METROPOLITAN SEWER DISTRICT OF
GREATER CINCINNATI

Eastern-Delta Modeling and Empress Avenue Flooding

TECHNICAL MEMORANDUM

November 9, 2017

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1.0 BACKGROUND AND PURPOSE

Following a series of large storm events, a portion of the Eastern-Delta area in Cincinnati, Ohio experienced repeated flooding, as reported by residents. The Eastern-Delta area is tributary to the Little Miami Wastewater Treatment Plant with three (3) nearby combined sewer overflows (CSO): 467, 468, and 469. The study area is located near the intersection of Delta Avenue and Widman is distinguished by two (2) large topographic depressions located northeast of Columbia Parkway. The northern depression, referred to as the “Widman Bowl,” is surrounded by multiple residences on either side of the bowl with a low-lying street (Empress Ave.) running through the center. The southern depression, referred to as the “Hoge Bowl”, currently is surrounded by four (4) homes, several businesses and significant open space. A multi-unit residential development is proposed to be built on this site. Repeated street flooding also has been reported at the intersection of Delta Ave. and Lawler St., which is referred to as the “Delta Bowl.” The overall project study area is illustrated in **Figure 1-1**.

The purpose of this study is to identify the potential causes of the flooding, understand the impact of the proposed development on current flooding and evaluate conceptual improvement alternatives to relieve flooding in the study area. The study approach will include review of flooding documentation, review and upgrades to the current computer models used to predict the flow of water through to the existing sewer system, analysis of the impact of the proposed development, and analysis of conceptual relief sewer alternatives on flooding.

2.0 DATA REVIEW

Available information was reviewed to examine the source and severity of the reported flooding in the study area. The Metropolitan Sewer District of Greater Cincinnati (MSDGC) provided a variety of information to support this effort. Residents of the area provided videos, photos, and descriptions of the overland flooding to MSDGC. The information contained evidence of flood levels, flow paths, and overflowing manholes. A news segment from ABC Channel 9 News also provided photos and testimonials from residents. Other information was gathered in the field and through additional research.

Figure 1-1 Eastern-Delta Project Study Area

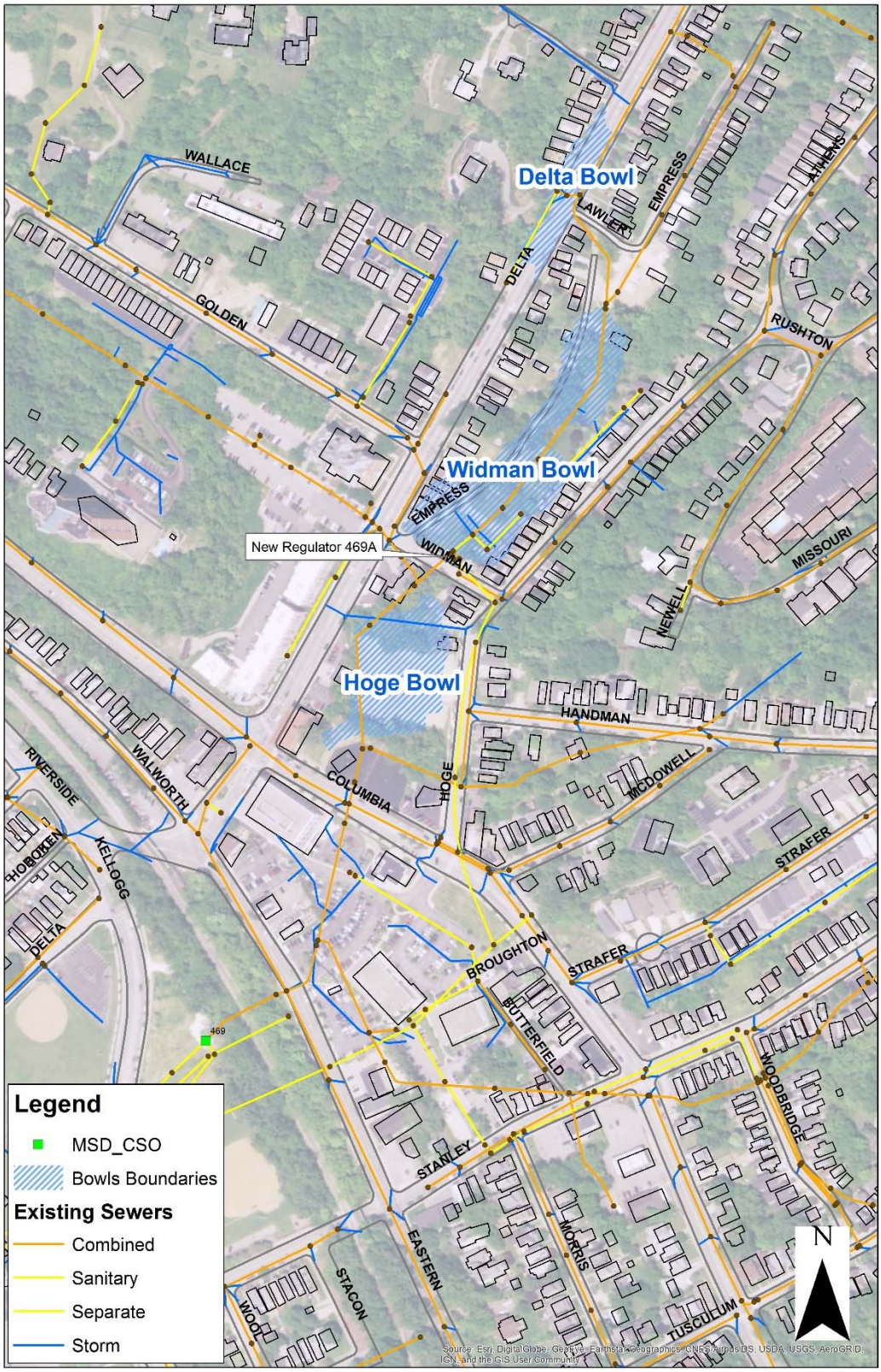
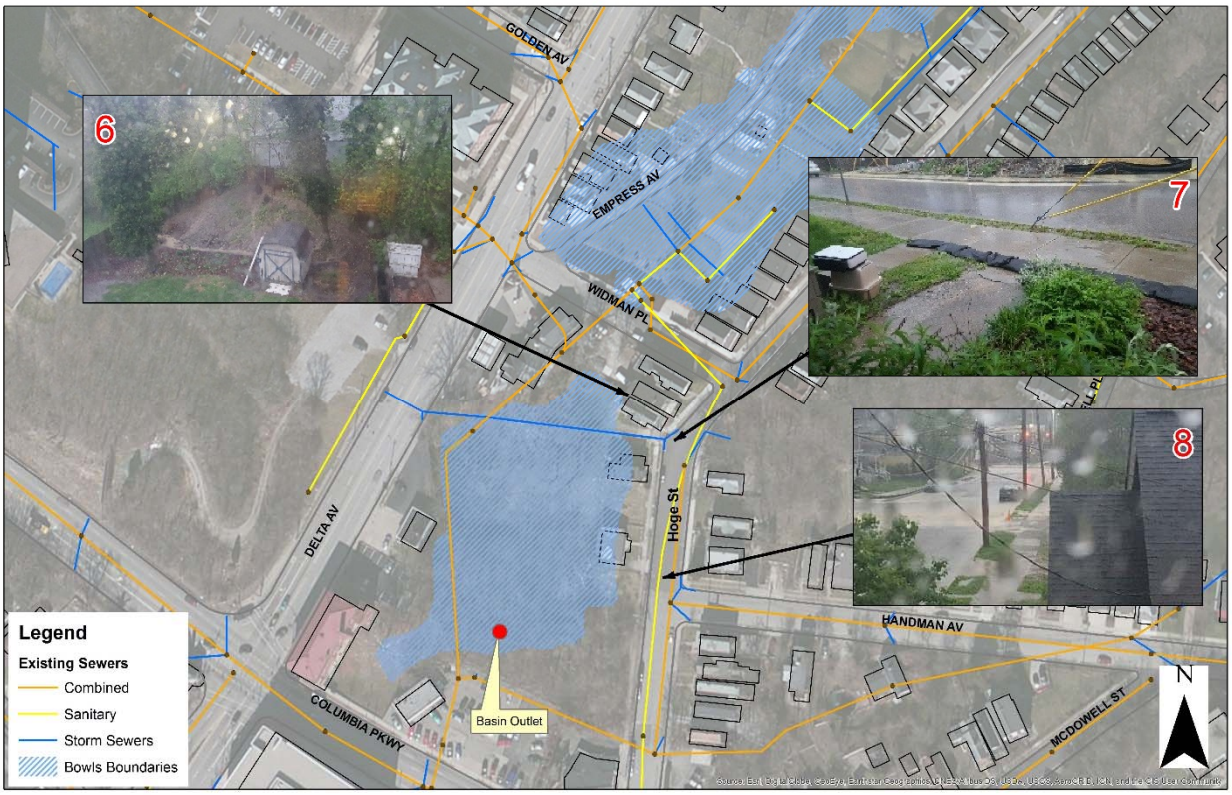


Figure 2-1 illustrates evidence of flooding in the Delta and Widman Bowl areas. Photos 1 and 2 are from the April 16, 2017 storm event. Photo 1 shows street flooding occurring at Delta Ave. and Lawler. Photo 2 shows significant curb flow from Golden Ave. turns South down Delta Ave, but remains on the Southbound side of the road. The date of the storm for Photos 3, 4 and 5 is unknown. Photo 3 shows overland flow and Photo 4 shows flooding from a manhole at the upper end of Widman Bowl. Photo 5 shows approximately 4 feet of standing water at the southern end of the Widman Bowl.

Figure 2-1 Widman Bowl Flooding

Figure 2-2 illustrates evidence of surface and street flooding near the Hoge Bowl. The photos were taken during the April 16, 2017 event. Photo 6 shows overland flow coming from the upper portion of Hoge Bowl, which is likely local runoff from Widman Place. Field investigations found a potential entry location for Hoge St. west curb flow to enter the Hoge Bowl, should that curb convey significant flow. Photo 7 shows minimal flow in the west curb of Hoge St. and the use of sand bags to prevent potential overland flooding from excessive curb flow. Photo 8 shows street flooding from Handman Ave. which does not enter the Hoge Bowl, but rather is conveyed by the curb down Hoge St. The documentation reviewed did not present evidence that flooding occurs within the Hoge Bowl.

Figure 2-2 April 16, 2017 Hoge Bowl Flooding



MSDGC also provided precipitation and flow data from three (3) sewage flow monitors used to measure data on the amount and extent of flows during dry and wet weather for the periods from June 2016 to March 2017. A review of the precipitation data indicated that large storm events occurred during that period as shown in **Table 2-1**.

Table 2-1 Summary of Large Storm Events

Precipitation Gage - LM-DA-002					
		Max Rainfall Depth (in)			
Event	Event Date	1-hr	6-hr	24-hr	Total
1	8/1/2016	1.84	2.54	2.54	2.54
2	3/1/2017	1.18	1.94	3.61	4.04
3	4/16/2017	1.25	2.45	2.50	2.50
4	4/29/2017	1.12	1.66	2.49	2.49

A review of the flow data showed significant increases in sewer system flows during large storm events. However, the flow monitor during the largest storm events appeared to malfunction, likely due to the extremely high velocities occurring in the sewer pipes. As a result, the measured flow data was not sufficient to verify the extent of the observed surface flooding.

3.0 MODEL UPDATES

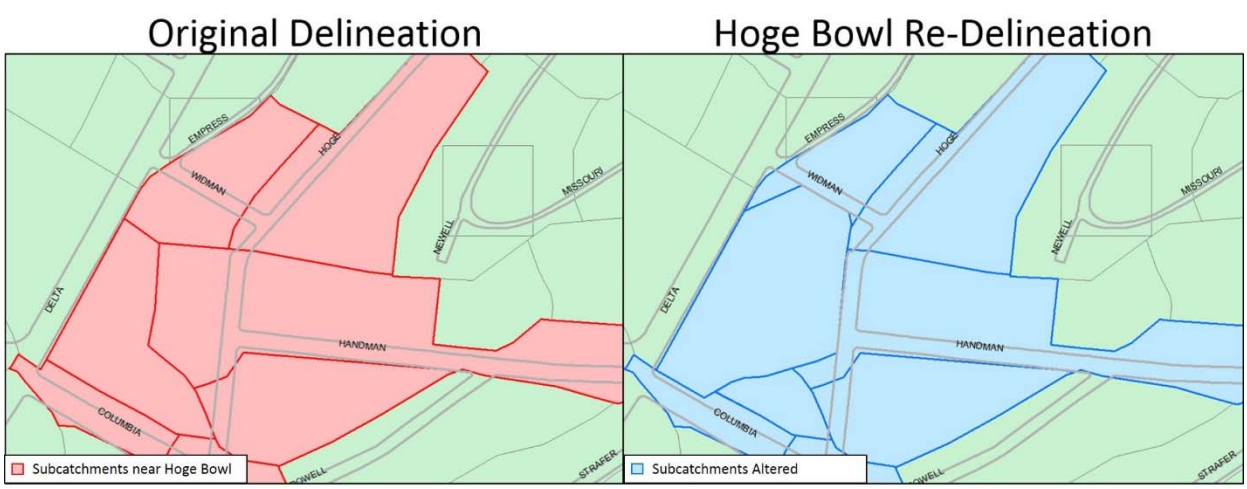
MSDGC maintains an existing computer model that represents the surface flow and the impact on the sewer collection system. A hydrology model converts rainfall data to flow rates based on the land use and predicts the flow to catch basin inlets. Flows pass though the inlets into a series of sewer pipes. At key junctions, several combined sewer regulating devices control the amount of flow sent down to the Little Miami Wastewater Treatment plant. During storm events, when the capacity of the plant is exceeded, excess combined sewer flow is diverted via outfall pipes to the Ohio River. The purpose of this model is to generally evaluate the performance of the sewer system during storms seen in most typical years and not for evaluation of extreme storm events. As a part of the study, we reviewed the current representation in the model and made revisions to allow for analysis of the extreme storm conditions that have led to observed flooding.

The latest version of the Little Miami SWM (version 5.0.021) model was provided by MSDGC, named “Little_Miami_2015_UDAB_CurrentConditions_update_042617”. The model representation of the surface routing, storage and collection system in the study area was reviewed. Based on the review, changes were made to the hydrologic and hydraulic elements to refine the representation.

3.1. Hydrology Update

A minor change was made to the tributary area of the Hoge Bowl which was altered with re-delineation of subcatchments. Using contours provided by MSDGC, the delineation was adjusted such that Hoge Bowl was represented as one subcatchment as shown in **Figure 3-1**. Note that interbasin transfer of flow from Widman to the Hoge Bowl occurs during extreme conditions such as when the 10-year 24-hour design storm occurs at the same time as the 10-year Ohio River level.

Figure 3-1 – Hoge Bowl Tributary Area Changes



3.2. Hydraulic Updates

Based on the results of the model review and findings from the flood documentation, updates to the model were made to improve the representation of large storm events. These updates included addition of above ground storage to represent flooding in the bowl areas, revisions to the CSO regulators, the addition of minor losses at significant pipe bends, minor re-delineation of tributary areas connected to the Hoge Bowl, and the addition of relevant street flow routing channel elements.

Channel elements were added and subcatchment routing was updated to track overland and overflow contributions to the bowls. A representation of Delta Ave. upstream of the Delta Bowl and Hoge Street was included. Storage representations of the Hoge Bowl, Widman Bowl, and the intersection of Delta Ave. and Lawler St. (Delta Bowl) were added to the model. Stage-storage curves were developed based on available Cincinnati Area Geographic Information System (CAGIS) 2-foot contours. The following elements were also added to convey surface flows to or from the bowls.

- Hoge Bowl outlet sewer connecting to the existing combined sewer.
- Manhole overflows and curb inlets were represented as orifices.
- Elements were added to represent flow between houses from Delta to Widman Bowl.
- Elements conveying flow between Widman Bowl and Hoge Bowl, including a storage for ponding at Delta Ave. and Widman Place, flows from Widman Bowl to the street, from the street to the sewer through curb inlets, and overflow from the street to Hoge Bowl.

Figure 3-1 illustrates a summary of the changes.

CSOs 469 and 469A regulator representation were updated. The model representation was adjusted to better match the flow path through the CSO regulator chamber, including raising the invert of the backwater gates at CSO 469 by 3.67 feet. Record drawings and photos were utilized to update the representation.

Minor losses are typically not explicitly accounted for in sanitary and combined sewer modeling. Sewer velocities are not typically high enough for minor losses to have a significant impact on sewer capacity. The model predicted high velocities during large storm events, around 25 cubic feet per second (cfs) for the 10-year storm, throughout the main combined sewer in the project area. With such high velocities and presence of bends in sewer alignment and CSO structures, minor losses can have a significant impact on sewer capacity and predicted sewage flood levels. Due to these high velocities, minor losses where added at sewer bends and CSO structures.

Minor losses were assigned to the large sewer passing through the area based on guidance from the MSDGC guidelines and the *Applied Fluid Dynamics Handbook by Robert D. Blevins*. Minor losses in CSO structures (CSOs 469 and 469A) are more complex, with expansions, contractions, turns, etc. Therefore, hand calculations where completed for the minor losses throughout each CSO structure. The model representation was then adjusted to match those losses. Model parameters adjusted were Entry, Exist, and Average Loss Coefficients and Discharge Coefficients. **Table 3-1** and **Figure 3-2** summarize the minor losses incorporated into the model.

Figure 3-1 Map of Flow Routing Updates

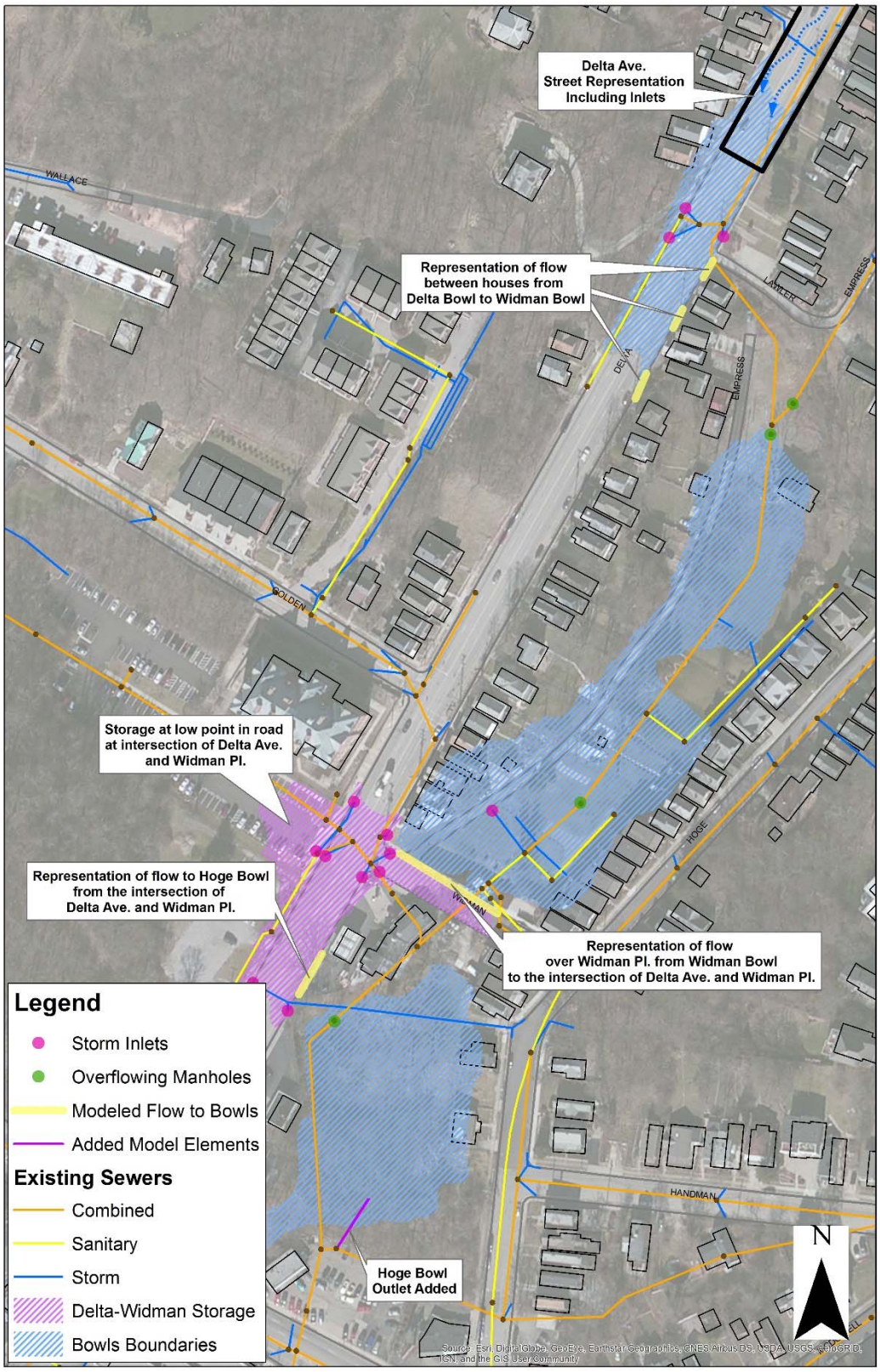
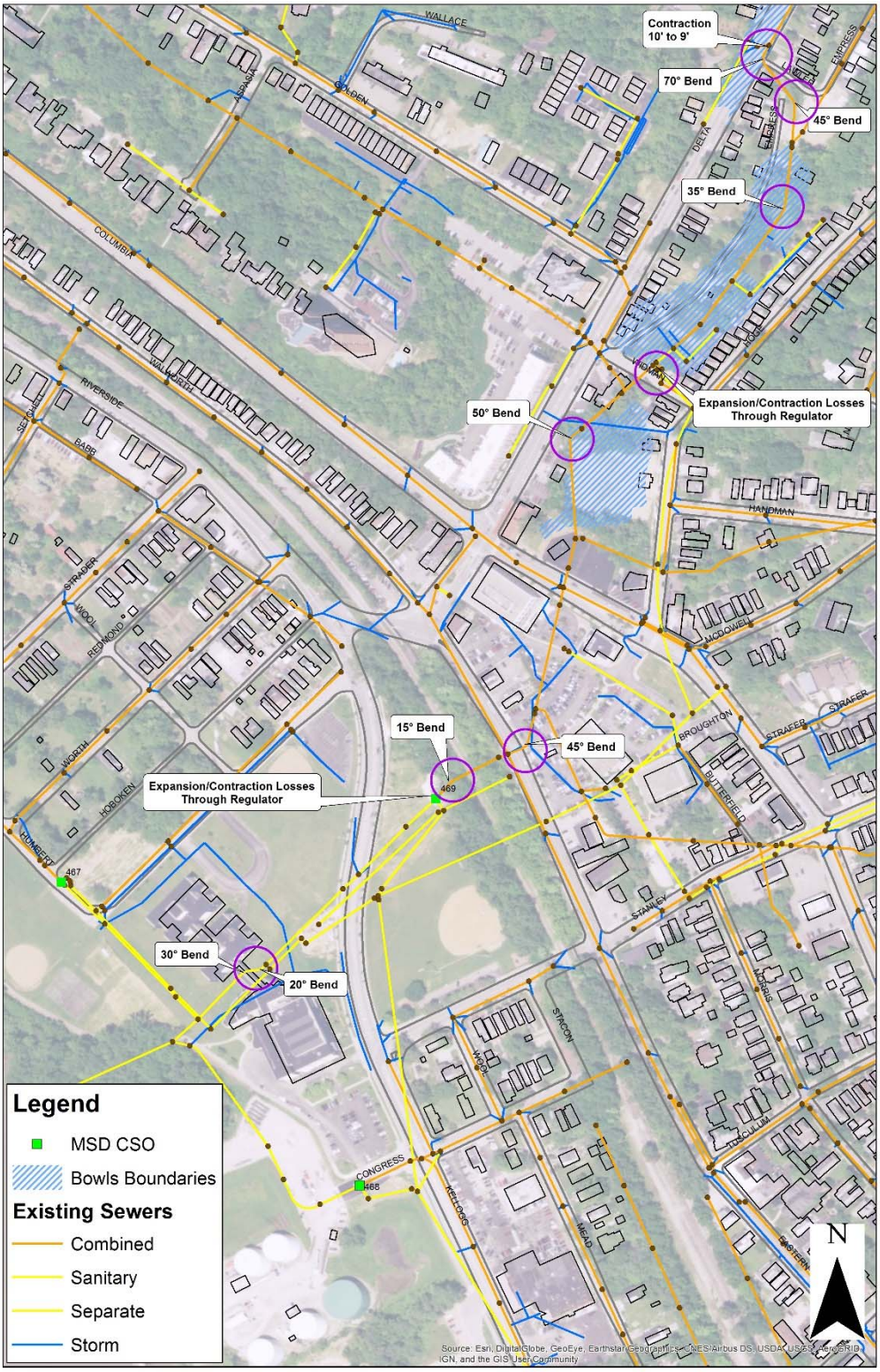


Table 3-1 Minor Losses

Loss Type	Modeled Conduit	Entry Loss Coef.	Exist Loss Coef.	Avg. Loss Coef.
Contraction from 10' to 9' diameter	40913029-40912040	0.095		
70° Bend				0.25
45° Bend				0.16
35° Bend	40912024-40912055			0.11
CSO 469A Structure	40912079-40912078		0.308	
	40912078-40912078A	0.296		
50° Bend	40912010-40905041	0.19		
45° Bend	40905064-40905005			0.16
15° Bend	40905004-40906041C			0.03
CSO 469 Structure*	40905105-40906041	0.32		
20° Bend	40903020-40903026	0.05		
30° Bend		0.09		
Note: *CSO 469 structure included twin orifices to represent backwater gates. The orifice coefficients where adjusted as part of the minor loss equivalency.				

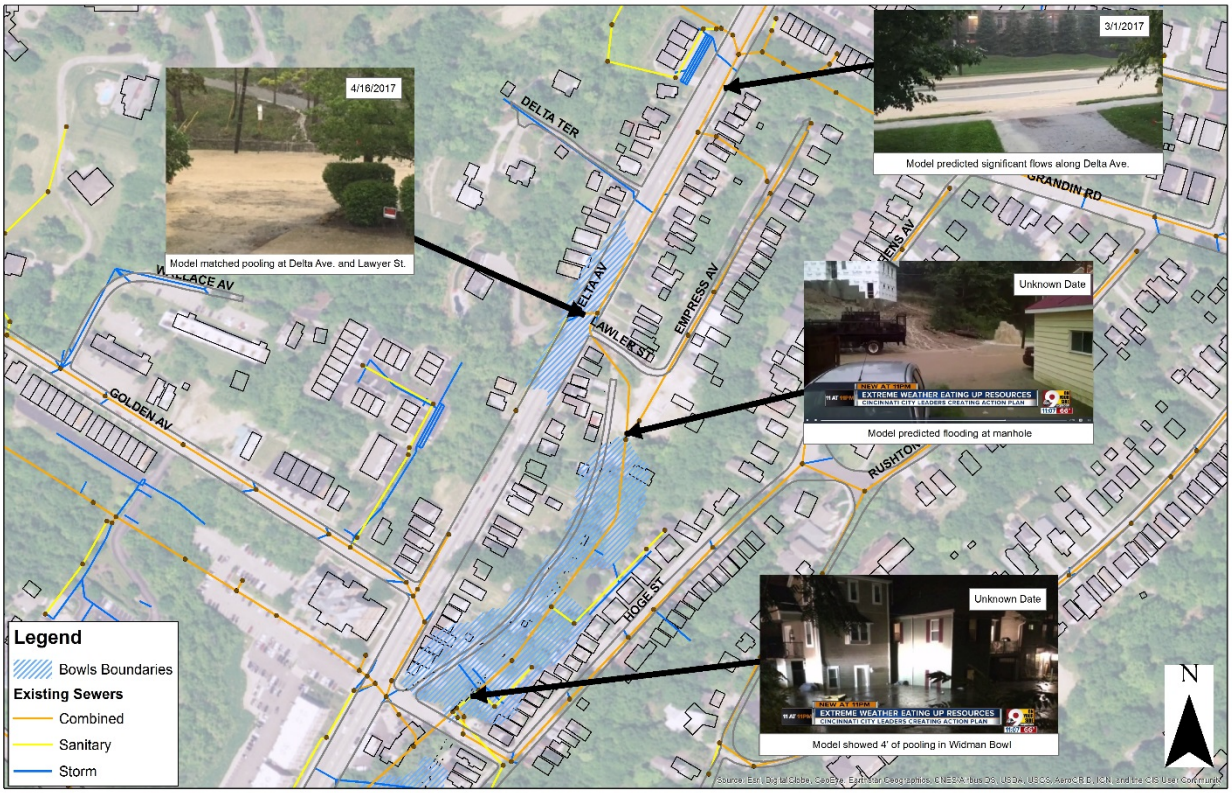
Figure 3-2 Map of Minor Loss Locations



3.3. Analysis of Existing Flooding

After changes were made to the model, an analysis was conducted to compare the model performance during a storm event that resulted in flooding. Using the findings of the April 16, 2017 event, the model was found to reasonably predict the flooding experienced during this storm. Photo comparisons of modeled flooding to actual reports are provided in **Figure 3-3**. The surface depth of water in the Widman Bowl was approximately 4 feet in the model, which compared well with the photo of nearby flooding. The model also predicted flooding from the manhole at the upstream end of Widman Bowl, at Delta Ave. and Lawyer St., street flooding along Delta Ave. upstream of Lawler St., and flow from Delta Ave. and Lawler St. to Widman Bowl between the houses. The model did not predict flooding in Hoge Bowl, which also compared well with the available evidence. Based on this finding, the model was considered sufficient for use with further flood impact analysis.

Figure 3-3 Comparison of Modeled Flooding to Historical Flood Documentation



4.0 ANALYSIS OF HOGE BOWL SITE DEVELOPMENT

An analysis comparing the Existing Conditions to various development scenarios was conducted to assess the impact of the proposed development on flooding in the area. The proposed development includes filling a portion of the Hoge Bowl and placing a parking lot with an access drive below the residential units.

The updated SWM model represented Existing Conditions. Next, the Hoge Bowl subcatchment drainage area was split into three subcatchments: (1) the residential development area, (2) an Upper Hoge Bowl area; and, (3) a Lower Hoge Bowl area. The Hoge Bowl storage was also split into two separate storage areas – one for the Upper and the other for the Lower Hoge Bowl. The impact of the development was reviewed for two conditions:

- Storm Condition 1 - The 10-year 24-hour design storm with no Ohio River flooding impacts
- Storm Condition 2 - The 10-year 24-hour design storm with a 10-yr Ohio River level of elevation 488 ft., which was obtained from the FEMA Flood Insurance Study.

Next a series of Scenarios were developed for evaluation of potential flooding. These included:

Scenario A – Existing Conditions
Scenario B – Proposed Development with a lowest parking elevation of 490.0 ft
Scenario C – Proposed Development with a lowest parking elevation of 495.8 ft
Scenario D – Proposed Development with a lowest parking elevation of 498.0 ft

Figure 4-1 shows the proposed layout of the development scenarios on the Hoge Bowl site.

During the 10-year storm event with no Ohio River impacts, with only slight ponding of direct runoff in the bowl for Existing Conditions. Under the development scenarios, the depth of stored water in the Lower and Upper Hoge Bowls increased slightly, with the peak water depths remaining below the parking lot elevation.

During the 10-year 24-hour design event with a 10-year Ohio River level, flooding was predicted to occur in the Hoge Bowl during Existing Conditions. The proposed development does cause an increase in water surface level in the Hoge Bowl.

Table 4-1 below summarizes the scenarios and the impacts on Hoge and Widman Bowl. The development does cause an increase in water surface elevation for all the scenarios, but does not have a significant impact on Widman Bowl water elevations. **Appendix A** contains more information on this analysis. It is our understanding that the proposed development was approved by the City to move forward with Scenario D.

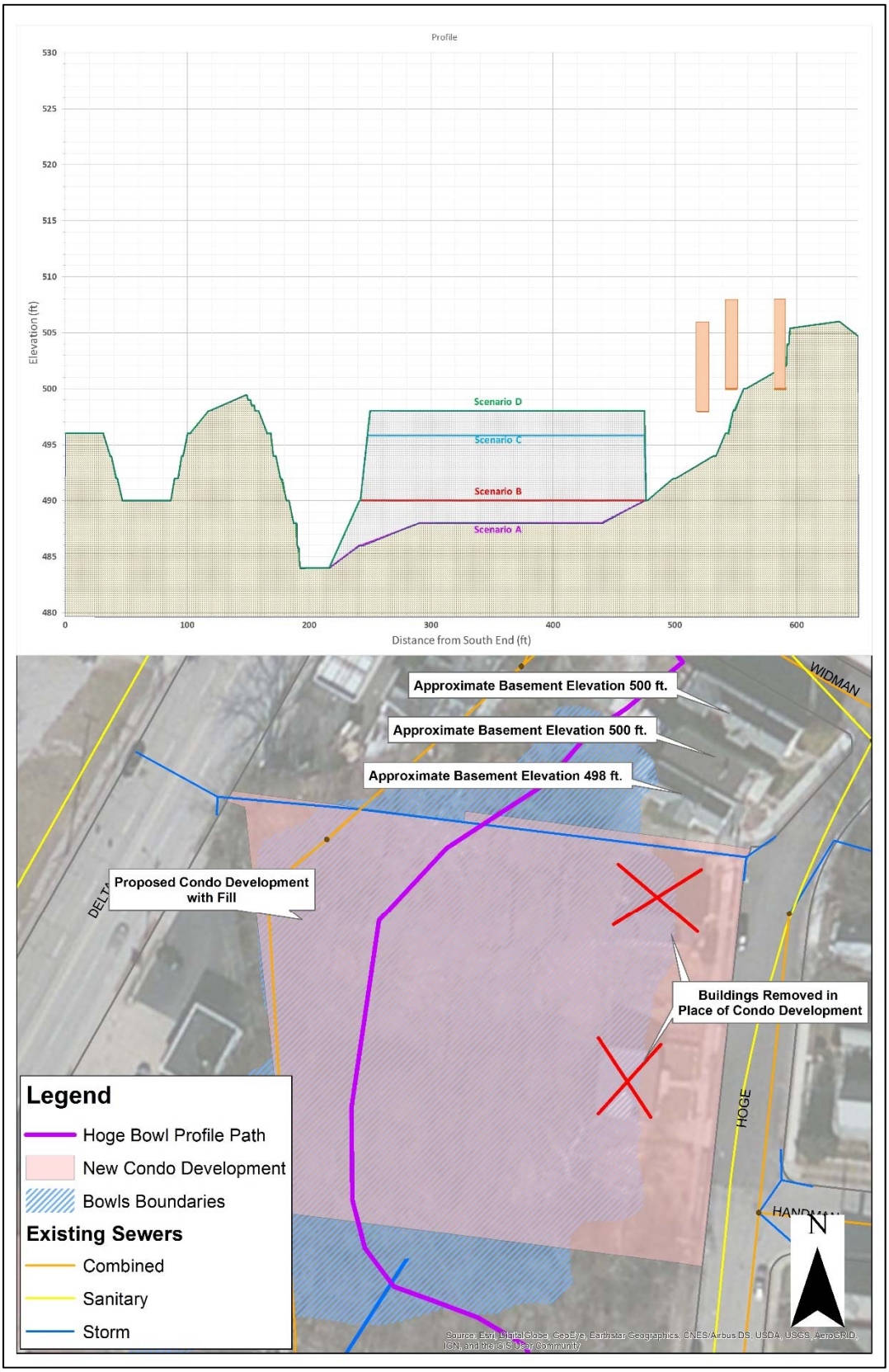
Table 4-1 Results of Hoge Bowl Development Analysis during the 10-year Storm Event (No Ohio River Flood Impact)

Scenario ID	Scenario Description	Peak Water Surface Elevation (ft)	
		Upper and Lower Hoge Bowl	Widman Bowl
A	Existing Conditions	485.5	505.8
B	Development with lowest point of parking lot@ 490ft	485.5	505.8
C	Development with lowest point of parking lot@495.8 ft	485.5	505.8
D	Development with lowest point of parking lot@498 ft	485.5	505.8

Table 4-2 Results of Hoge Bowl Development Analysis during the 10-year Storm Event with 10 Year Ohio River Flood Impact

Scenario ID	Scenario Description	Peak Water Surface Elevation (ft)	
		Upper and Lower Hoge Bowl	Widman Bowl
A	Existing Conditions	496.9	507.0
B	Development with lowest point of parking lot@ 490 ft	497.7	507.0
C	Development with lowest point of parking lot@495.8 ft	498.7	507.0
D	Development with lowest point of parking lot@498 ft	498.9	507.1

Figure 4-1 Hoge Bowl Development Scenarios



5.0 RELIEF SEWER IMPROVEMENTS

The next step of the study was to analyze conceptual relief sewer alternatives for reducing flooding in the Widman and Delta areas. Based on upon discussion with MSDGC, several options were identified. Each of the proposed options includes the following components:

- The proposed residential development in the Hoge Bowl area.
- The 48" storm pipe placed under the development connecting the Upper and Lower Hoge Bowl areas.
- A diversion structure placed at the downstream end of the storm sewer to allow flow from the Lower Hoge Bowl to be diverted to the existing sewer via a new 36" connection when flow levels reach a higher level.
- Provisions to allow for excess flow from the Delta Bowl to pass in a controlled fashion to the Widman Bowl near the location of 544 Delta Ave.

The upstream relief sewer options identified and evaluated were as follows:

Option 1 – A 36" storm sewer conveying flows from Widman Bowl to the new 48" storm sewer
Option 2 - A 48" storm sewer conveying flows from Widman Bowl to the new 48" storm sewer
Option 3 - A 60" sewer conveying flows from Widman Bowl but directly connected to the existing sewer just downstream of the CSO 469A regulator

Figures 5-1 and **5-2** present a layout and key features for the three options. The inlet into the new sewer was assumed to be grated, with the opening area varied based on pipe capacity to minimize losses across the catch basin inlet grates.

The three options were then evaluated for the 10-yr 24-hr rainfall considering two outlet conditions: (1) no Ohio River flood impact and (2) with a 1-year Ohio River level. The current FEMA Flood Insurance Study for the Ohio River does not report a 1-yr water surface elevation. Therefore, the maximum river level of 480 ft recorded during the year 1970 (which is the "Typical Year" of rainfall) was used to represent a 1-yr Ohio River level.

Table 5-1 summarize the results of the analysis for each of the four Bowl areas. In all cases, the depth of surface storage was reduced in the Delta and Widman Bowl areas. With the transfer of flow from the three upper areas to the lower areas, the depth of surface storage in the lower Hoge Bowl increases for all options under the two storm conditions analyzed. However, for these storm conditions, the depth of storage in the Lower Hoge bowl is below the proposed new development parking lot elevation when the Ohio River flood level is not impacting the sewer levels. During the 10-year rainfall event with a 1-year Ohio River level, the parking area and a residential structure is predicted to be impacted with the upstream sewer improvements. For this reason, additional improvements may be needed to address this condition.

Table 5-1 Results of Relief Sewer Options

Delta Ave. Bowl				
Scenario	**Peak Elevation (ft)**		**Change in Depth (ft)**	
	10-yr Rainfall	**10-yr Rainfall, 1-yr Ohio River**	**10-yr Rainfall**	**10-yr Rainfall, 1-yr Ohio River**
Existing Conditions	517.0	517.6	-	-
Option 1 (36" Relief)	516.3	516.6	(0.7)	(1.0)
Option 2 (48" Relief)	516.3	516.6	(0.7)	(1.0)
Option 3 (60” Relief)	516.4	516.6	(0.6)	(1.0)
Note: Delta Ave. Bowl curb cut invert is at 515.18 ft.				

Widman Bowl				
Scenario	**Peak Elevation (ft)**		**Change in Depth (ft)**	
	10-yr Rainfall	**10-yr Rainfall, 1-yr Ohio River**	**10-yr Rainfall**	**10-yr Rainfall, 1-yr Ohio River**
Existing Conditions	505.8	507.4	-	-
Option 1 (36" Relief)	504.5	507.2	(1.3)	(0.2)
Option 2 (48" Relief)	503.3	506.8	(2.4)	(0.5)
Option 3 (60” Relief)	501.8	506.6	(4.0)	(0.7)
Note: Widman Bowl invert is at 498 ft.				

Upper Hoge Bowl				
Scenario	**Peak Elevation (ft)**		**Change in Depth (ft)**	
	10-yr Rainfall	**10-yr Rainfall, 1-yr Ohio River**	**10-yr Rainfall**	**10-yr Rainfall, 1-yr Ohio River**
Existing Conditions	485.5	495.8	-	-
Option 1 (36" Relief)	491.4	498.6	5.9	2.8
Option 2 (48" Relief)	491.8	499.6	6.4	3.8
Option 3 (60” Relief)	491.5	498.8	6.1	3.0
Note: Upper Hoge Bowl invert is at 491 ft.				

Lower Hoge Bowl				
Scenario	**Peak Elevation (ft)**		**Change in Depth (ft)**	
	10-yr Rainfall	**10-yr Rainfall, 1-yr Ohio River**	**10-yr Rainfall**	**10-yr Rainfall, 1-yr Ohio River**
Existing Conditions	485.5	495.8	-	-
Option 1 (36" Relief)	490.3	497.8	4.9	2.0
Option 2 (48" Relief)	491.8	499.1	6.3	3.3
Option 3 (60” Relief)	487.6	497.0	2.2	1.2
Note: Lower Hoge Bowl invert is at 484 ft.				

The options were also run for the Typical Year sequence of storms to determine the impact of the proposed improvement on Remaining Overflow Volume (ROV) from the combined sewer outfall. **Table 5-2** summarizes the overflow impacts. The results were based on the SWMM detailed model output, which tabulates volume based on the calculation timestep. The model used for this analysis was the "Little_Miami_2015_UDAB_CurrentConditions_update_042617" provided June 1, 2017. The relief sewer options have a nominal impact on overflow volumes, increasing overflow volume by less than 1 MG for Option 3.

Table 5-2 Typical Year Remaining Overflow Volume Summary

Scenario	1970 Remaining Overflow Volume (MG/yr)
Existing Conditions (with Storage Basins)	171.0
Option 1 - 36" Relief Sewer	171.3
Option 2 - 48" Relief Sewer	171.3
Option 3 – 60" Relief Sewer	171.7

Figure 5-1 – Relief Sewer Options 1 and 2

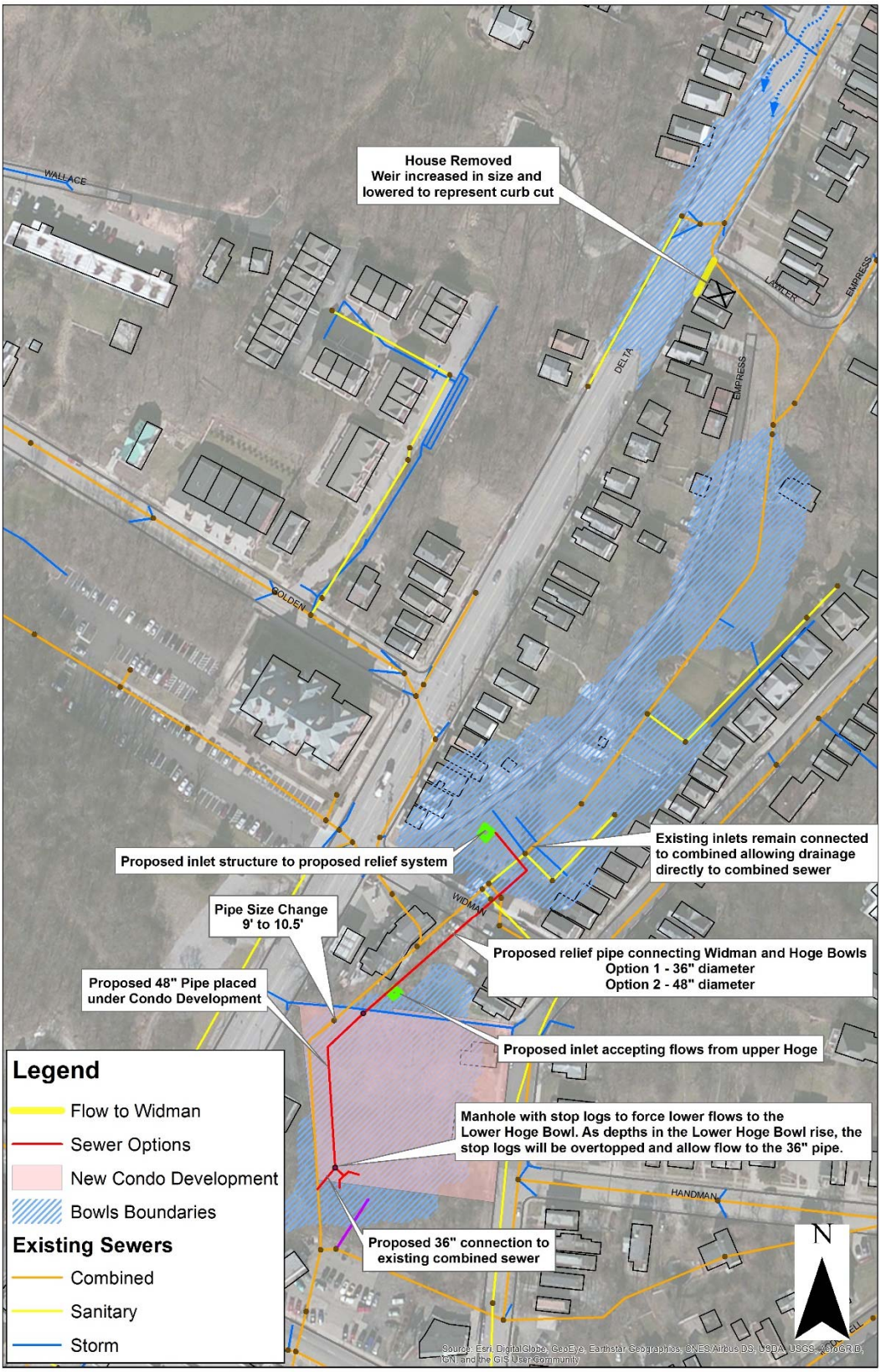
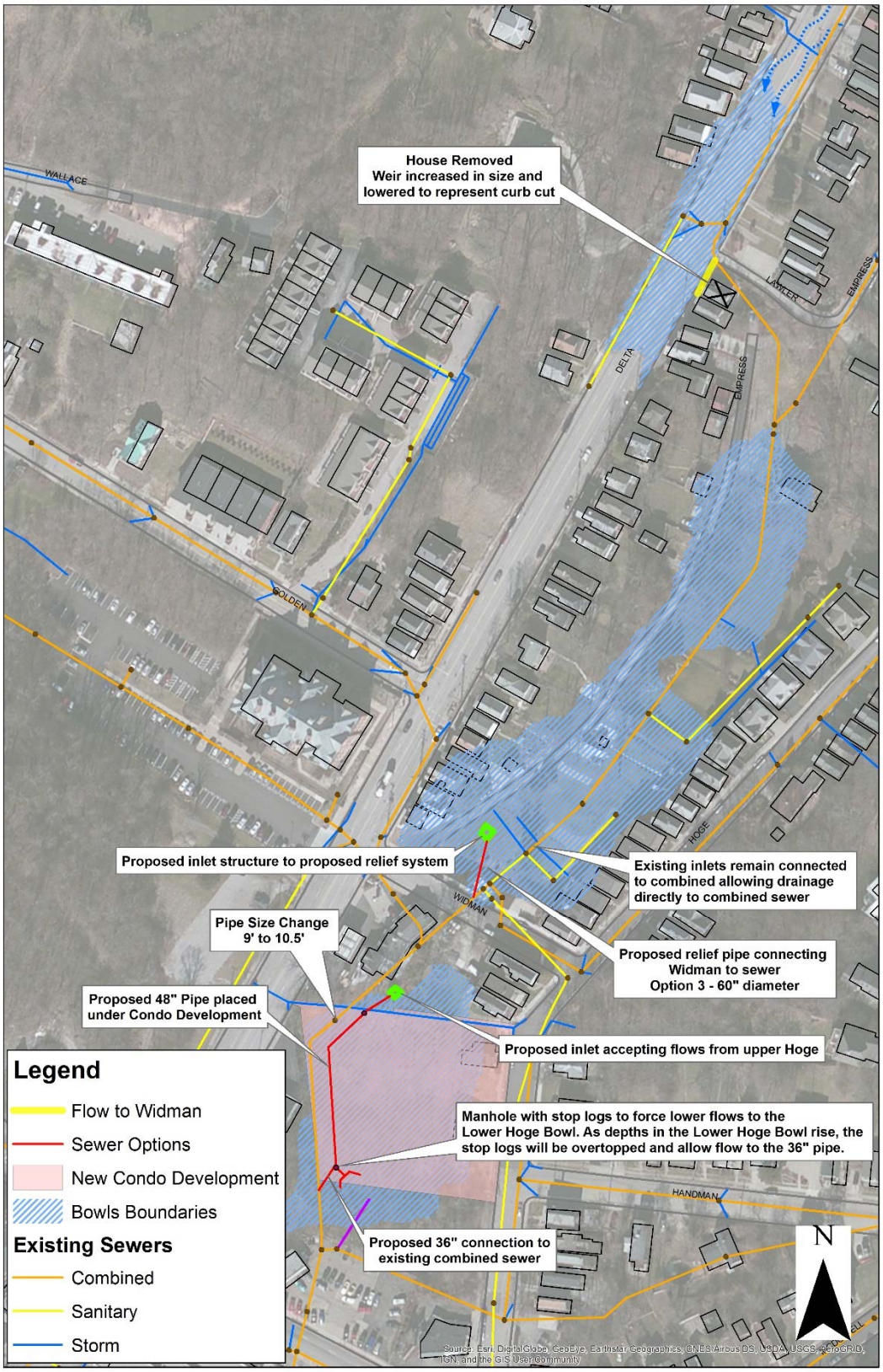


Figure 5-2 – Relief Sewer Option 3



6.0 CONCLUSIONS

Recent flooding in the project area is a result of significant rainfall in combination with limited sewer capacity. The proposed development within the Hoge Bowl is expected to have minimal impact on water surface elevations for the 10-year rainfall event under normal Ohio River levels. The proposed relief sewer options result in a reduction of flood levels in the Widman and Delta Bowls, but result in an increase in flood depths in the Hoge Bowls. Additional refinement of the hydrologic and hydraulic model should be conducted using monitored flow data and surveyed information of key surface features. Additional alternative analysis should then be conducted with the refined model prior to beginning design of upstream improvements. The analysis should determine if additional flood protection measures or home buy outs are required as part of the improvements.

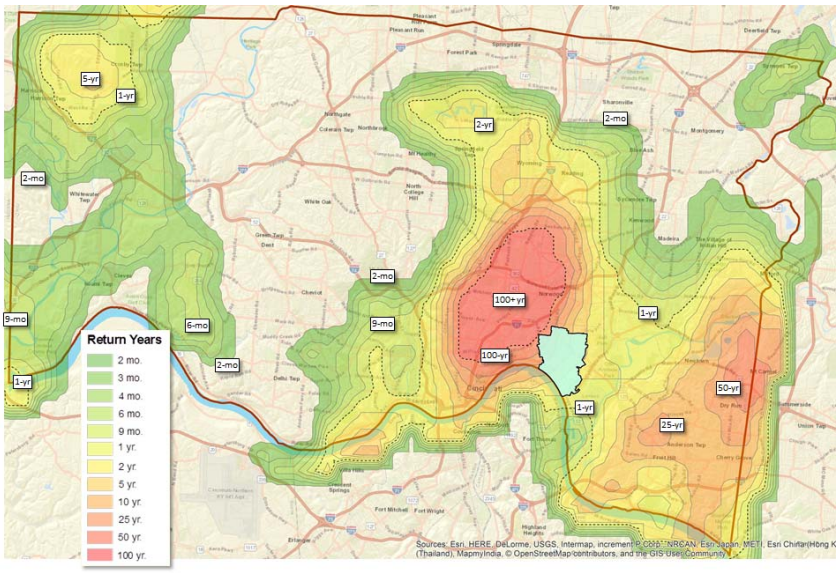
Appendix A

Eastern Delta – Development Analysis

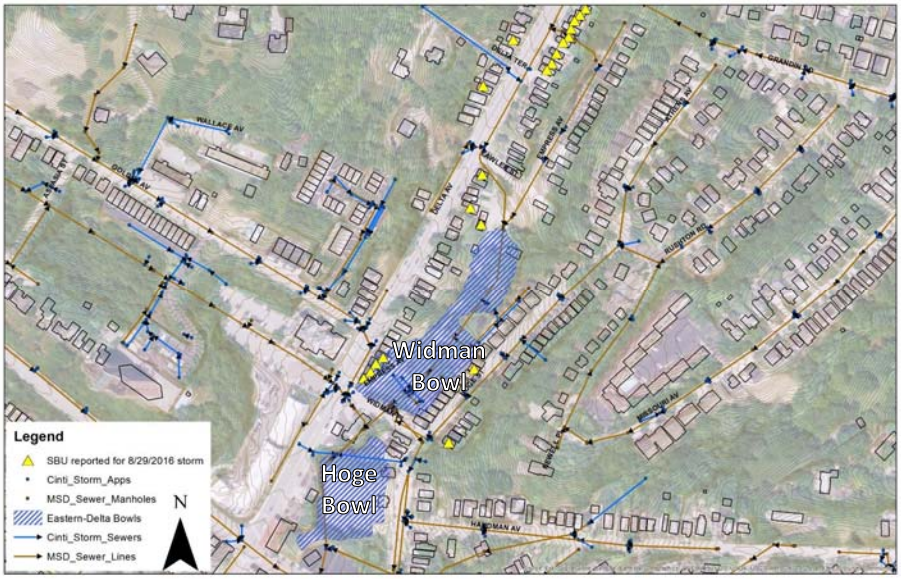
Draft – 6/16/2017

Flooding on Delta

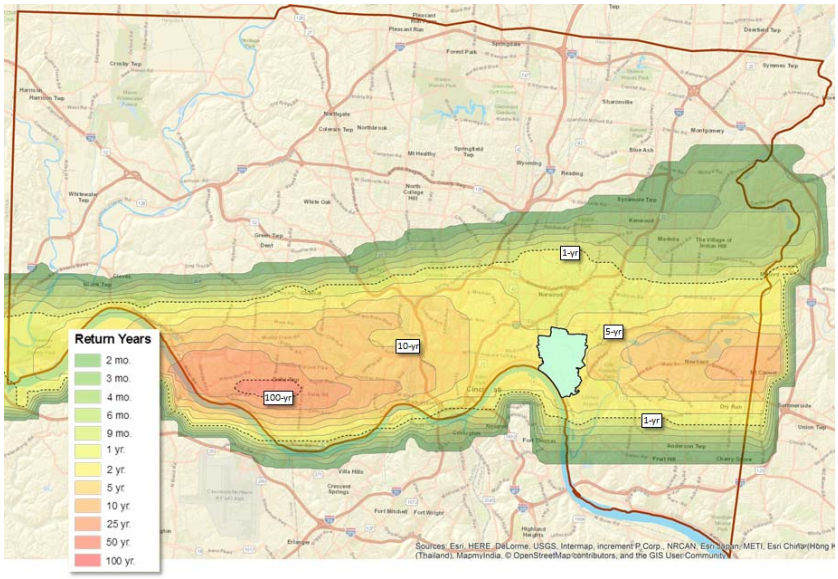
August 28th, 2016 Storm



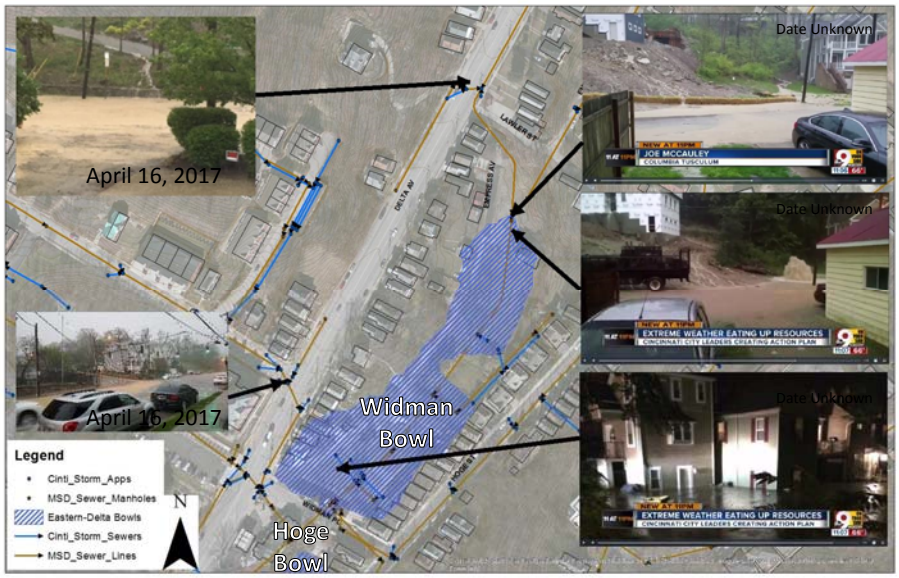
Flooding Complaint Map - August 29, 2016



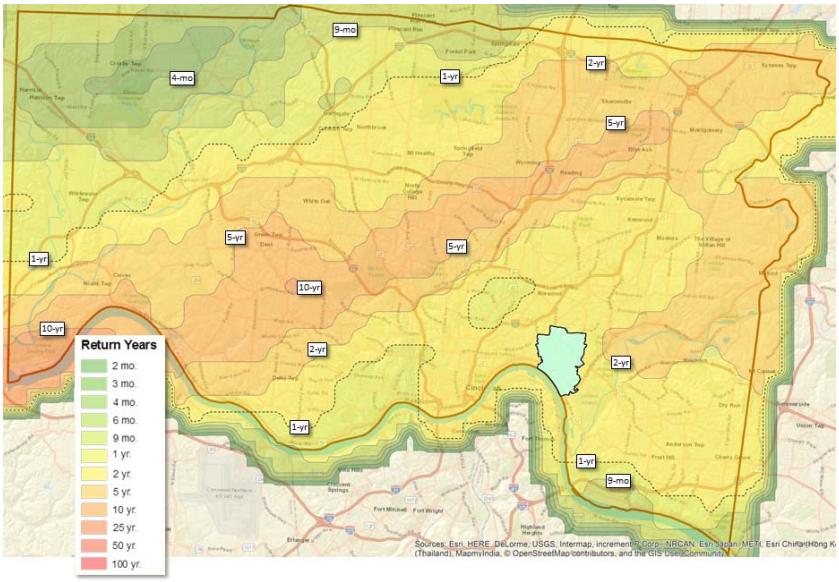
April 16th, 2016 Storm



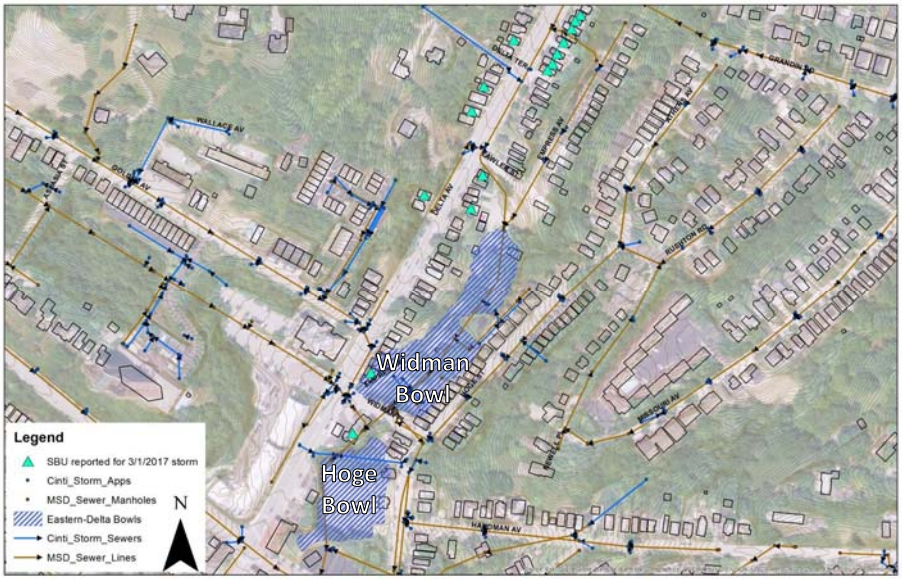
Widman Bowl Map



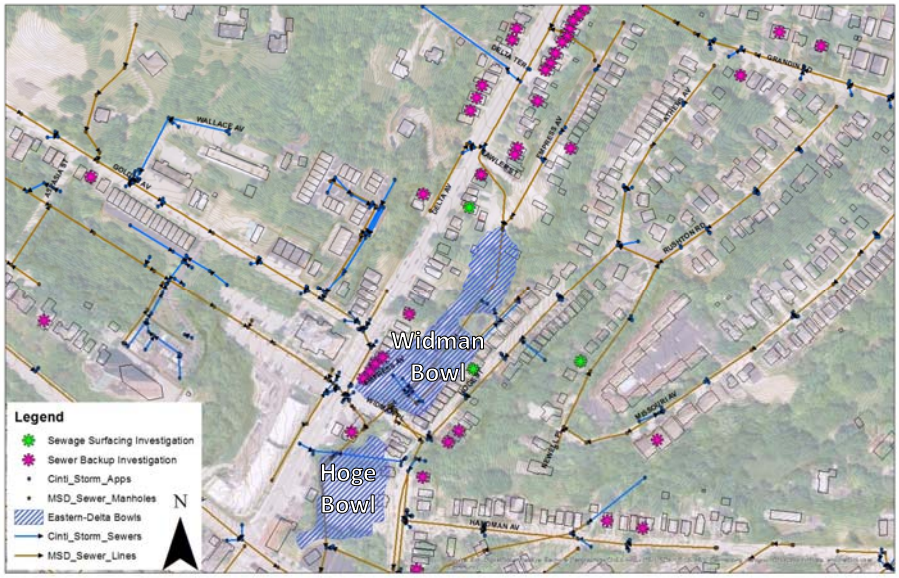
March 1st, 2017 Storm



Flooding Complaint Map - March 1, 2017

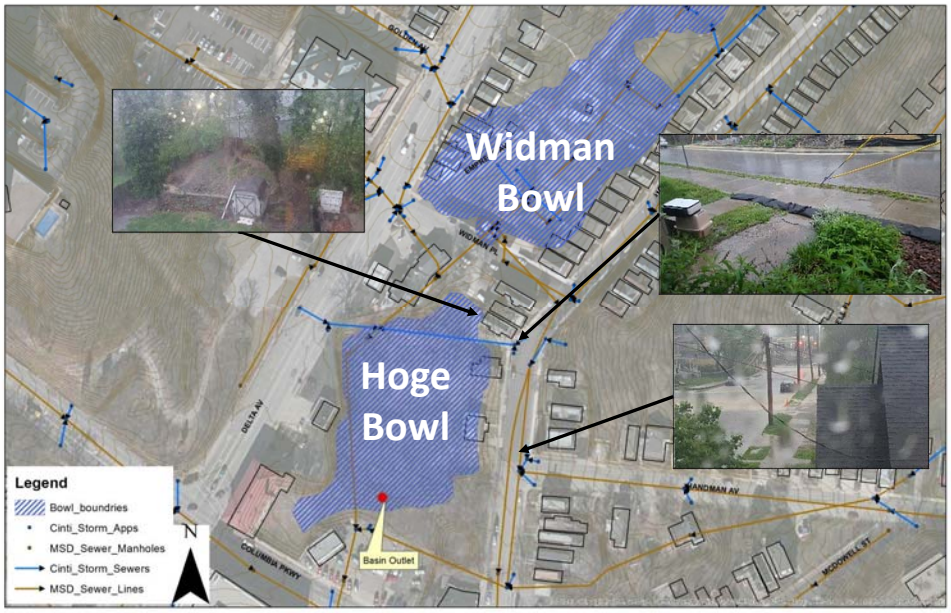


Widman Flooding Area (GIS Complaint Layer)



Hoge Bowl Analysis

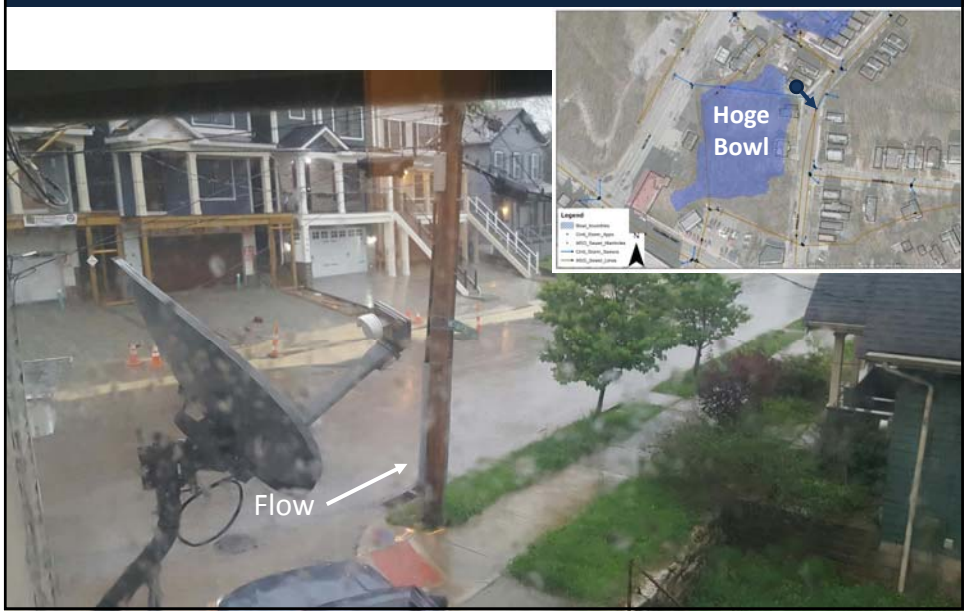
Hoge Bowl Map



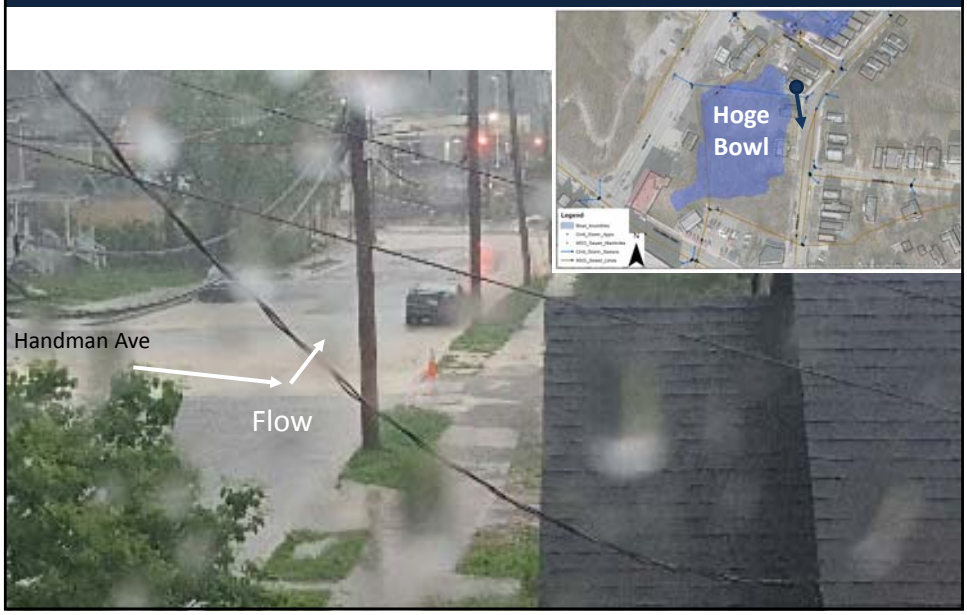
Hoge Bowl Map – 4/16/2017

Hoge Bowl Map – 4/16/2017

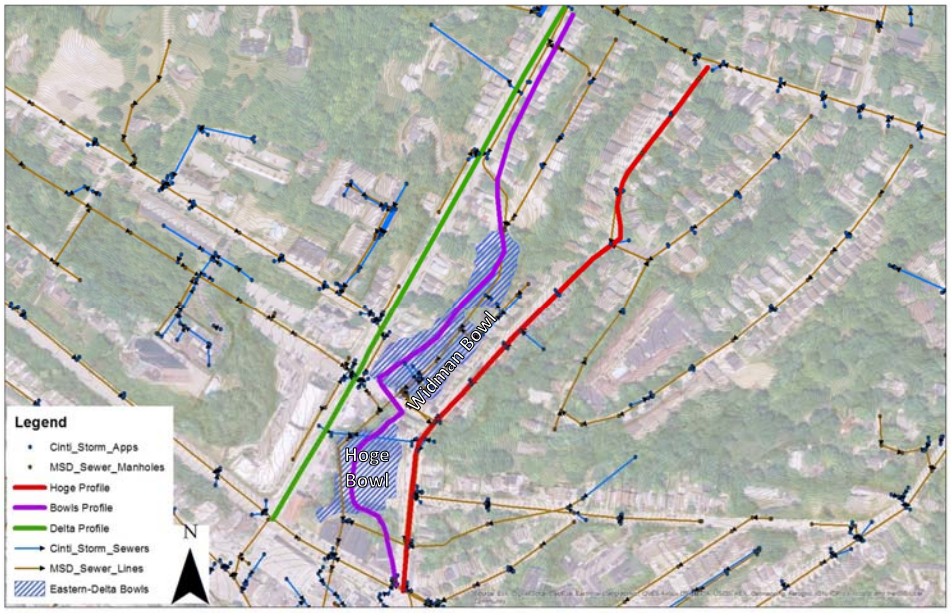
Hoge Bowl Map – 4/16/2017



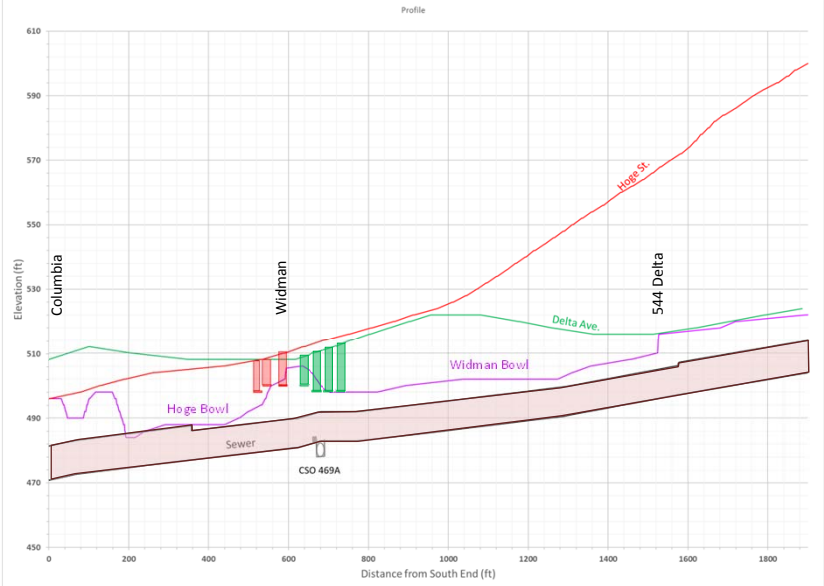
Hoge Bowl Map – 4/16/2017



Study Area Profiles - Locations

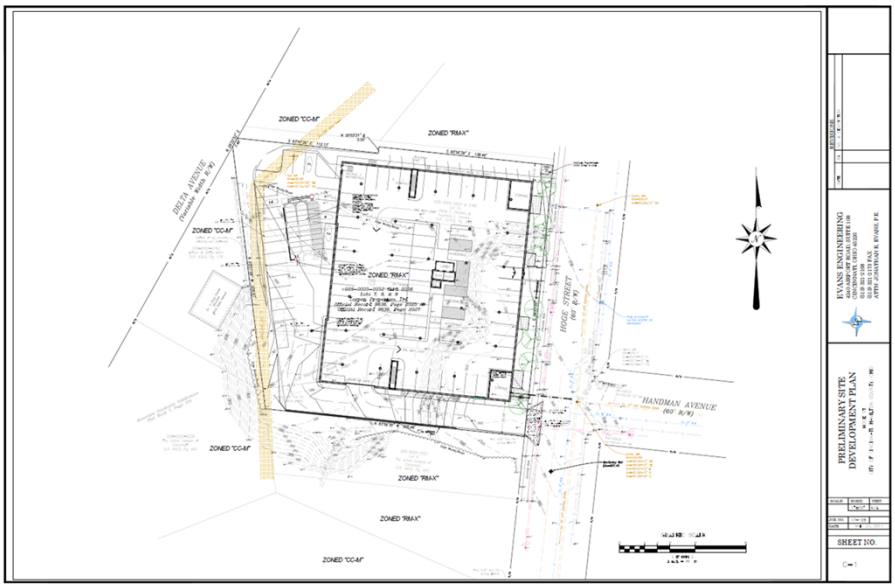


Study Area Profiles

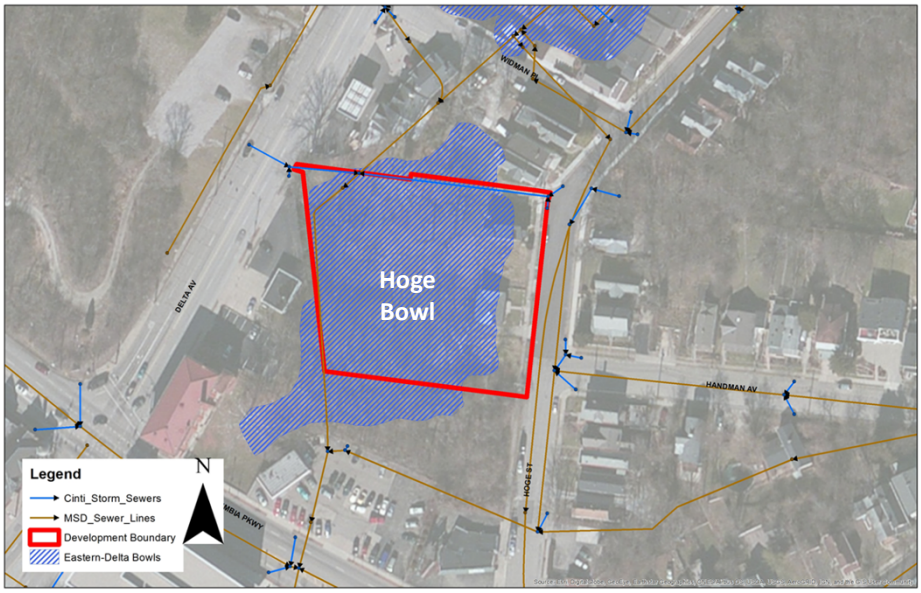


Proposed Development

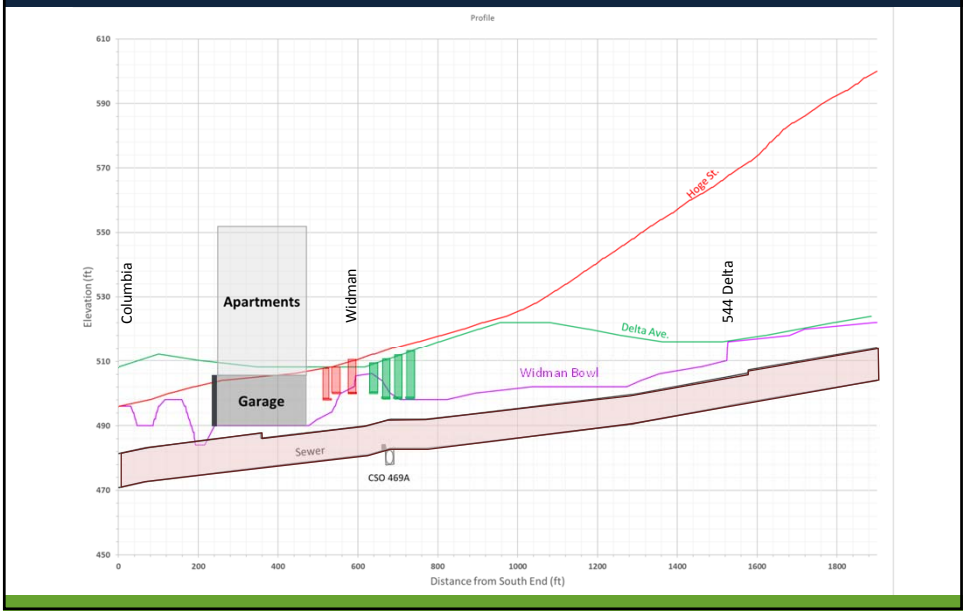
Proposed Development



Proposed Development

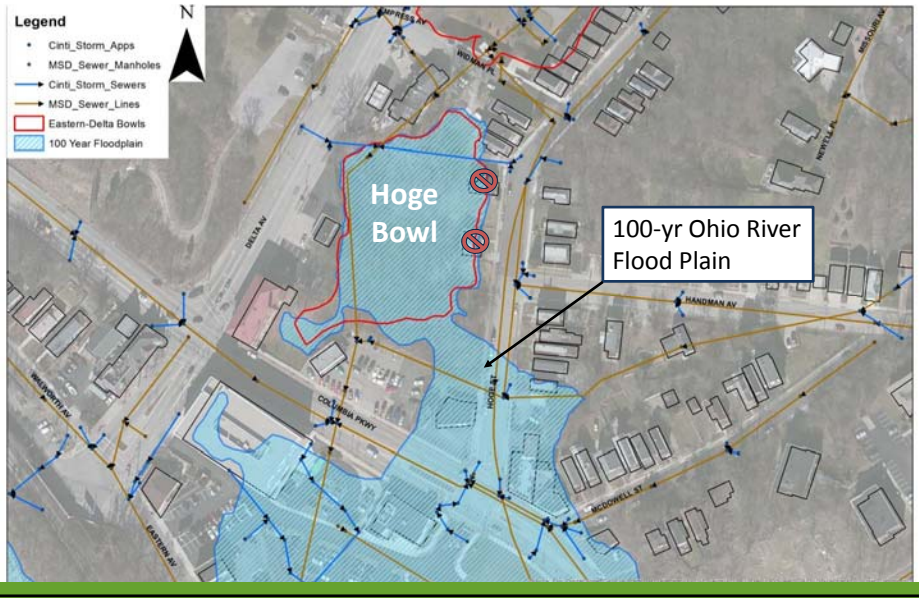


Study Area Profiles

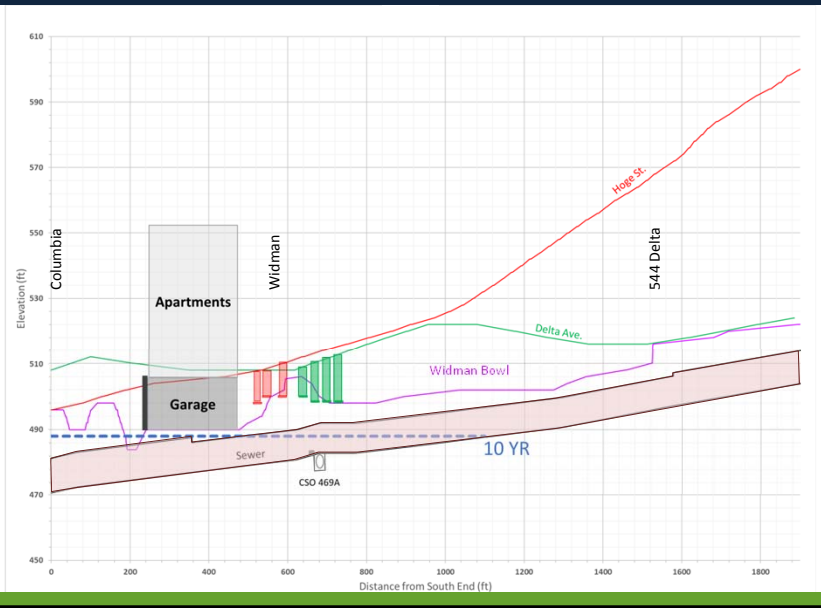


Impact of Development

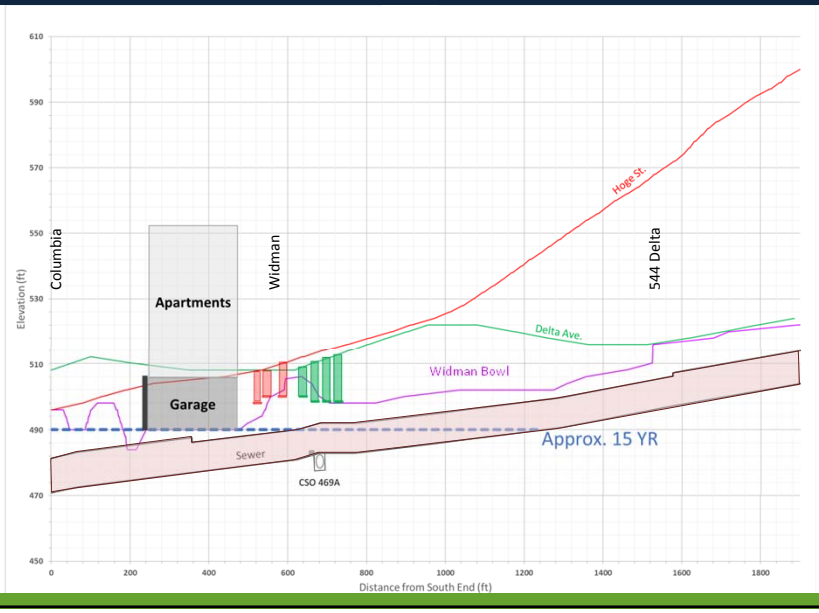
Ohio River 100-Year Floodplain



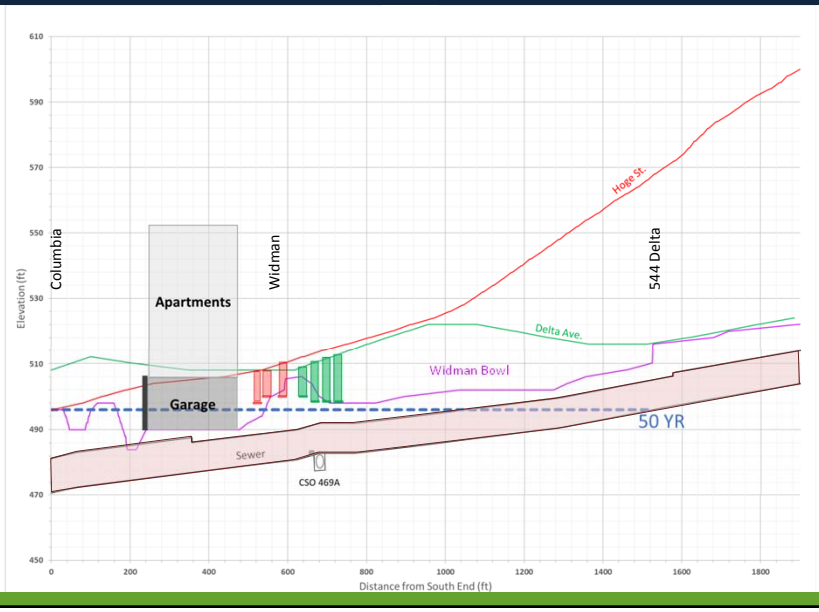
Ohio River 10yr Flood Profile – With Development



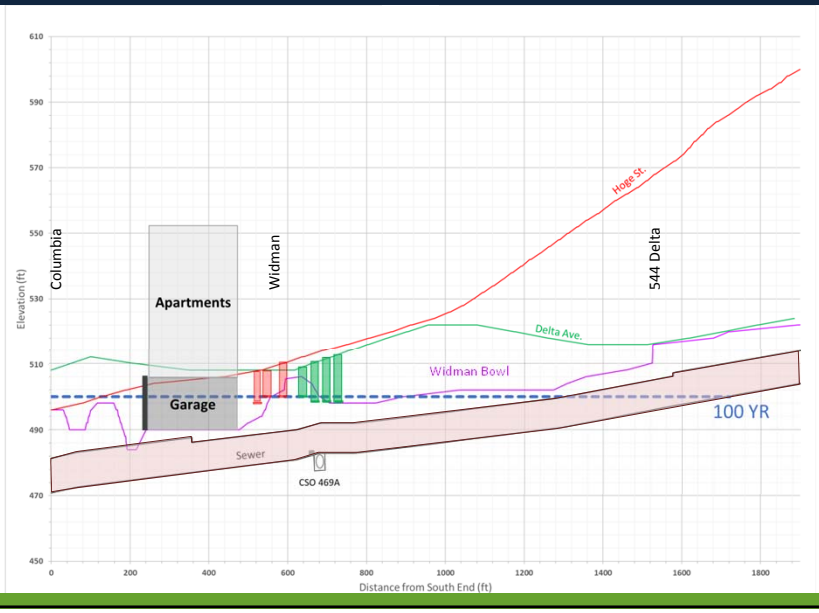
Ohio River 15yr Flood Profile – With Development



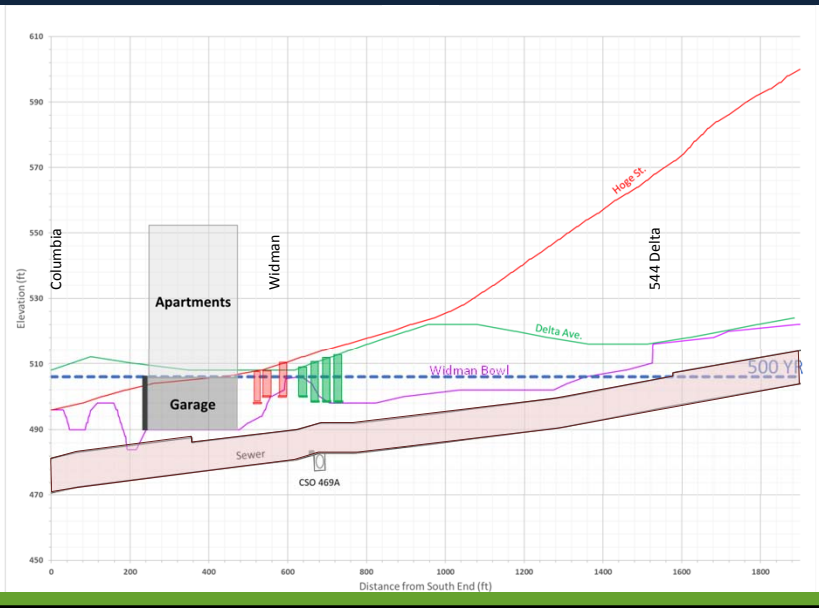
Ohio River 50yr Flood Profile – With Development



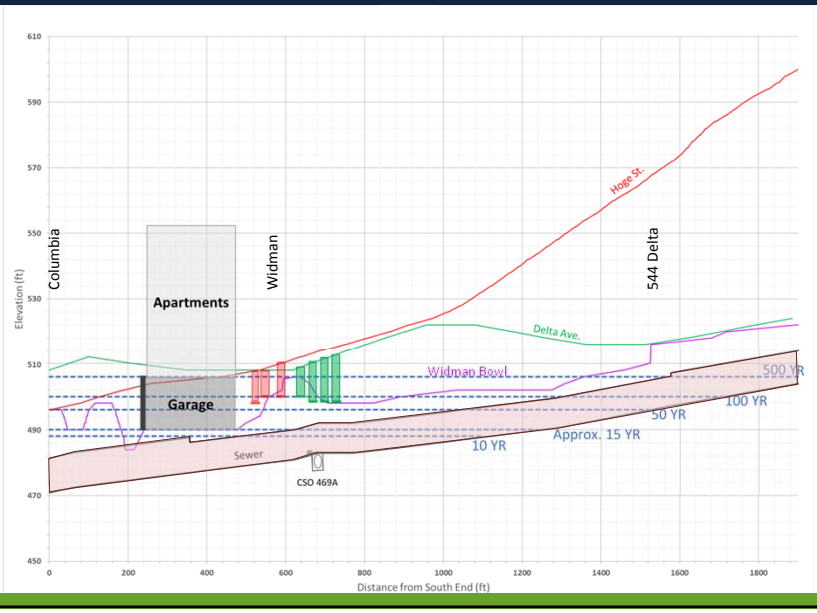
Ohio River 100yr Flood Profile – With Development



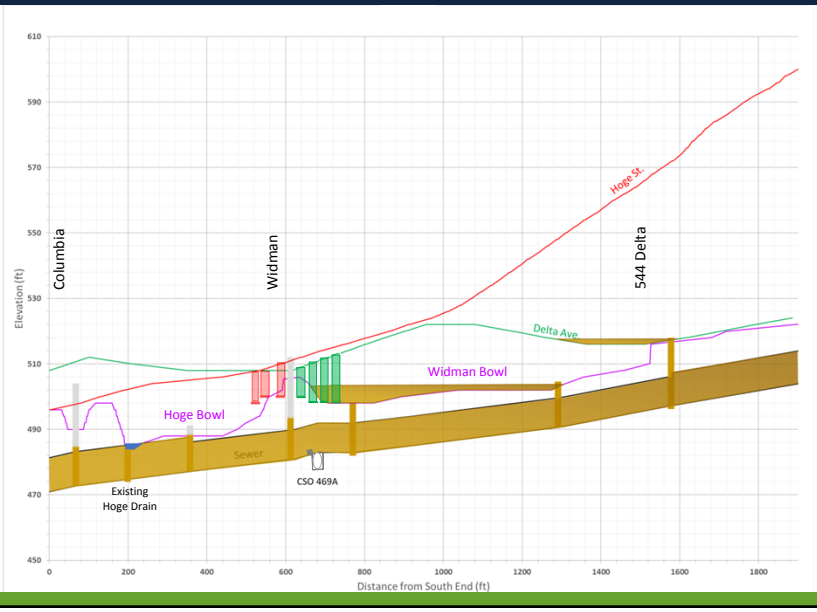
Ohio River 500yr Flood Profile – With Development



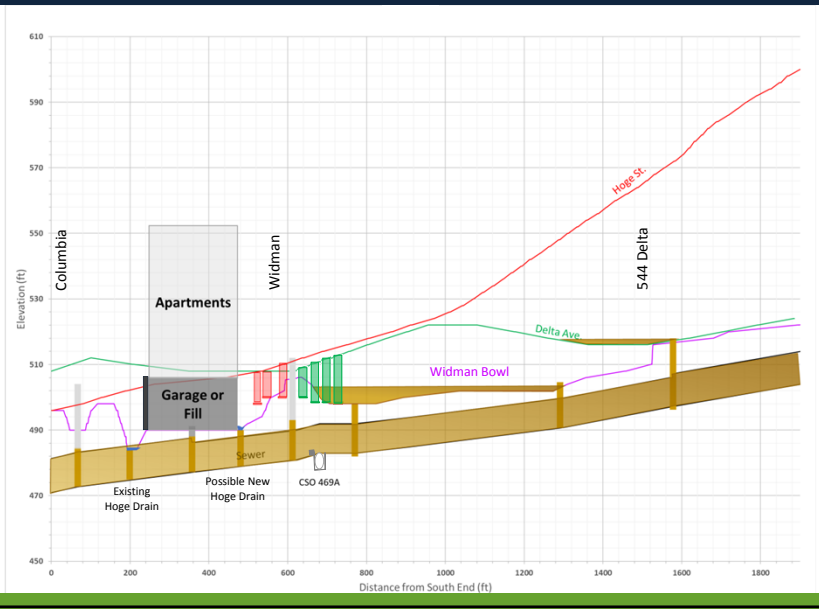
Ohio River Flood Profiles – With Development



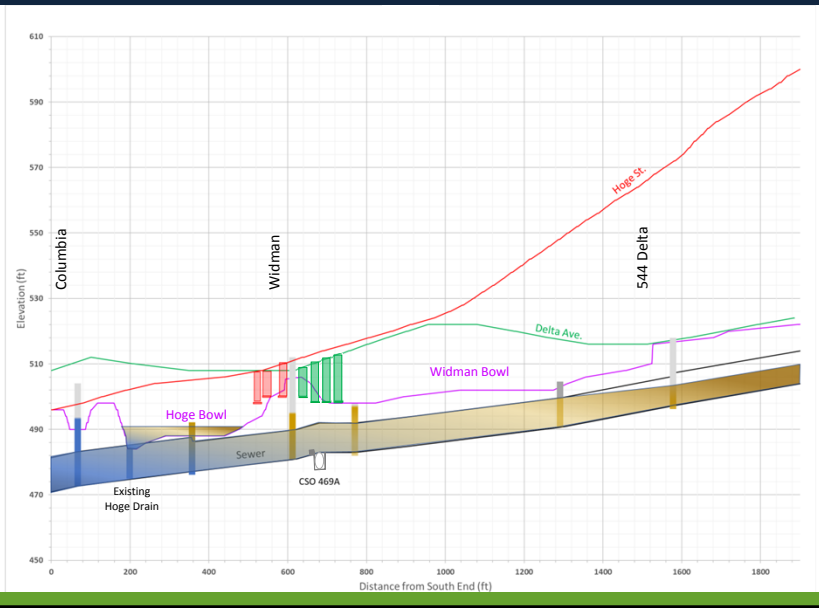
Existing Flood Profiles – 10 yr Storm



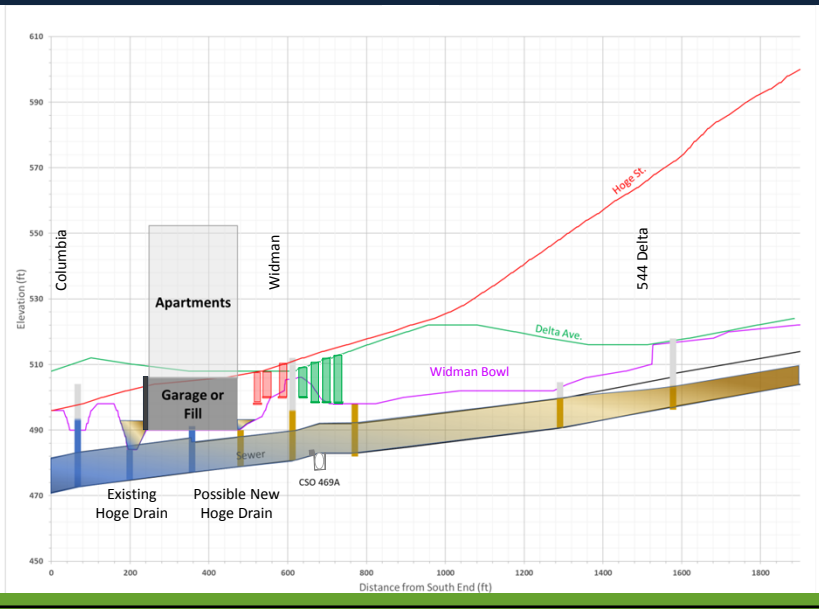
Flood Profiles with Development –10yr Storm



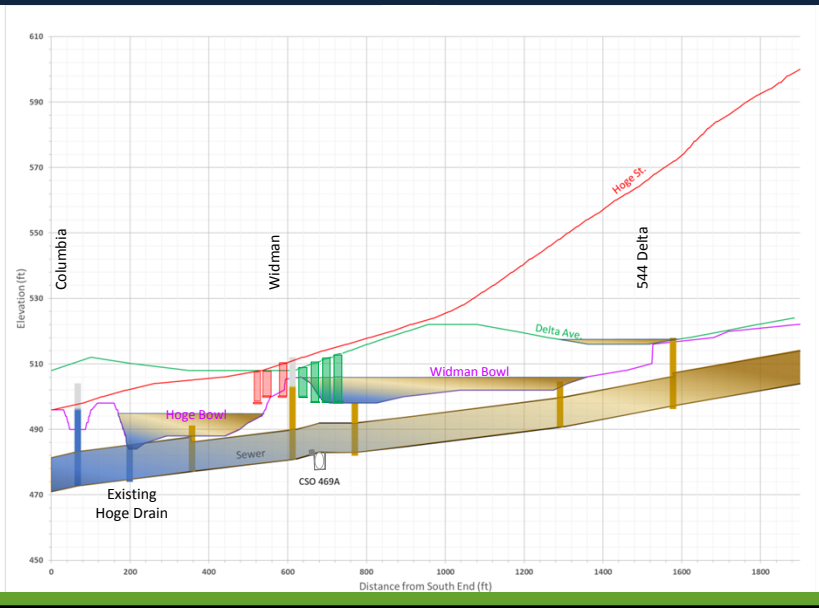
Existing Flood Profiles – 1yr Storm, 10yr Ohio



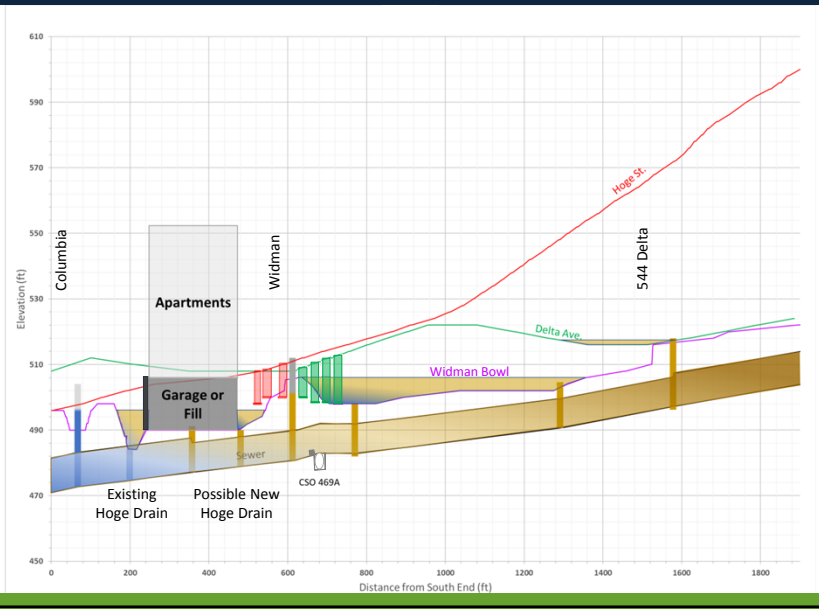
Flood Profiles with Development – 1yr Storm, 10yr Ohio



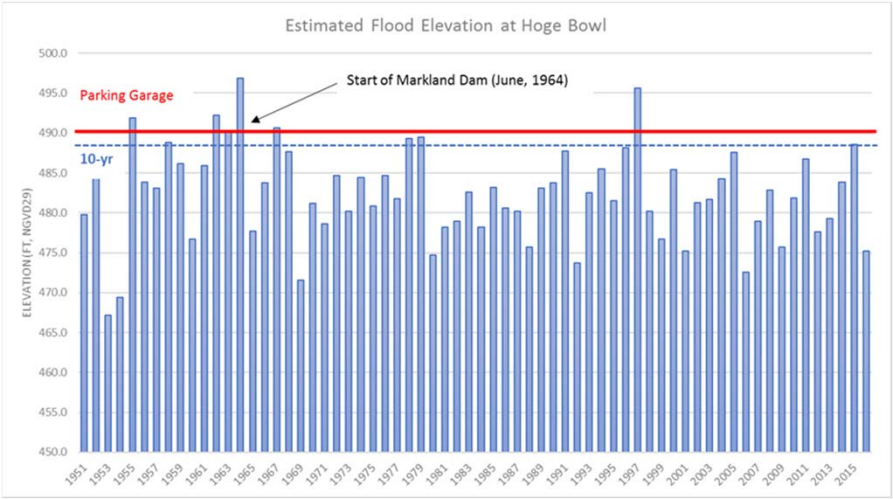
Existing Flood Profiles – 10yr Storm, 10yr Ohio



Flood Profiles with Development – 10yr Storm, 10yr Ohio



Ohio River Stage At Delta Ave.

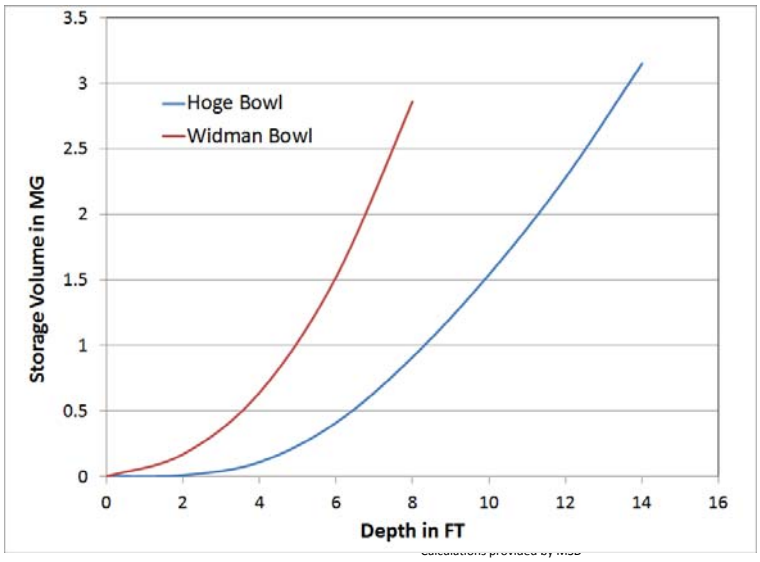


Conclusions

- Development present, some risk to adjacent properties
- Garage parking area will flood with sewage as proposed

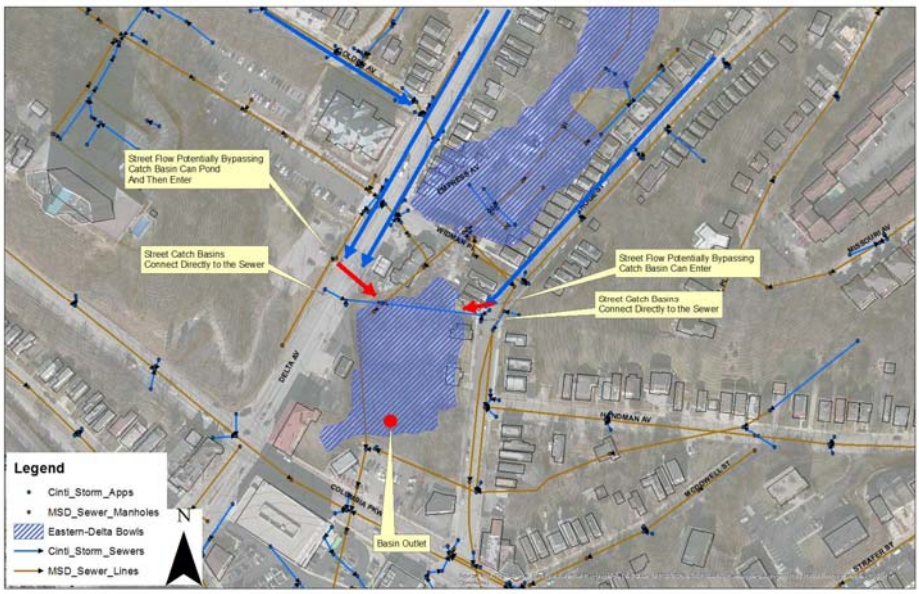
Option to Buy

Existing Storage



Calculations provided by MSD

Hoge Bowl Overview

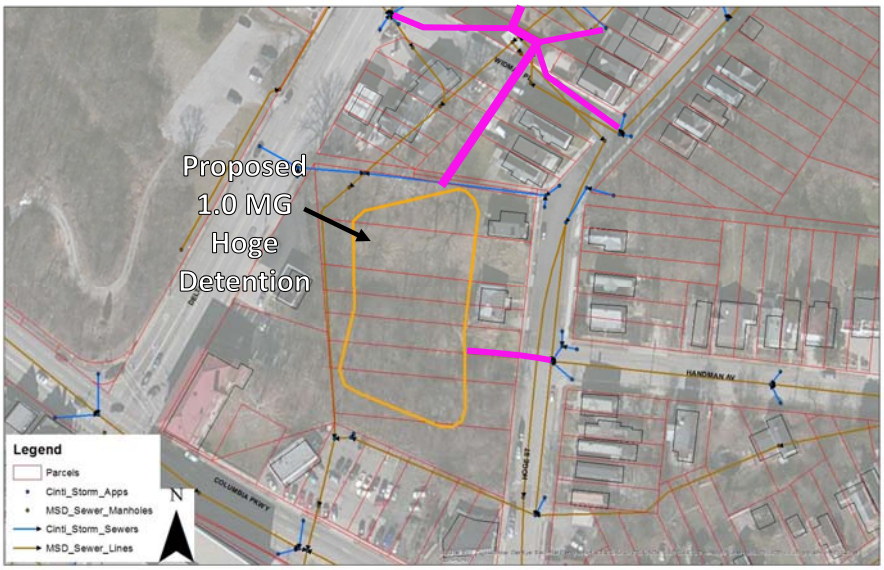


Hoge Bowl Overland Flow Paths

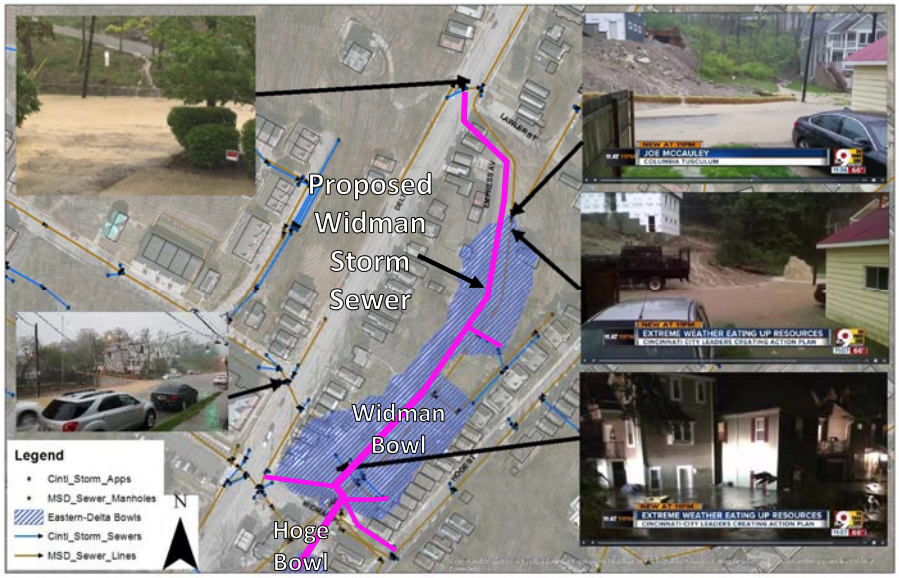
Potential Street Flow from Delta Ave.

Potential Street Flow from Hoge St.

Possible Construction



Widman Storm Sewer



Description of Improvement

- 1.0 MG Detention Pond
- 1,600 LF of 15”-36” storm sewer

Cost of Improvement

- Estimate of $5.00 per gallon of storage

Costs provided by MSD

Cost Per ROV Reduction

- Estimated 5 MG of ROV reduction
- $1.00 per gallon ROV removed

Calculations provided by MSD