TECHNICAL PROGRESS REPORT

Remediation and Treatment Technology Development and Support for DOE Oak Ridge Office: XPSWMM Model Preliminary Results Summary

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Executive Summary

A stormwater XPSWWM model was develop to provide a better understanding of the stormwater flow rates and water stages during rainfall events for selected ORNL area. The specific system of interest and its drainage area, herein referred to as the stormwater collection system up to Outfall 211 is 5 acres and it is located within several ORNL buildings. The system is bounded by mostly impervious land cover (due to roof top runoff through storm drains and pavement to the north, south, east, and west), with minor pervious areas throughout the drainage area. The author of this study (Heidi) has conducted an internship during the summer of 2012 and collected information about the physical parameters of the stormwater drainage system. A stomrwater hydrologic computer model was developed using XPSWWM software. The objective of the hydrologic model was to provide detailed information about flow, velocity and stage timeseries during stormwater events. The hydrologic information will be used to determine critical hydrologic parameters that affect mercury fluxes within the stormwater network, such as flow velocities and discharges for any selected period of rainfall events. The stormwater model for the contributing drainage areas to Outfall 211 consists of 53 link/54 nodes of closed circular conduits discharging into a free surface creek. The system is composed of sub-drainage areas with sub-catchment areas that are defined by an imperviousness, slope, width, and area. They are linked to a node so that once the rainfall is simulated it is routed into and through the system. Model inputs include topography, pervious and impervious drainage areas of each sub-catchment area, infiltration parameters, slope of sub-catchment areas, length and diameter of pipes, and Manning's coefficient for pipe roughness. A series of initial simulations were conducted, including calibration runs, simulations of one year rainfall (using 15 minutes time interval of observed rainfall data) and simulations for the period 1999-2012. This report presents model development steps, summary of results for each simulation category (calibration, 1 year simulations of rainfall with 15 minutes interval, 13 years simulations of rainfall with daily observations). The simulations demonstrated that the model can be used to determine all details of flow (discharges, velocities, water surface profile) within the stormwater network. The appendices show the timeseries and probability exceedance plots for selected pipe sections. The model is currently under development to incorporate fate and transport of chemical species which will be used to provide information for each outfall and for additional nodes once the model is expanded to include Y-12 NSC sections.

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Introduction

In the 1940's during World War II, the U.S. initiated its own research and development program—commonly referred to as the Manhattan Project—in a race to create the first atomic bomb. The 33,750 acre Oak Ridge Reservation (ORR) was the first site selected to support the Manhattan Project. This site consists of three major U.S. Department of Energy (DOE) facilities, the East Tennessee Technology Park (ETTP) formerly known as the Oak Ridge Gaseous Diffusion Plant or K-25 (2200-acres), the Y-12 National Security Complex (Y-12 NSC) (800-acres), and the Oak Ridge National Laboratory (ORNL) formerly known as X-10 (4470-acres). The reason for selecting ORR was because it provided the water supply (Clinch River), electricity (Tennessee Valley Authority), and workforce (citizens from the City of Knoxville) necessary for this operation. In addition to the workforce offered by the City of Knoxville, thousands of scientists, engineers, and support personnel relocated to the area in support of this mission (ORNL, 2008).

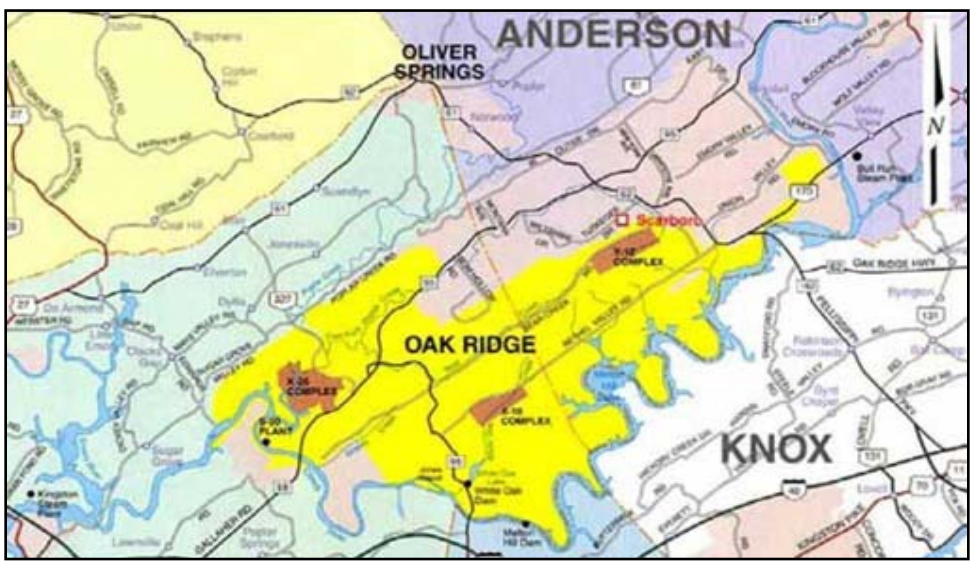

Figure 1 Oak Ridge Reservation (USEPA, 2004)

By the early 1950's, DOE began the production of thermonuclear weapons in support of the Cold War. A key active ingredient in the design of the thermonuclear weapon, or the hydrogen bomb, was lithium-6 (Li-6), which is produced by separating lithium isotopes using an aqueous solution

containing mercury (Hg) (Brooks and Southworth, 2011; Ragheb, 2012). In 1953, ORNL Buildings 4501 and 4505 were built to conduct a pilot-scale evaluation of the lithium exchange processes for the development of thermonuclear weapons. Building 4501, the High-Level Radiochemical Laboratory, was a pilot plant for the OREX process. In 1955, Building 4505, the Experimental Engineering Laboratory, was built to house another process named METALLEX. Although ORNL's major concern is Hg contamination many other pollutants have resulted from the previously described activities. More specifically, radionuclides (strontium-90 and radium-228) and inorganics are also of concern and remediation is needed (Taylor, 1989a).

Figure 2 ORNL Building 4501 and 4505 Location

ORNL is located within the White Oak Creek watershed (WOC), which is within the Central Bethel Valley watershed (a portion of the Bethel Valley watershed). WOC, a tributary of the Tennessee River, is the main stream running adjacent to ORNL along its south-eastern border and represents a major route for water and contaminant transport (USEPA, 2004; USEPA, 2006). The WOC watershed is comprised of approximately 2,098 acres and collects runoff and treated wastewater discharge from ORNL where it is drained into White Oak Lake and then the Clinch

River (ORNL, 2008; USDOE, 1999). In Figure 3, the location of the area of interest is located within the red circle.

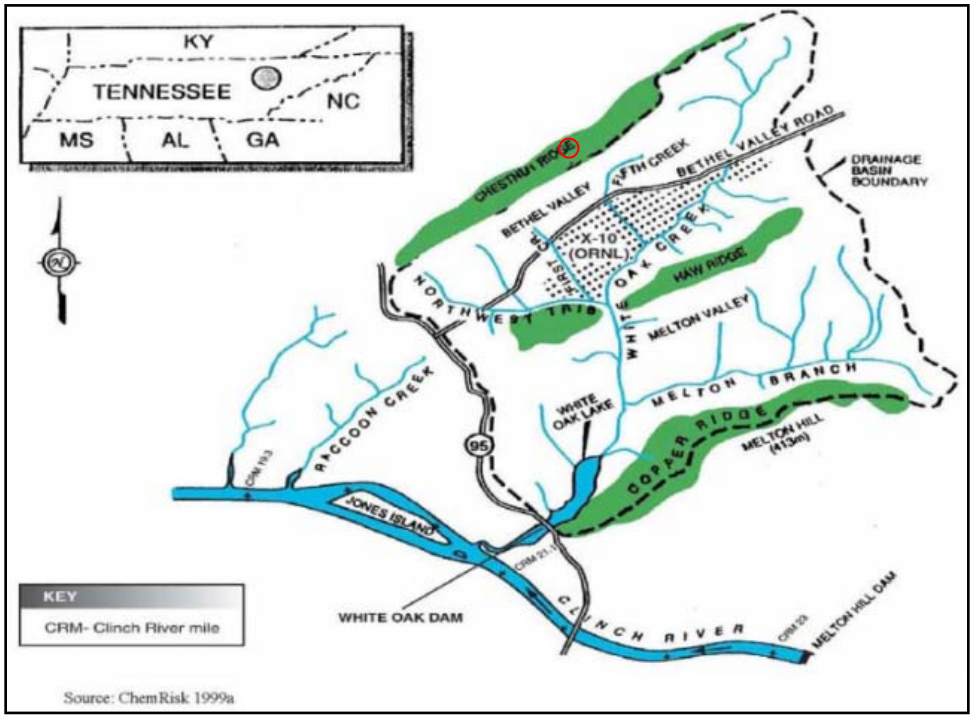

Figure 3 Oak Ridge Reservation (ChemRisk, 1999a)

The specific system of interest and its drainage area, herein referred to as the stormwater collection system up to Outfall 211, are located within the red circle as shown in Figure 1 and in more detail in Figure 2. It is 5 acres and encompasses the following ORNL buildings: 4500N Wings 1, 2, and part of Wing 3, 4500S Wings 1, 2, and part of Wing 3, 4501, 4505, 4507, 4508, 4556. The system is bounded by mostly impervious land cover (due to roof top runoff through storm drains and pavement to the north, south, east, and west); however, there are minor pervious areas throughout the drainage area.

Figure 4 Area of Interest and Building Identification

Figure 5 Area of Interest Boundary

A stormwater model for the contributing drainage areas to Outfall 211 has been developed and consists of 53 link/54 nodes of closed circular conduits discharging into a free surface creek. The node elevations range from 793 ft, NAD to 803 ft, NAD respectively. The system is composed of sub-drainage areas where there can be up to five sub-catchment areas for one inlet. The sub-catchment areas are defined by an imperviousness, slope, width, and area. They are linked to a node so that once the rainfall is simulated it is routed into and through the system. Model inputs include topography, pervious and impervious drainage areas of each sub-catchment area, infiltration parameters, slope of sub-catchment areas, length and diameter of pipes, and Manning's coefficient for pipe roughness.

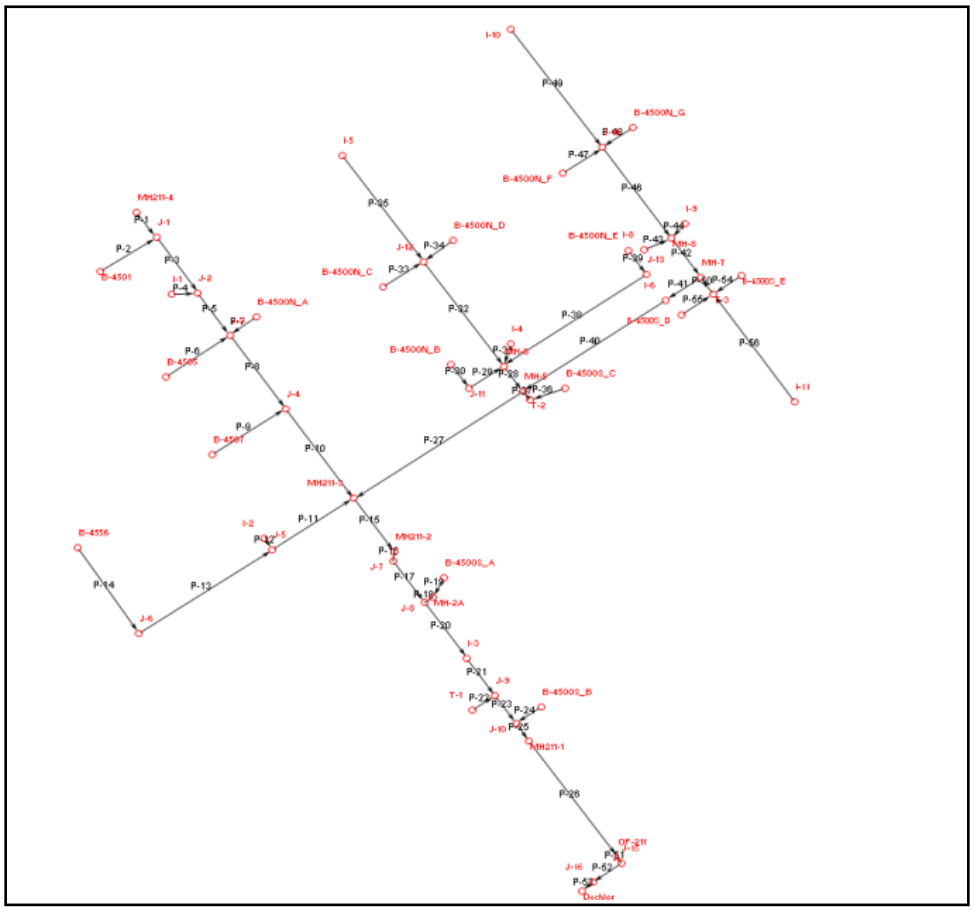

Figure 6 Stormwater Collection System

The system is also composed of sub-drainage areas where there can be up to five sub-catchment areas for one inlet. An example of this is inlet 2 (I-2). The sub-catchment areas are given an

impervious area, slope, width, and area. They are linked to a node so that once the rainfall is simulated it is routed into and through the system.

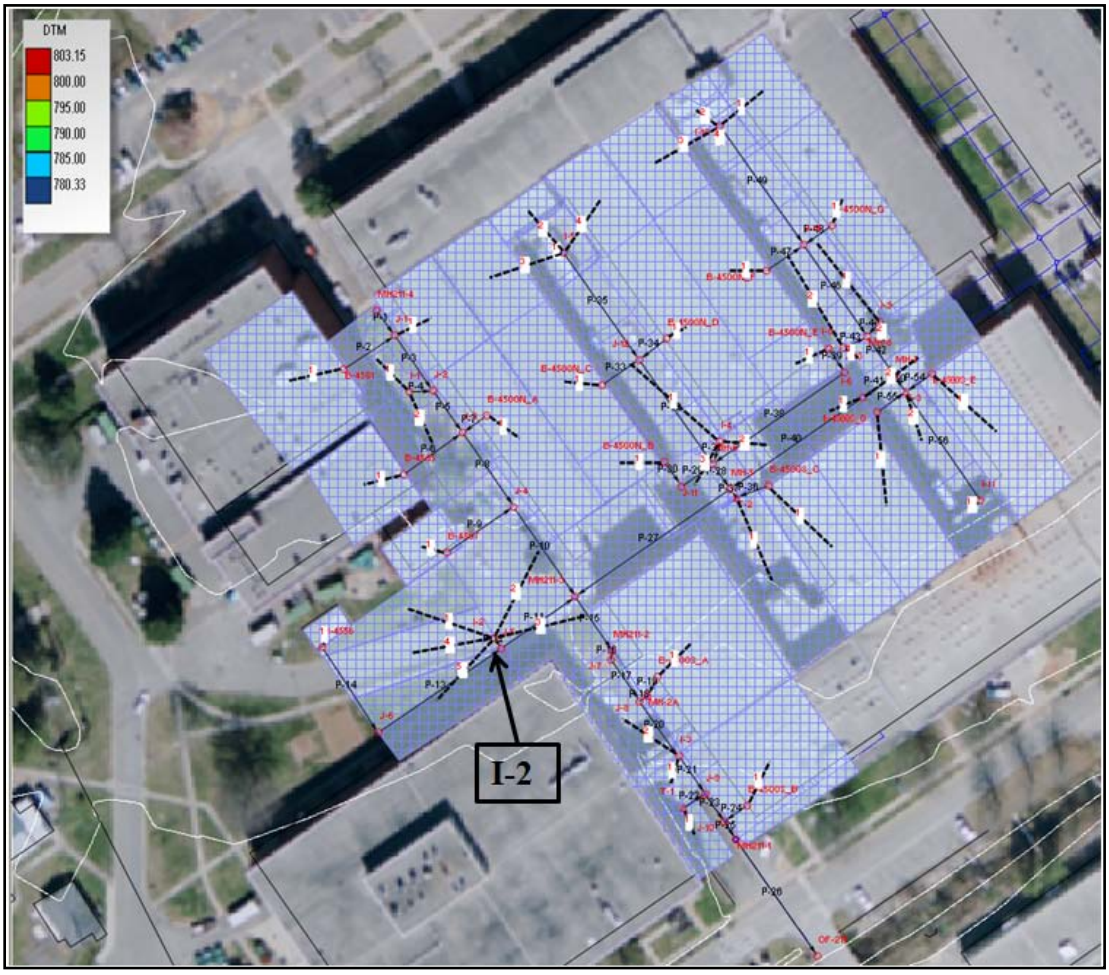

Figure 7 Subcatchment Delineation of System

This stormwater system is unique in that sources from the adjacent buildings, such as cooling water and condensate from various AC units contribute to the Outfall 211 drainage system as well as discharge from the Creep Laboratory (Building 4500S). The water leaving the Creep Laboratory has been treated with chlorine prior to its release, thus a dechlorinator is located after Outfall 211 in order to reduce the chlorine concentration prior to its discharge into WOC.

Currently, there is only one sump connecting to Outfall 211 which is Sump P. Sump P is located within Building 4556 and is only active when a large rainfall event occurs, thus is not modeled at this time due to the fact that typical monthly rainfall is being simulated at this time. One month

of rainfall has been simulated for the preliminary results for the sensitivity analysis as described in section 3 of this report.

From Building 4556 a 4” VP connects to a 10” VP which conveys water into MH211-3. MH211-3 is located at the northwest corner of Building 4500S. The main storm line runs west of 4500N and 4500S and contains MH211-1, MH211-2, MH211-2a, MH211-3, MH211-4, and Outfall 211. It begins at MH211-4 and ends at Outfall 211. From MH211-4 to MH211-3, the main storm line is constructed of 15” RCP. South of MH211-3 the line is 30” RCP. Outfall 211 is a culvert located under a bridge. However, prior to its release during dry periods the water is held back by a 65” long, 13.5” high metal plate accompanied by an 8” PVC orifice. The 8” PVC conveys the water into the dechlorinator. Just prior to the dechlorinator the 8” PVC splits into two 4” PVC as it is directed through the dechlorinator for disinfection prior to its final release into WOC. It seems that only one of the two 4” PVC conveys water through the dechlorinator where the other is closed via a ball valve. This immediately impacts the system by restricting flow from an 8” PVC to a 4” PVC. Thus, for this project the dechlorinator will not be modeled and the point of discharge for the system will be immediately after Outfall 211.

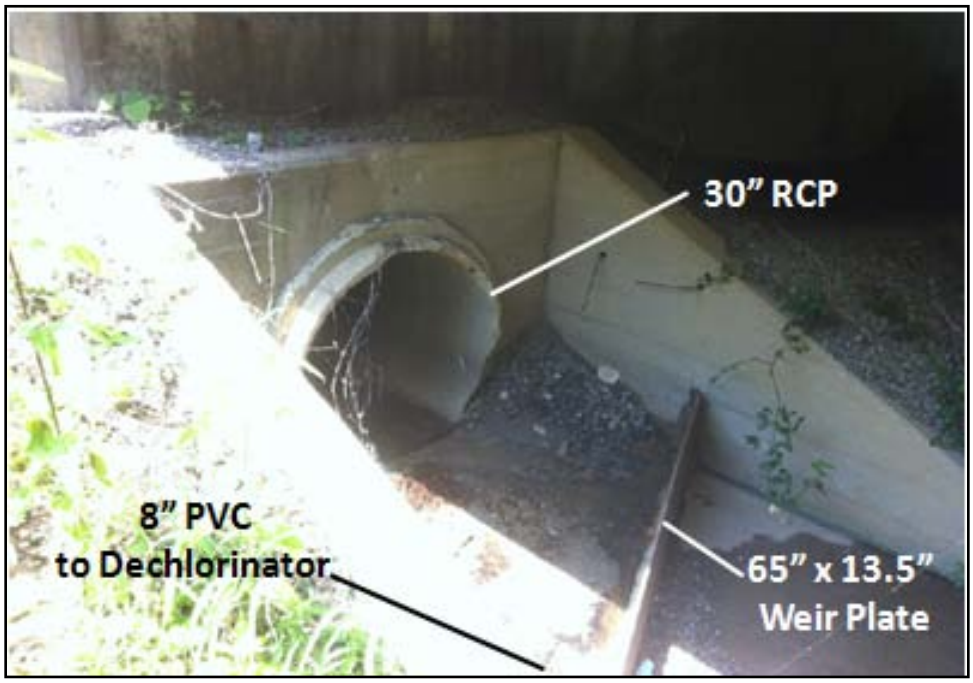

Figure 8 Outfall 211

Figure 9 WOC East of Outfall 211

Figure 10 Dechlorinator in WOC

As an industrial area, ORNL is composed of mostly impervious areas with sparse pervious areas and lies within the Tennessee State Plane North American Datum (NAD) 1983. The area bordering the area of interest ranges in elevation from 780 ft NAD to 855 ft NAD as shown on the digital terrain model (DTM). However, the area of interest is relatively flat ranging from 780 ft NAD to 810 ft NAD.

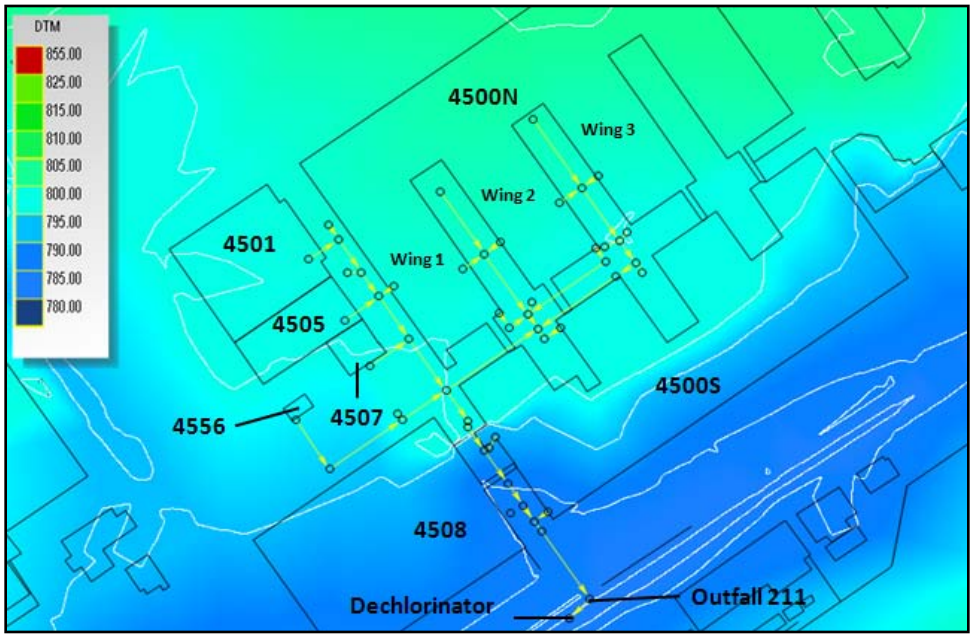

Figure 11 XPSWMM Digital Terrain Model

XPSWMM Model

XPSWMM uses a spatially distributed link/node network to analyze the hydraulic, hydrologic, and quality of a stormwater or wastewater system. The XPSWMM software package applies the Saint-Venant equations to solve for the one-dimensional unsteady open channel flow. The Saint-Venant equations are composed of the continuity, momentum, and energy equations (Chanson, 2004). XPSWMM is the Microsoft Windows version of the Environmental Protection Agency (EPA) stormwater modeling (SWMM) tool (USEPA, 2012).

Open Channel Flow

The system will be modeled as one-dimensional steady uniform flow as well as unsteady non-uniform flow. The water flow is simulated to operate as open channel flow because both the

closed conduits and the creek are open to atmospheric pressure. However, it is possible that during a large storm event some pipes will encounter full flow. The conveyance of water within the system is solved by the Manning's formula below for open channel flow through the conduits. Manning's formula:

$$v = \frac{1.49}{n} R^{\frac{2}{3}} \sqrt{S}$$

$$Q = v * A$$

$$R = \frac{A}{P}$$

Where Q represents water flow (cfs), v is the velocity (fps), A is the cross-sectional area of flow (sf), n is the Manning's coefficient (dimensionless), R is the hydraulic radius (ft), and S is the slope of the water surface or the linear hydraulic head loss (ft/ft). The hydraulic radius is equal to the cross-sectional area of flow divided by the wetted perimeter (ft) as shown in the third equation above. The wetted perimeter for partially filled circular conduits may be found by the following information and measurements:

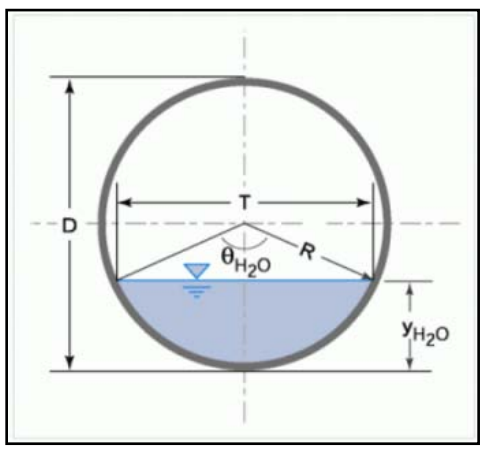

Figure 12 Partially Filled Circular Conduit

Where: Angle from the centerline to the water level, $\Theta = cos^{-1}\left(1 - \frac{y}{r}\right)$; Depth of water in culvert, $y = r(1 - \cos[\Theta)]$; Cross-sectional area of flow, $A = r^2(\Theta - \cos\Theta \sin[\Theta)]$; Wetted Perimeter of water, $P = 2r(\Theta)$; Top width of water surface, $T = 2r(\sin\Theta)$

The Manning's roughness coefficient is based on the material of the pipe or the type of channel. It is inversely proportional to the flow rate where the smaller the coefficient the larger the flow due to the friction caused by the channels roughness. The network contains the following types of pipes: wrought iron (WI), vitrified clay pipe (VP), concrete pipe (CP), reinforced concrete pipe (RCP), and Polyvinyl chloride (PVC).

A typical link setup is shown on Figure 18, the software requires information about downstream and upstream levels, pipe length and Manning's n number. The links connect the nodes of the system which are typically manholes, slope changes or junctions in the network system.

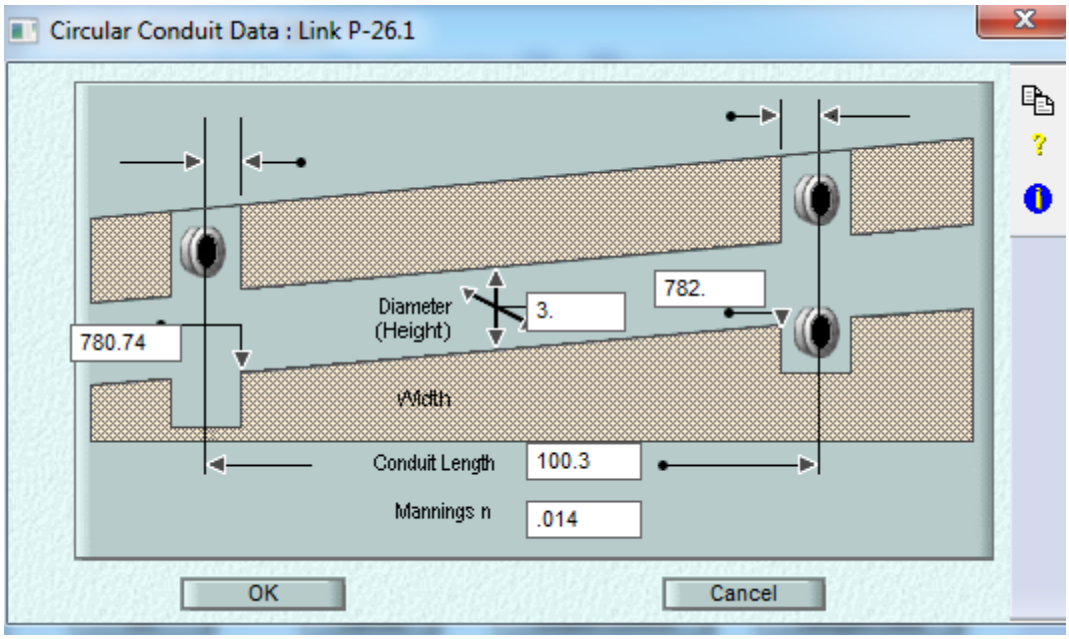

Figure 13 A typical link setup, the example shows the profile of P-26.1

A node setup requires knowledge of the elevations of the inverts and the spill crest, Figure 14. Additional information is entered for storage within the node, inflow into the node and stage storage relations which are used for determining the water and mass balance information.

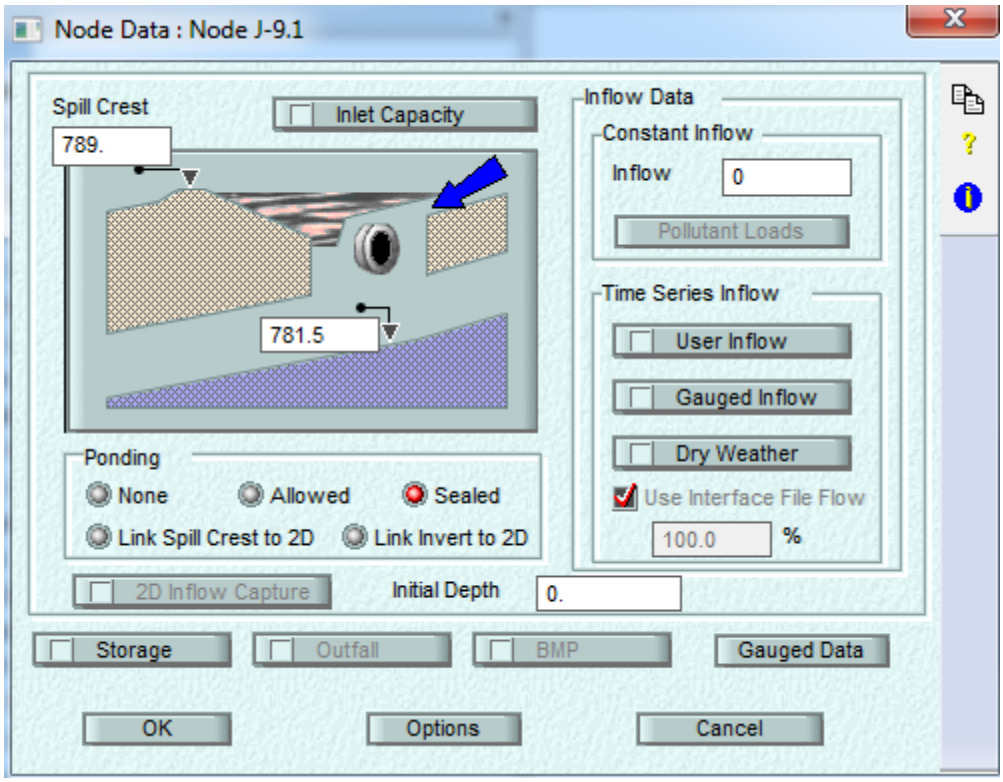

Figure 14 A typical node setup, the example shows node J-9.1

Infiltration

The ORNL site is composed of buildings, pavement, and a minor pervious area. Soils in the area are a mixture of reddish-brown clays and silts resulting from in-situ weathering of shalow limestone bedrock. Clay soils unlike sandy soils do not allow for high infiltration rates. At this time the infiltration rates within the system are divided into three categories: building rooftop, pavement, and pervious areas. Horton's equation was used for the latter two and Uniform loss method for the building rooftops.

Rainfall

The model was calibrated using a stepwise procedure with respect of rainfall events. Three rainfall events were used: 1) Short synthetic rainfall event of 5 minute and 0.2 inches/hour intensity, 2) One year simulation using observed rainfall with interval of 15 minute and 3) Twelve year simulation with observed rainfall and interval of 1 day.

Synthetic rainfall of 5 minutes

Initially a rainfall with intensity of 0.2 inches/hour for 5 minutes was used to determine the response of the model and to verify the water balance between nodes, catchments, links and model convergence. The timestep was 1 minutes and data was recorded for each 1 minute.

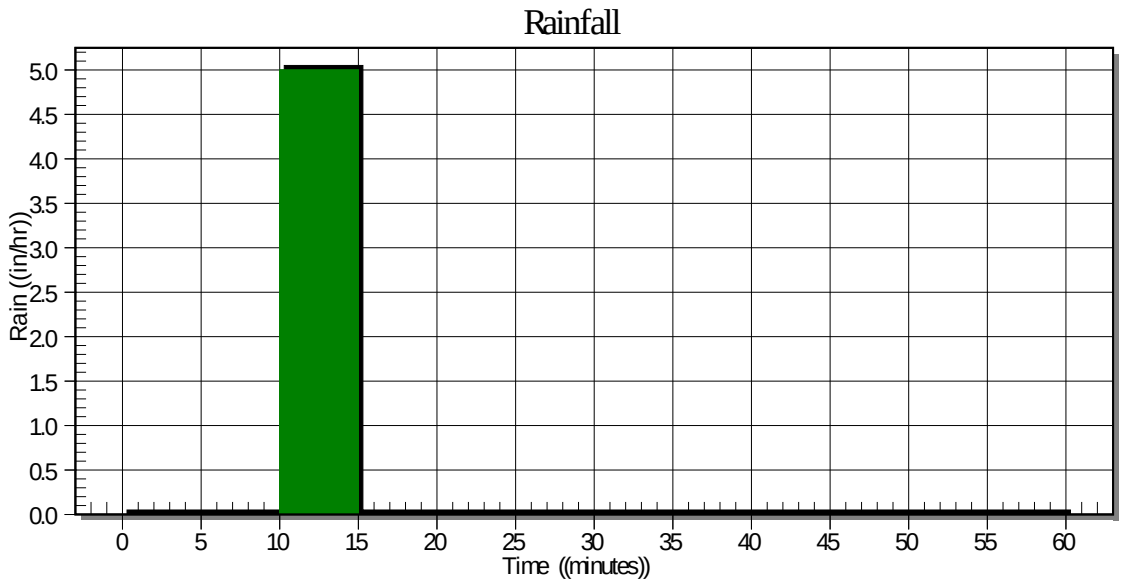

Figure 15 Rainfall input

The resulting hydrographs at the outfall are shown on Figure 16 and Figure 17

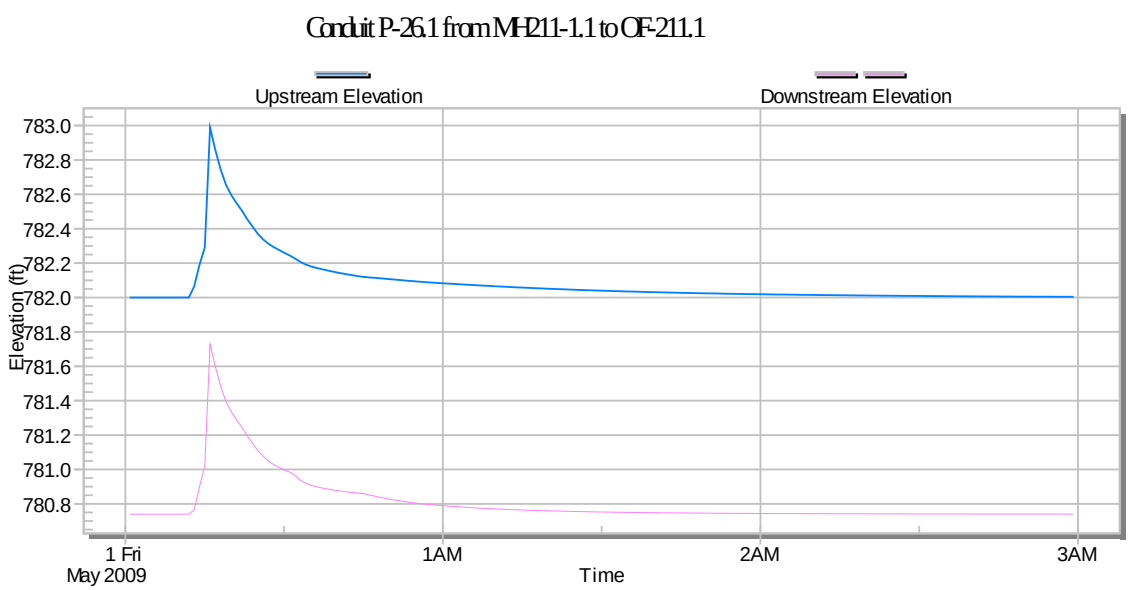

Figure 16 Upstream (OF211) and downstream (MH211-1) stages for link P-26.1

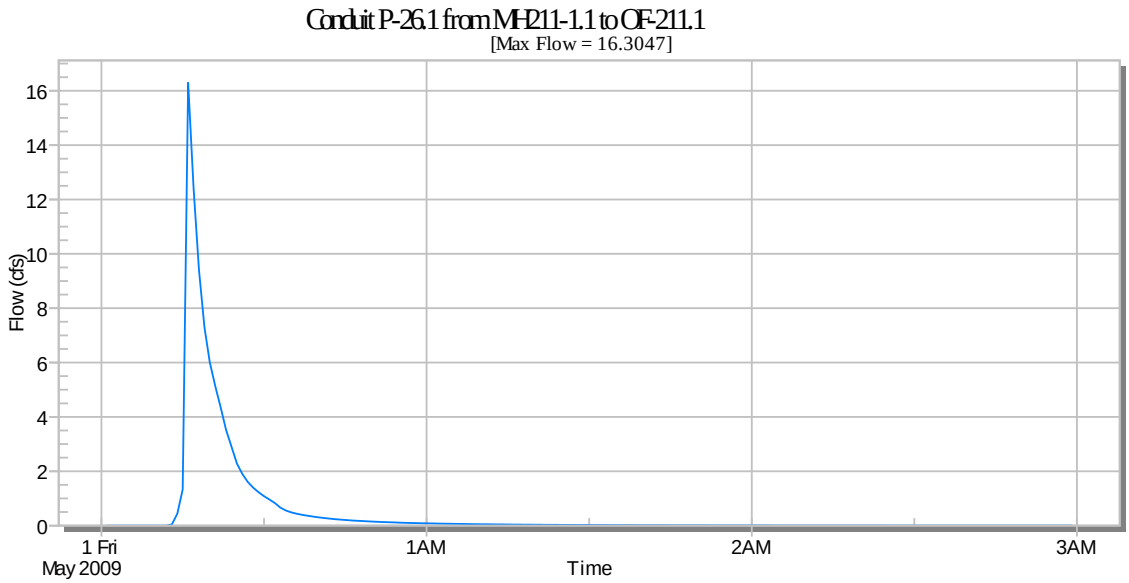

Figure 17 Flow through link P-26.1 and calculated discharge at OF211

One year rainfall

One year simulation using observed rainfall with interval of 15 minute was used to determine the flow through the system.

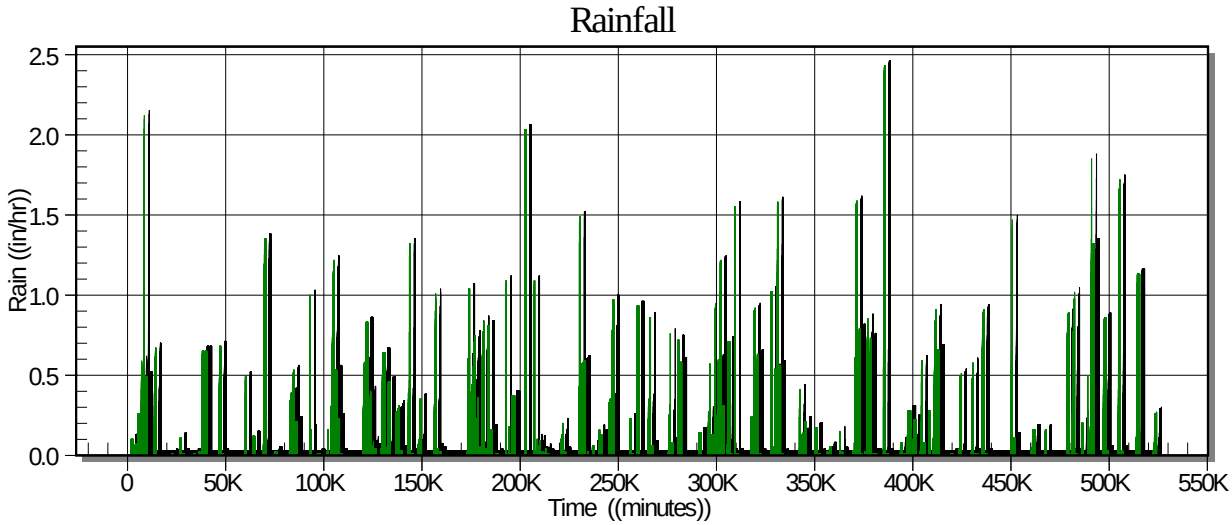

Figure 18 One year rainfall events based on 15 minute observations during 2009

The resulting hydrographs at the outfall are shown on Figure 19 and Figure 20

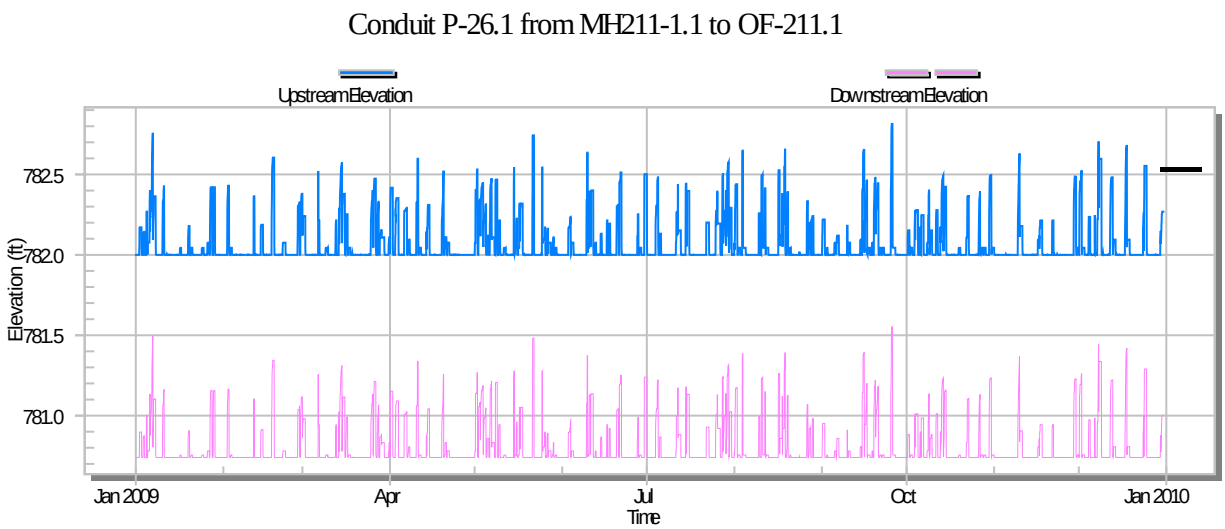

Figure 19 Upstream (OF211) and downstream (MH211-1) stages for link P-26.1

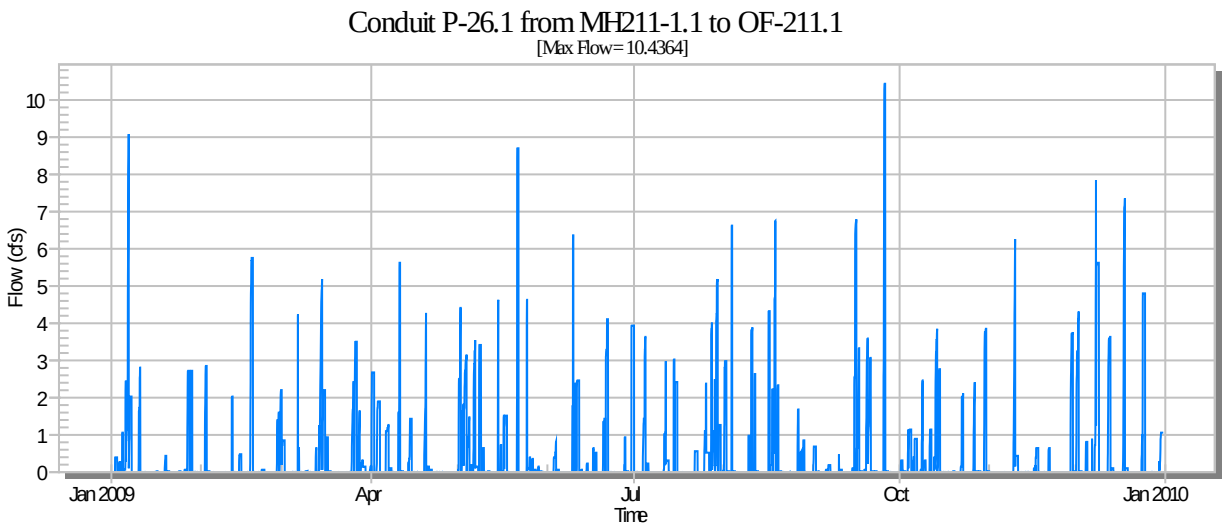

Figure 20 Flow through link P-26.1 and calculated discharge at OF211

Twelve years of simulations

Twelve years of simulations using observed rainfall with interval of one day was used to determine the flow through the system.

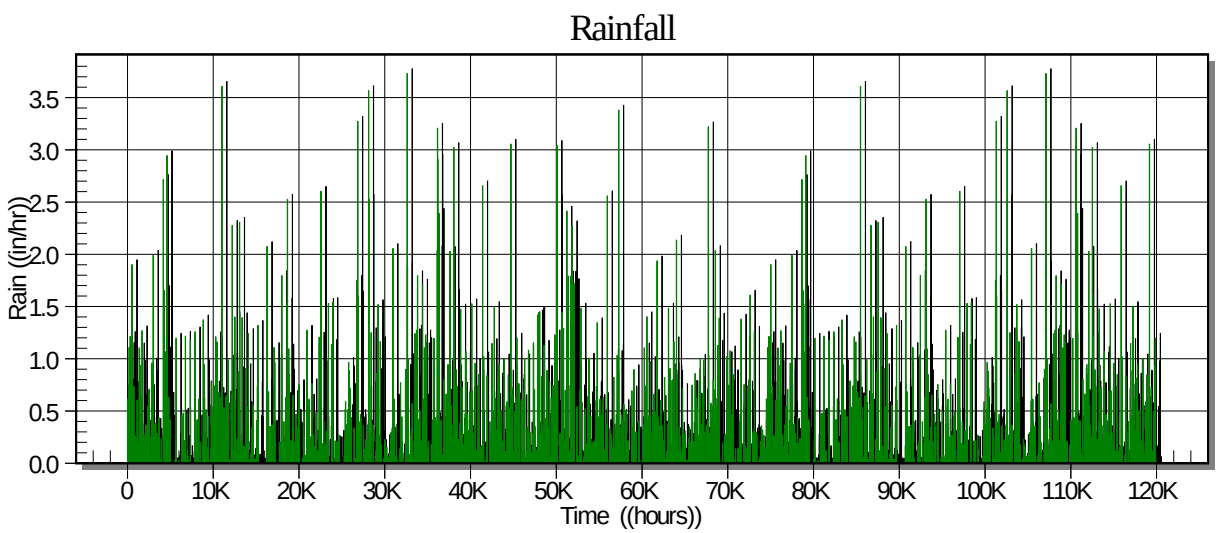

Figure 21 Twelve years of rainfall events based on one day observations (1999-2012)

The resulting hydrographs at the outfall are shown on Figure 19 and Figure 20

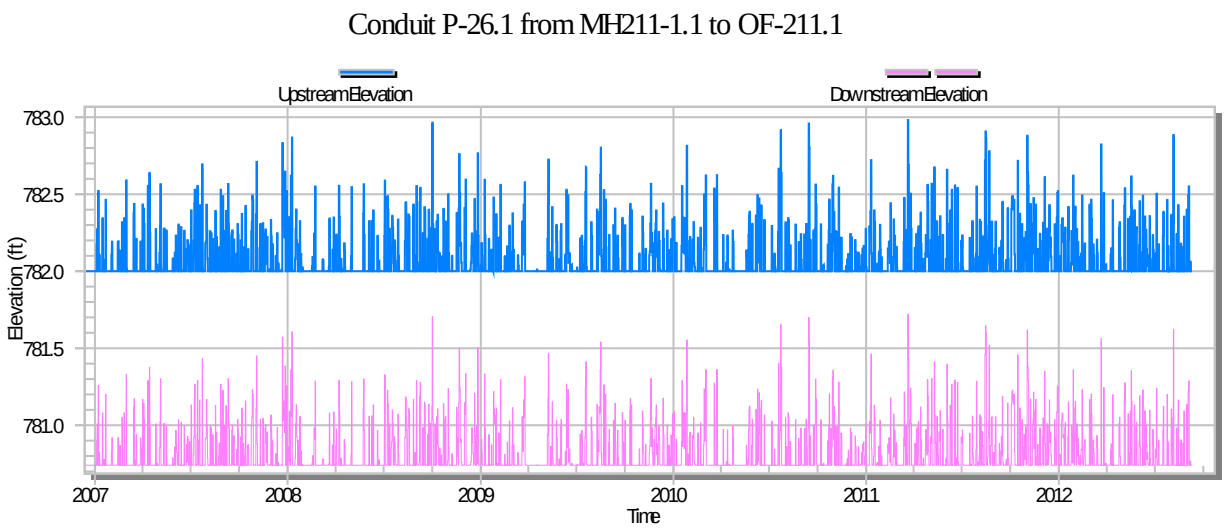

Figure 22 Upstream (OF211) and downstream (MH211-1) stages for link P-26.1 (the figure shows simulation period between 2007 and 2012)

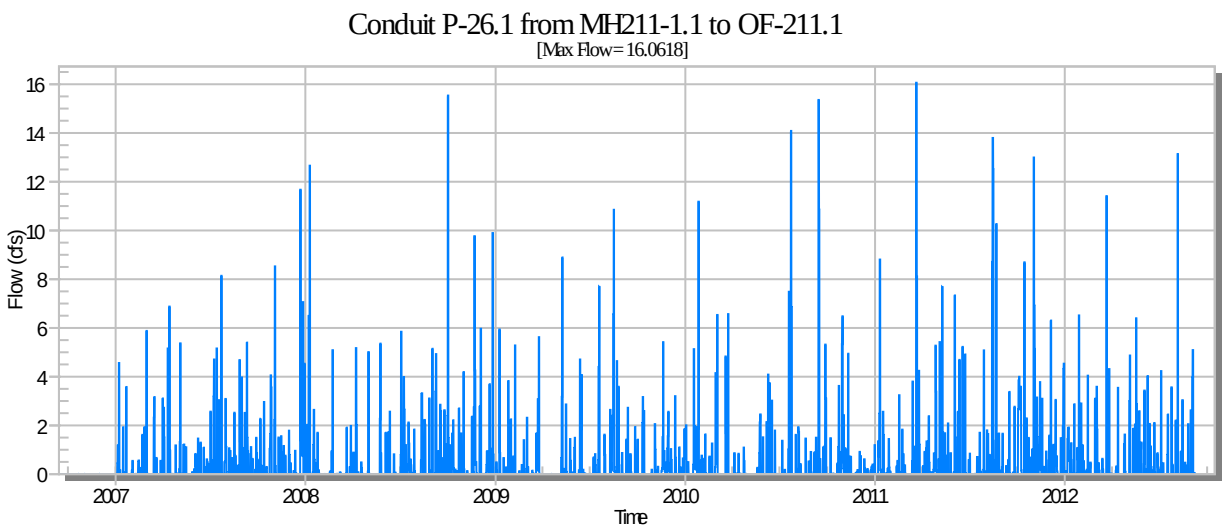

Figure 23 Flow through link P-26.1 and calculated discharge at OF211(the figure shows simulation period between 2007 and 2012)

The simulations showed that the model had accurate response to the flow and stages in the system.

Routing Method

The routing method chosen was the runoff method because the infiltration was defined for the pervious and impervious areas according to their land uses.

Boundary Conditions

The boundary condition is immediately after the discharge via Outfall 211. Outfall 211's outlet control is type 1, free outfall, where the discharge exits freely into WOC for the purposes of this study.

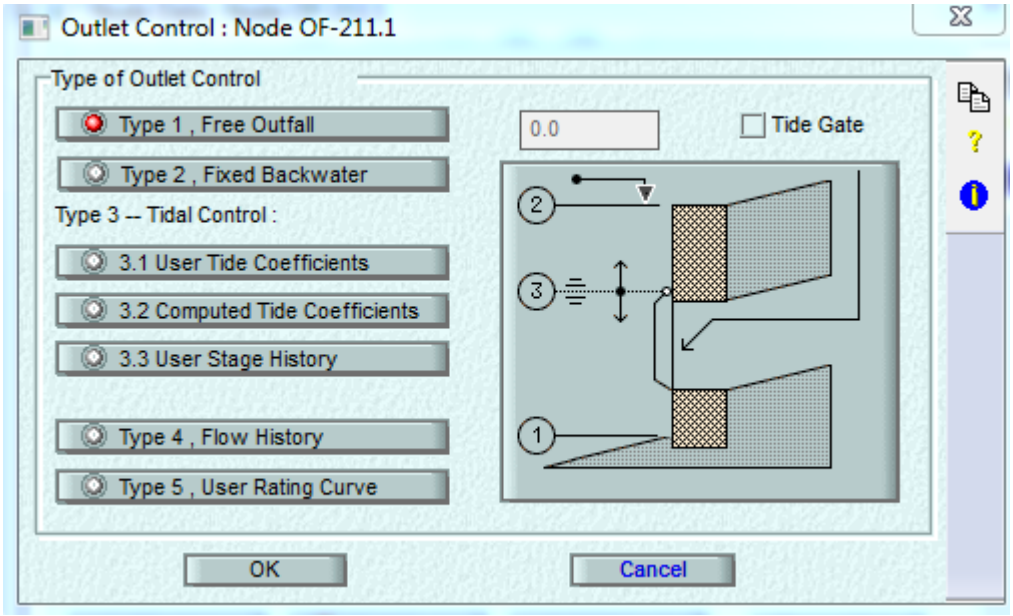

Figure 24 Outfall 211 specifications, the boundary condition was assumed "Free outfall", using the minimum of critical depth or normal depth of flow

A sensitivity analysis via probability exceedance (PE) curves has been conducted by simulating the rainfall for year 2009 over the system. Because the rainfall is continuous series of rainfall events, the resulting time series has many peaks throughout the duration of the simulation; thus, the analysis of the PE curves provides insight into the stage or flow rate that the node or pipe will encounter (meet or exceed) for 95% of the time of the storm event.

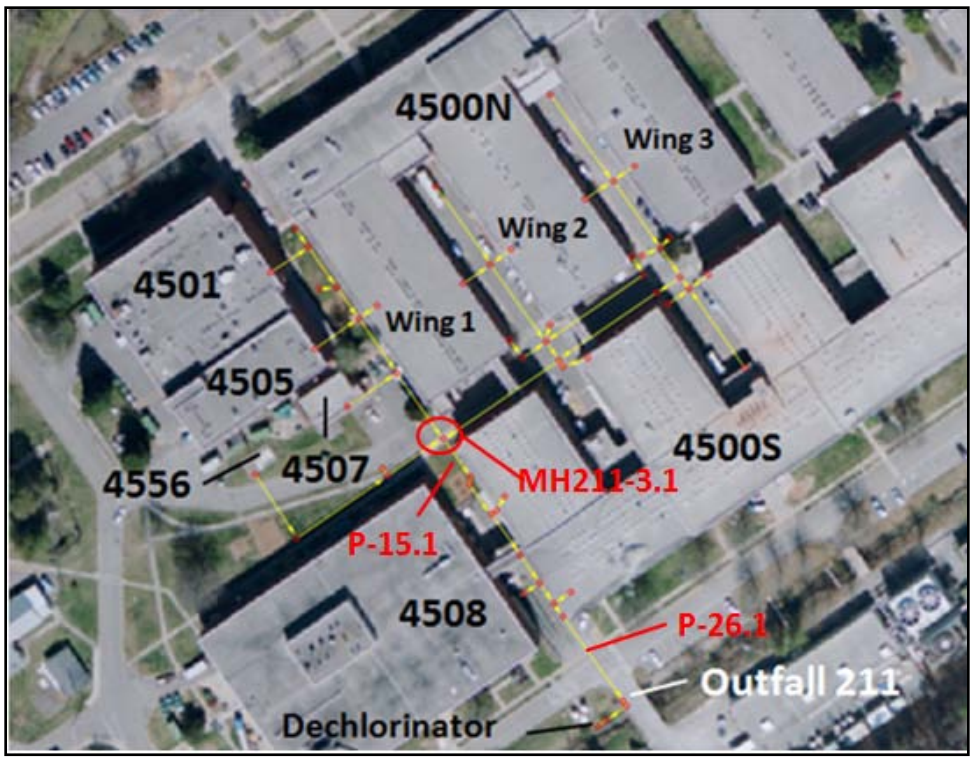

Figure 25 Node and Link Locations for PE Analysis

From the curve in Figure 20, it is approximated that the water level within P-15.1 will meet or exceed 15.83 cfs for 95% of the time provided the rainfall is consistent with the month of May 2009.

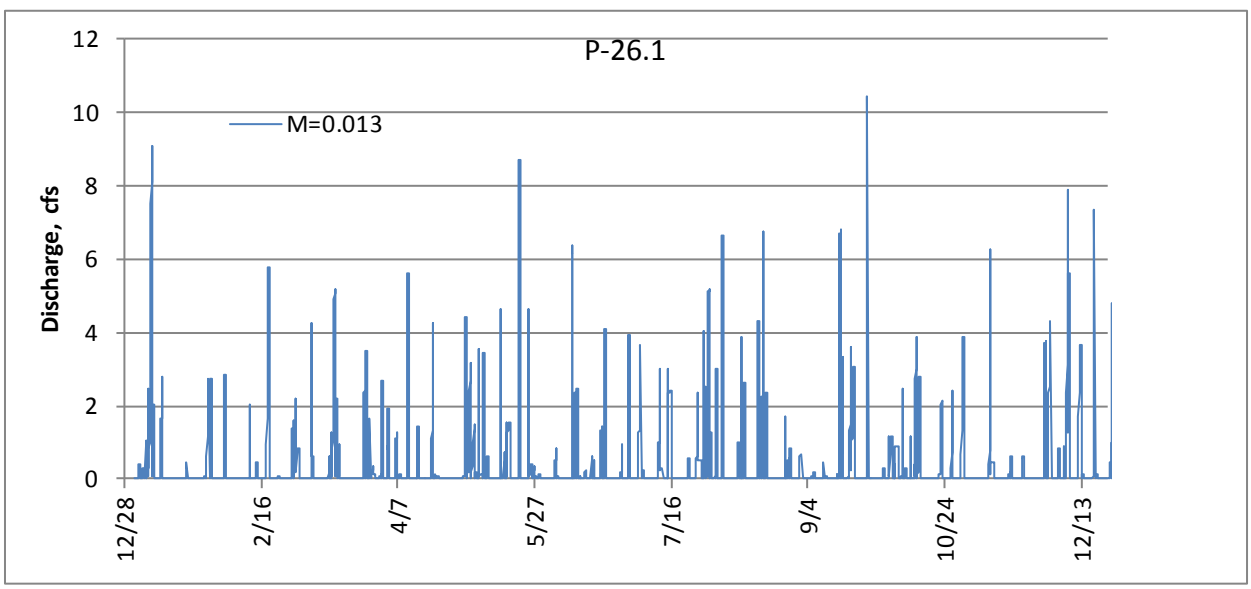

Figure 26 P-26.1 Timeseries of discharge through OF 211

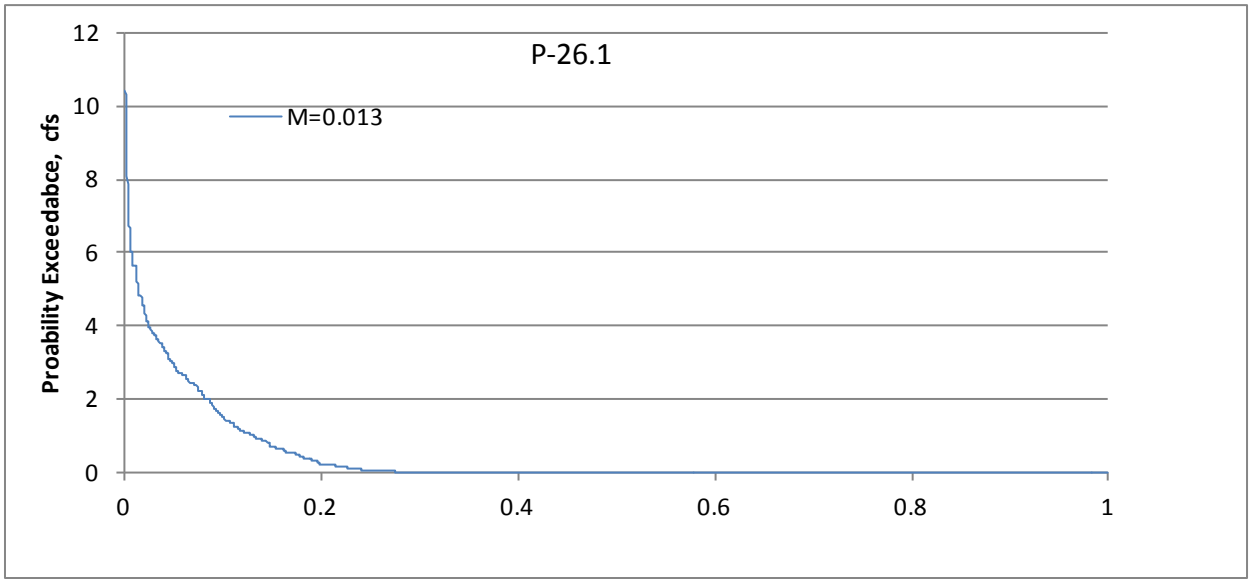

Figure 27 P-26.1 Probability Exceedance of discharge through OF 211

From the curve in Figure 21, it is approximated that the flow rate within P-26.1 will meet or exceed 40.7 cubic feet per second (cfs) for 95% of the time provided the rainfall is consistent with the rainfall used. The PE curve again takes the shape of a line because the range of flow rates within the pipe does not vary far from the peak flow rates throughout the storm event.

Summary of preliminary results

In order to decide which Manning's coefficient to use in order to produce the most accurate results for the model, further investigation of the model's parameters is required. Based on the sensitivity analysis, both Manning's coefficients (0.011 and 0.017) provide a flow rate one magnitude too large based on the samples provided by ORNL.

Table 1 Flow Rate Data Provided by ORNL

Outfall		gpm	cfs
211	5/12/2009	100	0.223
211	11/16/2009	110	0.245
211, composite	11/15/2010	138	0.307
211, grab	11/15/2010	125	0.279
211	11/14/2011	130	0.290

ORNL does not seem to monitor outflow from Outfall 211 on a continual basis thus no time series data for Outfall 211 is available. The samples above are the only available data.

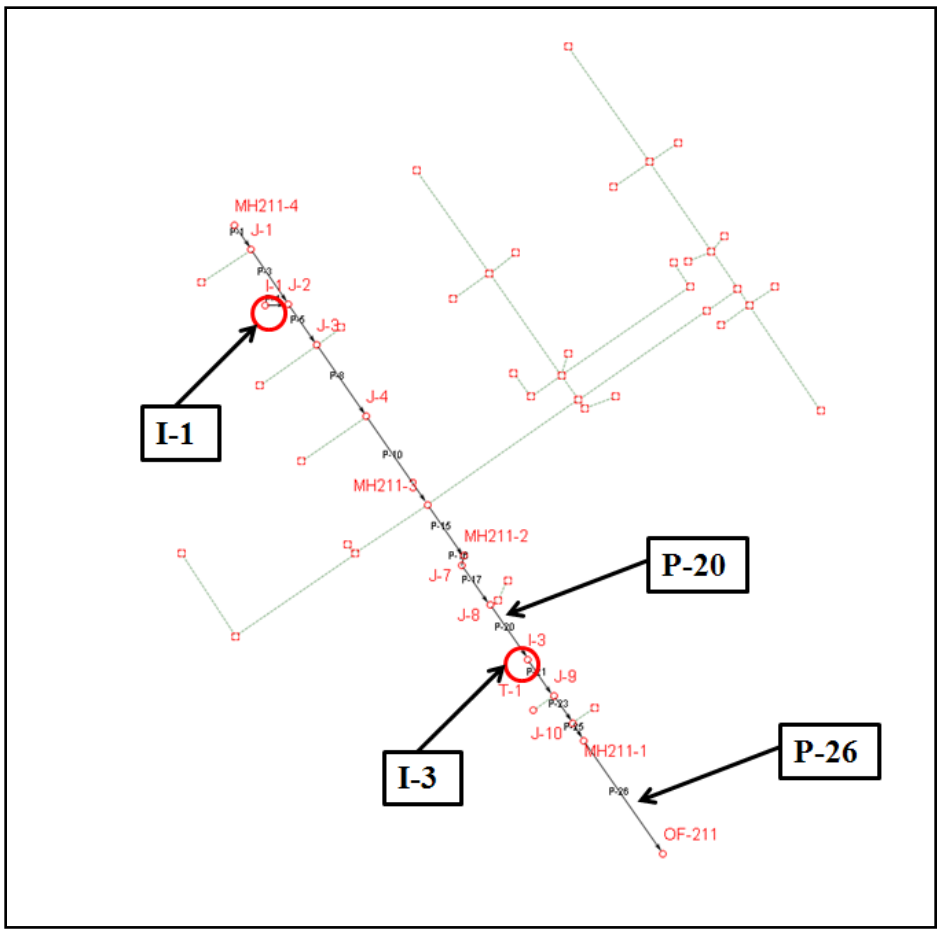

Figure 28 Stormwater Collection System for Steady Uniform Flow

The system was analyzed using the conservation of mass equation (mass in equals mass out).

Where ρ is the density of the surface water in pounds per square foot (lb/sf) and Q is the flow rate of the surface water in cubic feet per second (cfs). Knowing that the density of the surface water is constant, the density can be cancelled out leaving the flow rate of I-1 plus the flow rate of I-3 to equal the flow rate out.

Where

Where c is the dimensionless runoff coefficient, i is the rainfall intensity in inches per hour (in/hr), A is the area of the sub-drainage area in acres (ac). The flow is in cfs and represents the peak flow rate through the pipe. The flow for the I-1 was calculated as follows:

—

The sub-drainage area is mostly green space with an estimated impervious area of 95%, thus, the runoff coefficient was estimated to be 0.22 with rainfall intensity of 0.5 in/hr and a sub-drainage area total of 0.173 ac. The flow for the I-3 was calculated as follows:

—

Link P-20 is located immediately before I-3 (as shown in Figure 28) thus the peak flow rate in P-20 should be equal to . The XPSWMM results indicate that the peak flow rate is 0.02 cfs which complies with the mass balance equation for Q_{out} that equals 0.019cfs.

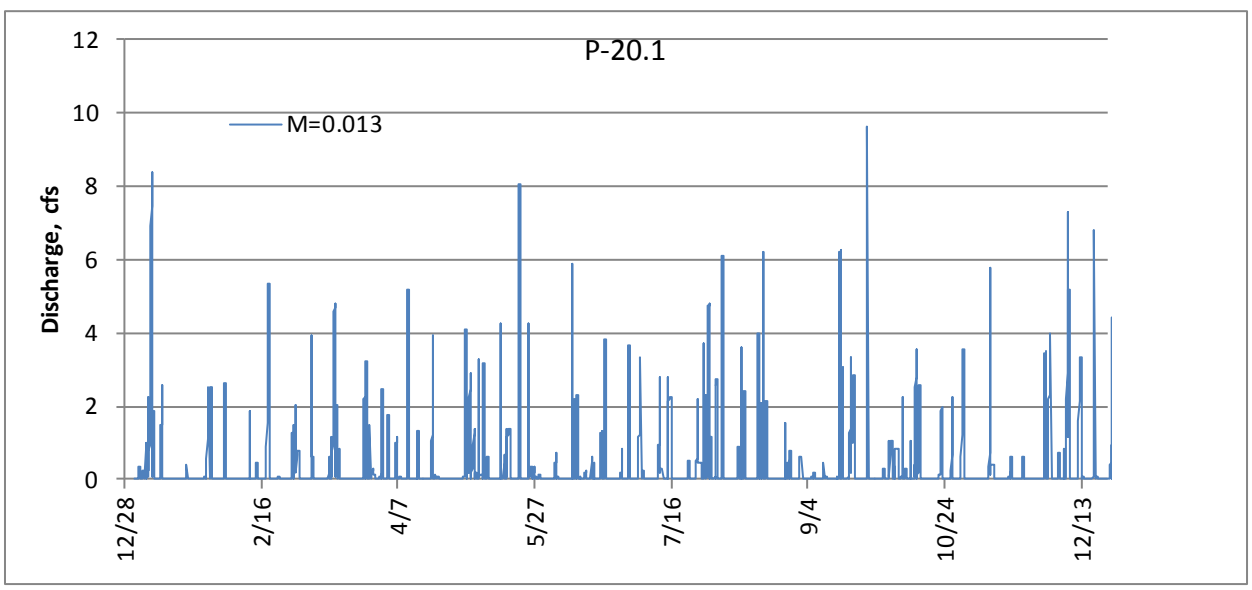

Figure 29 P-20 XPSWMM Hydrograph

Link P-26 is located immediately before Outfall 211 thus the peak flow rate in P-26 should be equal to . The XPSWMM results indicate that the peak flow rate is 0.06 cfs which complies with the mass balance equation for $_t$ and thus may be considered calibrated for steady uniform flow.

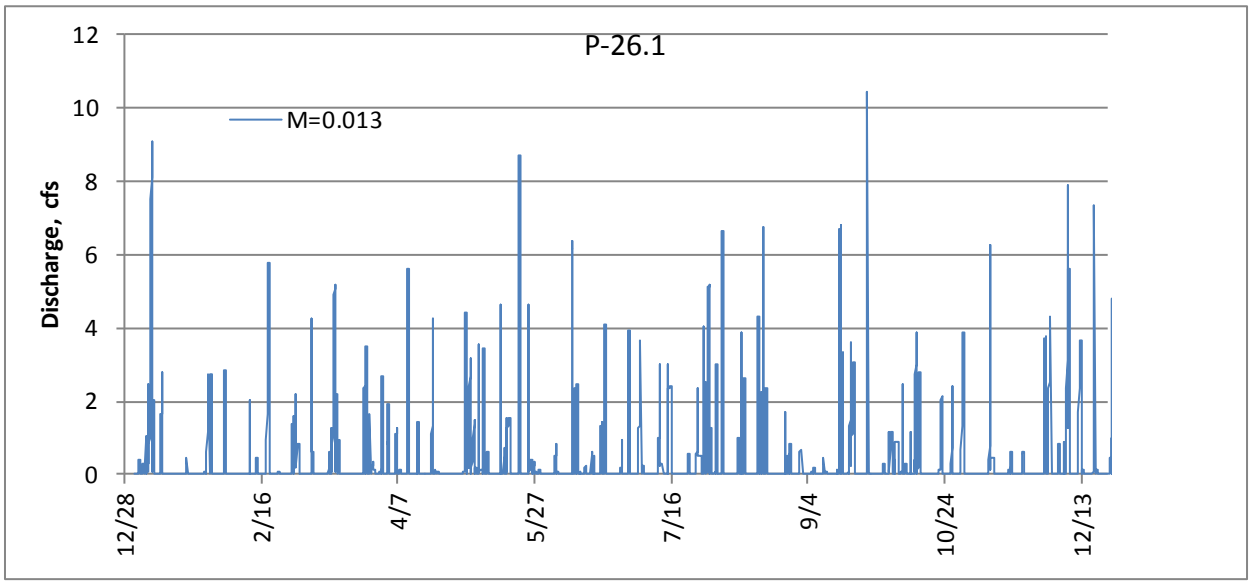

Figure 30 P-26 XPSWMM Hydrograph

The 24-hour precipitation for the rainfall event on May 11, 2009 at 10AM through May 12, 2009, 10AM, assuming the sample was taken around 10AM on May 12, 2009, was retrieved from the ORNL's Tower C and was simulated through the entire stormwater collection system. The rainfall data was unsteady non uniform rainfall. The model produced a peak discharge of 0.34 cfs. The results are relatively close to the 0.2 to 0.3 cfs that is needed for calibration purposes and may be considered a reasonable result. The model will continue to be analyzed and revised as necessary to achieve a closer range of flow rate for Outfall 211 as the study continues. The model may be considered verified when the XPSWMM results are consistent with the sample flow rates.

The network profile from J-7.1 to OF211, the flowrates and the water surface for two selected days are shown on Figure 31, Figure 32, Figure 33 and Figure 34

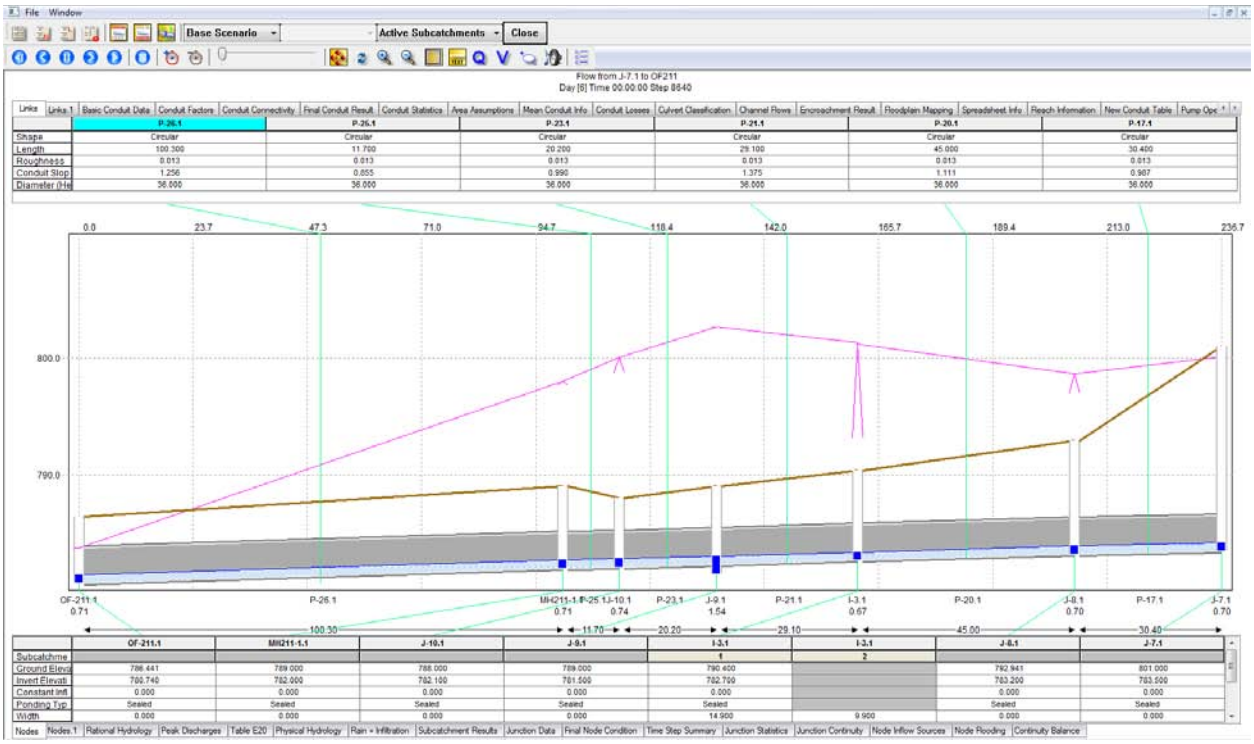

Figure 31 Profile of network and water surface from J-7.1 to OF211

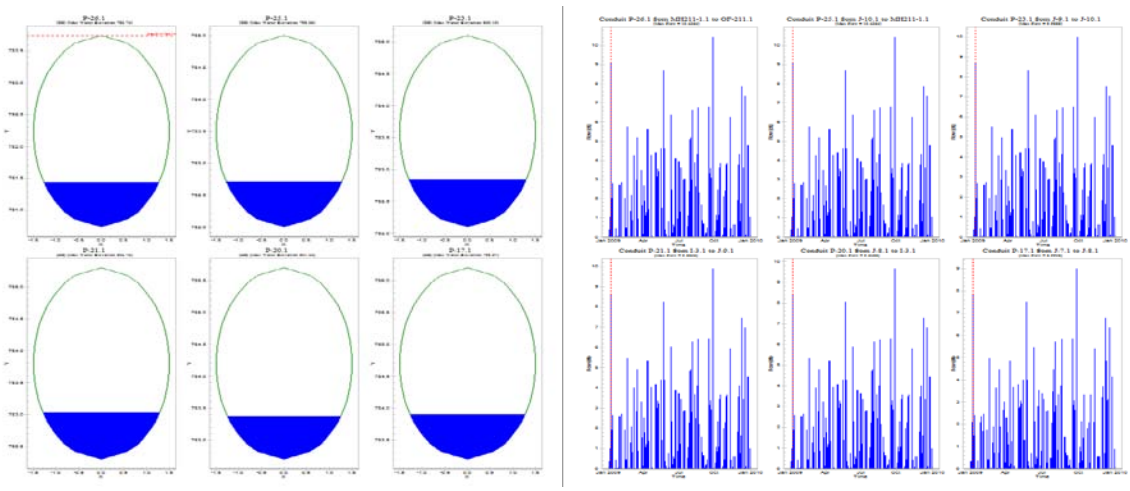

Figure 32 Flow from J-7.1 to OF211 on day 6.

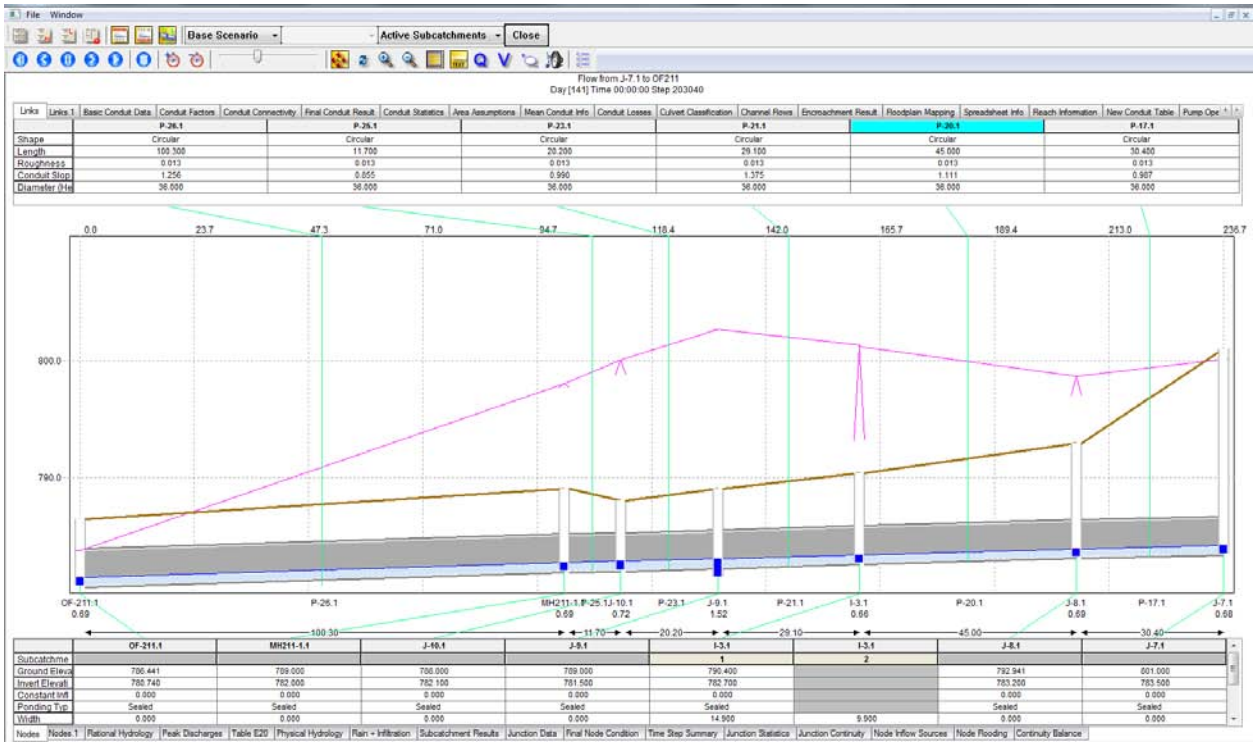

Figure 33 Profile of network and water surface from J-7.1 to OF211

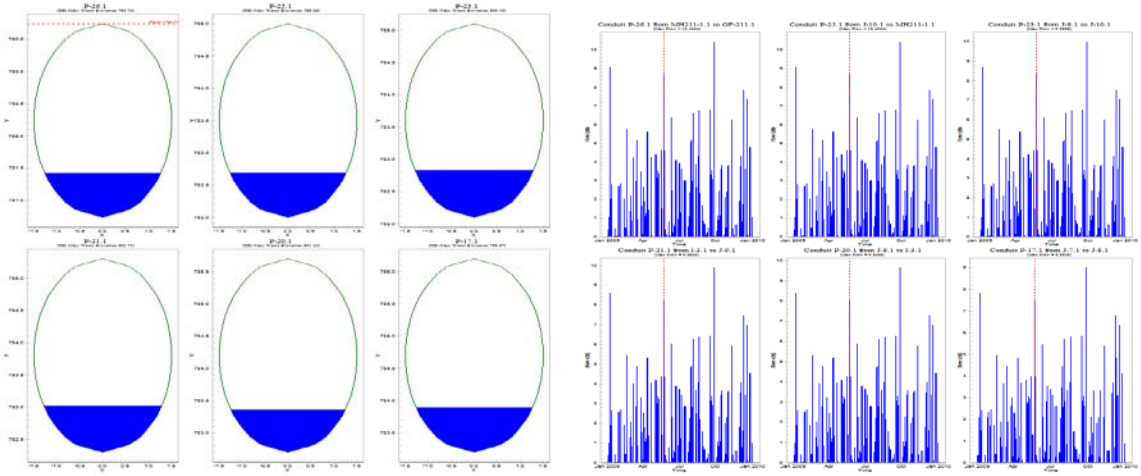

Figure 34 Flow from J-7.1 to OF211, on day 141

A full set of simulation figures is shown the appendix.

Future Work

- The next step will be to analyze the infiltration parameters closely in order to achieve flow rates similar to the sample flow rates provided by ORNL for monthly rainfall events. Also, there is currently user inflow into the system for various AC units. This will also be adjusted in order to get outflow from Outfall 211 closer to the 0.2 cfs as shown in the sample provided by ORNL.
- A tracer has been added to the system at different points. The tracer is used to determine the mixing of various streams within the system. A first order decay and generation rates will be used throughout the drainage network to determine the contribution to transport from different sections and to provide correlation of flow and transport.

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APPENDICES

Flow and stage simulations for year 2009

A summary of flow through all links is provided in Table 2.

Table 2 Maximum flow computed for observed rainfall with 15 minutes interval

Name	Max Flow cfs	Max Flow/Design Flow (fraction) %	Max Water Depth ft	Max Water Depth ft	Max d/D (depth/diameter)
P-26.1	16.305	0.242	0.988	0.988	0.413
P-15.1	11.432	0.198	5.756	0.266	0.391
P-16.1	11.410	0.017	0.266	0.902	0.369
P-12.1	1.787	0.058	0.205	0.406	0.328
P-37.1	1.272	0.387	0.216	3.593	2.297
P-27.1	8.383	0.429	3.593	5.756	1.938
P-50.1	2.184	0.338	0.268	3.476	5.438
P-41.1	3.078	0.315	3.476	3.681	2.522
P-31.1	0.941	0.118	0.290	0.359	0.289
P-43.1	0.160	0.164	1.065	5.867	11.750
P-44.1	0.288	0.392	1.364	5.867	19.583
P-40.1	3.607	0.620	3.681	3.593	2.522
P-42.1	1.044	2.761	5.867	3.476	14.687
P-4.1	0.793	0.047	1.204	5.801	5.801
P-5.1	1.008	1.651	5.801	5.101	11.603
P-14.1	0.057	0.506	0.194	0.138	0.584
P-17.1	11.237	0.205	0.902	0.863	0.391
P-20.1	11.018	0.222	0.863	0.807	0.391
P-25.1	12.333	0.298	1.016	0.988	0.413
P-24.1	0.620	1.073	1.229	1.016	4.557
P-19.1	0.670	1.751	7.018	2.056	28.143
P-18.1	0.626	1.080	2.056	0.863	4.690
P-13.1	0.042	0.313	0.138	0.406	0.418
P-11.1	1.765	0.176	0.406	5.756	5.777
P-39.1	0.208	0.262	0.180	0.165	0.360
P-38.1	0.197	0.243	0.165	0.359	0.723
P-28.1	3.502	0.182	0.359	3.593	0.919

P-30.1	0.182	0.085	0.099	0.197	0.397
P-29.1	0.178	0.332	0.197	0.359	0.723
P-9.1	0.137	0.770	2.046	5.921	18.085
P-10.1	1.611	1.199	5.921	5.756	8.459
P-2.1	0.458	0.851	1.830	5.100	12.445
P-3.1	0.641	0.152	5.100	5.801	4.641
P-6.1	0.368	0.067	0.145	5.101	2.404
P-8.1	1.584	0.318	5.101	5.921	5.383
P-7.1	0.398	0.115	0.114	5.101	10.205
P-21.1	11.014	0.203	0.807	1.746	0.400
P-33.1	0.526	0.279	0.180	0.828	1.664
P-32.1	2.228	1.129	0.828	0.359	0.666
P-34.1	0.853	0.392	0.218	0.828	1.664
P-47.1	0.543	0.241	0.167	4.284	8.572
P-46.1	1.072	0.206	4.284	5.867	4.700
P-48.1	0.466	0.182	0.145	4.284	8.572
P-49.1	0.788	0.100	2.096	4.284	3.429
P-35.1	0.939	0.472	0.768	0.828	0.666
P-36.1	0.575	0.776	0.385	0.216	0.771
P-23.1	11.283	0.268	1.746	1.016	0.400
P-22	0.203	0.382	2.627	1.746	6.662
P-54.1	0.626	0.607	0.290	0.268	0.579
P-55.1	0.651	0.664	0.316	0.268	0.633
P-56.1	0.270	0.202	0.204	0.268	0.401

Summary of hydrographs for critical links

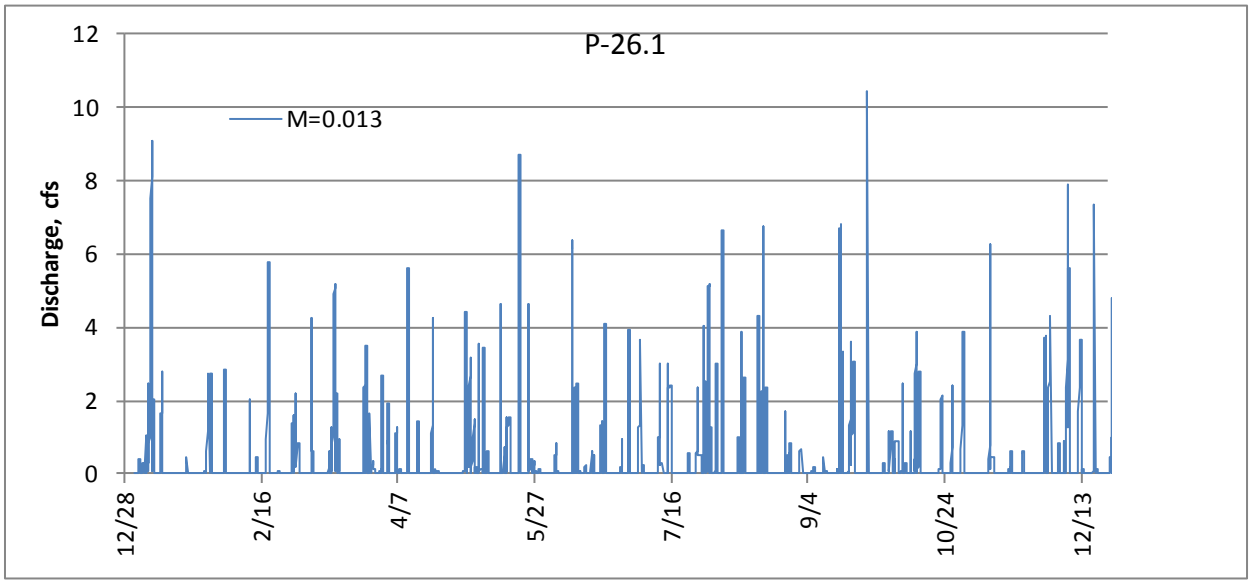

Figure 35 Discharge through P-26.1 (outfall 211)

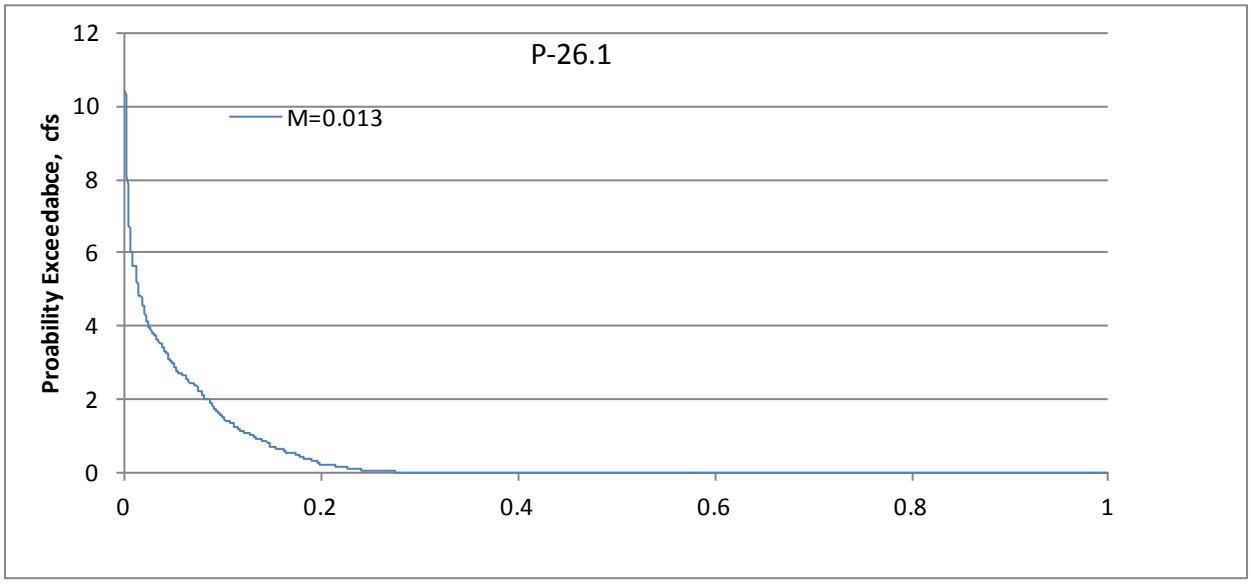

Figure 36 Probability exceedance of flow through P-26.1(outfall 211)

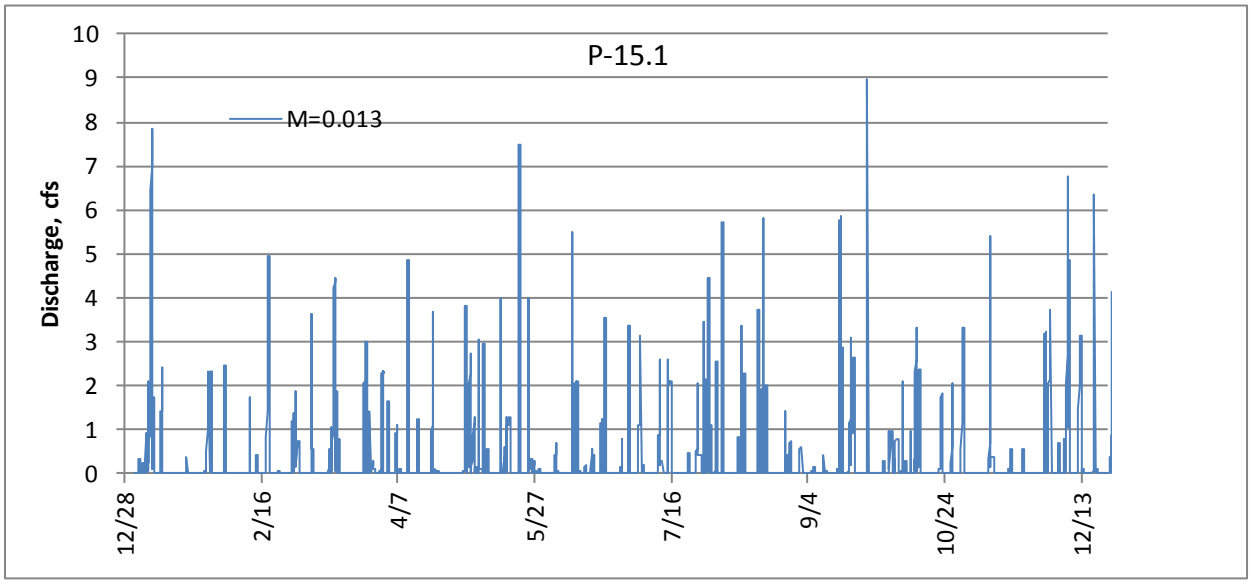

Figure 37 Discharge through P-15.1

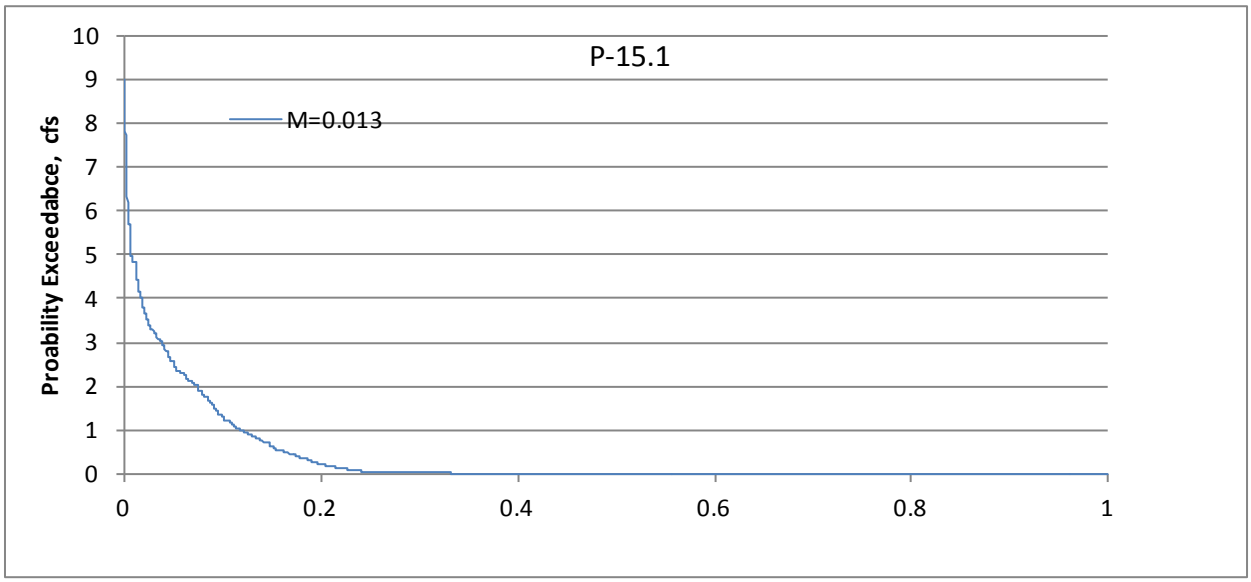

Figure 38 Probability exceedance of flow through P-15.1

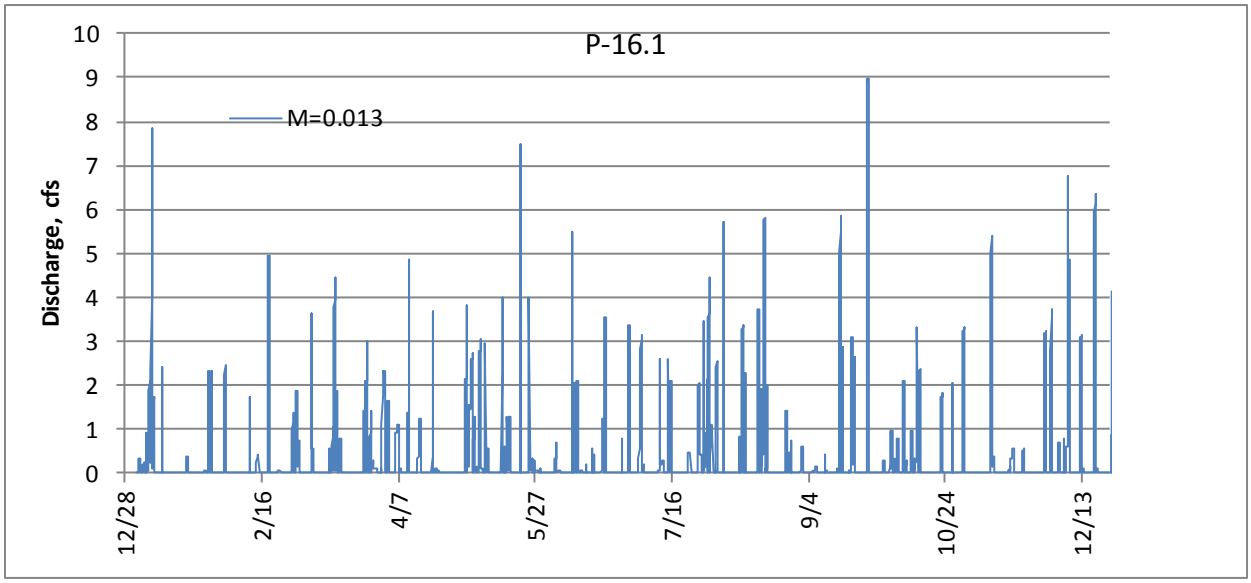

Figure 39 Discharge through P-16.1

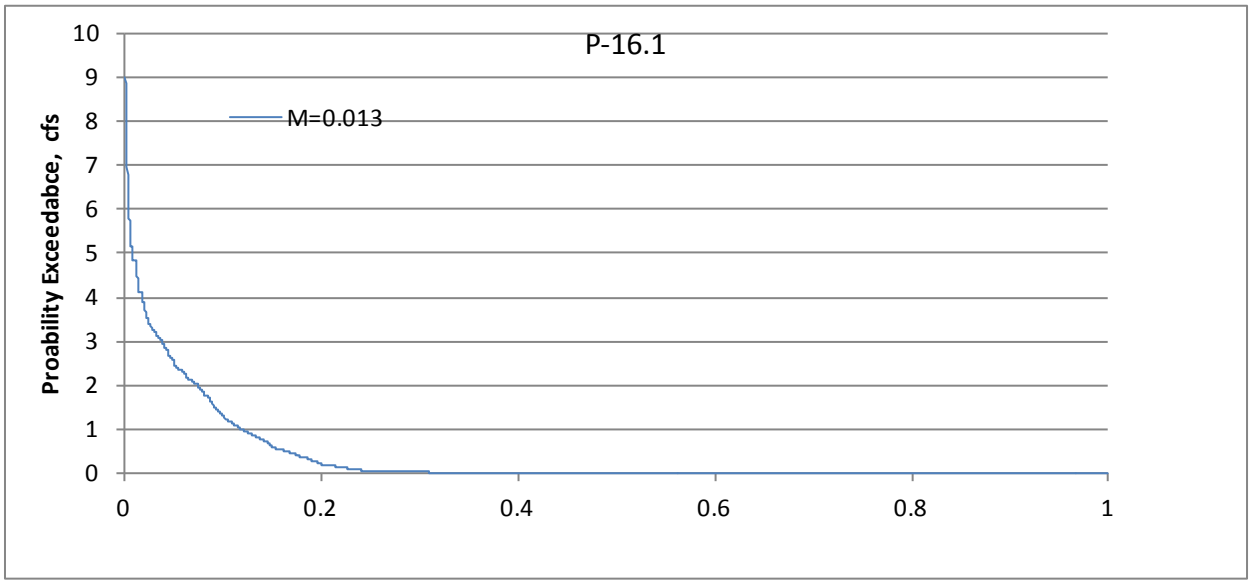

Figure 40 Probability exceedance of flow through P-16.1

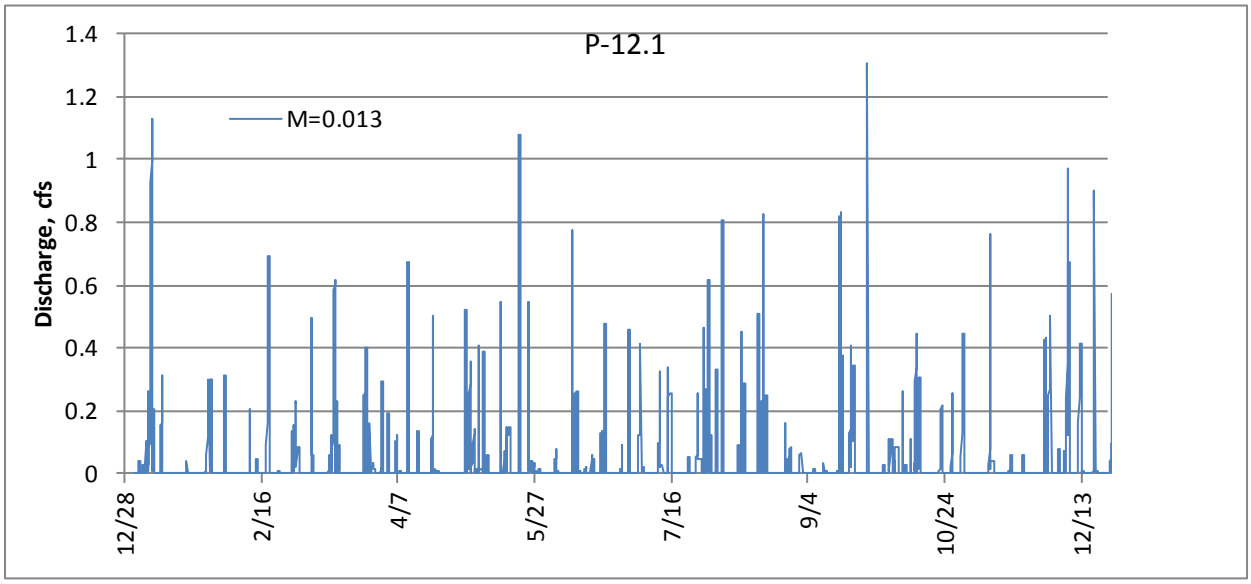

Figure 41 Discharge through P-12.1

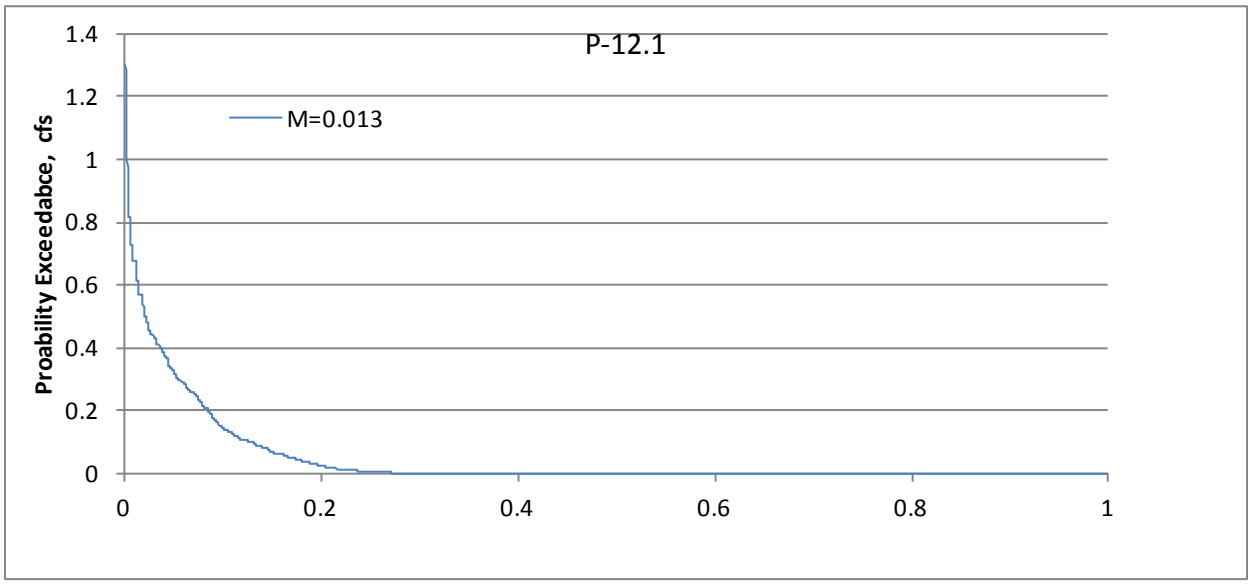

Figure 42 Probability exceedance of flow through P-12.1

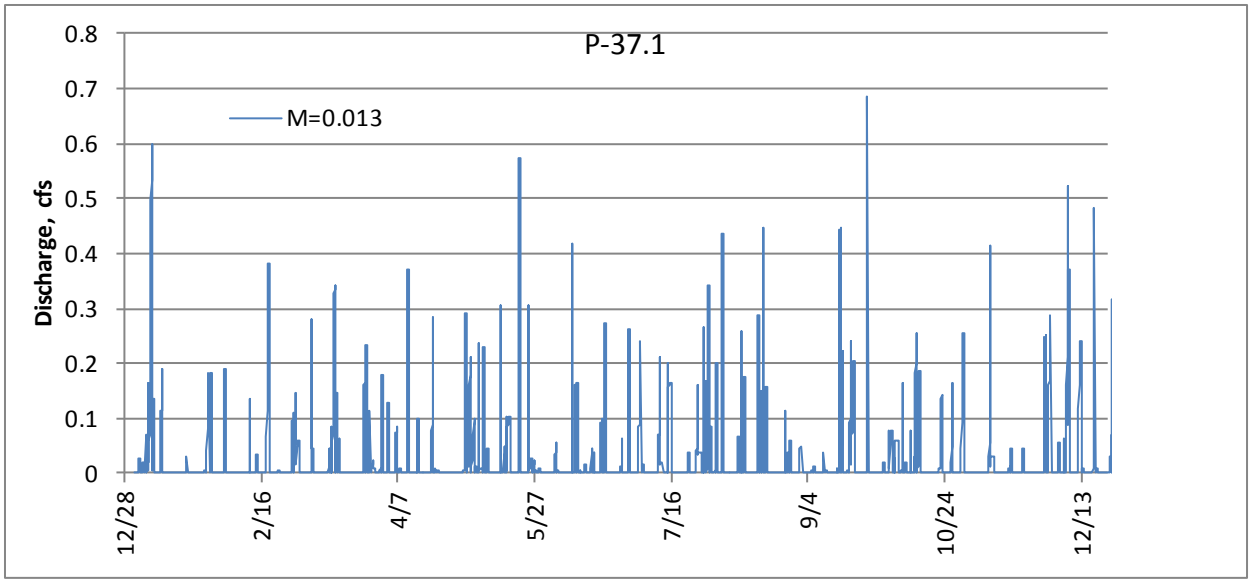

Figure 43 Discharge through P-37.1

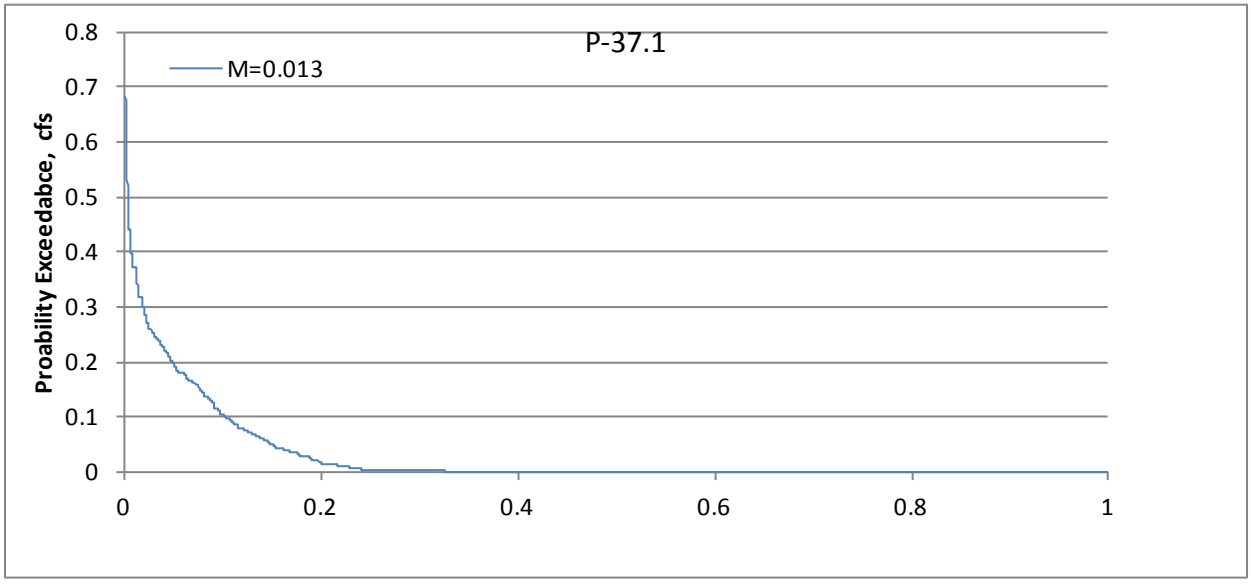

Figure 44 Probability exceedance of flow through P-15.1

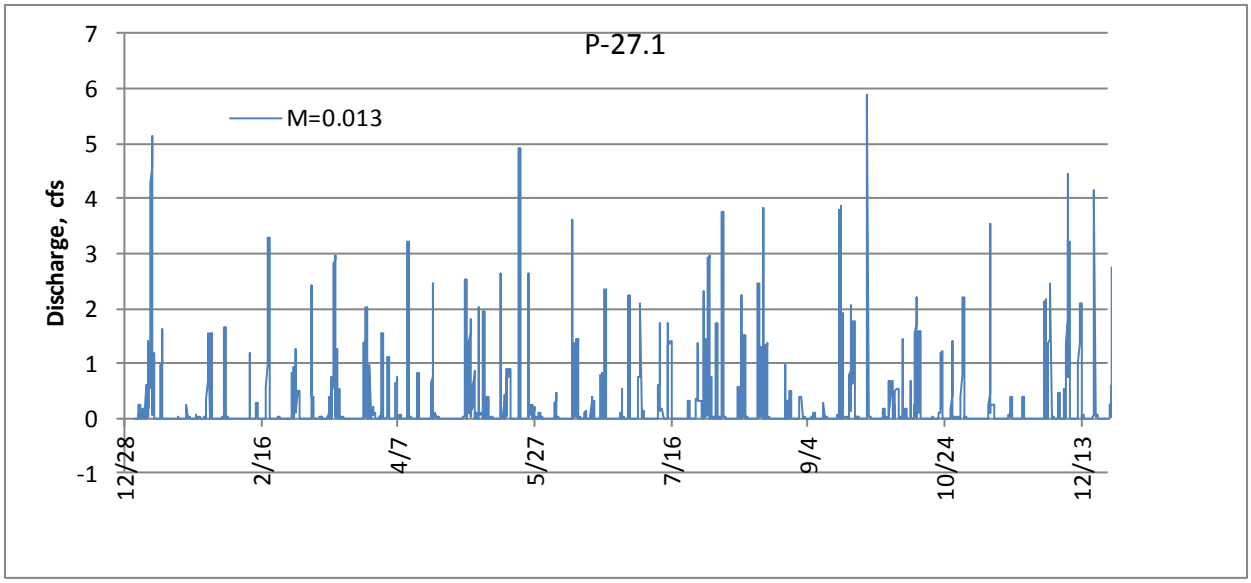

Figure 45 Discharge through P-27.1

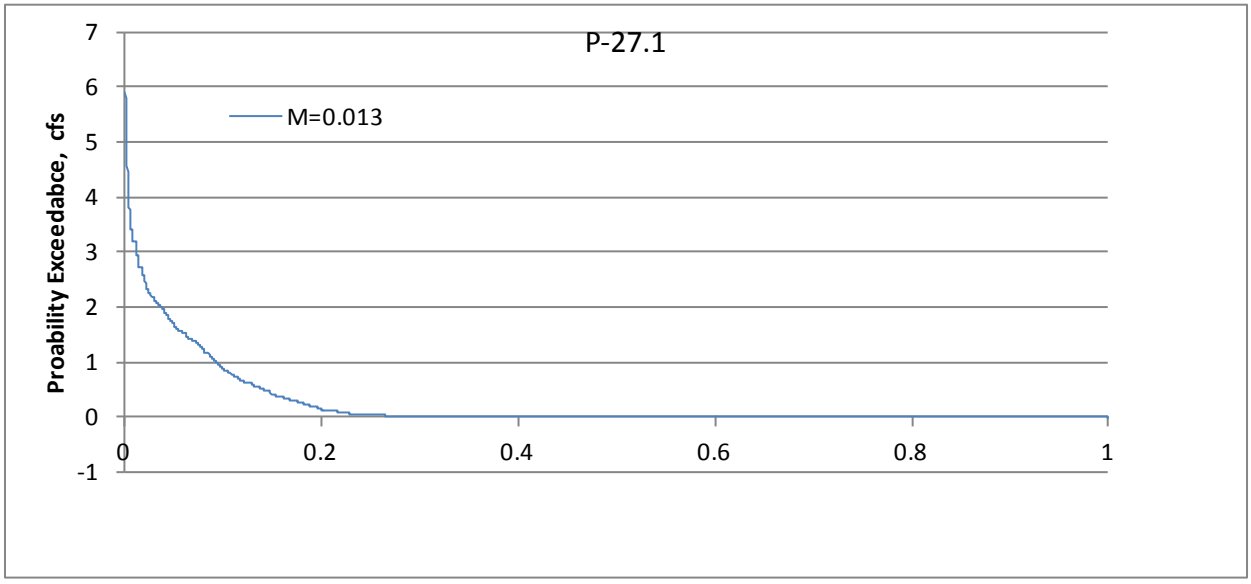

Figure 46 Probability exceedance of flow through P-27.1

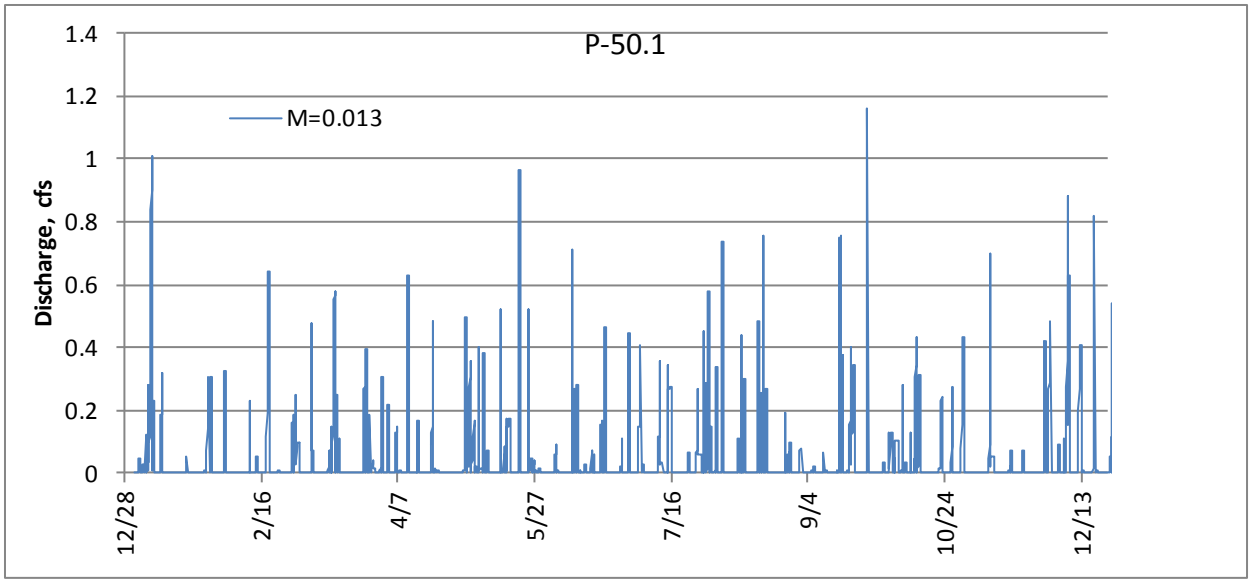

Figure 47 Discharge through P-50.1

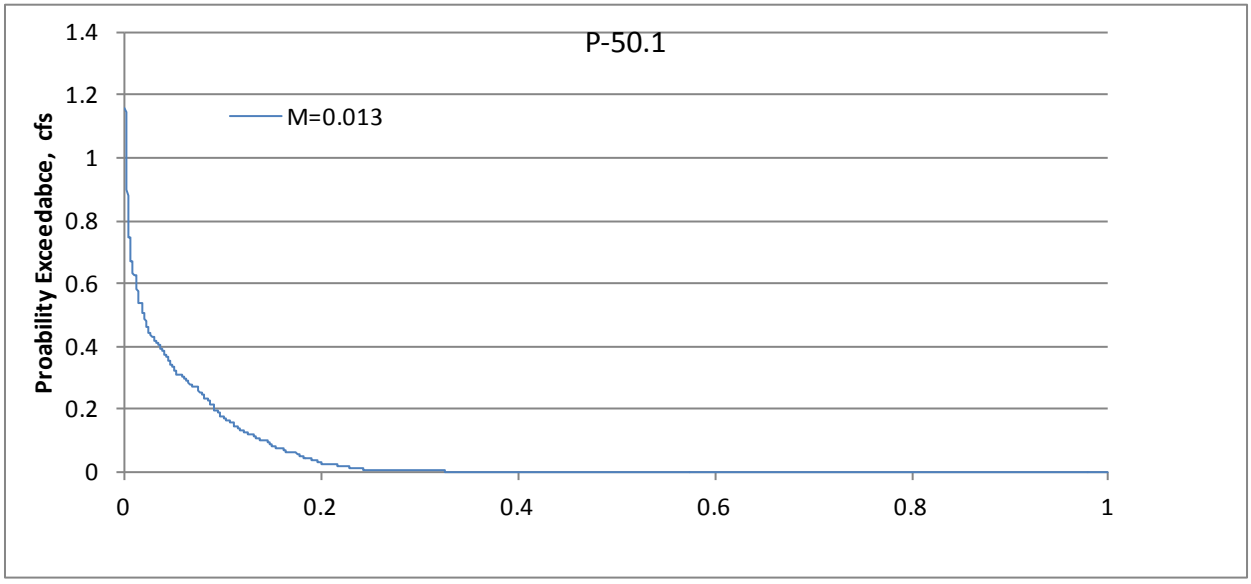

Figure 48 Probability exceedance of flow through P-50.1

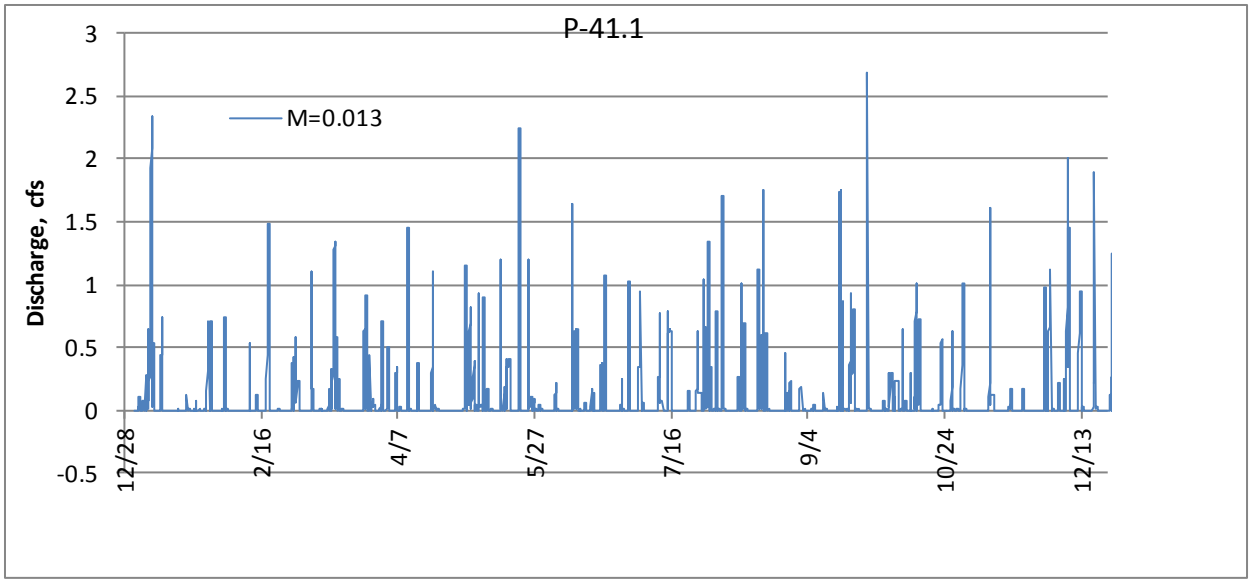

Figure 49 Discharge through P-41.1

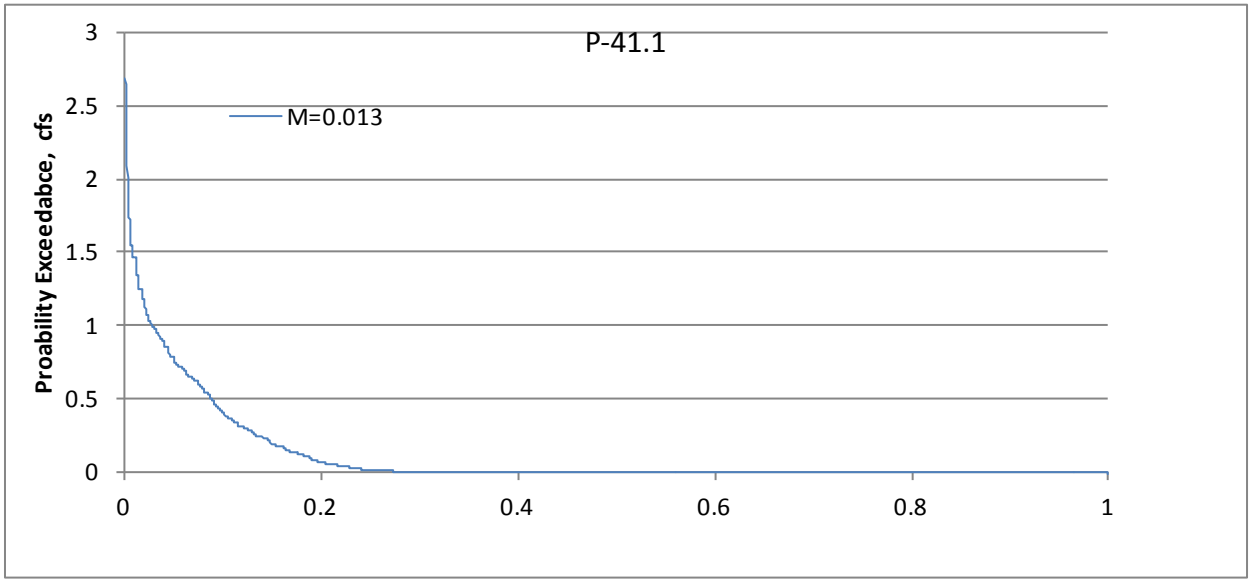

Figure 50 Probability exceedance of flow through P-41.1

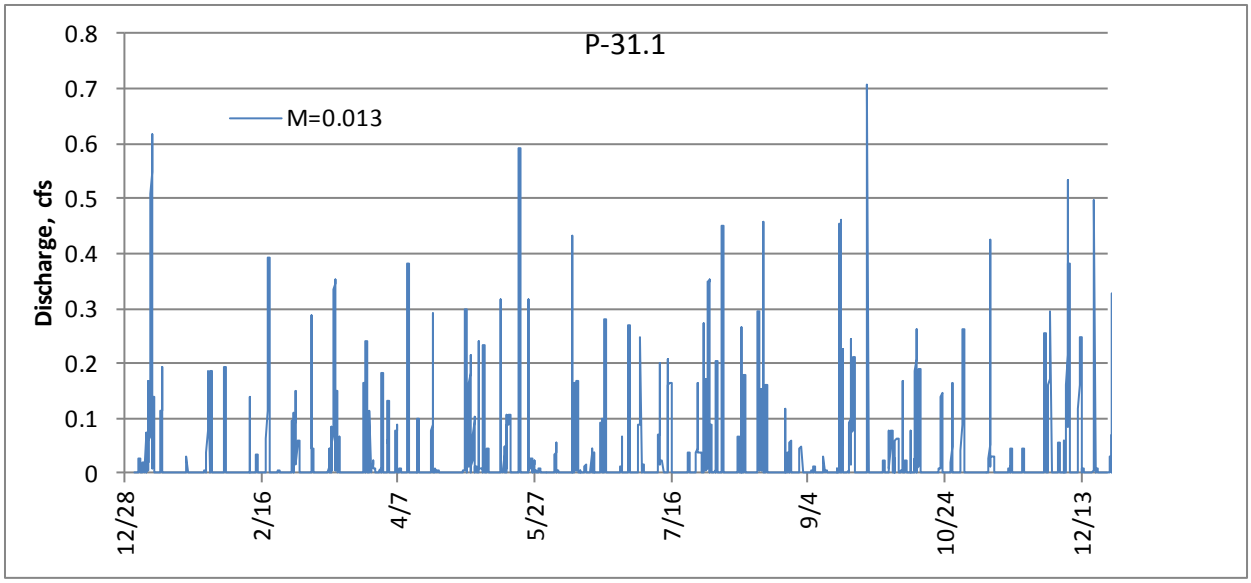

Figure 51 Discharge through P-31.1

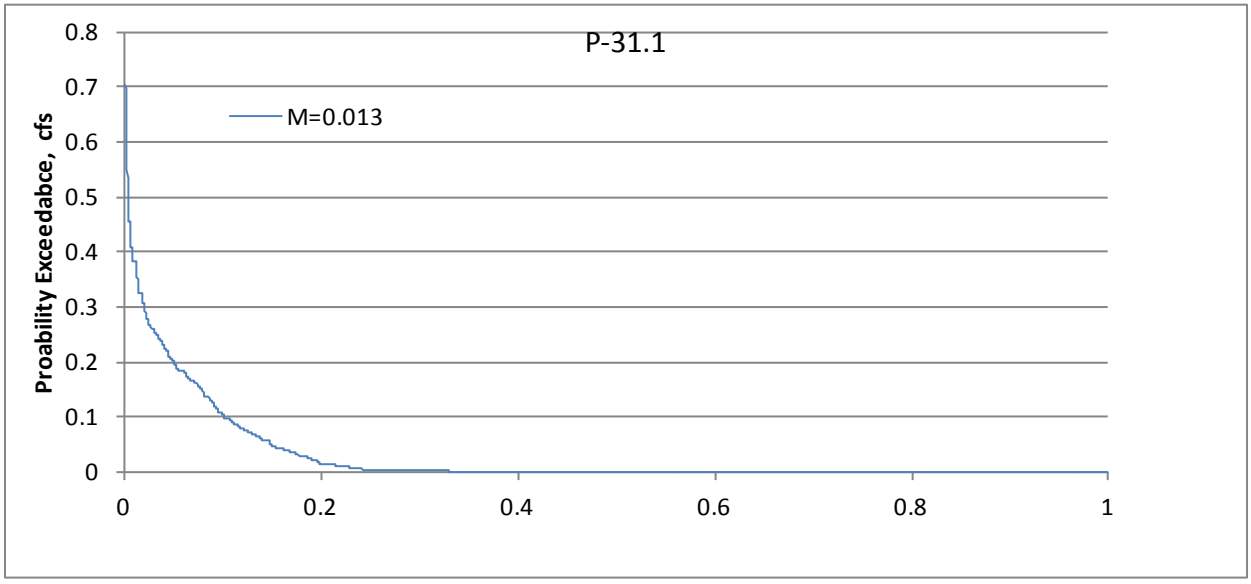

Figure 52 Probability exceedance of flow through P-31.1

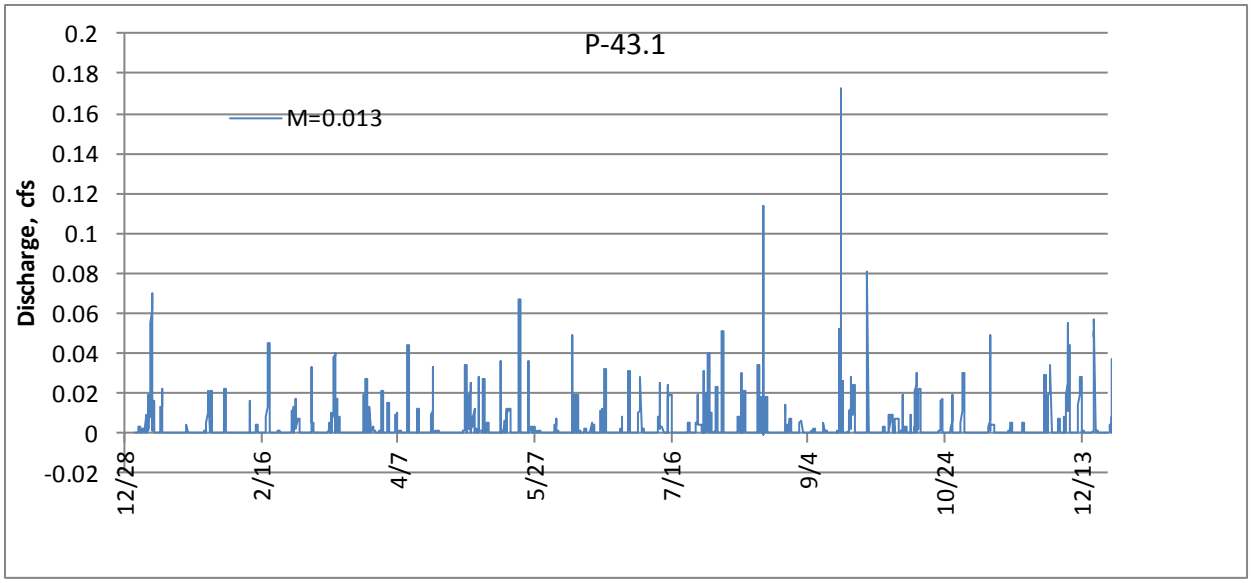

Figure 53 Discharge through P-43.1

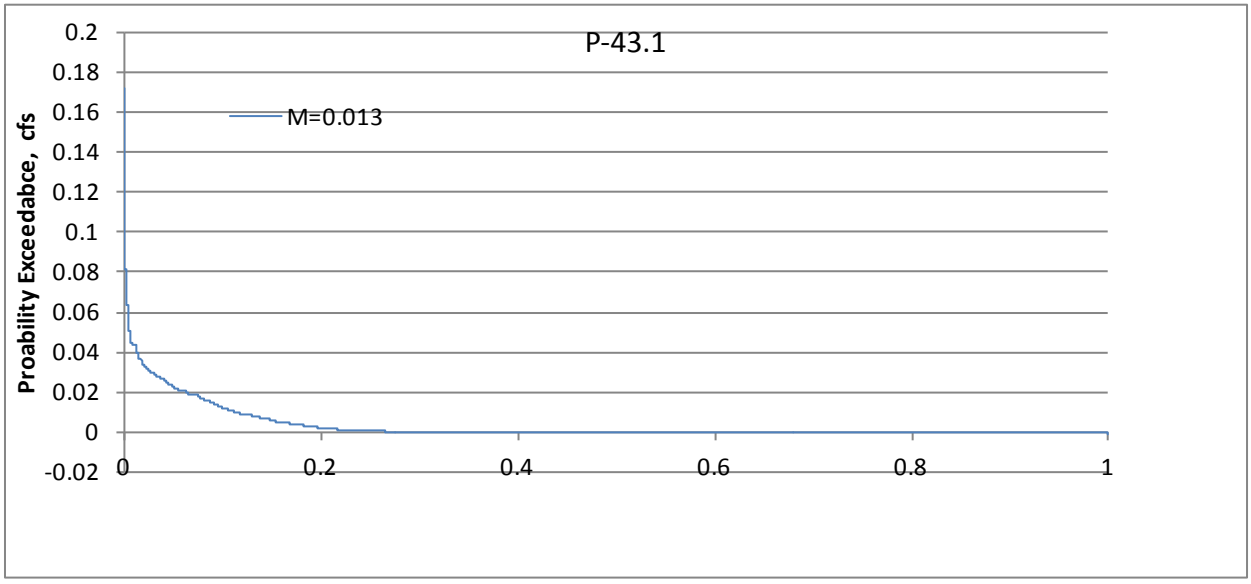

Figure 54 Probability exceedance of flow through P-43.1

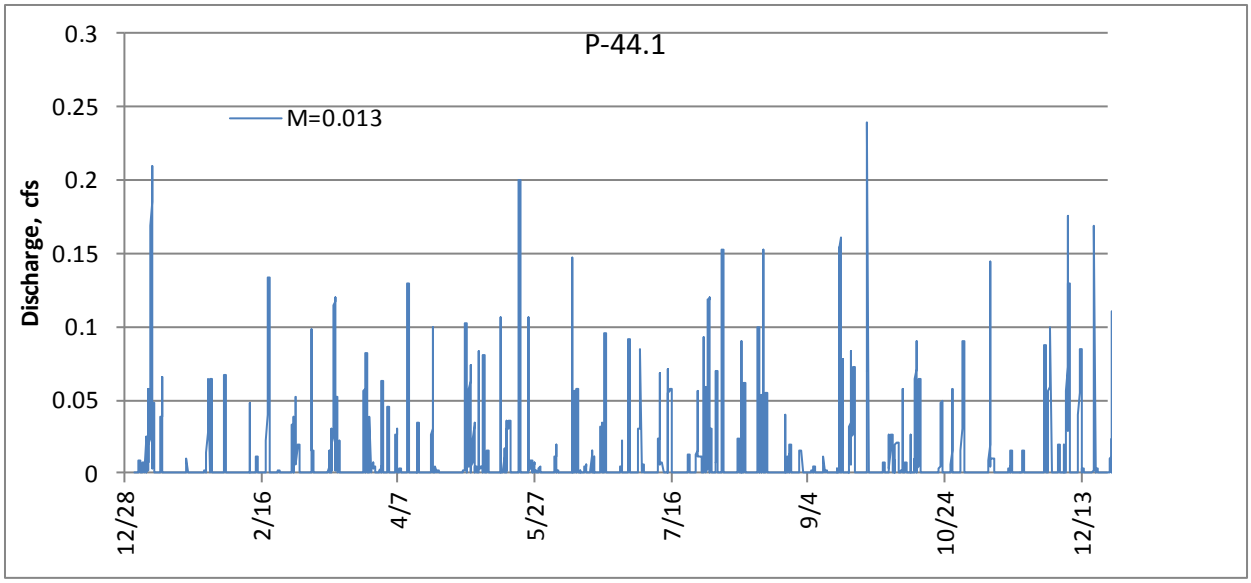

Figure 55 Discharge through P-44.1

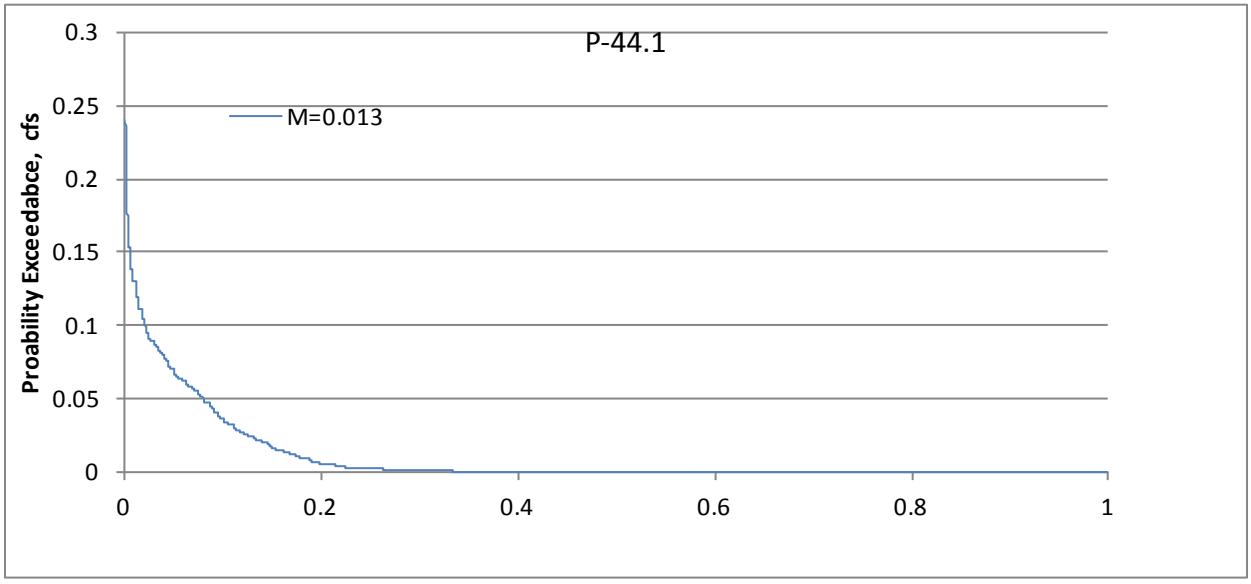

Figure 56 Probability exceedance of flow through P-44.1

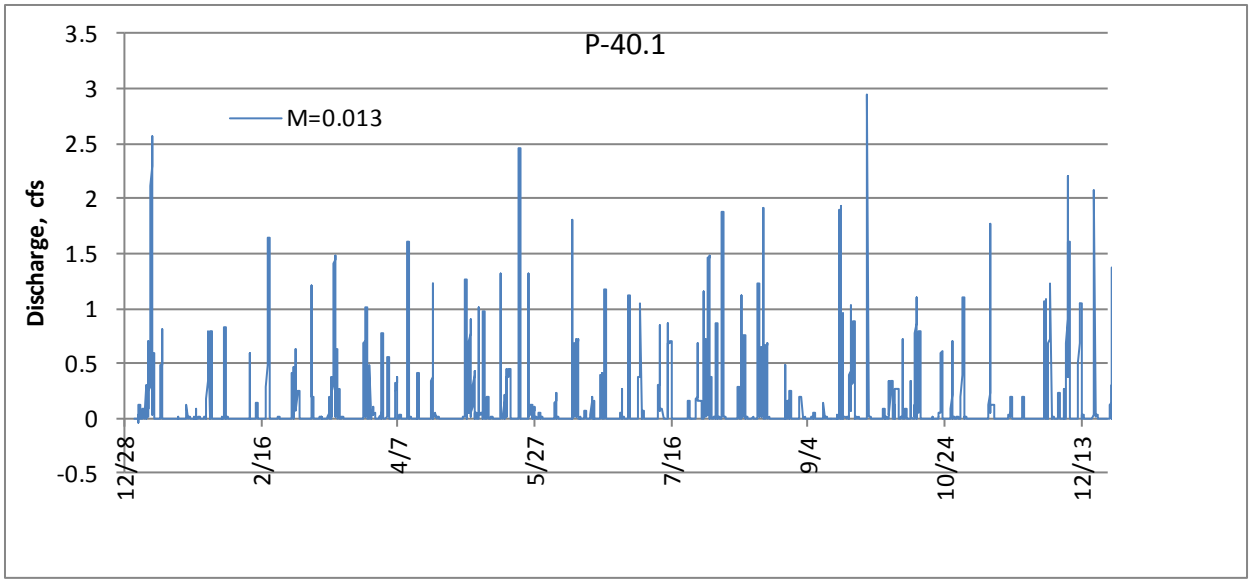

Figure 57 Discharge through P-40.1

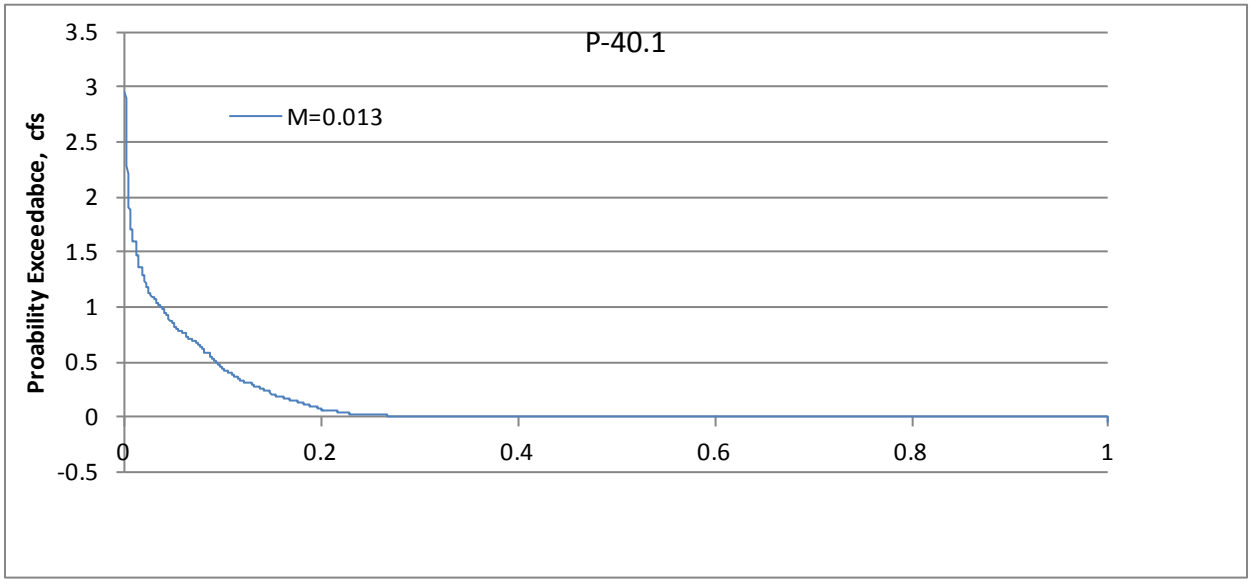

Figure 58 Probability exceedance of flow through P-40.1

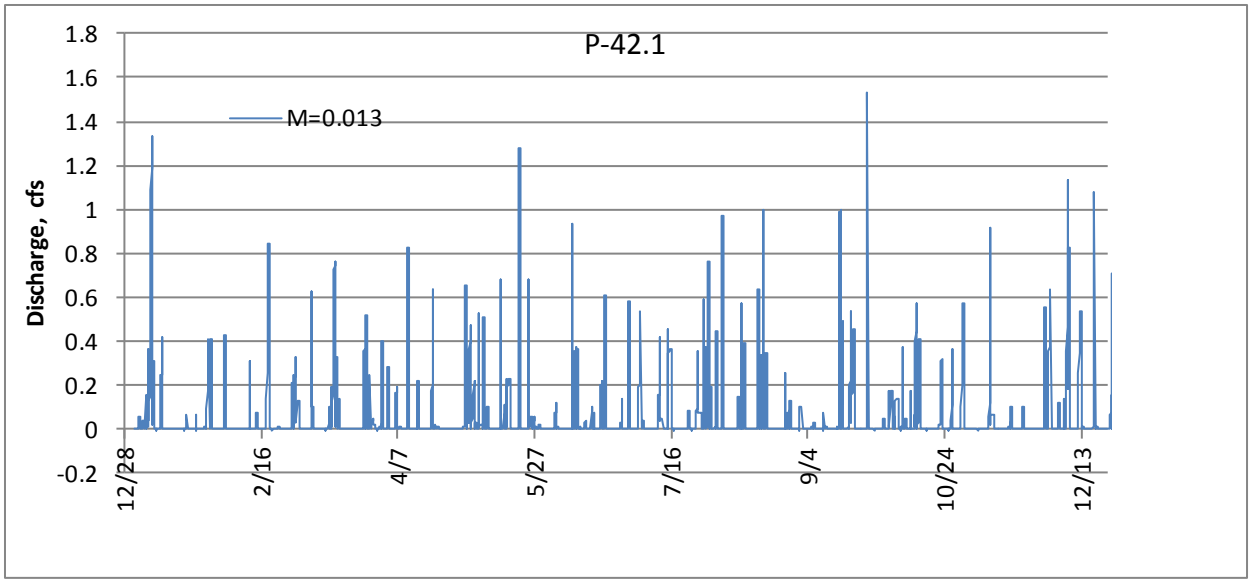

Figure 59 Discharge through P-42.1

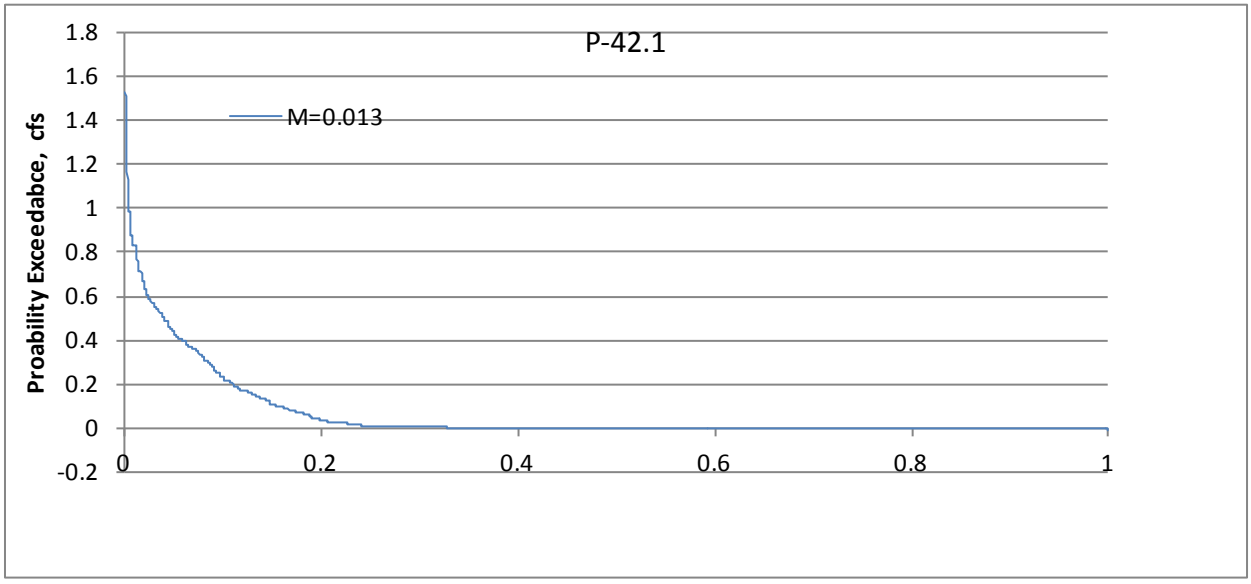

Figure 60 Probability exceedance of flow through P-42.1

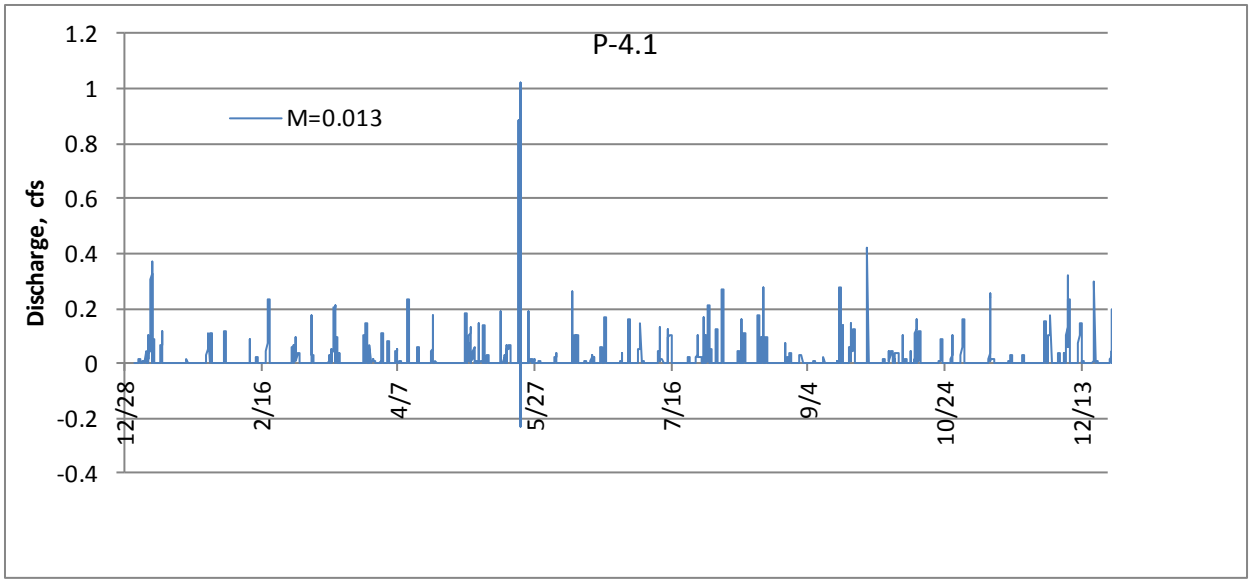

Figure 61 Discharge through P-4.1

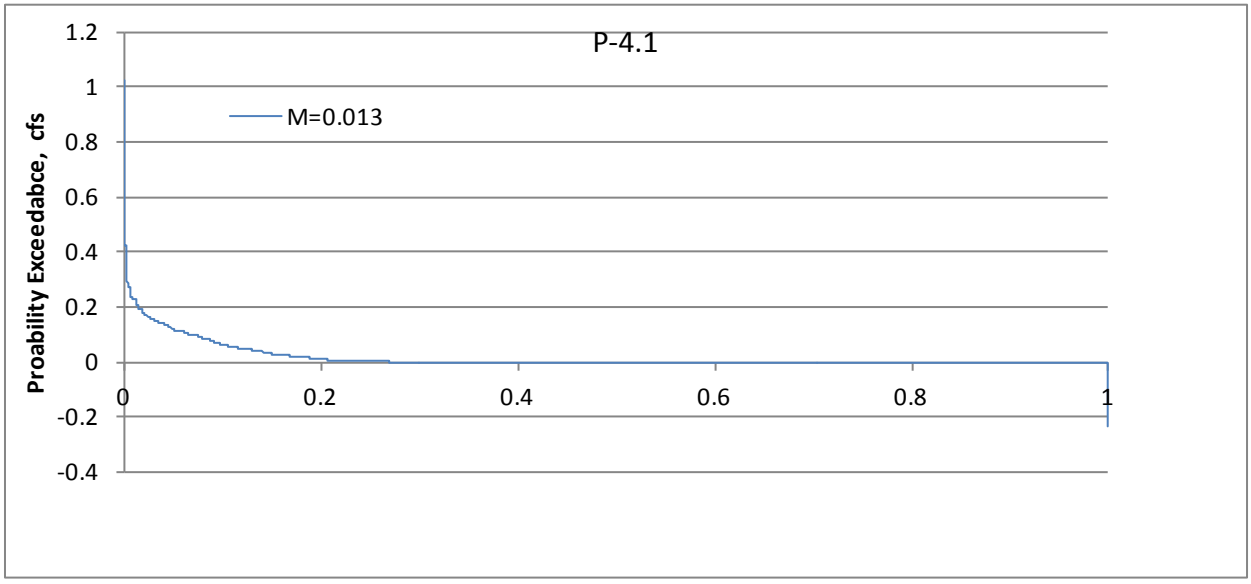

Figure 62 Probability exceedance of flow through P-4.1

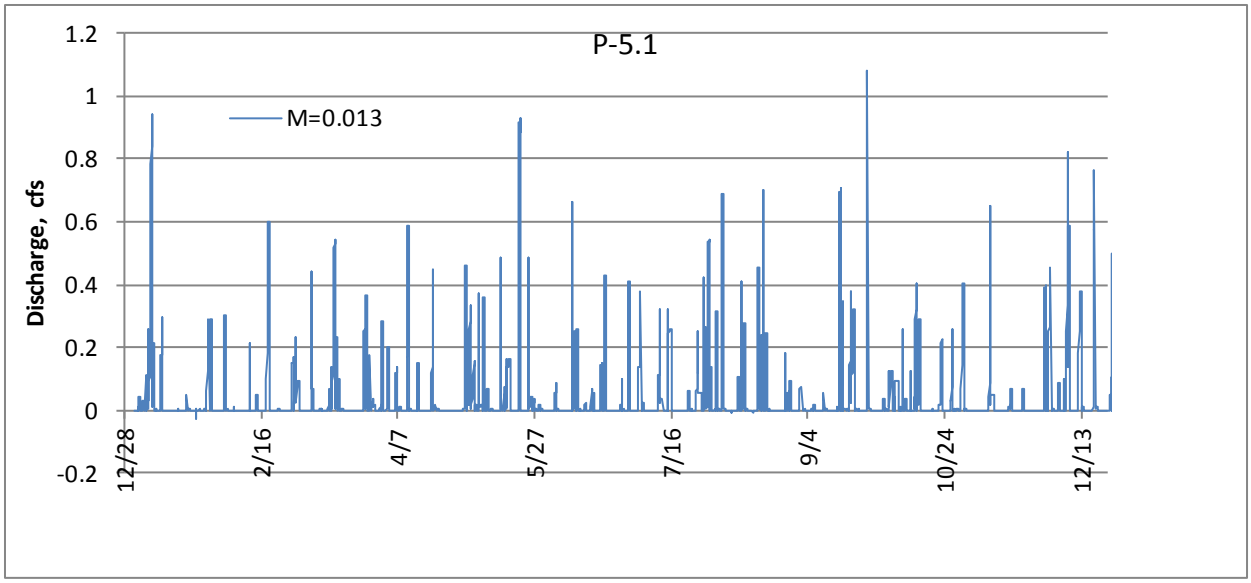

Figure 63 Discharge through P-5.1

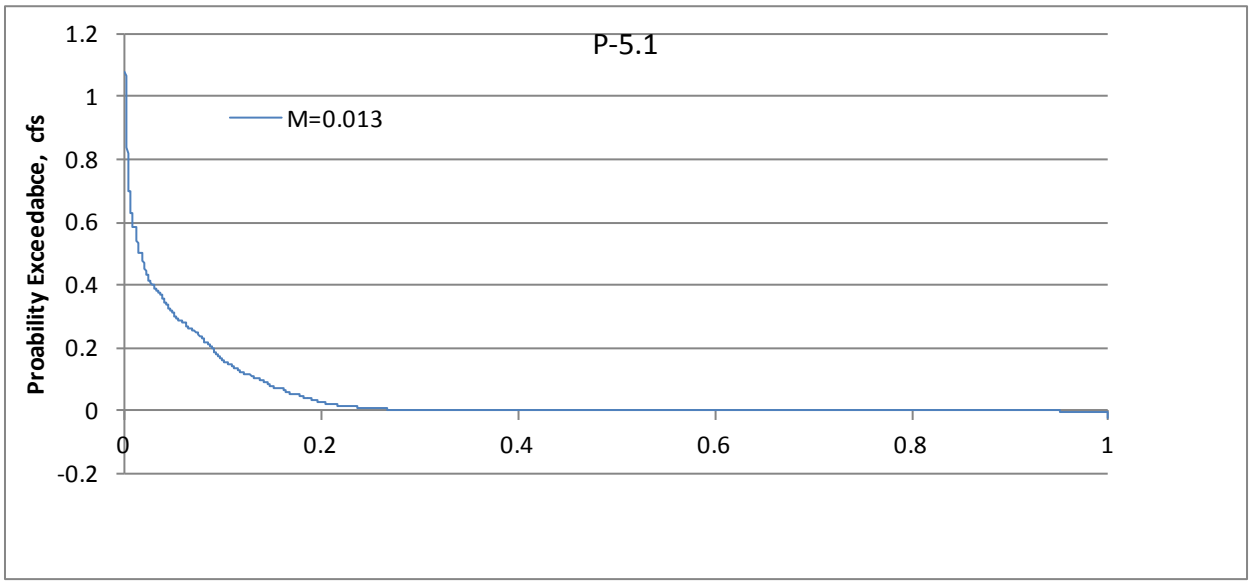

Figure 64 Probability exceedance of flow through P-5.1

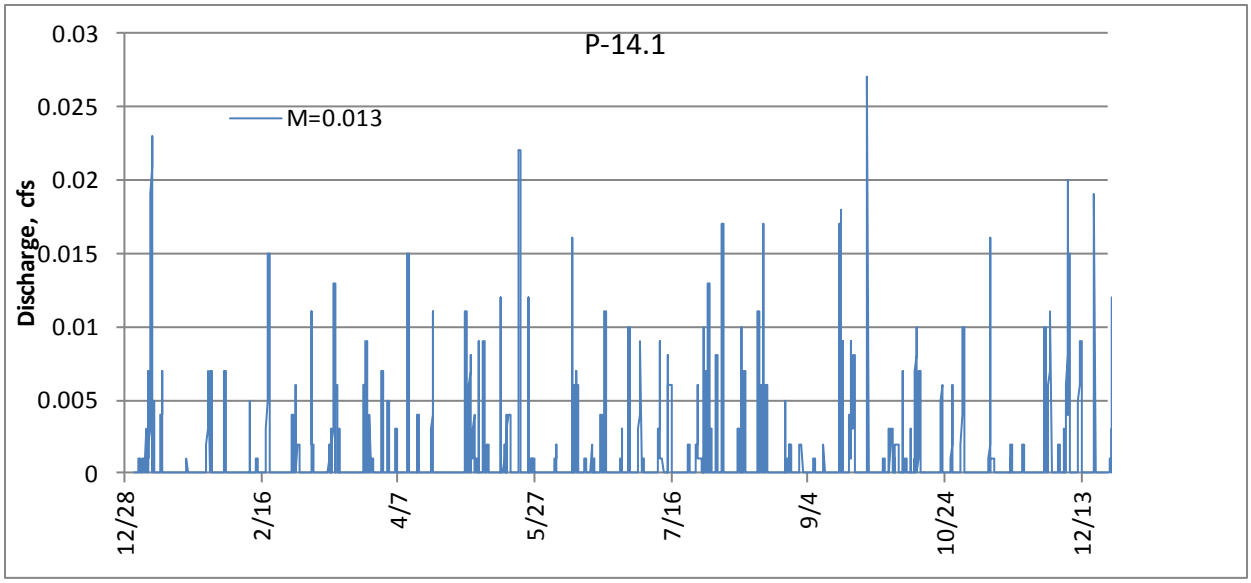

Figure 65 Discharge through P-14.1

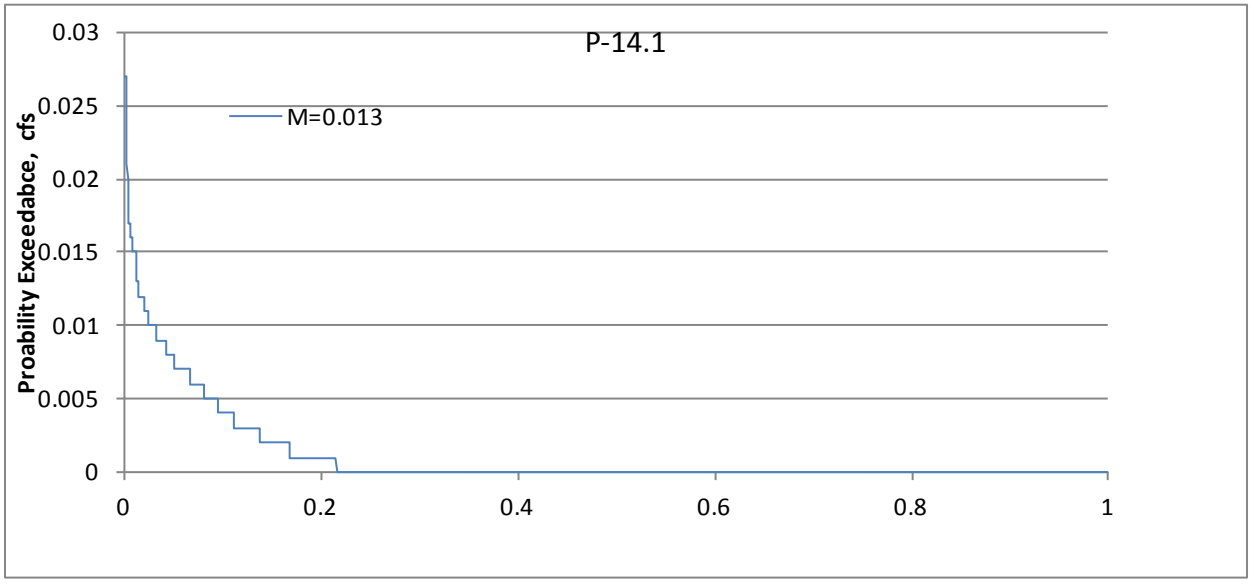

Figure 66 Probability exceedance of flow through P-14.1

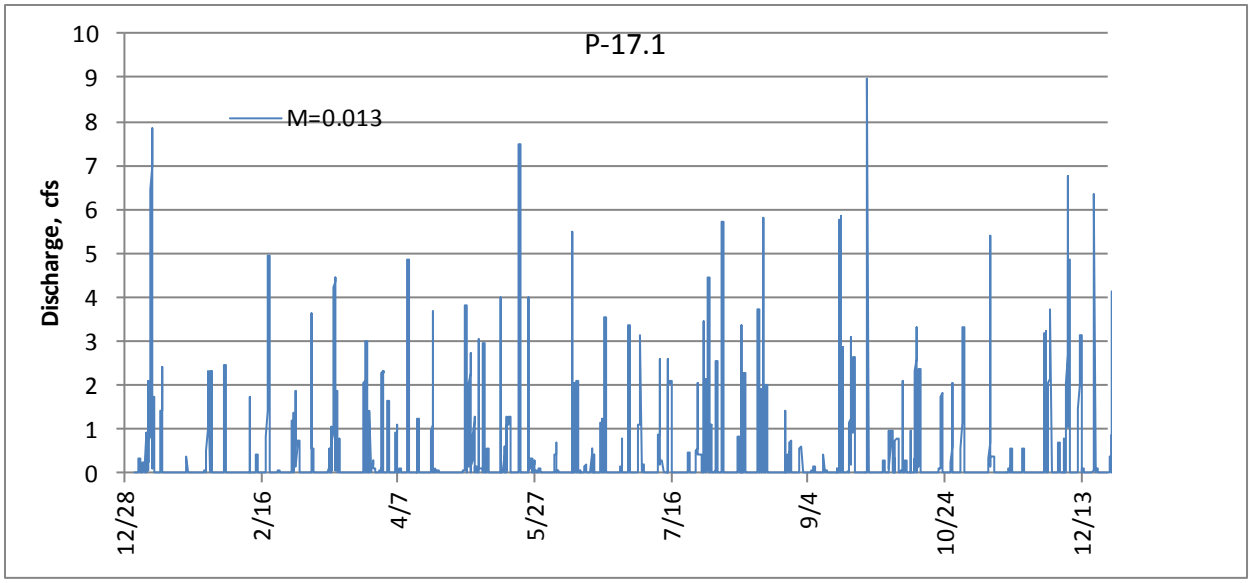

Figure 67 Discharge through P-17.1

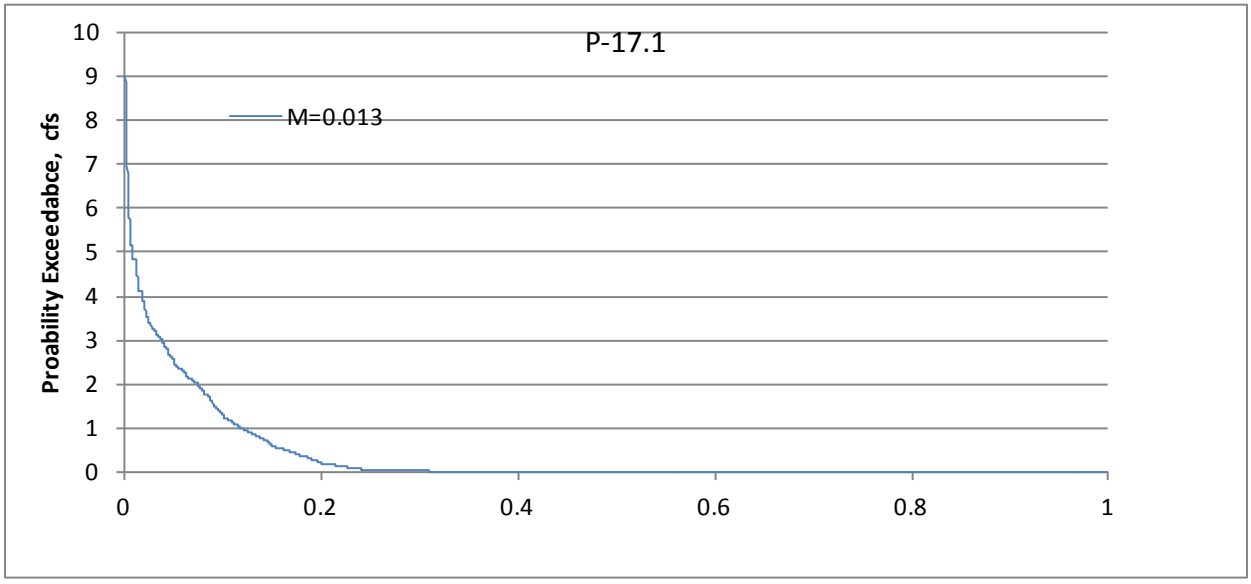

Figure 68 Probability exceedance of flow through P-17.1

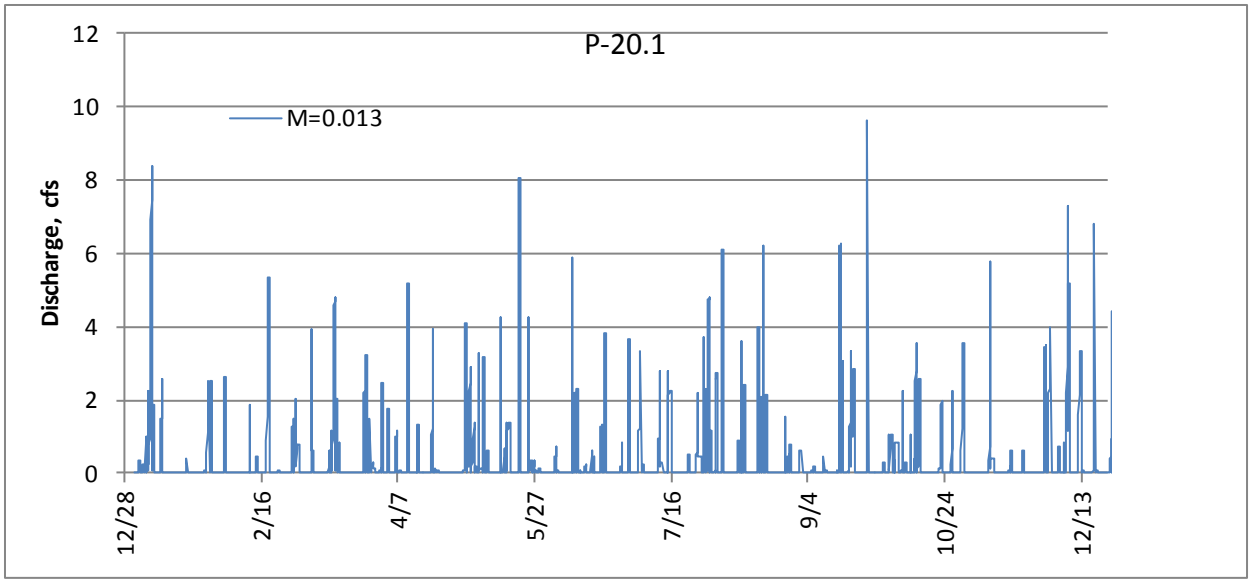

Figure 69 Discharge through P-20.1

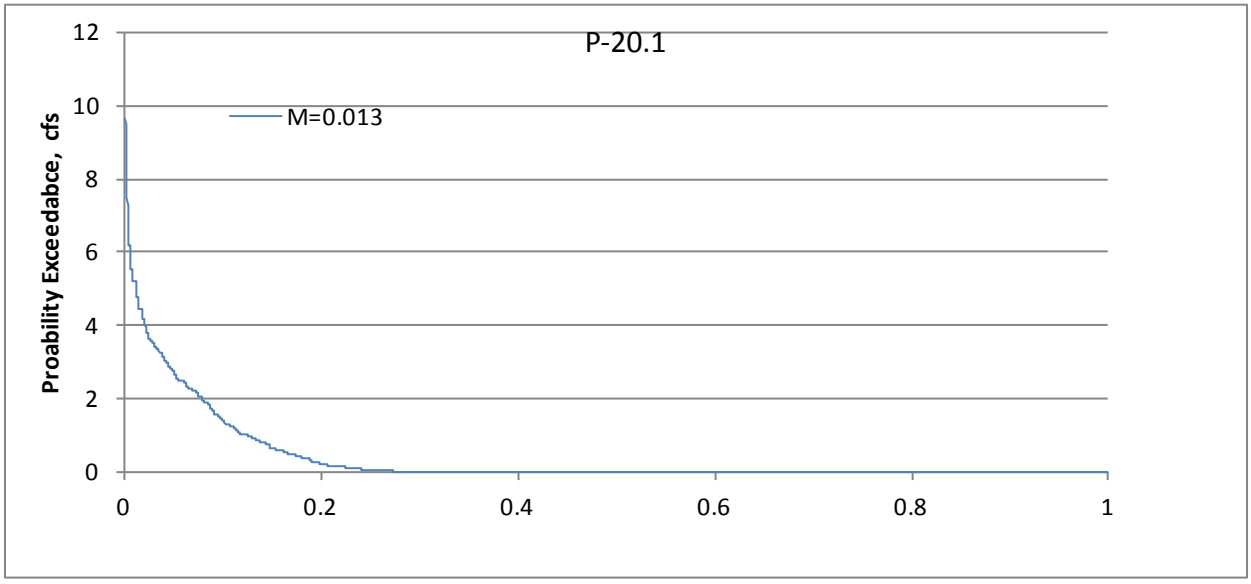

Figure 70 Probability exceedance of flow through P-20.1

Nodes of the XPSWWM Model

Table 3.NODES developed in the XPSWWM model

Name	Subcatch-ment	Ground Elevation (Spill Crest) ft	Invert Elevation ft	Ponding Type	Width ft	Slope	Area ac	Impervious Percentage %
B-4500N_A.1	1	799.75	799.2	Sealed	15.3	0.01	0.161	100
B-4500N_B.1	1	799.60	799.1	Sealed	13	0.01	0.043	100
B-4500N_C.1	1	800.15	799.6	Sealed	24.1	0.01	0.129	100
B-4500N_D.1	1	800.15	799.6	Sealed	47	0.01	0.183	100
B-4500N_E.1	1	799.20	798.7	Sealed	12.5	0.01	0.054	100
B-4500N_F.1	1	800.10	799.6	Sealed	32	0.01	0.14	100
B-4500N_G.1	1	800.10	799.6	Sealed	22.4	0.01	0.14	100
B-4500S_A.1	1	789.60	789	Sealed	37.1	0.01	0.269	100
B-4500S_B.1	1	786.50	786	Sealed	26.7	0.01	0.183	100
B-4500S_C.1	1	797.00	796.5	Sealed	48.6	0.01	0.129	100
B-4500S_D.1	1	797.40	796.9	None	64	0.01	0.14	100
B-4500S_E.1	1	797.40	796.9	None	52.5	0.01	0.14	100
B-4501.1	1	796.80	796.47	Sealed	32.2	0.01	0.183	100
B-4505.1	1	797.70	796.8	Sealed	19	0.01	0.086	100
B-4507.1	1	793.55	793	Sealed	16.7	0	0.032	100
B-4556.1	1	796.10	795.75	Sealed	10.6	0.01	0.011	100
I-1.1	1	800.57	795	Allowed	43.3	0	0.065	5
I-1.1	2				52.2	0	0.108	5
I-10.1	1	803.15	795.7	Allowed	20.3	0.01	0.075	100
I-10.1	2				12.8	0.01	0.032	100
I-10.1	3				20.3	0.01	0.075	100
I-10.1	4				14	0.02	0.032	100
I-11.1	1	798.20	797.5	None	50	0.015	0.054	100
I-2.1	1	799.00	795.8	Allowed	18	0.02	0.065	80
I-2.1	2				40	0.02	0.237	80
I-2.1	3				5	0.02	0.065	95
I-2.1	4				10.2	0.02	0.086	100
I-2.1	5				13.2	0.01	0.108	5
I-3.1	1	790.40	782.7	Allowed	14.9	0.015	0.022	90
I-3.1	2				9.9	0.015	0.075	95
I-4.1	1	799.00	795.5	Allowed	14	0.01	0.161	100
I-4.1	2				17.9	0.02	0.054	95
I-4.1	3				15.5	0.02	0.075	95

I-5.1	1	802.21	795.4	Allowed	18.4	0.01	0.054	100
I-5.1	2				15.6	0.01	0.022	100
I-5.1	3				22.3	0.01	0.075	100
I-5.1	4				22.5	0.01	0.075	100
I-6.1	1	800.00	791	Allowed	12.15	0.02	0.043	95
I-6.1	2				7.7	0.02	0.065	95
I-8.1	1	798.20	796.7	Allowed	12	0.02	0.003	100
I-8.1	2				12	0.015	0.03	100
I-9.1	1	798.00	796.5	Allowed	5.3	0.015	0.065	100
I-9.1	2				5.3	0.02	0.011	100
I-9.1	3				21	0.02	0.011	100
I-9.1	4				21	0.02	0.011	100
J-1.1	1	802.50	791.10	Sealed	22.6	0.01	0.086	100
J-10.1		784.90	782.10	Sealed	0	0	0	0
J-11.1		796.00	795.50	Sealed	0	0	0	0
J-12.1		796.60	795.30	Sealed	0	0	0	0
J-13.1		798.80	798.20	Sealed	0	0	0	0
J-14.1		794.80	793.50	Sealed	0	0	0	0
J-2.1		794.40	790.40	Sealed	0	0	0	0
J-3.1		797.00	789.90	Sealed	0	0	0	0
J-4.1		799.50	789.00	Sealed	0	0	0	0
J-5.1		795.20	793.70	Sealed	0	0	0	0
J-6.1		795.80	795.45	Sealed	0	0	0	0
J-7.1		801.00	783.50	Sealed	0	0	0	0
J-8.1		792.94	783.20	Sealed	0	0	0	0
J-9.1		785.10	782.00	Sealed	0	0	0	0
MH-2A.1		793.16	785.50	Sealed	0	0	0	0
MH-5.1		799.00	790.40	Sealed	0	0	0	0
MH-6.1		800.00	795.20	Sealed	0	0	0	0
MH-7.1		800.00	791.30	Sealed	0	0	0	0
MH-8.1		797.20	791.90	Sealed	0	0	0	0
MH211-1.1		789.00	782.00	Sealed	0	0	0	0
MH211-2.1		800.40	791.90	Sealed	0	0	0	0
MH211-3.1		799.50	788.10	Sealed	0	0	0	0
MH211-4.1		801.70	791.40	Sealed	0	0	0	0
OF-211.1		786.44	780.74	Allowed	0	0	0	0
T-1.1	1	786.00	782.00	Allowed	9.5	0.015	0.043	100
T-2.1	1	800.00	796.00	Allowed	52.9	0.015	0.151	100
T-3.1	1	800.00	796.00	Allowed	18	0	0.14	100

Links of XPSWMM Model

Table 4. LINKS developed in the XPSWWM model

Name	Shape	Length ft	Roughness	Conduit Slope	Diameter (Height) in
P-1.1	Circular	22	0.014	1.36	15
P-10.1	Circular	79.4	0.014	1.13	15
P-11.1	Circular	59.3	0.014	9.44	15
P-12.1	Circular	8	0.014	26.25	15
P-13.1	Circular	100.6	0.014	0.60	4
P-14.1	Circular	71.7	0.014	0.42	4
P-15.1	Circular	41.5	0.014	4.82	30
P-16.1	Circular	6.6	0.014	127.27	30
P-17.1	Circular	30.4	0.014	0.99	30
P-18.1	Circular	6.6	0.014	34.85	6
P-19.1	Circular	16.1	0.014	21.74	6
P-2.1	Circular	42	0.014	10.41	4
P-20.1	Circular	45	0.014	1.11	30
P-21.1	Circular	29.1	0.014	1.38	30
P-22.1	Circular	18.27	0.014	0.00	6
P-23.1	Circular	20.2	0.014	0.99	30
P-24.1	Circular	20.37	0.014	19.15	6
P-25.1	Circular	11.7	0.014	0.86	30
P-26.1	Circular	100.3	0.014	1.26	30
P-27.1	Circular	41.56	0.014	8.42	24
P-28.1	Circular	21.8	0.014	10.55	15
P-29.1	Circular	27.9	0.014	1.08	6
P-3.1	Circular	48.6	0.014	1.44	15
P-30.1	Circular	21.35	0.014	16.86	6
P-31.1	Circular	17	0.014	1.77	15
P-32.1	Circular	88.5	0.014	0.11	15
P-33.1	Circular	32.6	0.014	13.19	6
P-34.1	Circular	24.7	0.014	17.41	6
P-35.1	Circular	90.1	0.014	0.11	15
P-36.1	Circular	24.6	0.014	2.03	6
P-37.1	Circular	7.8	0.014	39.74	6
P-38.1	Circular	115.9	0.014	2.59	6
P-39.1	Circular	21.1	0.014	2.37	6

P-4.1	Circular	17.1	0.014	26.90	12
P-40.1	Circular	115.9	0.014	0.26	24
P-41.1	Circular	28.14	0.014	1.07	24
P-42.1	Circular	34.37	0.014	1.75	15
P-43.1	Circular	19	0.014	25.26	15
P-44.1	Circular	14.1	0.014	32.62	15
P-46.1	Circular	80.29	0.014	1.99	15
P-47.1	Circular	32.34	0.014	18.86	6
P-48.1	Circular	25.3	0.014	24.11	6
P-49.1	Circular	104.7	0.014	2.10	15
P-5.1	Circular	36	0.014	1.39	15
P-50.1	Circular	14.5	0.014	32.41	8
P-54.1	Circular	22.8	0.014	3.95	6
P-55.1	Circular	25.3	0.014	3.56	6
P-56.1	Circular	108.2	0.014	1.39	8
P-6.1	Circular	51	0.014	7.45	10
P-7.1	Circular	21	0.014	44.29	6
P-8.1	Circular	64.3	0.014	1.40	15
P-9.1	Circular	52	0.014	5.00	6

Typical Manning's n Values

The selection of an appropriate value for Manning's is very significant to the accuracy of the computed water flow profiles. The value of Manning's is variable and depends on number of factors including: surface roughness, vegetation, channel alignment, size and shape of channel, etc.

Generally, Manning's values can be calibrated if the water surface profile information (e.g. gaged data) is available. The n values computed for similar stream condition or values obtained from experimental data should be used as guides in selection n values.

The Manning'n values for the typical channels also can be found in several references [Chow, 1959; Bedient et al., 2008]. Several tables are available in the general literature for the selection of Manning's roughness coefficient for a particular channel (see Table 1)

Table 5 Channel roughness coefficient n [Chow, 1959; Bedient et al., 2008]

Type of Channel and Description	Minimum	Normal	Maximum
A. Metal			
a. Steel			
1. Riveted and Spiral	0.013	0.016	0.017
b. Cast ion			
1. Coated	0.010	0.013	0.014
2. Uncoated	0.011	0.014	0.016
c. Corrugated metal			
1. Subdrain	0.017	0.019	0.021
2. Storm drain	0.021	0.024	0.030
B. Nonmetal			
a. Cement			
1. Mortar	0.011	0.013	0.015
b. Concrete			
1. Culvert, straight and free of debris	0.010	0.011	0.013
2. Culvert, with bends, connections, and some debris	0.011	0.013	0.014
3. Finished	0.011	0.012	0.014
4. Sewer with manholes, inlets, and so on, straight	0.013	0.015	0.017
5. Unfinished, steel form	0.012	0.013	0.014
6. Unfinished, smooth wood form	0.012	0.014	0.016
7. Unfinished, rough wood form	0.015	0.017	0.020
c. Wood			
1. Stave	0.010	0.012	0.014
2. Laminated, treated	0.015	0.017	0.020
d. Clay			
1. Common drainage title	0.011	0.013	0.017
2. Vitrified sewer	0.011	0.014	0.017
3. Vitrified sewer with manholes, inlet, and so on	0.013	0.015	0.017
e. Brickwork			
1. Glazed	0.011	0.013	0.015
f. Sanitary sewers coated with sewer slimes, with bed and connections	0.012	0.013	0.016
g. Paved inlet, sewer, smooth bottom	0.016	0.019	0.020

In this study, the Manning's values for straight concrete with manhole and inlet channel are selected. The simulations were computed using the minimum, normal, and maximum Manning's values (0.013, 0.015 and 0.017) for this type of channel.