

Comprehensive Hydraulic Analysis of a Small Urban Drainage System Using SSA Simulation, Python Stage–Storage Evaluation, and HEC-HMS Modeling (*Phase II of a Two-Phase Study on Urban Drainage Modeling*)

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Abstract: This paper presents the second phase of a continuing study on urban stormwater modeling. Building upon the detailed Civil 3D design developed in the first paper, including the accurate pavement detention volume and complete pipe network, the full drainage system is modeled in Autodesk Storm and Sanitary Analysis (SSA) to obtain the true hydraulic outflow based on both the geometric storage and the actual pipe flow behavior. The outflow results from SSA are compared with those computed using the Rational Method to evaluate differences between simplified hydrologic estimations and detailed hydraulic simulation. The same drainage configuration is also modeled in HEC-HMS to review the hydrologic response under a 100-year, 24-hour design storm and to provide an additional layer of model comparison. Furthermore, a new Python script is introduced that automatically processes SSA output files to generate a precise stage–storage curve for the underground detention system and reports the corresponding water surface elevation for any selected storage volume. This integrated workflow offers a comprehensive evaluation of stormwater performance using CAD-based geometry, hydraulic simulation, hydrologic modeling, and automated volume computation.

Keywords: Urban Drainage System, Rational Method, Civil 3D, SSA, Python Automation, HEC-HMS, Stage–Storage.

1. INTRODUCTION

Modern urban drainage design increasingly requires an integrated approach that moves beyond simplified hydrologic equations and incorporates the detailed hydraulic behavior of stormwater infrastructure. While the Rational Method provides a rapid and practical estimate of peak runoff for small catchments, it cannot capture the dynamic storage, flow routing, and time-dependent interactions that occur within underground detention systems and pipe networks. As cities expand and develop more complex subsurface conveyance structures, the need for accurate, geometry-based, and temporally resolved modeling has become essential. Hydrologic–hydraulic tools such as Autodesk Storm and Sanitary Analysis (SSA) and the HEC modeling suite are therefore widely used to simulate real rainfall events, evaluate detention performance, and verify compliance with modern municipal drainage criteria [1].

Building upon the automated Rational Method framework developed in the companion paper, this second study advances the analysis by integrating the complete project geometry into dynamic hydrologic, hydraulic modeling platforms. The fully documented 2022 Houston drainage design was reconstructed in Autodesk Civil 3D, exported into SSA, and evaluated under detailed hydraulic conditions including inlet responses, pipe routing, and underground detention performance. A key innovation of this study is the development of a custom Python script capable of computing precise pipe-based stage–storage curves directly from geometric parameters, a capability not provided by any existing hydrologic or hydraulic software, including SSA, HEC-HMS, SWMM, or Civil 3D [2]. This tool eliminates the

need for manual tabulation and allows highly accurate volume determination for any pipe configuration. In later sections, the computational method and functionality of this script are described in detail. To broaden the validation, the same drainage system was additionally modeled in HEC-HMS, enabling comparison of hydrographs, runoff timing, and detention behavior across three independent methodologies. Altogether, this integrated workflow, combining automated hydrologic calculations, detailed CAD-based geometry, dynamic simulation, and a novel stage–storage computational tool, provides a comprehensive platform for evaluating the performance of urban stormwater systems [3, 4]. Advanced simulation techniques have been applied extensively in this model [5, 6].

Ramirez et al developed a risk-based method for generating Emergency Operation Schedules (EOS) using the REOS software, which combines synthetic streamflow generation, mass-balance calculations, and frequency analysis to estimate release decisions under uncertain future inflows. They applied the method to the Addicks and Barker reservoirs in Houston through HEC-HMS and HEC-ResSim simulations, showing that risk-based EOS can improve flood regulation and help quantify the probability of upstream flooding under alternative operating policies [7, 8].

Konan [9] investigated recurrent urban flooding in Abidjan, Côte d'Ivoire, where major flood events have caused significant annual losses. Their study modeled flood occurrence in the Bonoumin–Rivière Palmeraie watershed using a DEM processed in ArcGIS/HEC-GeoHMS to delineate sub-basins and extract hydrologic parameters. These

parameters were used to estimate runoff in HEC-HMS, and the resulting discharges were imported into HEC-RAS to simulate stormwater conveyance and floodwave propagation. The hydraulic results supported floodplain delineation in HEC-GeoRAS for improved flood preparedness and risk assessment.

Similarly, Timoth et al [10] analyzed the impact of rapid urbanization on stormwater runoff in the Msimbazi River watershed, Dar es Salaam. Using satellite imagery from 1998–2018, ArcGIS, and HEC-HMS, they quantified how land-use change increased impervious cover and peak discharges. Hydrologic modeling with SCS CN, SCS unit hydrograph, and lag routing showed a 23% rise in peak flow from 1998 to 2018. They grouped small sub-catchments into five larger basins and designed detention reservoirs at each outlet, capturing about 65% of peak runoff during extreme events. Their results highlight the need for integrated stormwater management in rapidly urbanizing cities.

In further research, Hanazaki et al [11] developed a risk-based methodology for generating Emergency Operation Schedules (EOS) to guide real-time reservoir releases during major floods. Their REOS model combines synthetic streamflow generation, mass-balance simulation, and frequency analysis to compute releases tied to storage levels, inflow conditions, and seasonal factors, each with an associated probability of exceeding critical storage. Applied to the Addicks and Barker reservoirs in Houston using HEC-HMS and HEC-ResSim simulations, including scenarios based on Tropical Storm Allison, the method demonstrated how risk-based EOS can improve flood regulation and help assess upstream flooding probabilities under alternative emergency policies.

In addition, Urgessa [12] examined the hydraulic design of road drainage structures along the Shishinda–Tepi road project in Ethiopia, where earlier systems were often under- or oversized due to limited data. Using collected land-use, soil, and rainfall information, they estimated peak discharges for each cross-drainage structure through the Rational Method, SCS method, or frequency analysis. Conveyance capacities were evaluated with Manning’s equation, and HEC-RAS was applied at key river crossings to compute steady-state water surface profiles, stage–discharge curves, and scour depths for multiple return periods. Their results highlight the strong influence of land cover, soil type, and rainfall intensity on runoff and drainage design.

In light of these limitations, the present study introduces a missing capability in modern stormwater modeling: a fully automated, geometry-based Python tool that derives precise pipe stage–storage relationships directly from CAD-defined underground detention systems. No existing hydrologic or hydraulic platform, including SSA, HEC-HMS, SWMM, or Civil 3D, can generate this level of volumetric accuracy for complex multi-pipe configurations without extensive manual tabulation. In this workflow, two Excel files exported from SSA are processed by the custom Python script, which computes total pipe volume and produces a high-resolution stage–storage curve that matches the physical geometry with exceptional precision. Because such accuracy is crucial for large-scale urban developments, particularly in rapidly expanding regions such as Texas, this tool has the potential to significantly influence future design reliability and decision-making at the municipal and regional scale. Addressing a long-standing engineering challenge, this contribution represents one of the most technically significant components

of the present work. Moreover, given the importance of precise storage quantification in large urban drainage systems, the author intends to extend this line of research with new, more innovative methods in future studies to push the accuracy and applicability of underground detention modeling even further.

2. Methodology

The methodology for this study follows a structured, multi-platform workflow that integrates geometric modeling, hydraulic simulation, automated storage computation, and independent hydrologic verification. The base drainage layout, originally developed in Autodesk Civil 3D and documented in the companion paper, is briefly summarized here as the foundation for subsequent analysis. The Civil 3D model was exported into Autodesk Storm and Sanitary Analysis (SSA) to evaluate inlet behavior, pipe routing, and detention performance under a 100-year design storm. Key SSA output files were then processed using a custom Python script created for this research, enabling precise computation of underground detention volume and high-resolution stage–storage curves directly from actual pipe geometry. Finally, the system was independently modeled in HEC-HMS using NOAA Atlas 14 rainfall data and a transform method appropriate for small urban catchments. Together, these steps provide a comprehensive and consistent framework for evaluating the drainage system using both CAD-based hydraulic tools and hydrologic simulation.

2.1 Civil 3D Configuration

The initial drainage model was constructed in Autodesk Civil 3D for a 0.344-acre project site divided into six catchments: A1, A2, A3, A4, Roof A, and Roof B. Each catchment drains into an assigned catch basin, with Roof A and Roof B discharging into the same inlets as A1 and A2 respectively. Pavement detention storage was computed by creating separate top and bottom TIN surfaces and calculating the volume between them using the Volume Surface tool, resulting in a geometric storage capacity of 7,666 cubic feet.

2.2 Export and Hydraulic Modeling in SSA

The complete Civil 3D pipe and catchment network was exported to Autodesk Storm and Sanitary Analysis (SSA) using the STM file format. After import, the model was configured for a 100-year design storm based on Harris County rainfall parameters, with intensity defined using the regional equation $i = b/(d + t)^e$. Default SSA IDF values were replaced with county-specific coefficients. The SSA model reproduced the hydraulic behavior of the pipe system and reflected the pavement detention storage originally defined in Civil 3D.

2.3 Python Based Stage Storage Computation

Two SSA output reports containing inlet and pipe data were exported as text files and converted directly to Excel without modification. A custom Python script processed these files, filtered out non-active structures, and computed the total detention volume of all contributing pipes. After the user confirmed uniform geometric parameters (length, width, height, flow line elevation), the script generated the complete storage volume and a detailed stage–storage curve. The tool

also allowed the user to request any percentage of volume (e.g., 25%, 50%, 70%) and instantly returned the corresponding water surface elevation.

2.4 HEC-HMS Hydrologic Modeling

For independent hydrologic verification, the project was also modeled in HEC-HMS using a 24-hour, 100-year rainfall depth obtained from NOAA Atlas 14. The Clark Unit Hydrograph method was selected due to its suitability for small urban basins and its ability to represent both time of concentration and storage coefficient. Because HEC-HMS does not allow conduit lengths to be shorter than 33 feet, several original pipe lengths (15, 18, and 28 feet) were adjusted to the minimum allowable length. The HEC-HMS configuration included all subbasins, junctions, and the restrictor structure to approximate the overall runoff behavior of the detention system within the constraints of the software.

3. Simulation and Results

This section presents the complete set of hydraulic and hydrologic simulation results obtained from Autodesk Storm and Sanitary Analysis (SSA), the custom Python stage-storage computation tool, and the HEC-HMS hydrologic model. The SSA simulations evaluate the detailed hydraulic behavior of the pipe network, including flow routing, hydraulic grade lines, energy grade lines, and system performance under a 100-year design storm. The Python script results provide precise underground detention volume and a high-resolution stage-storage curve directly derived from SSA-generated pipe geometry. Finally, the HEC-HMS model offers an independent hydrologic verification of runoff generation, storm response, and peak discharge using a 100-year, 24-hour hypothetical storm based on NOAA Atlas 14 rainfall data. Together, these three modeling platforms allow cross-validation of hydraulic and hydrologic behavior and provide a comprehensive understanding of system performance under extreme design conditions.

3.1 SSA Results

Figure 1 presents the initial plan view generated in Autodesk Storm and Sanitary Analysis (SSA), which serves as the starting point for the hydraulic simulation results. The figure illustrates the full layout of all 34 pipelines, showing how the Civil 3D drainage configuration was transferred into SSA for analysis. The routing of stormwater is clearly visible, from the upstream inlets where flow enters the system, through the parallel conduits, and ultimately toward the final outfall. This plan view establishes the overall geometric framework of the underground network before examining the detailed hydraulic performance in subsequent figures.

The profile view of one of the main pipes is shown in Figure 2. The pipe carries the designed flow under full-capacity conditions, and both the hydraulic grade line (HGL) and energy grade line (EGL) remain below the top of the structures, indicating that the system operates without surcharge. The cover depth along the pipe ranges from approximately 3.1 to 3.5 feet, confirming that the design meets the minimum burial requirements.

A portion of the detailed SSA output report is provided in Figure 3. The report summarizes all hydraulic parameters for the main pipes, including flow rate, slope, velocity, energy

loss, and junction elevations. Because the SSA output table is presented in a longitudinal format that extends horizontally across multiple columns, it was not possible to capture it in a single screenshot. Therefore, the report was divided into several segments and arranged vertically to clearly display all relevant data in sequence.

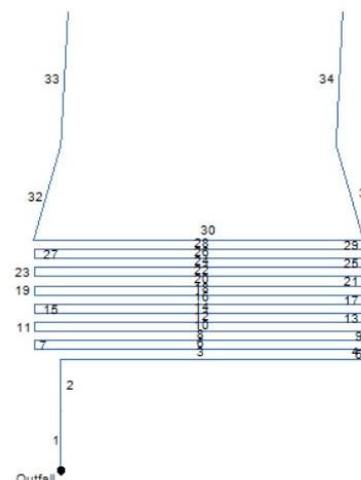


Figure 1. Plan view of the full SSA drainage network.



Figure 2. Pipe profile showing hydraulic and energy grade lines.

3.2 Python Script Results

The custom Python script was developed to automate the stage-storage analysis based on the output data exported from SSA. Two text reports were taken from SSA, one containing the inlet information and the other containing the pipe data. These reports were converted into Excel format and imported directly into the Python script without any manual modification or reformatting.

The script automatically reads all pipes and filters the active structures whose surface area is greater than zero, excluding null structures that were used in Civil 3D only as pipe connectors. Once the active structures are identified, the program prompts the user to confirm whether all of them share the same geometric dimensions. If confirmed, the user inputs the structure length, width, height, and base flowline elevation. Using these parameters, the script computes the total detention volume and allows the user to specify a percentage of the total storage to determine the corresponding water surface elevation.

Line No.	Area Dn (sqft)	Area Up (sqft)	Bypass Line No.	C1 (C)	C2 (C)	C3 (C)	Capacity Full (cfs)	Critical Depth (ft)	Cross Slope, Sw (ft/ft)	Cross Slope, Sx (ft/ft)	Curb Length (ft)	Defl Angle (Deg)	Depth Dn (ft)	Depth Up (ft)	DnStm Line No.	Drainage Area (ac)	Easting X (ft)	EGL Dn (ft)	EGL Up (ft)	Energy Loss (ft)	Flow Rate (cfs)	Sf Ave (%)	Sf Dn (%)	Grate Area (sqft)	Grate Length (ft)	Grate Width (ft)
1	0.20	0.20	n/a	0.20	0.50	0.90	0.32	0.50	---	---	---	-90.000	0.50	0.50	Outfall	0.00	2973.89	64.64	67.47	2.821	2.43	15.684	15.408	---	---	---
2	3.14	3.14	n/a	0.20	0.50	0.90	12.65	0.54	---	---	---	-0.061	2.00	2.00	1	0.08	2973.88	65.46	65.46	0.001	2.43	0.010	0.010	---	---	---
3	3.14	3.14	n/a	0.20	0.50	0.90	6.32	0.47	---	---	---	90.061	2.00	2.00	2	0.08	3033.93	65.46	65.47	0.003	1.82	0.006	0.006	---	---	---

Line No.	Gnd/Rm Elev Dn (ft)	Gnd/Rm Elev Up (ft)	Gutter Depth (ft)	Gutter Slope (ft/ft)	Gutter Spread (ft)	Gutter Width (ft)	HGL Dn (ft)	HGL Up (ft)	HGL Jct (ft)	HGL Jmp Dn (ft)	HGL Jmp Up (ft)	Incr Cx/A	Incr Q (cfs)	Inlet Depth (ft)	Inlet SF (%)	Inlet ID	Inlet Location	Inlet Time (min)	I Sys (in/hr)	I Inlet (in/hr)	Invert Dn (ft)	Invert Up (ft)	Jump Loc (ft)	Jump Len (ft)
1	62.81	65.45	---	---	---	---	62.27	65.09	65.45	---	---	0.00	0.00	---	---	Structure - (54)	On Grade	0.0	8.16	0.00	61.77	61.82	---	---
2	65.45	65.25	---	---	---	---	65.45	65.45	65.46	---	---	0.08	0.70	---	---	Structure - (55)	On Grade	21.4	8.17	9.20	61.82	61.86	---	---
3	65.25	64.04	---	---	---	---	65.46	65.46	65.46	---	---	0.08	0.70	---	---	Structure - (47)	On Grade	21.4	8.22	9.20	61.82	61.86	---	---

Line No.	Vel Hd Jmp Dn (ft)	Vel Hd Jmp Up (ft)	J-Loss Coeff	Junct Type	Known Q (cfs)	Cost RCP ((0))	Cost CMP ((0))	Cost PVC ((0))	Line ID	Line Length (ft)	Line Size (in)	Line Slope (%)	Line Type	Local Dep (in)	n-value Gutter	n-value Pipe	Minor Loss (ft)	Nothing Y (ft)	Pipe Travel (min)	Q Bypass (cfs)	Q Captured (cfs)	Q Carryover (cfs)	Line Rise (in)	Runoff Coeff (C)	Line Span (in)
1	0.00	0.00	0.15	None	0.00	120	108	102	Pipe - (47)	17.987	6	0.28	Cr	---	0.012	0.36	7384.99	0.10	---	---	---	6	0.00	6	
2	0.00	0.00	1.00	None	0.00	780	702	663	Pipe - (46)	15.000	24	0.27	Cr	---	0.012	0.01	7399.99	0.08	---	---	---	24	0.90	24	
3	0.00	0.00	1.00	None	0.00	2,424	2,182	2,060	Pipe - (43)	60.054	24	0.07	Cr	---	0.012	0.00	7399.99	0.33	---	---	---	24	0.90	24	

Subarea A1 (ac)	Subarea A2 (ac)	Subarea A3 (ac)	Tc (min)	Throat Ht (ft)	Total Area (ac)	Total Cx/A	Total Runoff (cfs)	Vel Ave (ft/s)	Vel Dn (ft/s)	Vel Hd Dn (ft)	Vel Hd Up (ft)	Cover Dn (ft)	Cover Up (ft)	Storage (cft)	
0.00	0.00	0.00	27.4	---	0.33	0.30	2.43	12.36	12.36	2.38	2.37	12.36	0.54	3.13	3.53
0.00	0.00	0.00	27.3	---	0.33	0.30	2.43	0.77	0.77	0.01	0.01	0.77	1.63	1.39	47.11
0.00	0.00	0.00	27.0	---	0.25	0.22	1.82	0.58	0.58	0.01	0.01	0.58	1.43	0.18	188.63

Figure 3. Extract from the SSA detailed output report.

As shown in Figure 4, the total storage volume for the system was calculated as 3,679.25 cubic feet. The script also identified that at 25 percent of total capacity, the stored volume was approximately 920 cubic feet with a corresponding elevation of 62.39 feet.

```

1 import pandas as pd
2 import math
3
4 # =====
5 # =====
6 # =====
7 PIPE_PATH = r"C:\Users\Name\Desktop\Stage-Storage\Pipe.xlsx"
8 DNLET_PATH = r"C:\Users\Name\Desktop\Stage-Storage\Inlet-Structure.xlsx"
9
10 # =====
11 # Read Excel Data
12 # =====
13 pipe_df = pd.read_excel(PIPE_PATH)
14 inlet_df = pd.read_excel(DNLET_PATH)
15
16 # =====
17 # Filter Active Structures (Area > 0)
18 # =====
19 inlet_df["Area"] = pd.to_numeric(inlet_df["Area"], errors="coerce")
20 active_structures = inlet_df[inlet_df["Area"] > 0]
21
22 print(f"Number of active inlet structures (Area > 0): {len(active_structures)}")
23
24 # =====
25 # Ask if structures are identical
26 # =====
27 same_structures = input("Are all active structures identical? (yes/no): ").strip()
28
29 if same_structures == "yes":
30     struct_length = float(input("Enter structure internal length (ft): "))
31     struct_width = float(input("Enter structure internal width (ft): "))
32     struct_height = float(input("Enter structure internal height (ft): "))
33     base_flowline = float(input("Enter base flowline elevation (ft): "))
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Figure 4. Python console output showing calculated total and partial storage volumes.

Figure 5 presents the stage-storage curve generated by the program, clearly illustrating the volumetric response of the underground detention system across different water surface elevations.

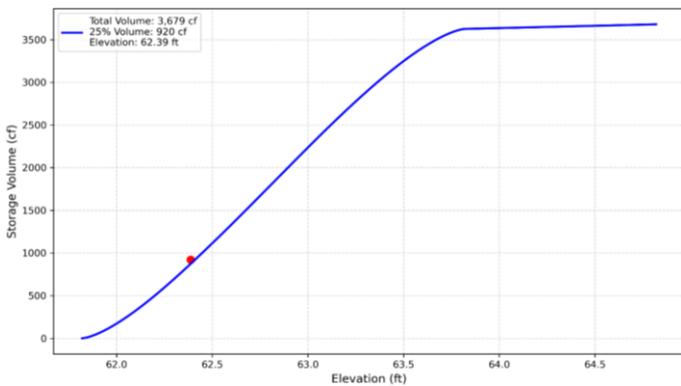


Figure 5. Stage-storage curve generated by the Python script for the underground detention system.

3.3 HEC-HMS Simulation Results

The same drainage system was modeled in HEC-HMS to simulate runoff hydrographs for a 100-year, 24-hour design storm. The project area of approximately 0.344 acres was divided into six subbasins, each draining toward its respective reservoir or catch basin. Figure 6 shows the overall basin layout, which includes subbasins, junctions, reservoirs, and the final outlet (Sink-JB4).

The simulation used the SCS Type III hypothetical storm method with a total point depth of 16.7 inches, obtained from NOAA Atlas 14 for the project location. Precipitation was uniformly distributed across all subbasins, and the transform method was set to the Clark Unit Hydrograph. This method was selected because it provides better performance for small drainage areas (less than one acre) where flow concentration and storage effects are more localized.

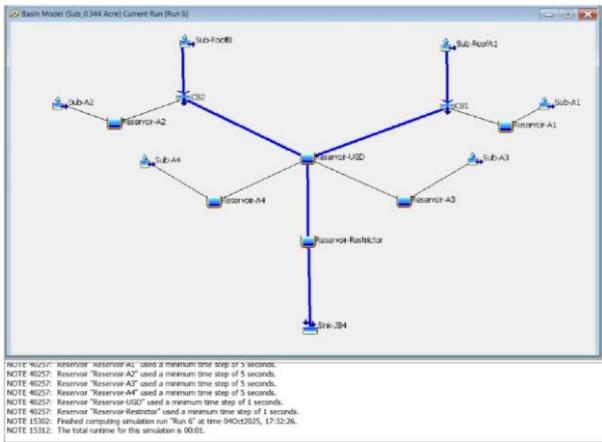


Figure 6. HEC-HMS basin model showing all subbasins, reservoirs, and outlets.

Since HEC-HMS requires a minimum reach length of 33 feet, all shorter links (15, 18, and 28 feet in the real drainage plan) were adjusted to 33 feet. This adjustment slightly reduces the precision of hydraulic routing but remains within acceptable tolerance for small-scale stormwater modeling. Figure 7 presents the global summary of simulation results, including the computed peak discharge for each hydrologic element.

The final hydrograph at the outlet (Sink-JB4) is shown in Figure 8. The model produced a peak discharge of approximately 1.98 cubic feet per second (cfs) at the outlet. The hydrograph illustrates a sharp rise and gradual recession typical of short-duration, high-intensity storms affecting small catchments.

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (IN)
Sub-A1	0.00013	0.64905	1 January 2000, 12:21	16.62
Reservoir-A1	0.00013	0.47357	1 January 2000, 12:41	16.64
Reach-RoofA1-CB1	0.00001	0.06564	1 January 2000, 12:19	16.63
CB1	0.00014	0.52063	1 January 2000, 12:37	16.64
Sub-RoofB	0.00001	0.06565	1 January 2000, 12:19	16.63
Sub-A2	0.00013	0.64905	1 January 2000, 12:21	16.62
Reservoir-A2	0.00013	0.47357	1 January 2000, 12:41	16.64
Reach-RoofB-CB2	0.00001	0.06564	1 January 2000, 12:19	16.63
CB2	0.00014	0.52063	1 January 2000, 12:37	16.64
Reach-CB2-Reservoir	0.00014	0.52061	1 January 2000, 12:37	16.64
Reach-CB1-Reservoir	0.00014	0.52061	1 January 2000, 12:37	16.64
Sub-A3	0.00013	0.64400	1 January 2000, 12:21	16.62
Reservoir-A3	0.00013	0.47067	1 January 2000, 12:41	16.64
Sub-A4	0.00013	0.64400	1 January 2000, 12:21	16.62
Reservoir-A4	0.00013	0.47067	1 January 2000, 12:41	16.64
Reservoir-UGD	0.00054	1.98025	1 January 2000, 12:39	16.67
Reach-Reservoir-Jb3	0.00054	1.98029	1 January 2000, 12:40	16.67
Reservoir-Restrictor	0.00054	1.98030	1 January 2000, 12:40	16.67
Reach-Res-JB4	0.00054	1.98029	1 January 2000, 12:40	16.67
Sub-RoofA1	0.00001	0.06565	1 January 2000, 12:19	16.63
Sink-JB4	0.00054	1.98029	1 January 2000, 12:40	16.67

Figure 7. Global summary table for 100-year, 24-hour hypothetical storm simulation.

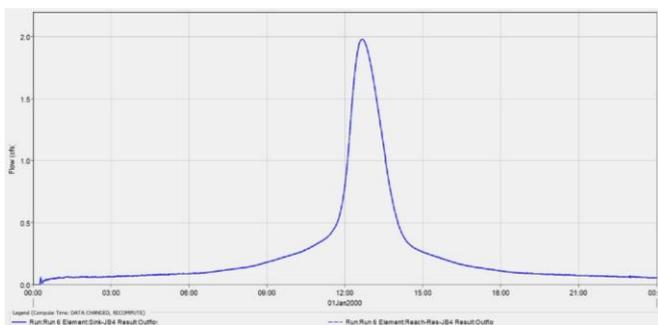


Figure 8. Outflow hydrograph at Sink-JB4 generated by the HEC-HMS model.

4. Discussion and Comparison

In this study, three different methods were used to evaluate the drainage system: the Storm and Sanitary Analysis (SSA), a Python script, and HEC-HMS. The results show that the SSA model provides the most realistic outcome because it was developed directly from the Civil 3D geometry, using the actual elevations, slopes, and pipe dimensions from the site. This makes the hydraulic behavior in SSA closely represent real flow conditions. The final discharge of 2.43 cfs can therefore be considered the most accurate reflection of the true performance of the system.

The Python script was designed to work with the raw output from SSA without requiring any manual editing. It automatically calculates the total detention volume and can determine the corresponding elevation for any selected percentage of volume. The script is fully automated and much

more precise than manual methods because it uses nonlinear numerical procedures to calculate pipe behavior and keeps adjusting the results until it reaches the closest possible value. This process would be extremely time-consuming and complex to perform by hand, but the script completes it within seconds, improving both accuracy and efficiency.

In the HEC-HMS model, the Clark Unit Hydrograph method was used, which relies on the time of concentration and storage coefficient parameters. This method is suitable for small drainage areas. For rainfall data, a 24-hour, 100-year Hypothetical Storm was applied. While HEC-HMS is generally developed for larger basins, the results from this project showed that it can still produce a realistic hydrologic response for a small site. The slight difference between the HEC-HMS and SSA results comes mainly from model limitations, since HEC-HMS does not accept pipe lengths shorter than 33 feet, and also from the type of rainfall distribution used in the simulation.

Overall, the peak discharge obtained from the SSA model was 2.43 cfs, from the HEC-HMS model was 1.98 cfs, and from the Rational Method used in the first paper was 2.49 cfs. The similarity between the Rational Method and SSA results confirms that both methods are reliable for small drainage areas. The HEC-HMS result also shows that the system works properly during a 100-year, 24-hour rainfall, with stable flow and no sign of flooding. These results confirm that the drainage design is hydraulically safe, accurate, and consistent with the required design standards.

5. Conclusion

The results of this study demonstrate that using SSA, a Python script, and HEC-HMS together provides accurate and consistent modeling for small drainage systems. The SSA model, which was based on real Civil 3D geometry, gave the most realistic result, showing a final discharge of 2.43 cfs that represents the actual site conditions.

The Python script proved to be a practical and reliable tool. It calculates the total detention volume, the corresponding elevation, and the percentage of storage automatically and with very high accuracy. Since it applies nonlinear iterative calculations, it can reach more precise results than manual methods, while also saving time and reducing possible human error.

The HEC-HMS model, which used the Clark Unit Hydrograph method along with a 24-hour, 100-year Hypothetical Storm, produced reasonable and realistic results even though the model is mainly designed for larger basins. The small difference between HEC-HMS and SSA results is expected and acceptable considering the difference in model structure and rainfall distribution.

In conclusion, the designed drainage system performs safely and efficiently under extreme rainfall conditions. The combination of SSA, Python automation, and HEC-HMS provides a powerful and accurate framework for analyzing and validating small-scale urban drainage designs.

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