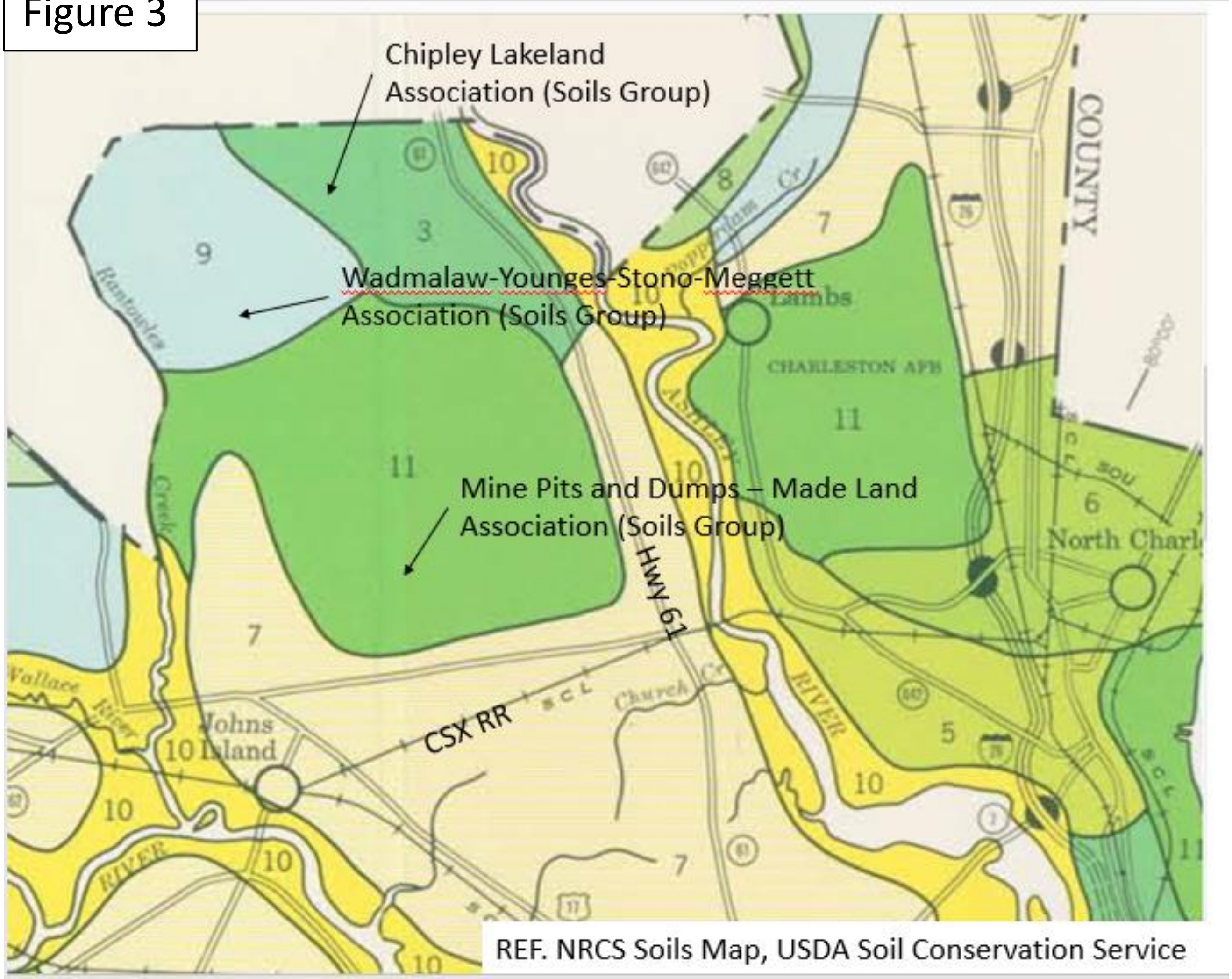
ACCURACY AND PERFORMANCE OF THE HYDRAULIC MODEL & UPGRADE TO ICPR4

The ICPR3 model data was reviewed and key elements of the conveyance system were inspected, and their input parameters verified. The ICPR3 model datum was based on NGVD 1929. The new ICPR model datum is based on NAVD 1988. There is a correlation of -0.97' to go from 29 to the 88 datum. This was applied to all of the model data prior to importing into ICPR4. All adjustments based on the surveying effort were made based on the NAVD 1988 datum elevations also. The model was used to develop scenarios that simulate 2, 10, 25, 50, 100 and 500 year storms along with the August 2015 and October 2015 storm events. The model boundary area was reviewed using a LiDAR based Ground Surface Digital Elevation Model (DEM) based on a 10-foot grid from the SC Department of Natural Resources. The data was acquired from 2007 to 2009 with final data QC being approved in 2015. Adjustments were made to account for development and modifications that have occurred since LiDAR data was collected. This enabled the basin boundary to be determined based on overland flow patterns mainly in the northern parts of the undeveloped areas between Highway 61 and Rantowles Creek. The original basin included in the ICPR3 Model included approximately 8.5 square miles. The basin boundary evaluated and modeled by the ICPR4 model includes approximately 15.9 square miles with approximate borders as shown below. Note that this is the study boundary and that there are portions of the study boundary that drain to outfalls other than Church Creek. These are however limited and the actual drainage basin still remains larger than was originally believed.



Model correlations with the recent storm events were simulated with acceptable accuracies. The August 2015 event was reviewed at two locations of high water marks in Bridgepoint. The model water surface elevations were within 0.2 feet of the observed water surface elevation. The October 2015 storm was reviewed also with two different Antecedent Moisture Conditions (AMC) applied. (Ref. Memorandum from Pete Singhofen, PE to Raju Vasamsetti, PE Dated August 11, 2017 attached) The October 2015 storm simulation achieved the greatest accuracy using AMC III which represents a wet or saturated condition. This AMC III condition is reasonable given what is known about the area and soil conditions especially during rainy periods. A detailed description of the model import along with all assumptions is included in Appendix A. This is supported by review of the NRCS Soils Map of the region along with soil type descriptions.

Figure 3



REF. NRCS Soils Map, USDA Soil Conservation Service

Beginning with the most northern areas of the basin, the Chipley type soils are characterized by nearly level, moderately well drained to somewhat poorly drained soils. Available water capacity is impeded by fluctuating water table and surface runoff is slow. The Wadmalaw, Younges, Stono and Meggett series soils have similar descriptions associated with being poorly drained and having high water tables and slow runoff. The areas noted as Made Land likely were similar soil types but have been impacted by mining leaving the land with characteristic ridges and trenches which impact the ability of the wetland and floodplain areas in this group to serve as stormwater storage. The characteristic high-water tables and flat grades support the position of using AMC III which represents a wet or saturated condition to represent severe build out conditions within the basin.

As a means of helping to identify the basin and to have a way to perform a high-level check of the overall performance of the basin, a Rain on Grid model was developed. The Rain on Grid was created using the same digital elevation model (DEM) but did not include any improvements associated with drainage. This model was strictly based on topography with modifications made to allow flow through physical boundaries such as elevated ground areas as would be the case across a raised roadway. This tool was used to help guide the development of conceptual alternatives for improvements by identifying flow corridors and volumes. It also served as a check to determine feasibility for diversions and outfall modifications. A rain on grid surface is shown below (Figure 4) with assorted colors representing various elevations. The red areas are the higher ground and yellows and greens represent the lower areas or flow ways. The illustration below also shows the locations in black of several transect lines where volumes were checked for several different storm events to aid in project development. The various drainage areas noted were used to help screen diversion capacity requirements associated with reducing the flows to the Church Creek Channel. The green shaded areas of the DEM used for the Rain on Grid Model (ROG) on the left below correlate to portions of the flood plain as mapped by FEMA on the right. More details about the Rain on Grid model are included along with a conceptual project evaluation in Appendix A. It should be noted here that the ROG model is used as a tool to determine flow directions, patterns, feasibility and volumes. The volumes shown on the evaluation do not represent target flow volumes but only maximums that could be reached under certain scenarios. This model served as a guide for modifications to the ICPR4 Model to more closely simulate actual system performance as components of improvement strategies were incorporated.

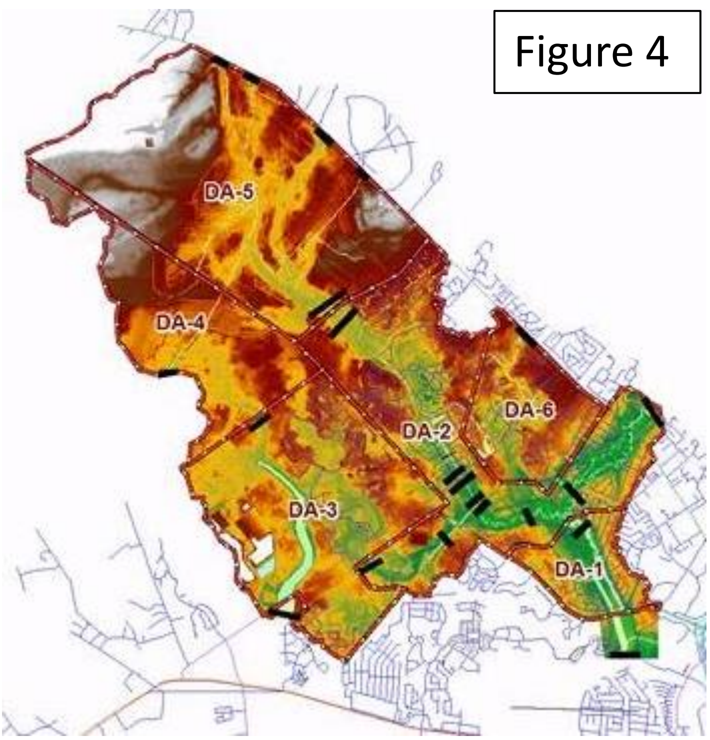


Figure 4

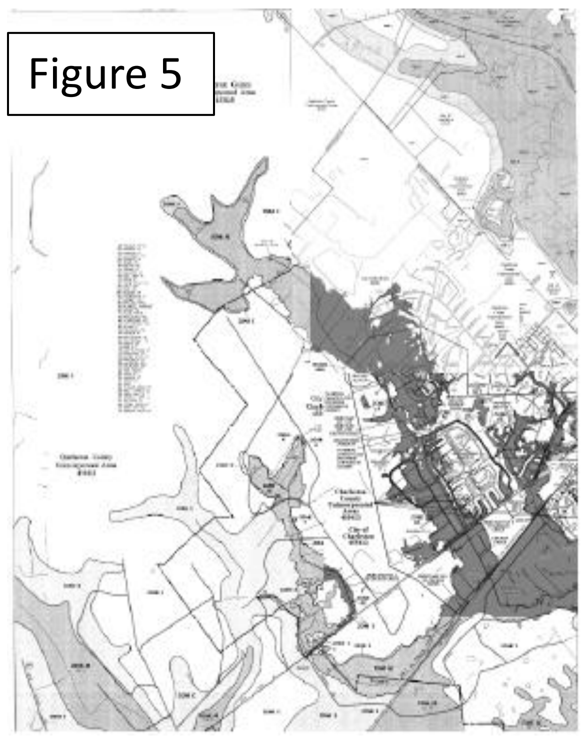


Figure 5

IMPROVEMENTS RECOMMENDED IN PRIOR STUDIES

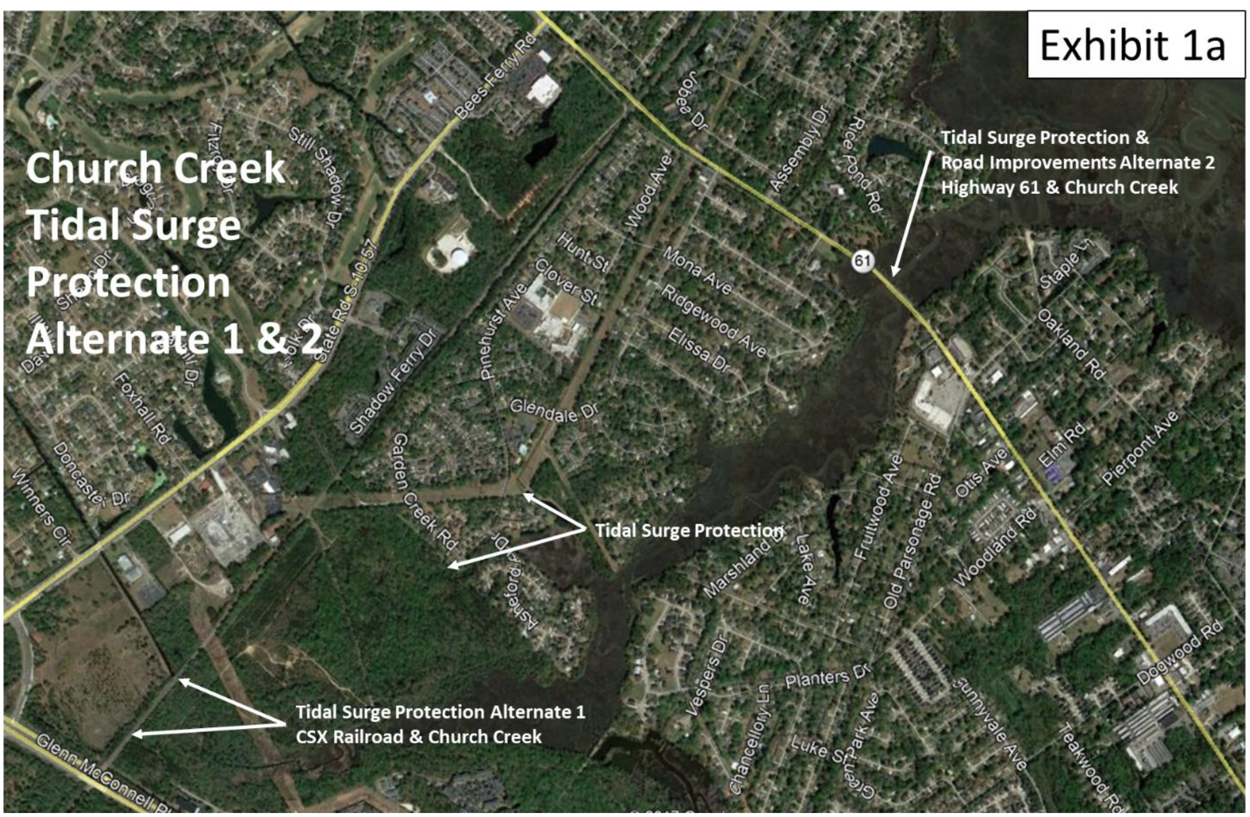
Improvements that have been proposed in prior studies include:

1. Diverting portions of the basin to the Ashley River including the area West of Village Green as well as portions of Village Green the area just North of Village Green. (Ref. Church Creek Watershed Stormwater Master Plan Summary Report (Vol.1) December 2001 by Woolpert)
2. Diverting eastern parts of Shadowmoss to the Ashley River (Ref. Church Creek Watershed Stormwater Master Plan Summary Report (Vol.1) December 2001 by Woolpert)
3. Channel Improvements along the Church Creek Channel in Shadowmoss (Ref. Church Creek Watershed Stormwater Master Plan Summary Report (Vol.1) December 2001 by Woolpert)
4. Buyout of property in Shadowood (Ref. Church Creek Watershed Stormwater Master Plan Summary Report (Vol.1) December 2001 by Woolpert)

While diverting flow out of the basin is a component of the overall improvement plan recommended in this report, it will not serve to prevent flooding unless it is combined with other more aggressive alternatives that have been previously proposed. The basin is so large and flat that several components must be implemented to make a substantial difference, the most effective of which is the stormwater pump station. In addition, long term, upstream storage strategies must be considered to continue to maintain the effectiveness of any implemented improvement. Additional discussion of storage strategies is included in the policy discussion section.

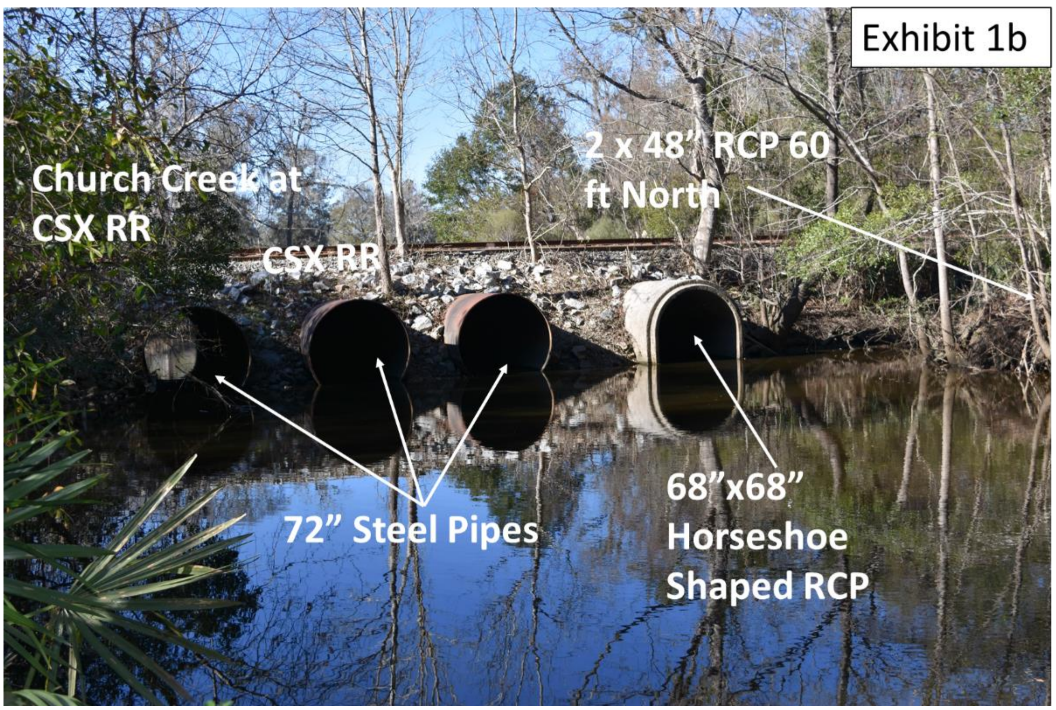
RECOMMENDATIONS FOR STRUCTURAL IMPROVEMENTS

1. Church Creek Tidal Surge Protection – The Southern part of the basin is crossed by the CSX Railroad right of way. There are currently 9 culvert crossings between Main Road and Highway 61 along this section of track. The track is elevated on a berm above the 100-year flood elevation. Three of these crossings are more significant than the rest. The three significant crossings include the box culvert constructed by the City near Shadow Pointe Apartments, the steel and concrete pipes at Church Creek and the 48" and 24" RCP crossings near Main Road. The remaining crossings are on smaller drainage ditches and are set at higher elevations than these main outfalls.



The Church Creek culvert crossing at the CSX railroad consists of six pipes. There are two 48” reinforced concrete pipes (RCP), three 72” steel pipes and one 68” x 68” concrete horseshoe section with a flat invert. These larger culverts have inverts between elevations 0.06’ and 0.85’ based on NGVD88. The two 48” RCPs inverts are 1.42’ and 2.00’ on the same datum. This elevation allows the lower pipes to see tidal fluctuations under normal conditions. In fact, the flow often is in the upstream direction under dry conditions when the tide is rising and near the high stage. Under a tidal surge however, there is potential for significant flow in the upstream direction if a surge precedes a significant rainfall. This was observed during Tropical Storm Irma when the surge elevation in the Ashley River was observed in conjunction with a high tide.

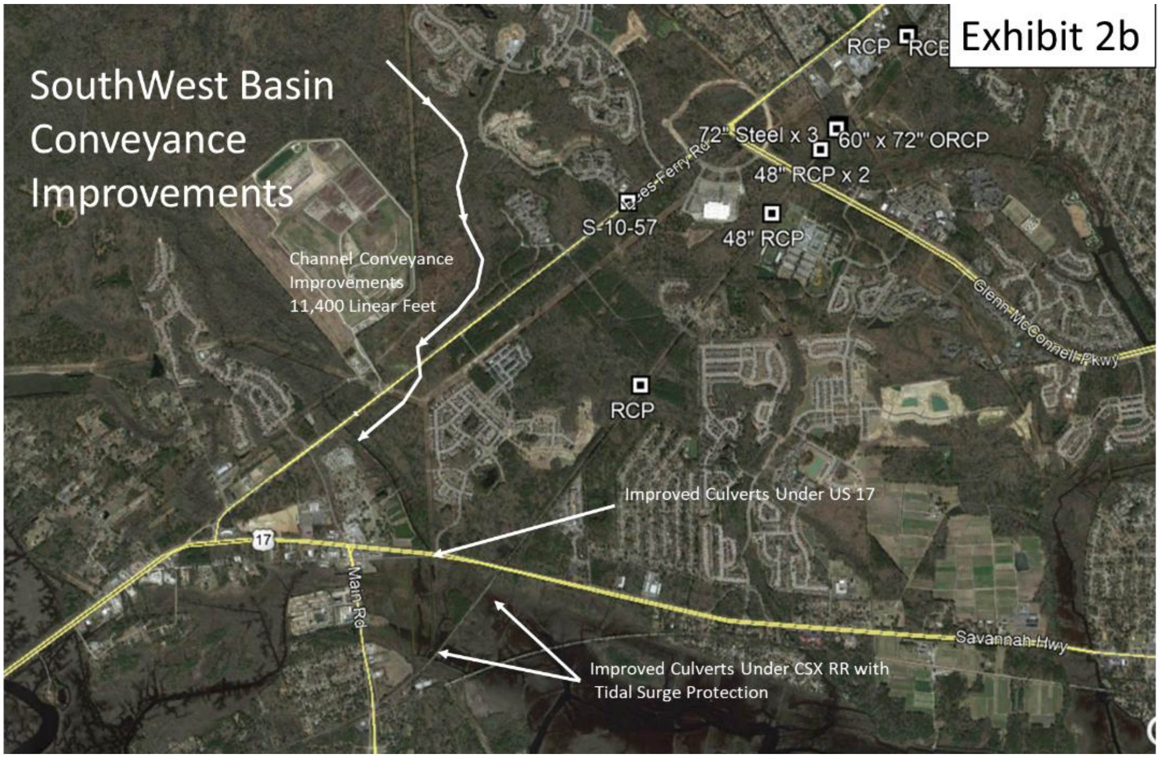
To verify the importance and impact of tidal surge, model runs were performed with storm events from Irma which had a moderate surge reaching elevation 7.03 (NAVD88) using two different tidal boundary conditions with the actual rainfall data. All ICPR4 model data is presented in the NAVD88 datum. Peak elevation reached with the observed tides (moderate surge) in the existing conditions model was 8.0. With surge protection added to the model, the same conditions reached a peak elevation of 7.1. The rainfall during Irma was below current 100-year rainfall intensity but the higher surge caused the water surface elevations to exceed that elevation. It is important to note here that surge protection is a necessity when any scenario is used that includes pumping within the basin. This serves to prevent recirculating and is required to ensure that the pumping alternative is effective.



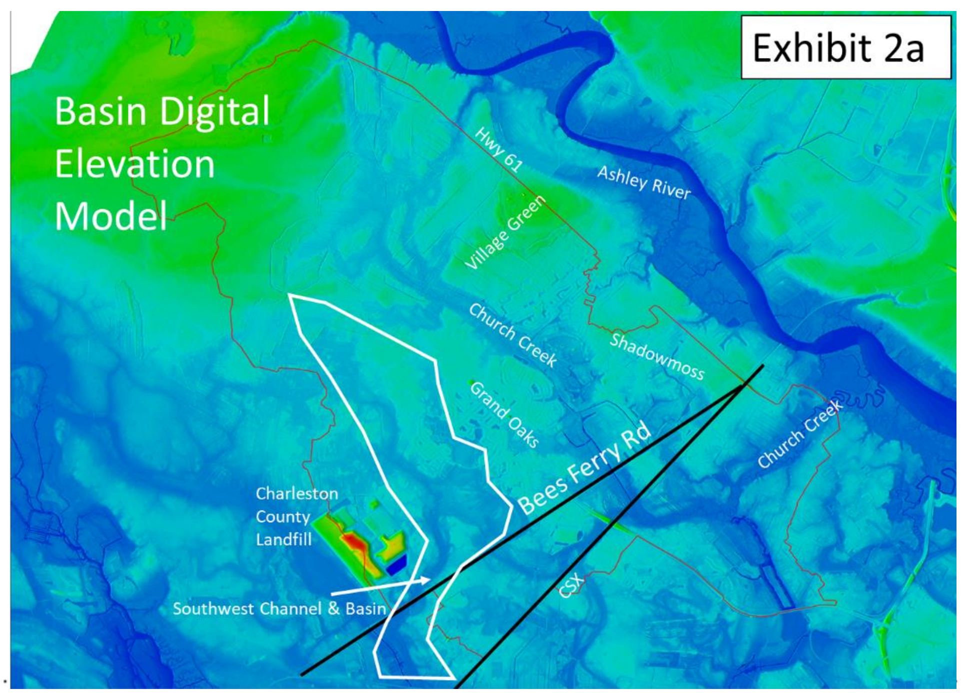
Surge protection for the Southwest areas is also recommended to take advantage of the impounded area bounded by Main Road, US 17 and the CSX Railroad. This area provides approximately 100 acres of potential storage that could be utilized to reduce and preserve a low tailwater condition for the Southwest Channel if protected from a tidal surge. This improvement could also greatly reduce or even mitigate flooding issues affecting Main Road near US 17. The 100-acre area was flooded during the surge associated with Irma and the adjacent water elevations took approximately 5 days to return to normal levels. Tidal surge design associated with this area should consider the habitat within the basin also. This habitat is primarily a salt marsh. Tidal surge protection improvements here should be designed to allow two-way flow under normal conditions. Culverts should be equipped with control devices that close during high tide conditions. These devices also allow storm water to outfall when upstream head elevations are higher than the receiving water elevation. Control devices should also be equipped with simple telemetry for monitoring during storm events. This is discussed also in the Southwest Basin Improvements section.

Other recommendations associated with surge also include considerations for additional tidal surge protection at other locations. These include Church Creek at Highway 61 in the future and other smaller outfalls along Church Creek serving portions of adjacent neighborhoods. The Highway 61 Church Creek crossing should be considered for a long-range planning effort to fully understand the costs and benefits of surge protection at that location. There are many homes along Church Creek on the upstream side of Highway 61 that are subjected to impacts from tidal surge. The bridge crossing along with the elevated embanked section of roadway create an opportunity to review the feasibility of incorporating surge measures when road improvements are planned. An effective surge project at this location would likely include raising the road profile to make a project like this more effective. As this is a long range planning item, the cost opinions are not included in any of the project estimates.

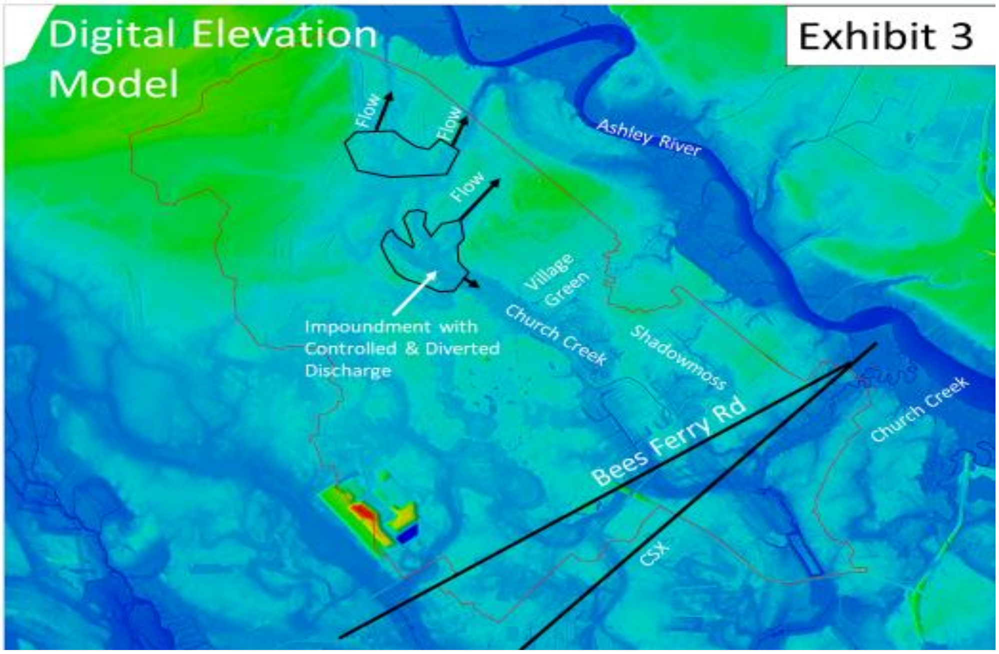
2. **Southwest Basin Conveyance & Outfall Improvements** – The Southwest part of the basin consists of areas that are located on the South Side of Proximity Drive. Portions of this area currently send storm water to the Southern Church Creek Tributary canal which crosses Bees Ferry Road approximately 530 feet Northeast of its intersection with Sanders Road. This canal flows along the rear of homes along Reverend Joseph Heyward Road and then along the CSX Railroad to the Northeast to intersect the Main Church Creek channel behind Crosstown Church. There is a tide gage in the channel at bees Ferry Road referred to as Planck. Flows have been observed in this channel near Verdier Boulevard under high water conditions moving to the North which does not contribute to the Church Creek Outfall. Improving the flow characteristics along this channel system to the Southwest would improve conditions in the Western portion of the existing developments while enabling water to flow along the natural channel as shown on the Digital Elevation Model (DEM). This part of the "Southwest" Basin needs additional improvements also associated with conveyance in addition to the surge protection. Channels should be restored to a consistent cross section with access re-established that will enable equipment such as an excavator equipped with a Gyro-Track head, mower or channel cleaning bucket to traverse the entire length. Sediment, trees, shrubs and debris should be removed to restore hydraulic capacity along this route. In addition, the single box culvert located under US 17 at its intersection with Old Charleston Road should be improved to accommodate current and future conditions which include flows from portions of the drainage basin extending between the Charleston County Landfill and Grand Oaks and for a large area to the North of this. This is also shown on the DEM below, as Exhibit 2a. Overall SW Basin Improvements are shown on Exhibit 2b below.



3. Northeast Basin Improvements – The overall basin boundary extends farther to the North than originally recognized. The DEM shows that this area extends approximately 3 miles North from Bees Ferry Road. The significance of this area is recognized when the hydraulic model is run to simulate buildout conditions by assuming the ground is saturated (AMC III). This simulation was modeled with six different synthetic storms 2, 10, 25, 50, 100 and 500-year. To simulate the buildout condition, the model assumed a severe antecedent moisture condition (saturated) which would generate the most runoff. Field inspections during and after recent storm events verified that this was an accurate way to model this simulation. This condition was called Antecedent Moisture Condition III (AMC III). Originally, it was believed that flows could potentially be diverted using a canal to either direct flows from the North area to the Ashley River or to Rantowles Creek. The development of several profiles on various routes using the DEM showed that this may be difficult due to the topography. Instead, the concept of upper basin storage was evaluated with better success. This will enable the development of a higher elevation of the water surface to use in directing the flow along a more topographically favorable alignment following existing outfalls. Outfall volume



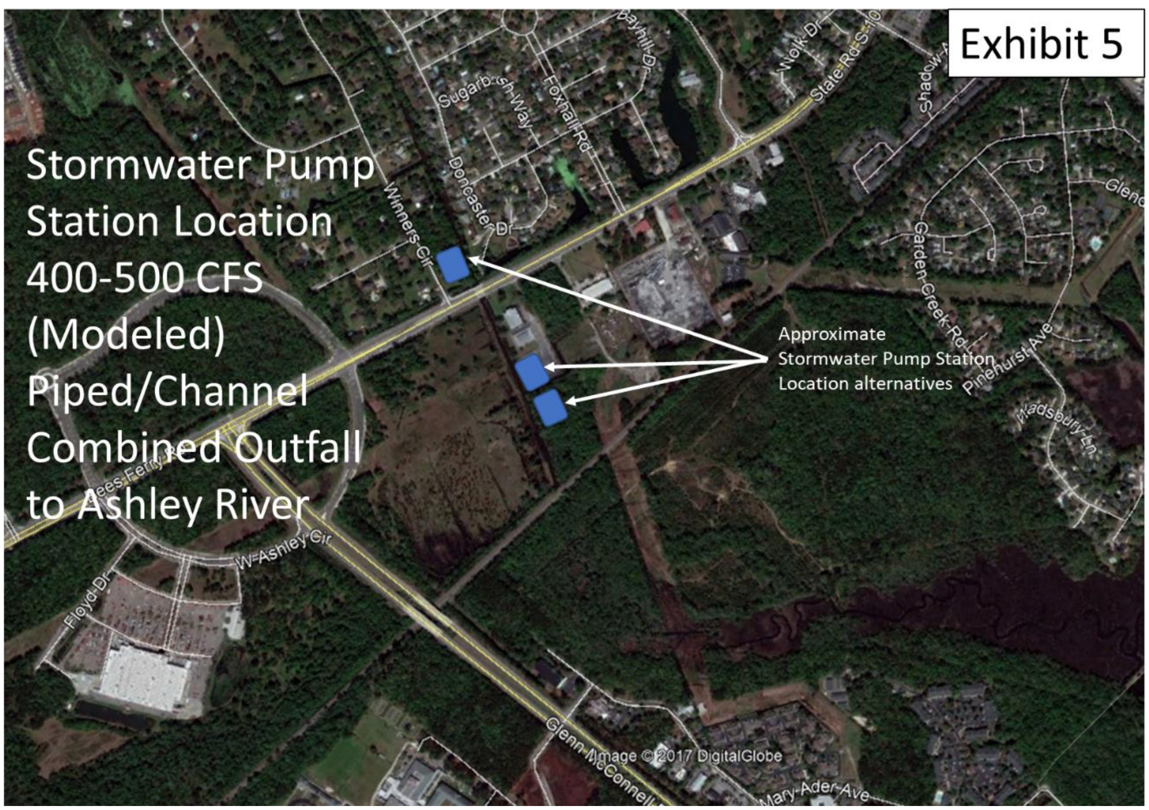
should be controlled to enable ponds to stage down over time especially if outfalls reach the existing Church Creek Channel. This alternative is very effective in significantly reducing the duration of a flooding or high water event. This alternative was modeled without the downstream pump station under a 100-year event with AMC III conditions and showed reductions of water levels at 50 hours from 6.1 feet to 4.9 feet. Overall peaks were not affected much letting us know that this alternative is certainly one to consider now while there is limited development in the upper basin area. This alternative could also be implemented in multiple stages to take advantage of existing topography. An exhibit showing this conceptual alternative is below. Implementing this alternative would involve purchasing the rights to store water or flood the impoundment area along with installing the actual dikes and outfall structures and new channels. Environmental concerns would need to be addressed but the project could be viewed as a wetland enhancement since the impoundments would hold water for considerable periods and impounded areas would likely extend above wetland boundaries.



4. Hickory Farms Overland Flow Diversion – Flows from an isolated wetland area located just West of Hickory Farms have become more severe during recent storm events. This wetland apparently overflowed at some point in the past in a Northeasterly direction towards Church Creek. Changes in drainage patterns have resulted in this wetland area overflowing during and for several days following storm events towards the East and onto the Winners Circle right of way. This has led to several shallow flooding events and affects capacity on the Winners Circle right of way drainage system that was likely not accounted for during the original design of that neighborhood system. Nearby storm water ponds also contribute flow to the wetland area during significant storm events serving to prolong the high flows contributing to this issue. At some point in the past, an overflow channel was partially constructed to allow the wetland to overflow to the South but was never completed. It is likely that the same alignment could be used to complete the wetland overflow channel. The overall length of this improvement is 1,472 linear feet.

5. **Church Creek Storm Water Pump Station** – Several model scenarios were performed using the existing conditions along with other improvements including improved upper basin storage, diversions and lower basin channel improvements. In all cases, there were no improvements that would have a significant improvement on the peak water surface elevations along the main conveyance systems of Church Creek and the main tributaries. Combined with the fluctuating boundary conditions of the Ashley River and the occurrence of frequent tidal surges, there were no scenarios that prevented flooding conditions without the installation of a storm water pump station. The initial model development to evaluate a pumping alternative used the scenario where the extended northern areas of the basin were diverted and improvements were made to portions of the Western areas to divert flows to the Stono River and Rantowles Creek. Initially, a station with a staged capacity reaching 450 CFS was used to run a simulation with a 100-year storm event with tidal surge protection.

   This alternative proved to be the most effective in maintaining control of the water surface elevation. Model runs resulted in maximum water surface elevations of 7.2 Ft (NGVD88) at Bees Ferry Road. Following this success, additional model manipulation was performed to simulate upper basin detention improvements along with the pump station in two various locations. The objective of this was to determine the impact of the Bees ferry bridge on the high flows that would be observed at that location. The alternative with the pump station on the South side of Bees Ferry resulted in water surface elevations that were 0.3' higher. The bridge opening as modeled, has a minor impact on the ability to get water to the pump station location. It may be possible to improve the channel in this area to improve performance on either side of the bridge. Improving the channel width and depth could most likely be more significant though if performed on both sides increasing depth upstream and both depth and width downstream of Bees Ferry Road. Optimizing the channel as well as the approaches to the pump station is an effort that would be evaluated as a part of the station design process.

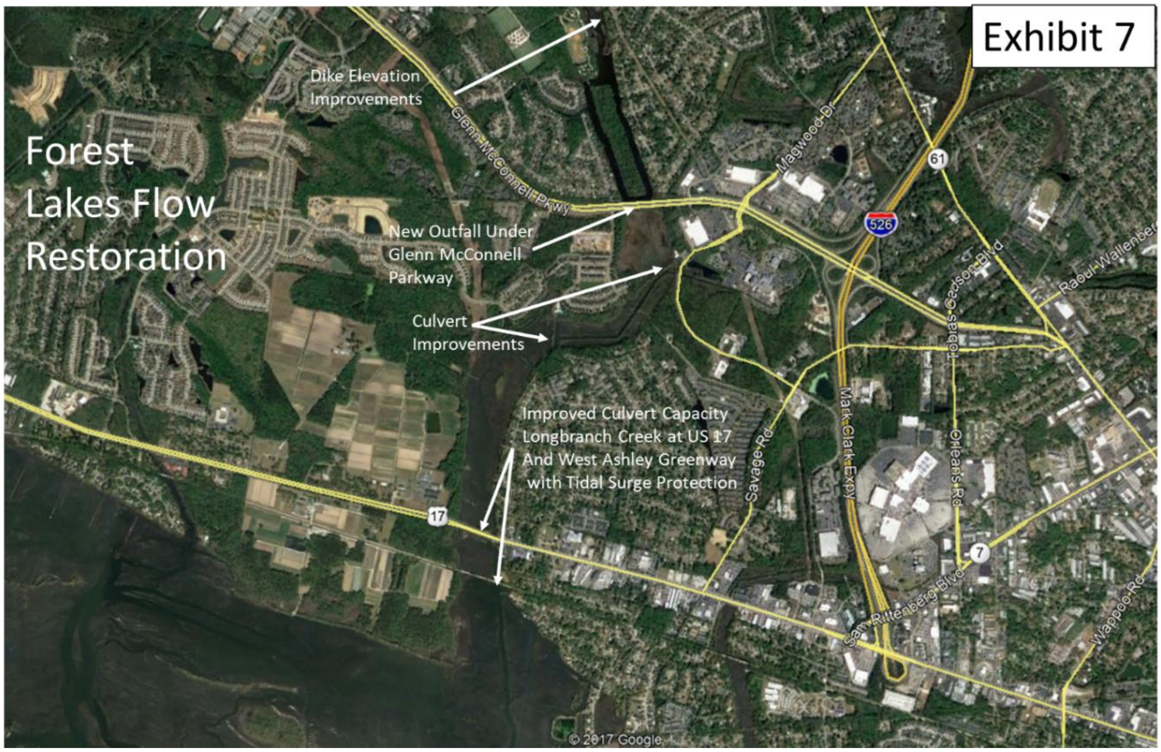


Additionally, it may be beneficial to add a sizable storage facility adjacent to the pump station and the Church Creek Channel. That would allow more operating flexibility during storm events requiring the station to operate while providing more constant operating conditions. This would also allow water quality considerations to be effectively addressed at a location where ample room is available as opposed to near the outfall location where space may be more limited. In any case, the modeled station combined with tidal surge protection and upper basin storage improvements and flows diverted to the Southwest as discussed in Section 2 resulted in maximum water surface elevations during a 100-year storm simulation of 6.5 ft. based on NGVD 88. Pump size and arrangements as well as the approaches and discharge configuration could certainly be optimized to find the most effective operating point(s) during anticipated storm events. A storm water pump station of this size and significance would be equipped with energy sources that would provide multiple levels of reliability. The preliminary cost estimate included represents a version utilizing stand-alone electric drives, direct diesel drives, and a backup power supply that could operate the electric drives under a power outage condition. The likely arrangement includes four high volume, high head pumps with a common discharge to a force main that would direct the flow to the Ashley River. The discharge would likely include some widened channel flow sections along with treatment to remove trash and debris and to improve dissolved oxygen (DO) levels during storm events which is also when DO levels in our estuaries are most challenged. This discharge along with the physical and regulatory aspects would need additional study associated with treatment, velocity and overall configuration as a part of a preliminary engineering effort prior to design.

6. Channel Conveyance and Collection System Improvements – The City of Charleston performs routine maintenance of main channels and at locations where easements are established. Accessibility, space restrictions and drainage ditches which do not have easements limit and even prevent maintenance in some areas. Several channels are key to maintaining water levels in the basin. These include primarily Church Creek and its tributaries shown on exhibit 6. With the recommendation to install a pumping station on Church Creek near Bees Ferry Road, having channels that are a uniform cross section, adequate depth to prevent nuisance weed growth (in wet channels) and to keep channels free from encroaching trees shrubs and other vegetation will be essential in maintaining water surface elevations at acceptable levels. The ability to move water through the basin more efficiently will also make channel access more important as well. Having a clear access and a maintenance shelf is essential in maintaining significant drainage assets. Channel width plus the width required to freely access the bank with an excavator is necessary for a sustainable channel. Channel maintenance should be implemented in phases to avoid creating additional flooding in the lower parts of the basin until plans for tidal surge and pumping capabilities are initiated. Initially, channel clearing, access establishment and improvements should be performed on all City owned & maintained drainage easements. Easement acquisitions will also be necessary on many key conveyance assets to enable implementation of an effective maintenance program. A systematic approach with a supervisor or crew chief that is responsible for assigned areas based on a simple asset management system that plans regular inspections followed by the routine implementation of rehabilitation projects where necessary to address deficiencies has proven to be a successful approach for similar systems. Initially, to establish a base condition, it is likely that specialized equipment and contractor effort would be necessary to make considerable progress over a short period. Where the City does not have an existing easement on a conveyance channel, easements should be obtained that include ample width for channel maintenance. Key maintenance channels are shown on the exhibit below. Additional channel sections extending farther to the north should also be considered as future efforts. The neighborhoods of Springfield and Canterbury Woods offer challenges also associated with multiple jurisdictions. Springfield mainly is an open ditch drainage system area that also has parts affected by tidal outfalls. Both of these areas will benefit significantly by a reduction of the flows entering Church Creek based on the recommendations included in this report. In addition, key elements of the collection system should be reviewed and maintained to reduce standing water on or near roads. The channel along the SCE&G power right of way is a significant asset for these neighborhoods that should be routinely maintained with jurisdictional collaboration.

7. **Forest Lakes and Lake Dotterer** – Forest Lakes, Providence Commons and the adjacent areas are subject to tidal surges mainly in areas that are adjacent to the lake or wetland areas. The capacity of Lake Dotterer as a stormwater facility is much larger than would typically be required to serve these neighborhoods collectively. This overall area is approximately 50 acres and was formerly part of the estuarine area which connected Church Creek with the Stono River. As an added measure to reduce the flow that Church Creek receives during a rain event, diverting the flow exiting the lake from the rice trunks was modeled as a part of the overall effort. To simulate this, culverts were installed beneath the Glenn McConnell Expressway to allow flow towards the Stono River through an impounded area located on the South Side of the Glenn McConnell. This had a positive impact on the flows in Church Creek especially following a tidal surge event when Lake Dotterer becomes inundated. When the water level in Church Creek exceeds the top of the dike at Lake Dotterer, it takes several days for the lake to return to normal levels. Flooding also occurs along Forest Lakes Boulevard, Mariners Ferry, and Wayan Drive, Bishop Drive, Dotterers Run, Arrowind Terrace and adjacent streets when the surge reaches higher elevations as occurred during Irma. Adjusting the rice trunks to only allow flow out under favorable conditions in Church Creek while installing an outfall to the South would significantly reduce the risk of flooding to these areas if combined with adding additional height to the dike on the North end of the lake. Flow has been observed entering Lake Dotterer through the rice trunk structures. Under this application, using the rice trunks as an outfall for a stormwater pond, the flap gates should be configured to only allow flow out of the lake. A diver should be used to verify the condition of the flap gate on the saltwater side to insure proper vertical alignment and condition.

   This alternative would also include careful study of drainage conditions along this corridor as well as coordination with property owners and neighborhoods along Longbranch Creek as well as Carolina Bay and the Department of Agriculture which are located to the South of Lake Dotterer. Proper coordination of this alternative with these communities is essential to ensuring that implementation provides benefits to all downstream areas while avoiding adverse impacts. These offsite improvements would include the outfall from the impounded area adjacent to the Glenn McConnell currently owned by the Carolina Bay Property Owners Association, twin culvert pipes on a causeway which connects Melrose with Essex Farms, the box culvert under US 17 and dual culvert pipes under the West Ashley Greenway. These offsite assets are not currently incorporated into the ICPR4 model but should be. Tidal surge consideration should also be given here to improving the downstream culverts on Longbranch Creek at the West Ashley Greenway to enable two-way flow while being able to prevent tidal surge from encroaching into the basin during storms and severe tidal events.



8. Policy Recommendations – Past policy recommendations have included more aggressive approaches to storm water storage and design standards associated with eliminating submerged pipes on conveyance systems. After inspecting most of the Church Creek conveyance system before, during and after Tropical Storm Irma, considerations should be given to the following items to provide a more robust stormwater system that operates at a high level of reliability while enduring years of service, severe weather and the wear and tear and routine maintenance. The following recommendations should be fully vetted, by a committee made up of representatives of city staff, property owners, engineers and developers to ensure that future development plays a role in the improvement of drainage conditions in the basin in the future. The committee should take the recommendations and draft policies that are consistent, complementary and compatible with current policies while accomplishing the results desired by the discussions below which will result in improved drainage conditions.

    a. Main conveyance components should utilize open drainage channels and ponds to move large volumes of storm water over long distances. Box culverts or pre-engineered spans or bridges should be considered in lieu of pipes for locations where significant drainage channels cross roadways or trails. Channels must be sized to operate at full capacity with reasonable vegetation growth. Channel right of way width should be adequate for the channel as well as access and maintenance shelves on both sides sufficient to allow large mowing equipment, excavators and other equipment required for effective operation to traverse, function and freely move without risks associated with encroaching private property such as fences, outbuildings or other improvements.

    b. Conveyance culverts must be sized to insure operation at full required capacity under severe conditions common in the area of installation. Minimum sizes should be established to reduce the potential for fouling or clogging due to trapped debris. Maintenance access right of ways should be provided on each side of culvert crossings parallel to the flow way to enable maintenance equipment to stage and operate without risk of inflicting permanent damage to improvements in the right of way. Culvert headwalls should include robust components not easily damaged by a backhoe or excavator bucket.

c. Floodplain storage impacts that reduce storage must be prevented if possible or mitigated when necessary to prevent deterioration of basin storage capacity over time. Mitigation should be within the same basin having an effect on the same water surface elevations and hydraulics as the proposed impact. A mitigation strategy should include a contribution to the cost of a common facility installed, constructed or enhanced by the City such as a regional storage improvement.

d. Tidal surge prevention considerations must be evaluated on projects adjacent to tidally affected waters. The City should consider adopting a standard design approach, materials and configuration for surge prevention devises that ensure reliability, endurance and enable routine maintenance without special equipment, unusual traffic control or permitting.

e. Significant fill is usually a component of a land development project. A long-term strategy should be to enable a review of the soil characteristics of fill material placed on nonstructural areas to insure that granular soils are used which promote infiltration and reduce runoff.

f. A Church Creek Advisory Committee should be established and made up of community representatives, owners of undeveloped property, resident representatives, Engineers, SCDOT representatives, SCDHEC-OCRM representatives, and City Staff or appropriate members to provide continued collaboration and policy direction associated with improving drainage conditions in the basin.

OPINIONS OF PROBABLE COST

Summary of Improvements (In order of priority)		
Project	Description	Cost
1	Church Creek Channel Tidal Surge Protection	$1,531,650
2	Church Creek Stormwater Pump Station	$26,692,520
3	North Basin Storage Improvements	$3,983,542
4	Hickory Farms Overland Flow Diversion	$482,322
5	Southwest Basin Conveyance & Outfall Improvements	$2,594,120
6	Large Channel Conveyance System Improvements	$4,977,357
7	Forest Lakes Flow Restoration	$3,148,866
	Total	**$44,410,377**

Project #	1				
Description	**Church Creek Channel Tidal Surge Protection**				
Location	**CSX Railroad at Church Creek Channel**				
Item	**Description**	**Quantity**	**Unit**	**Cost**	**Extended Cost**
1	72" Surge Prevention Device	3	EA	$80,000	$240,000
2	68" x 68" Horseshoe Surge Prevention Device	1	EA	$120,000	$120,000
3	48" Surge Prevention Device	2	EA	$55,000	$110,000
4	Site work	1	LS	$250,000	$250,000
5	Telemetry	1	LS	$40,000	$40,000
6	Labor	1	LS	$175,000	$175,000
7	Mobilization, Bonds, Insurance (20%)	1	LS	$144,000	$144,000
			Subtotal		$1,079,000
			Property		$75,000
			Engineering		$161,850
			Contingency		$215,800
			Total		$1,531,650

Project #	2				
Description	**Church Creek Stormwater Pump Station**				
Location	**Church Creek near Crosstowne Church**				
Item	**Description**	**Quantity**	**Unit**	**Cost**	**Extended Cost**
1	Pumps, Controls Electric Drives, 250 CFS	2	EA	$3,200,000	$6,400,000
2	Pumps, Controls Diesel Drives, 250 CFS	2	EA	$4,000,000	$8,000,000
3	Clearing	5	AC	$6,000	$30,000
4	Stabilization	1	LS	$20,000	$20,000
5	Site work & Access	1	LS	$500,000	$500,000
6	Enclosure, approaches security	1	LS	$1,500,000	$1,500,000
7	Misc. Labor	1	LS	$300,000	$300,000
8	Mobilization, Bonds, Insurance (20%)	1	LS	$1,185,200	$1,185,200
9	Standby Generator	1	LS	$2,500,000	$2,500,000
			Subtotal		$20,435,200
			Property		$2,500,000
			Engineering		$1,610,280
			Contingency		$2,147,040
			Total		$26,692,520

Project #	3				
Description	**North Basin Storage Improvements**				
Location	**Church Creek North of Village Green**				
Item	**Description**	**Quantity**	**Unit**	**Cost**	**Extended Cost**
1	New Dike	2000	LF	$350	$700,000
2	Clearing	10	AC	$6,000	$60,000
3	Access Road Improvements	3000	LF	$100	$300,000
4	Site work	1	LS	$125,000	$125,000
5	Telemetry	1	LS	$40,000	$40,000
6	Misc. Labor	1	LS	$175,000	$175,000
7	Mobilization, Bonds, Insurance (20%)	1	LS	$69,290	$69,290
			Subtotal		$1,469,290
			Property		$2,000,000
			Engineering		$220,394
			Contingency		$293,858
			Total		$3,983,542

Project #	4				
Description	**Hickory Farms Overland Flow Diversion**				
Location	**West of Hickory Farms**				
Item	**Description**	**Quantity**	**Unit**	**Cost**	**Extended Cost**
1	Excavation	5500	CY	$6	$33,000
2	Clearing	2	AC	$6,000	$12,000
3	Stabilization	1	LS	$7,500	$7,500
4	Site work	1	LS	$15,000	$15,000
5	Misc. Labor	1	LS	$175,000	$175,000
6	Mobilization, Bonds, Insurance (20%)	1	LS	$40,701	$40,701
			Subtotal		$283,201
			Property		$100,000
			Engineering		$42,480
			Contingency		$56,640
			Total		$482,322

Project #	5				
Description	**Southwest Basin Conveyance & Outfall Improvements**				
Location	**Channel Improvements, CSX Culverts, Surge Protection**				
Item	**Description**	**Quantity**	**Unit**	**Cost**	**Extended Cost**
1	Clearing	13	AC	$6,000	$78,000
2	Channel Improvements	11400	LF	$75	$855,000
3	Stabilization	13	AC	$4,000	$52,000
4	Site work & Access	1	LS	$150,000	$150,000
5	Cofferdam	1	LS	$120,000	$120,000
6	Install new Box Culvert	1	LS	$150,000	$150,000
7	Surge Protection/Box Culvert	1	LS	$150,000	$150,000
8	Surge Protection/ 48" Culvert	2	EA	$75,000	$150,000
9	Surge Protection 24" Culvert	1	EA	$75,000	$75,000
10	Mobilization, Bonds, Insurance (20%)	1	LS	$86,015	$86,015
			Subtotal		$1,866,015
			Property/Access		$75,000
			Engineering/Permitting		$279,902
			Contingency (20%)		$373,203
			Total		$2,594,120

Project #	6				
Description	**Large Channel Conveyance System Improvements**				
Location	**South Tributary, Shadowmoss, Church Creek**				
Item	**Description**	**Quantity**	**Unit**	**Cost**	**Extended Cost**
1	Clearing	30	AC	$6,000	$180,000
2	cleaning/restoring channel section	26440	LF	$100	$2,644,000
3	Stabilization	30	AC	$3,000	$90,000
4	Site work, Access, Restoration	1	LS	$250,000	$250,000
5	Misc. Labor	1	LS	$300,000	$300,000
6	Mobilization, Bonds, Insurance (20%)	1	LS	$111,820	$111,820
			Subtotal		$3,575,820
			Property		$150,000
			Engineering		$536,373
			Contingency		$715,164
			Total		$4,977,357

Project #	7				
Description	**Forest Lakes Flow Restoration**				
Location	**Forest Lakes at I-526**				
Item	**Description**	**Quantity**	**Unit**	**Cost**	**Extended Cost**
1	Jack & Bore 48” Culvert under Glenn McConnell	190	LF	$500	$95,000
2	Culvert Improvements to Impoundment & DS Dike	1	LS	$50,000	$50,000
3	Culvert Improvements at US 17 & Greenway	1	LS	$1,500,000	$1,500,000
4	Site work, Access, Restoration	1	LS	$250,000	$250,000
5	Misc. Labor	1	LS	$300,000	$300,000
6	Mobilization, Bonds, Insurance (20%)	1	LS	$111,820	$111,820
			Subtotal		$2,306,820
			Property		$150,000
			Engineering		$230,682
			Contingency		$461,364
			Total		$3,148,866

APPENDICES

Appendix A - ROG Alternative A Results Evaluation

Appendix B - ICPR4 Model Conceptual Alternatives

Appendix C - ICPR4 2D Model Setup