West Park Storm Sewer Analysis and Repair Project

August 30, 2011

Prepared For:

City of Ann Arbor
Project Management Services Unit
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In association with:
CTI and Associates, Inc.

OHM
Advancing Communities℠

City of Ann Arbor
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Prepared by

OHM

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Introduction

Two sets of new, underground AS-12 AquaSwirl Concentrator (ASC) units (one on the north branch and one on the south branch of the drain – see Figure 1 on Page 2) were installed to improve the water quality of the Allen Creek Drain as part of the West Park Improvement Project. Each set consists of four units each capable of treating 25 cfs for a total capacity of 100 cfs per set. Flow is diverted to the units via two diversion chambers equipped with weirs that direct flow to the two sets of units for treatment. The intent was to divert first flush flow while flows in excess of the first flush event overflow the weirs continue through the 54-inch storm sewer and are ultimately discharged into the Huron River.

In the summer of 2010, the City experienced significant flooding along the south branch of the drain. In October 2010, one of the ASC units (TS-4) collapsed along the north branch. These events prompted the City to remove the weirs from the diversion chambers, bulkhead the sewers to the treatment units and fence off the treatment units to protect the public from possible further collapse.

There were two main goals for the current "phase" of the project. The first goal was to identify possible causes for the collapse and subsequent failure of TS-4 and to determine if other units may be under similar stress conditions through a forensic review of certain engineering and construction related information. A second goal was to provide recommendations for improving the stormwater flow conveyance through West Park while still providing stormwater treatment for the first flush event.

As part of this project, temporary flow meters were installed on both the north and south branches of the drain. The meters provided field data for determining the first flush flow rates as well as estimating the frequency at which the design peak flow rates may be exceeded.

Findings

Results of the forensic review indicate that TS-4 collapsed due to the roof structure material thickness being insufficient to withstand the structural loads imposed above its top. The structural loads are primarily believed to be caused from the backfilled soils. The other north ASC units (TS-1, TS-2 and TS-3) are also structurally failing. It was observed the beams in these three other units are separating from the tank sides. Additionally, it was discovered that some of the piping system that encompasses the treatment units is presenting conditions that are of some concern. This includes the presence of soil within the pipes at certain locations and the failure of some pipe connections at manufactured joints and fittings.

The ASC units along the south branch (TS-5, TS-6, TS-7 & TS-8) do not appear to exhibit the same pattern of cracking and structural distress as was observed in the north ASC units. However, since there is evidence that TS-1, TS-2, TS-3 and TS-4 are structurally failing and no evidence that TS-5, TS-6, TS-7 or TS-8 were manufactured differently, it is anticipated the south units have similar defects. In addition, a broken vent pipe was observed in TS-7.

It was also determined that the diversion weir in Structure ST-19 was constructed nearly two feet higher than the elevation approved in the shop drawing. No explanation could be found as to why this occurred.

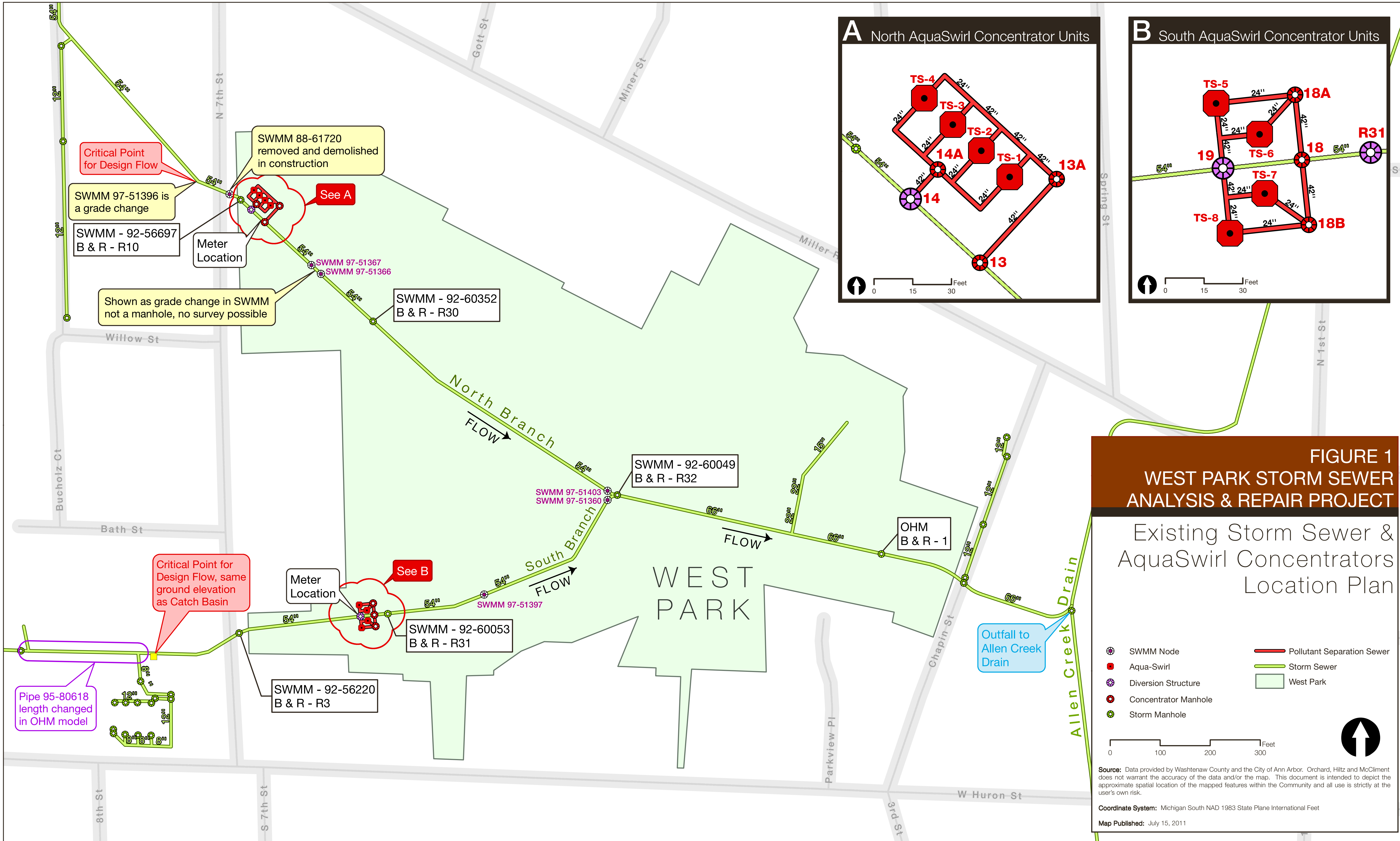


FIGURE 1
WEST PARK STORM SEWER ANALYSIS & REPAIR PROJECT
Existing Storm Sewer & AquaSwirl Concentrators Location Plan
A North AquaSwirl Concentrator Units
TS-4
TS-3
TS-2
TS-1
14A
13A
14
13
B South AquaSwirl Concentrator Units
TS-5
18A
TS-6
R31
19
18
TS-7
TS-8
18B
Feet
0
15
30
Critical Point for Design Flow
SWMM 97-51396 is a grade change
SWMM - 92-56697
B & R - R10
SWMM 88-61720 removed and demolished in construction
See A
Meter Location
SWMM 97-51367
SWMM 97-51366
Shown as grade change in SWMM not a manhole, no survey possible
SWMM - 92-60352
B & R - R30
North Branch
FLOW
SWMM - 92-60049
B & R - R32
SWMM 97-51403
SWMM 97-51360
South Branch
OHM
B & R - 1
WEST PARK
Critical Point for Design Flow, same ground elevation as Catch Basin
Meter Location
See B
SWMM 97-51397
SWMM - 92-60053
B & R - R31
SWMM - 92-56220
B & R - R3
Pipe 95-80618 length changed in OHM model
Outfall to Allen Creek Drain
Allen Creek Drain
Willow St
Bath St
Bucholz Ct
N 7th St
Gott St
Miner St
Miller Rd
Spring St
N 1st St
Chapin St
Parkview Pl
W Huron St
8th St
S 7th St
3rd St
SWMM Node
Aqua-Swirl
Diversion Structure
Concentrator Manhole
Storm Manhole
Pollutant Separation Sewer
Storm Sewer
West Park
Feet
0
100
200
300
Source: Data provided by Washtenaw County and the City of Ann Arbor. Orchard, Hiltz and McCliment does not warrant the accuracy of the data and/or the map. This document is intended to depict the approximate spatial location of the mapped features within the Community and all use is strictly at the user's own risk.
Coordinate System: Michigan South NAD 1983 State Plane International Feet
Map Published: July 15, 2011

Since the first flush peak flow rates influence the height of the weirs in the diversion structures upstream of the treatment units, these flow rates were re-evaluated. This re-evaluation utilized actual flow metering data as well as a frequency based methodology, which resulted in first flush flow rates of 50 cfs and 55 cfs in the north and south branches respectively.

The City SWMM model was updated with newly acquired survey data which was used to develop peak design flow rates as well as make system recommendations. The peak design flow rates were determined to be 125 cfs and 198 cfs (with small existing weir removed in R31) in the north and south branches respectively.

Design event modeling simulations indicated the existence of what is referred to as super-critical flow conditions upstream of the treatment units. Actual flow metering data also showed peak flow velocities upwards of 10 ft/sec during large flow events. Such flow regimes have the potential to introduce what is referred to as hydraulic jump-like phenomena, causing flow depths to rise uncharacteristically high in storm sewers. The potential for such occurrences in the West Park project area and their associated effects need to be considered in future design improvements, which may involve options for safe surface relief of excess pressure induced flows.

Sensitivity analyses were performed which show there is a large enough drop between the area of the treatment units and the storm sewer downstream where both branches converge (R32) that downstream conditions are not expected to impact the design recommendations.

Preliminary Recommendations

Additional testing and analysis should be performed on the south ASC units (T-5, T-6, T-7 and T-8) to verify if the units were manufactured according to the technical specifications. Additionally, further investigative work should be performed to verify if the units are exhibiting signs of structural failure, as the existing information for these units is not 100% conclusive.

Several recommendations for improving flow conveyance while maintaining treatment of the first flush flow rate were determined. The recommendations were based on providing first flush treatment of 50 cfs and a peak design flow of 125 cfs for the north branch and first flush treatment of 55 cfs and a peak design flow of 198 cfs for the south branch.

One of the design considerations for the diversion weirs located in structures 19 and 14, which direct flow to the south and north treatment units respectively, was to prevent the area downstream the weir from acting as a restriction in the event the weir becomes flooded. This was accomplished by developing a geometric design that ensures the area within the manhole in front of and behind each weir is equal. For the North Branch, this resulted in a 10 foot weir that passes through the center of the existing manhole/diversion structure. For the south branch, this results in a wedge shaped weir with the point of the wedge facing incoming flow.

Since hydraulics for the north branch were fairly straightforward, a single alternative for accommodating the flow was developed. The alternative includes the construction of a 10 ft long weir that is 3.5 ft in height in the north diversion structure ST-14 (North Alternative 1). It is unknown at this time if the 10 ft long weir can be retrofitted in the existing 10 ft diameter diversion structure (Option A), therefore the cost of a second option to build the weir in a new 12 ft structure is provided (Option B). The option selected will be confirmed during design. The configuration of the north ASC units includes three 90º bends that may pose a maintenance problem in the future. While not needed for flow conveyance, an additional optional recommendation and associated cost of replacing these bends with manhole structures to facilitate maintenance is provided. A summary of the north branch recommendations is included in Table A (below).

Table A: Summary of Recommendations and Costs for North Branch

Recommendation Options	Estimated Cost
North Alternative 1 – Option A Modify Existing Diversion Structure ST-14 and construct new 10 ft long 3.5 ft high weir	$70,000
North Alternative 1 – Option B Replace Diversion Structure ST-14 with a new 12-foot diameter structure and construct new 10 ft long 3.5 ft high weir	$83,300
Maintenance Recommendation – Optional Remove the three existing 24-inch diameter 90 degree pipe bends and replace them with new 5-foot diameter drainage structures	$55,100

For the north branch, Alternative 1 either Option A or Option B will need to be selected. The proposed maintenance recommendation is optional.

The hydraulic performance of the south branch is more complex; therefore, five different alternatives were developed as follows:

South Alternative 1: Construct new 12 ft long 2.75 ft high weir in diversion structure ST-19.

South Alternative 2: Construct new 12 ft long 2.75 ft high weir in diversion structure ST-19, replace and lower the 54-inch diameter pipe segment located between Structures ST-18 and R31 and replace Structure R31 with a new 10-foot diameter structure.

South Alternative 3: Alternative 2 plus remove and/or abandon the 42-inch diameter pipe segments located between Structures ST-18, and ST-18A and ST-18B, and install new pipe that would be redirected to a new Structure R31, which would be replaced with a specialty structure rather than a 10 ft structure.

South Alternative 4: Identical to South Alternative 3 with the exception the weir height is 1 ft high.

South Alternative 5: Construct 12 ft long 1.0 ft high weir and remove and/or abandon the 42-inch diameter pipe segments located between Structures ST-18, and ST-18A and ST-18B, and install new pipe that would be redirected to a new Structure R31, which would be replaced with a specialty structure.

Similar to the north branch discussion, it is unknown at this time if the 12 ft long weir can be retrofitted in the existing 10 ft diameter diversion structure (Option A); therefore, the cost of a second option to build the weir in a new 12 ft structure is provided (Option B). The option selected will be confirmed during design. A summary of the south branch recommendations and costs are included in Table B.

Table B: Summary of Recommendations and Costs for South Branch

Recommendation Options	Weir Improvements Estimated Cost	54" Pipe Improvements Estimated Cost	42" Pipe Improvements Estimated Cost	Total Cost
South Branch Alternative 1 - Option A Modify Diversion Structure ST-19 and construct new 12 ft long 2.75 ft high weir.	$80,100			$80,100
South Branch Alternative 1 - Option B Replace Diversion Structure ST-19 with a new 12-foot diameter structure and construct new 12 ft long 2.75 ft high weir.	$90,700			$90,700
South Alternative 2 Alternative 1 Option A or Option B plus replace and lower the 54-inch diameter pipe segment located between Structures ST-18 and R31, and replace Structure R31 with a new 10-foot diameter structure.	$80,100 or $90,700	$65,100		$145,200 – $155,800
South Alternative 3 Alternative 2 plus remove and/or abandon the 42-inch diameter pipe segments located between Structures ST-18, and ST-18A and ST-18B, and install new pipe that would be redirected to a new Structure R31, which would be replaced with a specialty structure rather than a 10 ft structure.	$80,100 or $90,700	$65,100 *	$87,400 *	$232,600 – $243,200
South Alternative 4 Identical to South Alternative 3 with the exception the weir height is only 1 ft high.	$80,100 or $90,700	$65,100 *	$87,400 *	$232,600 – $243,200
South Alternative 5 Construct 12 ft long 1.0 ft high weir and remove and/or abandon the 42-inch diameter pipe segments located between Structures ST-18, and ST-18A and ST-18B, and install new pipe that would be redirected to a new Structure R31, which would be replaced with a specialty structure.	$80,100 or $90,700		$87,400	$167,500 – $178,100

* The cost for upgrading R31 is included in both estimates. Therefore, if South Alternative 3 or South Alternative 4 is selected, the total cost range can be reduced by $24,800 which is the cost savings of eliminating the redundant R31 structure.

Forensic Evaluation of Available Background Information

Forensic Evaluation of Available Background Information

OHM has completed its review of the West Park Renovations Project and the information provided by the City pertaining to the design and construction of certain storm sewer improvements completed during the project. The objective of this review was to 1) understand the engineering and construction history leading up to the observed collapse of one of these improvements – a swirl concentrator unit – 2) develop engineering conclusions from available information regarding the causes of the observed collapse and 3) develop recommendations for the remediation of the storm sewer improvements. The following sections summarize the results of this review.

The attached Exhibit A (Page 13), Document Review Summary, contains a partial list of the documents OHM reviewed. Our review was limited to the 54-inch diameter storm sewer segments, the AS-12 AquaSwirl Concentrator (ASC) units, and the related piping and drainage structures that were constructed to complete the treatment systems. These systems were designed to divert portions of the stormwater flow from branches of the Allen Creek Drain, and then after treatment, return it to the drain for ultimate discharge into the Huron River. As part of the review, OHM requested and received a number of documents from the City. Although this information represented a substantial sampling of the project record, it did not provide a first-hand accounting of all of the discussions, decisions or efforts that produced the project, or may have had some effect on its outcome. We therefore have drawn certain conclusions based on our best understanding of the information provided.

The information that was reviewed can generally be categorized as being part of one of the three project phases: Design, Construction and Post-Construction phases. For the purposes of our review, the construction phase was assumed to cover the period from the time of project bidding through the collapse and observed failure of ASC unit TS-4. The post-construction phase shall include the period following the collapse and continuing through the investigation efforts that followed up to the time of this writing.

The goal of the forensic review was to help determine if the treatment systems were constructed in accordance with the contract documents, the approved shop-drawing and material submittals, and the recommendations of the designer and manufacturer. An expected outcome of this review is an explanation of why some of the treatment units have failed and whether failures, or other system limitations, contributed to the upstream flooding that has been observed. Another expected outcome is if deficiencies were discovered, options could be recommended for their mitigation, including a cost-effective repair(s), to minimize further disruption or public inconvenience and restore West Park to its full and intended use.

Design Phase

As part of this phase, OHM reviewed various meeting minutes, correspondence, photographs, record drawings, bidding documents and addenda. We also reviewed related information that could be obtained from the City's GIS database. Based on this review, OHM made the following observations:

1. The Contract Documents for the project did not include specifications for ASC units. The only reference to storm sewer construction is covered in the Standard Specifications, which references the Public Services Department Standard Specifications. Upon review of these City standards for storm sewer construction, no reference or specification could be found for ASC units or even generic swirl concentrator storm sewer treatment units. It should be noted, however, the plans did include AquaShield details and schematic layouts for ASC units and corresponding pipe manifold systems.

2. Upon reviewing the plans and details that were included, conflicting information was observed in regard to pipe sizes and invert elevations for the storm sewer construction relating to the treatment systems.

3. Sheet C8.2 of the plans indicates the weir heights in the diversion structures were to be constructed at 30 inches for the south branch and 42 inches for the north branch. However, due to plan discrepancies, it appears both weirs were intended to be constructed at heights of 42 inches. The plan discrepancies appear to be the result of information that may not have been updated during plan preparation. No specific elevations were shown on the plans for the tops of the weirs.

4. Plan details call for Class II granular material to be used for pipe bedding and backfilling within one foot of the storm sewers within turf areas, and up to grade at locations which were in direct influence of paved areas. This is consistent with standard engineering practices.

5. Addendum No. 2 included the statement, “Backfill for the treatment units shall be MDOT Class II sand.”

6. The approved shop-drawing submittals for the ASC units specify backfill to be comprised of “Class I or II stone materials, (well graded gravels, gravely sands; contains little or no fines) as defined by ASTM D 2321, Section 5, Material, and compacted to 95% proctor density.” It would appear there was some confusion as to what type of backfill was to be used for the treatment units.

Construction Phase

As part of this phase, OHM reviewed various meeting minutes, correspondence, photographs, observation reports, material test reports, and materials and shop drawing submittals and approvals. Based on this review, there were a number of observations made which include:

1. Based on a review of the approved materials certifications and construction photographs, it appears the ASC units were backfilled with MDOT Class 6A aggregate. However, the sieve analysis that was provided as part of the certification submittal indicated the material did not meet MDOT’s specified maximum of one percent loss of fines by wash. The average of five tests indicated a loss of 3.9 percent. In addition, the gradation of the material did not meet the criteria for a “well-graded material,” as specified by AquaShield. It is unclear as to whether these material differences would be considered significant by AquaShield. No information could be found indicating these material differences were discussed with AquaShield or called out specifically and waived by Beckett & Raeder, Inc. (BRI).

2. Based on a review of the approved shop drawings and plans, it was determined that unit TS-4 had the greatest amount of earth cover, approximately 9.4 feet, when compared to the other units. It was also determined the other ASC units along the north branch (TS-1, TS-2 and TS-3) had more earth cover than the remaining ASC units along the south branch (TS-5, TS-6, TS-7 and TS-8). The attached Exhibit B (Page 15), Earth Cover Summary, contains information pertaining to the depth of bury for all of the ASC units.

3. Based on the record drawings provided by BRI. The following comparisons (Table C, Page 8) can be made regarding the top of weir elevations.

Table C: Top of Weir Elevations

	Per Plan	Approved Shop Drawings	Record Drawings
North Diversion Structure No. 14	N/A	816.5	816.78
South Diversion Structure No. 19	N/A	811.87	813.73*

* This compares to 811.74, which was identified in the Construction Report for June 18, 2010, as the constructed weir elevation.

Post-Construction Phase

As part of this phase, OHM reviewed various correspondence, photographs, video inspections and submitted remediation plan, all relating to the ASC units and treatment system. Based on this review, there were a number of observations made which include:

1. It was determined that at least four of the eight ASC units (TS-1, TS-2, TS-3 and TS-4) have failed with either total or partial ceiling collapse based on video inspections performed by the City and Terra Contracting. In addition, the vent pipe for TS-7 has failed. Due to the limitations of these video inspections, a conclusive statement as to the conditions of the remaining treatment units could not be made. Further investigation would be needed before a recommendation could be made as to their condition and acceptance.

2. A review of the video inspection performed by Terra Contracting indicates certain sections of the piping are restricted by the presence of what appears to be sand or gravel. It is unclear as to how this material was deposited. In addition, there are a few locations where it appears fine soils may be entering the pipe through pipe and manhole connections. For a more detailed explanation of what was observed, please reference attached Exhibit C (Page 16), Summary of Terra Video Inspection.

3. It would appear portions of the treatment units within the north branch may not be able to meet the City's requirement of having Vactor trucks access as close as 20 feet from the access manholes and riser sections. This distance would allow vehicles in some cases to encroach within the 1H:1V loading influence zone of the roofs and side walls of the treatment units.

4. Based on corings that were obtained from TS-4, the average roof thickness was determined to be approximately 0.371 inches, and not 0.787 inches as claimed by the manufacturer.

5. Based on a review of the project plans, record drawings and OHM field survey work, some pipe inverts and slope differences were observed. For a summary of this information, please reference attached Exhibit D (Page 17) Invert Data Sources and Differences, and Exhibit E (Page 18), Comparison of Treatment Units and Associated Structure Elevations.

Failure Evaluation

OHM has completed its evaluation of TS-4 and the factors that may have contributed to the collapse of its roof and the structural failures that have been observed in the remaining ASC units of the north branch (TS1, TS-2 and TS-3). Our evaluation centered on the possible modes of failure of the units and whether factors relating to their design, manufacture or installation, all or in part, contributed to the failures that have been observed. Although our evaluation concentrated on the units of the north branch, and unit TS-4 most specifically, much of our findings, including possible concerns of structural deficiencies or lower than expected factors of safety (FS) for the specific application(s), could raise similar concerns for the ASC units of the south branch (TS-5, TS-6, TS-7 and TS-8). The following sections summarize the results of this evaluation.

Mode of Failure

The first recorded evidence of the collapse of the TS-4 unit was the observation by on-site construction personnel of a sinkhole centered on TS-4. Photos taken during exploratory excavation of this sinkhole show the top of TS-4 had disconnected from the sides, collapsed into TS-4, and was subsequently buried under backfill material which fell in the now open structure. The top was removed from TS-4 for further investigation. The four fiber-reinforced plastic (FRP) beams that stiffen the top of TS-4 were broken on each side – apparently sheared away from the sidewalls due to deflection under the action of loads on the top. Also, the additional fiber reinforcement placed at the top connection to the sidewall appears to have completely sheared away from the sidewall FRP. Video recordings provided by the City of Ann Arbor show the remaining three north ASC units (TS-1, TS-2, and TS-3) also show signs of distress – cracks and delamination – at the beam connections to the sidewalls. Therefore, the structures all appear to show signs of loading in excess of the structure's structural capacity as manufactured and constructed to accept.

Evaluation of TS-4 Loading

According to the field observations, the collapse of ASC unit TS-4 appears to have been caused by excessive loading (defined as loading in excess of the structure's structural capacity as manufactured and constructed) leading to shearing at the support walls. From the construction drawings, it appears the bituminous path/park access drive passes within 2 feet of TS-4. Even though daily construction inspection reports state the area near the north path was used by construction traffic, no direct evidence is available to suggest vehicles drove directly over, or in direct contact with, the north units. This limited offset distance would allow certain vehicles in some cases to encroach within the 1H:1V loading influence zone of the roof and side wall of TS-4. However, based on comments and calculations received from LF Manufacturing, Inc. (LFM) at our May 11, 2011 meeting to discuss their proposed Remediation Plan, it was their assertion that truck traffic on the ground above TS-4 should not have caused the collapse. In fact, this argument was supported in their basis for claiming that some direct contact between construction traffic, or an unknown vehicle(s), with the access riser(s) of TS-4 was the actual cause for the observed damage. This claim was, in our opinion, unsupported and would not have resulted in the nearly uniform distress seen in the remaining north units.

Upon review of the contract documents for the project, we could find no provisions for placing fencing or any other type of barrier to prevent vehicles from driving near or above the installed treatment units. However, Site Development, Inc. (SDI) has stated construction fencing was placed after the installation of the treatment units to prevent traffic from driving over the access castings and covers. This appears to be supported by photographs taken during the construction which show placement of orange construction fencing separating the north units from what appears to be a construction traffic access path. It suggests these measures were only temporary, however, and it is unclear as to what discussions SDI may have had with the City or BRI prior to the fence placement and the timing of its removal.

The construction drawings include an AquaShield note that states "Bollards shall be placed around access riser(s) in non-traffic areas to prevent inadvertent loading by maintenance vehicles." Further, the approved shop drawings include details that specify where traffic loading (H-20) is required or anticipated, depending on the amount of earth cover, either a small 5-foot by 5-foot concrete pad or larger engineered concrete pad would be required to support the access castings and covers.

From an engineering point of view, it is unclear as to what was the intent of the original designer in this regard. Were these recommendations ignored, or were they just missed? Either way, it would appear construction traffic is not the most likely cause of the collapse, but rather the thinner-than designed roof thickness, as discussed in the following subsections.

The design burial depth for TS-4 is approximately 9.4 feet. This depth appears to have been constructed in general conformance with the proposed drawings. Therefore, the actual soil loading appears to be nominal per design.

Evaluation of TS-4 Installation

Backfill materials and methods of backfill are important factors in the performance of buried structures. Post-failure field compaction tests and soil analysis performed by CTI and Associates, Inc. on the backfill materials around TS-4 suggest the specified compaction for the base course may not have been achieved. In addition, it also suggests MDOT Class 6A aggregate was most likely used for the backfill material however, the analysis performed on the sampled material could not render a definitive comparison to the required material properties because of possible post-failure contamination of the backfill aggregate with fine materials since the time of construction. None of the testing reports received from the inspector discuss testing of backfill material around the units. It is also not clear from inspection reports if any compactive efforts were applied to the backfill around TS-4. No obvious distress has been noted in the TS-4 sidewall, suggesting the stone backfill may be providing adequate support to TS-4. Knowledge of TS-4 installation is inconclusive regarding the cause of TS-4 failure. As for the acceptability of MDOT Class 6A aggregate as backfill material for the treatment units, we would need to defer this question to the original designer and AquaShield. However, it would appear MDOT Class 6A aggregate, as a coarse aggregate, meets most of AquaShield's stated requirements.

Evaluation of TS-4 Design and Manufacture

The design plans and shop drawings lack typical details such as dimensions and thickness for the FRP structure of TS-4. The design plans reference ASTM D3299, "Standard Specification for Filament-Wound Glass-Fiber-Reinforced Thermoset Resin Corrosion-Resistant Tanks." This standard describes the design, material and workmanship requirements for FRP tanks. The standard is for above-ground tanks but allows for the calculation of external pressures. External pressures are expected to act on tanks buried in soil. The standard includes a required thickness calculation for torispherical FRP top heads. For tanks buried under 9 feet of soil overburden, this calculation yields required thickness values >0.67 inches. Based on the seven core samples taken by OHM from the top of TS-4, the average thickness of the top is 0.371 in. Also, the standard does not mention flat top heads. Therefore, the structures as built did not match the criteria set forth in the ASTM standards identified on the unit shop drawings – necessitating engineering calculations to support an alternate design.

It is clear from ASTM D3299 that torispherical top heads are regarded as the typical and appropriate configuration for FRP tank top heads. Due to the orientation of the reinforcement in FRP, the joint between the tank wall and torispherical top head is expected to be more robust under load than a flat top head of equal thickness. A joint with a torispherical top head would conduct more of the load in compression in the direction of reinforcement, a loading mode where FRP is relatively strong, instead of shear transverse to the reinforcement, a loading mode where FRP is relatively weak and prone to delamination. Therefore, the thickness of a flat top head required to deliver the same structural performance as a torispherical top head is expected to be significantly greater. In lieu of a thicker top head for the flat top design, beams can be used to stiffen the top head and increase the load it can safely carry. However, ASTM D3299 does not provide guidance for performing the required calculations. Therefore, separate engineering calculations are required.

These engineering calculations were eventually received from LFM. Based on these calculations, performed by Chemco Engineering, Inc., cover thickness values of 0.588 inches and 0.787 inches would provide a FS of one and five respectively, for conditions where there would be nine feet of earth cover at a soil unit weight of 120 lbs/cu ft, over the units. This assumed unit weight is less than that measured in the field (129 lbs/cu ft) for the MDOT Class 6A aggregate that was used as backfill for the ASC units. Also, saturated aggregate would have an even greater unit weight (144 lbs/cu ft). A higher unit weight would result in a lower FS value for the same cover thickness. In addition, earth loading may have been exacerbated by other factors, including mounding of backfill materials during construction.

LFM fabrication drawings indicate a thickness of 0.750 inches was selected for the top. At this thickness, the theoretical FS would have been less than five. Therefore, since the average measured top thickness is 0.371 inches, it appears the top of unit TS-4 was constructed with a thickness that provides a factor of safety of less than one. In other words, the top of TS-4 is not capable of handling the design site conditions and is therefore prone to fail, which is what was observed. Furthermore, LFM calculations suggest the design top thickness, based on an assumed 0.787 inches, was also capable of supporting construction traffic loading. Therefore, the inadequate top thickness appears to be the most conclusive cause of the observed collapse of TS- 4.

At our May 11, 2011 meeting with LFM, they asserted an FS of less than one would provide conditions that would be theoretically prone to failure due to loading. In addition, they provided no explanation as to why the specified roof thickness of at least 0.750 inches (per their fabrication drawing) was not provided.

Evaluation of South Branch ASC Units

The south ASC units (TS-5, TS-6, TS-7 and TS-8) do not appear to exhibit the same structural distress as was observed in the north units; however, they are subject to less earth loading than the north ACS units (TS-1, TS-2, TS-3 and TS-4), as their overburden depths are less. Based on the observed manufacturing defect of TS-4, and the observation the other north units are failing, it is anticipated the south units have similar defects. Additional testing and analysis would need to be performed before an opinion could be rendered as to their suitability and acceptance. Precautionary measures should continue to be implemented to restrict access near all of the remaining units to reduce the risk of possible roof failure and collapse.

Document Review Summary
City of Ann Arbor - West Park Swirl

Reviews completed through June 30, 2011

Document Author	Document Title	Date	Notes
Chemco Engineering, Inc.	Letters	11/18/2011 2/15/2011	Reviewed.
L.F. Mfg., Inc. AquaShield, Inc. Site Development, Inc.	Correction Action Plan Summary	5/16/2011	Reviewed.
L.F. Mfg., Inc. AquaShield, Inc. Site Development, Inc.	Remediation Plan	5/11/2011	Reviewed.
Terra Contracting	Summary of Video Inspection	5/2/2011	Info has been reviewed.
Victor F. Sanchez, PE	Structural Concrete Slab Calculations	4/30/2011	Reviewed.
City of Ann Arbor	Summary of Video Inspection	3/31/2011	Info has been reviewed.
Beckett & Raeder	Construction Report [IDR]	11/15/2010 and 11/17/2010	AquaShield, L.F. Manufacturing, Inc., GAB Robins, WCWRC, BRI, and City of Ann Arbor personnel observed excavation of collapsed unit (TS#4). “It appears that the top of the tanks sheared off at the connections with the sides and collapsed inside the structure.”
Beckett & Raeder	As-Built Drawings	7/13/2010	Reviewed.
Beckett & Raeder	Construction Report [IDR]	7/6/2010 to 11/11/2010	7/20/10: Reference to rain overnight causing displacement of the top to structure #19. 8/11/10: Reference to heavy rain causing water to pour out of TS#7, TS#8 and #19. Also, water overtopping the curb on 7th Street and the top of structure #19 being shifted. 8/12/10: City gave direction to remove diversion wall in structure #19 8/16/10: The diversion wall was removed from structure #19. 8/17/10: Reference to surveyor (Nederveld) being on site staking walk. 8/26/10 – 8/31/10: some areas of Area 2 pathway used for haul road and required repair. 9/7/10: Area 2 paving 9/22/10: gaps between castings and risers for TS#1 through TS#4 were grouted per WCWRC. 11/15/10: It was discovered that TS#4 apparently collapsed over the weekend. 11/17/10: Stuart Ellis (AquaShield) Kenneth Glasgow (LF Manufacturing, Inc.), and Mark Welton (GAB Robins) were on site to observe the unearthing of TS#4. Harry Sheehan and Dennis Wojick (WCWRC), and Amy Kuras (City of Ann Arbor) were also on site part of the time to observe the excavation/work. SDI dug down to the top of the structure and, at the request of AquaShield, two feet around the outside of the structure so the top of the structure could be removed for observation. It appeared that the top of the unit sheared off at the connections with the sides and collapsed inside the structure. It appeared that the baffle inside of the structure also appeared to be damaged.
Beckett & Raeder	Construction Progress Meeting Notes	3/15/2010 to 11/17/2010	3/11/10: Pre-Construction Meeting.
Beckett & Raeder	Construction Photographs	3/15/2010 to 11/17/2010	Reviewed.
Beckett & Raeder	Construction Report [IDR]	3/15/2010 to 6/29/2010	5/20/10: First reference to surveyor being on site to stake storm structures in area 2. 5/26/10: TS#8 set 5/27/10: excavation of TS#4; concern about reducing tees not matching drawings and no submittal was approved for the fittings prior to installation. 5/28/10: TS#4 and TS#7 set 6/2/10: TS#3 and TS#5 set 6/3/10: TS#2 and TS#6 set 6/8/10: “[SDI] laid remaining manifold north of AquaSwirl units and manifold south of AquaSwirl units TS 4 to TS 3 as well as backfilling around AquaSwirl units with stone.” Crews prepared for rainfall. 6/15/10: AquaSwirl rims set There is no mention of TS#1 being set 6/22/10: Reference to rain overnight causing the top of structure #19 to shift approximately 6 inches, and pea gravel and sand was discovered in the manifold from structure #14A to TS#1 and TS#2.

Document Review Summary

City of Ann Arbor - West Park Swirl

Reviews completed through June 30, 2011

Document Author	Document Title	Date	Notes
Site Development, Inc. and AquaShield, Inc.	Submittal No. [shop drawings/submittal]	3/5/2010	Shop drawings for all treatment units were approved, signed and dated.
			Assumed ground water elevations for units TS#1 –TS#4 vary as follows: 816.70 TS#1 816.18 TS#2 818.90 TS#3 819.60 TS#4
			Assumed ground water elevations for units TS#5 –TS#8 vary as follows: 809.70 TS#5 808.70 TS#6 808.00 TS#7 808.10 TS#8
Site Development, Inc. and AquaShield, Inc.	Submittal No. 00000.01 [shop drawings/submittal]	1/26/2010	Fiber Reinforced Polyester (FRP) construction indicated for swirl concentrator units.
			No approval stamp/letter noted.
			AquaShield unable to release product without approval.
			AquaShield requesting confirmation of design dimensions and burial depth.
			AquaShield asking whether or not a concrete pad is required.
			No concrete pad above units shown on drawings.
			Reinforced top indicated on drawings.
Beckett & Raeder	Bid Set	9/28/2009	Reviewed.
			North Branch There is 0.65' (0.44'- 0.47' AB) of fall between the invert of the weir manhole outlet pipe and the invert of the treatment units. There is 0.65' (2.08'-2.11' AB) of fall between the treatment units and the 54" storm sewer.
			South Branch There is 0.30' (0.21'-0.36' AB) of fall between the invert of the weir manhole discharge pipe and the invert of the treatment units. There is 0.05' (0.09'-0.24' AB) of fall between the treatment units and the 54" storm sewer.
Beckett & Raeder	Basis of Design Report	9/4/2009	Reviewed.
City of Ann Arbor	Contract Documents for West Park Renovations	9/1/2009	Reviewed
Beckett & Raeder	Design Meeting Notes	12/8/2008, 11/20/2008, 8/22/2009	Reviewed.
McNamee, Porter & Seeley	Allen's Creek Drainage Improvement Project	4/14/1995	Construction Drawings, Reviewed.
Menefee and Dodge	West Park Miller Avenue Drain	1928	Reviewed.
City of Ann Arbor	Plan and Profile of Sanitary Sewer	3/18/1915	Reviewed.

West Park Storm Sewer Analysis and Repair Project
Earth Cover Summary at ASC Treatment Units

Unit	Earth Cover * (in)	Earth Cover * (ft)
TS-1	84 3/16	7.016
TS-2	95	7.917
TS-3	104 5/8	8.719
TS-4	113	9.417
TS-5	69 9/16	5.797
TS-6	57 9/16	4.797
TS-7	49 3/16	4.099
TS-8	50 3/8	4.198

* Estimated maximum earth cover per approved shop drawings

West Park Storm Sewer Analysis and Repair Project

Summary of Video Inspection Performed by Terra Contracting 5/2/2011

North Branch

1. Units TS-1, TS-2 and TS-3 have remnants of debris stuck to their ceilings and chimneys.
2. The ceilings of each unit are supported by composite beams or channels that run parallel to each other and are oriented in one direction.
3. Units TS-1, TS-2 and TS-3 have roof sections that have begun to fail, and it appears that the failure is occurring where the beams connect to the outside walls of the structures.
4. Unit TS-1 appears to be much worse than the other units.
5. The discharge manifold that connects the treatment units to MH # 13A appears to be partially filled with sand and gravel. This may have resulted from the failure of Unit TS-4.
6. The inlet manifold that connects Units TS-2 and TS-1 to MH # 14A appears to be filled with 3-4 inches of wet sand and gravel.
7. The inlet manifold that connects Unit TS-4 to the 42 inch by 24 inch reducer is filled with sand and gravel. This may have resulted from the failure of Unit TS-4.
8. It was not possible to video inspect the 42-inch diameter storm sewer from MH # 13A to MH # 13 due to the presence of several inches of water. It appears that there may be some accumulated sand or gravel, but it is inconclusive. The bulkhead at MH # 13 would need to be removed to lower the water level and allow for additional inspection.
9. The west pipe connection at MH #13A (inlet) is leaking.
10. The east pipe connection at MH #14A (outlet) is leaking.
11. The south 90 degree bend at Unit TS-4 (inlet) is leaking at its easterly pipe connection and at the manufactured seam at the outside of the fitting.
12. The north 90 degree bend at Unit TS-4 (outlet) is leaking at the manufactured seam at the inside of the fitting.
13. There are some pipe joints/leaks that appear to be allowing the intrusion of fine soils.
14. The treatment units are isolated from the 54-inch storm sewer by way of bulkheads that were placed in MH #s 13 and 14.
15. There is some debris located in MH # 14 near the location where the diversion weir was removed.
16. At the time of the video inspection the 54-storm sewer had approximately 4 inches of flow.

South Branch

1. All Units have remnants of debris stuck to their ceilings and chimneys.
2. The ceilings of each unit appear to be reinforced with composite beams or channels that run parallel to each other and are oriented in one direction.
3. The inlet manifold that connects Units TS-7 and TS-8 to MH # 19 appears to be filled with more than 12 inches of wet sand and gravel (reference photo 122.jpg, 6/24/11).
4. The inlet pipe of Unit TS-6 appears to have some sand and gravel accumulation.
5. The vent Pipe for Unit TS-7 has failed, and it appears to be full of leaves and debris.
6. The weir plate in MH # 19 has not been completely removed. It is diverting approximately 6 inches of flow.
7. At the time of the video inspection the 54-storm sewer had approximately 5 inches of flow.

Exhibit D

West Park Storm Sewer Modeling
Invert Data Sources and Differences

Treatment Unit Manhole/Structure For North Branch

Beckett- Raeder As-Builts				OHM Survey				Rim Difference From As-Builts	Invert Difference From As Builts
Name	Rim	Direction	Inverts	Name	Rim	Direction	Inverts		
14	823.9	NW 54"	813.39	316	824.16	NW 54"	813.59	0.26	0.20
		SE 54"	812.49			SE 54"	812.62		0.13
		NE 42"	813.07			NE 42"	813.30		0.23
14A	823.9	SW 42"	812.76	314	823.84	SW 42"	812.74	-0.06	-0.02
		NW 42"	812.7			NW 42"	812.69		-0.01
		SE 42"	812.72			SE 42"	812.64		-0.08
13	821.3	NW 54"	810.67	315	821.1	NW 54"	810.72	-0.20	0.05
		SE 54"	810.4			SE 54"	810.58		0.18
		NE 42"	810.55			NE 42"	810.65		0.10
13A	824	NW 42"	812.53	314	824.06	NW 42"	812.57	0.06	0.04
		SW 42"	812.49			SW 42"	812.53		0.04

Treatment Unit Manhole/Structure For South Branch

Beckett- Raeder As-Builts				OHM Survey				Rim Difference From As-Builts	Invert Difference From As Builts
Name	Rim	Direction	Inverts	Name	Rim	Direction	Inverts		
18	815.8	E 54"	807.6	301	815.79	E 54"	807.62	-0.01	0.02
		W 54"	807.66			W 54"	807.60		-0.06
		N 42"	807.6			N 42"	807.61		0.01
		S 42"	807.6			S 42"	807.57		-0.03
18A	816.11	S 42"	807.61	302	816.11	S 42"	807.62	0	0.01
		W 24"	807.63			W 24"	807.62		-0.01
		SW 24"	807.8			SW 24"	807.79		-0.01
18B	814.8	N 42"	807.61	311	814.78	N 42"	807.53	-0.02	-0.08
		W 24"	807.63			W 24"	807.62		-0.01
		NW 24"	807.66			NW 24"	807.54		-0.12
19	817.2	W 54"	808.2	312	817.09	W 54"	808.21	-0.11	0.01
		E 54"	808.14			E 54"	807.95		-0.19
		N 42"	808.05			N 42"	808.05		0
		S 42"	808.05			S 42"	807.97		-0.08

West Park Storm Sewer Modeling
Comparison of Treatment Units and Associated Structure Elevations

North Branch

From Structure	To Structure	Plan Elevations		Plan Fall	As-Built Elevations		As-Built Fall Per Line	As-Built Cumulative Fall	OHM Elevations		OHM Fall Per Line	OHM Total Fall
Treatment Unit 1												
STR 14	STR 14A	813.00	812.50	0.50	813.07	812.76	0.31	0.31	813.30	812.74	0.56	0.56
STR 14A	TS-1	812.50	812.35	0.15	812.72	812.65	0.07	0.42	812.64	N/A	-	-
TS-1	STR 13A	812.35	812.20	0.15	812.65	812.53	0.12	0.54	N/A	812.57	0.07	0.73
STR 13A	STR 13	812.20	811.70	0.50	812.49	810.55	1.94	2.52	812.53	810.65	1.88	2.65
Treatment Unit 2												
STR 14	STR 14A	813.00	812.50	0.50	813.07	812.76	0.31	0.31	813.30	812.74	0.56	0.56
STR 14A	TS-2	812.50	812.35	0.15	812.72	812.63	0.09	0.44	812.64	N/A	-	-
TS-2	STR 13A	812.35	812.20	0.15	812.63	812.53	0.10	0.54	N/A	812.57	0.07	0.73
STR 13A	STR 13	812.20	811.70	0.50	812.49	810.55	1.94	2.52	812.53	810.65	1.88	2.65
Treatment Unit 3												
STR 14	STR 14A	813.00	812.50	0.50	813.07	812.76	0.31	0.31	813.30	812.74	0.56	0.56
STR 14A	TS-3	812.50	812.35	0.15	812.70	812.66	0.04	0.41	812.69	N/A	-	-
TS-3	STR 13A	812.35	812.20	0.15	812.66	812.53	0.13	0.54	N/A	812.57	0.12	0.73
STR 13A	STR 13	812.20	811.70	0.50	812.49	810.55	1.94	2.52	812.53	810.65	1.88	2.65
Treatment Unit 4												
STR 14	STR 14A	813.00	812.50	0.50	813.07	812.76	0.31	0.31	813.30	812.74	0.56	0.56
STR 14A	TS-4	812.50	812.35	0.15	813.39	812.66	0.73	0.41	812.69	N/A	-	-
TS-4	STR 13A	812.35	812.20	0.15	812.66	812.53	0.13	0.54	N/A	812.57	0.12	0.73
STR 13A	STR 13	812.20	811.70	0.50	812.49	810.55	1.94	2.52	812.53	810.65	1.88	2.65
Collector Pipe												
STR 13A	STR 13	812.20	811.70	0.50	812.49	810.55	-	1.94	812.53	810.65	-	1.88
Overflow / Bypass												
STR 14	STR 13	812.74	811.90	0.84	812.49	810.67	-	1.82	812.62	810.72	-	1.90

West Park Storm Sewer Modeling
Comparison of Treatment Units and Associated Structure Elevations

South Branch

From Structure	To Structure	Plan Elevations		Plan Fall	As-Built Elevations		As-Built Fall Per Line	As-Built Cumulative Fall	OHM Elevations		OHM Fall Per Line	OHM Cumulative Fall
North Outer Loop												
STR 19	TS-5	808.37	808.07	**0.30**	808.05	807.69	**0.36**	**0.36**	808.05	N/A	-	-
TS-5	STR 18A	808.07	808.18	-0.11	807.69	807.63	**0.06**	**0.42**	N/A	807.62	**0.43**	**0.43**
STR 18A	STR 18	808.18	808.02	**0.16**	807.61	807.60	**0.01**	**0.45**	807.62	807.61	**0.01**	**0.44**
North Inner Loop												
STR 19	TS-6	808.37	808.07	**0.30**	808.05	807.83	**0.22**	**0.22**	808.05	N/A	-	-
TS-6	STR 18A	808.07	808.18	-0.11	807.83	807.80	**0.03**	**0.25**	N/A	807.79	**0.26**	**0.26**
STR 18A	STR 18	808.18	808.02	**0.16**	807.61	807.60	**0.01**	**0.45**	807.62	807.61	**0.01**	**0.44**
South Outer Loop												
STR 19	TS-8	808.37	808.07	**0.30**	808.05	807.83	**0.22**	**0.22**	807.97	NA	-	-
TS-8	STR 18B	808.07	808.18	-0.11	807.83	807.63	**0.20**	**0.42**	N/A	807.54	**0.43**	**0.43**
STR 18B	STR 18	808.18	808.02	**0.16**	807.61	807.60	**0.01**	**0.45**	807.53	807.57	-0.04	**0.40**
South Inner Loop												
STR 19	TS-7	808.37	808.07	**0.30**	808.05	807.84	**0.21**	**0.21**	807.97	N/A	-	-
TS-7	STR 18B	808.07	808.18	-0.11	807.84	807.66	**0.18**	**0.39**	N/A	807.62	**0.35**	**0.35**
STR 18B	STR 18	808.18	808.02	**0.16**	807.61	807.60	**0.01**	**0.45**	807.53	807.57	-0.04	**0.40**
Overflow / Bypass												
STR 19	STR 18	808.30	808.10	**0.20**	808.14	807.66	**0.48**	**0.48**	807.95	807.60	**0.35**	**0.35**

West Park SWMM Modeling Technical Memorandum

West Park SWMM Modeling Technical Memorandum

Existing Conditions

The purpose of this technical memorandum is to recommend design modifications to the treatment systems to assure that appropriate flows are treated while upstream and downstream flow regimes are maintained. The project area and manholes referenced in this technical memorandum are shown in Figure 1on Page 2.

Revised Survey Information

In the process of reviewing the City of Ann Arbor SWMM model, City as-built elevations and survey data collected in the field as part of the West Park design project, some inconsistencies were noticed. This led to the decision for OHM to re-survey manhole structures in the West Park project area. This revised survey data was used in the project area SWMM model. Figure 2 on Page 21 shows the manholes surveyed as well as the difference between survey information from a variety of sources.

Development of First Flush Peak Flow Rate

The treatment units in the north and south branches are intended to provide treatment for a maximum flow rate corresponding to what is referred to as the first flush event. First flush peak flow rates were determined based on a 90% probability of non-exceedance criteria identified in the Southeast Michigan Council of Governments (SEMCOG) low impact development (LID) manual, the principles of which are accepted by the Michigan Department of Environmental Quality (MDEQ). The essence of the method is to size the system so there is only a 10% likelihood the first flush flow rate would be exceeded in any given year. Performing such an analysis necessitated the installation of temporary flow meters in both the north and south branches of the storm water system. Two meters were subsequently installed and collected several rain event responses, ranging from small to large events under a variety of antecedent moisture conditions for a total duration of approximately three months (April through June 2011). To determine the 90% probability of non-exceedance, an antecedent moisture hydrologic model was applied and calibrated to the existing flow data for each of the north and south branches. Table D showing the first flush flow rates and the plots of the flow data are shown below.

Table D: First Flush Flow Rates Based on Probability of Exceedance

	First Flush Flow Rates (cfs)	Probability of Exceedance
North Branch	50	10%
South Branch	55	10%

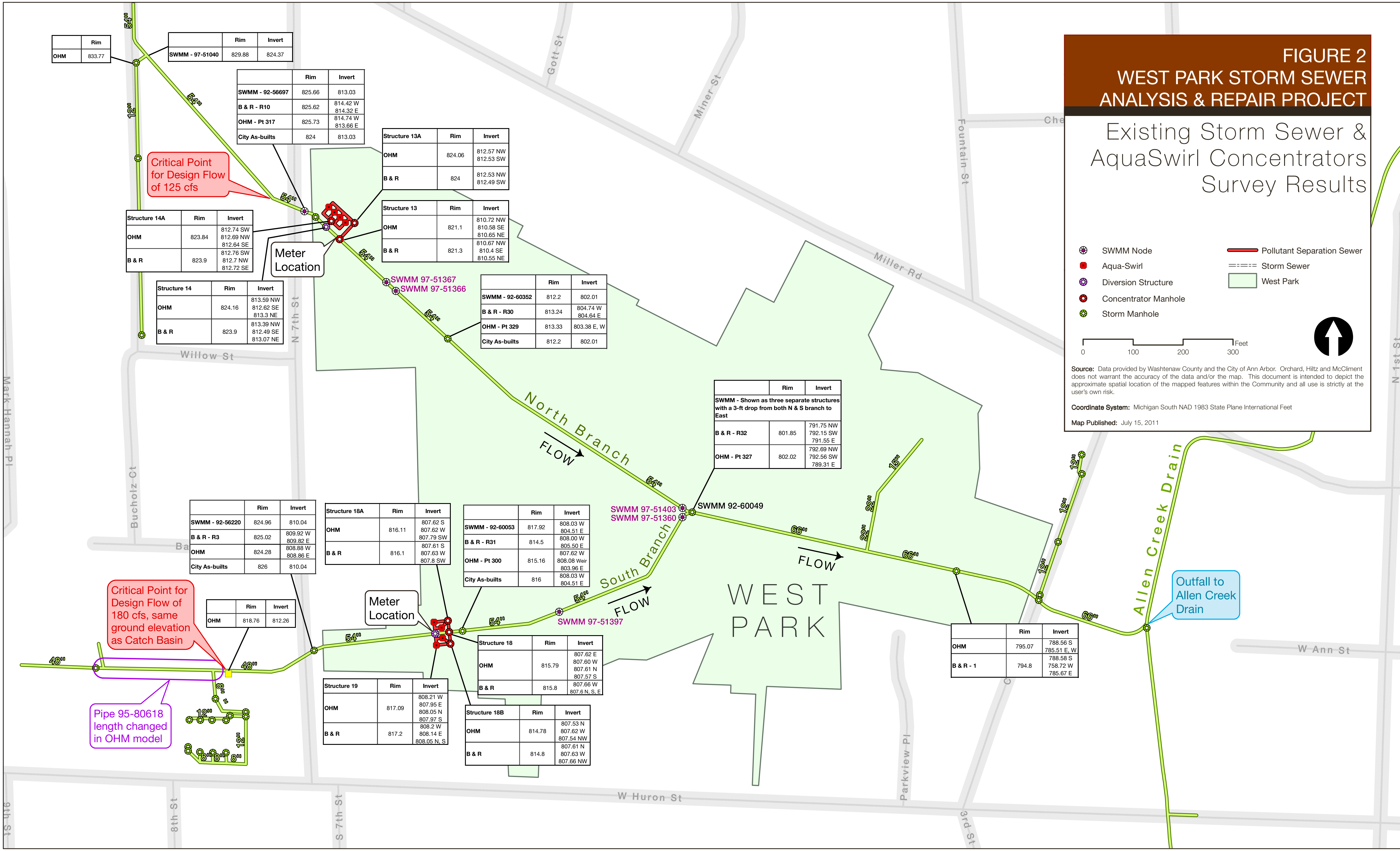


FIGURE 2
WEST PARK STORM SEWER
ANALYSIS & REPAIR PROJECT
Existing Storm Sewer &
AquaSwirl Concentrators
Survey Results
SWMM Node
Aqua-Swirl
Diversion Structure
Concentrator Manhole
Storm Manhole
Pollutant Separation Sewer
Storm Sewer
West Park
0 100 200 300 Feet
Source: Data provided by Washtenaw County and the City of Ann Arbor. Orchard, Hiltz and McCliment does not warrant the accuracy of the data and/or the map. This document is intended to depict the approximate spatial location of the mapped features within the Community and all use is strictly at the user's own risk.
Coordinate System: Michigan South NAD 1983 State Plane International Feet
Map Published: July 15, 2011
Rim | OHM 833.77
Rim | Invert | SWMM - 97-51040 829.88 824.37
Rim | Invert | SWMM - 92-56697 825.66 813.03 | B & R - R10 825.62 814.42 W 814.32 E | OHM - Pt 317 825.73 814.74 W 813.66 E | City As-builts 824 813.03
Structure 13A | Rim | Invert | OHM 824.06 812.57 NW 812.53 SW | B & R 824 812.53 NW 812.49 SW
Structure 13 | Rim | Invert | OHM 821.1 810.72 NW 810.58 SE 810.65 NE | B & R 821.3 810.67 NW 810.4 SE 810.55 NE
Structure 14A | Rim | Invert | OHM 823.84 812.74 SW 812.69 NW 812.64 SE | B & R 823.9 812.76 SW 812.7 NW 812.72 SE
Structure 14 | Rim | Invert | OHM 824.16 813.59 NW 812.62 SE 813.3 NE | B & R 823.9 813.39 NW 812.49 SE 813.07 NE
Rim | Invert | SWMM - 92-60352 812.2 802.01 | B & R - R30 813.24 804.74 W 804.64 E | OHM - Pt 329 813.33 803.38 E, W | City As-builts 812.2 802.01
Rim | Invert | SWMM - Shown as three separate structures with a 3-ft drop from both N & S branch to East | B & R - R32 801.85 791.75 NW 792.15 SW 791.55 E | OHM - Pt 327 802.02 792.69 NW 792.56 SW 789.31 E
Critical Point for Design Flow of 125 cfs
Meter Location
SWMM 97-51367
SWMM 97-51366
North Branch
FLOW
SWMM 97-51403
SWMM 97-51360
SWMM 92-60049
Rim | Invert | SWMM - 92-56220 824.96 810.04 | B & R - R3 825.02 809.92 W 809.82 E | OHM 824.28 808.88 W 808.86 E | City As-builts 826 810.04
Structure 18A | Rim | Invert | OHM 816.11 807.62 S 807.62 W 807.79 SW | B & R 816.1 807.61 S 807.63 W 807.8 SW
Rim | Invert | SWMM - 92-60053 817.92 808.03 W 804.51 E | B & R - R31 814.5 808.00 W 805.50 E | OHM - Pt 300 815.16 807.62 W 808.08 Weir 803.96 E | City As-builts 816 808.03 W 804.51 E
Critical Point for Design Flow of 180 cfs, same ground elevation as Catch Basin
Rim | Invert | OHM 818.76 812.26
Meter Location
South Branch
FLOW
SWMM 97-51397
WEST PARK
Outfall to Allen Creek Drain
Allen Creek Drain
Structure 18 | Rim | Invert | OHM 815.79 807.62 E 807.60 W 807.61 N 807.57 S | B & R 815.8 807.66 W 807.6 N, S, E
Structure 19 | Rim | Invert | OHM 817.09 808.21 W 807.95 E 808.05 N 807.97 S | B & R 817.2 808.2 W 808.14 E 808.05 N, S
Structure 18B | Rim | Invert | OHM 814.78 807.53 N 807.62 W 807.54 NW | B & R 814.8 807.61 N 807.63 W 807.66 NW
Rim | Invert | OHM 795.07 788.56 S 785.51 E, W | B & R - 1 794.8 788.58 S 758.72 W 785.67 E
Pipe 95-80618 length changed in OHM model
54" 12" 48" 66" 22" 16" 8" 6"
Gott St
Miner St
Fountain St
Miller Rd
N 7th St
Willow St
Mark Hannah Pl
Bucholz Ct
N 1st St
W Ann St
W Huron St
Parkview Pl
8th St
S 7th St
9th St
3rd St

Figure 3: Antecedent Moisture Model of North Branch Flow Rates

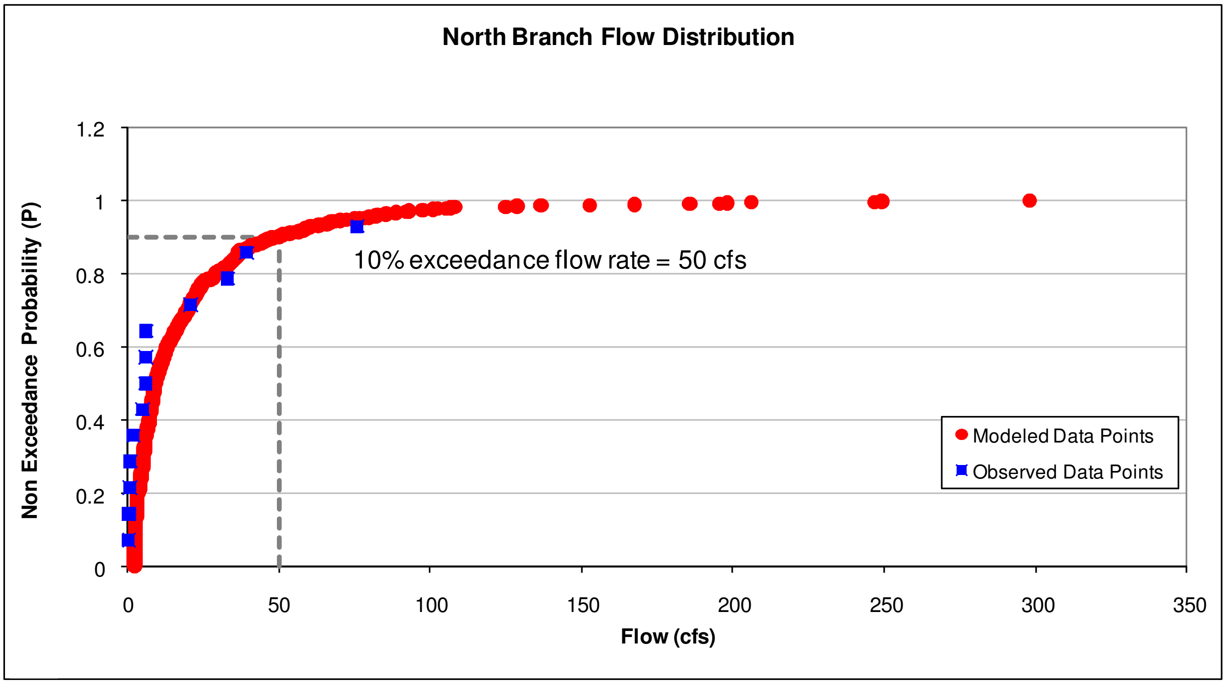
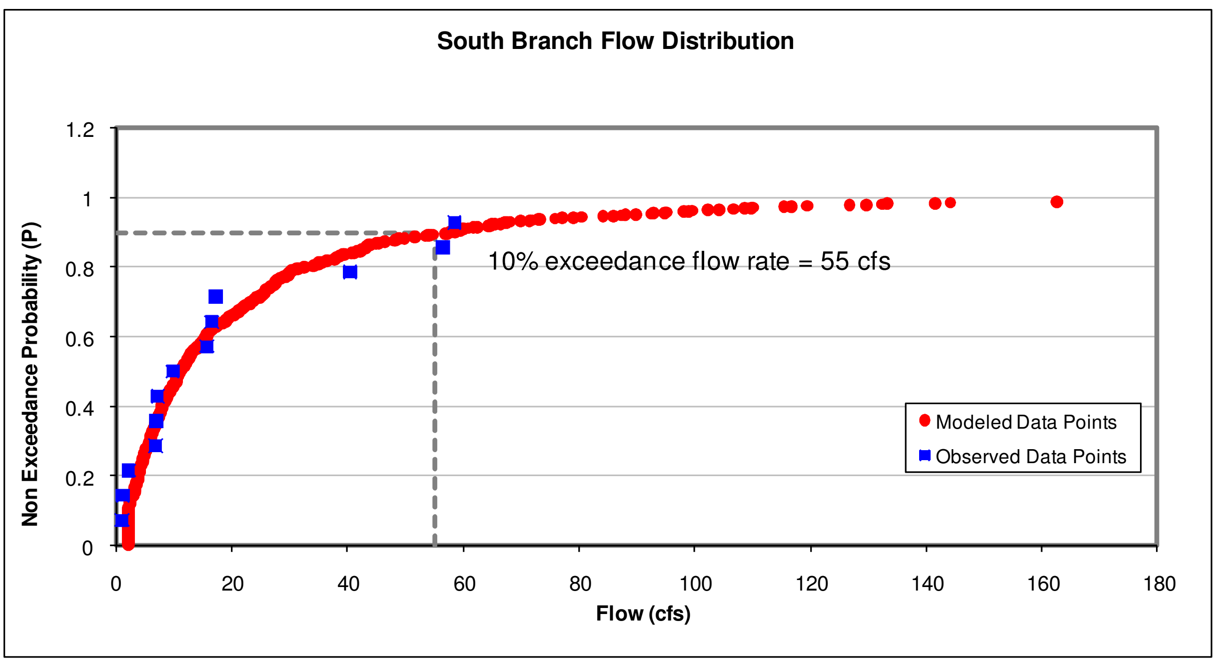


Figure 4: Antecedent Moisture Model of South Branch Flow Rates



Review of Modeling Assumptions

SWMM modeling results outlined in the subsequent sections of this technical memorandum included a set of important assumptions. These are further explained in the relevant sections at various parts of this technical memorandum. They include:

- The North Branch design capacity is reached when full pipe flow conditions exist upstream of the treatment units.
- The South Branch design capacity is reached when a critical manhole upstream is surcharged to ground level.
- For all proposed designs, a small weir located in the incoming pipe to MH 92-60053 (R31) has been removed.
- The length of pipe between structure 18 and R31 is shorter than originally estimated based on field observations. It appears to be only half the length listed in the original model.
- All treatment unit invert elevations were determined using the elevation offset from the upstream structure obtained by as-built plans provided by the City for the treatment units. This is because a survey is not possible of the treatment unit inverts.
- All buried pipes are assumed to follow a uniform slope between known points. This is necessary to determine the elevation of the tee junctions in the model.
- The City SWMM model shows pipe 95-80618 to be 15.78 ft. The City's GIS model shows the same pipe to be 218.76 feet. The length shown in the City GIS model was used in the revised model.
- The City's SWMM model shows a grade change (SWMM nodes 97-51367 and 97-51366) along the north branch that could not be verified in the field. Revised model removed the grade change and assumed a uniform pipe slope.
- An inlet (SWMM node 88-61720) was demolished during construction on the north branch. For the purposes of model stability, this node was removed and a uniform grade assumed for the OHM model.

Development of Design Event Peak Flow Rates

In addition to the first flush peak flow rate, a design event peak flow rate needed to be established in order to assess the impact of first flush driven proposed improvements on hydraulic grade lines (HGL) during larger design event level flow rates. In order to determine the design flow rates for the north and the south branches of the West Park storm sewer, data from the OHM survey of existing structures and ground elevations was used with two criteria. The north branch was considered to be at design capacity when a pipe upstream of the proposed treatment units became surcharged. The south branch was considered to be at design capacity when the HGL in the system upstream of the treatment units reached the elevation of a catch basin near a resident's garage to the West of 7th Street. Using these two criteria, the design flow rates were determined iteratively under steady state flow conditions. Based on these assumptions, the estimated design flow rates are summarized in Table E (Page 24).

Table E: Design Flow Rate and Return Periods for West Park Storm Sewer

	Design Flow Rates (cfs)	Return Period (year)
North Branch	125	1.7
South Branch (with weir)	180	2.1
South Branch (without weir)	198	2.5

During the OHM field survey, it was discovered a small weir-like structure had been installed in the incoming pipe to MH 92-60053 (R31 as per BRI plans) in the south branch. The small weir itself is located in the incoming 54" pipe and has a height of 0.49 feet. Unlike a typical weir, there is a smooth transition upstream of the small weir, much like a broad crested weir. Since the history of this weir is uncertain, it is important to understand effects this weir-like structure would have on the estimation of design flow rates.

To determine the flood mitigation effects of this structure, the small weir was removed in the existing conditions model. This was done by simply lowering the downstream invert of the conduit that contained the weir from 808.08 to 807.62.

With the small weir removed, it was observed the design capacity increased to 198 cfs from 180 cfs. This implies the small weir potentially attenuated approximately 18 cfs of peak flow and prevented it from reaching downstream. It should be noted that since OHM survey data was confined to the limits of West Park, the location of any potential downstream flooding due to this additional flow is uncertain.

Since flow metering data was collected and an antecedent moisture model was calibrated to it, this allowed for the generation of annual exceedance probability plots, which provided a context for the developed design peak flow rates. The plots showing the annual exceedance model are also shown on the next page. These plots suggest in broad terms, the design event peak flow rates should be expected about once every two years.

Figure 5: Annual Exceedance Plot for North Branch Flow Rates

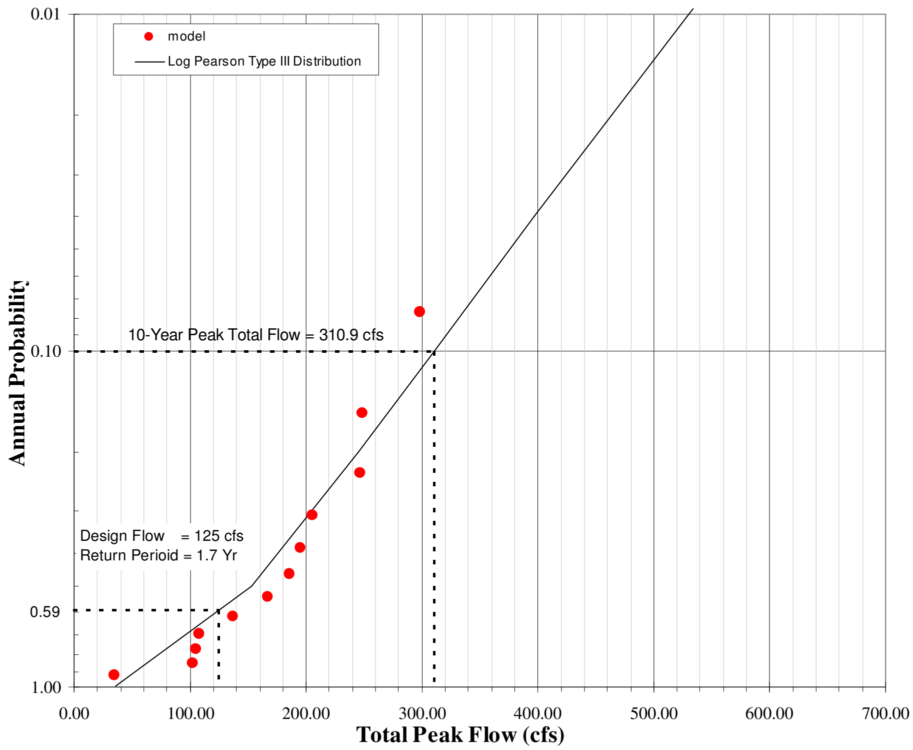
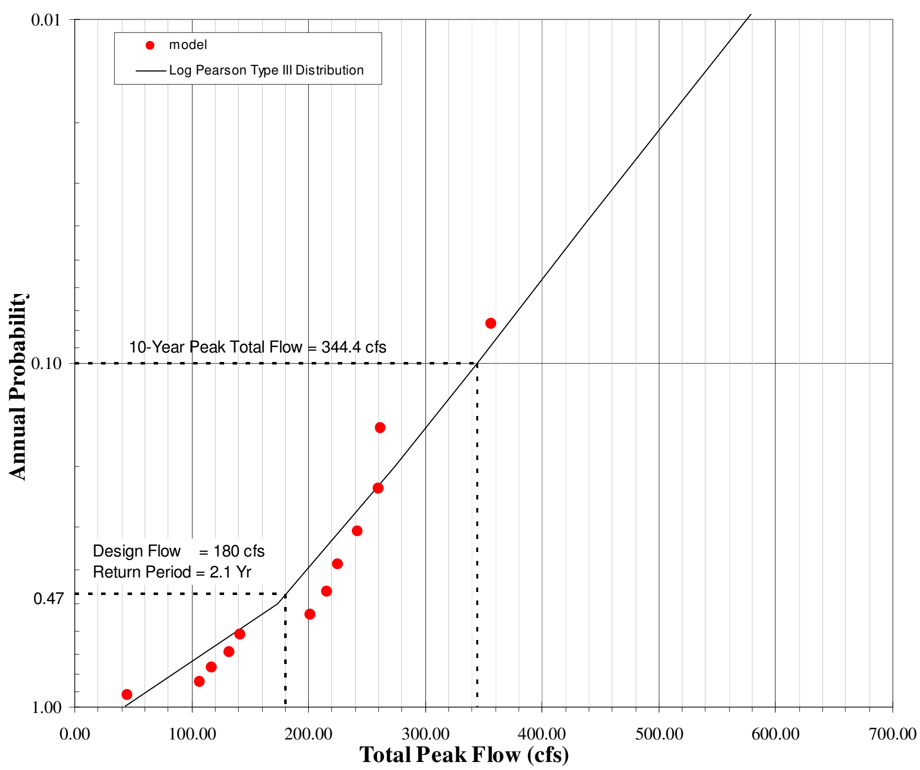


Figure 6: Annual Exceedance Plot for South Branch Flow Rates



Proposed Conditions

Changes were evaluated with the intention of balancing the flow between the treatment units and not adversely impacting the system carrying capacity during design peak flow rates.

One of the design considerations for the diversion weirs located in structures 19 and 14, which direct flow to the south and north treatment units respectively, was to prevent the area downstream the weir from acting as a restriction in the event the weir becomes flooded. This was accomplished by developing a geometric design ensuring the area within the manhole in front of and behind each weir is equal. For the North Branch, this resulted in a 10 foot weir that passes through the center of the existing manhole/diversion structure. For the south branch, this results in a wedge shaped weir with the point of the wedge facing incoming flow.

North Branch

Since the diversion weir located in the structure has been removed, a new weir needs to be installed in Structure 14 in order to divert the proper amount of flow to the treatment units. The weir to be re-constructed in structure 14 needed to meet two criteria:

- divert flow to the treatment units for any flow rate lower than the first flush flow rate of 50 cfs
- not change the upstream HGL for the design flow rate

The north branch contains about a four foot drop in elevation upstream of the treatment units and just to the East of 7th Street. A profile showing the drop prior to Structure 14 is shown below. Table F (Page 27) shows the results of the simulation.

Figure 7: Elevation Profile of the North Branch: Between 7th Street and Treatment Units

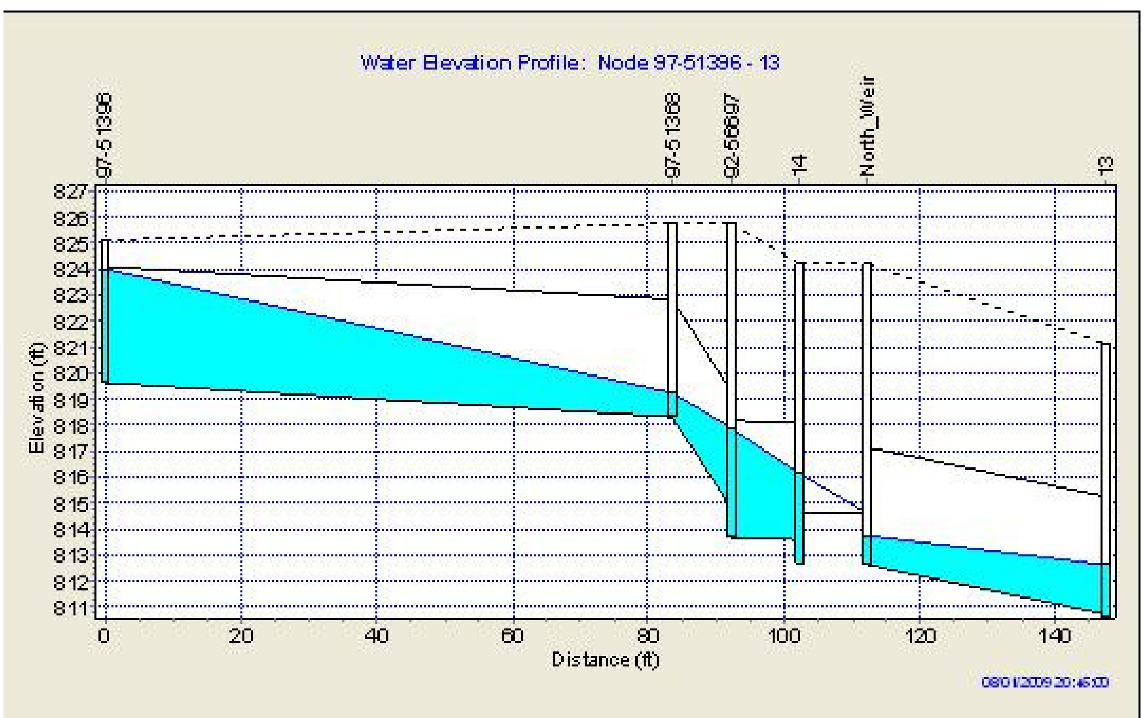


Table F: Summary of North Branch Proposed Design

North Branch Proposed Design	Model Results		
	Capacity	Flow Distribution (cfs)	
Alternative 1			
No other changes	125 cfs	TS-1	20
Weir Height: 3.5 ft		TS-2	21
Weir Length: 10 ft		TS-3	20
		TS-4	18
		SUM	79

South Branch

During the OHM survey, it was discovered there was one section of pipe, from structure 18B to structure 18 that had 0.04 ft of back fall. The remainder of the existing pipes had a positive slope. The only exception was the pipe that connects structure 18 to MH 92-60053. This pipe is flat in the absence of the weir that was discussed earlier and has an adverse slope when the weir is present.

The result of the modeling indicates there are several different alternatives for the south branch treatment system. The alternatives consist of a combination of three different choices, which include:

- Taking full advantage of the drop structure MH 92-60053 by installing a steep 54” pipe section between structure 18 and MH 92-60053 (R31)
- Re-routing the 42” collector pipes that originate at structures 18A and 18B and connecting them to MH 92-60053 (R31) in order to take advantage of the drop
- Changing the height of the diversion weir.

Table G (Page 29) provides various combinations of these choices as well as the system capacity and flow distribution for each combination. In all cases, the small weir just prior to MH 92-60053 (R31) was removed. It should be noted with a 1.0 ft diversion weir height, the collector pipes must be re-routed in order to meet the first flush flow rate requirements.

The two different routing options for the 42” collector pipes are shown on the next page. For the re-routed pipe option, the collector pipes would take full advantage of the drop in MH 92-60053. Results of the analyses are presented in Table G on Page 29.

Figure 8: Existing South Branch Layout

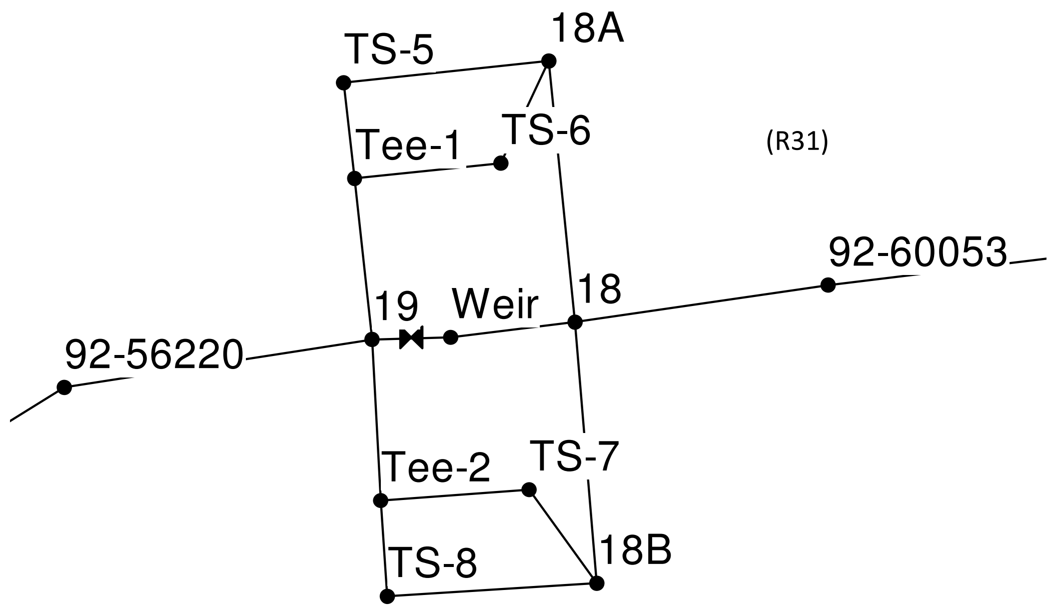


Figure 9: Rerouted Collector Pipes Layout

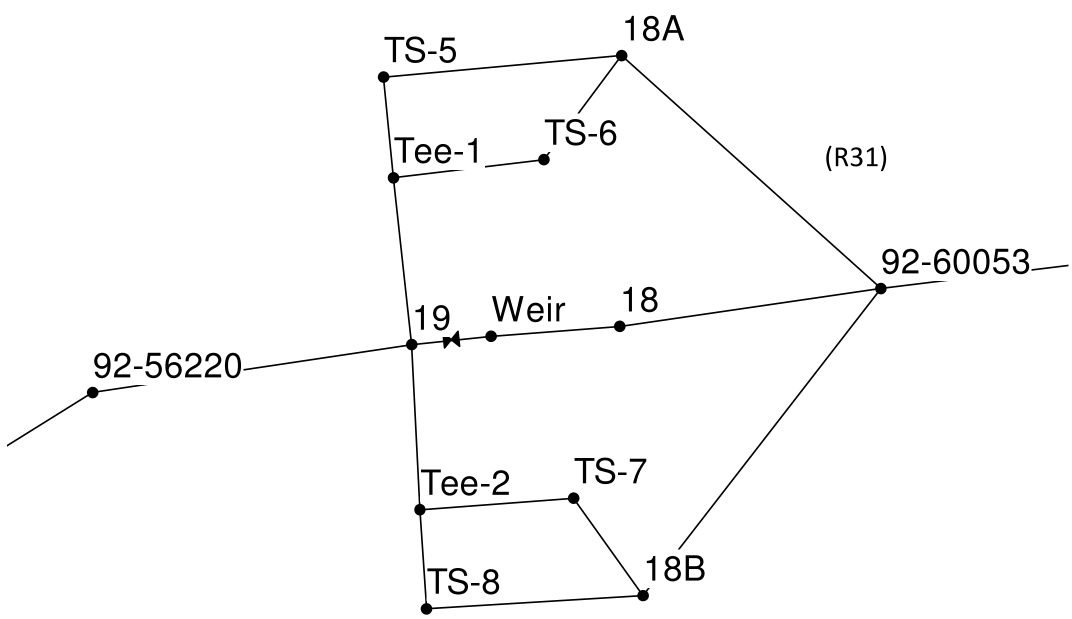


Table G: Summary of South Branch Design Alternatives

South Branch SWMM Modeling Alternatives	Model Results		
	Capacity	Flow Distribution (cfs)	
Alternative 1 No other changes Weir Height: 2.75 ft Weir Length: 12 ft Note: Weir becomes submerged	197 cfs	TS-5 TS-6 TS-7 TS-8	24.0 25.0 25.0 24.0
		SUM	98.0
Alternative 2 Lower downstream end of 54” pipe Weir Height: 2.75 ft Weir Length: 12 ft	204 cfs	TS-5 TS-6 TS-7 TS-8	33.0 33.0 29.0 270
		SUM	122.0
Alternative 3 Lower downstream end of 54” pipe Re-route 42” collector pipes Weir Height: 2.75 ft Weir Length: 12 ft	204 cfs	TS-5 TS-6 TS-7 TS-8	30.0 41.0 43.0 42.0
		SUM	156.0
Alternative 4 Lower downstream end of 54” pipe Re-route 42” collector pipes Weir Height: 1.0 ft Weir Length: 12 ft Note: Weir becomes submerged	204 cfs	TS-5 TS-6 TS-7 TS-8	23.5 31.0 37.0 36.0
		SUM	127.5
Alternative 5 Re-route 42” collector pipes Weir Height: 1.0 ft Weir Length: 12 ft Note: Weir becomes submerged	204 cfs	TS-5 TS-6 TS-7 TS-8	25.0 33.0 30.0 33.0
		SUM	121.0

Sensitivity Analysis

A sensitivity analysis was performed for the purposes of assessing the sensitivity of recommended design modifications on the overall results. The four factors investigated include the following:

- Simulation of impact of manholes downstream of the north branch, which were not found in the field but exist in the City of Ann Arbor SWMM model.
- Imposing a fixed tail water condition (i.e. imposing a water depth downstream of the area of interest, which stays constant throughout the modeling simulation period) for the downstream outlet in order to simulate a full receiving storm sewer downstream.
- Reduced weir lengths.
- Head losses through the treatment units.

North Branch Grade Change Impact

During this project, it was noted that two manholes, suggesting a grade change as well as slope changes in the storm sewer on the north branch, downstream of the treatment units could not be located in the field. However, the City verified these two manholes were shown in old as-built drawings from the 1960s era. The intention of this sensitivity analysis was to assess the sensitivity of modeling results at the treatment units on the recommendations made for the north branch. It was discovered the steep grade change did not have an impact on the upstream design flow capacity.

Fixed Tail Water (starting water elevation)

As stated earlier, OHM survey was limited to the confines of West Park and a few specific upstream manholes. Since structure 1 is the lowest surveyed data point in the park and is subject to unknown downstream conditions, an analysis was performed in order to understand what effects a fixed tail water at structure 1 would have on the system. The intent was to simulate conditions which may arise due to the receiving storm sewer downstream of West Park being full. The elevation of the tail water at structure 1 was incrementally raised to determine where flooding might first occur.

The limit for the tail water elevation at structure 1 was found to be 797 ft using BRI as-built topographic contours. This elevation is approximately two feet above the rim of structure 1 and will contain the water within the park. If the surcharge increases beyond 797 feet, Chapin Street would begin to flood. Flooding of the structures upstream does not occur for the design flow rates.

Reduced Weir Lengths

To account for the possibility of construction limitations and flow contractions across the diversion weirs, the analysis was run again using shorter weir lengths ranging from 10% to 40%. The starting weir length for the north branch was assumed at 10 ft and 12 ft for the south branch. In both branches, the HGL is raised upstream and more flow is forced through the treatment units. In the north branch, there is not a change in flow capacity due to the large drop just upstream. The south branch sees small losses in capacity. Table H on Page 31 shows the results of the weir length sensitivity analysis. It is important to note the model used for this simulation does not include any modifications to the 54” or 42” sewers downstream of the treatment units, summarized as alternatives 2 through 4 in Table G (Page 29).

Table H: Weir Length Sensitivity Analysis Results

Weir Length Reduction	Location	Peak Design Flow (cfs)	Treated Flow (cfs)
0%	North Branch	125.00	60
	South Branch	198.00	98
10%	North Branch	125.00	61
	South Branch	197.87	102
20%	North Branch	125.00	62
	South Branch	196.70	106
30%	North Branch	125.00	65
	South Branch	195.40	111
40%	North Branch	125.00	67
	South Branch	193.80	115

Treatment Unit Losses

To account for head losses through the treatment units, a flow rate-head loss curve obtained from AquaShield for the Pioneer High school project was used to calibrate the model. It is believed by OHM, this loss curve would be applicable for the units in West Park, although this has not been established for certain. It was observed there was a small loss in capacity in the south branch and no change in capacity for the north branch. The amount of treated flow, however, changed with the addition of the friction factors.

Table I: Treatment Unit Loss Sensitivity Analysis Results

Treatment Unit K Factor	Location	Peak Design Flow (cfs)	Treated Flow (cfs)
0.0	North Branch	125.00	60
	South Branch	198.00	98
1.5	North Branch	125.00	53
	South Branch	194.7	69
2.0	North Branch	125.00	51
	South Branch	192.90	65

Depth Variation Based on Flow Metering Data

As mentioned earlier, flow metering data was collected as part of this study. This data showed significant peak velocities during the largest event recorded in the metering period (May 25, 2011). In the north branch, for example, velocities increased to about 10 cfs for a flow rate of about 170 cfs. A similar observation was made with the meter in the south branch. Subsequent modeling indicated that during the design peak flow rate simulations, supercritical flow was seen, i.e. flows for which the calculated Froude Numbers in the model upstream of the treatment units were higher than one. In addition, modeling simulations did not show as large of a depth increase as recorded by the meters, even while simulating proposed weirs in the diversion structures. This suggests there may be hydraulic dynamics in the system during such high flow rates, for example, a hydraulic jump-type phenomenon, which may explain the high flow depth readings.

Design Decisions and Recommendations – Hydraulic Perspective

The driving requirement of the weir height is the height necessary to convey first flush flow rates to the treatment units. Since the actual frictional losses for the treatment units and the true pipe lengths and slopes between the treatment units are not available, it is not possible to precisely quantify losses and thus, the required height of the weir. Therefore, some flexibility for weir height adjustments needs to be accounted for in the final design.

In the case of the north branch, the design of the treatment system and the weir height has flexibility from the large drop immediately upstream of the diversion weir manhole structure. The added losses of the treatment units would, therefore, have the effect of raising the HGL and reducing the amount of flow through the treatment units. The rise in HGL is not expected to be larger than 0.5 ft, which is not large enough to travel beyond this drop.

In the case of the south branch, where there is not a large drop prior to the treatment units, another approach needed to be implemented to ensure any unknown factors in the treatment system did not increase the likelihood of capacity restrictions upstream. In this case, the solution is to simply take advantage of the large drop (3.64 ft) immediately downstream of the treatment units. To do this, the end of the 54”storm sewer from structure 18 to R31 would need to be lowered as discussed earlier. This would provide additional capacity and an additional margin of protection for upstream areas.

Since frequency simulations suggest system flows in the magnitude of the design flow rates may be experienced every other year and metering data suggests rather high velocities during high flow rates, it would be reasonable to incorporate a mechanism in the final design which potentially allows for relief of excess flows near the treatment units as opposed to such flow dynamics resulting in elevated hydraulic grade lines upstream. It also needs to ensure flows being relieved at the treatment units do not generate undesirable flooding conditions downstream.

Remediation Recommendations and Opinions of Probable Cost

Remediation Options

North Branch

Alternative 1 (Weir Improvements)

Based on the system modeling that was performed, it has been determined the weir configuration in diversion structure ST-14 needs to be modified. This improvement proposes making the necessary modifications to the weir so it will function in accordance with the modeling recommendations. Two options were considered for accomplishing this: Option A assumes modifications can be made to the existing structure. Option B assumes the structure would need to be removed and replaced.

Option A

This option proposes modifying the existing diversion structure to allow for the construction of a longer weir. Modeling has indicated a 10-foot long weir is needed, which is the same dimension as the inside diameter of Structure ST-14. Based on the design requirements, it may be necessary to shorten the weir length some to fit it into the existing structure. This may require some adjustment of the weir height to maintain the design flow rate to be treated. Further design investigation and modeling would be required to answer this question.

The weir to be constructed would be an adjustable stop-log assembly. The assembly would be constructed of a series of 6-inch high stop logs that could be removed and/or reconfigured to adjust the weir height. The top log would include a bolted stainless steel plate that would provide slotted holes for making fine adjustments in weir height.

The drainage structure would include multiple openings for providing access and allowing for lifting and removing the stop logs.

Option B

Due to the size limitation of the existing diversion structure (ST-14), it may be necessary to increase its diameter to construct the required weir configuration. This option proposes removing the existing 10-foot diameter diversion structure and replacing it with a new 12-foot diameter structure.

Similar to Option A, the weir to be constructed would be an adjustable stop-log assembly. The assembly would be constructed of a series of 6-inch high stop logs that could be removed and/or reconfigured to adjust the weir height. The top log would include a bolted stainless steel plate that would provide slotted holes for making fine adjustments in the weir height.

The drainage structure would include multiple openings for providing access and allowing for lifting and removing the stop logs.

Maintenance Recommendation – Optional

This optional recommendation proposes removing the three existing 24-inch diameter 90º bends within the treatment system and replacing them with 5-foot diameter drainage structures to provide better access to the system for cleaning and maintenance.

South Branch

Alternative 1 (Weir Improvements)

Based on the system modeling that was performed, it has been determined the weir configuration in diversion structure ST-19 needs to be modified. This improvement proposes making the necessary modifications to the weir so it will function in accordance with the modeling recommendations. Two options were considered for accomplishing this: Option A assumes modifications can be made to the existing structure. Option B assumes the structure would need to be removed and replaced.

Option A

This option proposes modifying the existing diversion structure to allow for the construction of a longer weir. Modeling has indicated a 12-foot long V-shaped weir is needed. Based on the design requirements, it may be necessary to shorten the weir length some to fit it into the existing structure. This may require some adjustment of the weir height to maintain the design flow rate to be treated. Further design investigation and modeling would be required to answer this question.

The weir to be constructed would be comprised of two sections which would form the legs of the "V". Each assembly would be constructed of a series of 6-inch high stop logs that could be removed and/or reconfigured to adjust the weir height. The top log would include a bolted stainless steel plate that would provide slotted holes for making fine adjustments in weir height.

The drainage structure would include multiple openings for providing access and allowing for lifting and removing the stop logs.

Option B

Due to the size limitation of the existing diversion structure (ST-19), it may be necessary to increase its diameter to construct the required weir configuration. This option proposes removing the existing 10-foot diameter diversion structure and replacing it with a new 12-foot diameter structure.

Similar to Option A, the weir to be constructed would be comprised of two sections, which would form the legs of the "V". Each assembly would be constructed of a series of 6-inch high stop logs that could be removed and/or reconfigured to adjust the weir height. The top log would include a bolted stainless steel plate that would provide slotted holes for making fine adjustments in weir height.

The drainage structure would include multiple openings for providing access and allowing for lifting and removing the stop logs.

54-Inch Pipe Improvements

This improvement includes removing, replacing and lowering the existing segment of 54-inch diameter concrete pipe located between Structures ST-18 and R31. This option would also require removing Structure R31 and replacing it with a new 10-foot diameter structure.

42-Inch Pipe Improvements

This improvement proposes removing and/or abandoning portions of the existing 42-inch diameter N-12 pipe located between Structure ST-18, and Structures ST-18A and ST-18B, respectively. This option would also include constructing new 42-inch diameter N-12 pipe and connecting both redirected-pipe segments to a new Specialty Structure that would replace Structure R31. It should be noted if both the 54-inch pipe improvement and the 42-inch pipe improvement options are selected, the 10-foot diameter structure, which is proposed as part of the 54-inch pipe improvement option would no longer be needed, and its cost would need to be removed from the combined estimated cost for the work. The proposed Specialty Structure would be sized to accommodate all of the required pipe connections.

We have attached cost estimates for each option. Please reference Appendix A.

Appendix A – Cost Estimates

Engineer's Opinion of Probable Project Costs

Owner:	City of Ann Arbor	Date:	7/15/2011
Project:	West Park Storm Sewer Analysis and Repair Project	Project No.	0028-11-0021
Work:	Storm Sewer Modifications - North Branch	Prepared By:	R. Craigmile
	Weir Improvements	Reviewer:	V. Putala
	Alternative 1 - Option A	Current ENR:	
	Modify Diversion Structure ST-14 and Construct Weir		

Item No.	Item Description	Est. Quantity	Unit	Unit Price	Total Cost
1	Mobilization 5%	1	LS	$1,975.63	$1,975.63
2	Modifications to Existing Structure (#14)	1	Ea	10,000.00	10,000.00
3	Flat Top Slab for Dr Structure 120 inch dia	1	Ea	4,000.00	4,000.00
4	Dr Structure Cover	1	Ea	1,000.00	1,000.00
5	Bypass Pumping	1	LS	3,000.00	3,000.00
6	Stop Log Assembly	1	LS	12,000.00	12,000.00
7	Turf Restoration	280	Syd	25.00	7,000.00
8	Sidewalk Rem	17	Syd	25.00	425.00
9	Remove Fence	1	LS	1,000.00	1,000.00
10	Sidewalk, 4 inch	150	Sft	6.00	900.00
11	Erosion Control, Silt Fence	75	Ft	2.50	187.50
				SUBTOTAL	$41,488.13
	General Conditions	10%			$4,148.81
	General Requirements	5%			2,074.41
	Contingencies	20%			8,297.63
		TOTAL CONSTRUCTION COST			$56,008.97
	PROJECT COSTS				
	Engineering, Testing and Inspection	25%			$14,002.24
		TOTAL ESTIMATED PROJECT COST			$70,000.00
ENGINEER'S OPINION OF PROJECT COST					$70,000.00

Assumptions:

1. If multiple options are selected within each branch, the work will be performed under one contract.

Engineer's Opinion of Probable Project Costs

Owner:	City of Ann Arbor	Date:	7/15/2011
Project:	West Park Storm Sewer Analysis and Repair Project	Project No.	0028-11-0021
Work:	Storm Sewer Modifications - North Branch	Prepared By:	R. Craigmile
	Weir Improvements	Reviewer:	V. Putala
	Alternative 1 - Option B		
	Replace Diversion Structure ST-14 and Construct Weir	Current ENR:	

Item No.	Item Description	Est. Quantity	Unit	Unit Price	Total Cost
1	Mobilization 5%	1	LS	$2,350.63	$2,350.63
2	Dr Structure Rem, 120 inch dia (#14)	1	Ea	4,500.00	4,500.00
3	Dr Structure 144 inch dia	1	Ea	16,000.00	16,000.00
4	Dr Structure Cover	1	Ea	1,000.00	1,000.00
5	Bypass Pumping	1	LS	4,000.00	4,000.00
6	Stop Log Assembly	1	LS	12,000.00	12,000.00
7	Turf Restoration	280	Syd	25.00	7,000.00
8	Sidewalk Rem	17	Syd	25.00	425.00
9	Remove Fence	1	LS	1,000.00	1,000.00
10	Sidewalk, 4 inch	150	Sft	6.00	900.00
11	Erosion Control, Silt Fence	75	Ft	2.50	187.50
				SUBTOTAL	$49,363.13
	General Conditions	10%			$4,936.31
	General Requirements	5%			2,468.16
	Contingencies	20%			9,872.63
				TOTAL CONSTRUCTION COST	$66,640.22
	PROJECT COSTS				
	Engineering, Testing and Inspection	25%			$16,660.05
				TOTAL ESTIMATED PROJECT COST	$83,300.00
	ENGINEER'S OPINION OF PROJECT COST				$83,300.00

Assumptions:

1. If multiple options are selected within each branch, the work will be performed under one contract.
2. The repair/replacement of the treatment units will not require changes in pipe layout or treatment configuration.

Engineer's Opinion of Probable Project Costs

Owner:	City of Ann Arbor	Date:	7/15/2011
Project:	West Park Storm Sewer Analysis and Repair Project	Project No.	0028-11-0021
Work:	Storm Sewer Modifications - North Branch	Prepared By:	R. Craigmile
	Optional Maintenance Recommendation	Reviewer:	V. Putala
	Remove 24-inch Diameter 90 Degree Bends and Construct 60-inch Diameter Drainage Structures	Current ENR:	

Item No.	Item Description	Est. Quantity	Unit	Unit Price	Total Cost
1	Mobilization 5%	1	LS	$1,437.00	$1,437.00
2	Storm Sewer Rem, 42 inch N-12	12	Ft	20.00	240.00
3	Dr Structure 60 inch dia	3	Ea	6,000.00	18,000.00
4	Dr Structure Cover	3	Ea	1,000.00	3,000.00
5	Turf Restoration	300	Syd	25.00	7,500.00
6	HMA Pathway, Remove and Replace	25	Syd	100.00	2,500.00
				SUBTOTAL	$32,677.00
	General Conditions	10%			$3,267.70
	General Requirements	5%			1,633.85
	Contingencies	20%			6,535.40
		TOTAL CONSTRUCTION COST			$44,113.95
	PROJECT COSTS				
	Engineering, Testing and Inspection	25%			$11,028.49
		TOTAL ESTIMATED PROJECT COST			$55,100.00
ENGINEER'S OPINION OF PROJECT COST					$55,100.00

Assumptions:

1. If multiple options are selected within each branch, the work will be performed under one contract.
2. The repair/replacement of the treatment units will not require changes in pipe layout or treatment configuration.

Engineer's Opinion of Probable Project Costs

Owner:	City of Ann Arbor	Date:	7/15/2011
Project:	West Park Storm Sewer Analysis and Repair Project	Project No.	0028-11-0021
Work:	Storm Sewer Modifications - South Branch	Prepared By:	R. Craigmile
	Weir Improvements	Reviewer:	V. Putala
	Alternative 1 -Option A	Current ENR:	
	Modify Diversion Structure ST-19 and Construct Weir		

Item No.	Item Description	Est. Quantity	Unit	Unit Price	Total Cost
1	Mobilization	1	LS	$2,259.38	$2,259.38
2	Modify Existing Drainage Structure (#19)	1	Ea	10,000.00	10,000.00
3	Flat Top Slab for Dr Structure 120 inch dia	1	Ea	4,000.00	4,000.00
4	Dr Structure Cover	2	Ea	1,000.00	2,000.00
5	Bypass Pumping	1	LS	3,000.00	3,000.00
6	Stop Log Assembly	1	LS	16,000.00	16,000.00
7	Turf Restoration	280	Syd	25.00	7,000.00
8	Gravel Path Restoration	1	LS	2,000.00	2,000.00
9	Remove Fence	1	LS	1,000.00	1,000.00
10	Erosion Control, Silt Fence	75	Ft	2.50	187.50
				SUBTOTAL	$47,446.88
	General Conditions	10%			$4,744.69
	General Requirements	5%			2,372.34
	Contingencies	20%			9,489.38
		TOTAL CONSTRUCTION COST			$64,053.28
	PROJECT COSTS				
	Engineering, Testing and Inspection	25%			$16,013.32
		TOTAL ESTIMATED PROJECT COST			$80,100.00
ENGINEER'S OPINION OF PROJECT COST					$80,100.00

Assumptions:
1. If multiple options are selected within each branch, the work will be performed under one contract.
2. The repair/replacement of the treatment units will not require changes in pipe layout or treatment configuration.
3. If Options 4 and 5 are selected as part of the modifications that are proposed to the South Branch, an adjustment will be needed to eliminate the proposed 120-inch diameter drainage structure that is part of Option 4. The Specialty Structure that is proposed as part of Option 5 will allow for all of the required connections.

Engineer's Opinion of Probable Project Costs

Owner:	City of Ann Arbor	Date:	7/15/2011
Project:	West Park Storm Sewer Analysis and Repair Project	Project No.	0028-11-0021
Work:	Storm Sewer Modifications - South Branch	Prepared By:	R. Craigmile
	Weir Improvements Alternative 1 - Option B Replace Diversion Structure ST-19 and Construct Weir	Reviewer:	V. Putala
		Current ENR:	

Item No.	Item Description	Est. Quantity	Unit	Unit Price	Total Cost
1	Mobilization (5%)	1	LS	$2,559.38	$2,559.38
2	Dr Structure, Rem (#19)	1	Ea	3,000.00	3,000.00
3	Dr Structure, 144 inch dia	1	Ea	16,000.00	16,000.00
4	Dr Structure, Cover	2	Ea	1,000.00	2,000.00
5	Bypass Pumping	1	LS	4,000.00	4,000.00
6	Stop Log Assembly	1	LS	16,000.00	16,000.00
7	Turf Restoration	280	Syd	25.00	7,000.00
8	Gravel Path Restoration	1	LS	2,000.00	2,000.00
9	Remove Fence	1	LS	1,000.00	1,000.00
10	Erosion Control, Silt Fence	75	Ft	2.50	187.50
				SUBTOTAL	$53,746.88
	General Conditions	10%			$5,374.69
	General Requirements	5%			2,687.34
	Contingencies	20%			10,749.38
		TOTAL CONSTRUCTION COST:			$72,558.28
	PROJECT COSTS				
	Engineering, Testing and Inspection	25%			$18,139.57
		TOTAL ESTIMATED PROJECT COST:			$90,700.00
ENGINEER'S OPINION OF PROJECT COST					$90,700.00

Assumptions:
1. If multiple options are selected within each branch, the work will be performed under one contract.
2. The repair/replacement of the treatment units will not require changes in pipe layout or treatment configuration.
3. If Options 4 and 5 are selected as part of the modifications that are proposed to the South Branch, an adjustment will be needed to eliminate the proposed 120-inch diameter drainage structure that is part of Option 4. The Specialty Structure that is proposed as part of Option 5 will allow for all of the required connections.

Engineer's Opinion of Probable Project Costs

Owner:	City of Ann Arbor	Date:	7/15/2011
Project:	West Park Storm Sewer Analysis and Repair Project	Project No.	0028-11-0021
Work:	Storm Sewer Modifications - South Branch	Prepared By:	R. Craigmile
		Reviewer:	V. Putala
	54" Pipe Improvements	Current ENR:	
	Remove, Replace and Lower 54-inch Diameter Pipe Segment		

Item No.	Item Description	Est. Quantity	Unit	Unit Price	Total Cost
1	Mobilization (5%)	1	LS	$1,837.50	$1,837.50
2	Sewer, Rem, 54 inch	10	Ft	100.00	1,000.00
3	Dr Structure, Rem (#18)	1	Ft	4,500.00	4,500.00
4	Sewer, 54 inch, Tr Det B	10	Ft	350.00	3,500.00
5	Dr Structure, 120 inch dia	1	Ea	14,000.00	14,000.00
6	Dr Structure, Cover	1	Ea	1,000.00	1,000.00
7	Bypass Pumping	1	LS	4,000.00	4,000.00
8	Gravel Path Restoration	1	LS	2,000.00	2,000.00
9	Turf Restoration	270	Syd	25.00	6,750.00
				SUBTOTAL	$38,587.50
	General Conditions	10%			$3,858.75
	General Requirements	5%			1,929.38
	Contingencies	20%			7,717.50
		TOTAL CONSTRUCTION COST			$52,093.13
	PROJECT COSTS				
	Engineering, Testing and Inspection	25%			$13,023.28
		TOTAL ESTIMATED PROJECT COST			$65,100.00
ENGINEER'S OPINION OF PROJECT COST					$65,100.00

Assumptions:
1. If multiple options are selected within each branch, the work will be performed under one contract.
2. The repair/replacement of the treatment units will not require changes in pipe layout or treatment configuration.
3. If Options 4 and 5 are selected as part of the modifications that are proposed to the South Branch, an adjustment will be needed

Engineer's Opinion of Probable Project Costs

Owner:	City of Ann Arbor	Date:	7/15/2011
Project:	West Park Storm Sewer Analysis and Repair Project	Project No.	0028-11-0021
Work:	Storm Sewer Modifications - South Branch	Prepared By:	R. Craigmile
		Reviewer:	V. Putala
	42" Pipe Improvements	Current ENR:	
	Replace, Lower and Realign 42-inch Diameter Pipe Segments		

Item No.	Item Description	Est. Quantity	Unit	Unit Price	Total Cost
1	Mobilization 5%	1	LS	$2,465.50	$2,465.50
2	Modify Existing Dr Structures(18A & 18B)	2	Ea	1,500.00	3,000.00
3	Sewer, Rem, 42 inch	12	Ft	30.00	360.00
4	Dr Structure, Rem (R31)	1	LS	3,000.00	3,000.00
5	Sewer, 42 inch, HDPE, N12, Tr Det B	60	Ft	70.00	4,200.00
6	Dr Structure, Box, Special	1	Ea	25,000.00	25,000.00
7	Dr Structure, Cover	1	Ea	1,000.00	1,000.00
8	Bypass Pumping	1	LS	4,000.00	4,000.00
9	Gravel Path Restoration	1	LS	2,000.00	2,000.00
10	Turf Restoration	270	Syd	25.00	6,750.00
				SUBTOTAL	$51,775.50
	General Conditions	10%			$5,177.55
	General Requirements	5%			2,588.78
	Contingencies	20%			10,355.10
		TOTAL CONSTRUCTION COST:			$69,896.93
	PROJECT COSTS				
	Engineering, Testing and Inspection	25%			$17,474.23
		TOTAL ESTIMATED PROJECT COST:			$87,400.00
ENGINEER'S OPINION OF PROJECT COST					$87,400.00

Assumptions:
1. Existing 42" between #18A and #18B to be cut and capped and abandoned.
2. If multiple options are selected within each branch, the work will be performed under one contract.
3. The repair/replacement of the treatment units will not require changes in pipe layout or treatment configuration.
4. If Options 4 and 5 are selected as part of the modifications that are proposed to the South Branch, an adjustment will be needed to eliminate the proposed 120-inch diameter drainage structure that is part of Option 4. The Specialty Structure that is proposed as part of Option 5 will allow for all of the required connections.