-FINAL REPORT-

NEW YORK CITY
DEPARTMENT OF ENVIRONMENTAL PROTECTION

FLOW MONITORING STUDY SUMMARY REPORT FOR:

4TH AVENUE BASIN, BROOKLYN
JUNIPER VALLEY PARK BASIN, QUEENS
UTOPIA PARKWAY CORRIDOR BASIN, QUEENS

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EXECUTIVE SUMMARY

SEWER SYSTEM FLOW METERING PROGRAM SUMMARY

The New York City Department of Environmental Protection (NYCDEP) contracted ADS Environmental Services, LLC (ADS) to conduct the Sewer System Flow Metering Program FMCW-09 in 2010. The purpose of this program was to measure dry and wet weather flows in multiple sewers located across three sewer basins in the boroughs of Brooklyn and Queens. Three flow metering networks totaling 35 open channel flow meters and four rain gauges were installed in DEP sewers by ADS. Over a one year period, ADS provided NYCDEP with monthly progress reports containing the recorded data and notable field observations for each monitoring site included in the study. This report provides a summary of the reports provided by ADS and the results of independent hydrological analyses that were performed to gain a broader understanding of the performance of selected sewer system elements in accordance with their design intent.

The rain gauges collected rainfall data continuously between April 1st, 2010 and March 31st, 2011 at 15-minute intervals. Based on rain gauge data, significant storm events (those exceeding two inches of rainfall) occurred only twice during the monitoring period: on April 25, 2010 and October 1, 2010. The October 1 storm was the most intense storm recorded by the rain gauges with an estimated return period between 3.1 and 11.2 years, depending on the rain gauge referenced. Because it was the largest storm event recorded during the monitoring period, the October 1 storm was used as the basis for evaluating the sewer system's response to wet weather flow conditions.

Similar to the rain gauges, the flow meters collected flow data continuously between April 1st, 2010 and March 31st, 2011 at 15-minute intervals. Other relevant flow variables collected during the study included water depth in inches relative to the pipe invert, flow rate in million gallons per day (MGD) and average fluid velocity in feet per second (fps). There was no evidence in the flow monitoring data to suggest that any surface flooding occurred during the most intense storm on October 1 (i.e. depth of flow in sewers was below manhole elevation at all times). The October 1 storm generated surcharge conditions (i.e. water surface elevation above sewer crown) at 21 of the 35 monitoring sites. At five of the sites (J11, P5, P6, P7, and P8), the water level in the sewer came within five feet of the manhole rim elevation, but did not cause surface flooding. One of the locations, P8, came within 3 feet of the manhole rim elevation.

CONCLUSION

Surface flooding was not recorded at any of the 35 monitoring locations during the one-year Sewer System Flow Metering Program study period. The largest storm recorded during the study period caused surcharge conditions, but did not generate flooding. For that reason, the study provided valuable data and insight into the performance of the subject system in the context of its design characteristics by demonstrating the ability of the system to transport 3.1 year to 11.2 year storm intensities without causing surface flooding. Hydrologic/hydraulic simulation modeling, which used data from this flow monitoring study for calibration, further confirms that the systems function according to their original design. In addition, field investigations performed by BWSO indicate that there are no significant infrastructure deficiencies (e.g. blockages, collapsed sewers, etc.) in any of the study basins. However, complaint data and anecdotal evidence suggest that high-intensity, short duration storms can create flooding in the study areas. Continued analysis should be performed in an effort to further identify potential root causes not captured by this report, and potential mitigation strategies.

DESCRIPTION/LOCATION OF PROJECT

The New York City Department of Environmental Protection (NYCDEP) contracted ADS Environmental Services, LLC (ADS) to conduct the Sewer System Flow Metering Program FMCW-09 in 2010. The purpose of this program was to measure dry and wet weather flows in multiple sewers located across three sewer basins in the boroughs of Brooklyn and Queens. Over the period of April 1, 2010 to March 31, 2011, ADS provided NYCDEP with monthly progress reports containing the recorded data and notable field observations for each monitoring site included in the study. The main objective of this study was to evaluate the sewer system's response (i.e. flows, depths, velocities) to both dry and wet weather.

Three flow metering networks totaling 35 open channel flow meters and four rain gauges were installed in three drainage basins as shown in Figure 1.

Figure 1: Map of flow monitoring basins and rain gauges

In Figure 1, the red basin labeled P is the Brooklyn-Owl's Head-4th Avenue (4th Avenue) basin. The green basin labeled J, is the Queens-Bowery Bay-Juniper Valley Park (JVP) basin and the blue basin, labeled U is the Queens-Tallmans Island-Utopia Pkwy-Kissena corridor basin (Utopia Parkway corridor). The locations of the gauges are depicted as light blue circles in Figure 1 and are labeled from west to east as: RGB1, RGB3, RGQ3 and RGQ1. Many of the meters were installed upstream of chambers and sewer junctions. The table on the next page, Table 1, contains the meter locations.

Table 1: Flow Meter Locations

Meter ID	Geographic Location	Meter ID	Geographic Location
J1	West Bound Queens Access Road – West of 69th St	P7	243 7th St
J10	60-14 74th St. (South of 60th Ave.)	P8	3rd Ave & 8th St
J11	63-09 74th St & Pleasant View St	P9	165 7th St.
J2	69th St (South of Queens Blvd)	U1	73rd Ave (East of Utopia Pkwy)
J3	69th St (South of Queens Blvd)	U10	4910 Utopia Pkwy (N of Peck St)
J4	50-29 69th St (Near Garfield)	U11	69th Ave. (Btwn Fresh Meadow Ln & Utopia Pkwy)
J5	50-29 69th St (Near Garfield)	U12	69th Ave & Fresh Meadow Ln.
J6	Calamus Ave East of 69th St	U13	69th Ave. & Fresh Meadow Ln (South barrel)
J7	Calamus Ave East of 69th St	U14	Fresh Meadow & 50th Ave.
J8	7248 Calamus Ave	U2	Utopia Pkwy & Jewel Ave.
J9	74th St & 53rd Ave	U3	Utopia Pkwy & Jewel Ave.
P1	475 4th Ave (Btwn 11th and 12th St)	U4	68-29 Fresh Meadow Ln.
P10	401 4th Ave & 7th St	U5	Utopia Pkwy & 69th Ave.
P2	493 4th Ave (Btwn 12th and 13th)	U6	Utopia Pkwy & 69th Ave.
P3	573 3rd Ave & 15th St	U7	65-34 Utopia Pkwy & 67th Ave.
P4	169 12th St (Btwn 3rd & 4th Ave)	U8	65-34 Utopia Pkwy & 67th Ave.
P5	4th Ave & 4th St	U9	4910 Utopia Pkwy (N of Peck St)
P6	4th Ave & 4th St.	n/a	n/a

EQUIPMENT AND METHODOLOGY

FLOW QUANTIFICATION METHODS

There are two main equations used to measure open channel flow: the Continuity Equation and the Manning Equation. The Continuity Equation, which is considered the most accurate, can be used if both depth of flow and velocity are available. In cases where velocity measurements are not available or not practical to obtain, the Manning Equation can be used to estimate velocity from the depth data based on certain physical characteristics of the pipe (i.e. the slope and roughness of the pipe being measured). However, the Manning equation assumes uniform, steady flow hydraulic conditions with non-varying roughness, which is typically an invalid assumption in most sanitary sewers. The Continuity Equation was used exclusively for this study.

CONTINUITY EQUATION

The Continuity Equation states that the flow quantity (Q) is equal to the wetted area (A) multiplied by the average velocity (V) of the flow.

$$Q = A * V$$

This equation is applicable in a variety of conditions including backwater, surcharge, and reverse flow. Most modern flow monitoring equipment, including the ADS sensors used for this study, measure both depth and velocity and therefore use the Continuity Equation to calculate flow quantities.

FLOW MONITORING EQUIPMENT

The monitor selected for this project is the TRITON monitor. This flow monitor is an area velocity flow monitor that uses both the Continuity and Manning's equations to measure flow.

The TRITON monitor consists of data acquisition sensors and a battery-powered microcomputer. The microcomputer includes a processor unit, data storage, and an on-board clock to control and synchronize the sensor recordings. The monitor was programmed to acquire and store depth of flow and velocity readings at 15-minute intervals.

Three types of data acquisition sensors are available for the TRITON monitor. The primary depth measurement device is the ADS quad-redundant ultrasonic level sensor. This sensor uses four independent ultrasonic transceivers in pairs to measure the distance from the face of the transceiver housing to the water surface (air range) with up to four transceiver pairs, of the available ones, active at one time. The elapsed time between transmitting and receiving the ultrasonic waves is used to calculate the air range between the sensor and flow surface based on the speed of sound in air. Sensors in the transceiver housing measure temperature, which is used to compensate the ultrasonic signal travel time. The speed of sound will vary with temperature. Since the ultrasonic level sensor is mounted out of the flow, it creates no disturbance to normal flow patterns and does not affect site hydraulics.

Redundant flow depth data can be provided by a pressure depth sensor, and is independent from the ultrasonic level sensor. This sensor uses a piezo-resistive crystal to determine the difference between hydrostatic and atmospheric pressure. The pressure sensor is temperature compensated and vented to the atmosphere through a desiccant filled breather tube. Pressure depth sensors are typically used in large size channels and applications where surcharging is anticipated. Its streamlined shape minimizes flow distortion.

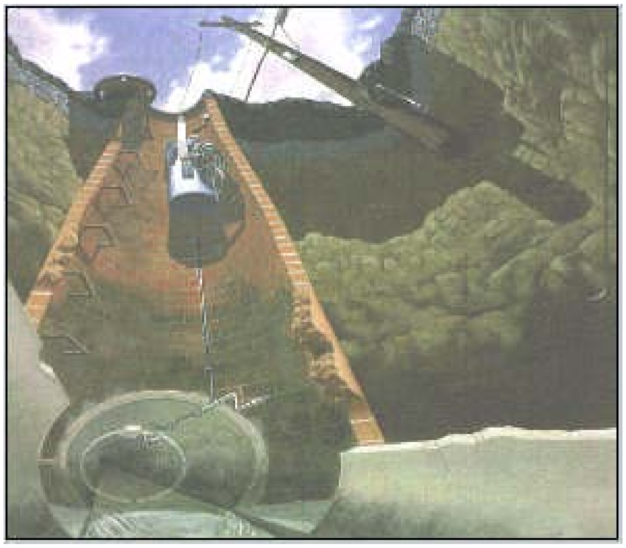
Velocity is measured using the ADS V-3 digital Doppler velocity sensor. This sensor measures velocity in the cross-sectional area of flow. An ultrasonic carrier is transmitted upstream into the flow, and is reflected by suspended particles, air bubbles, or organic matter with a frequency shift proportional to the velocity of the reflecting objects. The reflected signal is received by the sensor and processed using digital spectrum analysis to determine the peak flow velocity. Collected peak velocity information is filtered and processed using field confirmation information and proprietary software to determine the average velocity, which is used to calculate flow quantities. The sensor's small profile, measuring 1.5 inches by 1.15 inches by 0.50 inches thick, minimizes the effects on flow patterns and site hydraulics.

INSTALLATION

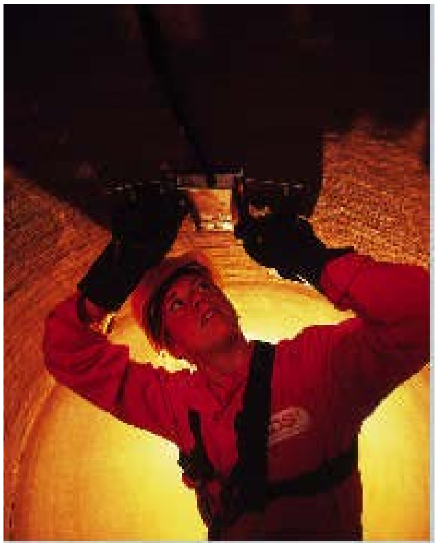
Installation of flow monitoring equipment typically proceeds in four steps. First, the site is investigated for safety and to determine physical and hydraulic suitability for the flow monitoring equipment. Second, the equipment is physically installed at the selected location. Third, the monitor is tested to assure proper operation of the velocity and depth of flow sensors and verify that the monitor clock is operational and synchronized to the master computer clock. Fourth, the depth and velocity sensors are confirmed and line confirmations are performed. A typical flow monitor installation is shown in Figure 2.

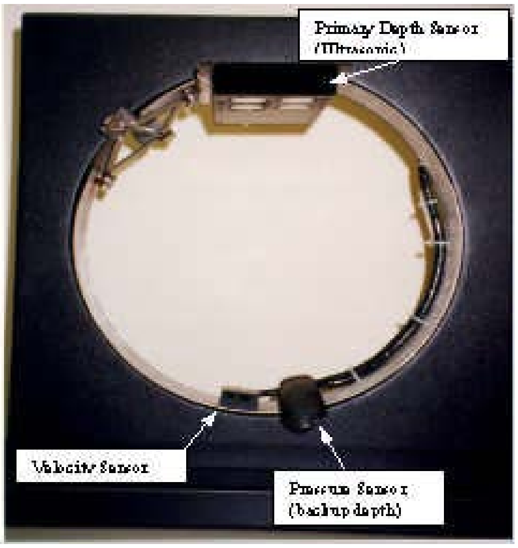
The installations depicted in Figures 2 are typical for circular or oval pipes up to approximately 104-inches in diameter or height. In installations into pipes 42-inches or less in diameter, depth and velocity sensors are mounted on an expandable stainless steel ring and installed one to two pipe diameters upstream of the pipe/manhole connection in the incoming sewer pipe. This reduces the effects of turbulence and backwater caused by the connection. In pipes larger than 42 inches in diameter, a special installation is made using two sections of the ring installed one to two feet upstream of the pipe/manhole connection; one bolted to the crown of the pipe for the depth sensor, and the other bolted to the bottom of the pipe (bolts are usually placed just above the water line) to hold the velocity sensor.

Figure 2: Typical Installation



Large Pipe (> 42" Diameter) Small Pipe (8" to 42" Diameter)





DATA COLLECTION, CONFIRMATION, AND QUALITY ASSURANCE

During the monitoring period, field crews visit each monitoring location to retrieve data, verify proper monitor operation, and document field conditions. The following quality assurance steps are taken to assure the integrity of the data collected:

- Measure Power Supply: The monitor is powered by a dry cell battery pack. Power levels are recorded and battery packs replaced, if necessary. A separate battery provides back-up power to memory, which allows the primary battery to be replaced without the loss of data.
- Perform Pipe Line Confirmations and Confirm Depth and Velocity: Once equipment and sensor installation is accomplished, a member of the field crew descends into the manhole to perform a field measurement of flow rate, depth and velocity to confirm they are in agreement with the monitor. Since the ADS V-3 velocity sensor measures peak velocity in the wetted cross-sectional area of flow, velocity profiles are also taken to develop a relationship between peak and average velocity in lines that meet the hydraulic criteria.
- Measure Silt Level: During site confirmation, a member of the field crew descends into the manhole and measures and records the depth of silt at the bottom of the pipe. This data is used to compute the true area of flow.
- Confirm Monitor Synchronization: The field crew checks the flow monitor's clock for accuracy.
- Upload and Review Data: Data collected by the monitor is uploaded and reviewed for comparison with previous data. All readings are checked for consistency and screened for deviations in the flow patterns, which indicate system anomalies or equipment failure.

RAINFALL DATA ANALYSIS

Official rainfall data for NYC is recorded at Central Park, LaGuardia Airport and JFK Airport. Because of the localized nature of rainfall events and the strong influence that the precipitation magnitude, location and timing has on sewer system response, ADS installed four rain gauges across the study areas to provide rainfall measurements geographically closer to the study areas. RGB1 AND RGB3 were located in Brooklyn; RGQ1 AND RGQ3 were located in Queens (refer to Figure 1).

Rain data were evaluated using two tools. The first tool is time-series data like that shown in the hyetograph in Figure 3 on the next page. The blue, green and yellow horizontal bars below the x-axis are blocking bars, which indicate periods when rain gauges were not installed or did not provide reasonable data. During such periods, data from the second closest rain gauge received the greatest weight.

The second tool is a depth-duration-frequency graph (DDF), shown in Figure 4, on the next page. This graph is used to evaluate durations and return frequencies for each storm, (e.g. 2-month storm, 6-month storm, 5-year storm,etc…). The DDF graph contains two kinds of data: 1) historical rainfall DDF data from NOAA represented as thin background lines and 2) actual rain gauge data from the 4 gauges used in this study represented as thick lines. The thin lines represent NOAA historical depth-duration-frequency data for New York City. Specifically, they represent the 4-month, 6-month, 9-month storms up to the 10-year storm at the top. They give historical context to actual rain storms illustrated by the thick orange, green and blue lines. In this case, the red line (RGB1) shows that the April, 25th storm reached its maximum return frequency of about a 5-month storm after 2,880 minutes. The green line represents RGB3 for the same April 25th storm. It shows that the RGB3 reached a maximum return frequency of about a 4-month storm, also after 2,880 minutes. The royal blue and the light blue lines show the more intense October 1, 2010 storm. The royal blue line shows that RGQ1 registered a maximum return frequency of a little more than an 11-year storm after 180 minutes.

Figure 3: Rainfall Hyetograph

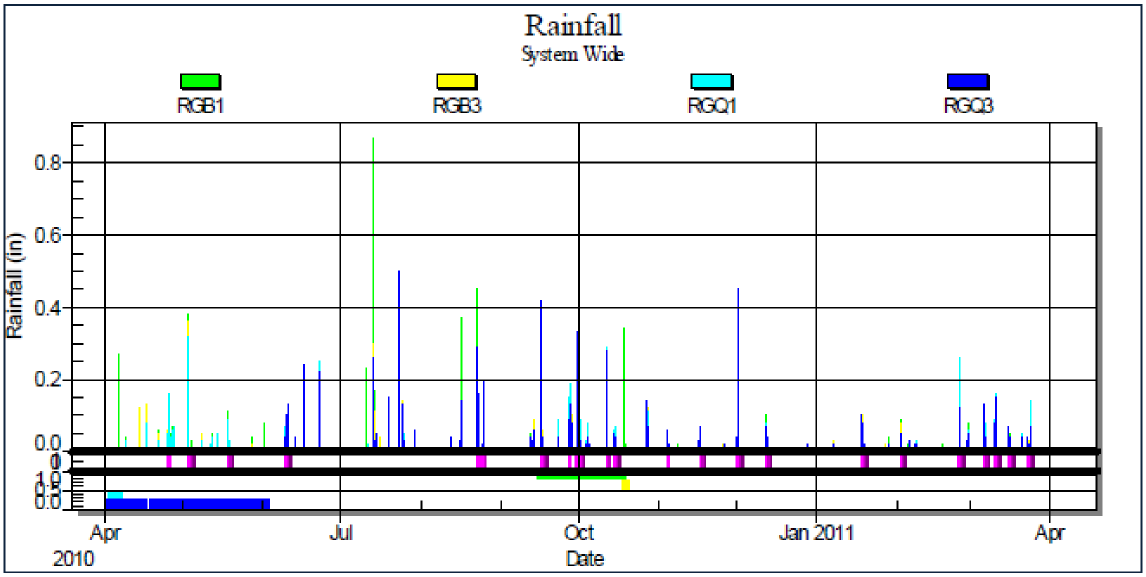
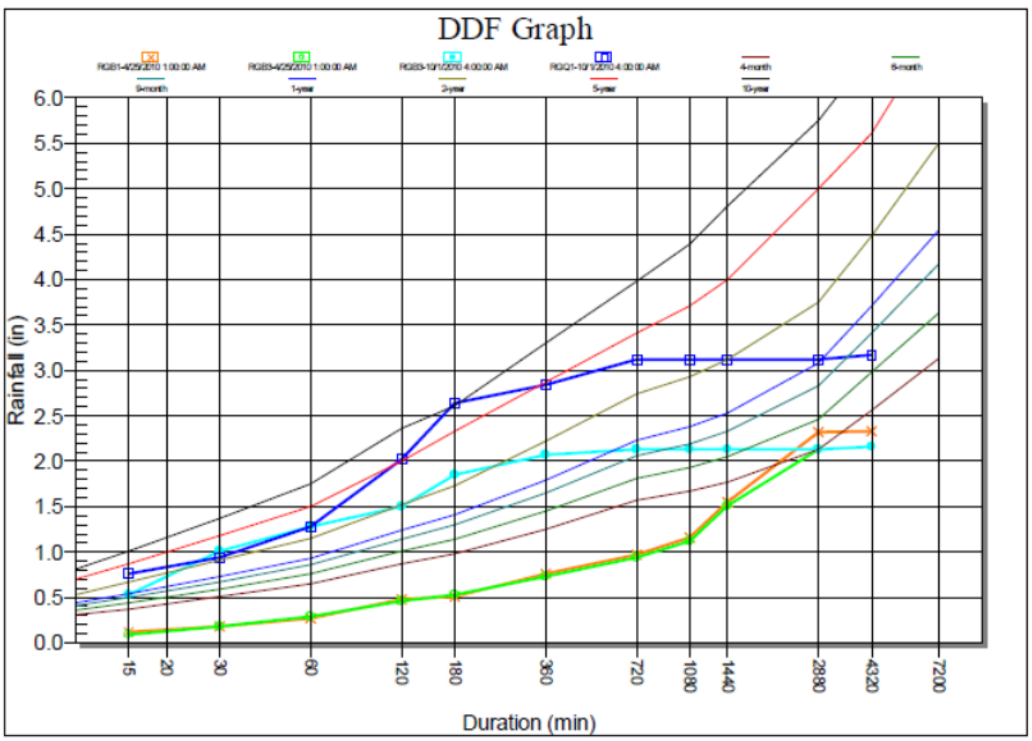


Figure 4: Rainfall Depth-Duration-Frequency Plots for April 25 and October 1, 2010 Storms

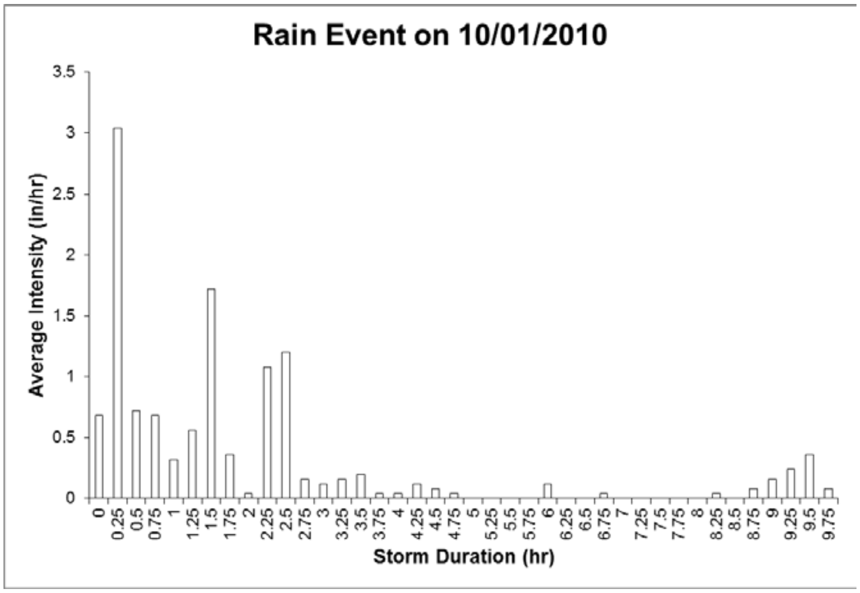


Rainfall depth data for all storms that occurred during the monitoring period are summarized in Table 2, below. Based on the rainfall depth data, the storm on October 1, 2010 was the largest storm with rain depth readings for RGB1, RGB3, RGQ1 and RGQ3 of 0 in, 2.16 in, 3.17 in and 2.92 in, respectively. (The time-series rainfall data recorded for the October 1st storm at RGQ1 in the U-basin is shown in Figure 4, on next page.) The largest storm in terms of intensity and return frequency was the October 1, 2010 storm which was between a 3.1-year storm and an 11.2-year storm depending on the rain gauge referenced. This storm produced the highest flows, and the greatest surcharge elevations at most of the sites. The next most intense storm was the July 13, 2010 storm, but only near RGB1, where it exceeded a 10-year storm; elsewhere it was less than a 6-month storm and as low as a 3-month storm. As illustrated by the July 13th storm, uneven rainfall distribution is common during the summer thunderstorm season.

Table 2: Rainfall depth and return frequency for all rain gauges

	Depth (in.)				Return Frequency				Duration of Maximum DDF			
Storm	RGB1	RGB3	RGQ1	RGQ3	RGB1	RGB3	RGQ1	RGQ3	RGB1	RGB3	RGQ1	RGQ3
4/25/2010	2.33	2.13	2.23	0	5.2-mo	4.0-mo	4.6-mo	2,880	2,880	2,880	0	
5/3/2010	1.17	1.01	1.08	0	4.3-mo	3.7-mo	4.2-mo	15	15	30	0	
5/18/2010	1.15	0.97	1.06	0	1.8-mo	1.6-mo	1.6-mo	180	180	720	0	
6/9/2010	1.2	0.9	0.95	1.08	2.0-mo	1.5-mo	1.7-mo	1.7-mo	360	360	360	360
7/13/2010	1.93	0.95	0.59	0.93	11.1-yr	5.5-mo	2.0-mo	5.3-mo	30	60	60	60
8/22/2010	1.45	1.49	1.57	1.96	11.5-mo	2.3-mo	3.3-mo	5.2-mo	30	1,440	720	1,080
8/25/2010	1.02	1.85	0.54	1.61	1.7-mo	7.8-mo	1.0-mo	4.2-mo	720	360	180	360
9/16/2010	0.3	0.5	0.52	0.58	0.6-mo	1.9-mo	1.7-mo	5.4-mo	360	15	30	15
9/27/2010	0	0.86	1.44	1.04		1.4-mo	2.5-mo	1.6-mo	0	720	1,080	720
9/30/2010	0	0.76	0.98	0.91		4.0-mo	6.3-mo	5.5-mo	0	60	60	60
10/1/2010	0	2.16	3.17	2.92		3.1-yr	11.2-yr	8.9-yr	0	60	180	30
10/11/2010	0	0.59	0.87	1.19		1.2-mo	2.3-mo	5.5-mo	0	180	60	60
10/14/2010	0	0.61	0.97	0.84		1.2-mo	1.8-mo	1.6-mo	0	360	360	360
11/4/2010	1.04	0.95	1.13	1.27	1.5-mo	1.3-mo	1.5-mo	1.8-mo	1,080	720	1,080	1,080
11/16/2010	0.48	0.47	0.53	0.51	0.8-mo	0.8-mo	1.0-mo	1.0-mo	360	360	360	360
12/1/2010	1.05	1.14	1.11	1.21	3.7-mo	3.3-mo	2.0-mo	6.5-mo	15	15	60	15
12/12/2010	1.16	1.13	1.1	1.16	1.6-mo	1.6-mo	1.6-mo	1.6-mo	1,440	1,440	1,440	1,440
1/18/2011	1.3	1.43	0.72	1.18	2.7-mo	4.5-mo	1.0-mo	2.4-mo	360	360	720	360
2/2/2011	0.91	0.9	0.03	0.83	1.5-mo	1.5-mo	0.1-mo	1.3-mo	720	720	15	720
2/24/2011	1.04	1.07	1.23	1.24	1.7-mo	1.7-mo	2.0-mo	2.0-mo	1,080	720	720	1,080
3/6/2011	1.8	1.93	1.89	2.12	4.9-mo	5.9-mo	5.5-mo	8.0-mo	1,080	1,080	1,080	1,080
3/10/2011	1.74	1.98	1.78	2.19	5.2-mo	7.6-mo	5.4-mo	10.6-mo	720	720	720	720
3/16/2011	0.69	0.64	0.54	0.73	1.4-mo	1.3-mo	1.1-mo	1.5-mo	360	360	180	360
3/23/2011	0.96	1.03	0.76	1.06	1.2-mo	1.3-mo	1.1-mo	1.3-mo	2,880	2,880	30	2,880

Figure 5: Rainfall hyetograph for the storm on October 1, 2010.

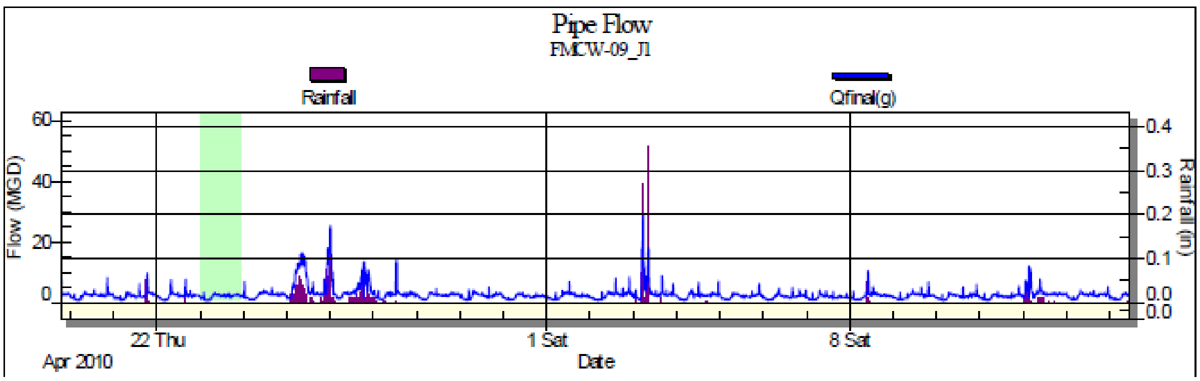


FLOW MEASUREMENT

ADS flow meters were used to measure depth relative to the pipe invert and fluid velocity. These data, in conjunction with the physical pipe characteristics (e.g. shape, size, slope), were used to calculate average velocity and flow rate. ADS field crews took manual depth and velocity readings to calibrate each set of sensors. ADS provided DEP with depth, average flow rate and average velocity measurements for all flow meters at 15-minute intervals.

The hydrograph in Figure 6, below, shows the flow monitoring data from Site U2 for 24 days during the one year monitoring period. The blue line shows flow, the vertical purple bars show weighted, interpolated rainfall and the vertical light green stripe indicates that April 22, 2010 was one of the dry days selected to create average dry weather flow curves.

Figure 6: Hydrograph for flow meter U2 over 24 day period

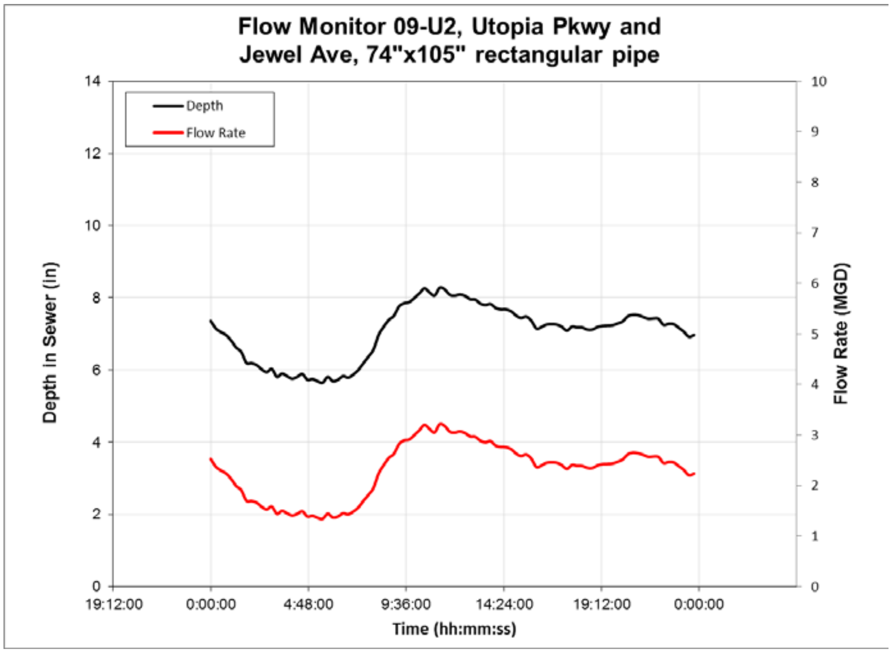


Both dry weather and wet weather periods were evaluated to determine the impact of wet weather on system capacities as well as to determine what storm intensity that the DEP can expect the systems to contain without surface flooding.

DRY WEATHER FLOW

During dry weather, the flows in combined and sanitary sewers typically mirror the diurnal water consumption pattern, with a shift along the time axis. Water consumption is lowest in the overnight hours, rises significantly in the morning as many consumers awaken and prepare for work or school, and typically experiences a secondary peak in the late afternoon/early evening as many consumers return home before returning to a minimum overnight value (see Figure 7, on the next page). Hydrographs for the other flow meters in the Utopia Parkway corridor (Basin U) are provided in Appendix A (Figures A1-A13). Dry weather hydrographs for the flow meters in the JVP basin (Basin J) and 4th Avenue basin (Basin P) are provided in Appendix B (Figures B1-B11) and Appendix C (Figures C1-C10), respectively.

Figure 7: Hydrograph for a 74-inch trunk main on Oct. 2, 2010 illustrating typical diurnal flow pattern during dry weather



WET WEATHER FLOW

Rainfall dependent inflow and infiltration (RDII) is that portion of inflow and infiltration (I/I) directly influenced by the intensity and duration of a storm event. It consists of storm water inflow and rainfall-dependent infiltration. RDII includes those amounts of infiltration and inflow that were generated by rain as opposed to other sources such as snowmelt, high river stages, high tides and groundwater.

Table 3, on the next page, lists the net volumes of RDII produced from each significant storm for the U basin (which includes the Utopia Parkway Corridor). The volume of RDII for each storm is expressed in million gallons (MG).

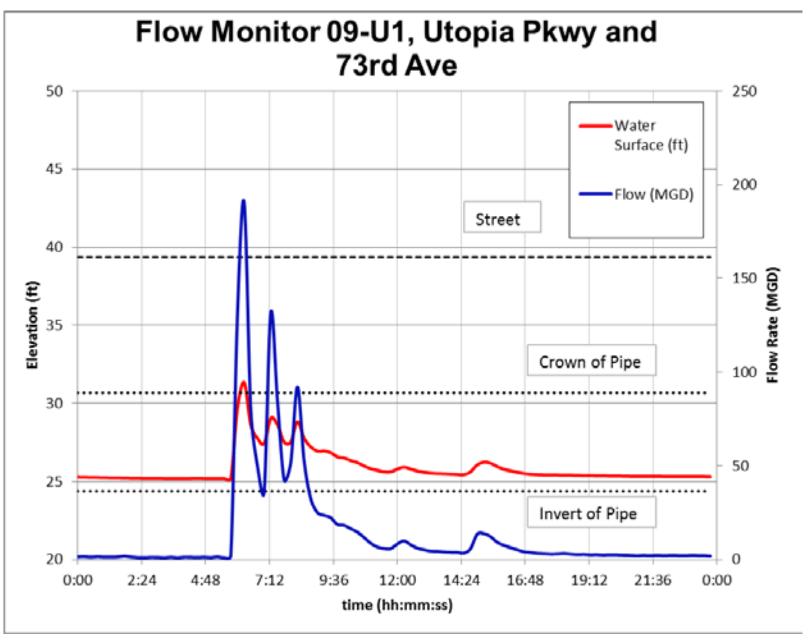
For most sites, the greatest flow responses were generated by the rain event on October 1, 2010 which ranges from a 3.2 year to an 11.2 year storm (depending on the rain gauge referenced). This storm was chosen to evaluate the wet weather performance of the sewers studied herein. Depth data for each flow meter during the October 1, 2010 storm were used to evaluate the sewer system's response to significant wet weather events.

Figure 8, on the next page, illustrates the flow rate and elevation at monitoring location 09-U1. The dotted horizontal lines show the elevations of the pipe invert, the pipe crown and the street elevation for a corresponding flow monitoring site. As shown in Figure 8, the water elevation does not exceed the street elevation during a surcharge period. The October 1, 2010 storm had a return frequency of a 3.1 to 11.2 year storm (depending on the rain gauge referenced) however, no surface flooding was observed at any of the 35 monitoring sites. Elevation and flow plots are provided in Appendix D for all remaining flow meters in the Utopia Parkway corridor (Basin U). Elevation and flow plots of the JVP basin (Basin J) and 4th Avenue basin (Basin P) are provided in Appendix E and Appendix F, respectively.

Table 3: Net RDII Volume by Storm in the U System

Storm	U1	U10	U11	U12	U13	U14	U2	U3	U4	U5	U6	U7	U8	U9	U13	U14
4/25/2010	11.169	7.747	0.73	14.729	7.082	5.968	9.737	0.074	20.068	0.325	2.66	0.025	0.023	13.192	7.082	5.944
5/3/2010	4.446	5.516	5.862	6.821	4.172	4.145	1.936	1.701	8.607	0.48	0.404	0.548	0.717	10.932	4.172	4.131
5/18/2010	3.324	3.017	0.662	5.321	3.018	2.021	3.525	0.03	7.77	0.14	0.797	0.007	0.004	4.875	3.018	2.02
6/9/2010	2.886	4.552	n/a	n/a	n/a	n/a	3.149	n/a	6.134	n/a-c	n/a-c	0.000-c	n/a-c	n/a-c	n/a	n/a
7/13/2010	1.627	n/a	0.834	2.34	1.425	n/a	1.182	0.372	3.666	0.308	0.742	0.002	0.003	n/a	1.425	n/a
8/22/2010	7.189	9.175	0.014	9.891	5.337	4.39	5.187	3.678	13.919	4.136	3.362	0.614	0.554	13.12	5.337	4.445
8/25/2010	3.263	1.989	0.269	4.455	3.036	1.898	3.324	0.272	6.998	0.597	1.312	0.029	0.028	2.774	3.036	1.901
9/16/2010	2.857	2.792	n/a	4.122	1.663	2.125	2.208	0.949	5.896	0.339-c	0.877-c	0.071	0.103	3.655	1.663	2.127
9/27/2010	4.688	5.348	1.638	6.849	4.885	3.951	3.989	1.345	10.019	1.108	1.58	0.272	0.393	7.834	4.885	3.962
9/30/2010	3.821	5.926	2.172	5.806	3.054	1.42	1.924	2.553	8.097	1.266	1.665	0.762	0.65	8.767	3.054	1.421
10/1/2010	13.002	20.402	14.392	21.977	11.703	27.587	3.791	9.086	2.916	4.396	0.174	8.249	6.349	28.503	11.703	27.596
10/11/2010	3.436	4.906	1.954	4.738	3.532	7.584	2.578	1.128	1.948	0.172	0.538	0.526	0.774	5.436	3.532	7.58
10/14/2010	4.182	3.783	0.439	5.752	2.634	0.425	3.904	0	11.516	0.029	0.547	0.195	0.499	6.565	2.634	0.419
11/4/2010	4.595	1.362	0.017	5.279	2.851	3.927	4.118	0	7.911	0.04	0.432	0.219	0.259	4.439	2.851	3.926
11/16/2010	2.431	0.68	0.536	2.572	1.68	1.97	2.629	0.026	4.141	0.009	0.191	0.117	0.141	2.55	1.68	1.967
12/1/2010	4.591	2.537	1.222	5.89	4.243	2.562	3.567	1.282	9.736	0.401	1.226	0.429	0.094	5.9	4.243	2.564
12/12/2010	5.294	0.881	0.513	5.823	3.597	2.671	4.961	0.061	9.559	0.022	0.575	0.073	0.118	5.832	3.597	2.664
1/18/2011	6.411	4.225	0	n/a	4.246	2.372	6.136	0	11.846	1.146	3.184	0.034	n/a	7.792-c	4.246	2.37
2/2/2011	2.909	0.444	0	n/a	2.717	1.639	2.735	n/a	6.057	0.000-c	0.000-c	0.032	0	2.322	2.717	1.641
2/24/2011	5.852	3.8	0.054	n/a	3.72	2.289	5.849	0.179	10.427	0.441	2.657	0.012	0.002	8.523	3.72	2.29
3/6/2011	9.494	10.393	3.162	12.957	7.468	4.882	8.296	0.862	17.295	0.238	2.148	0.06	0.162	15.115	7.468	4.866
3/10/2011	9.551	9.146	3.096	10.391	7.509	3.697	8.068	0.911	17.154	0.15	1.589	0.267	0.178	15.435	7.509	3.699
3/16/2011	3.025	1.535	0.093	4.303	1.78	1.044	2.987	0.062	5.394	0.016	0.473	0.024	0.002	3.573	1.78	1.047
3/23/2011	4.213	0.314	0	3.641	2.861	2.866	3.818	n/a	6.531	0.000-c	0.000-c	0.131	0.004	2.338	2.767	2.779

Figure 8: Elevation of water and flow rate in pipe at meter location 09-U1 during the October 1, 2010 storm. Dotted lines indicate street elevation, crown of pipe and pipe invert.



APPENDIX A: DRY WEATHER FLOW HYDROGRAPHS FOR THE U-BASIN

Figure A1: Hydrograph for meter 09-U1 on October 2, 2010 for a 75-inch trunk main.

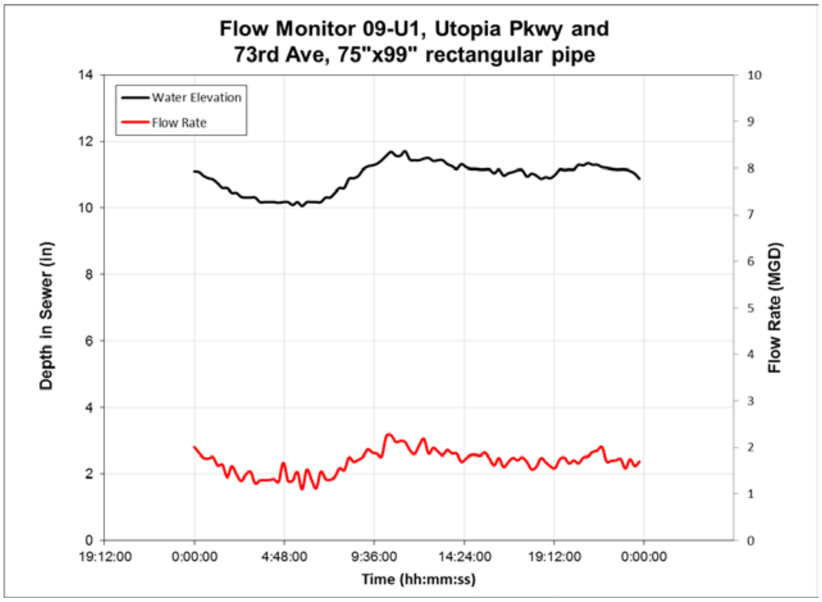


Figure A2: Hydrograph for meter 09-U3 on October 2, 2010 for an 88-inch trunk main.

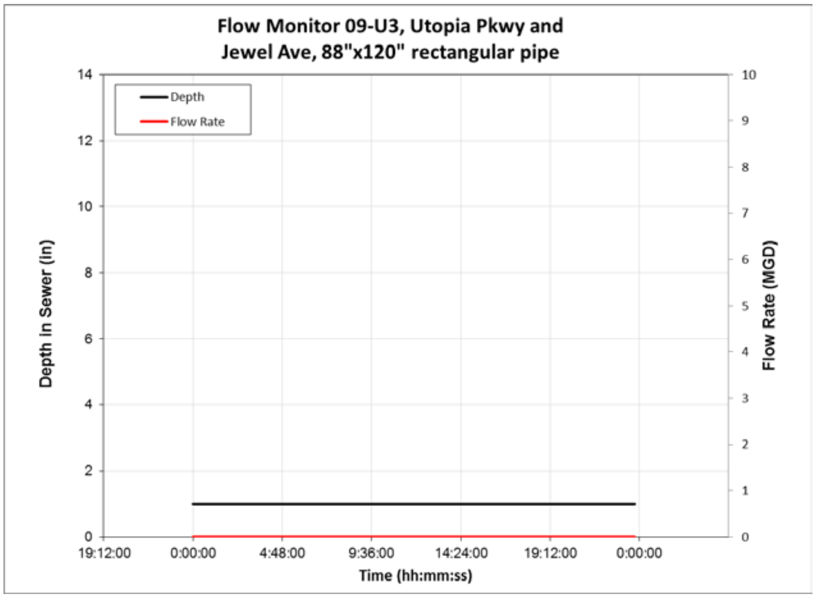


Figure A3: Hydrograph for meter 09-U4 on October 2, 2010 for a 72-inch trunk main.

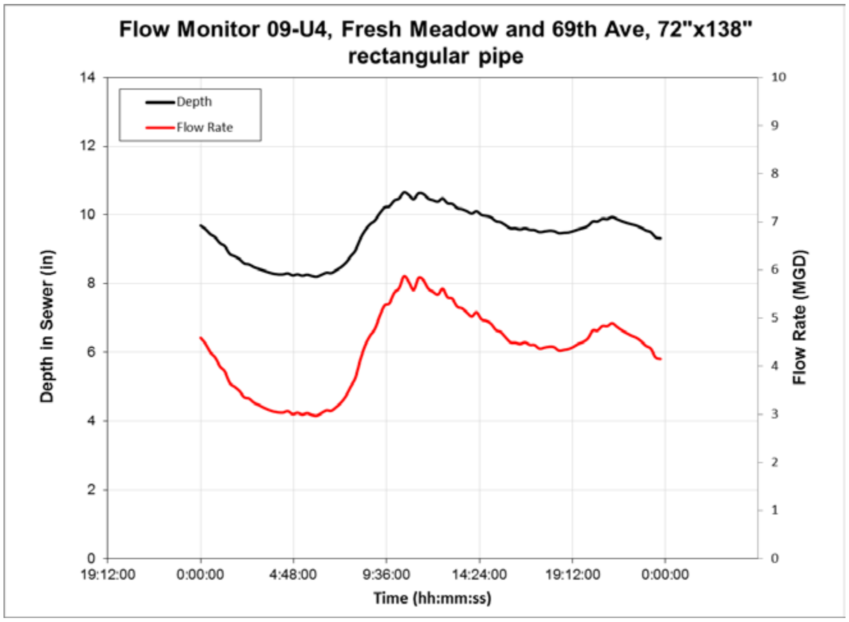


Figure A4: Hydrograph for meter 09-U5 on October 2, 2010 for an 88-inch trunk main.

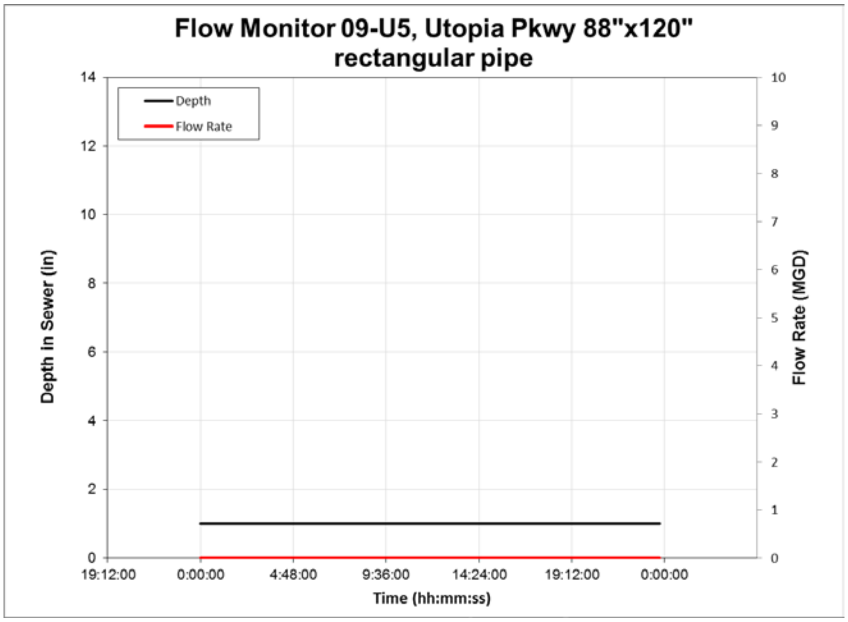


Figure A5: Hydrograph for meter 09-U6 on October 2, 2010 for an 87-inch trunk main.

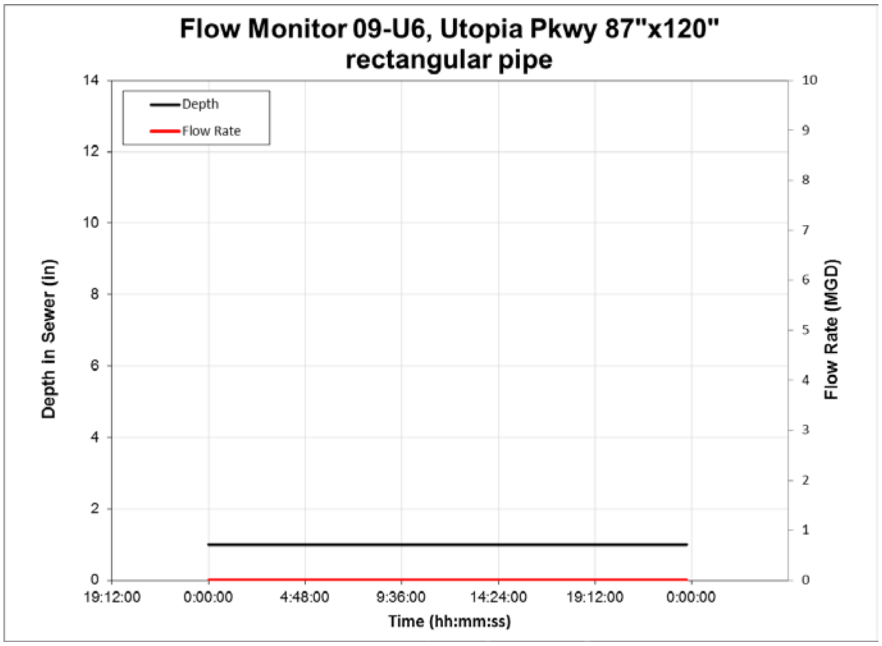


Figure A6: Hydrograph for meter 09-U7 on October 2, 2010 for a 107-inch trunk main.

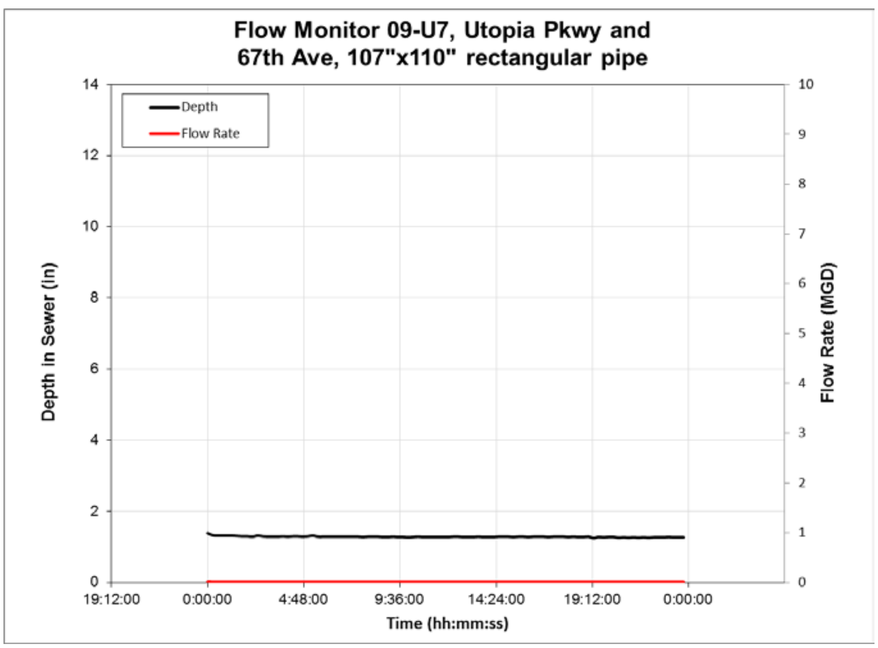


Figure A7: Hydrograph for meter 09-U8 on October 2, 2010 for a 107-inch trunk main.

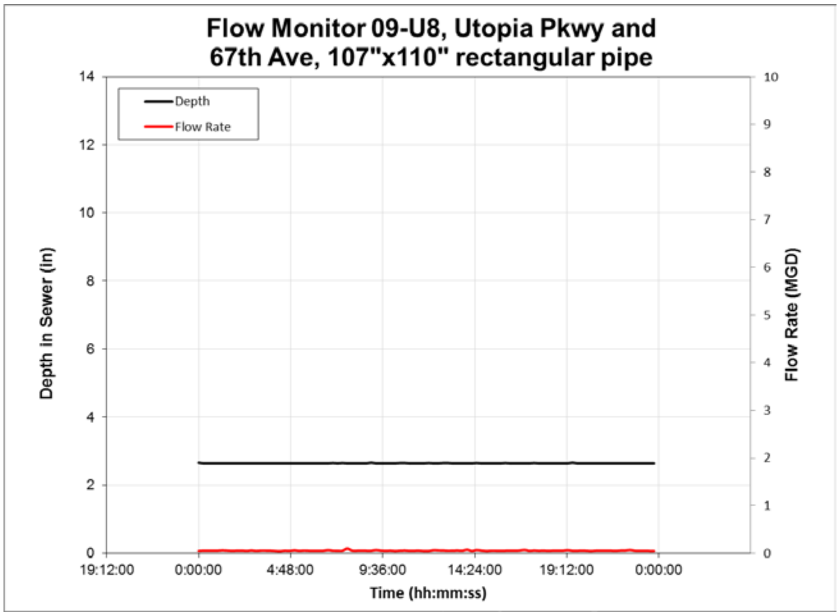


Figure A8: Hydrograph for meter 09-U9 on October 2, 2010 for a 109-inch trunk main.

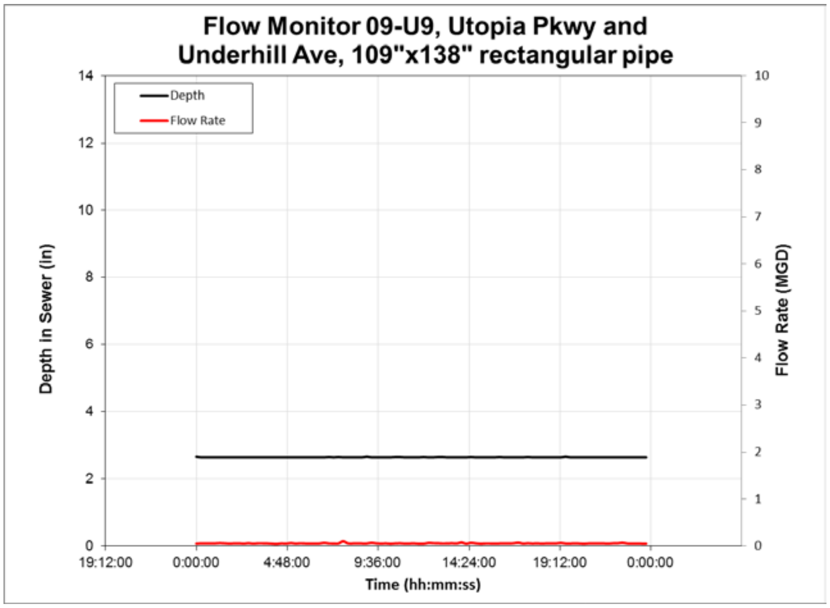


Figure A9: Hydrograph for meter 09-U10 on October 2, 2010 for a 108-inch trunk main.

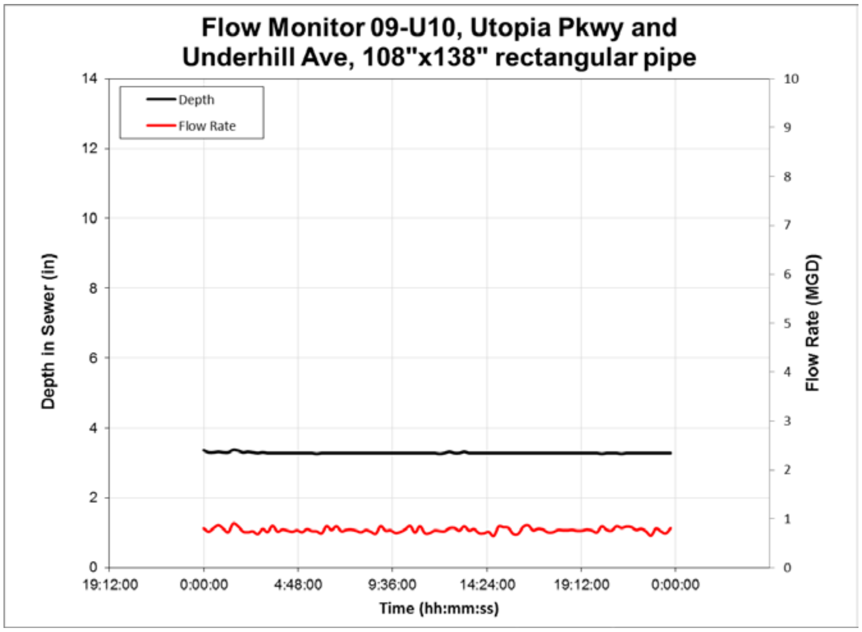


Figure A10: Hydrograph for meter 09-U11 on October 2, 2010 for an 84-inch trunk main.

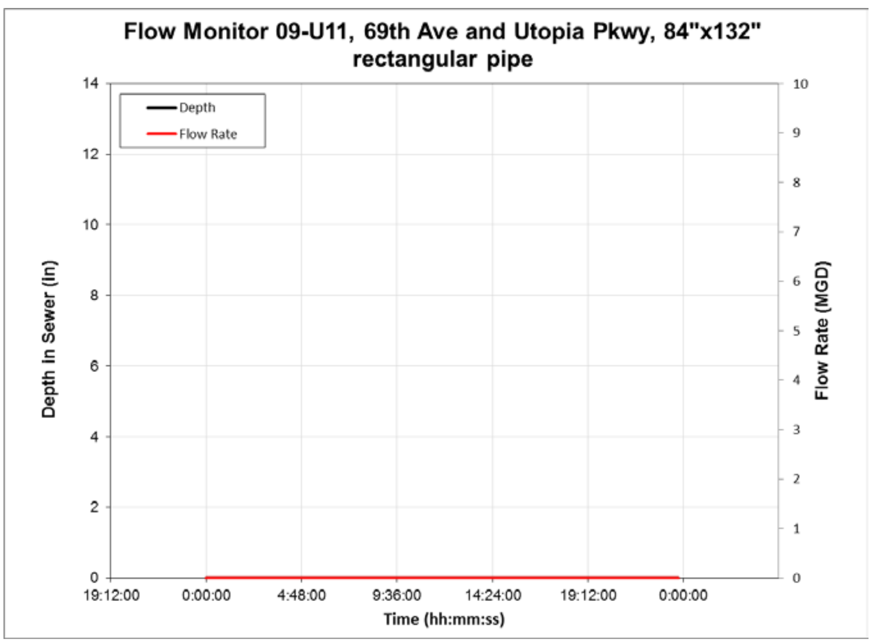


Figure A11: Hydrograph for meter 09-U12 on October 2, 2010 for a 99-inch trunk main.

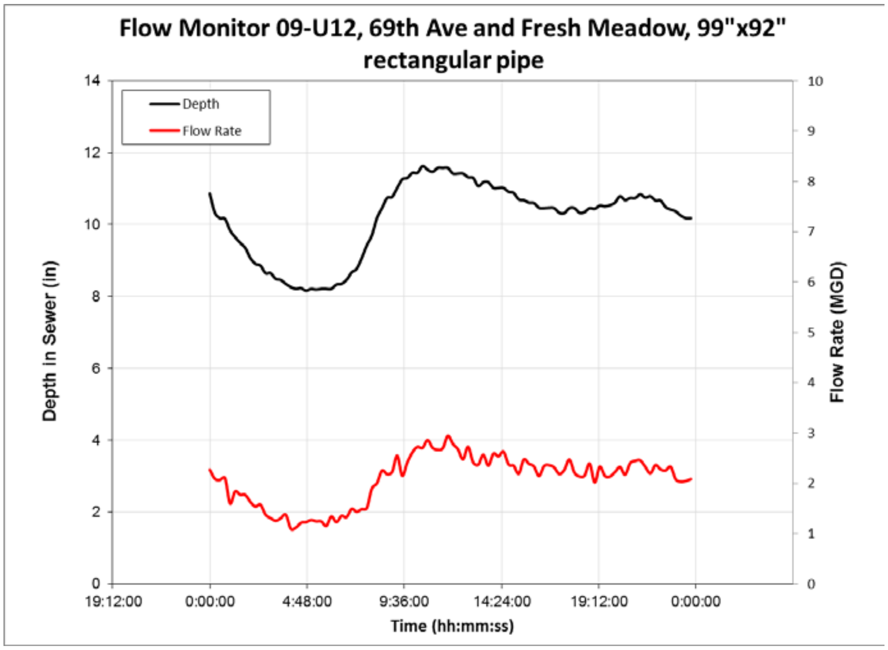


Figure A12: Hydrograph for meter 09-U13 on October 2, 2010 for an 84-inch trunk main.

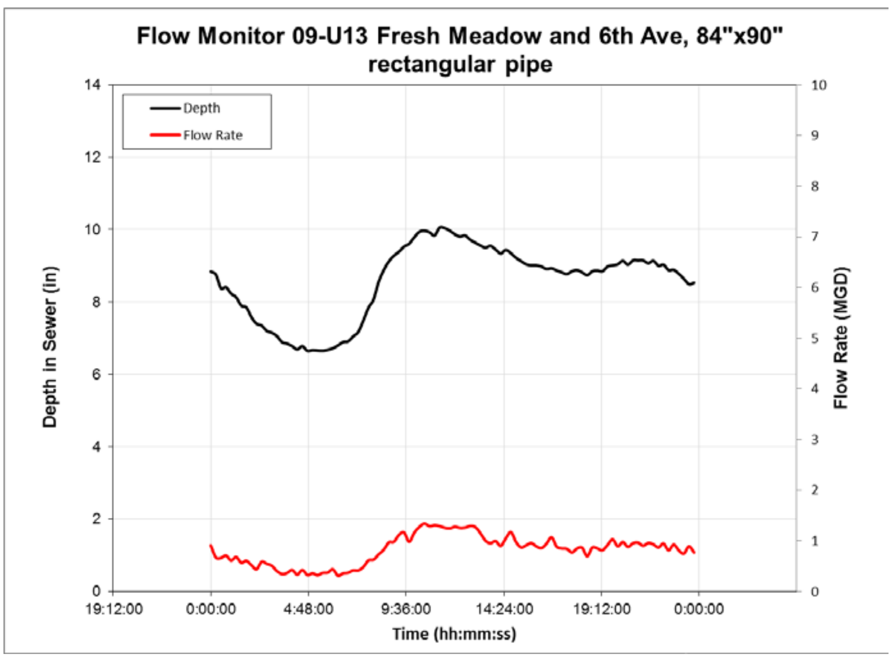
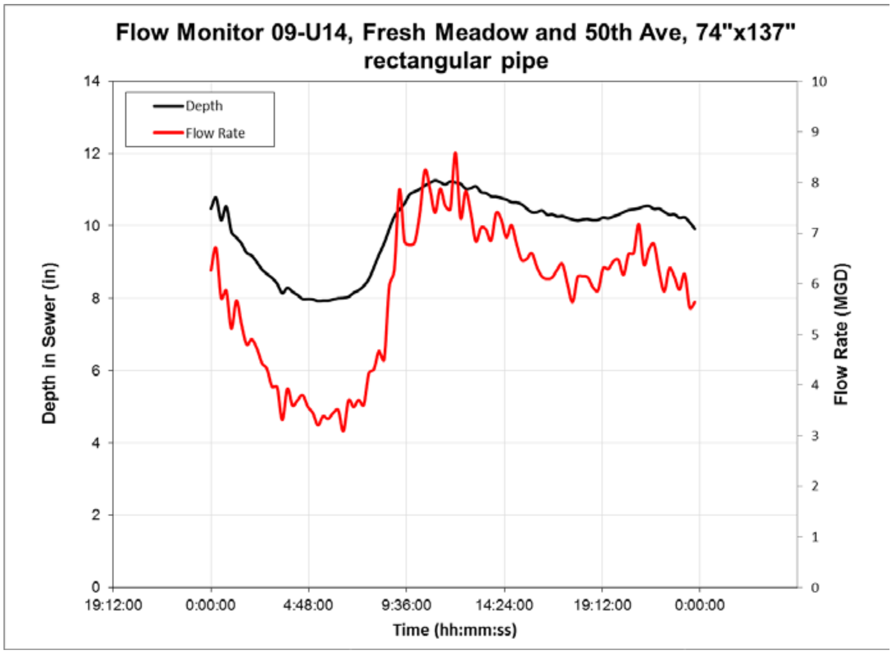


Figure A13: Hydrograph for meter 09-U14 on October 2, 2010 for an 84-inch trunk main.



APPENDIX B: DRY WEATHER FLOW HYDROGRAPHS FOR THE J-BASIN

Figure B1: Hydrograph for meter 09-J1 on October 2, 2010 for a 72-inch trunk main.

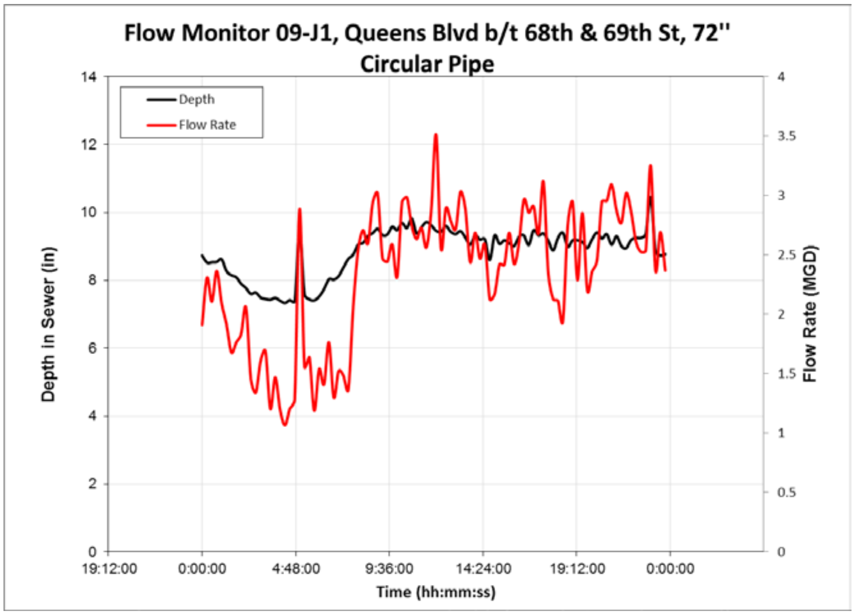


Figure B2: Hydrograph for meter 09-J2 on October 2, 2010 for a 96-inch trunk main.

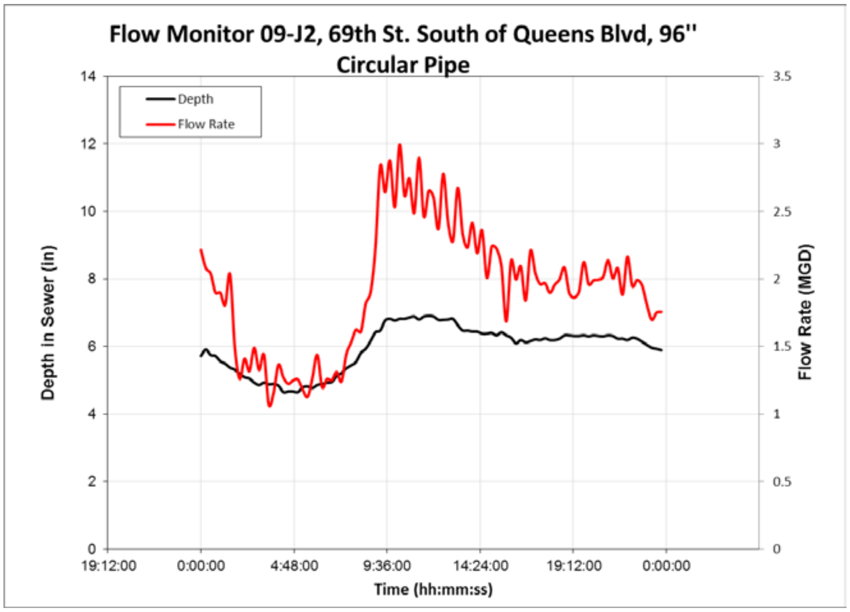


Figure B3: Hydrograph for meter 09-J3 on October 2, 2010 for a 96-inch trunk main.

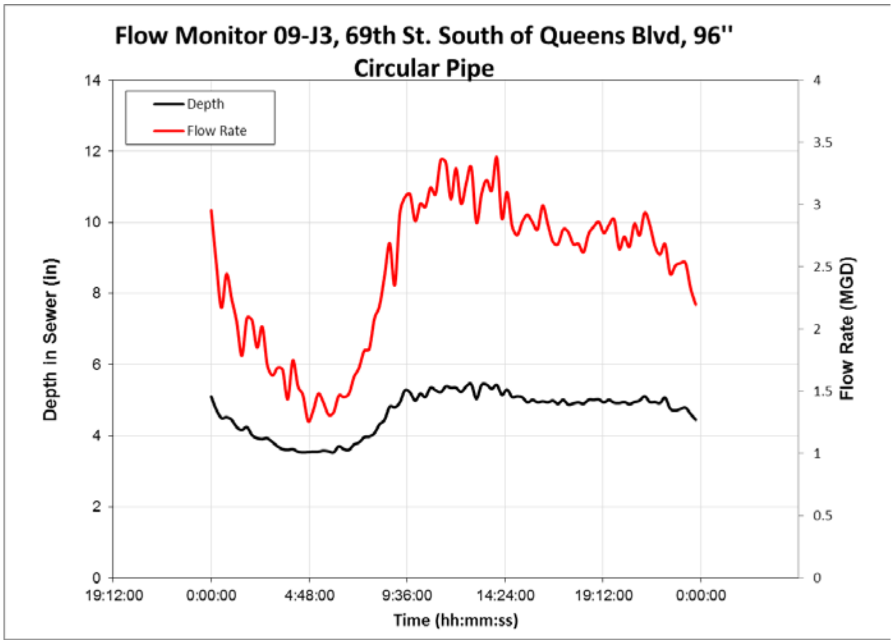


Figure B4: Hydrograph for meter 09-J4 on October 2, 2010 for a 96-inch trunk main.

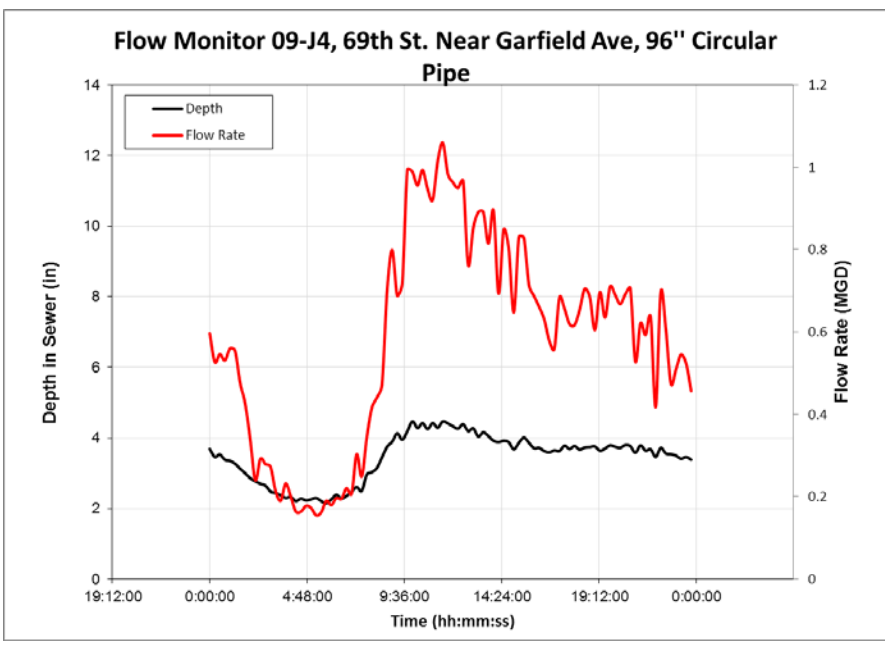


Figure B5: Hydrograph for meter 09-J5 on October 2, 2010 for a 96-inch trunk main.

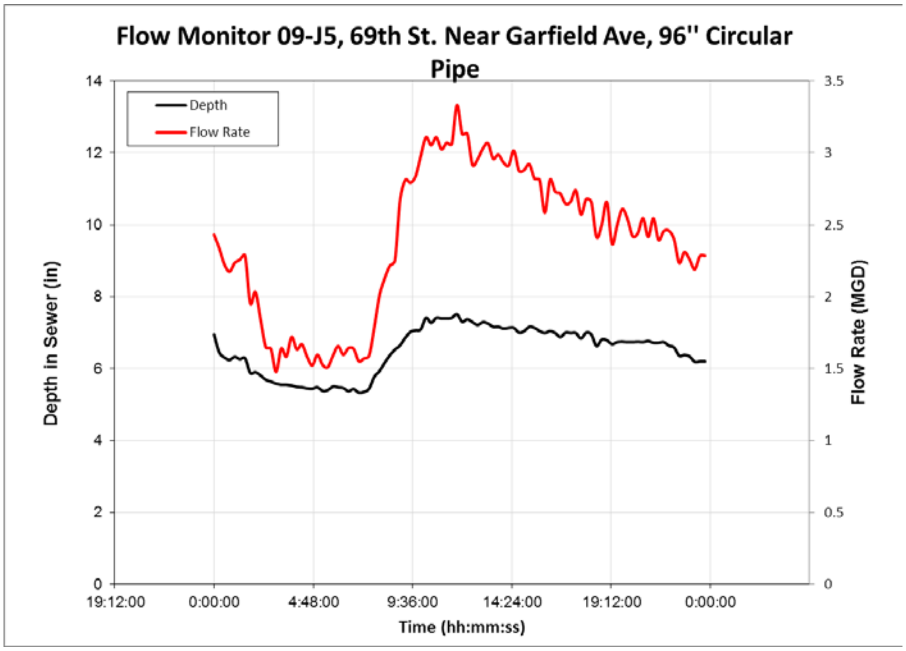


Figure B6: Hydrograph for meter 09-J6 on October 2, 2010 for a 96-inch trunk main.

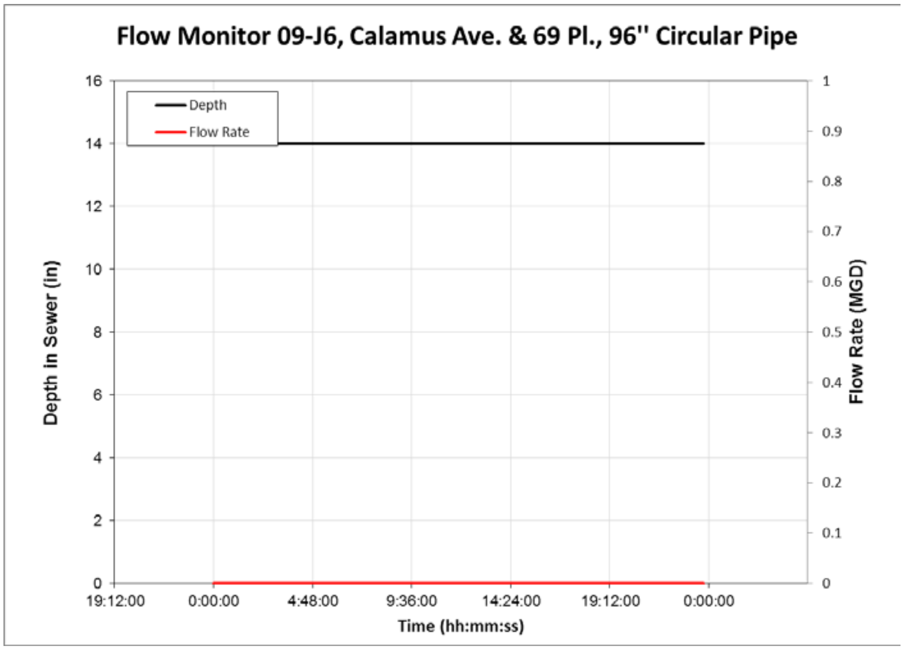


Figure B7: Hydrograph for meter 09-J7 on October 2, 2010 for a 96-inch trunk main.

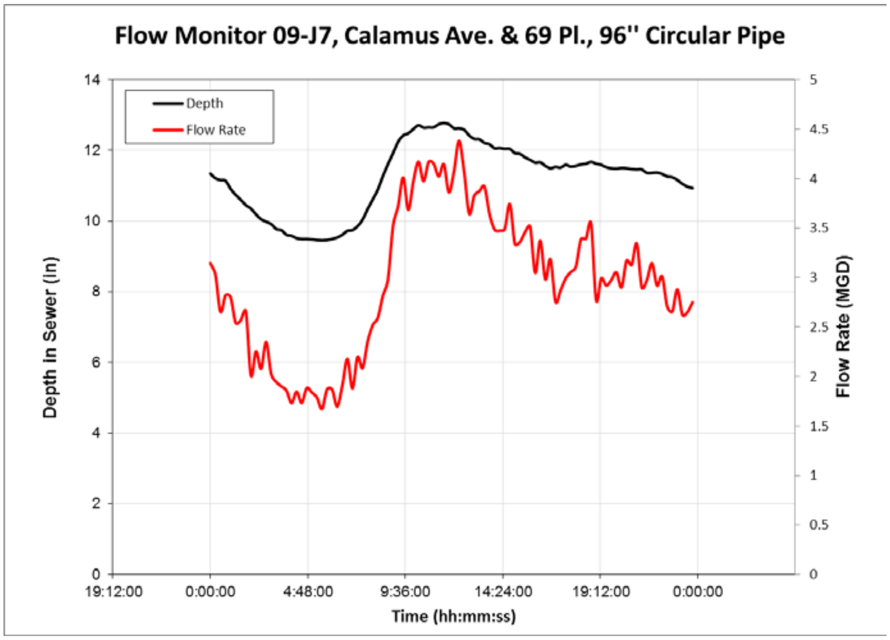


Figure B8: Hydrograph for meter 09-J8 on October 2, 2010 for a 96-inch trunk main.

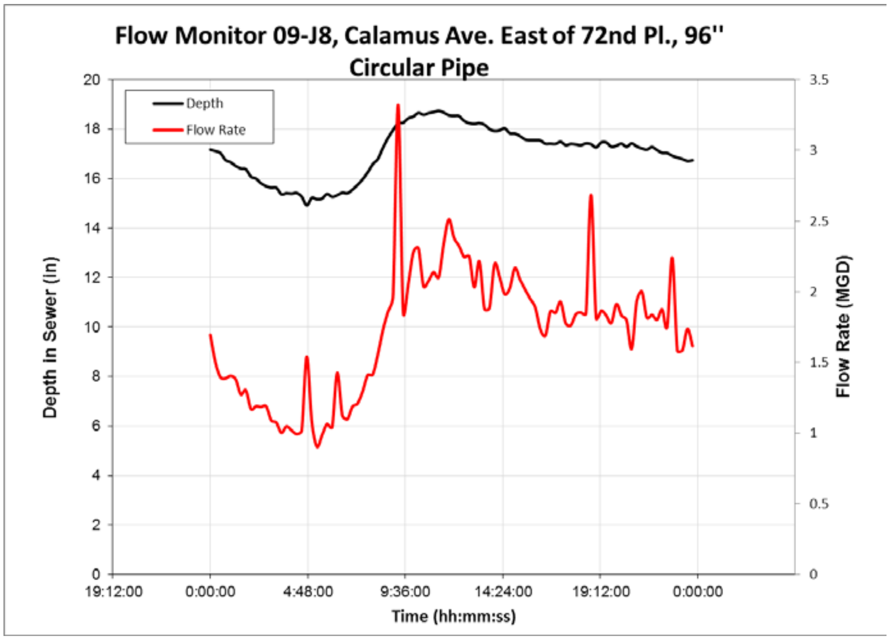


Figure B9: Hydrograph for meter 09-J9 on October 2, 2010 for a 96-inch trunk main.

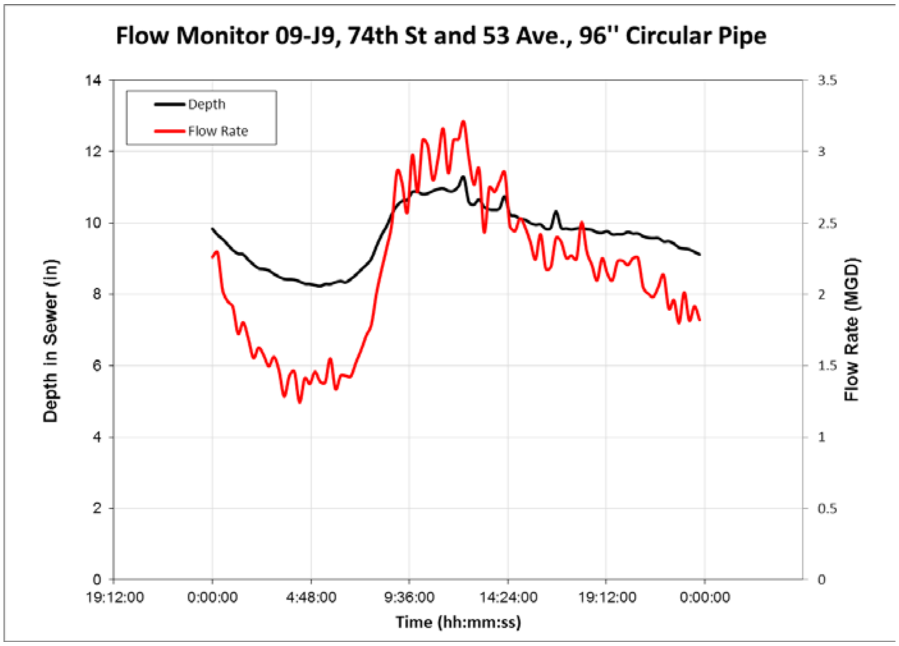


Figure B10: Hydrograph for meter 09-J10 on October 2, 2010 for a 96-inch trunk main.

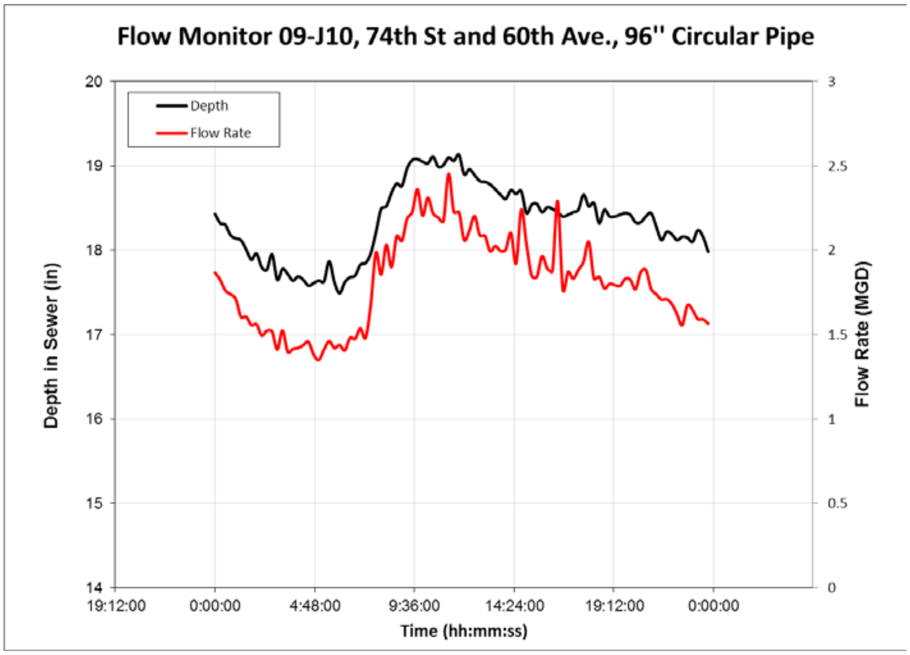
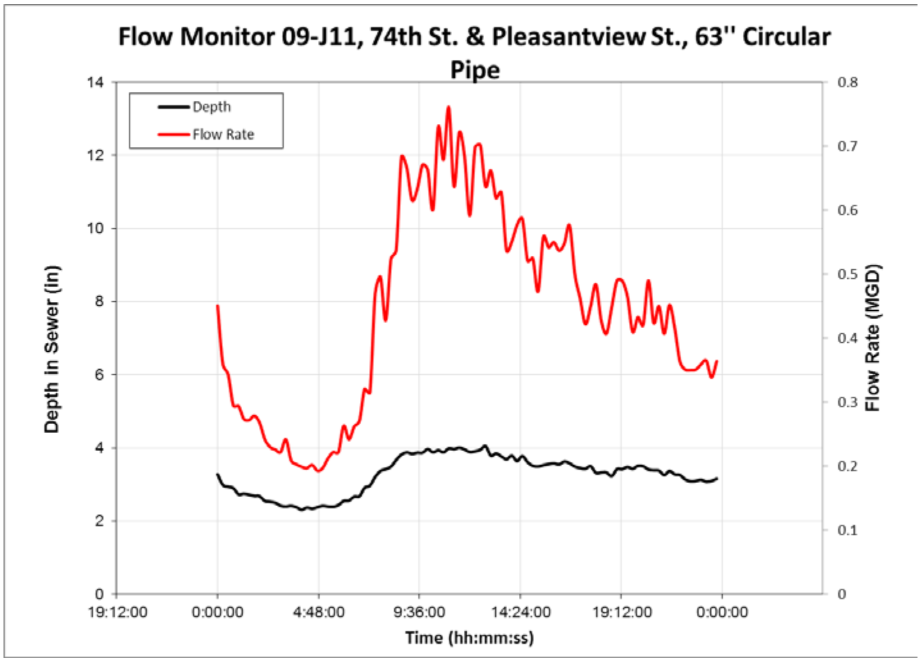


Figure B11: Hydrograph for meter 09-J11 on October 2, 2010 for a 63-inch trunk main.



APPENDIX C: DRY WEATHER FLOW HYDROGRAPHS FOR THE P-BASIN

Figure C1: Hydrograph for meter 09-P1 on October 2, 2010 for a 63-inch trunk main.

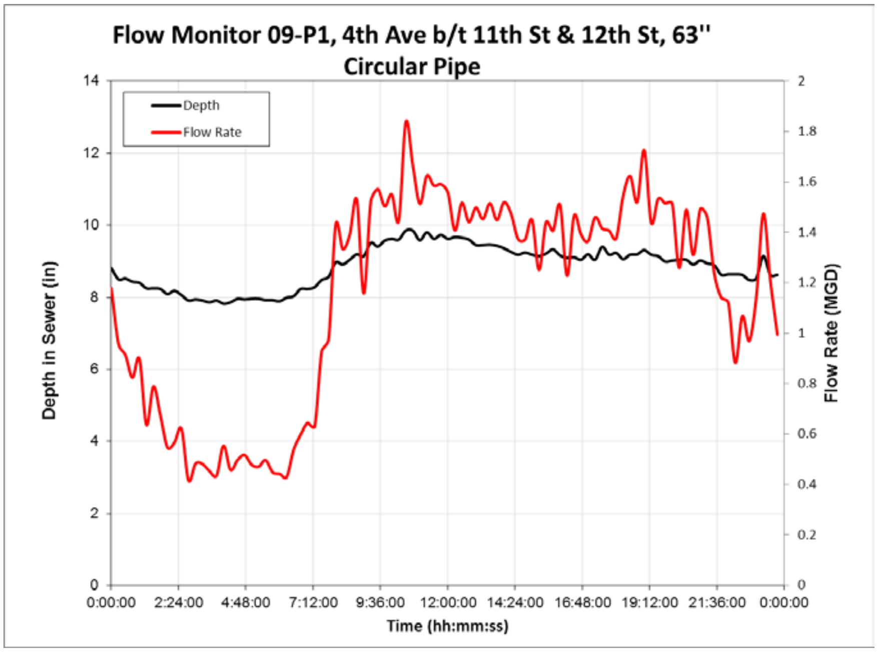


Figure C2: Hydrograph for meter 09-P2 on October 2, 2010 for a 63-inch trunk main.

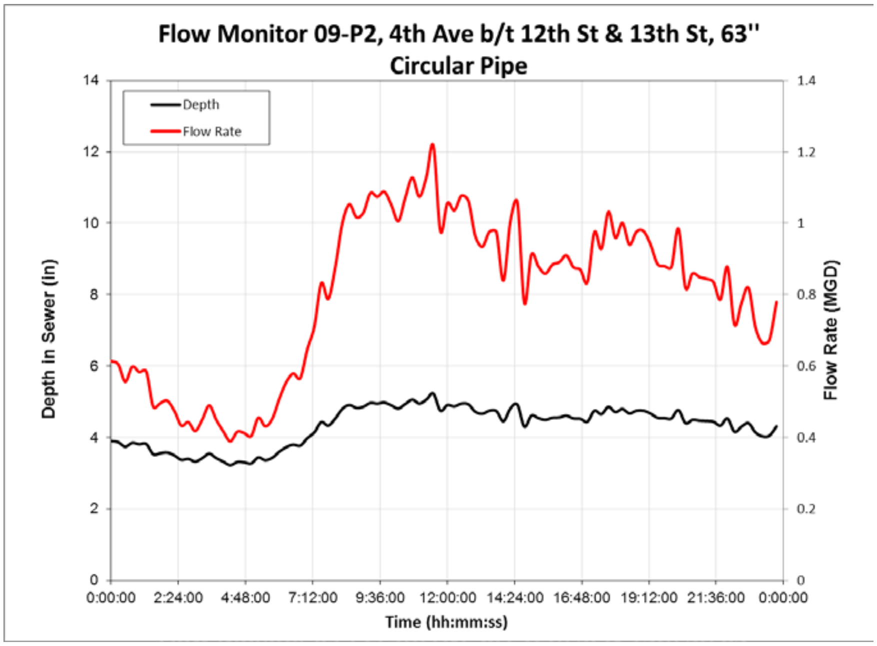


Figure C3: Hydrograph for meter 09-P3 on October 2, 2010 for a 73-inch trunk main.

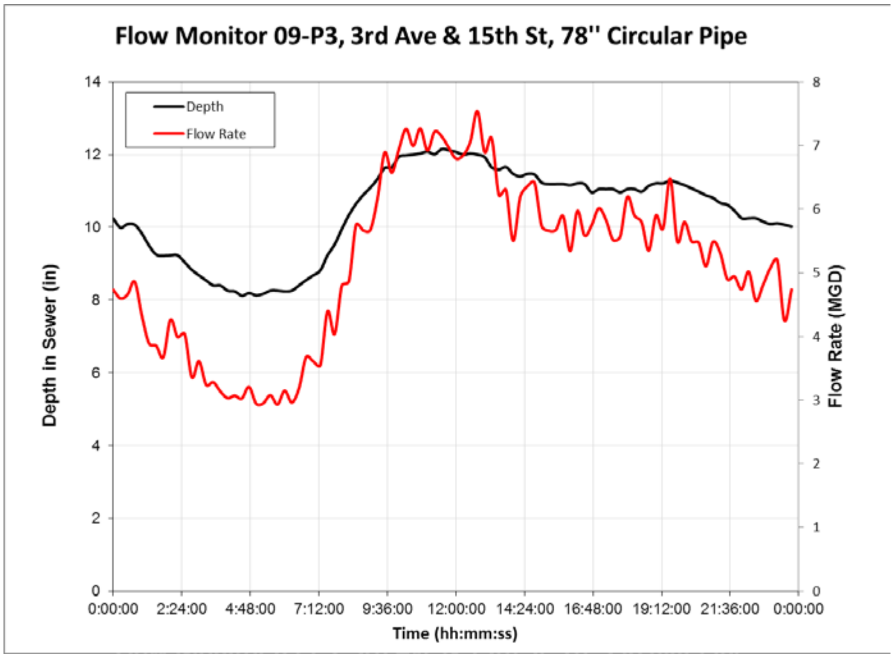


Figure C4: Hydrograph for meter 09-P4 on October 2, 2010 for a 66-inch trunk main.

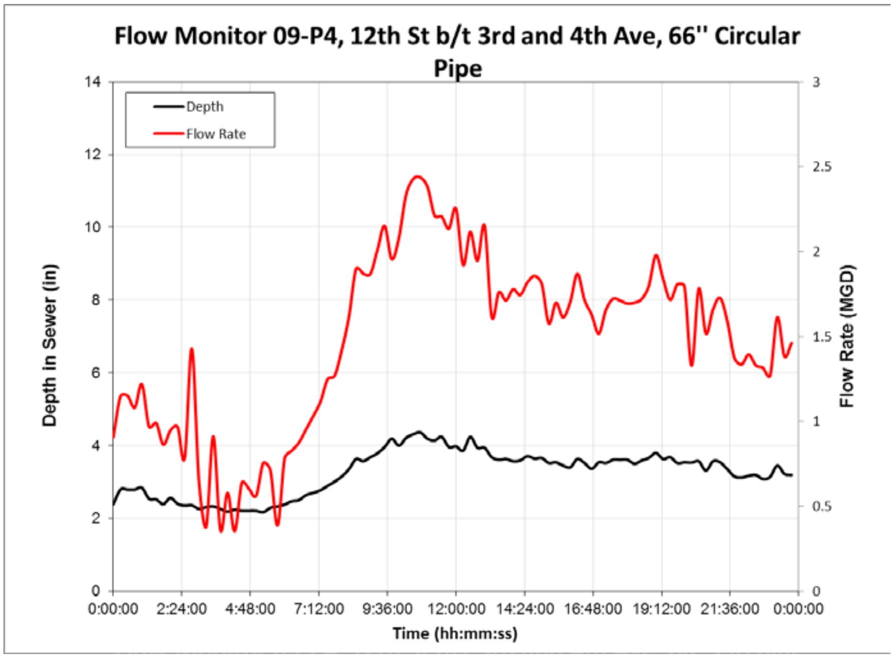


Figure C5: Hydrograph for meter 09-P5 on October 2, 2010 for a 100-inch trunk main.

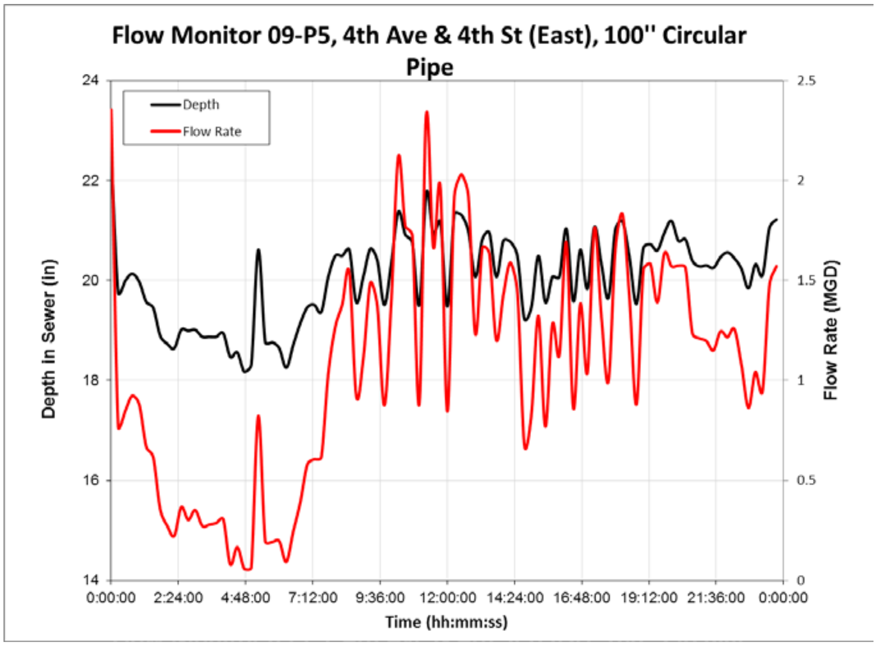


Figure C6: Hydrograph for meter 09-P6 on October 2, 2010 for a 60 inch trunk main.

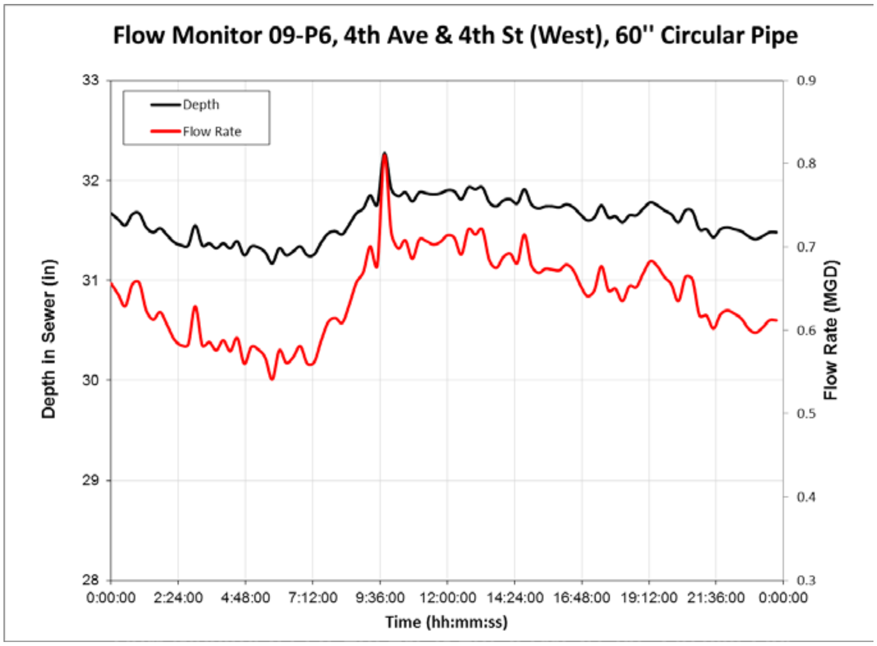


Figure C7: Hydrograph for meter 09-P7 on October 2, 2010 for an 86-inch trunk main.

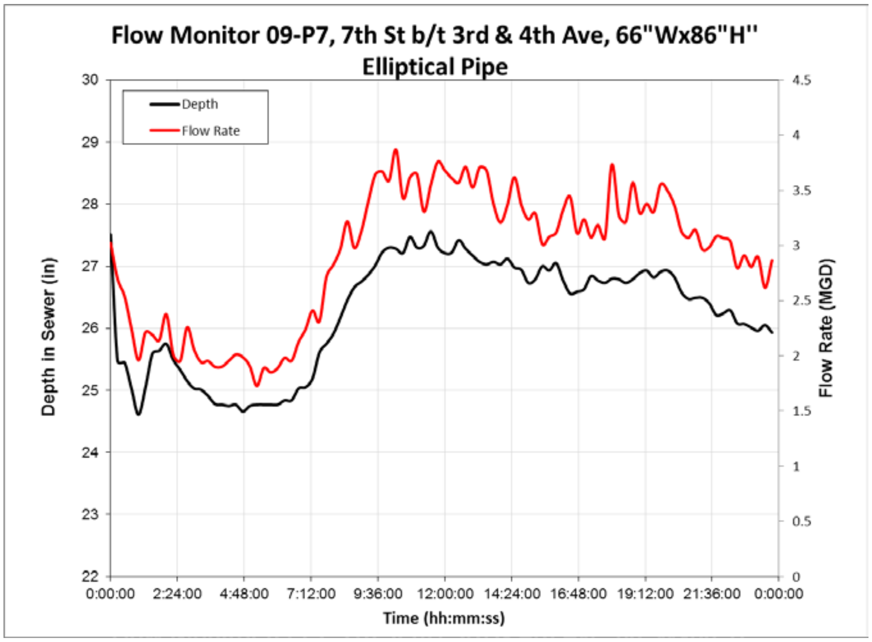


Figure C8: Hydrograph for meter 09-P8 on October 2, 2010 for a 72-inch trunk main.

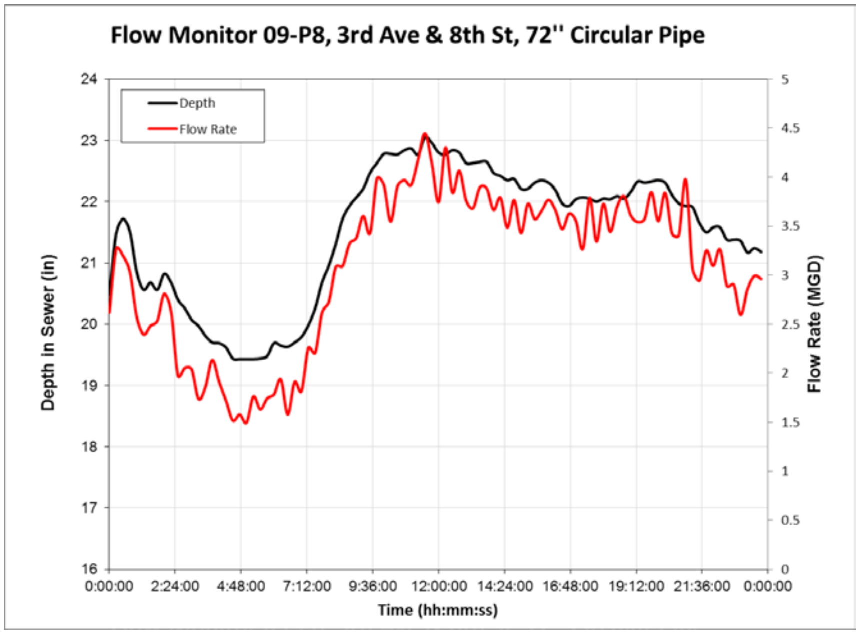


Figure C9: Hydrograph for meter 09-P9 on October 2, 2010 for a 59-inch trunk main.

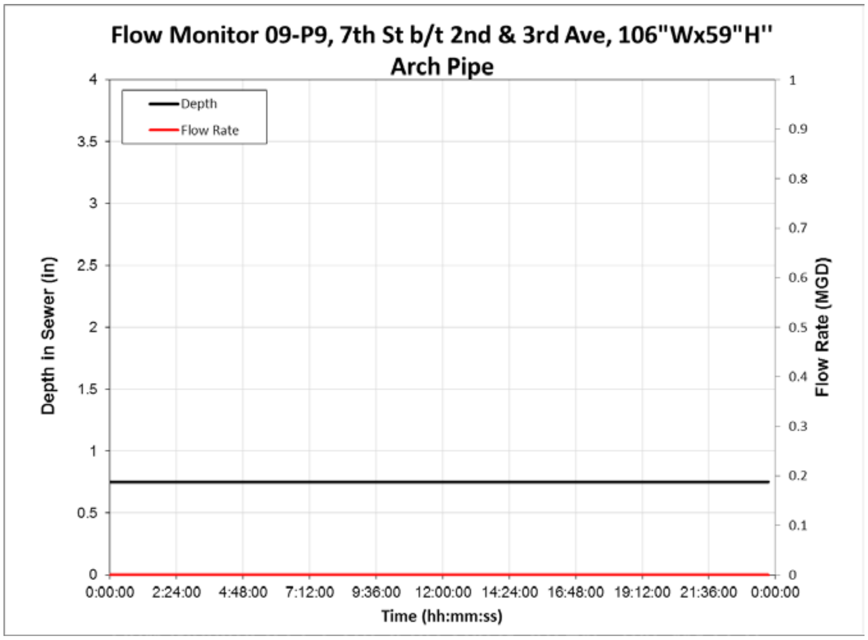
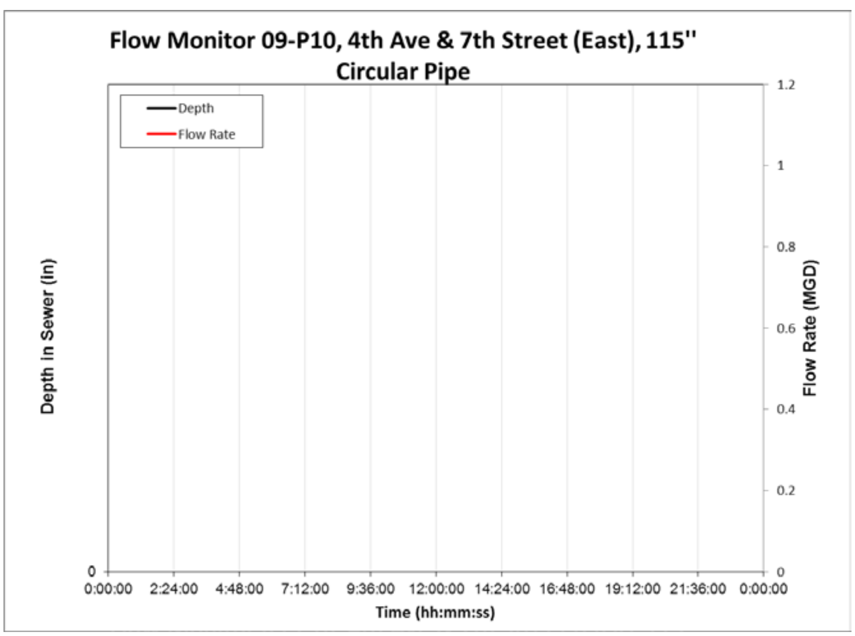


Figure C10: Hydrograph for meter 09-P10 on October 2, 2010 for a 115-inch trunk main. (Note: no data available at this site on October 2, 2010)



APPENDIX D: WET WEATHER FLOW HYDROGRAPHS FOR THE U-BASIN, 10/01/10 STORM

Note: Dotted lines indicate street elevation, crown of pipe and pipe invert for all plots in this appendix.

Figure D1: Elevation of water and flow rate in pipe at meter location 09-U2.

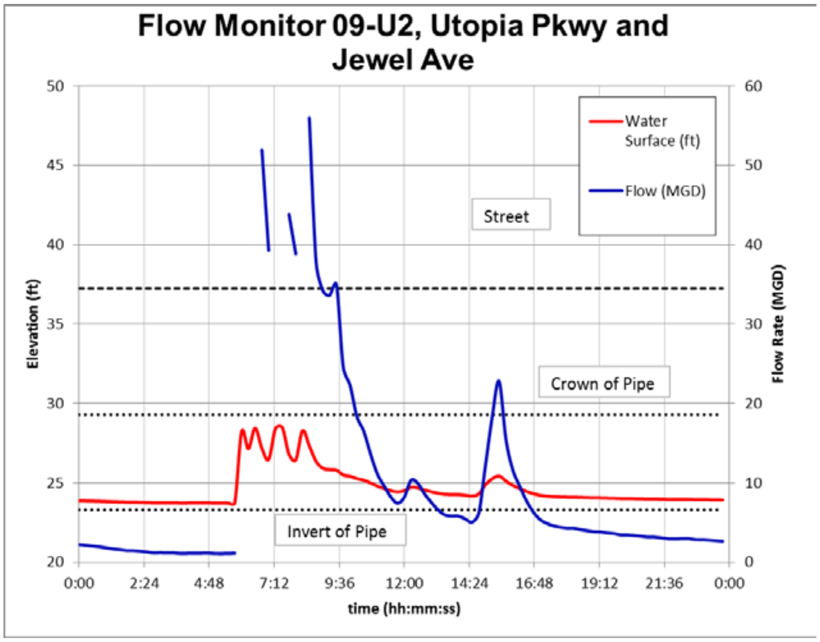


Figure D2: Elevation of water and flow rate in pipe at meter location 09-U3.

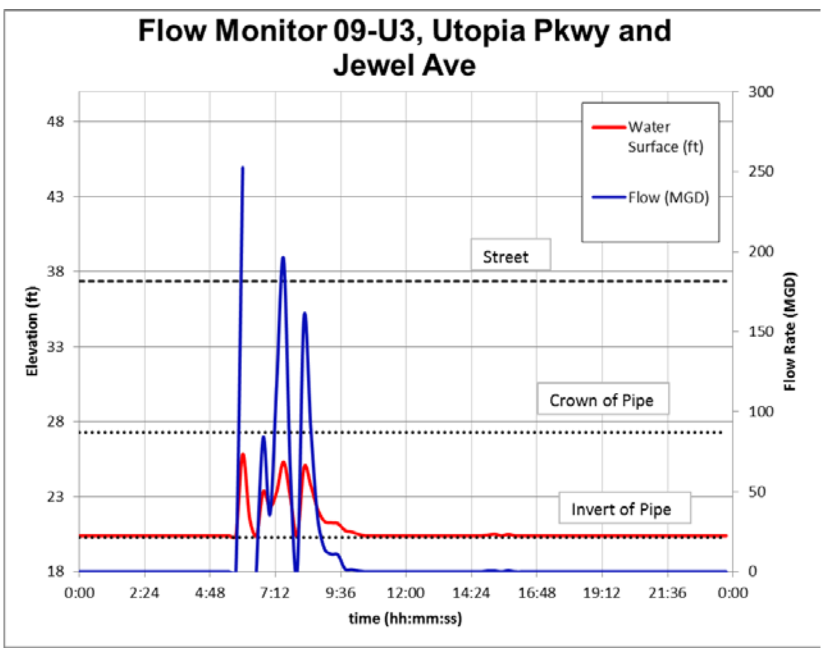


Figure D3: Elevation of water and flow rate in pipe at meter location 09-U4.

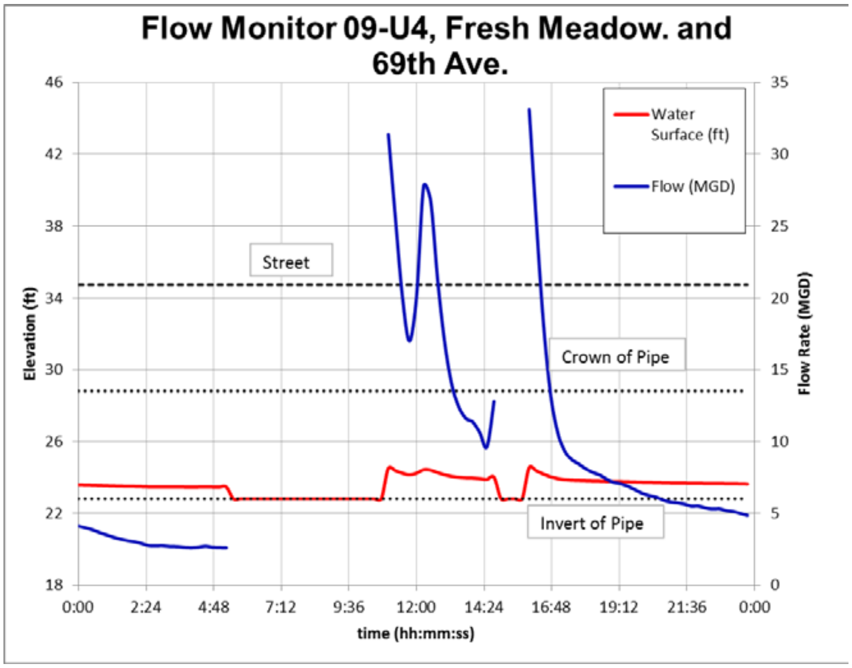


Figure D4: Elevation of water and flow rate in pipe at meter location 09-U5.

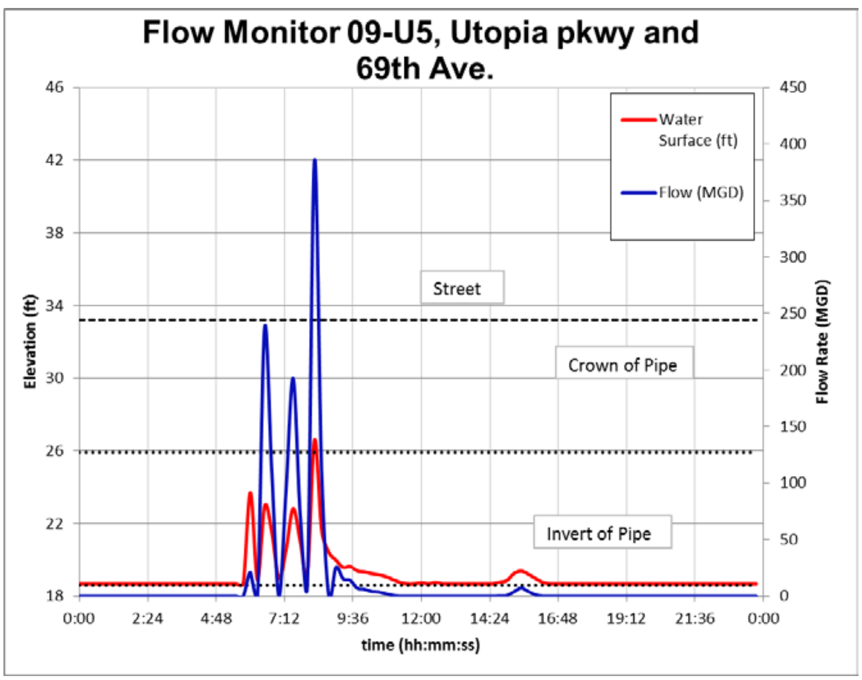


Figure D5: Elevation of water and flow rate in pipe at meter location 09-U6.

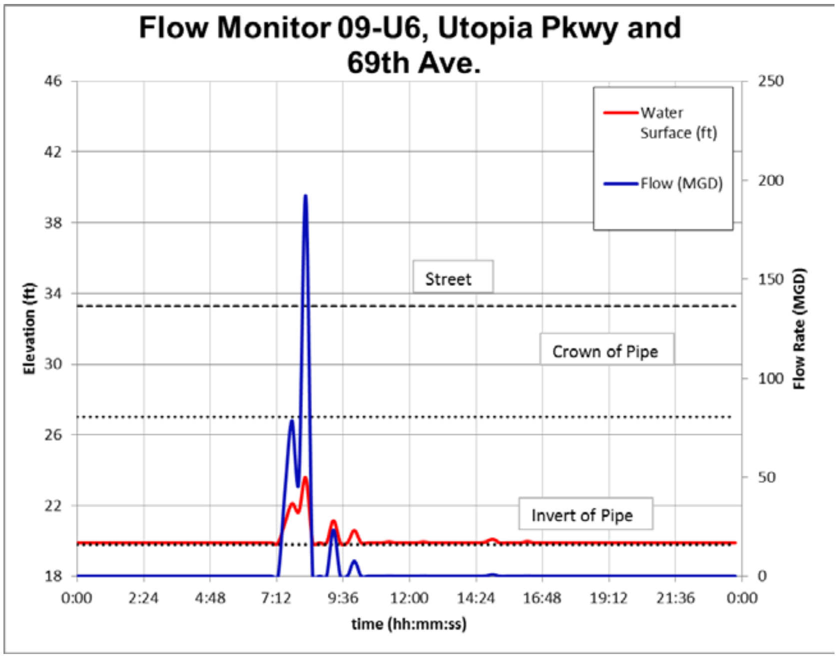


Figure D6: Elevation of water and flow rate in pipe at meter location 09-U7.

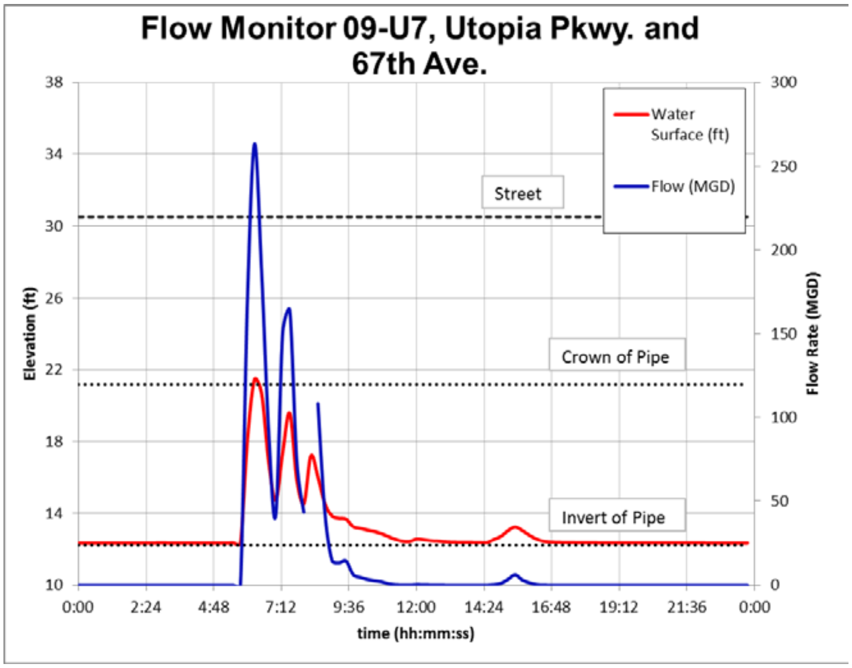


Figure D7: Elevation of water and flow rate in pipe at meter location 09-U8.

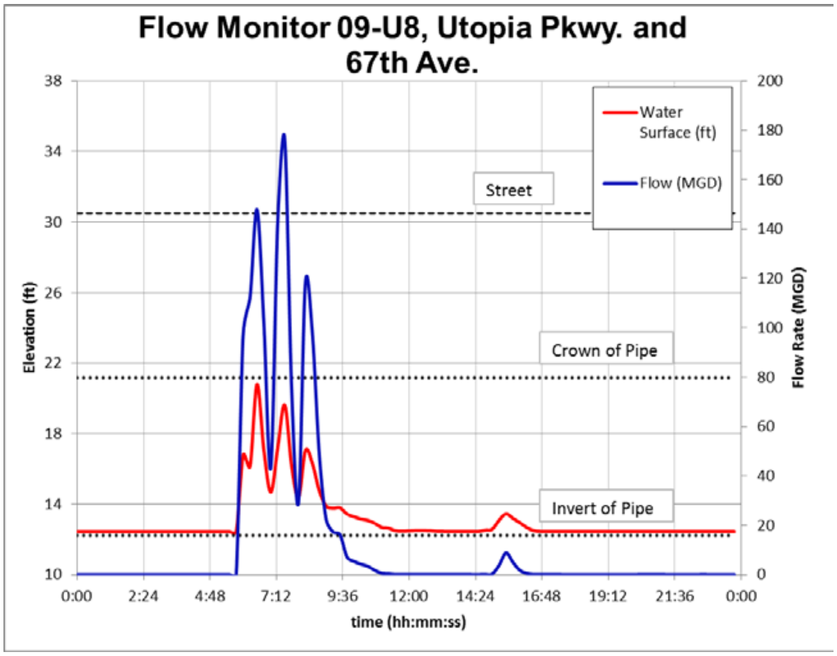


Figure D8: Elevation of water and flow rate in pipe at meter location 09-U9.

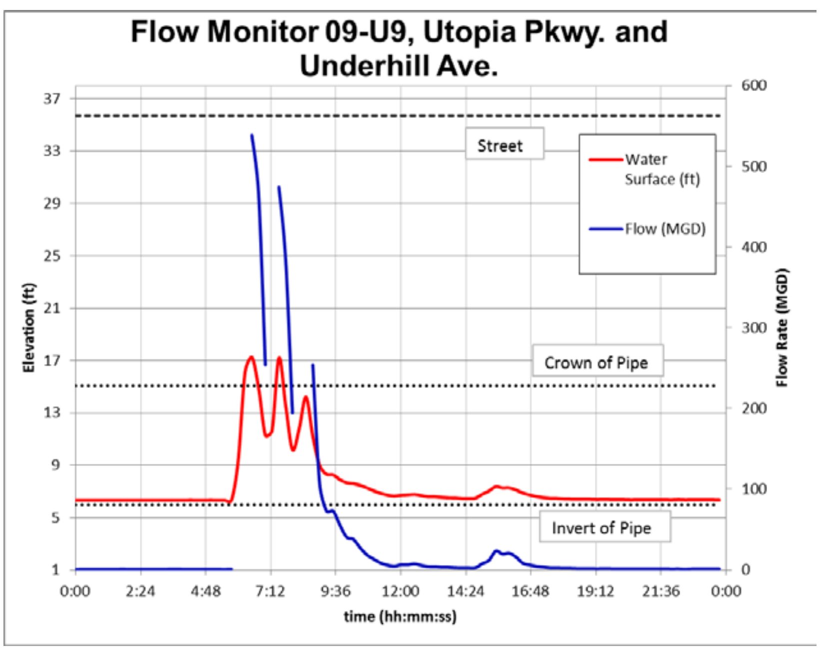


Figure D9: Elevation of water and flow rate in pipe at meter location 09-U10.

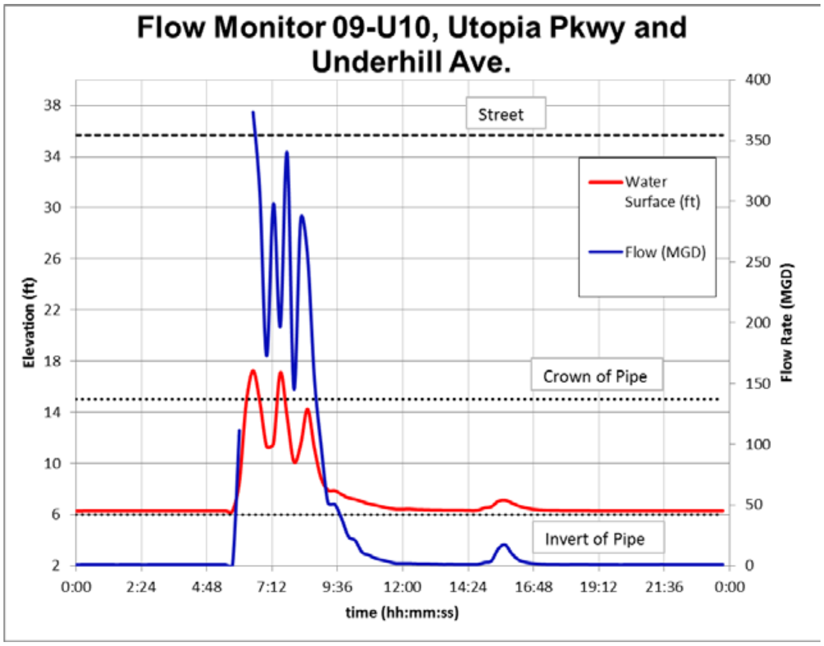


Figure D10: Elevation of water and flow rate in pipe at meter location 09-U11.

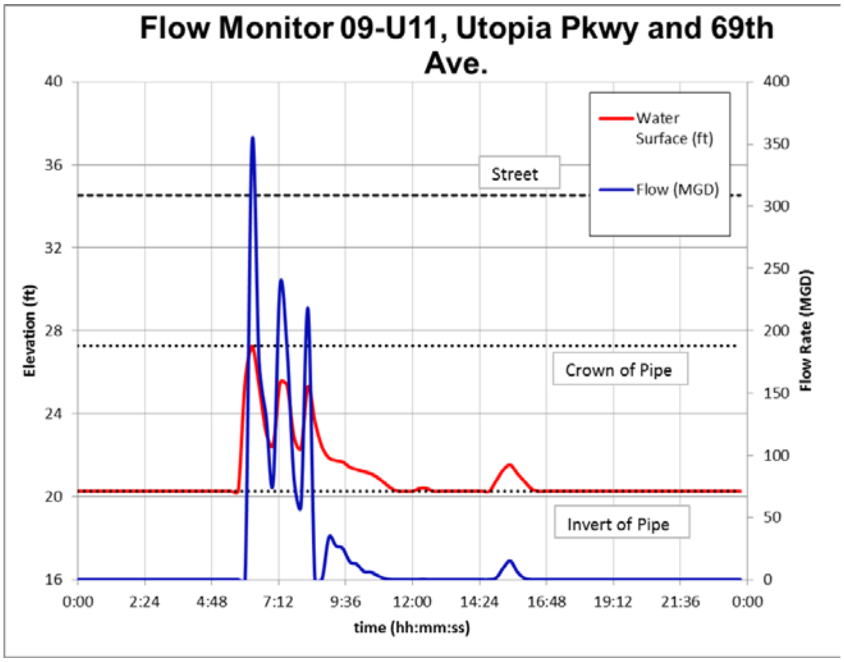


Figure D11: Elevation of water and flow rate in pipe at meter location 09-U12.

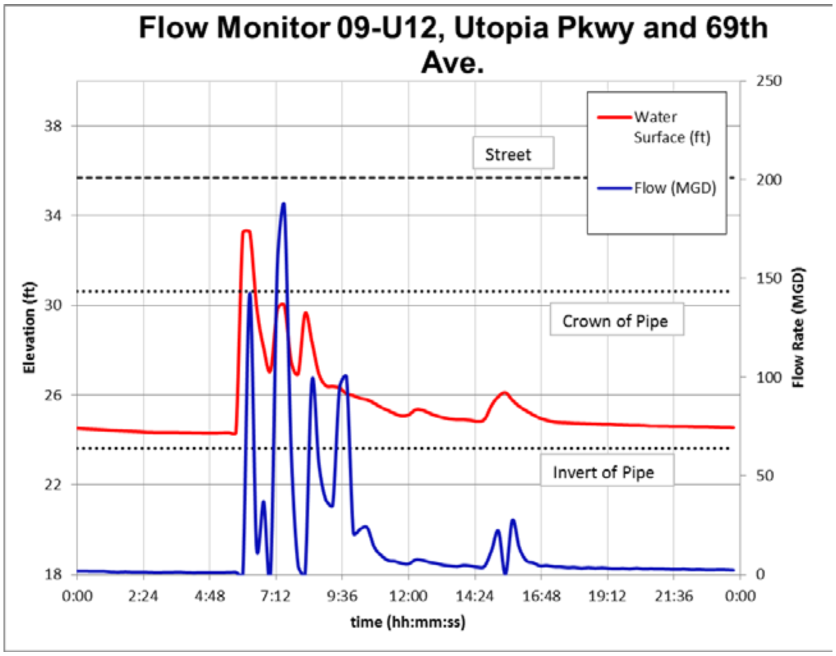


Figure D12: Elevation of water and flow rate in pipe at meter location 09-U13.

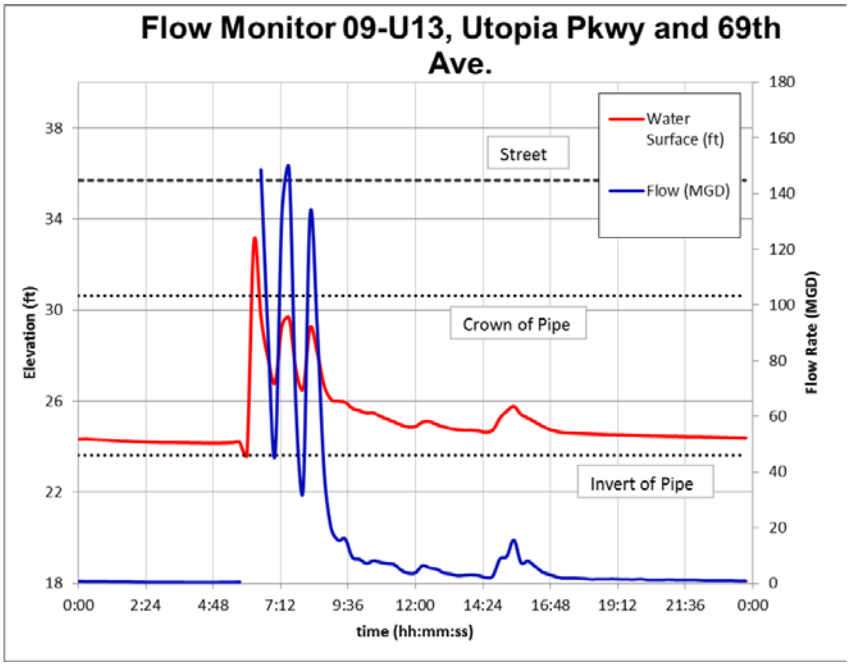
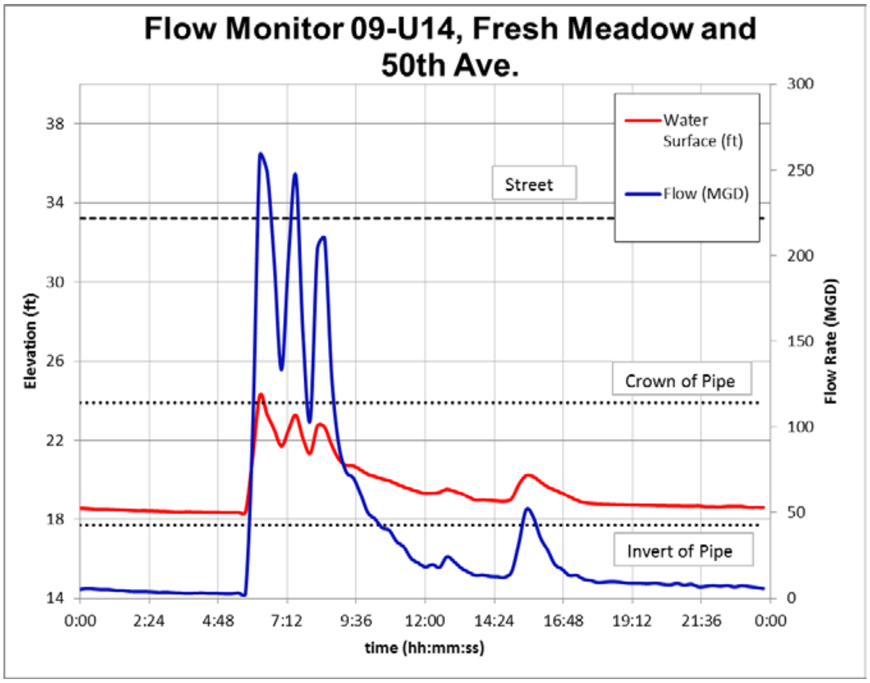


Figure D13: Elevation of water and flow rate in pipe at meter location 09-U14.



APPENDIX E: WET WEATHER FLOW HYDROGRAPHS FOR THE J-BASIN, 10/01/10 STORM

Note: Dotted lines indicate street elevation, crown of pipe and pipe invert for all plots in this appendix.

Figure E1: Elevation of water and flow rate in pipe at meter location 09-J1.

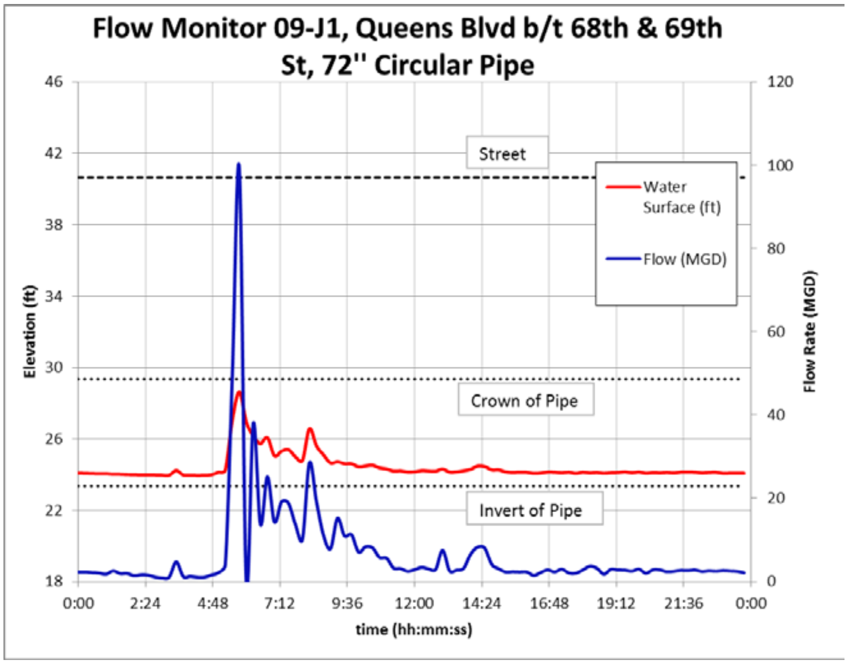


Figure D2: Elevation of water and flow rate in pipe at meter location 09-J2.

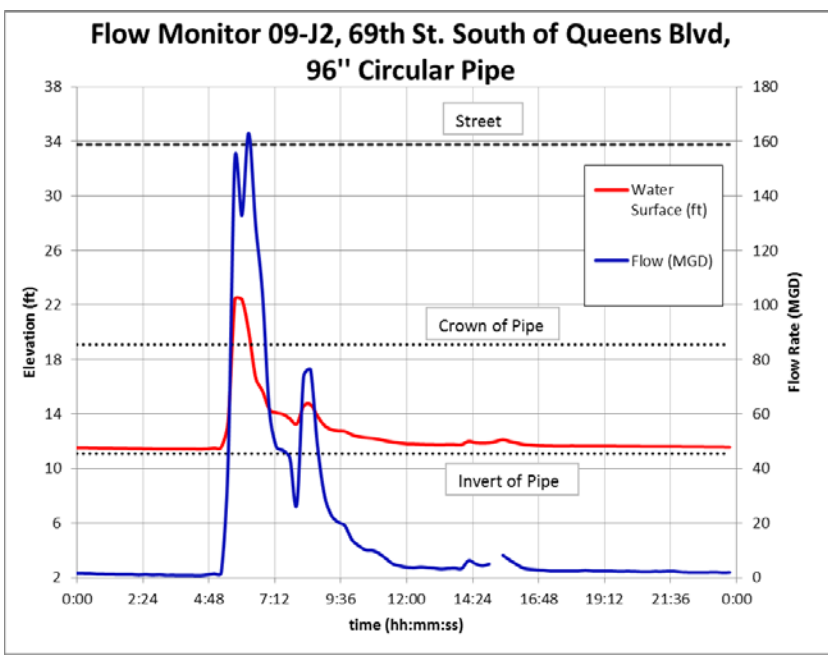


Figure E3: Elevation of water and flow rate in pipe at meter location 09-J3.

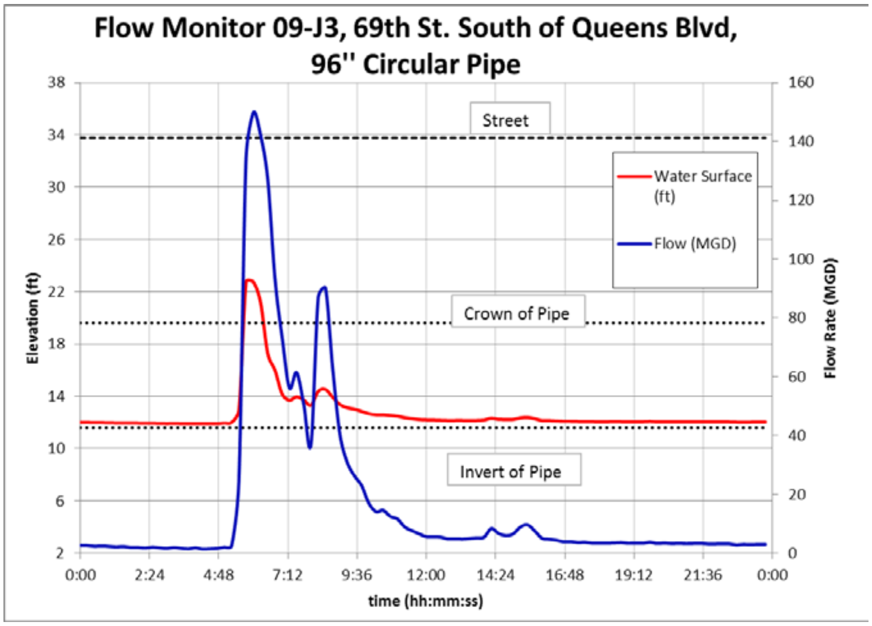


Figure E4: Elevation of water and flow rate in pipe at meter location 09-J4.

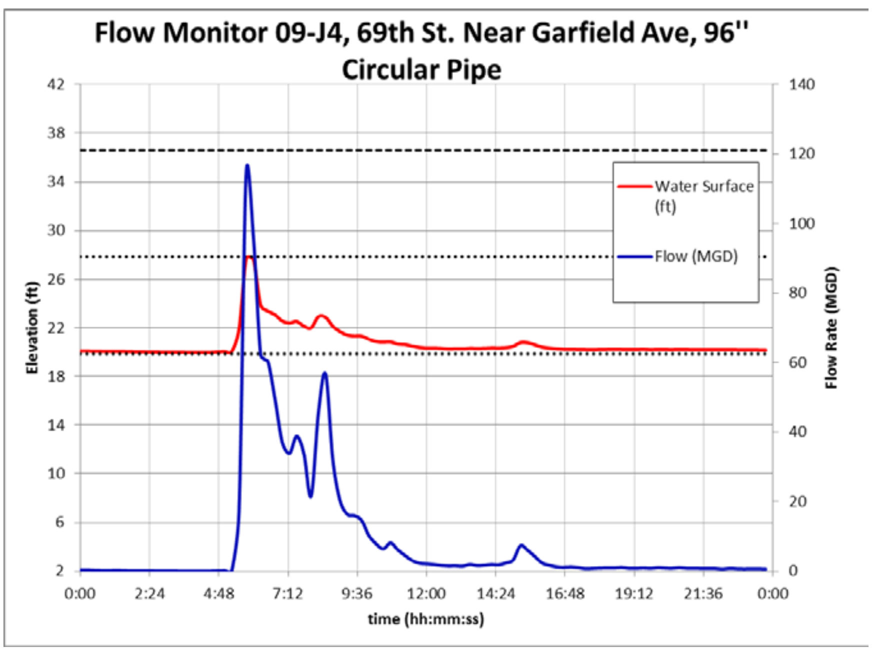


Figure E5: Elevation of water and flow rate in pipe at meter location 09-J5.

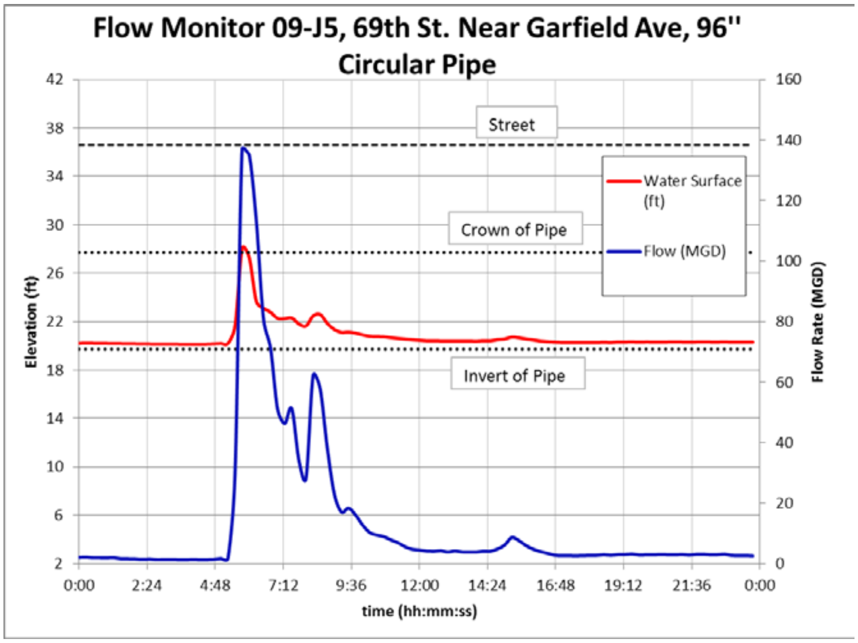


Figure E6: Elevation of water and flow rate in pipe at meter location 09-J6.

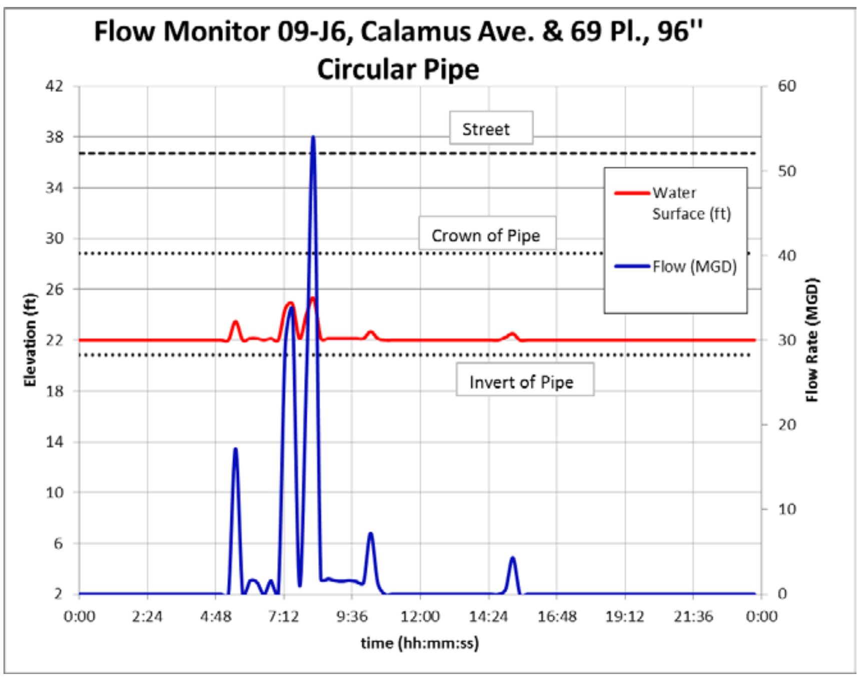


Figure E7: Elevation of water and flow rate in pipe at meter location 09-J7.

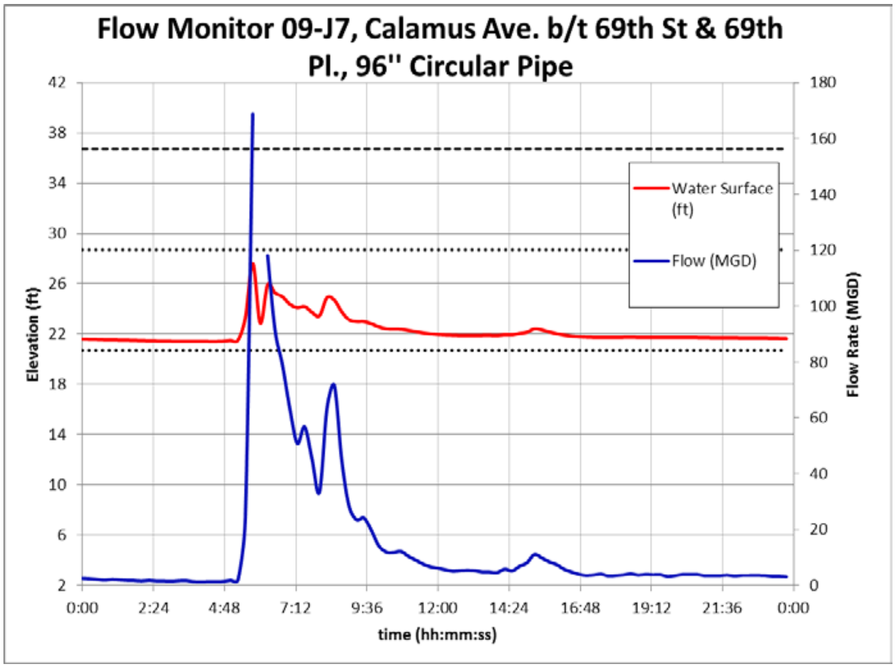


Figure E8: Elevation of water and flow rate in pipe at meter location 09-J8.

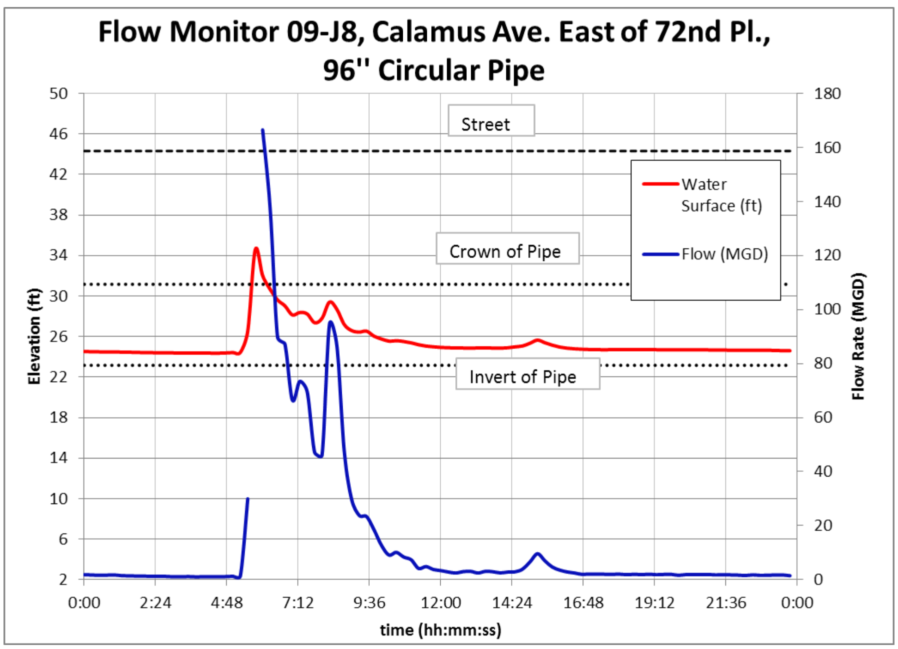


Figure E9: Elevation of water and flow rate in pipe at meter location 09-J9.

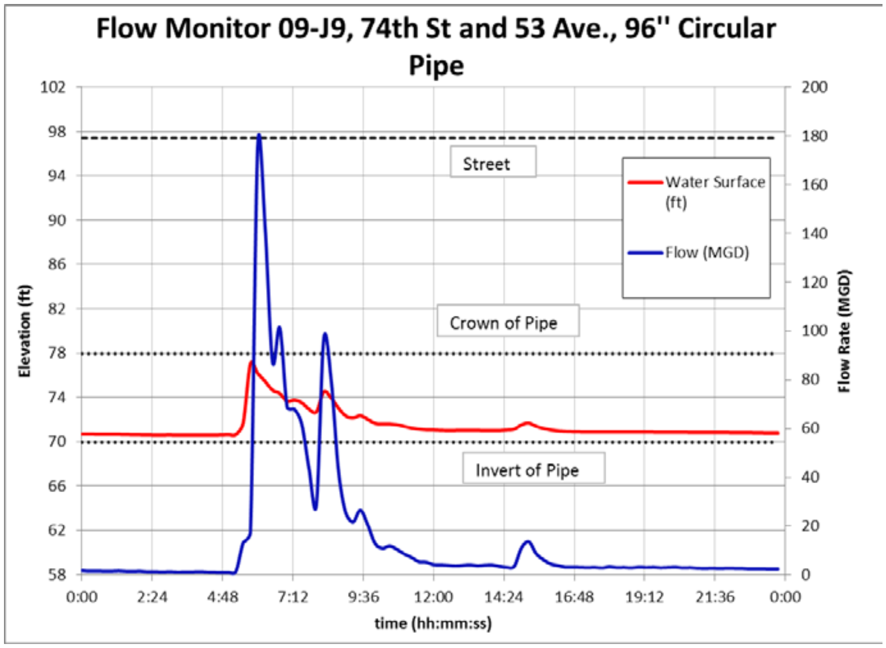


Figure E10: Elevation of water and flow rate in pipe at meter location 09-J10.

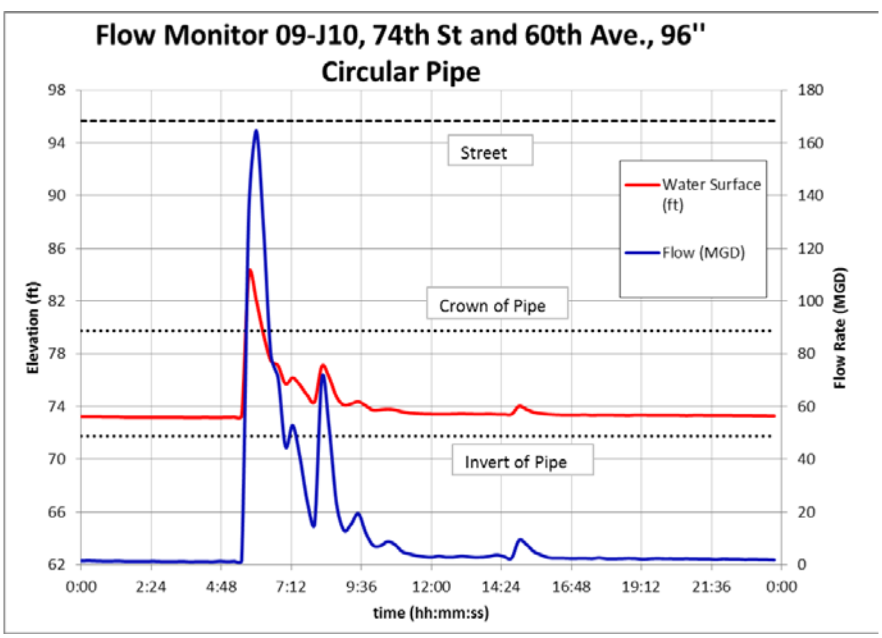
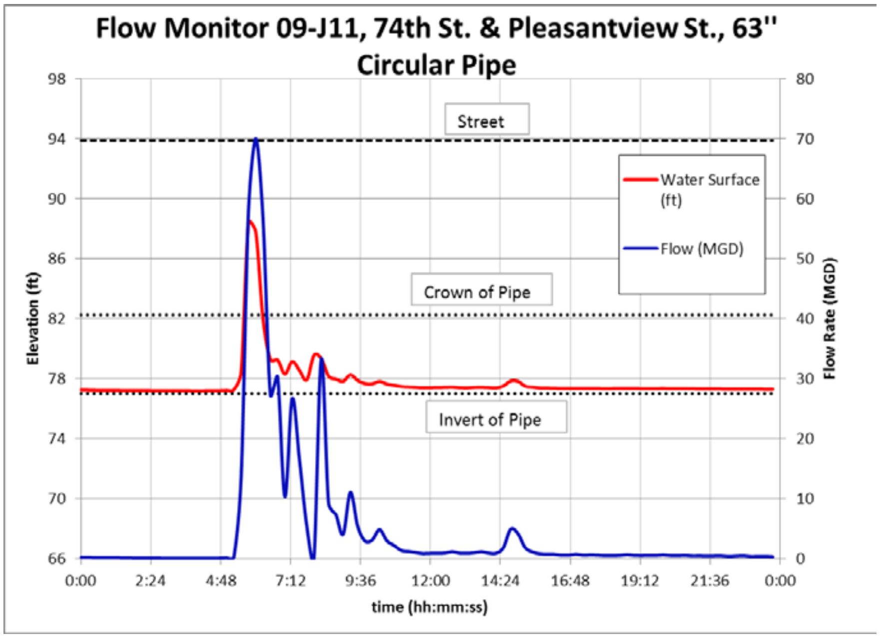


Figure E11: Elevation of water and flow rate in pipe at meter location 09-J11.



APPENDIX F: WET WEATHER FLOW HYDROGRAPHS FOR THE P-BASIN, 10/01/10 STORM

Note: Dotted lines indicate street elevation, crown of pipe and pipe invert for all plots in this appendix.

Figure F1: Elevation of water and flow rate in pipe at meter location 09-P1.

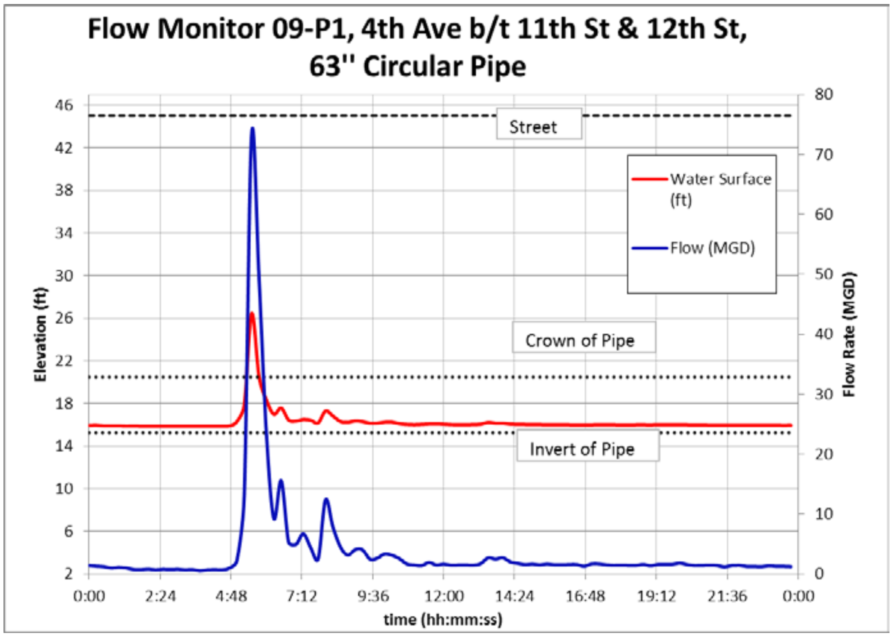


Figure F2: Elevation of water and flow rate in pipe at meter location 09-P2.

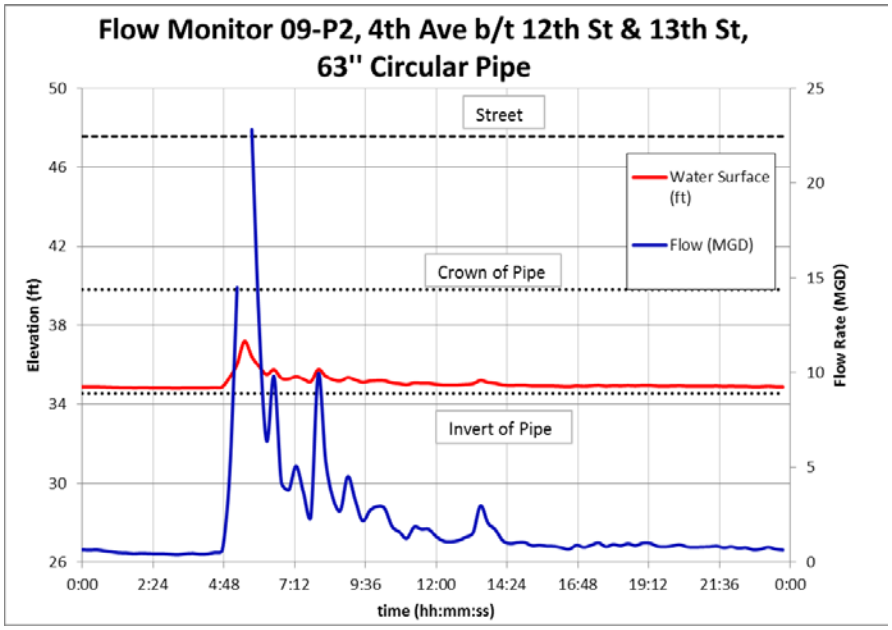


Figure F3: Elevation of water and flow rate in pipe at meter location 09-P3.

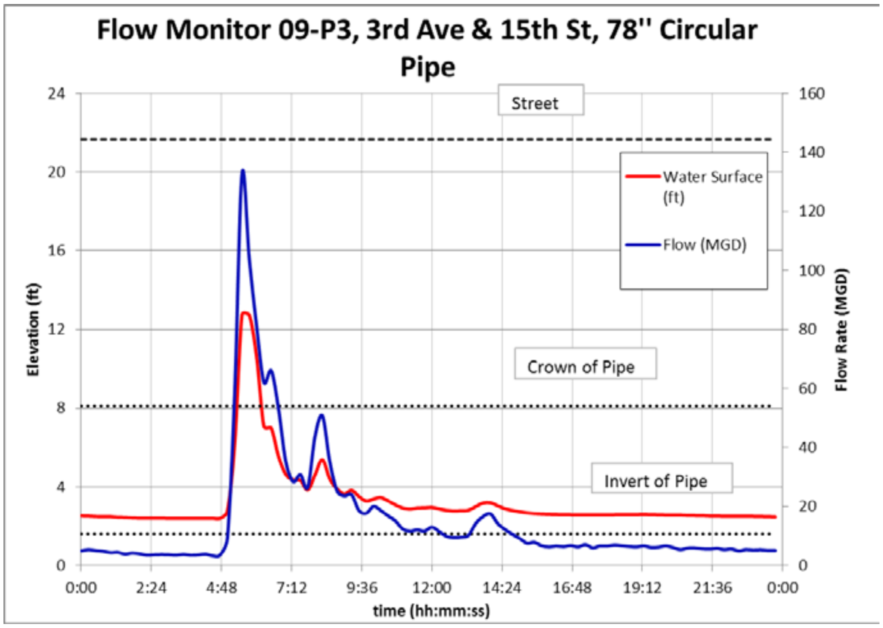


Figure F4: Elevation of water and flow rate in pipe at meter location 09-P4.

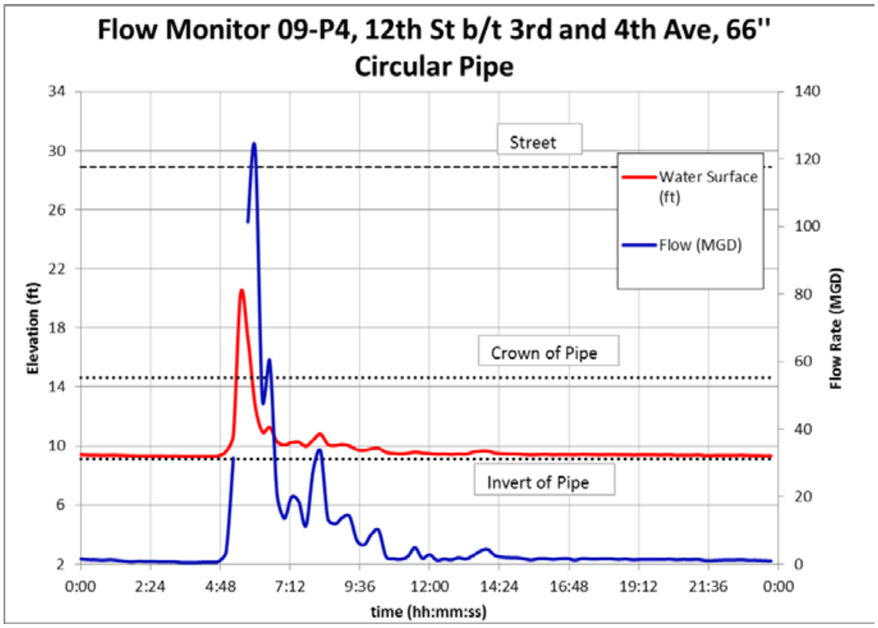


Figure F5: Elevation of water and flow rate in pipe at meter location 09-P5.

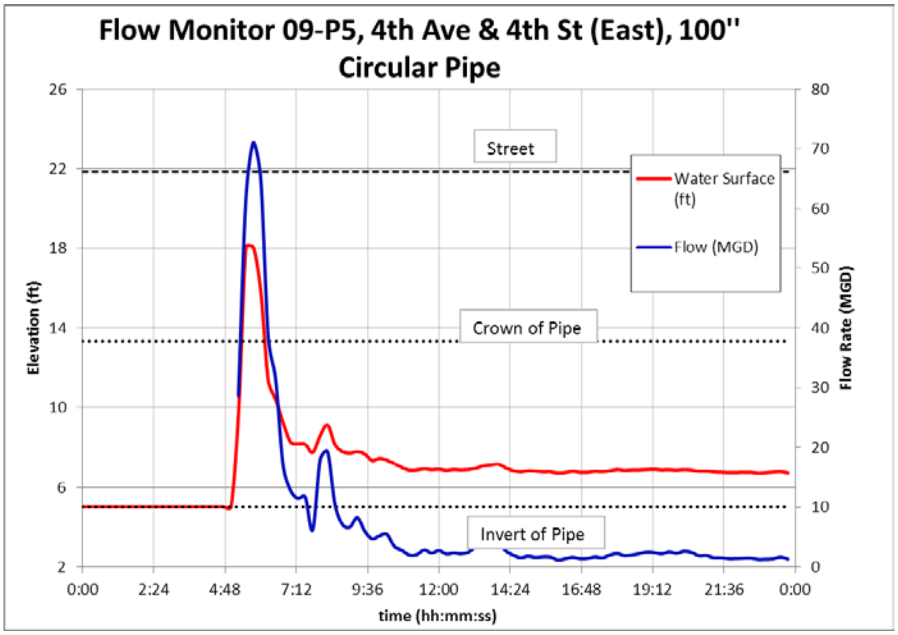


Figure F6: Elevation of water and flow rate in pipe at meter location 09-P6.

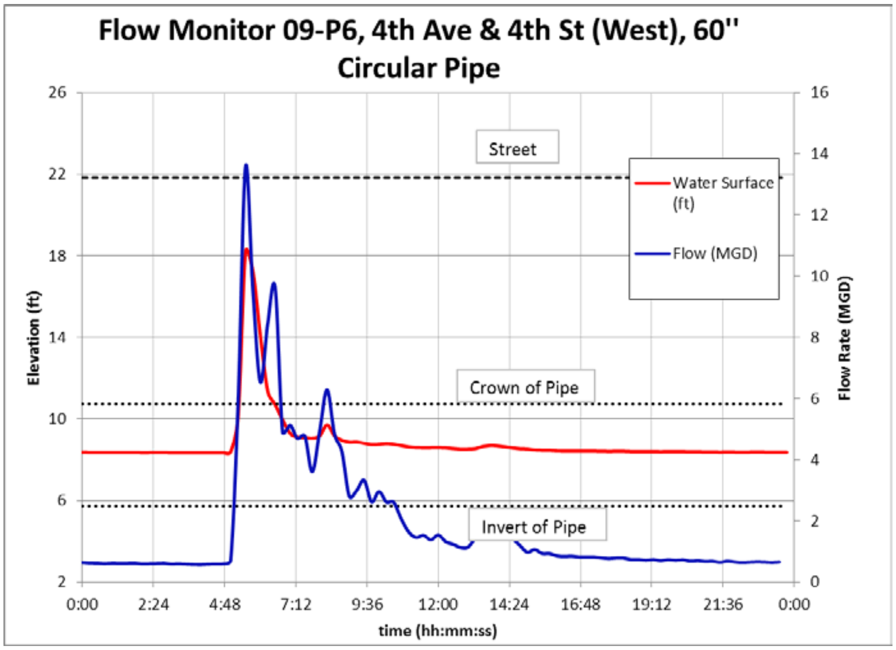


Figure F7: Elevation of water and flow rate in pipe at meter location 09-P7.

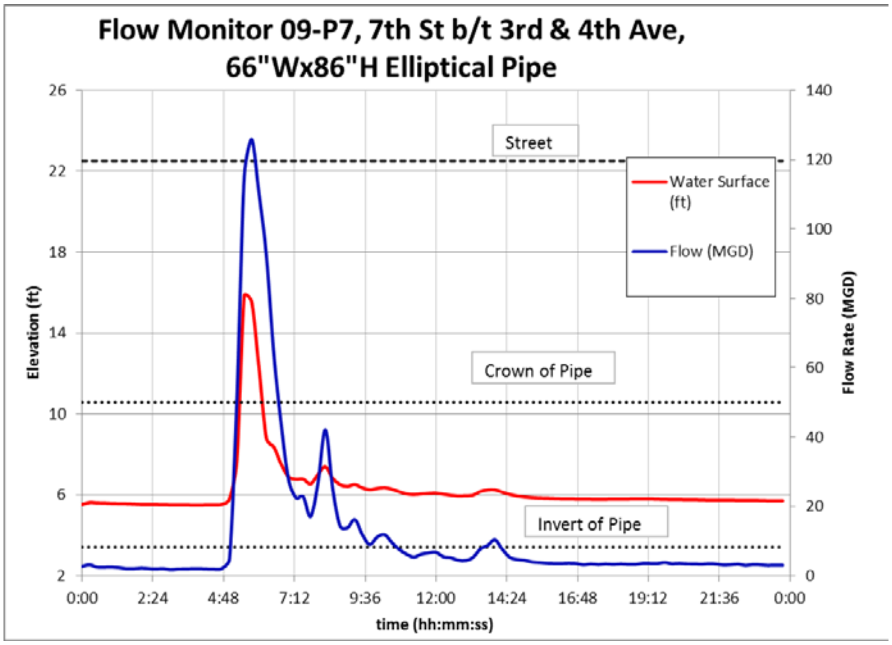


Figure F8: Elevation of water and flow rate in pipe at meter location 09-P8.

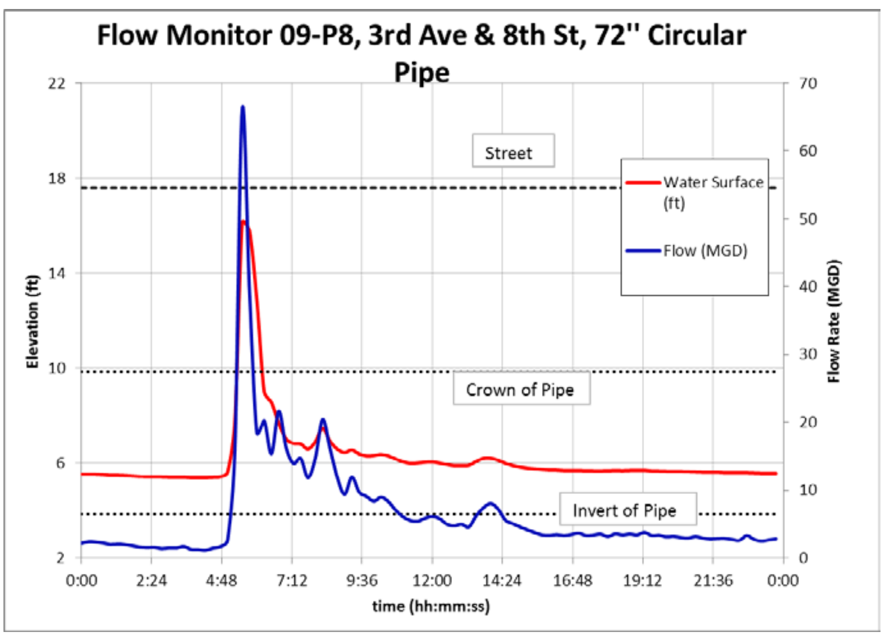


Figure F9: Elevation of water and flow rate in pipe at meter location 09-P9.

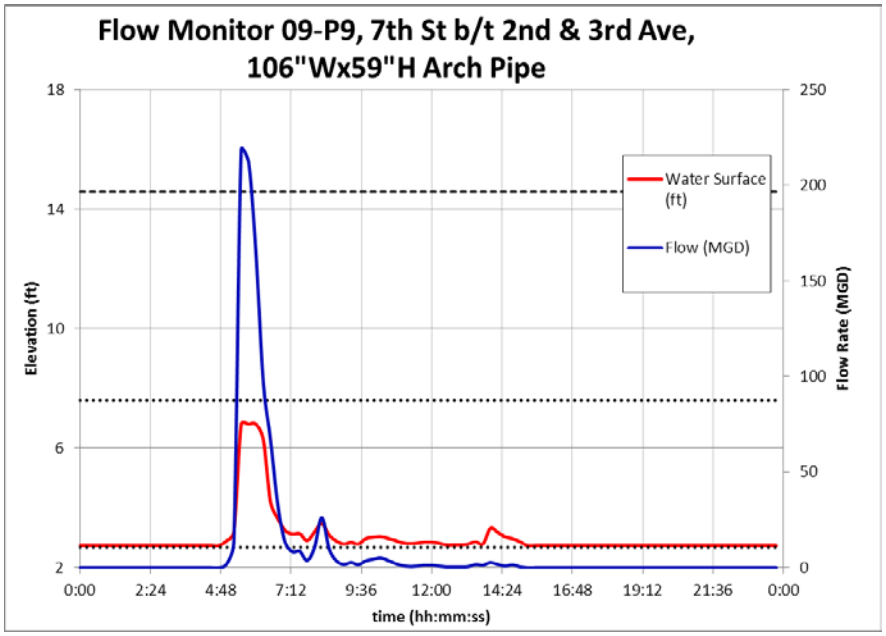


Figure F10: Elevation of water and flow rate in pipe at meter location 09-P10.
(Note: no data available at this site on October 1, 2010)