HYDROLOGY

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February 2024

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Hydrology

City of Houston Stormwater Infrastructure Model White Paper

Purpose

The purpose of this white paper is to present the hydrologic methods that are to be applied in the Stormwater Infrastructure Model. Data and discussion are provided to support the recommendations.

Summary

The NOAA Atlas 14 rainfall depths determined for the Harris County Flood Control District's (HCFCD) hydrologic Region 3 are to be applied throughout the Stormwater Infrastructure Model according to City criteria. The Green & Ampt loss method will be used to model infiltration, and rainfall will be applied to the surface instead of at discrete nodes. The hydrologic method for areas outside of City limits but within the watershed will be handled differently. These topics are described in further detail below.

Rainfall Parameters

Region 3 Rainfall

The City of Houston adopted HCFCD Region 3 NOAA Atlas 14 Rainfall in October 2019 which will be used for the stormwater model. Rainfall depths shown in **Table 1** were obtained from the MAAPnext White Paper 1a: Rainfall Depths and Intensities in Harris County (revised 5/31/2019). The 2-, 5-, 10-, 25-, 50-, 100-, and 500-year storm events will be modeled in the SIM.

Table 1: Annual Exceedance Probability Rainfall Data for Harris County Region No.3

Duration	50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.2% AEP
	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
15-min	1.20	1.50	1.76	2.13	2.42	2.72	3.48
30-min	1.72	2.14	2.50	3.01	3.40	3.81	4.95
60-min	2.29	2.88	3.38	4.09	4.65	5.25	6.98
2-hr	2.87	3.72	4.49	5.63	6.58	7.64	10.6
3-hr	3.23	4.26	5.23	6.71	7.98	9.42	13.4
6-hr	3.87	5.22	6.55	8.59	10.4	12.5	18.2
12-hr	4.56	6.24	7.88	10.4	12.6	15.2	22.8
24-hr	5.30	7.33	9.30	12.3	15.0	18.0	27.2

Since InfoWorks ICM is not capable of generating the same hyetograph generally used in the Houston region, HEC-HMS (version 4.8) was used to generate rainfall hyetographs which will be applied to the ICM model. The “Frequency Storm” precipitation method was selected in the Meteorologic Model, and the following parameters in were set:

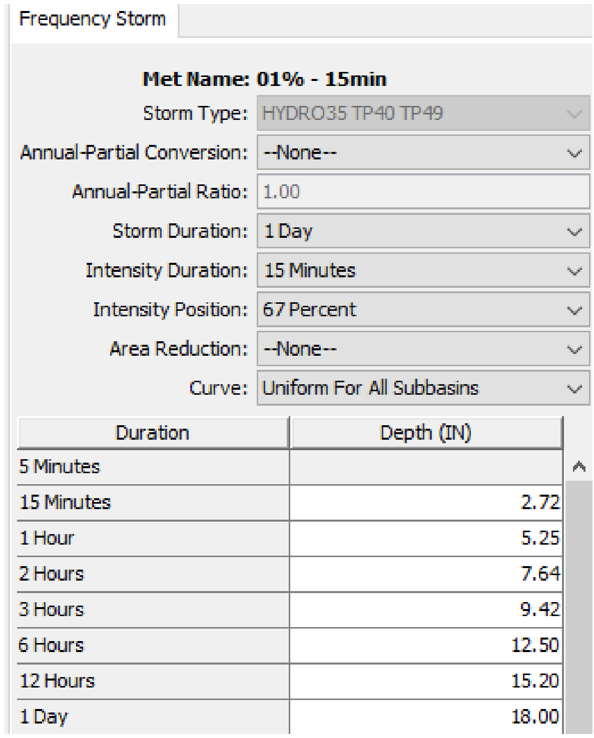


Figure 1: Frequency Storm tab in HEC-HMS v4.8

The “Precip (IN)” column in the Time-Series Result” table was converted from depth (inches) to intensity (inches per hour) for importing into ICM. shows the NOAA Atlas 14 rainfall intensity for the 100-Year storm event.

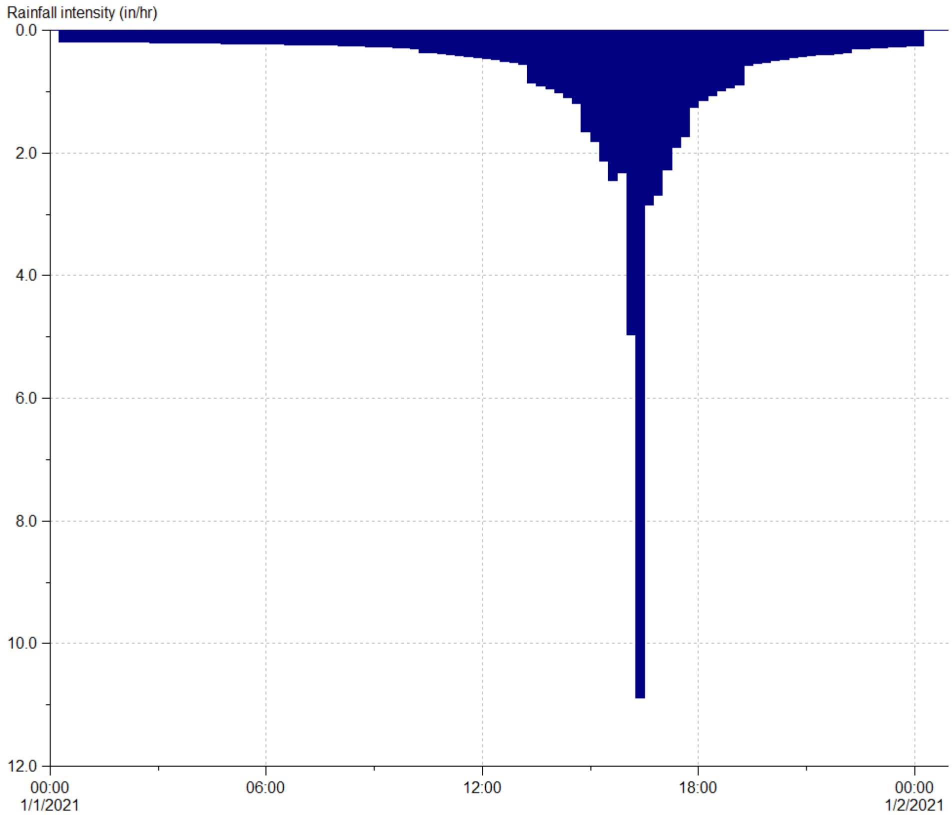


Figure 2: 100-Year frequency storm event from ICM "Rainfall event" window

Loss Methodology

A portion of the precipitation that falls on the surface infiltrates into the underlying soil and is removed from the runoff volume. In keeping with the IDM, the Stormwater Master Model will simulate these losses using the Green & Ampt loss method.

Green & Ampt Loss

The Green and Ampt loss parameters are found in the MAAPnext White Paper 3 (Replacing Green and Ampt) and they are shown in and below. Deficit was determined by subtracting Initial Content from Saturated Content (equation located in the HEC-HMS User's Manual Version 4.1, Green and Ampt Loss section).

Table 2: Green and Ampt Losses for White Oak Bayou, Greens Bayou, San Jacinto, and Luce Watersheds

Parameters	Value
Initial Content (estimate)	0.024
Saturated Content	0.46
Suction	3.50 in
Conductivity	0.024 in/hr
Deficit	0.436
Max Canopy Storage	0.1
Initial Canopy	0.0
Crop Coefficient	1.0

Table 3: Green and Ampt Losses for Buffalo, Brays, Hunting, Sims, and Armand Bayou Watersheds

Parameters	Value
Initial Content (estimate)	0.075
Saturated Content	0.46
Suction	12.45 in
Conductivity	0.024 in/hr
Deficit	0.385
Max Canopy Storage	0.1
Initial Canopy	0.0
Crop Coefficient	1.0

Impervious Cover

The percentage of impervious area should be uniform across each watershed. Because no loss calculations are carried out on the impervious area, all precipitation on that portion of the subbasin becomes excess precipitation and subject to direct runoff. When creating the rainfall event in ICM, excess rainfall will be applied directly to the mesh, and direct rainfall should be applied to the subcatchments for areas outside of the city limits. Impervious area for each watershed can be calculated using the impervious cover raster specified in the *Data Collection White Paper*.

Modeling Infiltration in ICM

Testing was conducted using infiltration zones within the mesh extents to account for infiltration. However losses within the 2D domain were not consistent with losses calculated using traditional methods. Innovyze has acknowledged the issue and is currently working on modifying software to correct the issue. Since a direct fix is not available and the City is highly urbanized, generic losses will be accounted for within the rainfall rather than within the 2D mesh.

Transform Methodology

Purpose

Hydrologic transform is the translation of rainfall into runoff into a drainage system such as a storm sewer inlet or roadside ditch. Traditional approaches to hydrologic transform calculations include the Rational Method, Small Watershed (Malcolm's) Method, and the Clark Unit Hydrograph. ICM has the capability to also apply rainfall directly on the mesh which hydraulically routes flows to the drainage network.

Rain-on-mesh modeling method was preferred and selected over traditional hydrology for the following reasons:

- Testing shows similar discharge results to traditional hydrologic methods
- Avoids basin delineation and development of basin-specific parameters
- Eliminates basin re-delineation during alternatives analysis and model adjustments
- Eliminates basin parameter adjustments during alternatives analysis and model adjustments
- Fewer variables and paths for error and review during model development
- Fewer engineering assumptions

Modeling rain-on-mesh in ICM

Rain-on-mesh will be performed in ICM by applying NOAA Atlas 14 rainfall throughout the entire 2D area. **Figure 1** shows the 2D zone properties table and how to apply rainfall directly to the 2D zone (red box). The direct rainfall file will be provided by the Program Manager and will need to be imported into the ICM model. Note that an excess rainfall file may be provided instead.

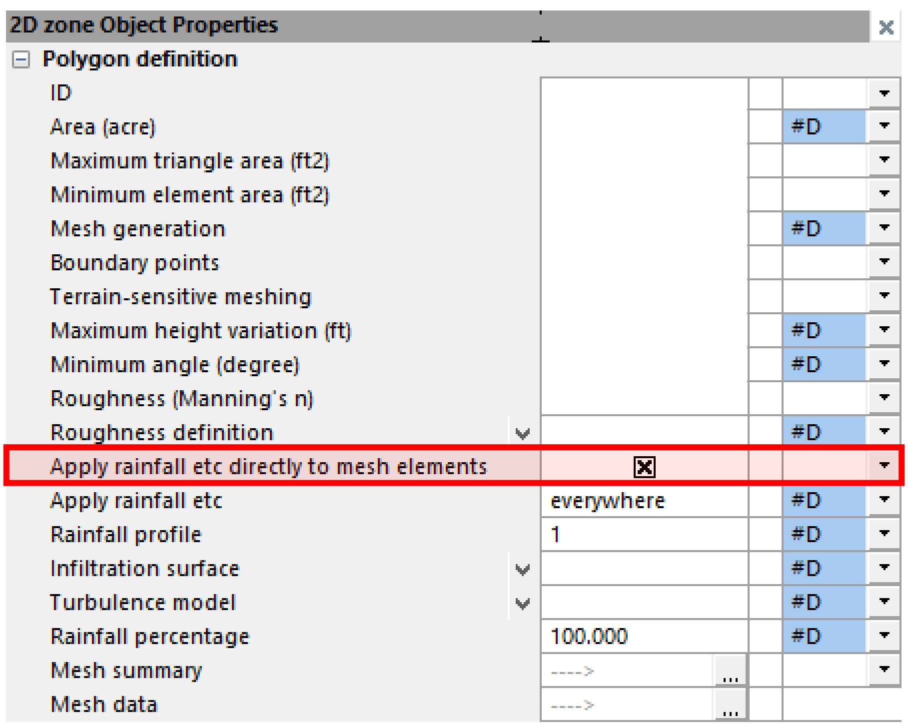


Figure 1: 2D zones properties table

Rain-on-Mesh Testing

The testing process consisted of simulating two similar hydraulic models of the Pilot Study area and comparing conduit flows and hydraulic grade lines. The testing procedure for each model is described in the following bullet points:

- Traditional Hydrology Model: Drainage areas for grouped inlets were delineated based on LiDAR and the storm sewer network. The Rational Method was used to calculate peak flows and the Clark Unit Hydrograph used to develop hydrographs in accordance with the City IDM. The hydrographs were applied directly to the nodes within ICM.
- Rain-on-mesh model: Rainfall was applied on the 2D surface in ICM following the rain-on-mesh method.

Modeling Offsite Areas

Purpose

Areas that are outside of the City limits will not be modeled in detail in ICM due to data and scope limitations. However, most watersheds have areas outside City limits that flow into City drainage infrastructure. These “offsite” areas will be modeled using standard drainage areas and traditional hydrology within ICM. Offsite areas will be modeled with the Basin Development Factor (BDF) hydrologic method as developed by the HCFCD to develop Clark Unit Hydrograph parameters for the ICM model. **Figure 2** shows an example of an offsite area that drains into City of Houston infrastructure.

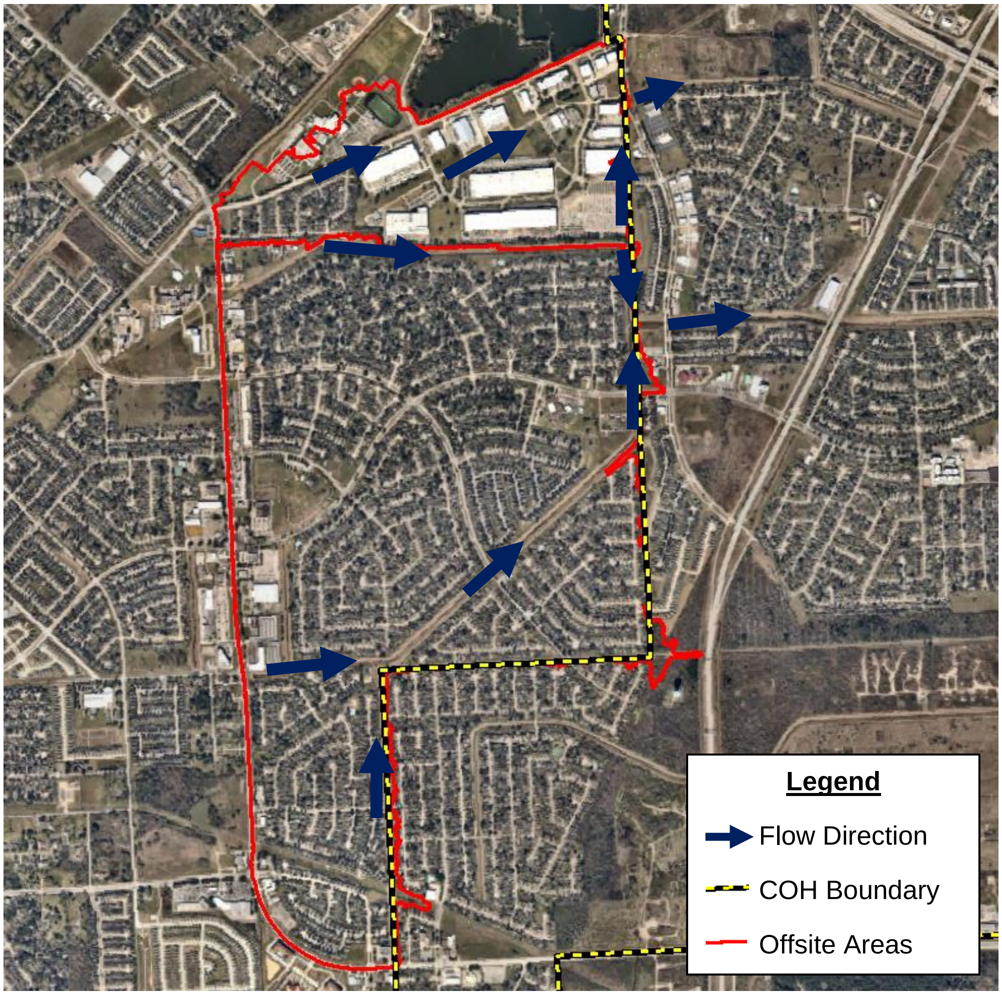


Figure 2: Example of an Offsite Area

Summary of Process

Basins were delineated for areas that are outside City limits but within the watershed being modeled. Information from the HCFCD MAAPnext efforts will be used to inform basin delineation, methodology, and discharge hydrographs as able. The BDF, the Rational Method, and HCFCD Site Runoff Curve methodologies were applied to the offsite basins, and the results are compared with resulting discharges from the hydrologic methods were also compared to MAAPnext discharges. Based on the comparisons, BDF methodology should be used for areas greater than 100 acres and the Rational Method for areas less than 100 acres.

Basin Delineation

Basins should be delineated using the HGAC 2018 LiDAR and account for any available drainage infrastructure. HCFCD MAAPnext subbasins can be used as original delineations and adjusted as needed to include any additional information or subdivision needed. Basins can be delineated using automated methods but must be verified as needed.

Rational Method

The Rational Method uses basin area, rainfall intensity, and runoff coefficients to calculate peak discharges. The runoff coefficients for each offsite basin were calculated by using the HGAC land use raster and assigning runoff coefficients to each land use based on the IDM. The Rational Method may be used for offsite basins less than 100 acres and parameters should align with the current City of Houston IDM.

Basin Development Factor Determination

The BDF method should be used to determine the TC and R parameters for the Clark Unit Hydrograph Method. The MAAPnext white paper "Tc and R Methodology in Harris County" is provided as **Attachment A**. The Program Manager may provide MAAPnext shapefiles for use, but these must be modified as needed for the Stormwater Master Model. A summary of the BDF process is provided below.

The BDF for the drainage basin being analyzed should be calculated using the "ratio method" as shown in the following equation.

$$\mathbf{BDF} = \frac{\mathbf{3(I) + 6(C)}}{\mathbf{N + C + I}} + \frac{\mathbf{OS + 1.5(R) + 3\left(SS_{pre-1984}\right) + 4.5\left(SS_{pre-1984-improved}\right) + 6(SS_{post-1984})}}{\mathbf{U + OS + R + SS_{pre-1984} + SS_{improved-1984} + SS_{post-1984}}}$$

The overall BDF is calculated by taking a weighted average of the BDF values provided in and using the corresponding lengths of major conveyance systems and corresponding areas of collector drainage systems (i.e. "land use') with the overall drainage area length or area.

Table 4: BDF Values for Major Conveyance Systems in the City

N – No Channel / Natural	0
I – Improved Channel	3
C – Channel Lining / Concrete	6

Table 5: BDF Values for Basic Land Uses in the City

Land Cover	BDF
U – Undeveloped	0
OS – Open Space (graded to drain)	1
R – Roadside Ditch Drainage	1.5
$SS_{pre-1984}$ – Curb and Gutter with Storm Sewer Pre-1984	3
$SS_{post-1984}$ – Curb and Gutter with Storm Sewer Post-1984	6

A land cover and major conveyance shapefile will be created manually for any area outside the city limits that drain to the City of Houston. MAAPnext land cover and conveyance shapefiles can be used as a base and adjusted as needed. **Figure 3** provides an example of land cover and conveyance shapefiles.

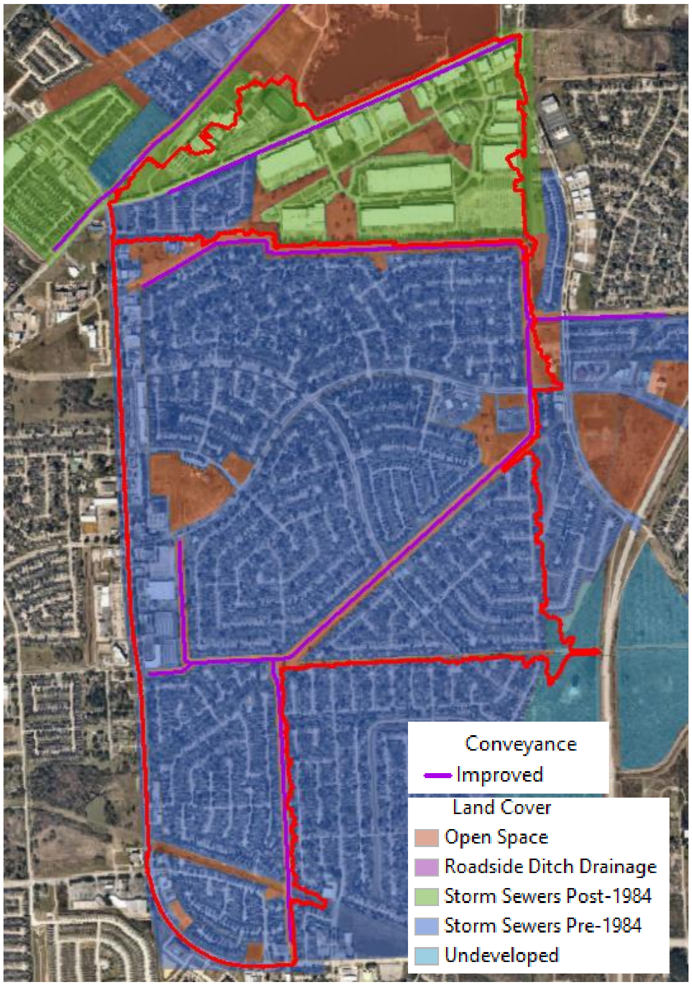


Figure 3: Example BDF Shapefile

TC & R Determination

Using the drainage area's BDF, calculate the Clark Unit Hydrograph parameters, TC and R, using the BDF spreadsheet provided. Slope adjustments should be made to the calculated TC and R. The slope adjustment factor considers the slope of the channel and the average slope of the overland area. A shapefile that follows the channel should be created. That shapefile will then have elevations extracted to get an average slope for the channel. A slope raster from MAAPnext can be used to calculate the overland slope and may be provided by the program manager.

Modeling Offsite Areas in ICM using Subcatchment Infiltration

The infiltration method in subcatchments is defined in the "Land Use" properties table and is found in the "Surface parameters" section (see **Figure 4** below for reference).

Surface parameters	
Surfaces management	Editor ...
Land use ID	Imperviouness
PDM Descriptor	
Area measurement type	Percent
Build-up/washoff land uses	...

Figure 4: Surface parameters properties table for subcatchments

The percent impervious/pervious should be determined based on the pervious shape file area provided by the City. **Figure 5** shows the "Land Use" properties table and parameters. Two surfaces should be used in the modeling representing the pervious surface and the impervious surface.

Land use Object Properties	
Land use properties	
Land use ID	Imperviouness
Description	
Population density (person/acre)	
Wastewater profile	
Connectivity (%)	
Pollution index	
Surfaces	
Runoff surface 1	1
Default area 1 (%)	62.000
Runoff surface 2	2
Default area 2 (%)	38.000

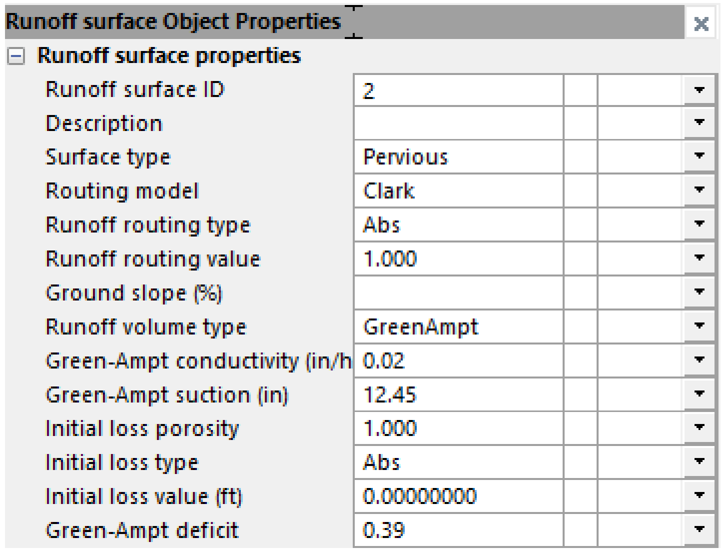
Figure 5: Land use properties tables for subcatchments

On the impervious runoff surface, it is assumed that there is no infiltration. This is achieved by utilizing the "Fixed" infiltration method (shown on **Figure 6**). Here, the "Fixed runoff coefficient" is set to 1, meaning 100% of the total rainfall will become runoff.

Runoff surface Object Properties	
Runoff surface properties	
Runoff surface ID	1
Description	
Surface type	Impervious
Routing model	Clark
Runoff routing type	Abs
Runoff routing value	1.000
Ground slope (%)	
Runoff volume type	Fixed
Fixed runoff coefficient	1.00000
Initial loss porosity	1.000
Initial loss type	Abs
Initial loss value (ft)	0.00000000

Figure 6: Runoff surface properties table for the impervious surface (Runoff surface 1)

For the pervious runoff surface, the Green and Ampt parameters are set in the properties table. An example of the properties table and parameters are shown in **Figure 7**. Note that Green-Ampt conductivity is 0.024 in/hr, but the properties table only displays up to the hundredth place for that field.



Runoff surface Object Properties

Runoff surface properties

Runoff surface ID	2
Description	
Surface type	Pervious
Routing model	Clark
Runoff routing type	Abs
Runoff routing value	1.000
Ground slope (%)	
Runoff volume type	GreenAmpt
Green-Ampt conductivity (in/h	0.02
Green-Ampt suction (in)	12.45
Initial loss porosity	1.000
Initial loss type	Abs
Initial loss value (ft)	0.00000000
Green-Ampt deficit	0.39

Figure 7: Runoff surface properties table for the pervious surface (Runoff surface 2)

In addition, the Green and Ampt deficit parameter must be set on the “Globals” tab found on the “Rainfall Event” section (see **Figure 8:**). ICM will compare the deficit value from the “Runoff surface properties” against “Green-Ampt SMD (%)” and choose the smallest deficit for the simulation.

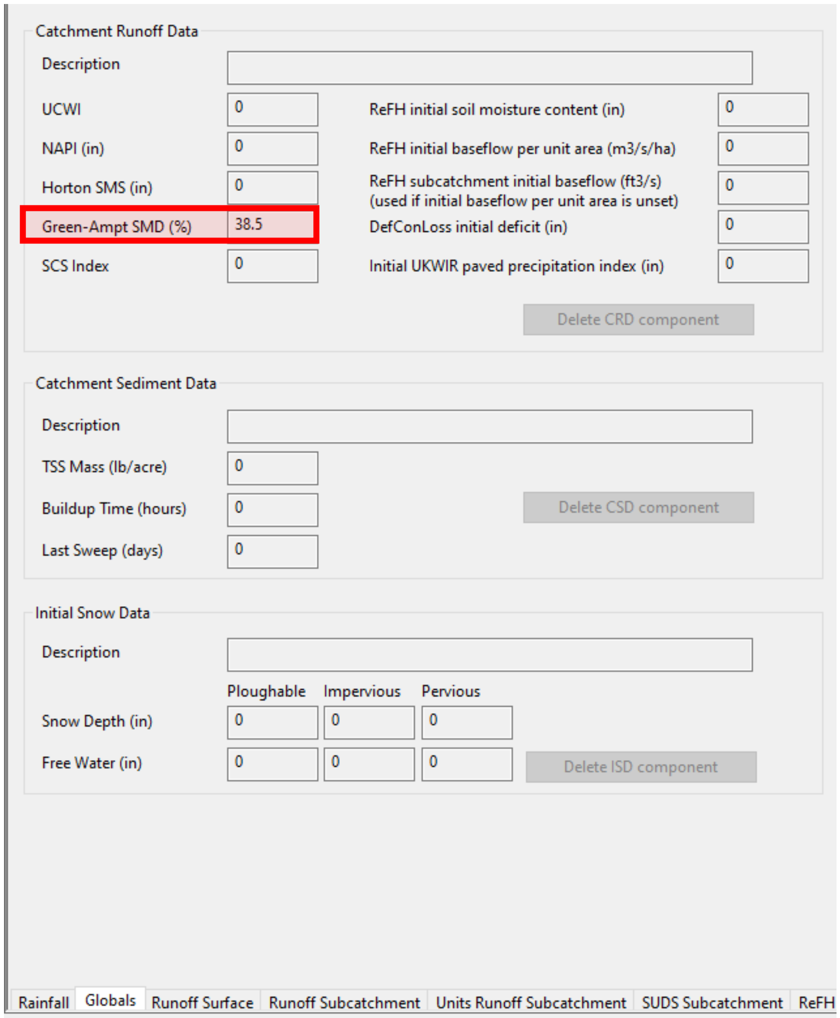


Figure 8: “Globals” tab on rainfall events