Berwyn Heights
Drainage Study Report

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1 Project Description

The following section provides the premise for the project and the goals and objectives addressed throughout the course of the project. later sections provide details on the methods, results, and recommendations offered by WBCM to the County in developing a strategy for reducing roadway flooding in the Berwyn Heights area.

1.1 Background

Berwyn Heights experienced flooding from the storm on June 10, 2014. The storm was approximately 4.7 inches of rainfall in a 90 minutes interval. WBCM had previously been contracted with Prince George's County Department of Public Works and Transportation (DPW&T) to visually analyze (site visits and video inspection), the existing drainage systems within the town through minor topographic survey, and analytically through preliminary hydrologic and hydraulic modelling. Hydrologic analysis was completed for existing conditions for the 10-, 25-, and 100-year events using Rational Methodology for closed systems, and TR-55/, TR-20 for open systems.

WBCM completed preliminary hydraulic gradient analysis of the storm drain for the 10-year storm event in accordance with Prince George's County Stormwater Management Design Manual, July 2014 (Chapter 8: Storm Drain Design Criteria). Hydraulic analysis was completed using FlowMaster, HY-8, and CulvertMaster and WBCM made recommendations to improve drainage throughout the town that included: increasing storm drain sizes, rehabilitating pipes, constructing new alignments, and building new inlets and manholes to meet current County criteria. WBCM also identified and mapped chronic flooding areas and properties. WBCM provided cost estimates to Prince George's County DPW&T, with the total construction cost at around $10 million.

1.2 Project Objectives & Methodology

The County requested WBCM to further study Berwyn Heights for ways to reduce costs through a combination of quantitative (peak reduction), Low Impact Development (LID) stormwater management and storm drainage improvements. Based on the ineffectiveness of LID techniques to address storm events of the magnitude related to the reported flooding, LID techniques were removed from consideration. Quantitative techniques were limited to the in-line storage benefits of increased pipe sizes, as there is no open space that could be used for effective detention. WBCM developed models using the US Environmental Protection Agency Stormwater Management Model (USEPA SWMM) to size stormwater collection and conveyance features for peak discharge reduction by routing of storm flows through the network, including modeling flows along the roadway surfaces. WBCM evaluated potential stormwater solutions for overland flood protection volume for the 10-year storm event with the intent to reduce the cost of storm drain replacement alone.

1.3 Project Area Descriptions

The Berwyn Heights area is comprised of 2 major drainage systems and 7 minor systems, as shown in the map below (*Figure 1*). *Figure 1* also shows the existing impervious surfaces and the ownership class of each, to aid in identifying the beneficiaries of the identified improvements, and to help with eventual cost-sharing arrangements. Maps of each drainage system and the areas of greatest concern, along with street-level photographs of the main points of analysis, are provided in Appendix A.

Figure 1: Berwyn Heights Drainage System

2 Methods, Tactics and Results

The methodology applied to the areas of concern in each storm drain system was primarily a sensitivity analysis of increased inlet collection and/or pipe conveyance capacity. Models were run to see the improvements that could be expected when each tactic was made independently, and when the tactics were combined. In limited cases adding an additional outfall to the drainage system was checked. A detailed discussion on the methods applied to each drainage system is provided in Appendix B.

3 Modeling Results

The results of the modeling (located in Appendix C) give the County the insight needed to determine where the most effective system improvements (i.e. Increased pipe sizes and added inlets) are located, and the general degree to which they need to be implemented. The results focus on reduced roadway flows, which are the flows that cannot be conveyed through the closed pipe system, either due to limited pipe or inlet capacity, and are the source of flooding. The results in Appendix C are grouped by Area of Concern and ordered by length of roadway flow segment to help quantity the extent of the improvement.

4 Findings & Recommendations

This section provides a summary of the recommended system improvement for the County to consider, as well as the tactics that were found to be ineffective and should be removed from further consideration. The results in Appendix C can guide the County in determining specific inlet and pipe improvements to make in the future and funding becomes available.

4.1 System 2

The number of roadway segments with high surface flows was limited (approx. 6), allowing for a vert prescriptive approach – wide-spread upgrades would not be needed. Therefore, from a hydraulic perspective, it was determined the following tactics would be most effective:

1. Increasing the number of inlets in the upper portions of the drainage system.
2. Increasing pipe diameters along the mainline of the system (Osage St).

From a cost of implementation perspective, the following tactics are recommended:

1. Increase the inlet capacity of the upper drainage system portions by increasing the length of the existing inlets at the roadway segments with the highest flows. The receiving pipes have the capacity to convey more runoff if collected.
    - Design costs will be reduced
    - Roadway and utility impacts will be avoided
    - There will be less disruption to traffic and the buried utilities
2. Use non-structural, programmatic tactics in critical locations:
    - Place “NO PARKING” signage at the sump locations where water does not have a bypass route and runs the risk of reaching depths that can damage vehicles and adjacent homeowner property
    - Schedule inlet cleanouts (grates & sumps, not the pipeline) in the fall, prior to forecasted large rainfall events, and to avoid clogging and allow the drainage system to work at its full potential more regularly.

Other tactics that should be ruled out are:

- Removal of impervious surfaces: The most plentiful type of impervious to remove is sidewalk, but they are essential and minimal (i.e. not on both sides of the road).
- Using Low Impact Development techniques: these tactics are meant to address small rainfall events (0.1 to 1.0 inches) and would have little to no impact on reducing flooding from typical flooding events (2- and 10-year) which represent rainfalls of 3 to 5 inches. They also are not capable of treating a large drainage area, further reducing any potential peak discharge rate reductions they may be capable of.
- Adding an additional outfall: while this had some hydraulic benefits, the potential cost and level of disruption to the community would excessive.

4.2 System 3

The number of roadway segments with high surface flows was more extensive than System 2 (over 30) and was found to be wide-spread upgrades would be needed. Therefore, from a hydraulic perspective, it was determined the following tactics would be most effective:

1. Increasing the number of inlets and increasing pipe diameters; increasing inlet capacity without increasing the receiving conveyance capacity had limited improvements and can also lead to transferring flooding from one area to another due to backflow.

From a cost of implementation perspective, the following tactics are recommended:

1. Selectively increase the pipe and inlet capacity of the portions identified in Appendix C with a combination of the highest flow reduction and length of flooding. Take special note of the roadway segment in the Appendix C results that showed an increased in flooding when only the inlets were increased in size – these are the areas subject to backflow impacts if the receiving pipe capacity is not increased prior to inlet size increases
    - Design costs will be controlled
    - Transferring flooding problems from one area to another will be avoided
2. Use non-structural, programmatic tactics in critical locations:
    - Place “NO PARKING” signage at the sump locations where water does not have a bypass route and runs the risk of reaching depths that can damage vehicles and adjacent homeowner property

- Schedule inlet cleanouts (grates & sumps, not the pipeline) in the fall and to avoid clogging and allow the drainage system to work at its full potential more regularly.

Other tactics that should be ruled out are:

- Removal of impervious surfaces: this area did not have areas that would be appropriate to remove. The school and commercial areas have the most impervious areas to reduce (theoretically). But from a practical perspective, both areas serve a very specific purpose and require rooftop and parking areas to do so. It would be cost-prohibitive to reduce peak discharge rates through the use of rooftop (e.g., cistern) or parking (e.g., underground) area storage features.
- Using Low Impact Development Techniques: these tactics are meant to address small rainfall events (0.1 to 1.0 inches) and would have little to no impact on reducing flooding from the more common events (2- and 10-year) which represent rainfalls of 3 to 5 inches. They also are not capable of treating a large drainage area, further reducing any potential peak discharge rate reductions they may be capable of.

4.3 Minor Systems

From a hydraulic perspective, it was determined the following tactics would be most effective:

1. Increasing pipe capacity for Systems 4 & 5
2. Increasing inlet capacity for Systems 1, 7, 8 & 10.

From a cost of implementation perspective, the following tactics are recommended:

1. Increasing pipe capacity for System 4.
2. Increasing inlet capacity for Systems 1 & 10.

Other tactics that should be ruled out are listed below:

- Improvements to systems 5, 6, 7, & 8 due to their limited size and limited benefits to be received. Systems 5, 7 & 8 had a very limited lengths of roadway flow; and System 6 had very little roadway flow (<0.2 cfs).
- Removal of impervious surfaces: The most plentiful type of impervious to remove is sidewalk, but they are essential and minimal (i.e. not on both sides of the road).
- Using Low Impact Development techniques: these tactics are meant to address small rainfall events (0.1 to 1.0 inches) and would have little to no impact on reducing flooding from typical flooding events (2- and 10-year) which represent rainfalls of 3 to 5 inches. They also are not capable of treating a large drainage area, further reducing any potential peak discharge rate reductions they may be capable of.

Appendix A: Project Area Descriptions

System 2

Berwyn Heights System 2 (*Figure 2*) consists of an area of approximately 94 acres with the a main pipeline running east to west along Osage St, extending to the north along 57th Ave to Quebec St, and to the south along Berwyn Rd, ultimately outfalling to Indian Creek to the west. Nine major problem areas were identified – these were locations, usually at intersections, determined to have the greatest concentrated roadway flow.

- Area #1: Berwyn Rd and Cunningham Dr.
- Area #2: Berwyn Rd and 58th Ave
- Area #3: Osage St and 60th Ave
- Area #4: Osage St and Natasha Dr
- Area #5: Pontiac St and 57th Ave/Quebec St
- Area #6: Quebec St and 58th Ave
- Area #7: Berwyn Rd and 57th Ave
- Area #8: Cunningham Dr and Osage St (Sump area)
- Area #9: 58th Ave (Sump area)

Figure 2: Outline of System 2 illustrating intersections of concern with pipe network (blue)

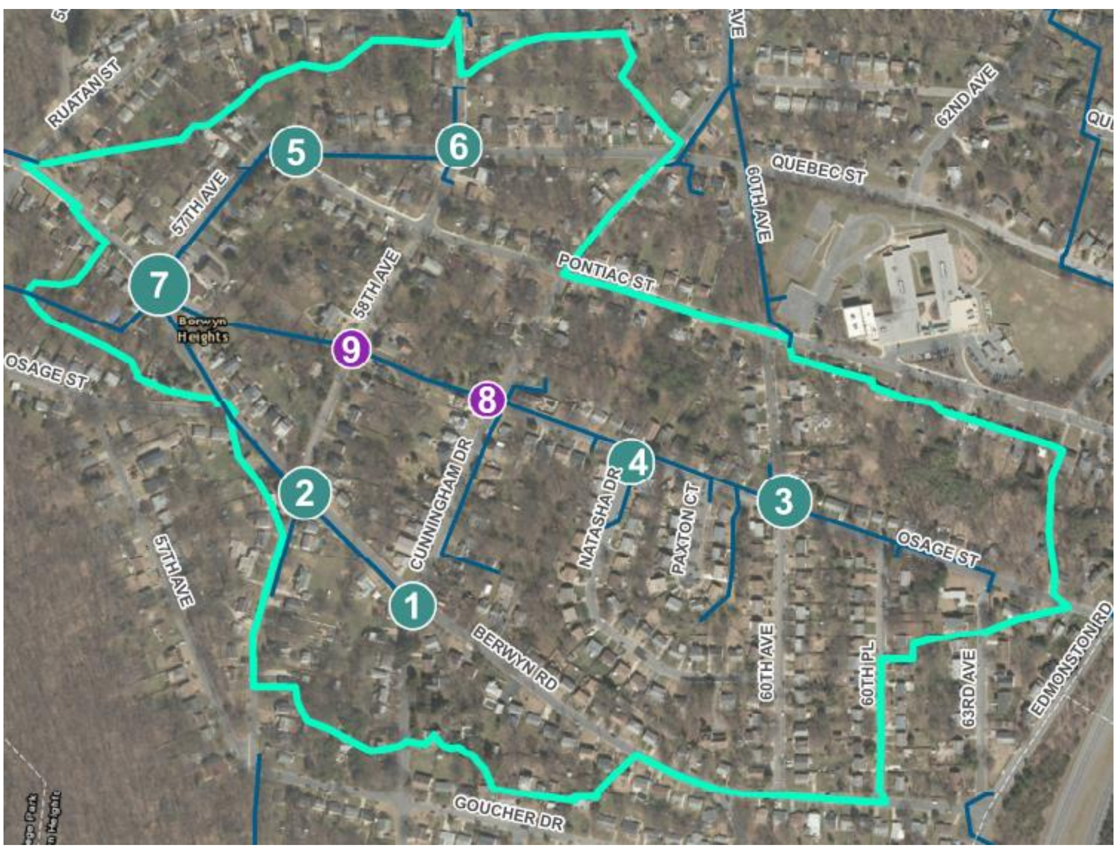


Figure 3: Area # 1- Berwyn Rd and Cunningham Dr

Figure 4: Area #2 - Berwyn Rd and 58th Ave

Figure 5: Area #3 - Osage St and 60th Ave

Figure 6: Area #4 - Osage St and Natasha Dr

Figure 7: Area #5 - Pontiac St and 57th Ave/Quebec St

Figure 8: Area #6 - Quebec St and 58th Ave

Figure 9: Area #7 -Berwyn Rd and 57th Ave

Figure 10: Area #8 - Cunningham Dr and Osage St

Figure 11: Area #9 - 58th Ave (midway)

System 3

The main areas of concern in system 3 are points where the side branches join the main branch. High volume in the mainline is seen to push water into the side branches. These intersections with high volume also have inadequate inlets in some spaces thus increasing the roadway flows in these areas. There are also a few areas where the elevation causes water to sump. Overall, there are four heavy flow intersections with flooding and roadway flow and four spaces where a sump is formed. Two of these locations are both sumps and heavy flow intersections for a total of 6 problem locations denoted by the orange circles on *Figure 12*. The red, orange, and yellow links below represent the location and severity of flooding pipes with red being the worst.

- Area #1- 59th Ave. (Sump area)
- Area #2 - Seminole St and 60th Ave. (Sump area)
- Area #3 - 60th Ave and Ruatan St.
- Area #4 - Cunningham Dr. between Seminole St and Ruatan St. (Sump Area)
- Area #5 - Seminole Pl. and 62nd Ave.(Sump area)
- Area #6 - Seminole St., Seminole Pl., Tecumseh Pl. and 63rd Ave.

Figure 12: GIS System 3 Map

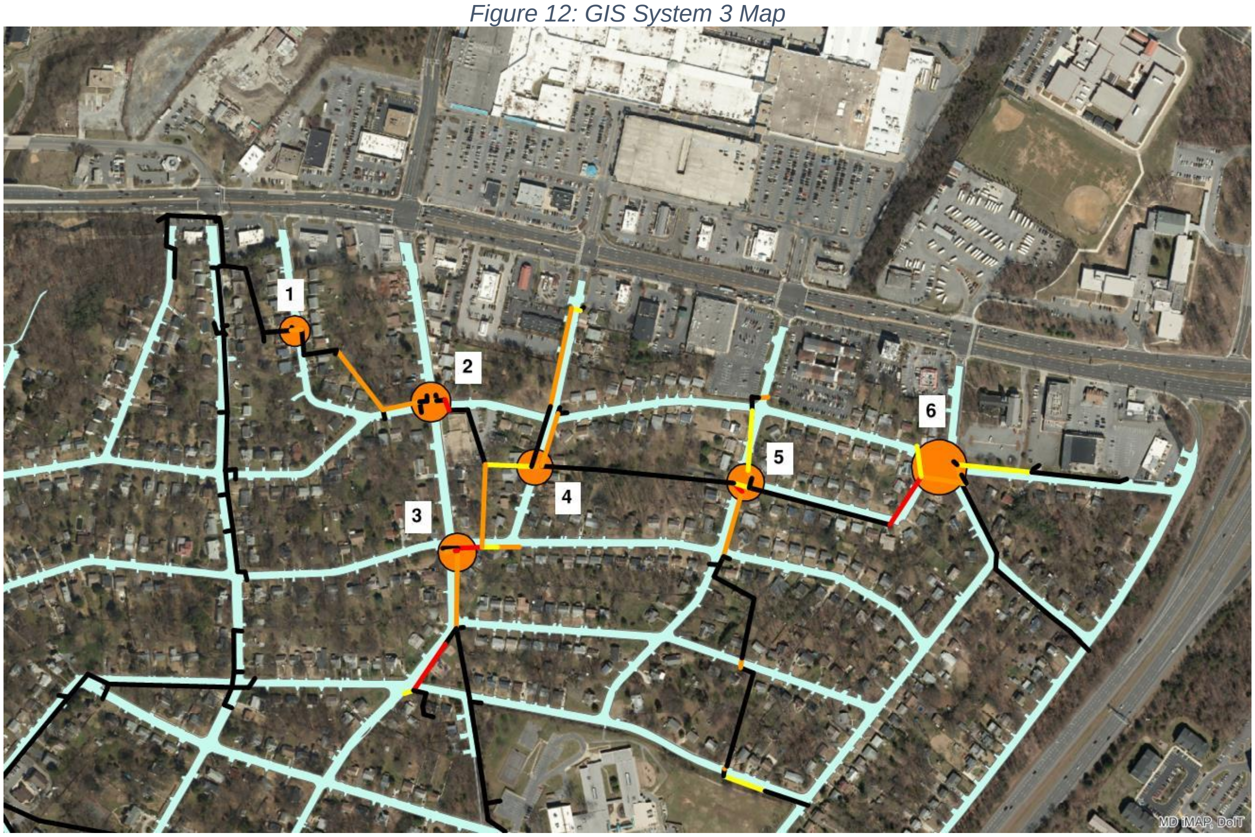


Figure 13: Area #1 - 59th Ave, Most Downstream Sump Area

Figure 14: Area #2 - Seminole St and 60th Ave

Figure 15: Area #3 - 60th Ave and Ruatan St

Figure 16: Area #4 - Cunningham Dr between Seminole St and Ruatan St.

Figure 17: Area #5 - Seminole Pl and 62nd Ave.

Figure 18: Area #6 - Seminole St, Seminole Pl, Tecumseh Pl and 63rd Ave

Minor systems

System 1 (*Figure 19*) is made up of two branches that converge at an outfall at the intersection of Nevada St and 58th Ave.

System 4 (*Figure 20*) includes 3 branches and a handful of yard inlets. It outfalls into a wooded area near Swarthmore Dr, Bryn Mawr Rd and Edmonston Rd. Some roadway flow could leave system and or flow into yards.

System 5 (*Figure 21*) is located at the intersection of Berwyn Rd and 63rd Ave with 4 inlets. Excess roadway could leave the system toward system 4 if not captured.

System 6 (*Figure 22*) consists of 1 inlet at the corner of Osage St and Edmonston Rd and one outfall in a wooded area with potential for overflow to system 5 or out of the study area.

System 7 (*Figure 23*) consists of 3 inlets at the intersection of Pontiac St and Edmonston Rd with an outfall at the same intersection into a grass ditch.

System 8 (*Figure 24*) is a large system of 6.43 acres all going to one 5 ft curb inlet and outfalling into a park near the intersection of Seminole St and 56th Ave.

System 10 (*Figure 25*) also has a large area into only 3 inlets on Berwyn Rd that outfalls into Indian Creek.

Figure 19: System 1 - Nevada St and 58th Ave

Figure 20: System 4 - Swarthmore Dr, Bryn Mawr Rd and Edmonston Rd.

Figure 21: System 5 - Berwyn Rd and 63rd Ave

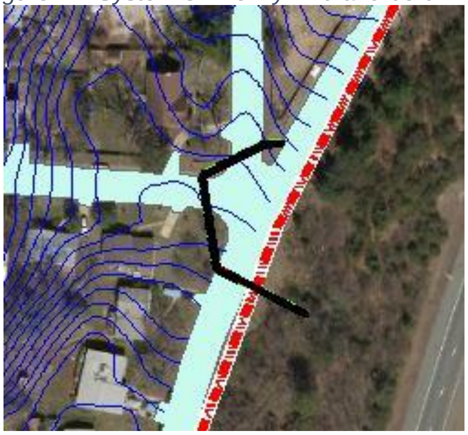


Figure 22: System 6 - Osage St & Edmonston Rd

Figure 23: System 7 - Pontiac St and Edmonston Rd

Figure 24: System 8 - Seminole St and 56th Ave

Figure 25: System 10- Berwyn Rd at Indian Creek

Appendix B: Methodology

General Modeling Methodology

WBCM developed an existing conditions model of the land use and drainage networks within the town limits using EPA SWMM 5.1. This task included creating models of the 2 main storm drain networks (Systems 2 & 3) and 7 minor systems (Systems 1, 4- 8 & 10) consistent with the drainage area (DA) boundaries used in the original Berwyn Heights Hydrologic and Hydraulic Analysis Report (WBCM, 2015). All naming conventions for critical features (catchments, basins, drainage systems, etc.) have remained the same as was used in the 2015 study. When features needed to be subdivided, a naming convention that clearly referenced the parent feature was used. WBCM used existing survey as obtained by WBCM in 2015 which will include the inverts, tops of structures, and pipe sizes.

The primary event modeled was the 10-year storm, which is the general level of service for the roadways in Berwyn Heights. While the SWMM models developed for this project can be used to calculate the surface flooding for larger events such as the 100-year event and the microburst event (a 3.5-hr, 6.6-inch rainfall), their practicality in identifying viable solutions that would have the most impact of residents was found to be insignificant as the storm drain system cannot collect nor convey such runoff. The existing model, which served as the base model for all proposed scenarios, included calculating flow along the roadways, addressing both undersized/surcharged receiving pipes as well as insufficient location/size of roadway

Initially a combination of LID and structural SWM practices such as bioretention, rain gardens, green street features such as bump-outs, and infiltration was to be considered. But after discussing the limits of such features to reduce runoff for events greater than the 1- to 2-year event, they were left out of consideration. The proposed models were focused on evaluate the feasible structural improvements to the system.

Modeling Approach for System 2

The following seven proposed scenarios were explored for System 2:

- Removal of Impervious Area
- Addition of Inlets Where None Existed
- Inlet Size Adjustment
- Pipe Size Adjustment
- Inlet and Pipe Size Adjustment
- Additional Outlet
- Inlet Size and Additional Outlet

Descriptions of each scenario are characterized below.

Removal of Impervious Area: The first option explored was to identify areas where impervious surfaces could potentially be removed and replaced with pervious surfaces. In this semi-urban landscape, sidewalks and driveways were targeted for potential removal.

Addition of Inlets Where None Existed: A second option examined was the addition of new inlets to any identifiable areas where no necessary inlets currently exist.

Inlet Size Adjustment: Increasing the existing inlet sizes was a third option investigated. For this option, doubling and tripling inlet sizes for existing inlets near the critical intersections were analyzed. Additional detail is provided below.

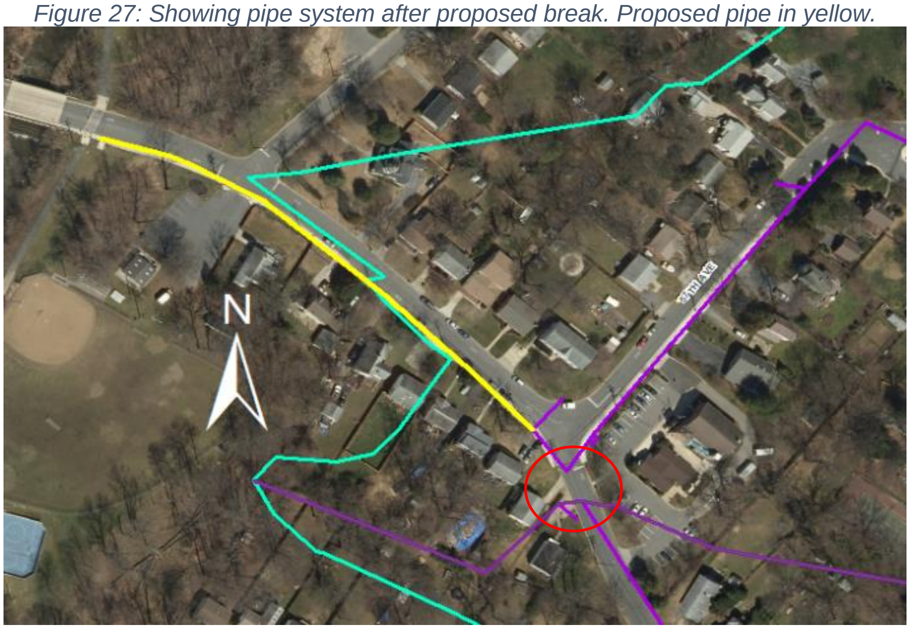
Pipe Size Adjustment: An increase in pipe diameter was another option for analysis. The mainline pipe diameters were doubled in size and run through the program.

Inlet and Pipe Size Adjustment: A fifth scenario was completed whereby the pipe size adjustment and existing inlet size adjustment scenarios were combined by using the doubled inlet size option coupled with the doubled mainline pipe diameter option.

Additional Outlet: The inclusive of an additional outlet was another option considered, similar to that suggested in the 2015 study. The diversion point placement occurs between existing manholes MH 2-30 and MH 2-35 (*Figure 26* and *Figure 27*) where pipe is removed and the system is essentially split into upper (roadway) and lower (in-pipe) flow conveyances, with most of the flow uninterrupted from the east-west mainline. New pipe (3.5 ft diameter) is added to existing inlet I2-245 and extends to Indian Creek as the ultimate outfall. Diversion placement was chosen to minimize disturbance while still following flow lines, in an area of existing concentrated inlets.

Figure 26: Diversion point (red) between MH 2-30 and MH 2-35

Figure 27: Showing pipe system after proposed break. Proposed pipe in yellow.



Combination Inlet Size and Additional Outlet: A combination of an additional outlet described above and doubling targeted existing inlet sizes was the seventh scenario examined.

Modeling Approach for System 3

The two main issues that contribute to flooding is overloaded pipes causing backups and water bypassing inlets from inadequate capture. When modeling the 10-year storm event was used and "serious" roadway flows were said to be those over 10 cubic feet per second (cfs). To combat these problems a few different approaches were taken.

- Removal of Impervious Area
- Inlet Size Adjustment
- Pipe Size Adjustment
- Inlet Size and Pipe Size Adjustment

Removal of Impervious Area: In order to reduce the amount of water entering the system an option that was explored was reducing the amount of impervious area which reduces the reduces the runoff. This option was more suited toward problem areas 4, 5 and 6 as they are in proximity to high impervious commercial areas. This tactic is less pertinent for the rest of the system as there is not much public impervious available to reduce. To model this scenario the percent impervious was reduced for the largest high impervious areas by half. Although ambitious, doing this only solved limited problems in the immediate sub catchments, all located in the headwaters of the catchments, and was deemed as an ineffective strategy on its own due to the added unlikelihood of property owner cooperation (ie the impervious areas, parking and rooftops, are essential).

Inlet Size Adjustment: Getting water into the pipes and off the road was examined by increasing existing sizes of inlets in the model to represent additional inlets in the same sub-catchment or actual increasing size of existing inlets. To start all inlets directly upstream of high flow roads were targeted.

Pipe Size Adjustment: The next step was to check where nodes were flooded and help alleviate the stress by enlarging pipe sizes to ensure that all water that was captured is staying in the pipes. The pipes adjusted were those immediately downstream of a flooded node. As the simulations ran more pipes were enlarged as flooding moved to other nodes.

Inlet and Pipe Size Adjustment: Knowing which methods were effective for different roadways from the previous strategies gave a good benchmark on how to approach a comprehensive strategy. Taking into account realistic sizes for both pipe sizes and inlet sizes a new strategy was utilized. By enlarging pipes downstream of flooding nodes and increasing inlets upstream of flooded roadways a system with minimal flooding could be possible. After each change the model was ran to see the effects each change had in conjunction with previous upgrades.

Modeling Approach for Smaller Systems

The two main issues that contribute to flooding is overloaded pipes causing backups and water bypassing inlets from inadequate capture. When modeling the 10-year storm event was used and "serious" roadway flows were said to be those over 10 cubic feet per second (cfs). To combat these problems approaches similar to those used for System 2 and System 3 were taken.

- Inlet Size Adjustment
- Pipe Size Adjustment
- Inlet Size and Pipe Size Adjustment

Appendix C: Results

The modeling results provided in this Appendix represent the potential magnitude and extend of improvements that can be made from general capital improvements. Explicit increases to inlet and pipe sizes for optimal improvements was not performed, because it was determined in 2015 that such an approach would need to be coordinated on a full-system scale (i.e. all or nothing), which was too costly to consider. It should be noted the allowable increases in pipe size, if a detailed design is pursued, may be limited to less than what has been modeled due to utilities and minimal cover requirements. When such is the case, the eventual design would use alternative pipe shapes (e.g. box or elliptical) or multiple pipes.

The results that follow give the County the insight needed to determine where the most effective system improvements (i.e. Increased pipe sizes and added inlets) are located, and the general degree to which they need to be implemented. The results focus on reduced roadway (and less often, rear yard swale denoted with "GR") flows denoted with "RD". Those are the flows that cannot be conveyed through the closed pipe system, either due to limited pipe or inlet capacity, and are the source of flooding. The results are grouped by Area of Concern and ordered by length of roadway flow segment to help quantity the extent of the improvement.

System 2

Removal of Impervious Area: Impervious area removal in System 2 was determined to be neither feasible nor beneficial, as the vast majority streets within this system only have one sidewalk per street (except for Paxton Court and 58th Ave). The locations with sidewalk on each side of the road were limited such that an appreciable reduction in surface flows could not be expected. Sidewalk removal in these areas would impact walkability, negatively effecting quality of life for the community. Additionally, the limited number and surface area of existing driveways would have a negligible effect on reducing surface flows if these impervious areas were to be removed. Therefore, no detailed modeling results are provided.

Addition of Inlets Where None Existed: Given the number and location of existing inlets, which are already clustered in and around the selected areas of concern, it was determined that this option would not provide significant benefit in surface reducing surface flows or lowering the HGL in critical locations.

Inlet Size Adjustment: For this option, doubling and tripling inlet sizes for existing inlets near the critical intersections were analyzed. Additional detail is provided below, and the numerical results are provided in Table 1.

<u>Doubled Inlet Size:</u> Doubling inlet sizes decreased maximum roadway overflow as much as 93% in some critical areas, with an average of a 48% reduction in roadway overflow. Sixteen roadway segments - 52% of total critical segments totaling 3500 ft in length - had an overflow reduction of 50% or greater.

<u>Tripled Inlet Size:</u> As expected, tripling inlet sizes also decreased maximum roadway overflow as much as 100% in some areas, with an average of a 62% reduction in roadway overflow in critical examined links. Twenty-three roadway segments - 74% of total critical segments totaling 5500 ft in length - had an overflow reduction of 50% or greater. However, with this level of size increase, tripled sizes are rather large and may be impractical to implement. In some locations, there simply is not enough curb within the area of concern to provide the space for three-times the number of inlets.

Pipe Size Adjustment: The mainline pipe diameters were doubled in size and run through the program. The result was an average reduction of 62% for maximum roadway flow in critical areas, with twenty-three segments – 74% of critical segments - yielding a 50% or greater reduction in roadway overflow. Additionally, this option deviates from all previous scenarios regarding outfall loading whereby the average outfall flow increases to 11 cfs from about 9 cfs in previously mentioned scenarios and the maximum flow increases to 370 cfs from 170 cfs. Also, in this scenario, the total volume of water at the outfall increases about 23% from previous scenarios. This analysis indicates a faster rate and higher volume of water being evacuated from the roadway, both desirable parameters in reducing roadway flooding.

Due to the length (approximately 3100 ft) and diameter of pipe required for this option, in addition to elevation adjustments required for affected existing inlets, this scenario may not be the most economical option to implement in its entirety, and consider increases in sizes which can improve conditions at the problem areas identified in the 2015 study may be the more feasible approach. More importantly, there may not to be enough minimum depth of pavement cover to accommodate increased pipe diameters.

However, in addition to limitations with minimum pavement depth requirements regarding increased pipe diameter accommodation discussed previously, other methods yield greater roadway reductions at a potentially lower estimated cost, so this option may not be the most effective approach. The full numerical results are provided in Table 2.

Inlet and Pipe Size Adjustment: The result of doubling the mainline pipe size (diameter) and doubling the size (length) of all inlets yields reduced maximum roadway flows averaging 48% in critical areas, with a higher volume and faster average and maximum flow to the outfall (total volume of 7×10^6 gal, average flow of 11.5 cfs and maximum flow of 417 cfs). Fifteen segments (52%) had a reduction of 50% or greater in roadway overflow. The full numerical results are provided in Table 3.

Additional Outlet: From a comparative roadway overflow perspective, adding an additional outlet (Outfall 2-2) does not appear to have a significant effect on the maximum surface flows on the roadways from the existing conditions. However, from an outfall loading perspective, the max inflow to existing Outfall 2 remains 173 cfs but an additional 66 cfs max total flow is released. The full numerical results are provided in Table 4.

Increased Inlet Size and Additional Outlet: The result yields reduced maximum roadway flows averaging 48% in critical areas and sixteen segments (53%) had a reduction of 50% or greater in roadway overflow totaling 3500 ft. While this scenario reduces roadway flow, these results are very similar to the lower-cost option of only doubling existing inlets. The full numerical results are provided in Table 5.

Table 1: System 2 - Inlet Size Adjustment Results

	Existing Information			***Doubled Inlets***		***Tripled Inlets***	
Area ID	Roadway Flow ID	Length of Roadway Flow Segment [ft]	Exist Max Flow [CFS]	Prop Max Flow [CFS]	% Change	Prop Max Flow [CFS]	% Change
1	RD27	387	1.9	0.8	-61%	0.7	-63%
1	RD31	510	4.5	1.4	-68%	0.5	-90%
2	RD26	350	3.1	2.7	-15%	2.7	-15%
2	RD60	705	4.2	2.2	-48%	1.6	-61%
3	RD4	25	15	11	-23%	8.5	-42%
3	RD8	30	3.7	2.1	-44%	1.3	-64%
3	RD7	165	20	12	-41%	7.3	-63%
3	RD11	175	6.4	1.6	-75%	0.3	-95%
4	RD16	60	1.2	1.2	0%	1.2	0%
4	RDXX5	85	6.4	1.6	-75%	0.3	-95%
4	RDXX3	105	2.0	1.1	-48%	1.1	-48%
4	RD18	115	17	8.2	-52%	4.3	-75%
4	RD14	185	0.3	0.3	0%	0.3	0%
4	RD10	250	19	12	-38%	8.1	-58%
4	RDXX1	285	17	8.1	-53%	4.2	-75%
5	RD48	84	7.4	3.4	-53%	2.9	-61%
5	RD49	140	3.0	0.2	-93%	0.0	-100%
6	RD42	41	5.3	1.8	-67%	0.6	-89%
6	RD56	60	6.4	1.2	-81%	0.2	-97%
6	RD40	400	0.4	0.1	-84%	0.0	-100%
6	RDXX11	452	6.0	1.0	-83%	0.1	-98%
7	RD35	34	1.5	0.7	-50%	0.6	-63%
7	RD51	45	11	7.9	-27%	5.0	-54%
7	RD50	390	6.7	4.7	-31%	4.6	-32%
8	RD20	42	10	2.5	-76%	0.4	-96%
8	RD21	56	12	15	23%	15	23%
8	RDXX2	275	1.9	0.9	-53%	0.9	-53%
8	RD140	400	0.2	0.0	-82%	0.0	-100%
8	RD145	400	6.0	3.7	-38%	2.3	-61%
9	RD23	35	26	19	-27%	14	-48%
9	RD24	405	18	12	-32%	8.0	-54%
				Average:	*-48%*	*Average:*	*-62%*

Table 2: System 2 - Increased Pipe Size Results

Area ID	*Roadway Flow ID*	*Length of Roadway Flow Segment [ft]*	*Exist Max Flow [CFS]*	*Prop Max Flow [CFS]*	*% Change*
1	RD27	387	1.9	0.7	-63%
1	RD31	510	4.5	0.5	-90%
2	RD26	350	3.1	2.7	-15%
2	RD60	705	4.2	1.6	-61%
3	RD11	175	6.4	0.3	-95%
3	RD4	25	15	8.5	-42%
3	RD7	165	20	7.3	-63%
3	RD8	30	3.7	1.3	-64%
4	RD10	250	19	8.1	-58%
4	RD14	185	0.3	0.3	0%
4	RD16	60	1.2	1.2	0%
4	RD18	115	17	4.3	-75%
4	RDXX1	285	17	4.2	-75%
4	RDXX3	105	2.0	1.1	-48%
4	RDXX5	85	6.4	0.3	-95%
5	RD48	84	7.4	2.9	-61%
5	RD49	140	3.0	0.0	-100%
6	RD40	400	0.4	0.0	-100%
6	RD42	41	5.3	0.6	-89%
6	RD56	60	6.4	0.2	-97%
6	RDXX11	452	6.0	0.1	-98%
7	RD35	34	1.5	0.6	-63%
7	RD50	390	6.7	4.6	-32%
7	RD51	45	11	5.0	-54%
8	RD140	400	0.2	0.0	-100%
8	RD145	400	6.0	2.3	-61%
8	RD20	42	10	0.4	-96%
8	RD21	56	12	15	23%
8	RDXX2	275	1.9	0.9	-53%
9	RD23	35	1.9	0.7	-48%
9	RD24	405	4.5	0.5	-54%
				Average:	*-62%*

Table 3: System 2- Increased Pipe and Inlet Size Results

Area ID	*Roadway Flow ID*	*Length of Roadway Flow Segment [ft]*	*Exist Max Flow [CFS]*	*Prop Max Flow [CFS]*	*% Change*
1	RD31	510	4.5	1.4	-68%
1	RD35	34	1.5	0.7	-50%
2	RD27	387	1.9	0.8	-61%
2	RD60	705	4.2	2.2	-48%
3	RD11	175	6.4	1.6	-75%
3	RD4	25	15	11	-23%
3	RD7	165	20	12	-41%
3	RD8	30	3.7	2.1	-44%
4	RD10	250	19	12	-38%
4	RD14	185	0.3	0.3	0%
4	RD16	60	1.2	1.2	0%
4	RD18	115	17	8.2	-52%
4	RDXX1	285	17	8.1	-53%
4	RDXX3	105	2.0	1.1	-48%
4	RDXX5	85	6.4	1.6	-75%
5	RD48	84	7.4	3.4	-53%
5	RD49	140	3.0	0.2	-93%
6	RD40	400	0.4	0.06	-84%
6	RD42	41	5.3	1.8	-67%
6	RD56	60	6.4	1.2	-81%
6	RDXX11	452	6.0	1.0	-83%
7	RD50	390	6.7	4.7	-31%
7	RD51	45	11	7.9	-27%
8	RD140	400	0.2	0.0	-82%
8	RD145	400	6.0	3.7	-38%
8	RD21	56	12	15	23%
8	RD23	35	26	19	-27%
8	RDXX2	275	1.9	0.9	-53%
9	RD26	350	3.1	2.7	-15%
				Average:	*-48%*

Table 4: System 2 - Additional Outlet Results

Area ID	*Roadway Flow ID*	*Length of Roadway Flow Segment [ft]*	*Exist Max Flow [CFS]*	*Prop Max Flow [CFS]*	*% Change*
1	RD27	387	1.9	1.9	0%
1	RD31	510	4.5	6.2	39%
2	RD26	350	3.1	3.1	0%
2	RD60	705	4.2	4.2	0%
3	RD11	175	6.4	6.4	0%
3	RD4	25	15	15	0%
3	RD7	165	20	20	0%
3	RD8	30	3.7	3.7	0%
4	RD10	250	19	19	0%
4	RD14	185	0.3	0.3	0%
4	RD16	60	1.2	1.2	0%
4	RD18	115	17	17	0%
4	RDXX1	285	17	17	0%
4	RDXX3	105	2.0	2.0	0%
4	RDXX5	85	6.4	6.4	0%
5	RD48	84	7.4	7.4	0%
5	RD49	140	3.0	3.0	0%
6	RD40	400	0.4	0.4	0%
6	RD42	41	5.3	5.3	0%
6	RD56	60	6.4	6.4	0%
6	RDXX11	452	6.0	6.0	0%
7	RD50	390	6.7	6.7	0%
7	RD51	45	11	11	0%
8	RD140	400	0.2	0.2	0%
8	RD145	400	6.0	6.0	0%
8	RD20	42	10	11	6%
8	RD21	56	12	11	-9%
8	RDXX2	275	1.9	1.9	0%
9	RD23	35	26	20	-26%
				Average:	*0%*

Table 5: System 2 - Increased Inlet Sizes and Additional Outlet Results

Area ID	*Roadway Flow ID*	*Length of Roadway Flow Segment [ft]*	*Exist Max Flow [CFS]*	*Prop Max Flow [CFS]*	*% Change*
1	RD27	387	1.9	0.8	-61%
1	RD31	510	4.5	1.4	-68%
2	RD26	350	3.1	2.7	-15%
2	RD60	705	4.2	2.2	-48%
3	RD11	175	6.4	1.6	-75%
3	RD4	25	15	11	-23%
3	RD7	165	20	12	-41%
3	RD8	30	3.7	2.1	-44%
4	RD10	250	19	12	-38%
4	RD14	185	0.3	0.3	0%
4	RD16	60	1.2	1.2	0%
4	RD18	115	17	8.2	-52%
4	RDXX1	285	17	8.1	-53%
4	RDXX3	105	2.0	1.1	-48%
4	RDXX5	85	6.4	1.6	-75%
5	RD48	84	7.4	3.4	-53%
5	RD49	140	3.0	0.2	-93%
6	RD40	400	0.4	0.2	-55%
6	RD42	41	5.3	1.8	-66%
6	RD56	60	6.4	1.2	-81%
6	RDXX11	452	6.0	1.0	-83%
7	RD35	34	1.5	0.7	-50%
7	RD50	390	6.7	4.7	-31%
7	RD51	45	11	7.9	-27%
8	RD140	400	0.2	0.0	-82%
8	RD145	400	6.0	3.7	-38%
8	RD20	42	10	2.5	-76%
8	RD21	56	12	14	13%
8	RDXX2	275	1.9	0.9	-53%
9	RD23	35	26	18	-34%
				Average:	*-48%*

System 3

Reduction of Impervious Area: As noted earlier, this option was more suited toward problem areas 4,5 and 6 as they are in proximity to high impervious commercial areas. This tactic is less pertinent for the rest of the system as there is not much public impervious available to reduce. To model this scenario the percent impervious was reduced for the largest high impervious areas by half. Although ambitious, doing this only solved limited problems in the immediate sub catchment and was deemed as an ineffective strategy on its own.

Inlet Size Adjustment: Getting water into the pipes and off the road was examined by increasing existing sizes of inlets in the model to represent additional inlets in the same sub-catchment or actual increasing size of existing inlets. To start all inlets directly upstream of high flow roads were targeted. Of the 32 problem roadways across all problem areas 14 responded with significant improvement when inlets were doubled; there was no need to assess performance if inlets were tripled in size (as done in System 2). Eight (8) areas saw some amount of increase on the immediate roadway likely due to additional water entering in other places causing flooding downstream. Ten (10) inlets saw minimal or still unfavorable flow from an increased inlet size and likely wouldn't benefit from any size increase. Results of the changes can be seen in Table 6.

Of the 32 problem roadways across all problem areas 14 responded with significant improvement when inlets were doubled. 8 areas saw some amount of increase on the immediate roadway likely due to additional water entering in other places causing flooding downstream. Ten (10) inlets saw minimal or still unfavorable flow from an increased inlet size and likely wouldn't benefit from any size increase.

Pipe Size Adjustment: Of the 47 pipes that were enlarged, 45 were doubled in size one was tripled and on was quadrupled in size. Of the 32 problem roadways 26 were successful in reducing high flows while 4 were unaffected by increased sizes and 2 roadways saw increased flows. Although successful doubling pipe sizes is not realistic as appropriate cover is needed. It does give a good idea on where pipes are flowing too full and that the problem in an area is not lack of inlets. The inlets adjusted and final results can be seen in Table 7.

In the end 47 pipes were enlarged. Forty-five (45) were doubled in size one was tripled and on was quadrupled in size. Of the 32 problem roadways 26 were successful in reducing high flows while 4 were unaffected by increased sizes and 2 roadways saw increased flows. Although successful doubling pipe sizes is not realistic as appropriate cover is needed. It does give a good idea on where pipes are flowing too full and that the problem in an area is not lack of inlets.

Inlet and Pipe Size Adjustment: After enlarging pipes downstream of flooding nodes and increasing inlets upstream of flooded roadways a system with minimal flooding could be possible, it was found the changes in one problem area often had effects on other areas such as more water in a downstream pipe could cause flooding where it wasn't previously. Because of this the mainline was the first to be addressed and changes were made outward from there. This was done and compounded at minimal size increments to find a strategy that was efficient. The results can be seen in Table 8.

Table 6: System 3 - Inlet Size Adjustment Results

		Existing Information			****Doubled Inlets***
Area ID	Roadway Flow ID	Length of Roadway Flow Segment [ft]	Exist Max Flow [CFS]	Prop Max Flow [CFS]	% Change
1	RD-100	39	37	18	-52%
1	RD-120	40	45	23	-48%
2	RD-240	34	11	10	-13%
2	RD-130	63	37	8.8	-77%
2	RD-140	92	41	11	-73%
2	RD-145	430	47	18	-63%
3	RD-285	24	25	18	-29%
3	RD-250	28	23	23	+1%
3	RD-255	70	33	6.4	-81%
3	RD-245	164	47	41	-14%
3	GR-310	200	14	13	-4%
3	RD-260	208	30	4.1	-86%
3	connect 1	285	56	44	-21%
4	RD-150	20	27	35	+26%
4	RD-231	303	50	39	-22%
4	RD-230	303	18	22	+23%
5	RD-392	20	16	15	-6%
5	RD-400	27	20	16	-22%
5	RD-175	43	36	48	+33%
5	RD-375	273	12	6.7	-45%
5	RD-365	277	11	7.4	-34%
5	RD-390	282	43	49	+14%
5	GR-391	315	24	27	+12%
5	GR-395	365	11	1.1	-91%
5	GR-155	725	17	20	+16%
6	RD-196	5	13	2.1	-84%
6	RD-190	16	14	3.3	-77%
6	connect	40	42	67	+61%
6	RD-210	59	23	23	0%
6	RD-195	71	14	36	+158%
6	RD-370	325	12	7.8	-33%
6	RD-200	361	20	0.0	-100%
				Average:	*-23%*

Table 7: System 3 - Increased Pipe Size Results

Area ID	*Roadway Flow ID*	*Length of Roadway Flow Segment [ft]*	*Exist Max Flow [CFS]*	*Prop Max Flow [CFS]*	*% Change*
1	RD-100	39	37	9.2	-75%
1	RD-120	40	45	4.0	-91%
2	RD-240	34	11	5.3	-53%
2	RD-130	63	37	10	-73%
2	RD-140	92	41	8.9	-78%
2	RD-145	430	47	2.9	-94%
3	RD-285	24	25	0.0	-100%
3	RD-250	28	23	4.0	-83%
3	RD-255	70	33	0.06	-100%
3	RD-245	164	47	4.3	-91%
3	GR-310	200	14	0.0	-100%
3	RD-260	208	30	1.3	-96%
3	connect 1	285	56	3.9	-93%
4	RD-150	20	27	22	-19%
4	RD-231	303	50	6	-87%
4	RD-230	303	18	9.5	-48%
5	RD-392	20	16	0.08	-99%
5	RD-400	27	20	9.5	-52%
5	RD-175	43	36	6.1	-83%
5	RD-375	273	12	12	0%
5	RD-365	277	11	11	0%
5	RD-390	282	43	7.3	-83%
5	GR-391	315	24	0.0	-100%
5	GR-395	365	11	2.0	-82%
5	GR-155	725	17	0.6	-96%
6	RD-196	5	13	2.1	-84%
6	RD-190	16	14	3.0	-79%
6	connect	40	42	56	+34%
6	RD-210	59	23	23	0%
6	RD-195	71	14	16	11%
6	RD-370	325	12	7.9	-32%
6	RD-200	361	20	0.0	-100%
				Average:	*-67%*

Table 8: System 3- Increased Pipe and Inlet Size Results

Area ID	*Roadway Flow ID*	*Length of Roadway Flow Segment [ft]*	*Exist Max Flow [CFS]*	*Prop Max Flow [CFS]*	*% Change*
1	RD-100	39	37	7.2	-80%
1	RD-120	40	45	4.0	-91%
2	RD-240	34	11	6.5	-44%
2	RD-130	63	37	6.8	-82%
2	RD-140	92	41	8.9	-78%
2	RD-145	430	47	0.0	-100%
3	RD-285	24	25	0.0	-100%
3	RD-250	28	23	2.0	-91%
3	RD-255	70	33	0.06	-100%
3	RD-245	164	47	4.1	-91%
3	GR-310	200	14	0.0	-100%
3	RD-260	208	30	1.3	-96%
3	connect 1	285	56	1.9	-97%
4	RD-150	20	27	0.3	-99%
4	RD-230	303	18	10	-48%
4	RD-231	303	50	6.0	-88%
5	RD-392	20	16	0.00	-100%
5	RD-400	27	20	5.9	-70%
5	RD-175	43	36	0.9	-97%
5	RD-375	273	12	9.1	-25%
5	RD-365	277	11	4.0	-64%
5	RD-390	282	43	0.03	-100%
5	GR-391	315	24	0.0	-100%
5	GR-395	365	11	0.0	-100%
5	GR-155	725	17	0.0	-100%
6	RD-196	5	13	5.7	-55%
6	RD-190	16	14	3.0	-79%
6	connect	40	42	18	-58%
6	RD-210	59	23	7.2	-69%
6	RD-195	71	14	3.9	-72%
6	RD-370	325	12	0.2	-98%
6	RD-200	361	20	0.3	-98%
				Average:	*-83%*

Minor Systems

System 1: Doubling inlets alone had a significant effect on the flow while upsizing pipes alone had a negligible effect. When inlet and pipe increases were applied together, significant improvement resulted.

Table 9: System 1 - All Results

	Existing Information		***Increased Inlet Sizes***	***Increased Pipes Sizes***	***Increased Inlet & Pipes Sizes***
Roadway Flow ID	Length of Roadway Flow Segment [ft]	Exist Max Flow [CFS]	Prop Max Flow [CFS]	Prop Max Flow [CFS]	Prop Max Flow [CFS]
RD-20	75	19	7.7	19	2.8
RD-10	413	13	5.5	12	2.4

System 4: Some roadway flow could leave system and or flow into yards. To prevent water from leaving system inlet 30 was upgraded to a 10-ft combo inlet. To prevent yard flooding pipe 241 was increased to a 3-foot diameter pipe. Also pipes 230, 231, 232 and 232 were upsized to 2-foot diameters.

Table 10: System 4 - All Results

	Existing Information		***Increased Inlet Sizes***	***Increased Pipes Sizes***	***Increased Inlet & Pipes Sizes***
Roadway Flow ID	Length of Roadway Flow Segment [ft]	Exist Max Flow [CFS]	Prop Max Flow [CFS]	Prop Max Flow [CFS]	Prop Max Flow [CFS]
RD-30	20	25	20	6.8	6.8
RD-45	48	23	23	0.0	0.0
RD-56	74	12	14	1.4	1.6
GR-50	105	25	3.3	1.7	1.7
RD-65	106	13	12	7.3	7.9
GR-25	160	19	6.6	2.7	2.7
RD-60	187	14	14	6.4	6.8

System 5: Increasing the size of inlets to capture the runoff is ineffective if the receiving system is not increased. Increasing the size of pipes 217 and 218 to 3 feet in diameter allowed the surface runoff to be accepted to the closed pipe system and reduced the roadway flow significantly.

Table 11: System 5 - All Results

	Existing Information		***Increased Inlet Sizes***	***Increased Pipes Sizes***	***Increased Inlet & Pipes Sizes***
Roadway Flow ID	Length of Roadway Flow Segment [ft]	Exist Max Flow [CFS]	Prop Max Flow [CFS]	Prop Max Flow [CFS]	Prop Max Flow [CFS]
RD-10	25	18	18	9.5	1.9

System 6: No recommendations are to be given as roadway flow is a maximum of 0.19 cfs at the peak of the 10-year storm for the lone overflow.

System 7: The results show a low amount of surface runoff not captured by the inlets and conveyed by the closed pipe system.

Table 12: System 7 - All Results

	Existing Information		***Increased Inlet Sizes***	***Increased Pipes Sizes***	***Increased Inlet & Pipes Sizes***
Roadway Flow ID	Length of Roadway Flow Segment [ft]	Exist Max Flow [CFS]	Prop Max Flow [CFS]	Prop Max Flow [CFS]	Prop Max Flow [CFS]
RD-10	19	1.1	0	0.03	1.1
RD-5	41	0.9	0.3	0.9	0.9
RD-1	47	2.4	0.5	2.4	2.4

System 8: Converting the inlet to a 15 ft combo inlet reduces water on the roadway significantly, which offered more effective results than increasing the pipe sizes.

Table 13: System 8 - All Results

	Existing Information		***Increased Inlet Sizes***	***Increased Pipes Sizes***
Roadway Flow ID	Length of Roadway Flow Segment [ft]	Exist Max Flow [CFS]	Prop Max Flow [CFS]	Prop Max Flow [CFS]
RD-1	50	22	3.4	22

System 10: It is important to capture water here as any water not picked up would flow to a sump located on the bridge over the creek. Some inlet upgrades could help alleviate roadway flows although no “serious” roadway flows were found. Pipe upsize had no effect on the system.

Table 14: System 10 - All Results

	Existing Information		***Increased Inlet Sizes***	***Increased Pipes Sizes***
Roadway Flow ID	Length of Roadway Flow Segment [ft]	Exist Max Flow [CFS]	Prop Max Flow [CFS]	Prop Max Flow [CFS]
RD-10	42	0.0	N/A	N/A
RD-1	213	9.6	2.5	9.6
RD-5	400	8.1	0.05	8.1