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Automated implementation of the rational method using Python and volume verification in Civil 3D for an Urban Drainage Design in Houston (Phase I of a Two-Phase Study on Urban Drainage Modeling)

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Abstract

This study introduces a generalized Python automation framework for the Rational Method, designed to generate complete peak-runoff and detention calculations for small urban drainage systems. The script incorporates all hydrologic components of the Rational Method, including time of concentration, rainfall intensity from editable IDF tables, pre- and post-development runoff, allowable release rates, detention storage, and automatic restrictor-orifice evaluation. The tool was validated using a fully documented 2022 drainage design project in Houston, and the automated results matched the original engineer-approved calculations exactly, confirming both accuracy and repeatability. To complement the computational workflow, the same project site was reconstructed in Autodesk Civil 3D using real grading, subbasins, catch basins, and the underground detention system. Detention volume was computed using surface-to-surface volumetric analysis, providing a geometry-based estimate that reflects actual site elevations. A comparison between Civil 3D volumetric results and the Rational Method output illustrates how precise grading and surface modeling influence detention capacity. This integrated methodology, combining automated hydrologic calculation with three-dimensional CAD reconstruction, establishes a robust foundation for subsequent hydraulic validation, which will be performed in Storm and Sanitary Analysis (SSA) in a companion study.

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

1. Introduction

The Rational Method is one of the most widely accepted and extensively used techniques for estimating peak discharge in small urban drainage areas, particularly in subbasins with relatively short times of concentration. Its strength lies in its simplicity, transparency, and strong theoretical grounding, which make it especially useful for engineering applications that require fast and reliable peak flow estimation. Because the method directly relates rainfall intensity, contributing area, and an empirically derived runoff coefficient, it performs exceptionally well in small catchments where flow response is rapid and dominated by surface runoff processes. For these compact basins, the Rational Method is known for producing highly accurate peak-discharge estimates when applied with properly selected rainfall intensities and runoff coefficients. In 2022, this method was applied to a real site in Houston, where all input parameters, calculations, and resulting design outputs were carefully documented, forming a validated reference dataset for subsequent modeling and comparison [1, 2].

Romans [3] evaluated twenty detention ponds in the Knoxville region of Tennessee to determine whether the constructed facilities matched their approved design plans. Their survey revealed that 17 of the 20 ponds were not built as designed, primarily due to insufficient storage volume, improperly constructed outlet structures, or both. As a result,

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many of the ponds failed to reduce downstream peak runoff effectively, creating increased flood risk and potential legal exposure for surrounding communities. Sima et al. emphasize that regular inspection during and after construction is essential to ensure compliance with design plans and to maintain the intended stormwater management performance.

Similarly, Thanapura [4] developed and evaluated the Composite Runoff Index (RIc) geographic model to streamline the traditionally labor-intensive process of estimating urban runoff indices in ungaged watersheds. Their approach uses an area-weighted remote sensing and GIS–based parameterization scheme to efficiently estimate two key inputs for widely used rainfall–runoff methods: the curve number (CN) for the NRCS-CN method and the runoff coefficient (C) for the Rational Method. Using case studies in Sioux Falls, South Dakota, and Las Vegas, Nevada, the authors demonstrated that the RIc model provides a more effective basis for urban drainage design and runoff prediction. They conclude that applying the RIc model in rapidly growing, ungaged urban areas can improve stormwater management, reduce uncertainty in peak flow estimates, and help mitigate flooding risks that threaten public safety and property.

In further research, Oxley et al [5] developed an optimization-based model for designing detention basin systems by integrating a simulated annealing (SA) algorithm with HEC-HMS. Their VBA–Excel framework automates repeated HEC-HMS simulations and extracts results through a Python script, allowing the SA algorithm to optimize basin size, placement, and outlet structures under design constraints. Through single-basin and multi-basin case studies, the authors show that despite the high computational demand, simulated annealing provides more effective detention basin designs compared to conventional practice.

In addition, Ferreira et al [6] developed an optimization model to size detention reservoirs in an urban watershed with the dual goals of minimizing implementation costs and reducing flood risks. Their approach integrates PCSWMM for watershed characterization, HEC-RAS 2D for flood-prone area delineation, and a nonlinear GAMS optimization model to determine reservoir height, surface area, and outlet diameter. Applied to a system of six reservoirs, the model identified configurations that effectively reduce peak flows, with a total inundated area of about 270,989 m^2 and maximum depths near 1.9 m. The optimized system costs roughly $ 1.16 million. The study offers a practical, replicable framework combining hydrologic/hydraulic modeling with optimization to improve flood control in urban watersheds. Investigations of thin structures often require consideration of stability, geometric nonlinearity, or material nonlinearity [7, 8]. SMA shell buckling studies [9, 10] provide insight into nonlinear response characteristics in thin-walled systems.

Moreover, Jainet [11] analyzed the theoretical basis of the Rational Method by showing that its instantaneous unit hydrograph (IUH) corresponds to the time–area concentration curve of a symmetric V-shaped watershed. Using HEC-HMS kinematic wave simulations for watersheds between 0.1 and 1 km^2, they demonstrated that increasing rainfall intensity causes kinematic-wave hydrographs to approach the triangular form characteristic of the Rational Method. Conversely, as the watershed area increases, the hydrographs deviate from that triangular shape. Their results confirm that the Rational Method is appropriate for small urban watersheds, not only for peak flow estimation but also for representing runoff volume distribution.To sum up, in this study, a Python script was developed to replicate the original Rational Method workflow automatically. The script accepts key inputs such as catchment area, surface elevation, and IDF rainfall data, and it performs all related calculations, such as time of concentration, peak discharge, restrictor design, pipe sizing, and detention volume, instantly and with 100% accuracy. The validation confirmed that the output from the script exactly matched the original 2022 Rational Method calculations, demonstrating the script's precision. One major advantage of the script is its flexibility: designers can simply update the return period (e.g., 2-year, 100-year storm) without redoing the calculations manually, making it highly efficient for both initial design and future iterations.

This automated workflow is particularly valuable for regions like Houston, where increasing flood frequency, rising groundwater levels, and rapid urbanization have intensified the demand for fast, accurate, and repeatable stormwater design tools. Following Hurricane Harvey in 2017, an event that fundamentally changed Houston's stormwater design standards by shifting many criteria from the traditional 100-year storm to 500-year requirements, local regulations became significantly stricter to prevent similar catastrophic impacts. As the region continues adopting more resilient and conservative detention criteria, the need for flexible computational methods has increased. The Python-based system developed in this study directly supports these post-Harvey objectives by enabling rapid recalculation of detention volumes and restrictor sizing across multiple storm scenarios, contributing to efforts aimed at lowering flood risk and managing shallow groundwater. This research is aligned with Houston's ongoing push for enhanced flood resilience, and it forms the foundation for future work in the U.S. that will incorporate more advanced, modernized methods to further strengthen detention system design.

In addition, the same site was modeled in AutoCAD Civil 3D, where the pavement area and pipe network were recreated. Using the Top and Bottom surface method, the actual detention volume was extracted. As expected, the Civil 3D volume was slightly lower than the Rational Method estimate, due to real-world grading and elevation factors.

In the next phase of this research, the complete model will be launched in Storm and Sanitary Analysis (SSA) to simulate the real hydraulic behavior of the system. Since the Civil 3D model was already developed with accurate grading and surface data, the input conditions in SSA fully represent the actual site characteristics. Through SSA, the true hydraulic outflow and system response will be obtained based on realistic geometry and flow conditions. These results will then be compared with those from the Python-based Rational Method, allowing evaluation of how closely the traditional method aligns with real hydraulic performance.

2. Methodology

This section presents the methodological framework adopted in this study, combining a traditional design approach with modern computational tools. First, in section 2.1, the baseline hydrologic behavior of the site is characterized using the Rational Method as originally applied in a 2022 Houston drainage study, providing a fully documented reference case for peak flow estimation. Building on this foundation, a custom Python script, developed specifically for this research, is introduced to automate and extend the Rational Method workflow, enabling flexible recalculation of peak discharge, detention volume, and restrictor sizing across multiple storm scenarios, Section 2.2. Finally, in the last section, Autodesk Civil 3D is used to construct a detailed 3D surface model of the site and to compute actual excavation and pavement-related detention volumes, allowing direct comparison between theoretical estimates and CAD-based volumetric results. Together, these three components form an integrated methodology that links an existing real-world design with enhanced automation and more realistic geometric representation.

2.1. Rational Method Framework

The Rational Method estimates peak discharge by relating rainfall intensity, drainage area, and surface runoff characteristics. The procedure begins with determining the time of concentration (Tc), which represents the travel time for runoff from the hydraulically most distant point to the outlet. The empirical formula used in the 2022 Houston study is [12]:

$$T_c = 10 \times (A^{0.144}) + 15 \qquad \dots\dots \qquad (1)$$

Where, T_c is the time of concentration (minutes), A is the drainage area (acres). Once T_c is calculated, the corresponding rainfall intensity (i) is obtained from Harris County's official IDF curves. The general intensity relationship is expressed as [13]:

$$i = \frac{b}{(d + T_c)^e} \qquad \dots\dots \qquad (2)$$

Where, i is rainfall intensity (in/hr), b, d, e are empirical IDF coefficients for the selected return period, and T_c is the time of concentration (minutes).

Next, the runoff coefficient (C) is determined based on the imperviousness ratio of the drainage area [13]:

$$C = 0.6\, I_a + 0.2 \qquad \dots\dots. \qquad (3)$$

In this Equation, C is the runoff coefficient, and I_a is the Impervious area ratio (impervious area / total area).

Using these parameters, the peak discharge is computed with the standard Rational Method equation [14]:

$$Q = C_i A \qquad \dots\dots \qquad (4)$$

Where, Q, C, i, and A are Peak flow (cfs), Runoff coefficient (unitless, based on land cover), rainfall intensity (in/hr), and the Drainage area ($acers$) respectively.

Both pre-development and post-development peak flows are evaluated using the same framework, forming the hydrologic basis for detention design. The required detention volume is then determined using the City of Houston's detention rate:

$$V_r = 14356 \times (Detection\ Rate) \times A_d \quad \text{.....} \quad (5)$$

Where, V_r is Required detention volume ($Cubic\ feet$), A_d is a Disturbed area ($acers$), and the Detention rate of Houston is 0.75 $ac - ft\ per\ acre$.

$$Q = C_d A_0 \sqrt{2gh} \quad \text{........} \quad (6)$$

Here, Q is Allowable outflow (cfs), A_0 is Orifice area (ft^2), h is Hydraulic head (ft), C_d is Discharge coefficient [15].

In this study, all baseline inputs, including T_c IDF intensities, runoff coefficients, and drainage areas, were taken directly from the verified 2022 Rational Method analysis for the same Houston site. This ensures methodological consistency with real-world design conditions while enabling direct comparison with the automated Python script results and Civil 3D volume modeling.

2.2. Python Script Implementation

A generalized Python script was developed to fully automate the Rational Method for any drainage project. The script functions as a flexible template: all required hydrologic equations, such as time of concentration, rainfall intensity from IDF curves, peak discharge, allowable release rate, detention storage, and orifice sizing, are embedded directly in the code. The user only inputs the essential project data (e.g., drainage area in acres, representative elevations), and the script automatically processes the complete Rational Method sequence. The IDF table is fully editable, allowing engineers to substitute rainfall data from any county or state without modifying the computational structure. The script instantly computes all Rational Method outputs and determines whether a restrictor is required, and if so, recommends the appropriate configuration, including potential pipe or orifice dimensions. This provides a rapid, standardized, and scalable workflow suitable for a wide range of urban drainage design applications.

2.3. Civil 3D Volume Modeling

To obtain a more accurate representation of the site's detention storage, the real project data were fully reconstructed in Autodesk Civil 3D. The grading plan, elevation points, and contour lines from the original Houston design were imported and used to build a precise three-dimensional surface model. All components of the drainage system, including the pavement detention area and the underground piping layout, were placed exactly according to the actual design drawings.

Using Civil 3D's surface tools, the excavation geometry, grading limits, and detention pavement area were modeled, and the exact storage volume was computed through Surface Volume Analysis. This provided a highly accurate, geometry-based detention estimate that could be directly compared with the theoretical volume predicted by the Rational Method. In the next phase of this research, the same Civil 3D model will be exported and launched in Autodesk Storm and Sanitary Analysis (SSA) to simulate the hydraulic response of the system, allowing evaluation of flow behavior, outflow hydrographs, and detention performance based on the real site geometry.

3. Results and Simulation: Rational Method Analysis

To initiate the results and simulation phase, the analysis begins with the 2022 Houston drainage project, which includes fully documented and engineer-approved Rational Method calculations. This project contains complete grading information, finished-floor elevations, and the exact layout of the underground detention system, all illustrated in the original site plan, **Figure 1,** making it a reliable baseline for validating the automated workflow. Figure 2 shows the real engineering drawings show the overall site layout, grading conditions, and placement of detention components, while a direct screenshot extracted from the original plan set presents the full step-by-step Rational Method computations exactly as performed by the design engineer.

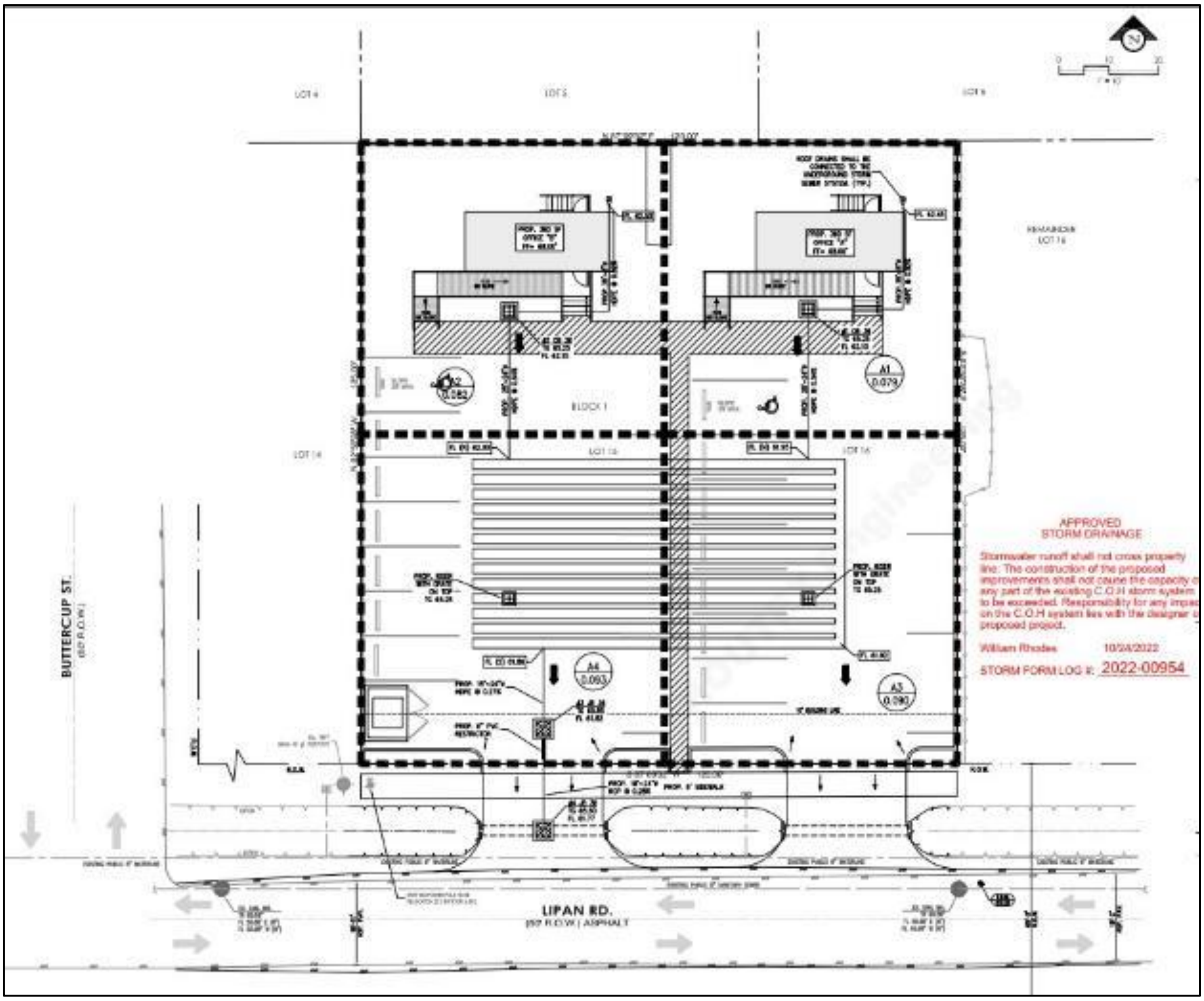
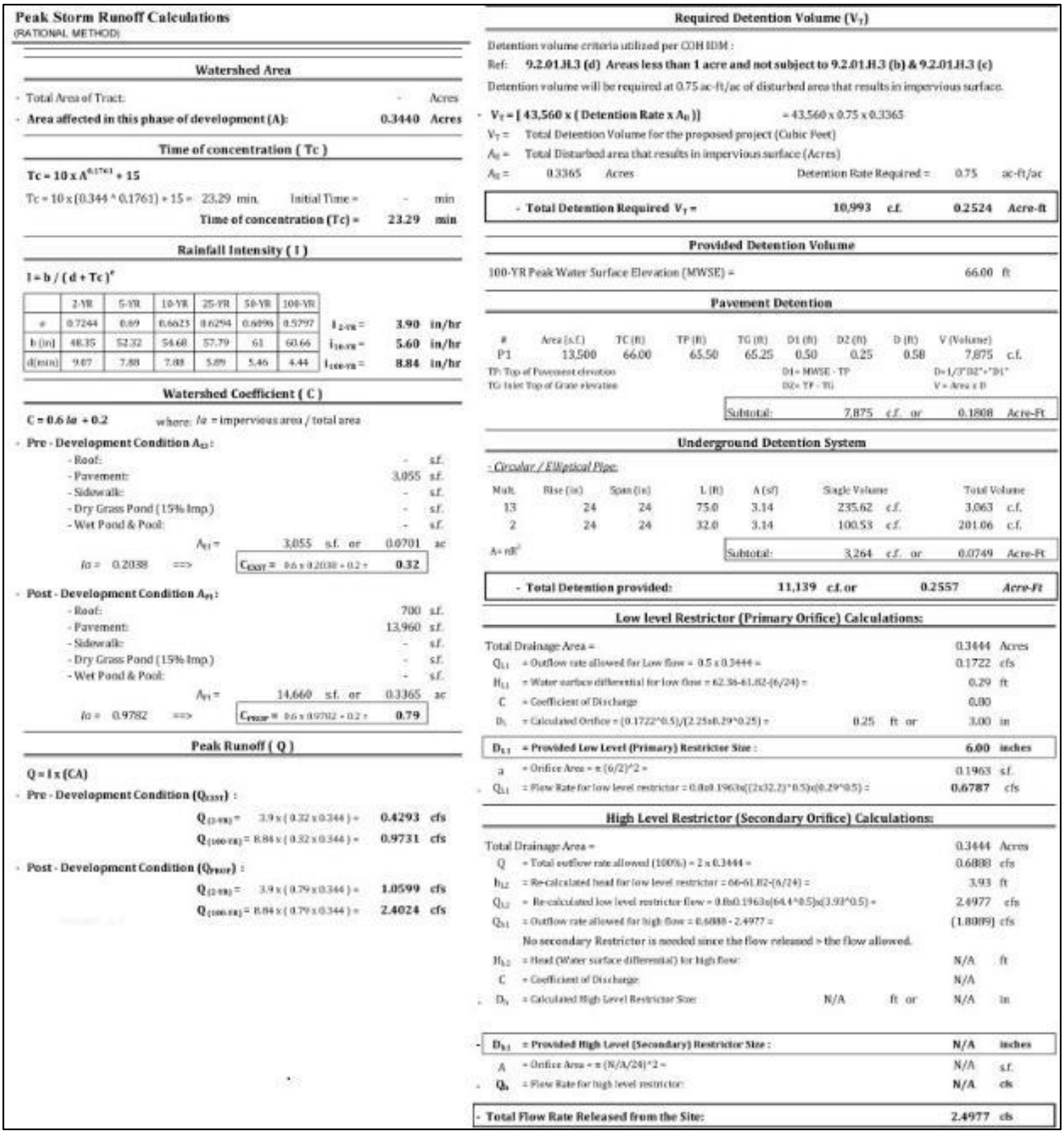


Figure 1 Approved 2022 Houston site plan illustrating the grading layout and underground detention system



Peak Storm Runoff Calculations
(RATIONAL METHOD)

Watershed Area

- Total Area of Tract: - Acres
- **Area affected in this phase of development (A): 0.3440 Acres**

Time of concentration (Tc)

$Tc = 10 \times A^{0.1761} + 15$

Tc = 10 x (0.344 ^ 0.1761) + 15 = 23.29 min. Initial Time = - min

Time of concentration (Tc) = 23.29 min

Rainfall Intensity (I)

$I = b / (d + Tc)^e$

	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR
e	0.7244	0.69	0.6623	0.6294	0.6096	0.5797
b (in)	48.35	52.32	54.68	57.79	61	60.66
d(min)	9.07	7.88	7.88	5.89	5.46	4.44

I_{2-YR} = **3.90 in/hr**
I_{10-YR} = **5.60 in/hr**
I_{100-YR} = **8.84 in/hr**

Watershed Coefficient (C)

C = 0.6 *Ia* + 0.2 where: *Ia* = impervious area / total area

- **Pre - Development Condition A_{EX} :**
  - Roof: - s.f.
  - Pavement: 3,055 s.f.
  - Sidewalk: - s.f.
  - Dry Grass Pond (15% Imp.) - s.f.
  - Wet Pond & Pool: - s.f.

A_{E1} = 3,055 s.f. or 0.0701 ac

Ia = 0.2038 ==> C_{EXST} = 0.6 x 0.2038 + 0.2 = **0.32**

- **Post - Development Condition A_{P1} :**
  - Roof: 700 s.f.
  - Pavement: 13,960 s.f.
  - Sidewalk: - s.f.
  - Dry Grass Pond (15% Imp.) - s.f.
  - Wet Pond & Pool: - s.f.

A_{P1} = 14,660 s.f. or 0.3365 ac

Ia = 0.9782 ==> C_{PROP} = 0.6 x 0.9782 + 0.2 = **0.79**

Peak Runoff (Q)

Q = I x (CA)

- **Pre - Development Condition (Q_{EXST}) :**

$Q_{(2-YR)}$ = 3.9 x (0.32 x 0.344) = **0.4293 cfs**
$Q_{(100-YR)}$ = 8.84 x (0.32 x 0.344) = **0.9731 cfs**

- **Post - Development Condition (Q_{PROP}) :**

$Q_{(2-YR)}$ = 3.9 x (0.79 x 0.344) = **1.0599 cfs**
$Q_{(100-YR)}$ = 8.84 x (0.79 x 0.344) = **2.4024 cfs**

Required Detention Volume (V_T)

Detention volume criteria utilized per COH IDM :
Ref: **9.2.01.H.3 (d) Areas less than 1 acre and not subject to 9.2.01.H.3 (b) & 9.2.01.H.3 (c)**
Detention volume will be required at 0.75 ac-ft/ac of disturbed area that results in impervious surface.

- **V_T = [43,560 x (Detention Rate x A_{II})]** = 43,560 x 0.75 x 0.3365

V_T = Total Detention Volume for the proposed project (Cubic Feet)
A_{II} = Total Disturbed area that results in impervious surface (Acres)
A_{II} = 0.3365 Acres Detention Rate Required = 0.75 ac-ft/ac

- Total Detention Required V_T = 10,993 c.f. 0.2524 Acre-ft

Provided Detention Volume

100-YR Peak Water Surface Elevation (MWSE) = 66.00 ft

Pavement Detention

#	Area (s.f.)	TC (ft)	TP (ft)	TG (ft)	D1 (ft)	D2 (ft)	D (ft)	V (Volume)
P1	13,500	66.00	65.50	65.25	0.50	0.25	0.58	7,875 c.f.

TP: Top of Pavement elevation; TG: Inlet Top of Grate elevation; D1 = MWSE - TP; D2 = TP - TG; D = 1/3*D2"+"D1"; V = Area x D

Subtotal: 7,875 c.f. or 0.1808 Acre-Ft

Underground Detention System

- *Circular / Elliptical Pipe:*

Mult.	Rise (in)	Span (in)	L (ft)	A (sf)	Single Volume	Total Volume
13	24	24	75.0	3.14	235.62 c.f.	3,063 c.f.
2	24	24	32.0	3.14	100.53 c.f.	201.06 c.f.

$A = \pi R^2$

Subtotal: 3,264 c.f. or 0.0749 Acre-Ft

- Total Detention provided: 11,139 c.f. or 0.2557 *Acre-Ft*

Low level Restrictor (Primary Orifice) Calculations:

Total Drainage Area = 0.3444 Acres
Q_{L1} = Outflow rate allowed for Low flow = 0.5 x 0.3444 = 0.1722 cfs
H_{L1} = Water surface differential for low flow = 62.36-61.82-(6/24) = 0.29 ft
C = Coefficient of Discharge 0.80
D_L = Calculated Orifice = (0.1722^0.5)/(2.25x0.29^0.25) = 0.25 ft or 3.00 in

D_{L1} = Provided Low Level (Primary) Restrictor Size : 6.00 inches

a = Orifice Area = π (6/2)^2 = 0.1963 s.f.
Q_{L1} = Flow Rate for low level restrictor = 0.8x0.1963x((2x32.2)^0.5)x(0.29^0.5) = **0.6787** cfs

High Level Restrictor (Secondary Orifice) Calculations:

Total Drainage Area = 0.3444 Acres
Q = Total outflow rate allowed (100%) = 2 x 0.3444 = 0.6888 cfs
h_{L2} = Re-calculated head for low level restrictor = 66-61.82-(6/24) = 3.93 ft
Q_{L2} = Re-calculated low level restrictor flow = 0.8x0.1963x(64.4^0.5)x(3.93^0.5) = 2.4977 cfs
Q_{H1} = Outflow rate allowed for high flow = 0.6888 - 2.4977 = (1.8089) cfs
No secondary Restrictor is needed since the flow released > the flow allowed.
H_{L2} = Head (Water surface differential) for high flow: N/A ft
C = Coefficient of Discharge N/A
D_H = Calculated High Level Restrictor Size: N/A ft or N/A in

D_{H1} = Provided High Level (Secondary) Restrictor Size : N/A inches

A = Orifice Area = π (N/A/24)^2 = N/A s.f.
Q_H = Flow Rate for high level restrictor: **N/A** cfs

- Total Flow Rate Released from the Site: 2.4977 cfs

Figure 2 Original engineer-approved Rational Method calculation sheet from the 2022 Houston drainage design

To improve clarity, as is illustrated in Table 1-a to Table 1-c, the key numerical outputs from that screenshot have been reorganized into a clean, structured that lists the essential inputs and results, such as time of concentration, rainfall intensity, pre-development and post-development peak flows, allowable release rate, and required detention volume. Presenting these three elements together, the site layout, the original calculation sheet, and the tabulated summary, provides a clear and verifiable reference point for comparing the historical Rational Method results with the automated Python-based outputs developed in this study.

Table 1-a Rainfall Intensity (IDF-Based).

Return Period	e	b (in)	d (min)	i (in/hr)
2-YR	0.7244	48.35	9.07	3.9
5-YR	0.69	52.32	7.88	-
10-YR	0.6623	54.68	7.88	5.6
25-YR	0.6294	57.79	5.89	-
50-YR	0.6096	61.01	5.46	-
100-YR	0.5797	60.66	4.44	8.84

Table 1-b Peak Runoff (Q).

Condition	Return Period	i (in/hr)	C	A (acres)	Q (cfs)
Pre	2-YR	3.9	0.32	0.344	0.4293
Pre	100-YR	8.84	0.32	0.344	0.9731
Post	2-YR	3.9	0.79	0.344	1.0599
Post	100-YR	8.84	0.79	0.344	2.4024

Table 1.c Detention Volumes.

Type	Volume (cf)	Volume (ac-ft)
Required	10993	0.2524
Pavement	7875	0.1808
UGD System	3264	0.0749
Total Provided	11139	0.2557

3.1. Python Script – Rational Method Implementation

The Python script developed in this study automates the complete Rational Method workflow by embedding all hydrologic and hydraulic equations directly into the code. The tool replicates the classical Rational Method procedure, including rainfall intensity calculations using IDF parameters (b, d, e) and peak discharge estimation through the standard equation. All survey-based and design-derived parameters that are typically used in manual Rational Method worksheets are supplied to the script as inputs, allowing it to produce a full set of hydrologic results and export them in structured Excel format for design documentation.

The script operates using the following input parameters, listed in order:

1. Total Area (acres)
2. Return Period (e.g., 2-year, 10-year, 100-year)
3. Pre-development Impervious Area (acres)
4. Post-development Impervious Area (acres)
5. Pavement Area (square feet)
6. Top of Curb Elevation, TC (ft)
7. Top of Pavement Elevation, TP (ft)
8. Top of Grate Elevation, TG (ft)
9. 100-Year Water Surface Elevation, WSE (ft)
10. Compute and Show Results

11. Pipe Sizing Sandbox (optional test length)
12. Toggle Rational Coefficient Factor
13. Reset Drainage Inputs
14. Rainfall Intensity Parameters (b, d, e) for each return period
15. Flowline Elevation, FL (ft)
16. MWSE – 25% (ft)
17. MWSE – 100% (ft)
18. Total Drainage Area (acres)
19. Low Flow Multiplier
20. High Flow Multiplier
21. Orifice Coefficient of Discharge, Cd
22. Orifice Offset Elevation (ft)
23. Execute Restrictor-Orifice Calculation
24. Reset Orifice Inputs
25. Generate Charts and Export to Excel

This structured input set enables the Python script to automatically compute peak discharge, evaluate detention storage requirements, and determine the appropriate restrictor-orifice configuration, providing a standardized and fully repeatable workflow suitable for Rational-Method-based drainage design across any jurisdiction.

3.2. Script Results Overview

The Python implementation environment is illustrated across four consecutive stages, showing how the automated workflow operates from input to final analysis. As shown in Figure 3, the initial script window displays the complete list of user inputs, numbered from 1 through 24, including all required drainage parameters such as total area, impervious percentages, pavement area, key elevations, IDF overrides, and orifice-related inputs; this view also confirms that the Harris County IDF table is pre-loaded in the code and can be edited for any jurisdiction. As seen in Figure 4, running Option 10 executes the full Rational Method computation and reports the hydrologic results, including drainage area, computed time of concentration, rainfall intensity derived from the IDF parameters, pre- and post-development peak flows, required detention volume, pavement storage, and the remaining storage needed in the underground detention system.

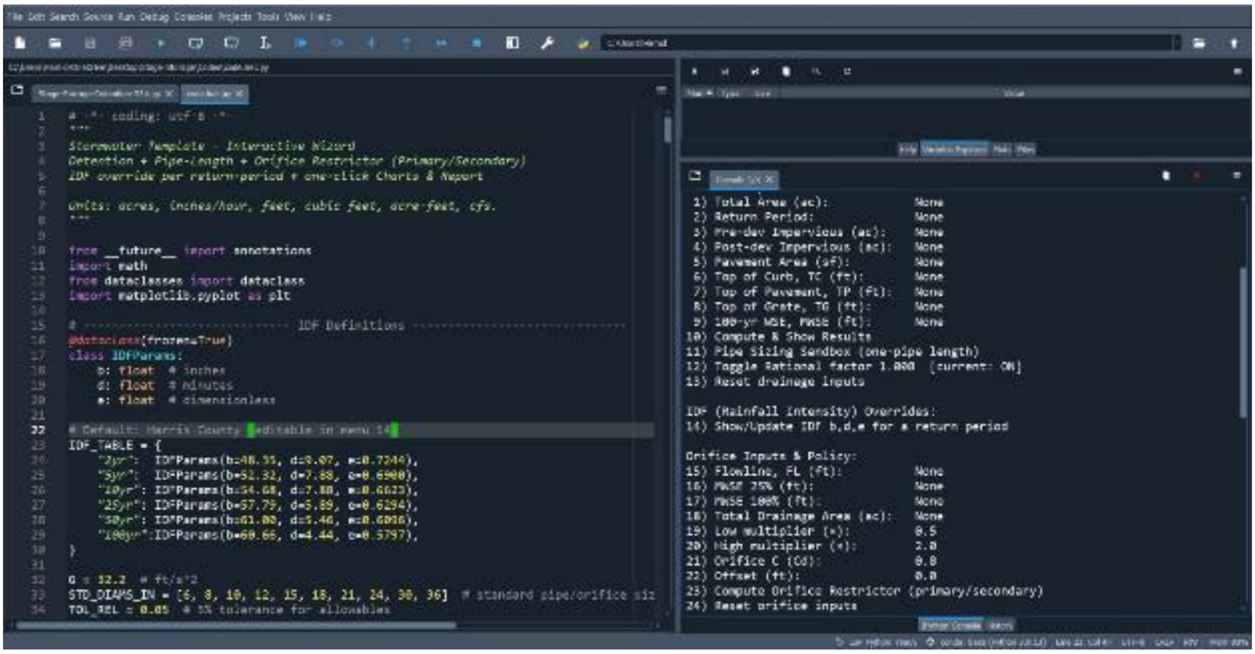
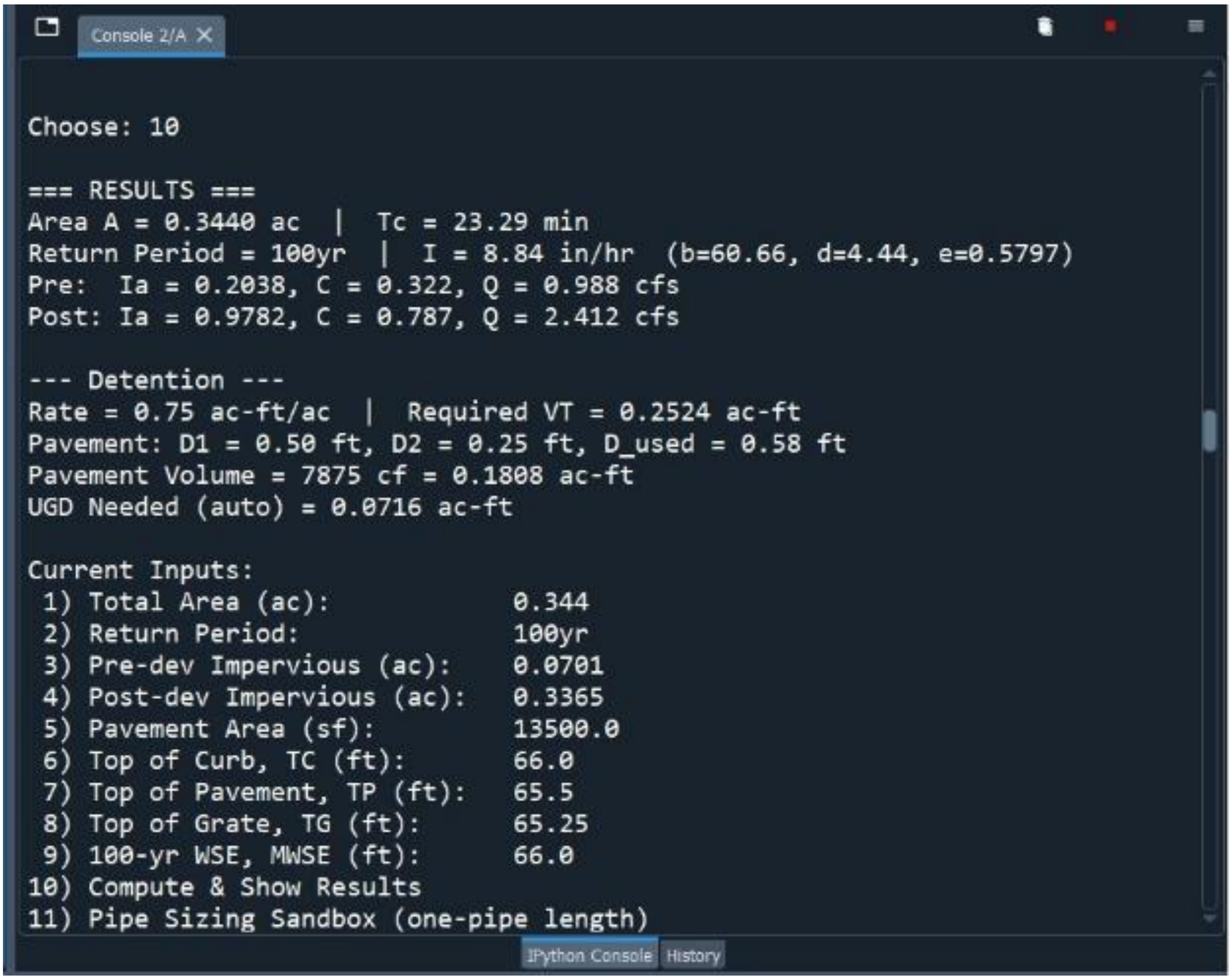


Figure 3 The image shows the Python environment and how the input parameters are defined



```
Console 2/A

Choose: 10

=== RESULTS ===
Area A = 0.3440 ac  |  Tc = 23.29 min
Return Period = 100yr  |  I = 8.84 in/hr  (b=60.66, d=4.44, e=0.5797)
Pre:  Ia = 0.2038, C = 0.322, Q = 0.988 cfs
Post: Ia = 0.9782, C = 0.787, Q = 2.412 cfs

--- Detention ---
Rate = 0.75 ac-ft/ac  |  Required VT = 0.2524 ac-ft
Pavement: D1 = 0.50 ft, D2 = 0.25 ft, D_used = 0.58 ft
Pavement Volume = 7875 cf = 0.1808 ac-ft
UGD Needed (auto) = 0.0716 ac-ft

Current Inputs:
 1) Total Area (ac):            0.344
 2) Return Period:              100yr
 3) Pre-dev Impervious (ac):    0.0701
 4) Post-dev Impervious (ac):   0.3365
 5) Pavement Area (sf):         13500.0
 6) Top of Curb, TC (ft):       66.0
 7) Top of Pavement, TP (ft):   65.5
 8) Top of Grate, TG (ft):      65.25
 9) 100-yr WSE, MWSE (ft):      66.0
10) Compute & Show Results
11) Pipe Sizing Sandbox (one-pipe length)

IPython Console  History
```

Figure 4 By entering parameters 1 to 9, the Python code generates the results shown here

As shown in Figure 5, executing Option 11 allows the user to specify a pipe diameter for the underground detention system, and the script automatically calculates the pipe length required to satisfy the remaining volume; the interface also provides guidance on how the required length scales when multiple pipes are incorporated into the design. As illustrated in Figure 6, running Option 23 performs the complete restrictor-orifice analysis, computing allowable low-flow and high-flow discharge, determining the required orifice diameter, and checking whether a secondary orifice is needed at the maximum water surface elevation; the results in this case indicate that a single primary orifice is sufficient. Together, these four stages demonstrate that the Python script successfully automates every component of the Rational Method workflow, from hydrologic calculations to detention sizing and outlet control, while providing a transparent, repeatable, and fully documented process.

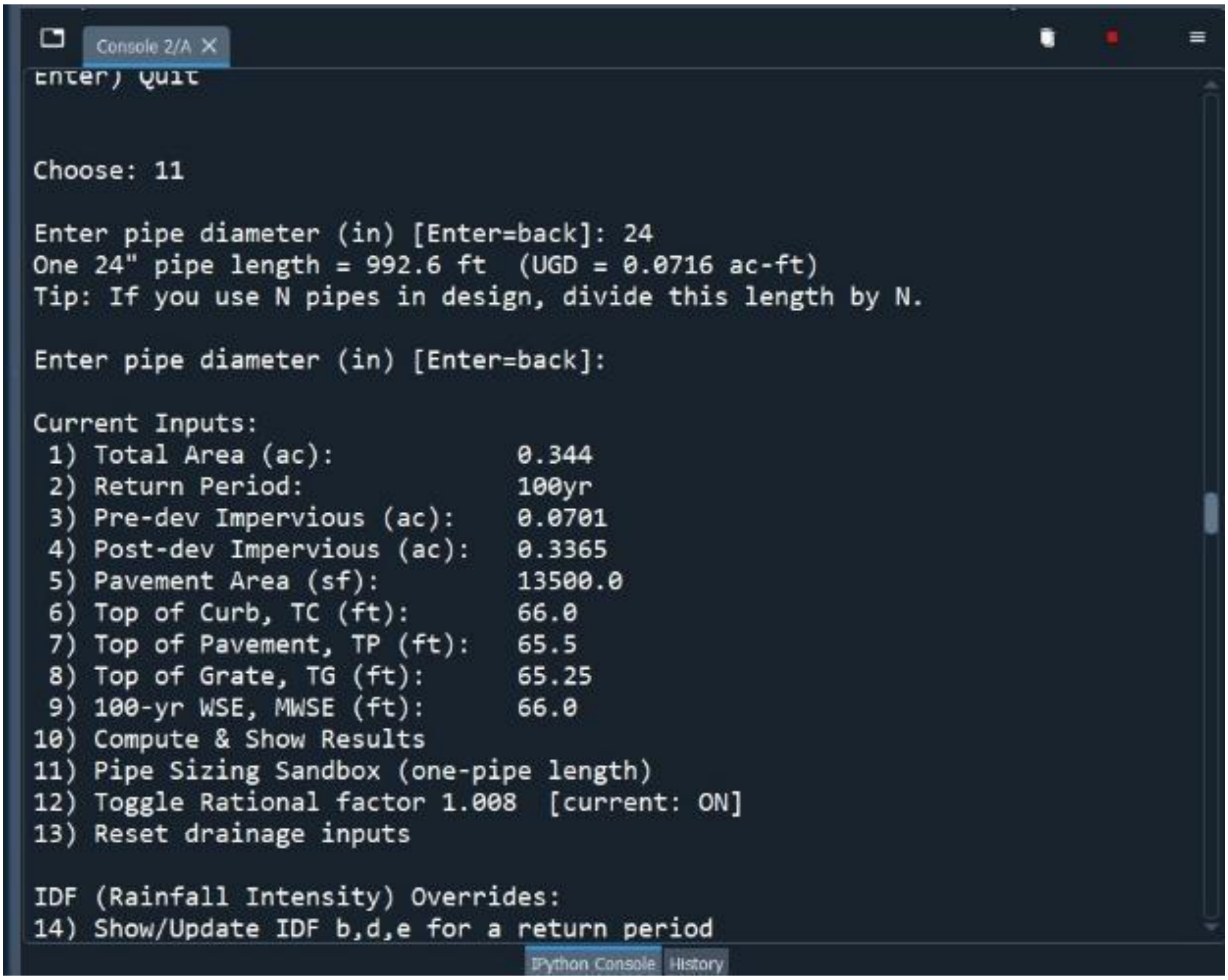


Figure 5 By entering only the pipe diameter, the Python code automatically calculates how many feet of that pipe are required to provide the needed UGD detention volume

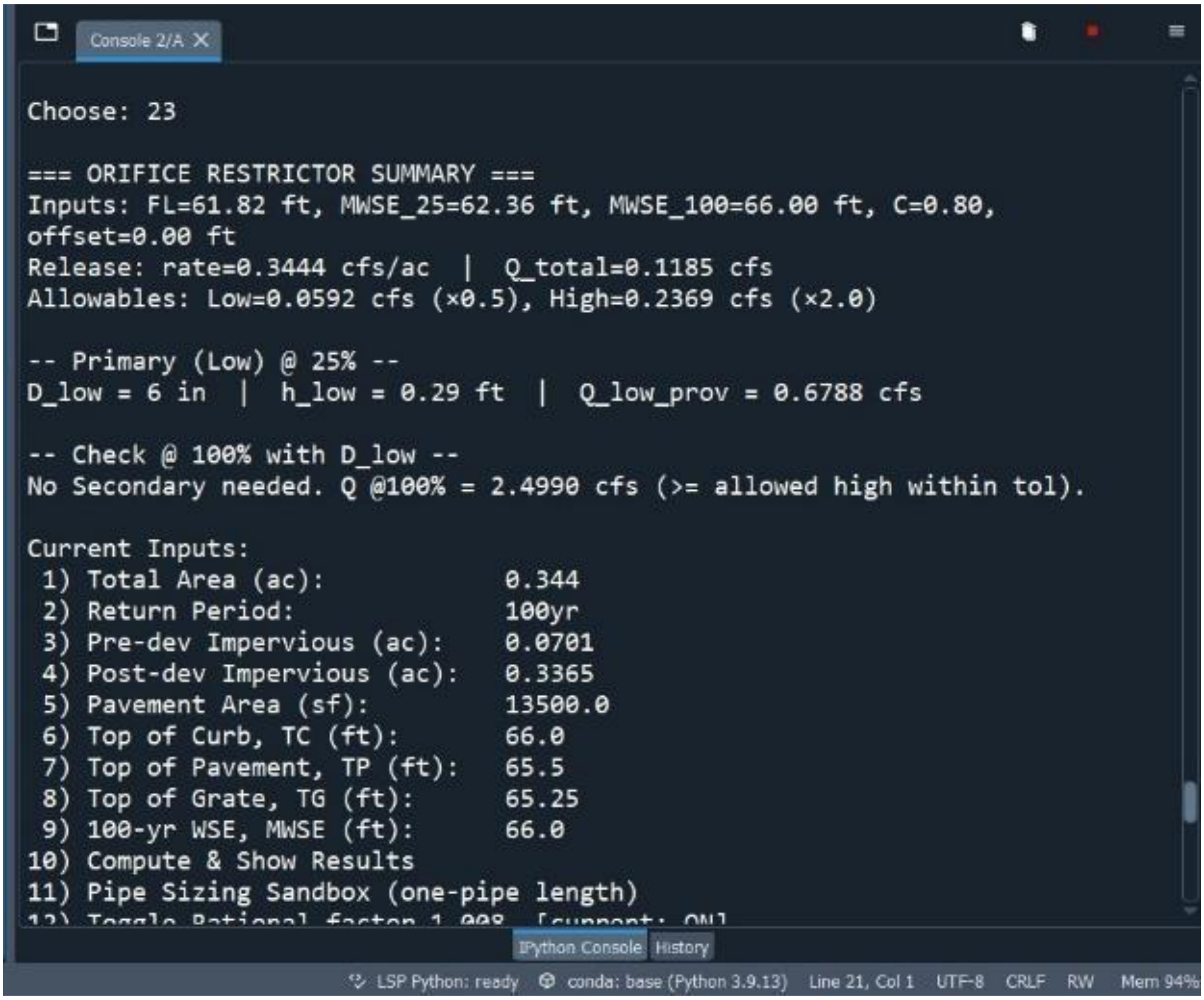


Figure 6 By entering parameters 15 to 22, the Python code automatically computes the orifice restrictor results shown in the figure

The Python script also generates graphical outputs, Figure 7, that summarize the key hydrologic and detention results in a visually intuitive format. As shown in the first chart, the detention summary is presented in acre-feet, illustrating the required storage volume, the pavement-based detention contribution, the remaining underground detention needed, and the total volume provided. This visual presentation allows the designer to quickly verify that the combined pavement and underground storage meets or exceeds the required detention criteria without having to examine the numerical tables in detail. The second chart displays the peak runoff comparison for pre-development and post-development conditions in cubic feet per second, clearly highlighting the increase in peak discharge resulting from site development. Together, these two charts provide an immediate visual understanding of both storage performance and hydrologic impact: even without reading the underlying numbers, the reader can quickly observe the relative contributions of each detention component as well as the contrast between pre- and post-development peak flows. These figures enhance interpretability by complementing the tabulated outputs with a straightforward graphical summary of the Rational Method results.

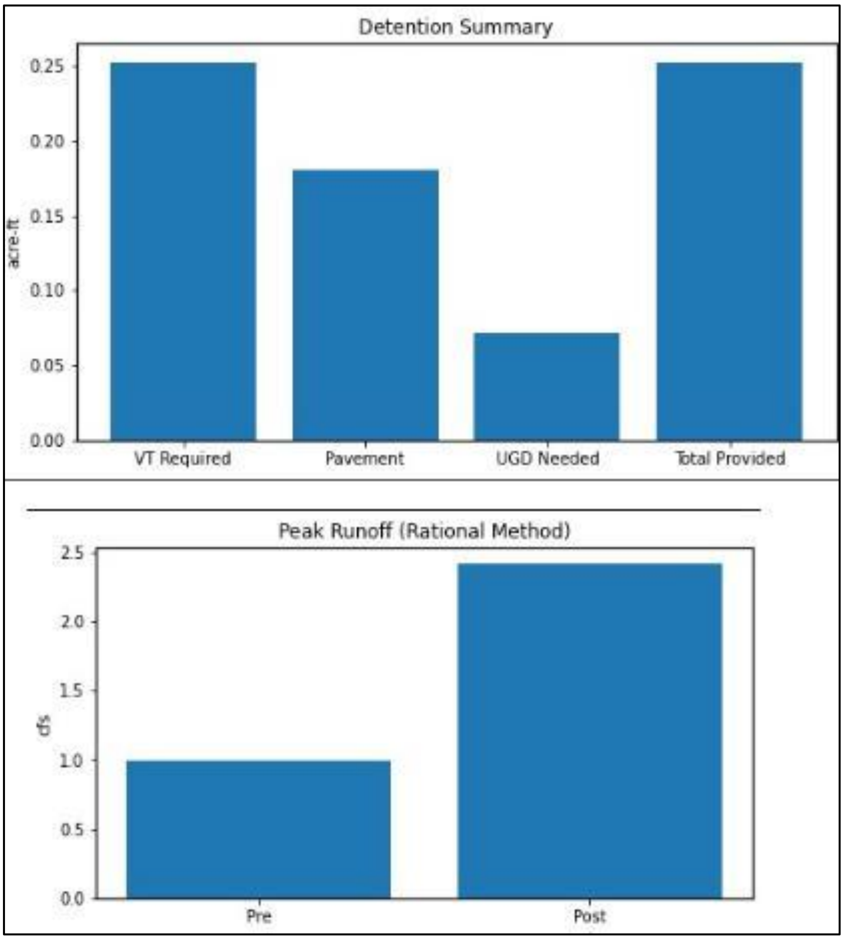


Figure 7 The Detention Summary chart shows the required and provided storage volumes (acre-ft), while the Peak Runoff chart compares pre- and post-development discharges based on the Rational Method

3.3. Civil 3D Results

For the Civil 3D component of the analysis, the entire site from the original 2022 drainage design was fully reconstructed and remodeled in Autodesk Civil 3D to provide a more realistic, geometry-based representation of the detention system. The grading plan, pavement elevations, and all finished-floor and grate elevations were imported and used to generate an accurate terrain model with proper slopes and breaklines. The pavement detention area was modeled precisely using a top-surface and bottom-surface approach, where two separate Civil 3D surfaces were created and the volumetric difference between them was calculated using the Volumetric Surface tool to obtain an exact pavement storage value. In addition, the underground detention pipes were redrawn exactly according to the real project's design, matching pipe diameters, lengths, invert elevations, structures, junctions, and flow paths, to accurately represent the drainage network. Catchments, junction boxes, inflow locations, and outlet conditions were defined exactly as shown in the original Rational Method project so that the Civil 3D model would reflect the true hydraulic layout of the site. This remodeled CAD environment provides a validated, geometry-accurate basis for extracting storage volumes and preparing the model for full hydraulic simulation in Autodesk Storm and Sanitary Analysis (SSA). In the present paper, only the Civil 3D grading and storage modeling results are reported; the full SSA hydraulic simulation will be conducted and presented in the subsequent publication.

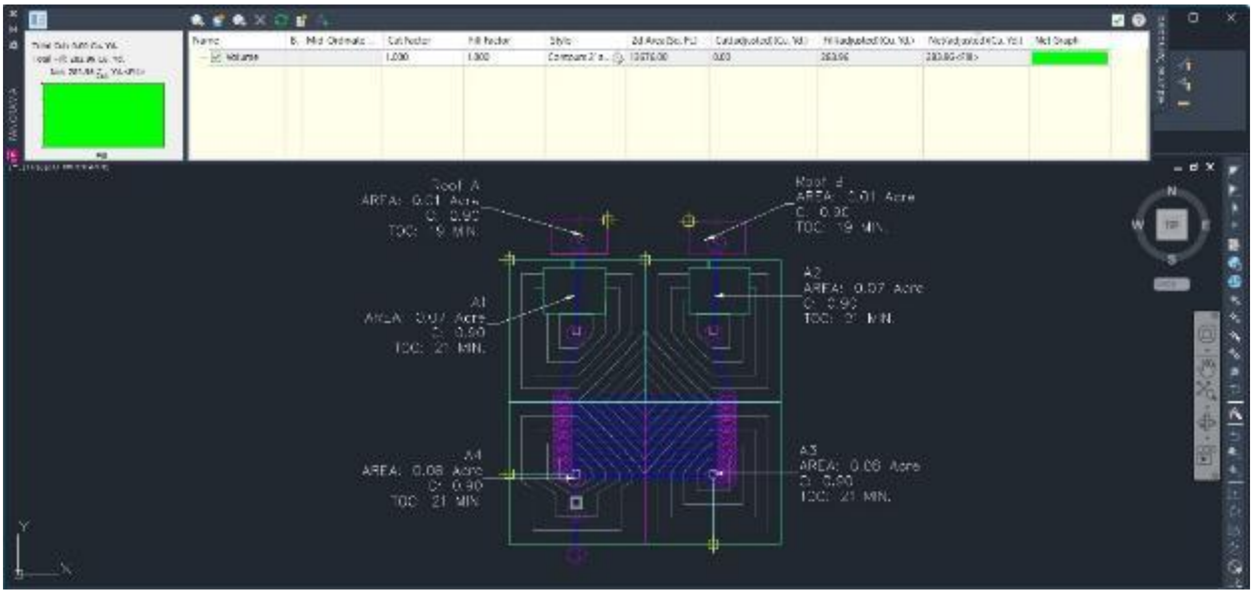


Figure 8 Catchments and Detention Volume (Civil 3D)

As shown in the Civil 3D model in Figure 8, the entire 2022 drainage design was fully reconstructed in a three-dimensional environment, including the grading, catch basins, underground detention (UGD), and all connecting pipes. The contour lines and slopes clearly illustrate how the finished grading directs runoff toward each catch basin, confirming that the drainage patterns in the model match the original design intent. The two rectangular roof areas (Roof A and Roof B) were extruded upward solely for visualization purposes, allowing the viewer to easily distinguish roof contributions from pavement flows; each roof and subbasin is connected through its respective inlet and routed to the UGD system through the same pipe layout used in the original engineering plans. The figure also displays hydrologic properties for each subbasin, including area, runoff coefficient, and time of concentration, directly annotated within the model. At the top of the interface, the computed pavement detention volume is shown, representing the precise excavation volume calculated using the difference between two Civil 3D surfaces: one representing the pavement top surface and the other representing the designed bottom elevation. This volumetric subtraction provides an exact measurement of the available storage within the paved detention area, ensuring that the CAD-based volume matches the actual constructed geometry. Overall, the figure demonstrates a complete, geometry-accurate reconstruction of the real project, including grading, subbasins, catch basins, UGD connectivity, and precise surface-based detention volume calculation.

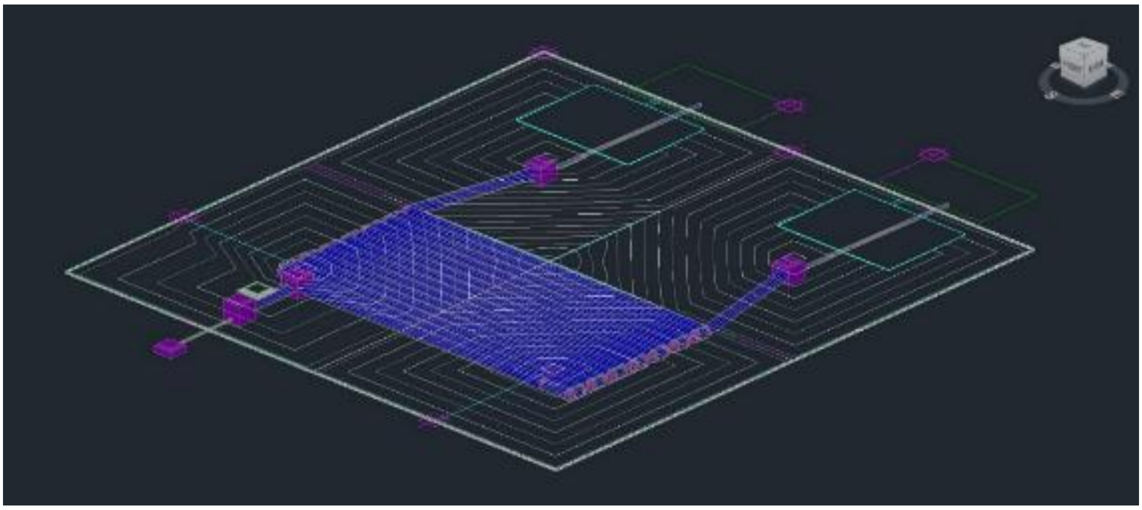


Figure 9 Isometric View – Pipes and Contours (Civil 3D)

In the isometric view of the Civil 3D model in Figure 9, the overall grading and the spatial configuration of the drainage system are clearly visible. The three-dimensional perspective makes it easier to distinguish the surface slopes, the arrangement of the pipe network, the connections between roof drains and catch basins, and the routing of flows toward the underground detention system. This view highlights the geometric relationships among all components, providing a clearer understanding of how the grading and drainage elements interact throughout the site.

4. Discussion

In this project, I started with the classic Rational Method that had already been applied to this site back in 2022. All parameters were predetermined, so instead of manually redoing the calculations, I decided to write a Python script that automates the Rational formula. The script uses the Harris County – BDE rainfall intensity table, and all other input values were pulled directly from the original Rational Method data. The final output matched the original results exactly, so this part of the work was mainly to automate the process and validate the code. There was no difference in the output compared to the manual version.

Next, I modeled the exact same Pavement area in AutoCAD Civil 3D. Using tools like Grading, Surface Creation, Contours, and Elevation assignment, I created a precise surface model. Then, by comparing the Top and Bottom surfaces, I calculated the actual detention volume from the Civil 3D model. The result was 7,666.92 cubic feet, while the Rational Method had estimated 7,875 cubic feet. This small difference is expected because Civil 3D accounts for real surface elevation and grading in more detail, while the Rational Method is simpler and does not include those vertical variations.

In future phases of this research, the complete model will be launched in Storm and Sanitary Analysis (SSA) to simulate the actual hydraulic outflow of the system based on the accurate pavement detention volume from Civil 3D and the real hydraulic behavior of the pipe network. This step will allow observing how the designed system performs under realistic flow conditions. Additionally, the second paper of this project will present a new Python script that uses the SSA outputs and provides interesting insights as part of the extended workflow.

5. Conclusion

This study demonstrated that implementing the Rational Method through a custom Python script can accurately reproduce traditional calculations when applied to a real-world drainage project in Houston. In addition, comparison with detailed modeling in Civil 3D showed that using surface-based elevation data can slightly reduce the estimated pavement detention volume, revealing the limitations of purely linear hydrologic methods.

In the next phase of this project, the model will be executed in Storm and Sanitary Analysis (SSA) to calculate the actual hydraulic outflow of the system based on the precise detention volume obtained from Civil 3D and the real hydraulic behavior of the pipe network. At this stage, the true outflow results from SSA will represent the real performance of the detention system under design conditions. Furthermore, in the second paper of this research, a new Python script will be presented that provides interesting additional insights.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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