HY-12 STORM DRAIN SOFTWARE COMPARISON STUDY

by

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GRADUATE COMMITTEE APPROVAL

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ABSTRACT

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The United States Federal Highway Administration (FHWA) has commissioned the creation of a new storm drain design software title referred to as HY-12. The program is intended to replace the previous software HYDRA. To ensure that the HY-12 program meets the design criteria set forth by the FWHA, several benchmark examples were created and compared between the two programs. From the comparative study, it was found that HY-12 provided valid solutions for a rational method design with a design difference between the software titles between zero and six inches. This difference is within the acceptable design limit and was found to be conservative. The hydrograph analysis is still currently under development and the results do not compare. From the findings of this study, the HY-12 program is acceptable for rational design but needs further comparative examples for hydrographic analysis.

ACKNOWLEDGMENTS

I would like to acknowledge Dr. E. James Nelson for advising my project and providing guidance for the HY-12 program. I would like to thank those at Aquaveo, namely Chris Smemoe, Eric Jones, and Clark Barlow, who provided assistance and instruction on using the HY-12 program. A special thank you is due to Daniel Woodbury from Sandy City for providing the data for the Falcon Way project.

Lastly I would like to thank my wife for supporting me through getting my degree. She has long been a support to me in my academic endeavors.

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1 Introduction

The United States Federal Highway Administration (FHWA) has commissioned the creation of a new storm drain design software title referred to as HY-12. The program is intended to replace the previous software HYDRA. To ensure that the HY-12 program meets the design criteria set forth by the FWHA, several benchmark examples were created and compared between the two programs. This report presents the results of the comparison study and the validity of the HY-12 program results.

1.1 HEC-22

The Federal Highway Administration (FHWA) has created the Hydraulic Engineering Circular 22 (HEC-22) document to provide guidelines for highway hydraulic design. Chapter 7 of the manual addresses the urban drainage design and storm drains. There are two design methods that are used to size storm drain pipes; gravity or open channel flow and pressure flow. For gravity flow, Manning's equation is used to calculate the velocity and diameter of the pipe. The Manning's n is used to calculate any head loss within the pipe and must be obtained from selected tables. The manual uses the rational method to calculate the required flow to pass through the pipe during design. The equations used in this manual were programmed into the HY-12 program to determine the necessary losses and pipe sizes.

1.2 HDS-2

The Hydraulic Design Series 2 (HDS 2) is used to determine hydrology methods of interest for highway hydraulic design. The primary interest is the frequency storms and the rainfall runoff expected to determine discharge. It describes the rational method that is commonly used and it also describes the hydrograph method. In addition to the rainfall determination, it uses select routing methods as it relates to highway drainage design. These equations and methods are employed in the HY-12 program to design and analyze storm drain pipe diameters.

1.3 HDS-4

The Hydraulic Design Series 4 (HDS 4) describes the hydraulic characteristics of overland flow on highways. These hydraulic characteristics include the orifice, weir, continuity, energy and momentum. The hydraulic equations describe how the water flows over the road surface and how it best enters the curb and gutter inlets. As the water travels across the roadway surface, it will experience certain losses and the HY-12 program used the methods described in this document to determine the expected overland flow rates and how they will enter the gutter inlets. These equations are used to find any losses within the system and determine how much flow will enter into the storm drain pipe.

2 Methods

Several HYDRA examples were provided by the FHWA and a corresponding HY-12 file was created for comparison. In addition to the standard examples, an actual project was designed using both programs for comparison.

2.1 HY-12 File Creation

Using the file creation templates created by the HY-12 programmer, each file was created traveling upstream from the outlet. This provided for an organized file and created links between each downstream item. For the purposes of this comparative study, a total of ten sample HY-12 files were created.

The first HY-12 files created were based on the HYDRA tutorial files included in the WMS tutorial. These samples included a rational method design and a hydrograph analysis for a storm drain system. The flow conditions were designed to be under gravity flow for both the examples. The following figures show the basic schematic used in the construction and creation of the HY-12 file:

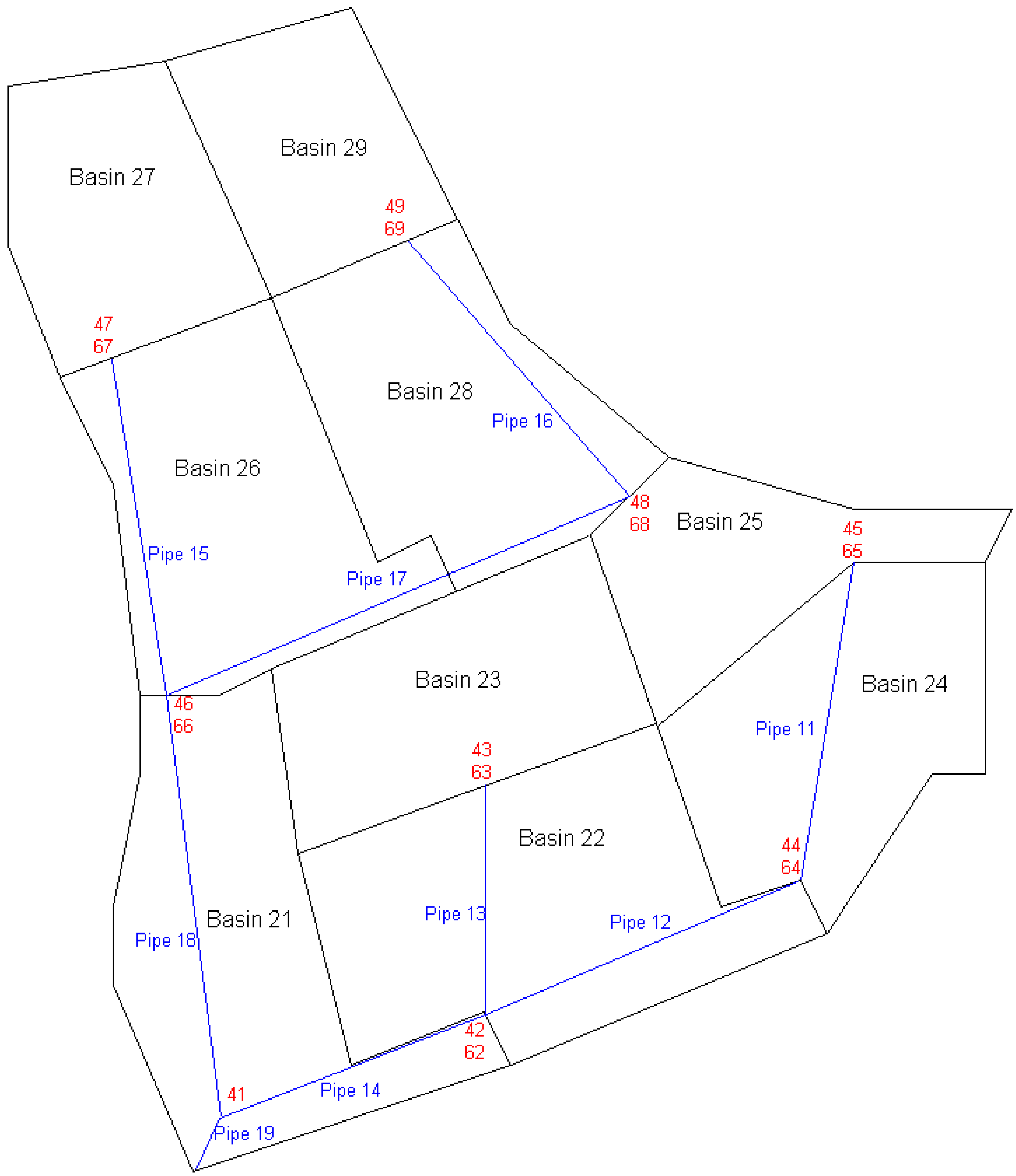

Figure 1. WMS Rational Tutorial Schematic

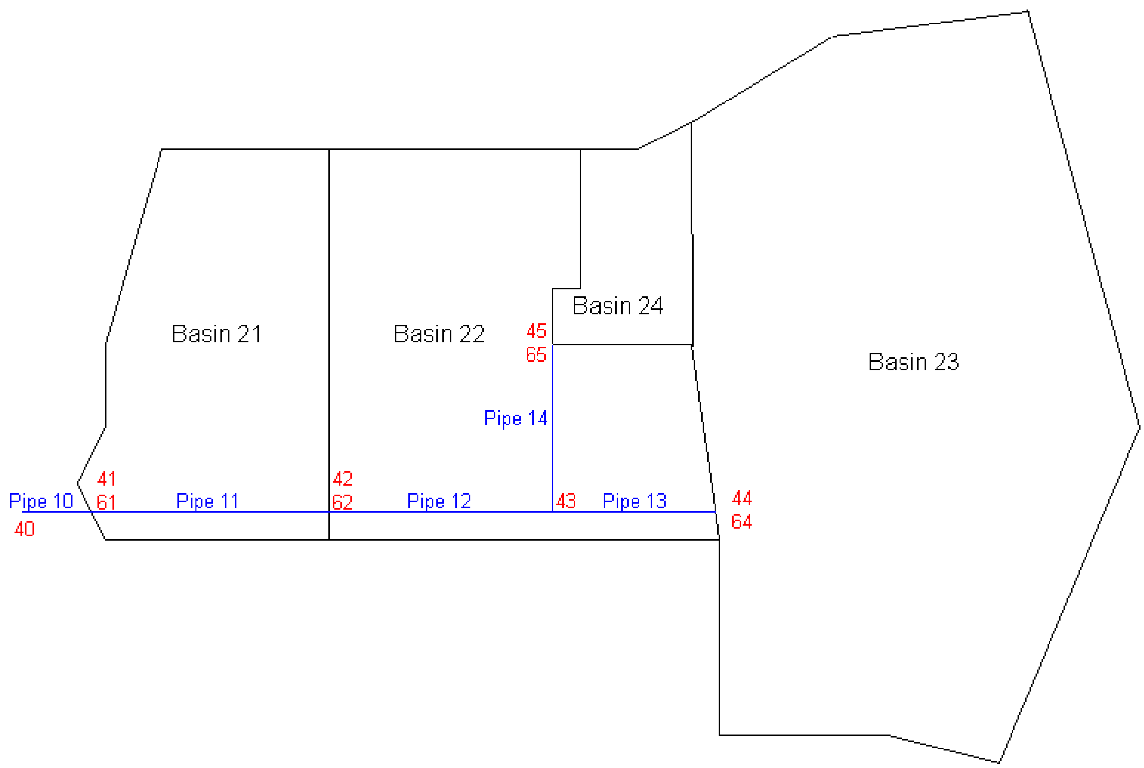

Figure 2. WMS Hydrograph Tutorial Schematic

Following the construction of these two files, a representative for Federal Highways requested that seven additional HYDRA tutorials be converted and compared. Each of the seven examples were written into an HY-12 format and checked for validity. The first HYDRA example was a simple rational method design assuming gravity flow through the entire storm drain network. The second HYDRA example used the same network as the first example and performed an analysis with pressure flow. The following figure shows the pipe network for the first two HYDRA example problems:

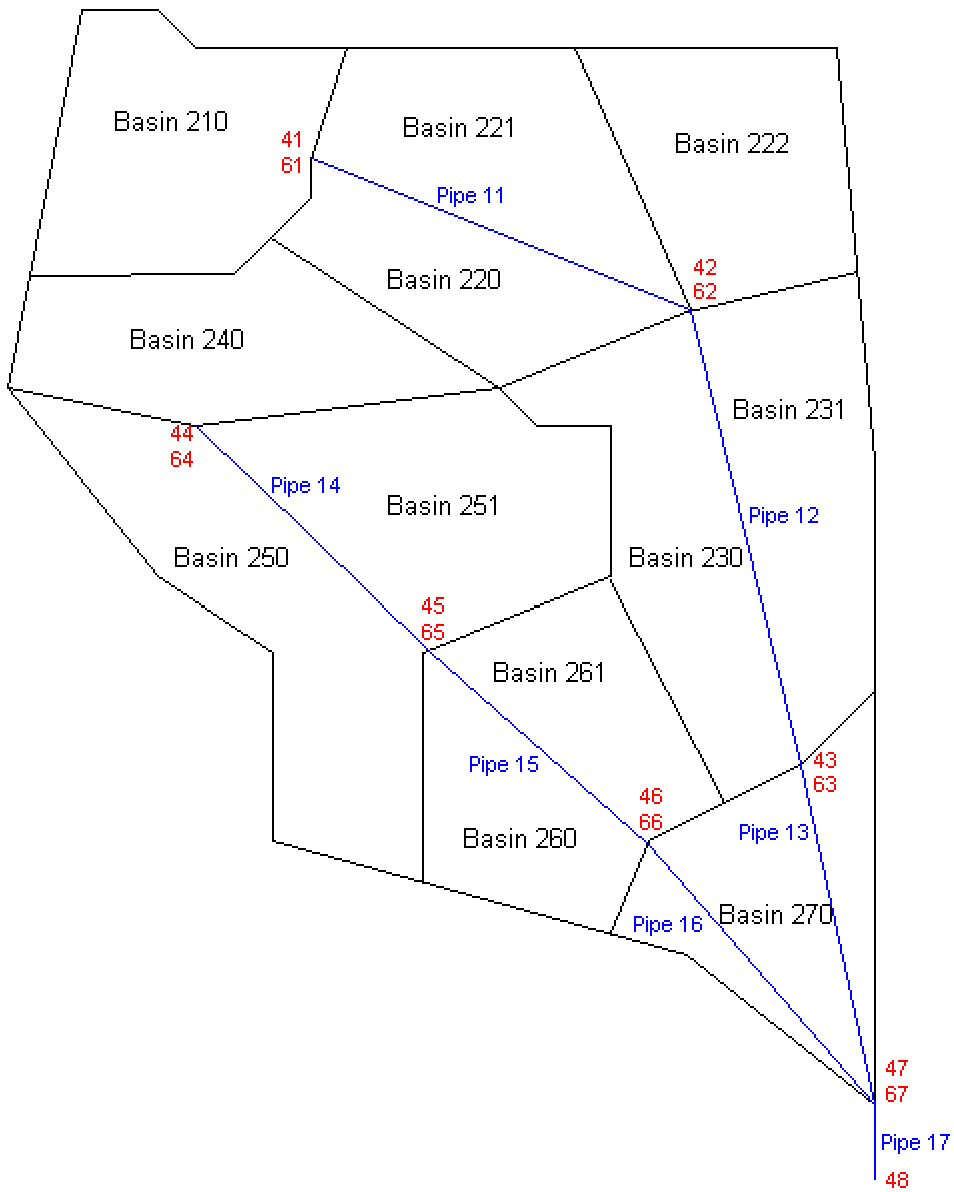

Figure 3. HYDRA Example 1 & 2 Schematic

The third HYDRA example was a hydrographic simulation analysis for a typical neighborhood storm drain network. The example assumed the same hydrograph would occur at each of the inlets located within the network. The example included more advanced elements such as gutter flow and a storage reservoir before the outfall. The following figure shows the basic schematic used in the example:

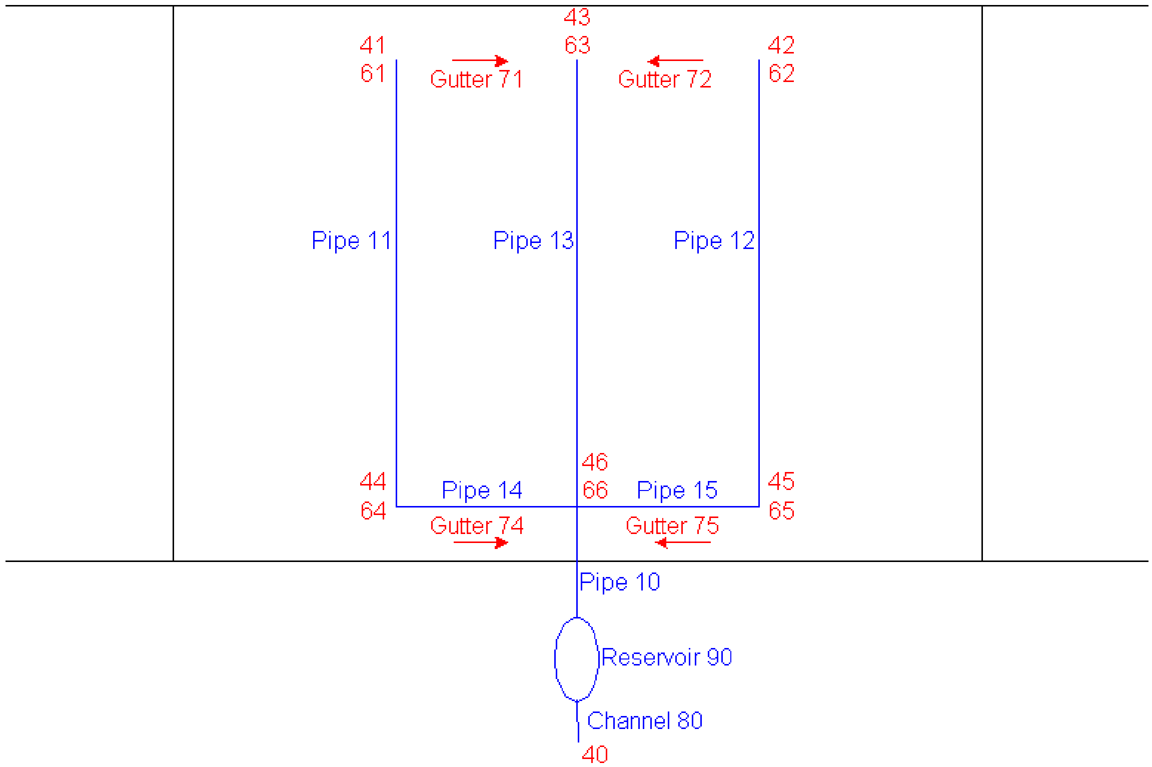

Figure 4. HYDRA 3 Example Schematic

The fourth HYDRA example was a hydrographic analysis and pressure flow simulation. Each gutter inlet had a specified hydrograph and pipes were kept the same size to allow for pressure flow to develop. The following figure shows the schematic used for the analysis:

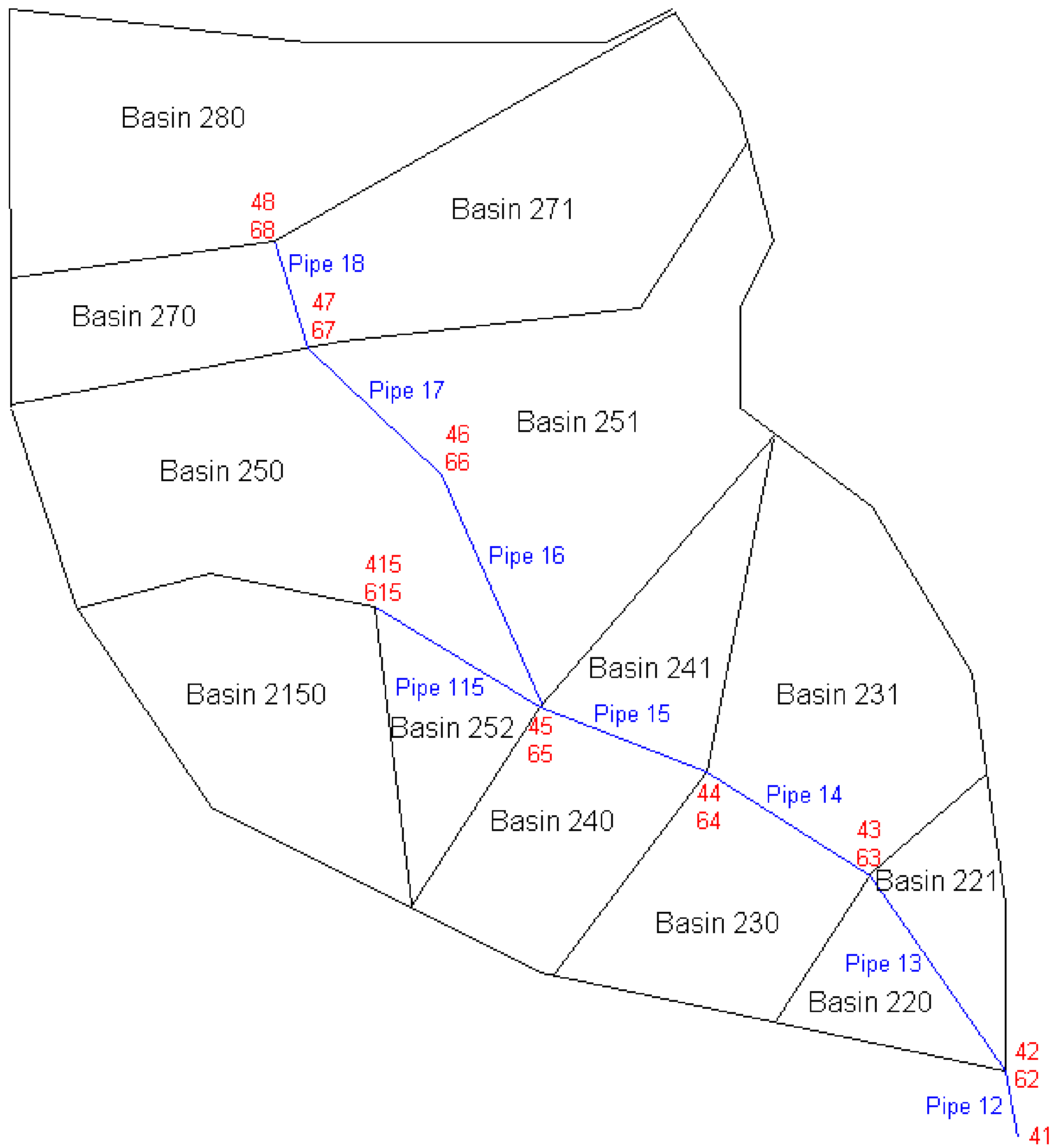

Figure 5. HYDRA Example 4 Schematic

It was determined that the final three HYDRA examples were not valid for comparison as they design sanitary flow systems which is outside the requirement for HY-12.

In addition to the theoretical tutorial files, a real world design comparison was requested by the software designer. After collaboration with the storm drain manager for Sandy, Utah, we determined that the HY-12 software was a good candidate for design of a replacement storm drain system. The data was obtained from Sandy City and a HYDRA and HY-12 design were completed and compared. For each of the examples, an object ID was created manually for each pipe, access hole, gutter inlet, gutter, and basin. The following schematic illustrates the outline of the storm drain system and corresponding basins:

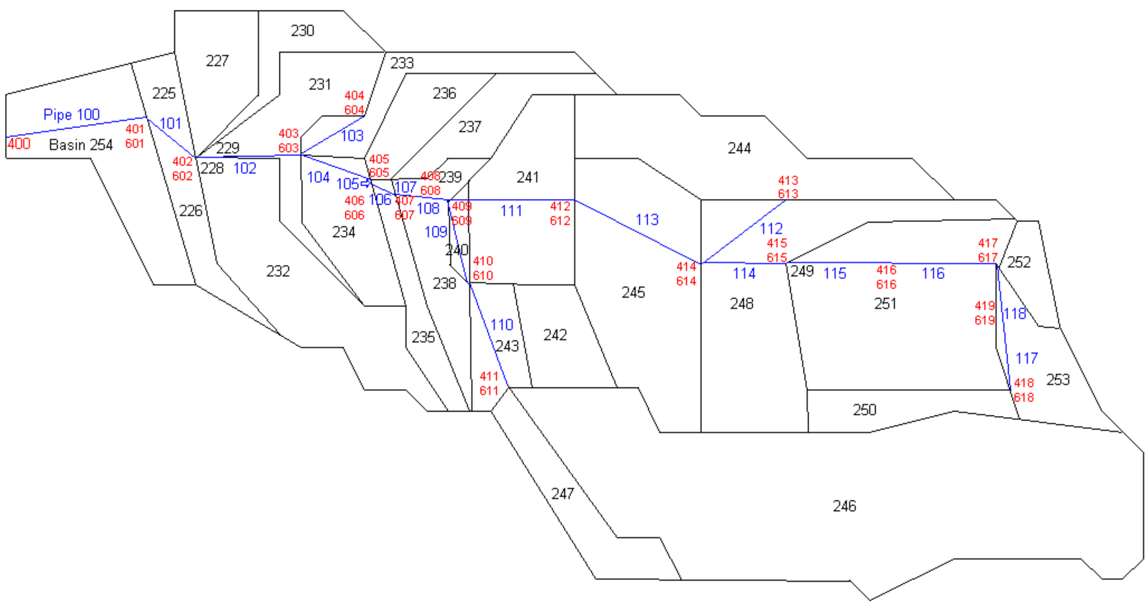

Figure 6. Sandy City Storm Drain Schematic

These identifying IDs were used to link upstream and downstream features. From the information found in the HYDRA files, the properties of each feature were matched identically. The Hydraulic Toolbox was used to create the proper format for these feature attributes. The Hydraulic Toolbox is a computer program that performs many of the calculations routinely done by highway hydraulic engineers and roadway designers. It was written and created for FHWA by Aquaveo.

For design purposes, each pipe was allowed to carry its maximum capacity flow. The minimum pipe size allowed for each example was 6” in diameter. A tutorial is provided in the Appendix that gives a more step-by-step explanation of how an HY-12 file is created.

3 Results

The HYDRA example files were run and compared to the HY-12 examples for any semblance in the results. Each file is presented separately and reported for comparison. For purposes of this study, the results were accepted if they were within 10% of each other. If the results varied more than this, an explanation is provided for acceptance or rejection of the results.

3.1 WMS Tutorial Files

The first files that were compared are the HYDRA tutorial files that are created using the WMS Tutorial Manual 8.3. The WMS manual provides a rational method design and a hydrograph design example. Each of the tutorials was completed and an HY-12 file was created for comparison.

3.1.1 Rational Method Tutorial

The WMS HYDRA rational tutorial did not specify any curb or gutter requirements and each gutter inlet was assumed to catch all of the runoff. Because inlet properties were not specified in HYDRA, full capture assumption was made in HY-12 and provides for a worst case scenario. Table 1 and Table 2 compare the pipe size, flow, velocity, and hydraulic grade line results of the HYDRA tutorial file and the HY-12 file:

Table 1. WMS Rational Tutorial Comparison Results

	HYDRA	HY-12		HYDRA	HY-12	
	Diameter (in)		%Difference	Flow (cfs)		%Difference
Pipe 11	9	8	11.1%	1.27	1.26	0.8%
Pipe 12	12	12	0.0%	3.16	3.13	0.9%
Pipe 13	12	10	16.7%	1.82	1.81	0.5%
Pipe 14	15	15	0.0%	6.26	6.43	-2.7%
Pipe 15	9	9	0.0%	1.74	1.75	-0.6%
Pipe 16	9	9	0.0%	1.55	1.56	-0.6%
Pipe 17	12	12	0.0%	3.29	3.25	1.2%
Pipe 18	15	15	0.0%	6.72	6.71	0.1%
Pipe 19	21	20	4.8%	12.22	12.24	-0.2%
Outlet 40	-	-	-	12.22	14.30	-36.3%

Table 2. WMS Rational Tutorial Comparison Results (Cont)

	HYDRA	HY-12		HYDRA	HY-12	
	Velocity (ft/s)		%Difference	HGL (ft)		Difference
Pipe 11	4.4	4.27	3.0%	4508.49	4508.97	-0.48
Pipe 12	5.5	5.48	0.4%	4505.88	4505.79	0.09
Pipe 13	4.8	4.79	0.2%	4504.60	4505.40	-0.80
Pipe 14	6.4	6.47	-1.1%	4502.39	4502.55	0.06
Pipe 15	4.6	4.62	-0.4%	4500.77	4501.48	-0.71
Pipe 16	4.6	4.57	0.7%	4504.74	4505.14	-0.40
Pipe 17	5.5	5.51	-0.2%	4500.74	4501.31	-0.57
Pipe 18	6.5	6.49	0.2%	4496.82	4497.63	-0.81
Pipe 19	7.7	7.62	1.0%	4501.39	4496.52	4.87
Outlet 40	-	-	-	-	-	-

From the above results, it is observed that the results are consistent with only a few outliers. The most noticeable difference in the pipe diameter is in pipe 13. The flow captured by pipe 13 is identical in both programs and the Hydraulic Toolbox was used to verify that the 9" pipe diameter would allow for the flow to pass at the given slope. It was able to pass without any problems and is therefore an acceptable design size.

The flows at the junctions have the greatest discrepancies with differences reaching up to 36%. The final outlet flow in HYDRA does not account for the basin immediately upstream like the HY-12 program does and this is one of the main causes for the largest discrepancy. The version of HY-12 has since been updated to reflect pipe lag and due to the similarities between the newest version of HY-12 and the previous program HYDRA, the results are accepted as valid.

The methods for computing the velocities have slightly changed from HYDRA to HY-12. All are within the acceptable 10% difference. Due to the similarities between the velocities and verifying the velocities using the Hydraulic Toolbox, the results are found to be acceptable for purposes of this comparison study.

The hydraulic grade line appears to be the biggest difference in the two programs. The percent difference is not that great due to the large numbers compared but it is a noticeable difference. The outlet hydraulic grade line for pipe 19 is more correct in HY-12 than in HYDRA. The HYDRA model predicts an increase of about 5 feet while the pipe is not inverted. Additional work is needed to verify that the results from HY-12 are valid.

3.1.2 Hydrograph Method Tutorial

The HY-12 program will only allow for analysis when using the hydrograph method. For this purpose, the pipe size was not compared and only the flow and velocities are presented. Because of the changing nature of the hydrograph method, HYDRA and HY-12 does not provide a hydraulic grade line for comparison. Table 3 compares the peak flow results from the hydrograph tutorial:

Table 3. WMS Hydrograph Tutorial Comparison Results

	HYDRA	HY-12		HYDRA	HY-12	
	Flow		%Difference	Velocity		%Difference
Pipe 1--13	12.58	16.89	-34.3%	8.3	7.02	15.4%
Pipe 2--14	12.58	4.81	61.8%	8.3	2.00	75.9%
Pipe 3--12	22.35	16.56	25.9%	9.5	5.27	44.5%
Pipe 4--11	34.68	29.69	14.4%	10.5	7.47	28.9%
Pipe 5--10	40.43	34.68	14.2%	11.0	8.42	23.5%
Outlet 40	-	-	-	-	-	-

The hydrographic flow models are very different in their results as illustrated above. Because the flow is different by such a great amount, the velocity is also different. The elevations provided in the HYDRA tutorial create different slopes between the two programs. The cause for the slope difference between the programs is not known. The HY-12 file was altered to match the new slopes calculated by HYDRA and this created a dramatic change in the flows as illustrated in the above tables. Further investigation is required to verify that the HY-12 results are valid.

3.2 HYDRA Benchmark Files

The HYDRA manual has provided seven examples on the functions that the program can perform. The first four are concerned with storm drain design while the final three deal with sanitary flow. Because HY-12 was not designed to handle sanitary flow, only the first four HYDRA examples were compared with HY-12.

3.2.1 Example 1

The HYDRA Example 1 uses the rational method to design the pipes within the system. The HYDRA example did not specify any curb or gutter requirements and each gutter inlet was assumed to catch all of the runoff. The full capture assumption was made in HY-12 and provides for a worst case scenario. Table 4 and Table 5 compare the pipe size, flow, velocity, and hydraulic grade line results of the HYDRA tutorial file and the HY-12 file:

Table 4. HYDRA Example 1 Comparison Results

	HYDRA	HY-12		HYDRA	HY-12	
	Diameter (m)		%Difference	Flow (cms)		%Difference
Pipe 11	0.45	0.45	0.0%	0.142	0.14	1.4%
Pipe 12	0.75	0.75	0.0%	0.949	1.05	-10.6%
Pipe 13	1.35	1.35	0.0%	1.492	1.50	-0.5%
Pipe 14	0.375	0.375	0.0%	0.306	0.31	-1.3%
Pipe 15	1.2	1.15	4.2%	0.983	0.99	-0.7%
Pipe 16	1.35	1.35	0.0%	1.565	1.55	-1.0%
Pipe 17	1.8	1.7	5.6%	3.026	3.03	-0.1%
Outlet 40	-	-	-	3.026	3.03	-0.1%

Table 5. HYDRA Example 1 Comparison Results (Cont)

	HYDRA	HY-12		HYDRA	HY-12	
	Velocity (m/s)		%Difference	HGL		Difference
Pipe 11	1.166	1.17	-0.3%	57.57	57.65	-0.08
Pipe 12	2.763	2.80	-1.3%	55.05	55.04	0.01
Pipe 13	1.33	1.33	0.0%	54.73	54.63	0.10
Pipe 14	3.687	3.69	-0.1%	55.42	55.33	0.09
Pipe 15	1.209	1.20	0.7%	54.93	54.84	0.08
Pipe 16	1.338	1.34	-0.1%	54.73	54.70	0.03
Pipe 17	1.597	1.57	-1.7%	54.47	54.56	-0.09
Outlet 40	-	-	-	-	-	-

From the above results, it is observed that the results are consistent with only a few outliers. The most noticeable difference in the pipe diameter is in pipe 17. The flow captured by pipe 17 is nearly identical between the programs and the difference is caused by the available pipe size options within each program. The version of HY-12 has computed the pipe lag times and the newest methods from the FHWA manuals have been implemented. Because the new methods in HY-12 match the older results of the HYDRA program, the results are accepted as valid.

Because the flows are slightly different, the calculated velocities reflect a difference. All but one is within the acceptable 10% difference. Due to the small numbers, the difference is minimal while making the percent difference larger. Using the Hydraulic Toolbox, the velocity computed in HY-12 is correct and is therefore found to be acceptable for purposes of this comparison study.

The differences in the flow and velocities have created a difference in the hydraulic grade line. The results seem reasonable based on the calculated depths and the pipe invert elevations. They have not been verified using hand calculations.

3.2.2 Example 2

The second HYDRA example was an analysis of a pressurized system due to the flows exceeding the gravity flow capacity. The pipe diameters were not compared because the problem is analyzing an existing system. The full capture assumption was made in HY-12 and provides for a worse case scenario. Table 6 and Table 7 compare flow, velocity and HGL results of the HYDRA tutorial file and the HY-12 program:

Table 6. HYDRA Example 2 Comparison Results

	HYDRA	HY-12		HYDRA	HY-12	
	Flow (cms)		%Difference	Velocity (m/s)		%Difference
Pipe 11	0.182	0.18	1.1%	1.147	1.15	-0.3%
Pipe 12	1.302	1.33	-2.2%	2.946	3.01	-2.2%
Pipe 13	4.6	4.92	-7.0%	3.214	3.44	-7.0%
Pipe 14	0.374	0.39	-4.3%	3.387	3.52	-3.9%
Pipe 15	1.205	1.25	-3.7%	1.25	1.10	12.0%
Pipe 16	1.954	1.98	-1.3%	1.365	1.38	-1.1%

Pipe 17	6.796	6.71	1.3%	2.67	2.64	1.1%
Outlet 40	6.796	6.71	1.3%	-	-	-

Table 7. HYDRA Example 2 Comparison Results (Cont)

	HYDRA	HY-12	
	HGL (m)		Difference
Pipe 11	58.98	58.48	0.50
Pipe 12	58.52	55.89	2.63
Pipe 13	56.17	55.42	0.75
Pipe 14	60.64	55.82	4.82
Pipe 15	56.38	55.95	0.43
Pipe 16	56.17	55.73	0.44
Pipe 17	56.20	55.01	1.19
Outlet 40	-	-	-

The flow and velocity results are within an acceptable range of each other. The biggest difference in the flow is higher in HY-12 than HYDRA and is slightly more conservative. The results are consistent with each other and are accepted as correct.

The hydraulic grade line showed the greatest difference in the results. The problem presented analyzed an existing system with pressure flow occurring. A better measure of the accuracy would be with the energy grade line because it includes pressure flow. The HYDRA program does not report the energy grade line and cannot be compared to the HY-12 program with this parameter. It is assumed that the energy grade line could be hand calculated and compared to HY-12 to verify the results. The pressure flow created different results and the results need to be verified for both software titles.

3.2.3 Example 3

The HYDRA benchmark example 3 was a hydrograph analysis problem. It incorporated a channel and a reservoir before the outlet. The flow was allowed to run down the gutter and pass over the gutter inlets. The pipe sizes were not compared because of the hydrographic analysis. Table 8 compares the flow and velocity results of the peak time of the HYDRA tutorial file and the HY-12 output:

Table 8. HYDRA Example 3 Comparison Results

	HYDRA Flow (cms)	HY-12 Flow (cms)	%Difference	HYDRA Velocity (m/s)	HY-12 Velocity (m/s)	%Difference
Pipe 10	0.46	1.32	-187.0%	4.95	11.93	-141.0%
Pipe 15	0.151	0.49	-224.5%	2.099	5.250	-150.1%
Pipe 12	0.076	0.26	-242.1%	3.528	3.74	-6.0%
Pipe 13	0.079	0.46	-482.3%	3.561	6.51	-82.8%
Pipe 14	0.151	0.49	-224.5%	2.099	5.25	-150.1%
Pipe 11	0.076	0.26	-242.1%	3.528	3.74	-6.0%
Outlet 40	0.398	1.25	-214.1%	-	-	-

The hydrograph examples provided need further analyses. The hydrograph that was provided produced results that differed significantly between the two programs. The values reported for HY-12 are the peak values while HYDRA does not specify the values it reports. It is assumed that the values reported are the peaks but no additional hydrographs are provided in the solution. Due to HYDRA not producing a hydrograph at the outlet or any access hole, the output hydrographs cannot be compared. The results cannot be accepted yet and need further analysis to ensure it is providing valid results.

3.2.4 Example 4

The HYDRA benchmark example 4 was a hydrograph analysis problem with pressure flow. Each junction had a different hydrograph and had to be manually entered. The full capture assumption was made in HY-12 and provides for a worse case scenario. The pipe sizes were not compared because of the hydrographic analysis. Table 9 and Table 10 compare the flow, velocity, and hydraulic grade line results during the peak time of the HYDRA tutorial file and the HY-12 output:

Table 9. HYDRA Example 4 Comparison Results

	HYDRA	HY-12		HYDRA	HY-12	
	Flow (cms)		%Difference	Velocity (m/s)		%Difference
Pipe 12	0.784	0.43	45.2%	4.32	2.5	42.1%
Pipe 13	0.773	0.42	45.7%	3.36	1.210	64.0%
Pipe 14	0.67	0.42	37.3%	1.516	0.96	36.7%
Pipe 15	0.566	0.34	39.9%	3.561	2.13	40.2%
Pipe 115	0.08	0.08	0.0%	2.972	1.11	62.7%
Pipe 16	0.184	0.09	51.1%	3.462	0.57	83.5%
Pipe 17	0.184	0.1	45.7%	3.463	0.82	76.3%
Pipe 18	0.08	0.07	12.5%	3.381	3.09	8.6%
Outlet 40	-	-	-	-	-	-

Table 10. HYDRA Example 4 Comparison Results (Cont)

	HYDRA	HY-12	
	HGL		Difference
Pipe 12	151.18	151.14	0.04
Pipe 13	151.81	151.29	0.52
Pipe 14	152.94	151.96	0.98
Pipe 15	153.65	152.25	1.40
Pipe 115	152.89	152.7	0.19
Pipe 16	152.81	152.52	0.29
Pipe 17	155.80	155.69	0.11
Pipe 18	158.98	158.86	0.12
Outlet 40	-	-	-

The hydrographic flow models more closely resemble one another but they are still significantly different. The slopes were verified to be the same but the flows and velocities differ greatly even when assuming that full capture occurs. These differences do not provide enough evidence to accept the results.

Because the flow results differ between the two models, the hydraulic grade lines differ greatly. If the flows are brought into closer proximity, the hydraulic grade line should adjust accordingly. These differences do not support acceptance of the presented results.

3.3 Sandy City File

Sandy City was experiencing flooding problems at different locations along Falcon Way during high intensity storm events. The initial engineering design was not adequate to pass the required flows. A meeting was set up with city storm drain manager Dan Woodbury. It was decided that the HY-12 program would be a good candidate for testing and comparison to the HYDRA program for a new design. The following figure illustrates the project location and the contributing watershed area:

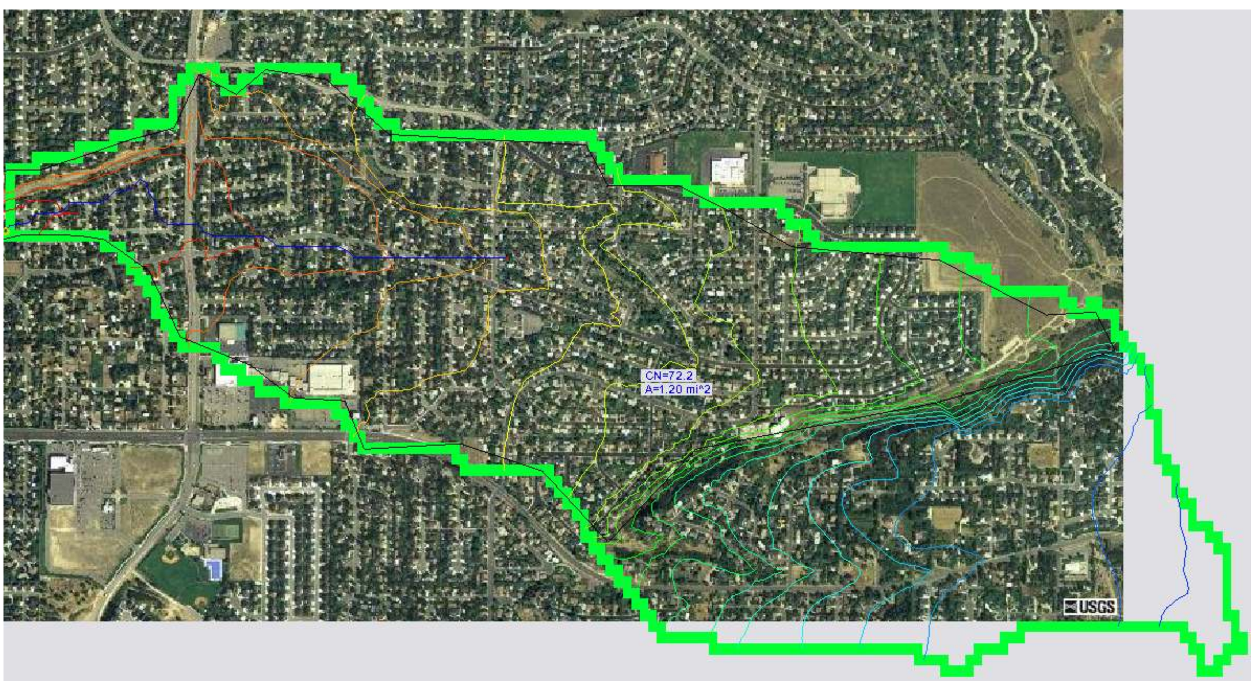

Figure 7. Sandy City Project Location Basin

The basin was divided into contributing areas and the existing pipe orientation was added to the model. It was decided that design with the rational method would be most appropriate for this project. The intensity-duration-frequency curve was obtained from the NOAA stations in the area. With the data made available, a HYDRA model was established and then compared to the HY-12 results. The following are the pipe design sizes and flows as provided by each program:

Table 11. Sandy City Comparison Results

	HYDRA	HY-12		HYDRA	HY-12	
	Diameter (in)		%Difference	Flow (cfs)		%Difference
Pipe 100	72	72	0.0%	432.88	400.05	7.6%
Pipe 101	72	66	8.3%	422.52	391.13	7.4%
Pipe 102	72	66	8.3%	422.59	377.88	10.6%
Pipe 103	24	22	8.3%	19.75	19.17	2.9%
Pipe 104	72	66	8.3%	410.21	367.79	10.3%
Pipe 105	66	66	0.0%	383.12	345.65	9.8%
Pipe 106	66	66	0.0%	368.93	333.86	9.5%
Pipe 107	66	66	0.0%	356.74	323.79	9.2%
Pipe 108	66	60	9.1%	335.85	306.69	8.7%
Pipe 109	30	36	-20.0%	77.73	132.06	-69.9%
Pipe 110	30	36	-20.0%	65.07	109.09	-67.7%
Pipe 111	54	54	0.0%	216.93	222.1	-2.4%
Pipe 112	30	30	0.0%	43.81	44.66	-1.9%
Pipe 113	45	45	0.0%	183.28	187.02	-2.0%
Pipe 114	36	36	0.0%	119.14	114.78	3.7%
Pipe 115	33	36	-9.1%	89.69	86.31	3.8%
Pipe 116	36	36	0.0%	73.08	70.23	3.9%
Pipe 117	24	21	12.5%	21.39	20.61	3.6%
Pipe 118	24	24	0.0%	43.47	43.11	0.8%
Outlet 40	-	-	-			-

As illustrated by the above table, the results varied significantly between the two programs. Upon further investigation, it was discovered that there were discrepancies between the inputs for the two files. The first discrepancy found was the method used by each program to extract the intensity value from the given IDF curve. Both programs allow for manual entry of the IDF curve and from the time of concentration given it will extract the appropriate value. The following table illustrates the values that both programs elected to use for the intensities:

Table 12. Intensity Values Comparison

	Intensity	
	HYDRA	HY-12
Pipe 100	1.06	0.84
Pipe 101	1.06	0.84
Pipe 102	1.06	0.84
Pipe 103	1.69	1.63
Pipe 104	1.06	0.85
Pipe 105	1.06	0.85
Pipe 106	1.06	0.85
Pipe 107	1.07	0.85
Pipe 108	1.07	0.85
Pipe 109	0.5	0.85
Pipe 110	0.51	0.85
Pipe 111	1.07	1.49
Pipe 112	1.08	1.09
Pipe 113	1.08	1.49
Pipe 114	1.26	1.21
Pipe 115	1.64	1.75
Pipe 116	1.64	1.57
Pipe 117	2.01	1.93
Pipe 118	1.78	1.76
Outlet 40		

As it can be observed, there are several differences. The first difference observed is found in pipes 109 and 110. The time of concentration for these pipes was found to be 86 minutes. This lies outside the given IDF curve and the value had to be extrapolated. HYDRA does not provide an explanation of how an intensity value is chosen beyond the given curve. HY-12 extrapolates the given data and pulls off the most appropriate value. Based on this information, the value provided by HY-12 is more representative and is more accurate based on observations.

The second discrepancy of note is found in pipes 100 through 108. HYDRA used the time of concentration of approximately 61 to 62 minutes for each of these pipes where HY-12 used a time of concentration of 86 to 87 minutes. Based on the rational method, the HY-12 results are correct while HYDRA should have used the higher time of concentration from one of the upper basins in the project reach. Due to these differences, the pipe diameters designed and the flows calculated vary. Based on the observations and analysis of the program, HY-12 provides more accurate results based on the time of concentration calculation and the extrapolation from the IDF curve.

Reviewing the results showed some other slight differences between the programs. The first is the outlet flow and the final basin immediately upstream of the outlet. From the WMS Rational Tutorial and this example, it has been observed that HYDRA does not account for the final basin if an access hole is not specified before the outlet. This creates a slightly lower flow at the outfall in HYDRA than in HY-12. The HY-12 program will direct the final basin flow directly to the outfall but will not place it within a pipe. If the primary objective is to design the pipe system, this final basin can be ignored but if the outfall is to a detention basin or other hydraulic structure, the final basin runoff must be considered.

Another minor difference observed between the programs are the accuracy of the access hole angles. Because the HY-12 program does not have a user interface, the angles of each pipe were estimated simply by using a protractor on a map. HYDRA has the ability to input angles directly from the pipe orientation entered in the WMS program. The difference is not great but it will slightly vary the losses and thereby vary the hydraulic grade line computed.

4 Conclusions

Based on the results of the comparisons of the two programs, HY-12 program provides accurate results for any rational method design problem. This is based on the resemblance of the results between the two programs and the four examples tested. The hydraulic grade line is the only result that requires additional testing for any rational design problem.

The differences between the two programs on the hydrographic flow are too great to accept the results provided by HY-12 without additional testing. In the three examples tested, the flows varied anywhere from 0% to nearly 500% of the HYDRA results with the majority of the results being over 20% different. The HYDRA 3 example is the least accurate with all of the HY-12 results being more than double the HYDRA results. All of these examples need additional analysis to determine the cause of the differences.

References

Brown, S. A., Schall, J.D., Morris, J.L., Doherty, C.L., Stein, S. M. & Warner, J. C., *Urban Drainage Design Manual, Hydraulic Engineering Circular No. 22*. Federal Highway Administration, US Department of Transportation, Washington DC, 2009.

McCuen, R.H., Johnson, P.A. & Ragan, R.M. *Highway Hydrology, Hydraulic Design Series Number 2*. Federal Highway Administration US Department of Transportation, Washington DC, 2002.

Schall, J.D., Richardson, E.V. & Morris, J.L. *Highway Hydraulics, Hydraulic Design Series Number 4*. Federal Highway Administration, US Department of Transportation, Washington DC, 2008.

Appendix A. HY-12 Tutorials

Chapter 1

HY-12: Rational Design

HY-12 is a hydraulic analysis and design program for storm drain systems. Developed by the Federal Highway Administration (FHWA), HY-12 provides hydraulic engineers with a quick and accurate method of computing the capacity of an existing system, or designing a system to meet a given set of input flows.

1 Objectives

In this exercise, we will review a drainage simulation input file based on the Rational Method for a proposed subdivision. The objective of this exercise is to teach you the basic steps for defining an HY-12 input file, running the numeric model, and viewing the output. Creating ID numbers for each item within the basin allows for easy interpretation of the results. The following table illustrates the numbering system used in this tutorial.

Table 13: Numbering for this project

ID	Description
10	Pipe
20	Basin/Rational
40	Access Hole
60	Pipe Inlet

The following is a schematic of a proposed subdivision:

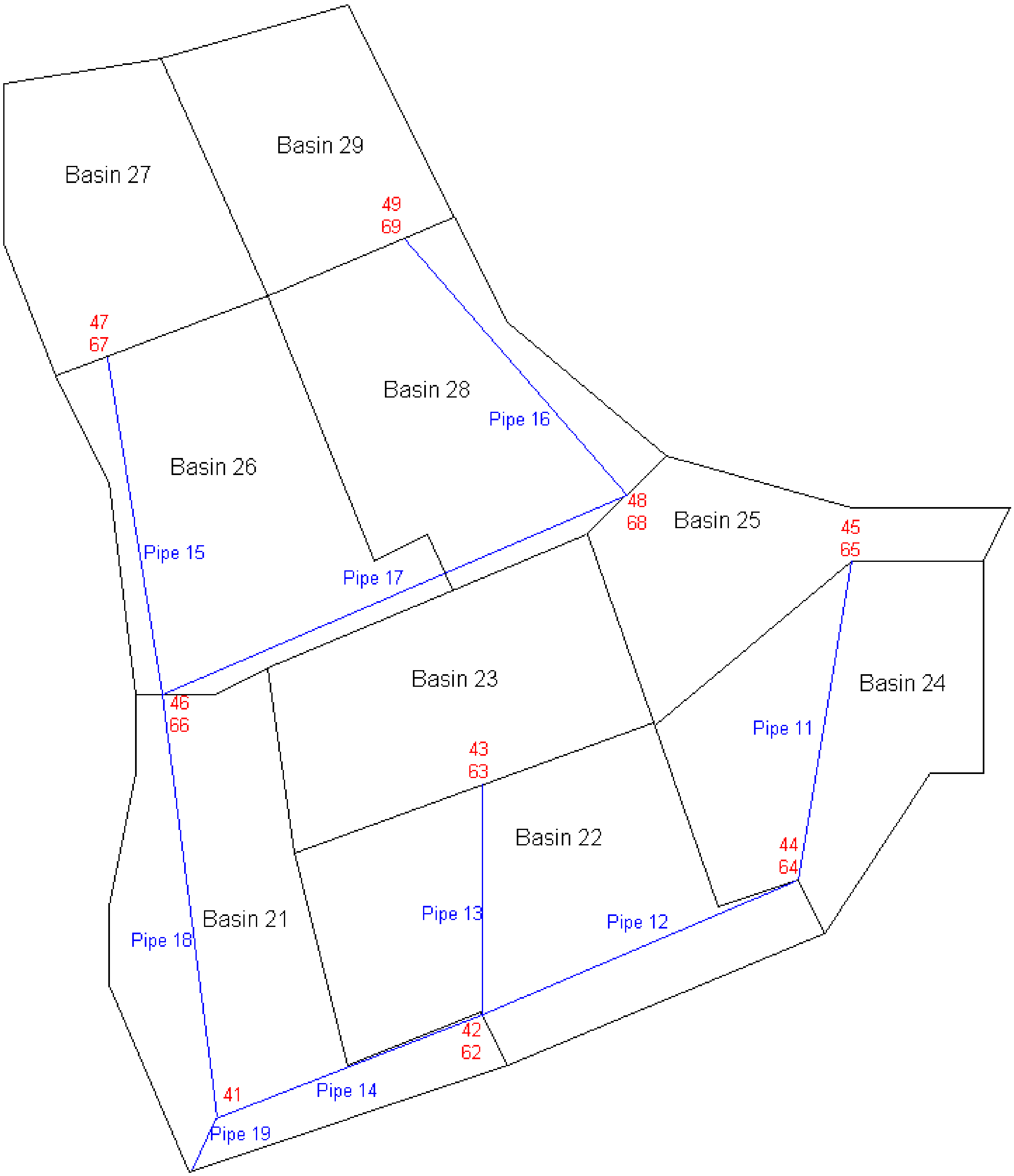

Figure 8. Drainage Basins and Streams for a Proposed Subdivision

In this workshop, you will create an HY-12 input file. An input file can be created using a text editor and by using text described in the HY-12 file format documentation. For many types of structures that can be implemented, you will need the FHWA Hydraulic Toolbox and will need to use files saved from the toolbox software in HY-12.

2 Defining the Project Parameters

The HY-12 input file requires a header to define the parameters that apply to the entire project. The header should be copied and pasted from the header template (included with the HY12 download) into a text file ending with the extension ".h12", signifying an HY-12 file. The header for this example was entered as follows:

```
HY12PROJECT 1.0
SIUNITS                0
DESIGN                 1
CALCGEOM               0
ASSUMEFULLCAPTURE      1
IGNOREGINLETS          1
ROUTEHYDROGAPHS        0
USEGLOBALIDF           1
DESIGNPERCENTAGE       100
MATERIALFILE           "materialDB.txt"
HYDROGRAPHTYPE         2
TIMESTEP
MINPIPEDIAMETER        1.0
MAXPIPEDIAMETER        2.0
MINCOVER               4.0
MAXCOVER               15.0
MINSLOPE               0.01
MAXSLOPE               0.1
MINVELOCITY            3.0
MAXVELOCITY            12.0
NOTES                  HY-12 Tutorial
TITLE                  HY-12 Tutorial
DESIGNER               Merrill M. Taylor
GLOBALIDF
IDF
TIMECONCMIN          5.000000
TIMECONCMINENABLE
IDFVARS
RESULTS
```

```
YEAR2
INTERVAL
MIN5                    2.280000
MIN10                   1.620000
MIN15                   1.440000
MIN30                   1.060000
MIN60                   0.690000
ENDINTERVAL
ENDRESULTS
ENDIDFVARS
ENDIDF
```

Notice that there is an IDF curve defined for the entire project. This curve will be used by HY12 for computing the intensity based on the time of concentration entered for any rational method computations in your model.

3 Overview of Storm Drain Data Entry in HY12 Files

Structures (inlets, pipes, junctions, etc.) in the storm drain network are defined from downstream to upstream. In other words, whenever you enter a structure, everything downstream from the structure must have already been entered (must be above the current structure) in the file. You must assign a unique ID to each structure in your HY12 file. The IDs do not need to be in any particular order or contain all the numbers from the minimum ID to the maximum ID. HY12 determines connectivity in your storm drain network by defining the downstream ID for every structure in your model (except Outfalls). It is useful to note that any line starting with a character or string that is not recognized (such as "#", "//", or "!") can be used as a comment to describe where you are in the file. A material database is needed to run HY12 and should be specified using the

MATERIALFILE card. Normally, you would want to specify both the path and the filename of the material database on the MATERIALFILE card. Only the filename is included in this project, so it will be up to you to specify the path.

4 Defining the Outfall

Since the outfall is located at the downstream end of your storm drain network, the outfall is the first required input parameter for the HY-12 program. The following code is used to define the outfall in the tutorial (enter this information in your HY-12 input file):

```
#Outfall
OUTFALLLIST            1
HY12OUTFALL
HY12NODE
HY12CALC
ID                   40
ENDHY12CALC
HY12POINT3D
Z                    4495.37
ENDHY12POINT3D
VELOCITY             0.000000
PRESSUREHEAD         0.000000
DEPTH                1.1
SURFACEELEV          4509.27
ENDHY12NODE
ENDHY12OUTFALL
```

5 Defining the Access Hole Locations & Pipe Inlets

For the purposes of this tutorial, each of the access holes and inlets has IDs that correspond to the basin IDs. For example, Basin 22 discharges to pipe inlet 62 which feeds into access hole 42. The second digit identifies which basin it is associated with. The following code identifies access hole 42:

```
#Access Hole ID 42 Computation
HY12ACCESSHOLE
HY12NODE
HY12CALC
ID                  42
DOWNSTREAMID        14
ENDHY12CALC
HY12POINT3D
Z                   4504.03
ENDHY12POINT3D
SURFACEELEV         4512.30
ENDHY12NODE
ACCESSHOLEWIDTH     4
BENCHTYPE           0
LOCKEDTOP           0
ENDHY12ACCESSHOLE
```

Table 14: A listing of all the access holes in the model and their associated data

ID	Downstream	Z (ft)	Ground	Width
41	19	4495.77	4509.53	4
42	14	4504.03	4512.30	4
43	13	4506.04	4513.04	4
44	12	4507.97	4515.55	4
45	11	4510.59	4517.59	4
46	18	4499.96	4510.75	4
47	15	4503.21	4510.21	4
48	17	4504.17	4515.54	4
49	16	4507.09	4514.09	4

Copy and paste the access hole data above and place the access holes in the file, ordering them from downstream to upstream based on Figure 8. A listing of the order of structures in the file is located toward the end of this tutorial. Make sure the data for each access hole is filled in correctly using Table 14. The following code is associated with the inlet of Basin 22:

```
#Gutter Inlet ID 21 Computation
HY12GUTTERINLET
HY12NODE
HY12CALC
ID                   62
DOWNSTREAMID         42
ENDHY12CALC
ENDHY12NODE

#<The following is Curb and Gutter Code from Hydraulic Toolbox>

CURBCALC
CURBNAME             Curb and Gutter Analysis
CURBNOTES
LOCATION             0
INLETLENGTH          4.000000
UNKNOWN              0
GRATEWIDTH           0.000000
GRATELENGTH          0.000000
GUTTERDEPRESSION     0.000000
LOCALDEPRESSION      0.250000
EFFICIENCY           0.000000
LONGSLOPE            0.020000
DEFINEGUTTERSLOPE    0
GUTTERSLOPE          0.020000
GUTTERWIDTH          2.000000
PAVEMENTSLOPE        0.020000
WIDTHOFSPREAD        0.000000
AREAOFFLOW           0.000000
VELOCITY             0.000000
INTERCEPTEDFLOW      0.000000
OPENING              0.000000
PERCENTCLOGGING      0.000000
GRATEPERIMETER       0.000000
GRATEEFFPERIMETER    0.000000
GRATEFLOWAREA        0.000000
GRATEEFFFLOWAREA     0.000000
GRATEDEPTH           0.000000
COMPUTEDGRATEDEPTH   0.000000
COMPUTEDSPREADWIDTH  0.000000
BYPASSFLOW           0.000000
MANNINGS             0.015000
SPLASHOVERVELOCITY   0.000000
DEFINESPLASHVELOCITY 0.000000
DEFINEOPENINGRATIO   0.000000
DESIGNFLOW           0.000000
INLETTYPE            1
GRATETYPE            0
CALCULATEDFLOW       0.000000
ESUBO                0.000000
CURBDEPTH            0.000000
ENDCURBCALC
```

```
#<End of Hydraulic Toolbox Curb and Gutter Code>

DEFINESPLASHVELOCITY          0.000000
DEFINEOPENINGRATIO            0.000000
CURBHEIGHT                    0.000000
ENDHY12GUTTERINLET
```

The data associated with all the inlets are shown in Table 15.

Table 15: A listing of all the inlets in the model and their associated data

ID	62	63	64	65	66	67	68	69
Downstream	42	43	44	45	46	47	48	49
Inlet Type	1	1	1	1	1	1	1	1
Inlet Length	4	4	4	4	4	4	4	4
Local	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Longitudinal	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Gutter Slope	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Pavement	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Manning's n	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Gutter Width	2	2	2	2	2	2	2	2

The section under the CURBCALC is obtained using the Hydraulic Toolbox. As different curb and inlet types are defined, these values will change and must be done in the hydraulic toolbox to ensure that the values correspond correctly. Enter all the inlet information shown in Table 15 into your HY12 input file. The inlet information should be entered after the access hole information.

6 Defining the Pipe Network

Each pipe is required to have an ID number. For the purposes of this tutorial, the following diagram illustrates each pipe's ID:

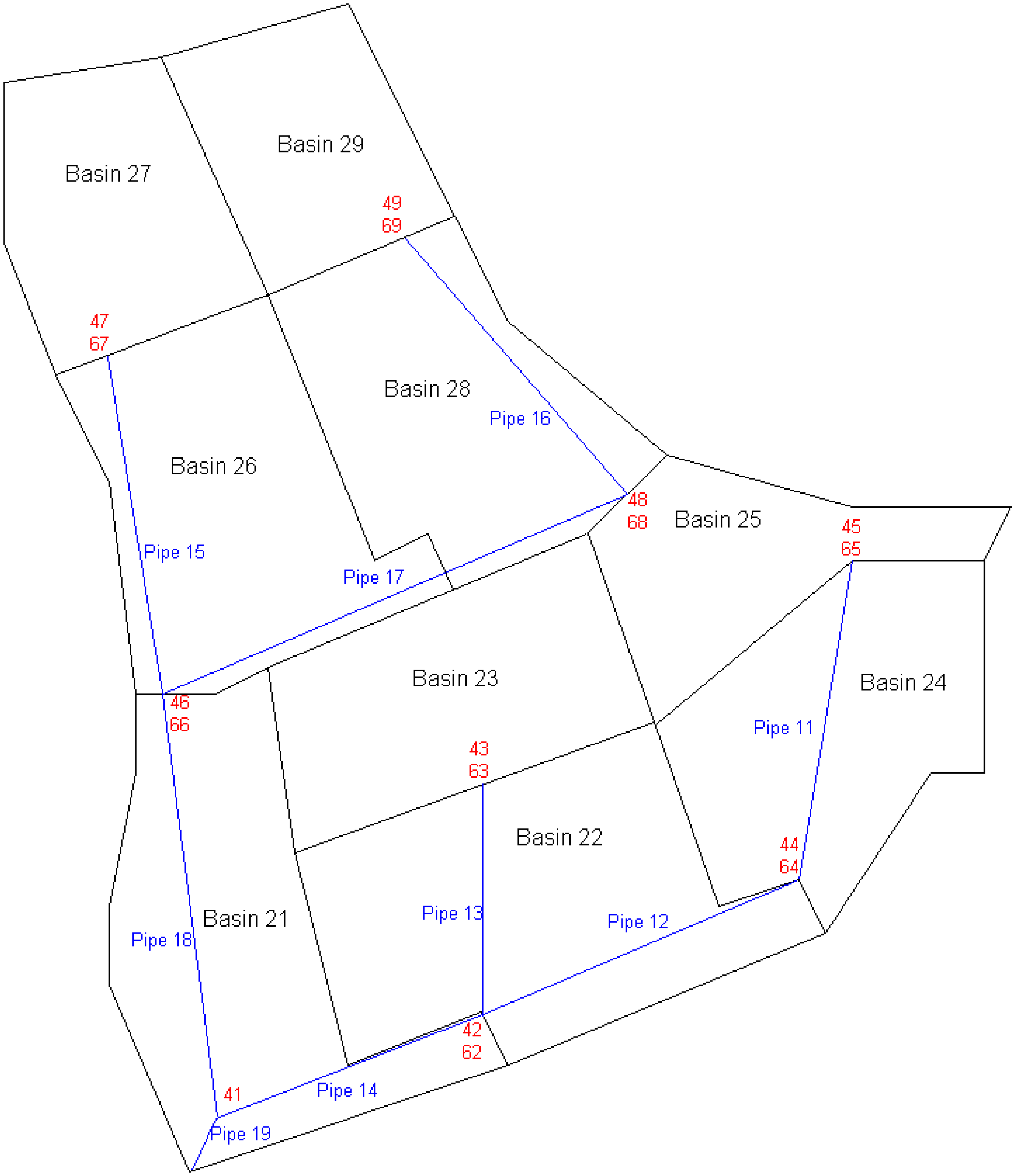

Figure 9. HY-12 Tutorial Pipe Schematic

Once the pipe IDs have been established, they are entered into the HY-12 input file. The pipes must be listed in a downstream to upstream order in the file. The following is a sample code for the most downstream pipe in the network. This should be entered immediately following the outfall:

```
#Pipe ID 19 Computation
HY12PIPE
HY12ARC
HY12CALC
ID                    19
DOWNSTREAMID          40
ENDHY12CALC

#The UPSTREAMNODE card defines the data at the upstream end of the pipe
UPSTREAMNODE
HY12NODE
HY12POINT3D
Z                     4495.77
ENDHY12POINT3D
ENDHY12NODE

#The DOWNSTREAMNODE card defines the data at the downstream end of the
pipe
DOWNSTREAMNODE
HY12NODE
HY12POINT3D
Z                     4495.37
ENDHY12POINT3D
ENDHY12NODE

LENGTH                41.000000

INLET ANGLE           235.000000
ENDHY12ARC

MATERIAL              6
SHAPE                 9
ENDHY12PIPE
```

The rest of the pipes should also be entered in the storm drain network, beginning at the most downstream pipe and going upstream. **Error! Reference source not found.** shows the data to be entered for each of the pipes.

Table 16. A listing of all the pipe properties

ID	11	12	13	14	15	16	17	18	19
Downstream ID	44	42	42	41	46	48	46	41	40
Upstream Elevation (ft)	4510.59	4507.97	4506.04	4504.03	4503.21	4507.09	4504.17	4499.96	4495.77
Downstream Elevation (ft)	4507.97	4505.11	4504.03	4501.39	4500.17	4504.17	4499.96	4495.77	4495.37

Length (ft)	262	285	201	264	305	292	421	419	41
Inlet Angle (Degrees)	180	270	180	270	180	180	270	180	235
Material (From Material Database File)	6	6	6	6	6	6	6	6	6
Shape (From Material Database File)	0	0	0	2	0	0	0	2	5

7 Defining the Rational Method Computations

Each basin requires a rational method input for the HY-12 input file. Because you have an IDF curve defined in the project heading, you do not need to define an intensity value for your basins. The intensity is computed from the IDF curve and the time of concentration. The following table contains the hydraulic values used in this study:

Table 17. Basin Parameters

Basin	Downstream	C	t_c (min)	A
21	40	0.76	14	1.81
22	62	0.71	11	1.78
23	63	0.72	6	1.20
24	64	0.73	8	1.40
25	65	0.81	7	0.78
26	66	0.75	9	1.67
27	67	0.78	5	1.01
28	68	0.74	8	1.37
29	69	0.80	5	0.88

The code from the HY-12 for one of the basins is as follows:

```
#Rational Basin ID 21 Computation
```

```
HY12RATIONAL
HY12AREA
HY12CALC
ID                     21
DOWNSTREAMID           40
ENDHY12CALC
AREA                   1.81
ENDHY12AREA
RATIONALCALC
RATNAME                 Rational Method Analysis
RATNOTES
CONSTANT                0.76
AREA                    1.81
TIMEOFCONC              14
ENDRATIONALCALC
ENDHY12RATIONAL
```

The format remains the same for each basin and only the values under ID, DOWNSTREAMID, CONSTANT, INTENSITY, AREA, and TIMEOFCONC will change according to Table 17. Enter the parameters for these basins in your model file, starting with the basins feeding downstream pipes and then going upstream.

8 File Overview

A summary of the order of input data in the HY12 file is shown in Table 18. Make sure the data in your input file is entered in this order.

Table 18: A summary of the input data order for this HY12 file

Description	ID
File Header	N/A
Outfall	40
Pipe	19
Access Hole	41
Pipe	18
Access Hole	46
Gutter Inlet	66

Pipe	17
Access Hole	48
Gutter Inlet	68
Pipe	16
Access Hole	49
Gutter Inlet	69
Pipe	15
Access Hole	47
Gutter Inlet	67
Pipe	14
Access Hole	42
Gutter Inlet	62
Pipe	13
Access Hole	43
Gutter Inlet	63
Pipe	12
Access Hole	44
Gutter Inlet	64
Pipe	11
Access Hole	45
Gutter Inlet	65
Rational	21
Rational	22
Rational	23
Rational	24
Rational	25
Rational	26
Rational	27
Rational	28
Rational	29

9 Running HY-12

Open a DOS command prompt by selecting start | run and entering “cmd” (or selecting Start and entering “Command Prompt” in the search field on Windows Vista and later) and navigate to the file containing the hy12.exe application. There are four levels of error reporting that can be selected. For the purpose of this tutorial, we will elect to use error level 1. Type the following into the command prompt window: "hy12 -1 [c:\path\wmstutrat.h12]" where [c:\path\wmstutrat.h12] is the path and filename of your input file. For example, if my HY12 input file is called "c:\hy12files\wmstutrat.h12", I would run HY12 by going to the directory where hy12.exe is located (you can use "cd <directory name>" to change directories in DOS) and typing "hy12 -1 "c:\hy12files\wmstutrat.h12"" at the command prompt. Once the program has completed running, it will generate a text report file in the same directory as the hy12 input file. The file can be reviewed by simply opening it with a text editor such as Notepad or Wordpad.

10 File Listing

A listing of the input and report files is shown below. Make sure your input and output files match these listings.

10.1 Input File Listing

```
HY12PROJECT 1.0

SIUNITS                 0
DESIGN                  1
CALCGEOM                0
ASSUMEFULLCAPTURE       1
IGNOREINLETS            1
ROUTEHYDROGRAPHS        0
USEGLOBALIDF            1
```

```
DESIGNPERCENTAGE        100.0
MATERIALFILE            "materialDB.txt"
HYDROGRAPHTYPE          2
TIMESTEP
MINPIPEDIAMETER         1.0
MAXPIPEDIAMETER         2.0
MINCOVER                4.0
MAXCOVER                15.0
MINSLOPE                0.01
MAXSLOPE                0.1

NOTES                   HY-12 Tutorial
TITLE                   HY-12 tutorial
DESIGNER                Merrill M. Taylor

GLOBALIDF
IDF
        TIMECONCMIN     5.0
        TIMECONCMINENABLE
        IDFVARS
        RESULTS
        YEAR2
        Interval
                MIN5    2.28
                MIN10   1.62
                MIN15   1.44
                MIN30   1.06
                MIN60   0.69
        ENDINTERVAL
        ENDRESULTS
        ENDIDFVARS
ENDIDF


OUTFALLLIST             1

HY12OUTFALL
        HY12NODE
                HY12CALC
                        ID                      40
                ENDHY12CALC
                HYPOINT3D
                        Z                       4495.37
                ENDHY12POINT3D
        VELOCITY        0.00
        PRESSUREHEAD    0.00
        DEPTH           1.1
        SURFACEELEV     4509.27
        ENDHY12NODE
ENDHY12OUTFALL

HY12PIPE
        HY12ARC
                HY12CALC
                        ID                      19
                        DOWNSTREAMID            40
                ENDHY12CALC
```

```
        UPSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4495.77
                ENDHY12POINT3D
        ENDHY12NODE
        DOWNSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4495.37
                ENDHY12POINT3D
        ENDHY12NODE
        LENGTH          41.0
        ANGLE           235
        ENDHY12ARC
        MATERIAL        6
        SHAPE           5
ENDHY12PIPE

HY12ACCESSHOLE
        HY12NODE
                HY12CALC
                        ID                      41
                        DOWNSTREAMID            19
                ENDHY12CALC
                HY12POINT3D
                        Z                       4495.77
                ENDHY12POINT3D
        SURFACEELEV             4509.53
        ENDHY12NODE
        ACCESSHOLEWIDTH         4.00
        BENCHTYPE             0
        LOCKEDTOP             0
ENDHY12ACCESSHOLE

HY12PIPE
        HY12ARC
                HY12CALC
                        ID                      18
                        DOWNSTREAMID            41
                ENDHY12CALC
        UPSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4499.96
                ENDHY12POINT3D
        ENDHY12NODE
        DOWNSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4495.77
                ENDHY12POINT3D
        ENDHY12NODE
        LENGTH          419.0
        ANGLE           180
        ENDHY12ARC
        MATERIAL        6
```

```
        SHAPE           2
ENDHY12PIPE

HY12ACCESSHOLE
        HY12NODE
                HY12CALC
                        ID                      46
                        DOWNSTREAMID            18
                ENDHY12CALC
                HY12POINT3D
                        Z                       4499.96
                ENDHY12POINT3D
        SURFACEELEV             4510.21
        ENDHY12NODE
        ACCESSHOLEWIDTH         4.00
        BENCHTYPE             0
        LOCKEDTOP             0
ENDHY12ACCESSHOLE


HY12GUTTERINLET
        HY12NODE
                HY12CALC
                        ID                      66
                        DOWNSTREAMID            46
                ENDHY12CALC
        ENDHY12NODE

CURBCALC
CURBNAME              Curb and Gutter Analysis
CURBNOTES
LOCATION              0
INLETLENGTH           4.000000
UNKNOWN               0
GRATEWIDTH            0.000000
GRATELENGTH           0.000000
GUTTERDEPRESSION      0.000000
LOCALDEPRESSION       0.250000
EFFICIENCY            0.000000
LONGSLOPE             0.020000
DEFINEGUTTERSLOPE     0
GUTTERSLOPE           0.020000
GUTTERWIDTH           2.000000
PAVEMENTSLOPE         0.020000
WIDTHOFSPREAD         0.000000
AREAOFFLOW            0.000000
VELOCITY              0.000000
INTERCEPTEDFLOW       0.000000
OPENING               0.000000
PERCENTCLOGGING       0.000000
GRATEPERIMETER        0.000000
GRATEEFFPERIMETER     0.000000
GRATEFLOWAREA         0.000000
GRATEEFFFLOWAREA      0.000000
GRATEDEPTH            0.000000
COMPUTEDGRATEDEPTH    0.000000
COMPUTEDSPREADWIDTH   0.000000
```

```
BYPASSFLOW           0.000000
MANNINGS             0.015000
SPLASHOVERVELOCITY   0.000000
DESIGNFLOW           0.000000
INLETTYPE            1
GRATETYPE            0
CALCULATEDFLOW       0.000000
ESUBO                1.000000
CURBDEPTH            0.000000
ENDCURBCALC

DEFINESPLASHVELOCITY          0.000000
DEFINEOPENINGRATIO            0.000000
CURBHEIGHT                    0.000000
ENDHY12GUTTERINLET

HY12PIPE
        HY12ARC
                HY12CALC
                        ID                      17
                        DOWNSTREAMID            46
                ENDHY12CALC
        UPSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4504.17
                ENDHY12POINT3D
        ENDHY12NODE
        DOWNSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4499.96
                ENDHY12POINT3D
        ENDHY12NODE
        LENGTH          421.0
        ANGLE           270
        ENDHY12ARC
        MATERIAL        6
        SHAPE           0
ENDHY12PIPE

HY12ACCESSHOLE
        HY12NODE
                HY12CALC
                        ID                      48
                        DOWNSTREAMID            17
                ENDHY12CALC
                HY12POINT3D
                        Z                       4504.17
                ENDHY12POINT3D
        SURFACEELEV             4515.54
        ENDHY12NODE
        ACCESSHOLEWIDTH         4.00
        BENCHTYPE             0
        LOCKEDTOP             0
ENDHY12ACCESSHOLE
```

```
HY12GUTTERINLET
        HY12NODE
                HY12CALC
                        ID                      68
                        UPSTREAMID              24
                        DOWNSTREAMID            48
                ENDHY12CALC
        ENDHY12NODE

CURBCALC
CURBNAME             Curb and Gutter Analysis
CURBNOTES
LOCATION             0
INLETLENGTH          4.000000
UNKNOWN              0
GRATEWIDTH           0.000000
GRATELENGTH          0.000000
GUTTERDEPRESSION     0.000000
LOCALDEPRESSION      0.250000
EFFICIENCY           0.000000
LONGSLOPE            0.020000
DEFINEGUTTERSLOPE    0
GUTTERSLOPE          0.020000
GUTTERWIDTH          2.000000
PAVEMENTSLOPE        0.020000
WIDTHOFSPREAD        0.000000
AREAOFFLOW           0.000000
VELOCITY             0.000000
INTERCEPTEDFLOW      0.000000
OPENING              0.000000
PERCENTCLOGGING      0.000000
GRATEPERIMETER       0.000000
GRATEEFFPERIMETER    0.000000
GRATEFLOWAREA        0.000000
GRATEEFFFLOWAREA     0.000000
GRATEDEPTH           0.000000
COMPUTEDGRATEDEPTH   0.000000
COMPUTEDSPREADWIDTH  0.000000
BYPASSFLOW           0.000000
MANNINGS             0.015000
SPLASHOVERVELOCITY   0.000000
DESIGNFLOW           0.000000
INLETTYPE            1
GRATETYPE            0
CALCULATEDFLOW       0.000000
ESUBO                1.000000
CURBDEPTH            0.000000
ENDCURBCALC

DEFINESPLASHVELOCITY          0.000000
DEFINEOPENINGRATIO            0.000000
CURBHEIGHT                    0.000000
ENDHY12GUTTERINLET

HY12PIPE
        HY12ARC
                HY12CALC
```

```
                        ID                      16
                        DOWNSTREAMID            48
                ENDHY12CALC
        UPSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4507.09
                ENDHY12POINT3D
        ENDHY12NODE
        DOWNSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4504.17
                ENDHY12POINT3D
        ENDHY12NODE
        LENGTH          292.0
        ANGLE           180
        ENDHY12ARC
        MATERIAL        6
        SHAPE           0
ENDHY12PIPE

HY12ACCESSHOLE
        HY12NODE
                HY12CALC
                        ID                      49
                        DOWNSTREAMID            16
                ENDHY12CALC
                HY12POINT3D
                        Z                       4507.09
                ENDHY12POINT3D
        SURFACEELEV             4514.09
        ENDHY12NODE
        ACCESSHOLEWIDTH         4.00
        BENCHTYPE             0
        LOCKEDTOP             0
ENDHY12ACCESSHOLE

HY12GUTTERINLET
        HY12NODE
                HY12CALC
                        ID                      69
                        DOWNSTREAMID            49
                ENDHY12CALC
        ENDHY12NODE

CURBCALC
CURBNAME                Curb and Gutter Analysis
CURBNOTES
LOCATION                0
INLETLENGTH             4.000000
UNKNOWN                 0
GRATEWIDTH              0.000000
GRATELENGTH             0.000000
GUTTERDEPRESSION        0.000000
LOCALDEPRESSION         0.250000
EFFICIENCY              0.000000
```

```
LONGSLOPE             0.020000
DEFINEGUTTERSLOPE     0
GUTTERSLOPE           0.020000
GUTTERWIDTH           2.000000
PAVEMENTSLOPE         0.020000
WIDTHOFSPREAD         0.000000
AREAOFFLOW            0.000000
VELOCITY              0.000000
INTERCEPTEDFLOW       0.000000
OPENING               0.000000
PERCENTCLOGGING       0.000000
GRATEPERIMETER        0.000000
GRATEEFFPERIMETER     0.000000
GRATEFLOWAREA         0.000000
GRATEEFFFLOWAREA      0.000000
GRATEDEPTH            0.000000
COMPUTEDGRATEDEPTH    0.000000
COMPUTEDSPREADWIDTH   0.000000
BYPASSFLOW            0.000000
MANNINGS              0.015000
SPLASHOVERVELOCITY    0.000000
DESIGNFLOW            0.000000
INLETTYPE             1
GRATETYPE             0
CALCULATEDFLOW        0.000000
ESUBO                 1.000000
CURBDEPTH             0.000000
ENDCURBCALC

DEFINESPLASHVELOCITY           0.000000
DEFINEOPENINGRATIO             0.000000
CURBHEIGHT                     0.000000
ENDHY12GUTTERINLET

HY12PIPE
        HY12ARC
                HY12CALC
                        ID                        15
                        DOWNSTREAMID              46
                ENDHY12CALC
        UPSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                         4503.21
                ENDHY12POINT3D
        ENDHY12NODE
        DOWNSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                         4500.17
                ENDHY12POINT3D
        ENDHY12NODE
        LENGTH          305.0
        ANGLE           180
        ENDHY12ARC
        MATERIAL        6
        SHAPE           0
```

```
ENDHY12PIPE

HY12ACCESSHOLE
        HY12NODE
                HY12CALC
                        ID                      47
                        DOWNSTREAMID            15
                ENDHY12CALC
                HY12POINT3D
                        Z                       4503.21
                ENDHY12POINT3D
        SURFACEELEV             4510.21
        ENDHY12NODE
        ACCESSHOLEWIDTH         4.00
        BENCHTYPE             0
        LOCKEDTOP             0
ENDHY12ACCESSHOLE

HY12GUTTERINLET
        HY12NODE
                HY12CALC
                        ID                      67
                        DOWNSTREAMID            47
                ENDHY12CALC
        ENDHY12NODE

CURBCALC
CURBNAME             Curb and Gutter Analysis
CURBNOTES
LOCATION             0
INLETLENGTH          4.000000
UNKNOWN              0
GRATEWIDTH           0.000000
GRATELENGTH          0.000000
GUTTERDEPRESSION     0.000000
LOCALDEPRESSION      0.250000
EFFICIENCY           0.000000
LONGSLOPE            0.020000
DEFINEGUTTERSLOPE    0
GUTTERSLOPE          0.020000
GUTTERWIDTH          2.000000
PAVEMENTSLOPE        0.020000
WIDTHOFSPREAD        0.000000
AREAOFFLOW           0.000000
VELOCITY             0.000000
INTERCEPTEDFLOW      0.000000
OPENING              0.000000
PERCENTCLOGGING      0.000000
GRATEPERIMETER       0.000000
GRATEEFFPERIMETER    0.000000
GRATEFLOWAREA        0.000000
GRATEEFFFLOWAREA     0.000000
GRATEDEPTH           0.000000
COMPUTEDGRATEDEPTH   0.000000
COMPUTEDSPREADWIDTH  0.000000
BYPASSFLOW           0.000000
MANNINGS             0.015000
```

```
SPLASHOVERVELOCITY   0.000000
DESIGNFLOW           0.000000
INLETTYPE            1
GRATETYPE            0
CALCULATEDFLOW       0.000000
ESUBO                1.000000
CURBDEPTH            0.000000
ENDCURBCALC

DEFINESPLASHVELOCITY          0.000000
DEFINEOPENINGRATIO            0.000000
CURBHEIGHT                    0.000000
ENDHY12GUTTERINLET

HY12PIPE
        HY12ARC
                HY12CALC
                        ID                       14
                        DOWNSTREAMID             41
                ENDHY12CALC
        UPSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                        4504.03
                ENDHY12POINT3D
        ENDHY12NODE
        DOWNSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                        4501.39
                ENDHY12POINT3D
        ENDHY12NODE
        LENGTH          264.0
        ANGLE           270
        ENDHY12ARC
        MATERIAL        6
        SHAPE           2
ENDHY12PIPE

HY12ACCESSHOLE
        HY12NODE
                HY12CALC
                        ID                       42
                        DOWNSTREAMID             14
                ENDHY12CALC
                HY12POINT3D
                        Z                        4504.03
                ENDHY12POINT3D
        SURFACEELEV            4512.30
        ENDHY12NODE
        ACCESSHOLEWIDTH        4.00
        BENCHTYPE           0
        LOCKEDTOP           0
ENDHY12ACCESSHOLE

HY12GUTTERINLET
        HY12NODE
```

```
                HY12CALC
                        ID                      62
                        DOWNSTREAMID            42
                ENDHY12CALC
        ENDHY12NODE

CURBCALC
CURBNAME              Curb and Gutter Analysis
CURBNOTES
LOCATION              0
INLETLENGTH           4.000000
UNKNOWN               0
GRATEWIDTH            0.000000
GRATELENGTH           0.000000
GUTTERDEPRESSION      0.000000
LOCALDEPRESSION       0.250000
EFFICIENCY            0.000000
LONGSLOPE             0.020000
DEFINEGUTTERSLOPE     0
GUTTERSLOPE           0.020000
GUTTERWIDTH           2.000000
PAVEMENTSLOPE         0.020000
WIDTHOFSPREAD         0.000000
AREAOFFLOW            0.000000
VELOCITY              0.000000
INTERCEPTEDFLOW       0.000000
OPENING               0.000000
PERCENTCLOGGING       0.000000
GRATEPERIMETER        0.000000
GRATEEFFPERIMETER     0.000000
GRATEFLOWAREA         0.000000
GRATEEFFFLOWAREA      0.000000
GRATEDEPTH            0.000000
COMPUTEDGRATEDEPTH    0.000000
COMPUTEDSPREADWIDTH   0.000000
BYPASSFLOW            0.000000
MANNINGS              0.015000
SPLASHOVERVELOCITY    0.000000
DESIGNFLOW            0.000000
INLETTYPE             1
GRATETYPE             0
CALCULATEDFLOW        0.000000
ESUBO                 1.000000
CURBDEPTH             0.000000
ENDCURBCALC

DEFINESPLASHVELOCITY           0.000000
DEFINEOPENINGRATIO             0.000000
CURBHEIGHT                     0.000000
ENDHY12GUTTERINLET

HY12PIPE
        HY12ARC
                HY12CALC
                        ID                      13
                        DOWNSTREAMID            42
                ENDHY12CALC
```

```
        UPSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4506.04
                ENDHY12POINT3D
        ENDHY12NODE
        DOWNSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4504.03
                ENDHY12POINT3D
        ENDHY12NODE
        LENGTH          201.0
        ANGLE           180
        ENDHY12ARC
        MATERIAL        6
        SHAPE           0
ENDHY12PIPE

HY12ACCESSHOLE
        HY12NODE
                HY12CALC
                        ID                      43
                        DOWNSTREAMID            13
                ENDHY12CALC
                HY12POINT3D
                        Z                       4506.04
                ENDHY12POINT3D
        SURFACEELEV             4513.04
        ENDHY12NODE
        ACCESSHOLEWIDTH         4.00
        BENCHTYPE           0
        LOCKEDTOP           0
ENDHY12ACCESSHOLE

HY12GUTTERINLET
        HY12NODE
                HY12CALC
                        ID                      63
                        DOWNSTREAMID            43
                ENDHY12CALC
        ENDHY12NODE

CURBCALC
CURBNAME             Curb and Gutter Analysis
CURBNOTES
LOCATION             0
INLETLENGTH          4.000000
UNKNOWN              0
GRATEWIDTH           0.000000
GRATELENGTH          0.000000
GUTTERDEPRESSION     0.000000
LOCALDEPRESSION      0.250000
EFFICIENCY           0.000000
LONGSLOPE            0.020000
DEFINEGUTTERSLOPE    0
GUTTERSLOPE          0.020000
```

```
GUTTERWIDTH          2.000000
PAVEMENTSLOPE        0.020000
WIDTHOFSPREAD        0.000000
AREAOFFLOW           0.000000
VELOCITY             0.000000
INTERCEPTEDFLOW      0.000000
OPENING              0.000000
PERCENTCLOGGING      0.000000
GRATEPERIMETER       0.000000
GRATEEFFPERIMETER    0.000000
GRATEFLOWAREA        0.000000
GRATEEFFFLOWAREA     0.000000
GRATEDEPTH           0.000000
COMPUTEDGRATEDEPTH   0.000000
COMPUTEDSPREADWIDTH  0.000000
BYPASSFLOW           0.000000
MANNINGS             0.015000
SPLASHOVERVELOCITY   0.000000
DESIGNFLOW           0.000000
INLETTYPE            1
GRATETYPE            0
CALCULATEDFLOW       0.000000
ESUBO                1.000000
CURBDEPTH            0.000000
ENDCURBCALC

DEFINESPLASHVELOCITY          0.000000
DEFINEOPENINGRATIO            0.000000
CURBHEIGHT                    0.000000
ENDHY12GUTTERINLET

HY12PIPE
        HY12ARC
                HY12CALC
                        ID                      12
                        DOWNSTREAMID            42
                ENDHY12CALC
        UPSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4507.97
                ENDHY12POINT3D
        ENDHY12NODE
        DOWNSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4505.11
                ENDHY12POINT3D
        ENDHY12NODE
        LENGTH          285.0
        ANGLE           270
        ENDHY12ARC
        MATERIAL        6
        SHAPE           0
ENDHY12PIPE

HY12ACCESSHOLE
```

```
        HY12NODE
                HY12CALC
                        ID                          44
                        DOWNSTREAMID                12
                ENDHY12CALC
                HY12POINT3D
                        Z                           4507.97
                ENDHY12POINT3D
        SURFACEELEV             4515.55
        ENDHY12NODE
        ACCESSHOLEWIDTH         4.00
        BENCHTYPE            0
        LOCKEDTOP            0
ENDHY12ACCESSHOLE

HY12GUTTERINLET
        HY12NODE
                HY12CALC
                        ID                          64
                        DOWNSTREAMID                44
                ENDHY12CALC
        ENDHY12NODE

CURBCALC
CURBNAME                 Curb and Gutter Analysis
CURBNOTES
LOCATION                 0
INLETLENGTH              4.000000
UNKNOWN                  0
GRATEWIDTH               0.000000
GRATELENGTH              0.000000
GUTTERDEPRESSION         0.000000
LOCALDEPRESSION          0.250000
EFFICIENCY               0.000000
LONGSLOPE                0.020000
DEFINEGUTTERSLOPE        0
GUTTERSLOPE              0.020000
GUTTERWIDTH              2.000000
PAVEMENTSLOPE            0.020000
WIDTHOFSPREAD            0.000000
AREAOFFLOW               0.000000
VELOCITY                 0.000000
INTERCEPTEDFLOW          0.000000
OPENING                  0.000000
PERCENTCLOGGING          0.000000
GRATEPERIMETER           0.000000
GRATEEFFPERIMETER        0.000000
GRATEFLOWAREA            0.000000
GRATEEFFFLOWAREA         0.000000
GRATEDEPTH               0.000000
COMPUTEDGRATEDEPTH       0.000000
COMPUTEDSPREADWIDTH      0.000000
BYPASSFLOW               0.000000
MANNINGS                 0.015000
SPLASHOVERVELOCITY       0.000000
DESIGNFLOW               0.000000
INLETTYPE                1
```

```
GRATETYPE            0
CALCULATEDFLOW       0.000000
ESUBO                1.000000
CURBDEPTH            0.000000
ENDCURBCALC

DEFINESPLASHVELOCITY          0.000000
DEFINEOPENINGRATIO            0.000000
CURBHEIGHT                    0.000000
ENDHY12GUTTERINLET

HY12PIPE
        HY12ARC
                HY12CALC
                        ID                      11
                        DOWNSTREAMID            44
                ENDHY12CALC
        UPSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4510.59
                ENDHY12POINT3D
        ENDHY12NODE
        DOWNSTREAMNODE
        HY12NODE
                HY12POINT3D
                        Z                       4507.97
                ENDHY12POINT3D
        ENDHY12NODE
        LENGTH          262.0
        ANGLE           180
        ENDHY12ARC
        MATERIAL        6
        SHAPE           0
ENDHY12PIPE

HY12ACCESSHOLE
        HY12NODE
                HY12CALC
                        ID                      45
                        DOWNSTREAMID            11
                ENDHY12CALC
                HY12POINT3D
                        Z                       4510.59
                ENDHY12POINT3D
        SURFACEELEV             4517.59
        ENDHY12NODE
        ACCESSHOLEWIDTH         4.00
        BENCHTYPE             0
        LOCKEDTOP             0
ENDHY12ACCESSHOLE

HY12GUTTERINLET
        HY12NODE
                HY12CALC
                        ID                      65
                        DOWNSTREAMID            45
```

```
                ENDHY12CALC
        ENDHY12NODE

CURBCALC
CURBNAME               Curb and Gutter Analysis
CURBNOTES
LOCATION               0
INLETLENGTH            4.000000
UNKNOWN                0
GRATEWIDTH             0.000000
GRATELENGTH            0.000000
GUTTERDEPRESSION       0.000000
LOCALDEPRESSION        0.250000
EFFICIENCY             0.000000
LONGSLOPE              0.020000
DEFINEGUTTERSLOPE      0
GUTTERSLOPE            0.020000
GUTTERWIDTH            2.000000
PAVEMENTSLOPE          0.020000
WIDTHOFSPREAD          0.000000
AREAOFFLOW             0.000000
VELOCITY               0.000000
INTERCEPTEDFLOW        0.000000
OPENING                0.000000
PERCENTCLOGGING        0.000000
GRATEPERIMETER         0.000000
GRATEEFFPERIMETER      0.000000
GRATEFLOWAREA          0.000000
GRATEEFFFLOWAREA       0.000000
GRATEDEPTH             0.000000
COMPUTEDGRATEDEPTH     0.000000
COMPUTEDSPREADWIDTH    0.000000
BYPASSFLOW             0.000000
MANNINGS               0.015000
SPLASHOVERVELOCITY     0.000000
DESIGNFLOW             0.000000
INLETTYPE              1
GRATETYPE              0
CALCULATEDFLOW         0.000000
ESUBO                  1.000000
CURBDEPTH              0.000000
ENDCURBCALC

DEFINESPLASHVELOCITY            0.000000
DEFINEOPENINGRATIO              0.000000
CURBHEIGHT                      0.000000
ENDHY12GUTTERINLET

HY12RATIONAL
        HY12AREA
                HY12CALC
                        ID                      21
                        DOWNSTREAMID            40
                ENDHY12CALC
                AREA                            1.81
        ENDHY12AREA
RATIONALCALC
```

```
RATNAME              Rational Method Analysis
RATNOTES
CONSTANT             0.76
AREA                 1.81
TIMEOFCONC           14.0
ENDRATIONALCALC
ENDHY12RATIONAL

HY12RATIONAL
        HY12AREA
                HY12CALC
                        ID                      22
                        DOWNSTREAMID            62
                ENDHY12CALC
                AREA                            1.78
        ENDHY12AREA
RATIONALCALC
RATNAME              Rational Method Analysis
RATNOTES
CONSTANT             0.71
AREA                 1.78
TIMEOFCONC           11.0
ENDRATIONALCALC
ENDHY12RATIONAL

HY12RATIONAL
        HY12AREA
                HY12CALC
                        ID                      23
                        DOWNSTREAMID            63
                ENDHY12CALC
                AREA                            1.20
        ENDHY12AREA
RATIONALCALC
RATNAME              Rational Method Analysis
RATNOTES
CONSTANT             0.72
AREA                 1.20
TIMEOFCONC           6.0
ENDRATIONALCALC
ENDHY12RATIONAL

HY12RATIONAL
        HY12AREA
                HY12CALC
                        ID                      24
                        DOWNSTREAMID            64
                ENDHY12CALC
                AREA                            1.40
        ENDHY12AREA
RATIONALCALC
RATNAME              Rational Method Analysis
RATNOTES
CONSTANT             0.73
AREA                 1.40
TIMEOFCONC           8.0
ENDRATIONALCALC
```

```
ENDHY12RATIONAL

HY12RATIONAL
        HY12AREA
                HY12CALC
                        ID                      25
                        DOWNSTREAMID            65
                ENDHY12CALC
                AREA                            0.78
        ENDHY12AREA
RATIONALCALC
RATNAME             Rational Method Analysis
RATNOTES
CONSTANT            0.81
AREA                0.78
TIMEOFCONC          7.0
ENDRATIONALCALC
ENDHY12RATIONAL

HY12RATIONAL
        HY12AREA
                HY12CALC
                        ID                      26
                        DOWNSTREAMID            66
                ENDHY12CALC
                AREA                            1.67
        ENDHY12AREA
RATIONALCALC
RATNAME             Rational Method Analysis
RATNOTES
CONSTANT            0.75
AREA                1.67
TIMEOFCONC          9.0
ENDRATIONALCALC
ENDHY12RATIONAL

HY12RATIONAL
        HY12AREA
                HY12CALC
                        ID                      27
                        DOWNSTREAMID            67
                ENDHY12CALC
                AREA                            1.01
        ENDHY12AREA
RATIONALCALC
RATNAME             Rational Method Analysis
RATNOTES
CONSTANT            0.78
AREA                1.01
TIMEOFCONC          5.0
ENDRATIONALCALC
ENDHY12RATIONAL

HY12RATIONAL
        HY12AREA
                HY12CALC
                        ID                      28
```

```
                        DOWNSTREAMID            68
                ENDHY12CALC
                AREA                            1.37
        ENDHY12AREA
RATIONALCALC
RATNAME              Rational Method Analysis
RATNOTES
CONSTANT             0.74
AREA                 1.37
TIMEOFCONC           8.0
ENDRATIONALCALC
ENDHY12RATIONAL

HY12RATIONAL
        HY12AREA
                HY12CALC
                        ID                      29
                        DOWNSTREAMID            69
                ENDHY12CALC
                AREA                            0.88
        ENDHY12AREA
RATIONALCALC
RATNAME              Rational Method Analysis
RATNOTES
CONSTANT             0.80
AREA                 0.88
TIMEOFCONC           5.0
ENDRATIONALCALC
ENDHY12RATIONAL

ENDHY12PROJECT
```

10.2 Report File Listing

```
//------------------------------------------------------------------------
--------
// Storm Drainage System Report
// HY12 version 1.0
//------------------------------------------------------------------------
--------



//------------------------------------------------------------------------
--------
// Project: HY-12 tutorial
//
//
// File: wmstutrat2.h12
//
// Notes: HY-12 Tutorial
//
//
//
```

```
// Unit System: English
//
// Steady Flow (Design Flow)
//
// Design Storm Sewer System
//   Allow the pipes to flow at 100% of full flow
//   The minimum allowed pipe diameter is 12 in
//   The maximum allowed pipe diameter is 24 in
//
// Assuming full capture at gutter inlets
//   No gutter inlets computations performed
//
//
//
//
// Date: 5/27/2010
// Time: 3:55 pm
//
//
//
// Designer: Merrill M. Taylor
//------------------------------------------------------------------------
--------
```

```
//------------------------------------------------------------------------
--------
// Pipe Geometry Summary
//------------------------------------------------------------------------
--------
```

ID	Diameter (in)	Length (ft)	Slope (ft/ft)	Invert Up (ft)	Invert Down (ft)	Cover Up (ft)	Cover Down (ft)
19	20.00	41.00	0.0098	4495.77	4495.37	--	--
18	16.00	419.00	0.0100	4499.96	4495.77	--	--
17	12.00	421.00	0.0100	4504.17	4499.96	--	--
16	12.00	292.00	0.0100	4507.09	4504.17	--	--
15	12.00	305.00	0.0100	4503.21	4500.17	--	--
14	16.00	264.00	0.0100	4504.03	4501.39	--	--
13	12.00	201.00	0.0100	4506.04	4504.03	--	--
12	12.00	285.00	0.0100	4507.97	4505.11	--	--
11	12.00	262.00	0.0100	4510.59	4507.97	--	--

```
//------------------------------------------------------------------------
--------
// Pipe Flow Summary
//------------------------------------------------------------------------
--------
```

ID	Flow	Flow Full	Velocity Normal	Velocity Full	Velocity Average

```
        (cfs)   (cfs)   (ft/s)          (ft/s)          (ft/s)
--------------------------------------------------------------------------
--------
19      12.24   14.89   7.62            6.82            3.81
18      6.71    8.31    6.63            5.95            5.56
17      3.25    3.86    5.51            4.91            2.07
16      1.56    3.86    4.66            4.91            3.33
15      1.75    3.85    4.79            4.91            3.51
14      6.43    8.31    6.57            5.95            6.57
13      1.81    3.86    4.84            4.91            3.57
12      3.13    3.87    5.48            4.92            5.48
11      1.26    3.86    4.39            4.91            2.99



//------------------------------------------------------------------------
--------
// Detailed Individual Component Report
//------------------------------------------------------------------------
--------

//-------------------
Rational Basin  ID: 26
        Runoff coefficient:     0.75
        Area:   1.67    acres
        Rainfall Intensity:     1.79    in/hr
        Flowrate:       2.26    cfs
        Time of Concentration: 9.00    min


//-------------------
Gutter Inlet    ID: 66
        Generic Gutter Inlet

//-------------------
Access Hole     ID: 46
        Elevation:      4499.96 ft
        Depth:  2.98    ft
        Pressure Head: 0.00    ft
        Surface Elevation:      4510.21 ft
        Time of Concentration + Travel Time:   9.27    min
        (Upstream Area)*(Runoff Coefficients):3.76    ac
        Flow:   6.71    cfs
        Bench Type:     Flat Bench
        Accesshole Width:       4.00    ft
        Depth of Access Hole below the Surface:         10.25   ft
        Relative Plunge Height:         0.00    ft
        Benching Headloss:      -0.039  ft
        Plunging Headloss:      0.000   ft
        Angled Flow Headloss:  1.283   ft


//-------------------
Pipe    ID: 18
        Pipe Shape:     Circular
        Length: 419.00  ft
```

```
        Manning's n:    0.012
        Slope:  0.0100  ft/ft
        Flow:   6.71    cfs
        Diameter:       1.33    ft
        -----------
        Pipe (inlet)
        Elevation:      4499.96 ft
        -----------
        Pipe (outlet)
        Elevation:      4495.77 ft
        Surface Elevation:      4509.53 ft


//--------------------
Access Hole     ID: 41
        Elevation:      4495.77 ft
        Depth:  2.26    ft
        Pressure Head: 0.00    ft
        Surface Elevation:      4509.53 ft
        Time of Concentration + Travel Time:  11.67   min
        (Upstream Area)*(Runoff Coefficients):7.54    ac
        Flow:   12.24   cfs
        Bench Type:     Flat Bench
        Accesshole Width:       4.00    ft
        Depth of Access Hole below the Surface:        13.76   ft
        Relative Plunge Height:         2.01    ft
        Benching Headloss:      -0.000  ft
        Plunging Headloss:      0.000   ft
        Angled Flow Headloss:   0.000   ft


//--------------------
Pipe    ID: 19
        Pipe Shape:     Circular
        Length: 41.00   ft
        Manning's n:    0.012
        Slope:  0.0098  ft/ft
        Flow:   12.24   cfs
        Diameter:       1.67    ft
        -----------
        Pipe (inlet)
        Elevation:      4495.77 ft
        -----------
        Pipe (outlet)
        Elevation:      4495.37 ft
        Surface Elevation:      4509.27 ft


//--------------------
Outfall ID: 40
        Elevation:      0.00    ft
        Depth:  1.10    ft
        Velocity:       0.00    ft/s
        Pressure Head: 0.00    ft
        Surface Elevation:      4509.27 ft
        Time of Concentration + Travel Time:  14.00   min
        (Upstream Area)*(Runoff Coefficients):8.92    ac
```

Flow: 14.30 cfs

//--------------------
Rational Basin ID: 28
Runoff coefficient: 0.74
Area: 1.37 acres
Rainfall Intensity: 1.88 in/hr
Flowrate: 1.92 cfs
Time of Concentration: 8.00 min

//--------------------
Gutter Inlet ID: 68
Generic Gutter Inlet

//--------------------
Access Hole ID: 48
Elevation: 4504.17 ft
Depth: 1.86 ft
Pressure Head: 0.00 ft
Surface Elevation: 4515.54 ft
Time of Concentration + Travel Time: 8.00 min
(Upstream Area)*(Runoff Coefficients):2.97 ac
Flow: 3.25 cfs
Bench Type: Flat Bench
Accesshole Width: 4.00 ft
Depth of Access Hole below the Surface: 11.37 ft
Relative Plunge Height: 0.00 ft
Benching Headloss: -0.000 ft
Plunging Headloss: 0.000 ft
Angled Flow Headloss: 0.000 ft

//--------------------
Pipe ID: 17
Pipe Shape: Circular
Length: 421.00 ft
Manning's n: 0.012
Slope: 0.0100 ft/ft
Flow: 3.25 cfs
Diameter: 1.00 ft

Pipe (inlet)
Elevation: 4504.17 ft

Pipe (outlet)
Elevation: 4499.96 ft
Surface Elevation: 4510.21 ft

//--------------------
Rational Basin ID: 29
Runoff coefficient: 0.80
Area: 0.88 acres
Rainfall Intensity: 2.20 in/hr
Flowrate: 1.56 cfs

Time of Concentration: 5.00 min

//-------------------
Gutter Inlet ID: 69
Generic Gutter Inlet

//-------------------
Access Hole ID: 49
Elevation: 4507.09 ft
Depth: 0.79 ft
Pressure Head: 0.00 ft
Surface Elevation: 4514.09 ft
Time of Concentration + Travel Time: 5.00 min
(Upstream Area)*(Runoff Coefficients):2.97 ac
Flow: 1.56 cfs
Bench Type: Flat Bench
Accesshole Width: 4.00 ft
Depth of Access Hole below the Surface: 7.00 ft
Relative Plunge Height: 0.00 ft
Benching Headloss: 0.000 ft
Plunging Headloss: 0.000 ft
Angled Flow Headloss: 0.000 ft

//-------------------
Pipe ID: 16
Pipe Shape: Circular
Length: 292.00 ft
Manning's n: 0.012
Slope: 0.0100 ft/ft
Flow: 1.56 cfs
Diameter: 1.00 ft

Pipe (inlet)
Elevation: 4507.09 ft

Pipe (outlet)
Elevation: 4504.17 ft
Surface Elevation: 4515.54 ft

//-------------------
Rational Basin ID: 27
Runoff coefficient: 0.78
Area: 1.01 acres
Rainfall Intensity: 2.20 in/hr
Flowrate: 1.75 cfs
Time of Concentration: 5.00 min

//-------------------
Gutter Inlet ID: 67
Generic Gutter Inlet

//-------------------
Access Hole ID: 47

```
        Elevation:     4503.21 ft
        Depth:  0.86    ft
        Pressure Head: 0.00    ft
        Surface Elevation:     4510.21 ft
        Time of Concentration + Travel Time:  5.00    min
        (Upstream Area)*(Runoff Coefficients):3.76    ac
        Flow:   1.75    cfs
        Bench Type:    Flat Bench
        Accesshole Width:      4.00    ft
        Depth of Access Hole below the Surface:       7.00    ft
        Relative Plunge Height:        0.00    ft
        Benching Headloss:     0.000   ft
        Plunging Headloss:     0.000   ft
        Angled Flow Headloss:  0.000   ft


//-------------------
Pipe    ID: 15
        Pipe Shape:    Circular
        Length: 305.00  ft
        Manning's n:   0.012
        Slope:  0.0100  ft/ft
        Flow:   1.75    cfs
        Diameter:      1.00    ft
        -----------
        Pipe (inlet)
        Elevation:     4503.21 ft
        -----------
        Pipe (outlet)
        Elevation:     4500.17 ft
        Surface Elevation:     4510.21 ft


//-------------------
Rational Basin  ID: 22
        Runoff coefficient:    0.71
        Area:   1.78    acres
        Rainfall Intensity:    1.65    in/hr
        Flowrate:      2.10    cfs
        Time of Concentration: 11.00   min


//-------------------
Gutter Inlet    ID: 62
        Generic Gutter Inlet

//-------------------
Access Hole     ID: 42
        Elevation:     4504.03 ft
        Depth:  1.81    ft
        Pressure Head: 0.00    ft
        Surface Elevation:     4512.30 ft
        Time of Concentration + Travel Time:  11.00   min
        (Upstream Area)*(Runoff Coefficients):7.54    ac
        Flow:   6.43    cfs
        Bench Type:    Flat Bench
        Accesshole Width:      4.00    ft
```

Depth of Access Hole below the Surface: 8.27 ft
Relative Plunge Height: 0.00 ft
Benching Headloss: -0.007 ft
Plunging Headloss: 0.000 ft
Angled Flow Headloss: 0.131 ft

//-------------------
Pipe ID: 14
Pipe Shape: Circular
Length: 264.00 ft
Manning's n: 0.012
Slope: 0.0100 ft/ft
Flow: 6.43 cfs
Diameter: 1.33 ft

Pipe (inlet)
Elevation: 4504.03 ft

Pipe (outlet)
Elevation: 4501.39 ft
Surface Elevation: 4509.53 ft

//-------------------
Rational Basin ID: 23
Runoff coefficient: 0.72
Area: 1.20 acres
Rainfall Intensity: 2.08 in/hr
Flowrate: 1.81 cfs
Time of Concentration: 6.00 min

//-------------------
Gutter Inlet ID: 63
Generic Gutter Inlet

//-------------------
Access Hole ID: 43
Elevation: 4506.04 ft
Depth: 0.88 ft
Pressure Head: 0.00 ft
Surface Elevation: 4513.04 ft
Time of Concentration + Travel Time: 6.00 min
(Upstream Area)*(Runoff Coefficients): 5.89 ac
Flow: 1.81 cfs
Bench Type: Flat Bench
Accesshole Width: 4.00 ft
Depth of Access Hole below the Surface: 7.00 ft
Relative Plunge Height: 0.00 ft
Benching Headloss: 0.000 ft
Plunging Headloss: 0.000 ft
Angled Flow Headloss: 0.000 ft

//-------------------
Pipe ID: 13

Pipe Shape: Circular
Length: 201.00 ft
Manning's n: 0.012
Slope: 0.0100 ft/ft
Flow: 1.81 cfs
Diameter: 1.00 ft

Pipe (inlet)
Elevation: 4506.04 ft

Pipe (outlet)
Elevation: 4504.03 ft
Surface Elevation: 4512.30 ft

//-------------------
Rational Basin ID: 24
Runoff coefficient: 0.73
Area: 1.40 acres
Rainfall Intensity: 1.88 in/hr
Flowrate: 1.93 cfs
Time of Concentration: 8.00 min

//-------------------
Gutter Inlet ID: 64
Generic Gutter Inlet

//-------------------
Access Hole ID: 44
Elevation: 4507.97 ft
Depth: 1.40 ft
Pressure Head: 0.00 ft
Surface Elevation: 4515.55 ft
Time of Concentration + Travel Time: 8.00 min
(Upstream Area)*(Runoff Coefficients):7.54 ac
Flow: 3.13 cfs
Bench Type: Flat Bench
Accesshole Width: 4.00 ft
Depth of Access Hole below the Surface: 7.58 ft
Relative Plunge Height: 0.00 ft
Benching Headloss: -0.006 ft
Plunging Headloss: 0.000 ft
Angled Flow Headloss: 0.145 ft

//-------------------
Pipe ID: 12
Pipe Shape: Circular
Length: 285.00 ft
Manning's n: 0.012
Slope: 0.0100 ft/ft
Flow: 3.13 cfs
Diameter: 1.00 ft

Pipe (inlet)
Elevation: 4507.97 ft

```
        -----------
        Pipe (outlet)
        Elevation:     4505.11 ft
        Surface Elevation:     4512.30 ft


//-------------------
Rational Basin ID: 25
        Runoff coefficient:    0.81
        Area:  0.78    acres
        Rainfall Intensity:    1.97    in/hr
        Flowrate:      1.26    cfs
        Time of Concentration: 7.00    min


//-------------------
Gutter Inlet   ID: 65
        Generic Gutter Inlet

//-------------------
Access Hole    ID: 45
        Elevation:     4510.59 ft
        Depth:  0.69    ft
        Pressure Head: 0.00    ft
        Surface Elevation:     4517.59 ft
        Time of Concentration + Travel Time:  7.00    min
        (Upstream Area)*(Runoff Coefficients):7.54    ac
        Flow:  1.26    cfs
        Bench Type:    Flat Bench
        Accesshole Width:      4.00    ft
        Depth of Access Hole below the Surface:       7.00    ft
        Relative Plunge Height:       0.00    ft
        Benching Headloss:     -0.000  ft
        Plunging Headloss:     0.000   ft
        Angled Flow Headloss:  0.000   ft


//-------------------
Pipe    ID: 11
        Pipe Shape:    Circular
        Length: 262.00  ft
        Manning's n:   0.012
        Slope:  0.0100  ft/ft
        Flow:  1.26    cfs
        Diameter:      1.00    ft
        -----------
        Pipe (inlet)
        Elevation:     4510.59 ft
        -----------
        Pipe (outlet)
        Elevation:     4507.97 ft
        Surface Elevation:     4515.55 ft


//-------------------
Rational Basin ID: 21
        Runoff coefficient:    0.76
```

Area: 1.81 acres
Rainfall Intensity: 1.49 in/hr
Flowrate: 2.06 cfs
Time of Concentration: 14.00 min

// Basin/Inlet Summary Table

Name	ID	Type of Structure	Peak Flow (cfs)	Bypass Flow (cfs)
	26	Rational Basin	2.26	--
	66	Gutter Inlet	2.26	0.00
	28	Rational Basin	1.92	--
	68	Gutter Inlet	1.92	0.00
	29	Rational Basin	1.56	--
	69	Gutter Inlet	1.56	0.00
	27	Rational Basin	1.75	--
	67	Gutter Inlet	1.75	0.00
	22	Rational Basin	2.10	--
	62	Gutter Inlet	2.10	0.00
	23	Rational Basin	1.81	--
	63	Gutter Inlet	1.81	0.00
	24	Rational Basin	1.93	--
	64	Gutter Inlet	1.93	0.00
	25	Rational Basin	1.26	--
	65	Gutter Inlet	1.26	0.00
	21	Rational Basin	2.06	--

// HGL/EGL Summary Table

Name	ID	Type of Structure	Invert Elev. (ft)	Crown Elev. (ft)	Ground Elev. (ft)	HGL Elev. (ft)	EGL	Pipe	Surfac Elev. (ft)	Sur-charge?	Overflow?

46	Access Hole	4499.96	--	4510.21	4502.94	4502.94	--	No
18	Pipe (inlet)	4499.96	4501.29	0.00	4500.29	4500.91	No	--
18	Pipe (outlet)	4495.77	4501.29	4509.53	4497.82	4498.18	No	--
41	Access Hole	4495.77	--	4509.53	4498.03	4498.03	--	No
19	Pipe (inlet)	4495.77	4497.44	0.00	4498.03	4498.03	Yes	--
19	Pipe (outlet)	4495.37	4497.44	4509.27	4496.86	4497.76	No	--
40	Outfall	0.00	--	4509.27	1.10	1.10	--	--
48	Access Hole	4504.17	--	4515.54	4506.03	4506.03	--	No
17	Pipe (inlet)	4504.17	4505.17	0.00	4506.03	4506.03	Yes	--
17	Pipe (outlet)	4499.96	4505.17	4510.21	4502.78	4503.04	No	--
49	Access Hole	4507.09	--	4514.09	4507.88	4507.88	--	No
16	Pipe (inlet)	4507.09	4508.09	0.00	4507.53	4507.87	No	--
16	Pipe (outlet)	4504.17	4508.09	4515.54	4505.99	4506.05	No	--
47	Access Hole	4503.21	--	4510.21	4504.07	4504.07	--	No
15	Pipe (inlet)	4503.21	4504.21	0.00	4503.68	4504.04	No	--
15	Pipe (outlet)	4500.17	4504.21	4510.21	4502.89	4502.97	No	--
42	Access Hole	4504.03	--	4512.30	4505.84	4505.84	--	No
14	Pipe (inlet)	4504.03	4505.36	0.00	4504.91	4505.58	No	--
14	Pipe (outlet)	4501.39	4505.36	4509.53	4502.56	4503.23	No	--
43	Access Hole	4506.04	--	4513.04	4506.92	4506.92	--	No
13	Pipe (inlet)	4506.04	4507.04	0.00	4506.52	4506.89	No	--
13	Pipe (outlet)	4504.03	4507.04	4512.30	4505.79	4505.87	No	--
44	Access Hole	4507.97	--	4515.55	4509.37	4509.37	--	No
12	Pipe (inlet)	4507.97	4508.97	0.00	4508.65	4509.12	No	--
12	Pipe (outlet)	4505.11	4508.97	4512.30	4505.99	4506.46	No	--
45	Access Hole	4510.59	--	4517.59	4511.28	4511.28	--	No
11	Pipe (inlet)	4510.59	4511.59	0.00	4510.98	4511.28	No	--
11	Pipe (outlet)	4507.97	4511.59	4515.55	4509.35	4509.39	No	--