

Modeling an Urban Watershed

The goal of this document is to help users understand the underlying methodology for modeling an urban watershed (subcatchment) in MAGNET-StormNET. The process is illustrated through application to a simple watershed involving a subcatchment and outfall as its outlet.

This document does include specific details for *all* options, settings, parameters, etc. that may be involved in some aspect of modeling a watershed. Readers are referred to the '?' realtime help pages embedded in the StormNET interface system, as well as other online resources on the magnet4water website and elsewhere.

Conceptual Model

Watershed modeling in StormNET is essentially a subcatchment-by-subcatchment water balance: inflows minus outflows equals the rate of storage (interception or depression storage).

The hydrologic processes involved include precipitation and snowmelt (inflows), as well as evaporation, infiltration, and overland runoff (outflows)

Watershed runoff is represented as an effective sheet flow. The sheet outflow is based on an "effective" Manning's equation. Runoff depths are computed from water balance analysis (see Figure 1).



Figure 1: Water Balance Runoff Model.

Modeling Steps

Define Subcatchment Geometry

The subcatchment geometry helps to define the subcatchment area and characteristic width, wich help to control runoff. Subcatchment area is automatically calculated from the georeferenced map display. Characteristic width should be computed/estimated by the user (see more below in Define Runoff Characteristics.

The first step is to draw the subcatchment in the map display:

- Navigate to: Network Objects > Hydrology > Subcatchments > Right-click and select 'Start Drawing'
- Click on the map to add vertices of the subcatchment polygon. For this example, a rectangular subcatchment is added along a stretch of the Grand River in southwest Lansing, Michigan, USA (see Figure 2).
- Double-click to close the subcatchment.
- Click 'Stop Drawing' in the Subcatchments submenu





Figure 2: Drawn subcatchment in the StormNET environment. This hypothetical development is situated along the Grand River in southwest Lansing, Michigan, USA.

Define Runoff Characteristics

Runoff is computed in the following manner: first, precipitation "losses" are calculated (interception/depression storage, surface evaporation, and infiltration), and the remaining (or "excess") precipitation dictates the amount of additional water that becomes runoff. The runoff depth (d) is used to compute runoff flow (Q) via Manning's equation:

$$Q = \frac{1.486}{n} W d^{5/3} S_0^{1/2}$$

The underlying conceptual model for runoff sheet flow assumes a rectangular subcatchment defined by a width (W), flow path length (L), and effective (uniform) slope (S_o). The one-dimensional runoff flow is aligned along the length axis and move towards a "collection channel" that instantaneously routes water to the subcatchment outlet (see Figure 3). The relationship between the characteristic width, subcatchment area, and average flow path length depends on the assumed position of the outlet:

- A "single-sided" subcatchment (Scenario A) gives the typical relationship between width, area and length: W=A/L.
- A "double-sided" subcatchment (Scenario B) yield: W=A/(L/2)=2A/L

In reality, subcatchments are often not rectangular. In that case, an average flow path length (computed or approximated from real, variable lengths) should be substituted for the uniform flow path length.

Note that stormnet allows modeling the mix of pervious and impervious land covers within a subcatchment, e.g., an impervious parking lot surrounded by pervious area of grass and other vegetation. Runoff is calculated separately for each subarea, and total combined runoff is routed to the subcatchment outlet.

Assign Slope, Width, and Manning's Roughness

In StormNET, the following parameters are needed as input to compute runoff with Manning's equation: subcatchment area (A), characteristic width (W), slope, and Manning's roughness.

Users use the Subcatchment editor interface to define the subcatchments runoff characteristics:

- Network Objects > Hydrology > Subcatchments > Edit SubCatchments
- Or, click within an existing subcatchment

Hydrology		
Rain Gag	jes	
Subcato		<u> </u>
Aquifer	Start Drawing	
Snow P	O Stop Drawing	
Unit Hy	Edit SubCatchment	
LID Con	Select Subcatchem	ent Type
Hydraulics		~

Use the drop-down menu at the top of the menu to select/change the Subcatchment to be edited (see Figure 4).

StormNET computes subcatchment *area* based on its drawn extent in the georeferenced map display. The computed area is automatically populated as the default value in the editor (but can be overwritten, if desired). See Figure 5

The area and estimated average flow path length should be used to calculate the subcatchment *width*. A default value of 500ft is provided (Figure 5).

In this example, the outlet will be placed at the bottom-right corner of the subcatchment - essentially the same configuration as shown in Scenario A of Figure 3. Therefore, W=A/L=(7.5acres)/(365ft)=895ft

The effective *slope* should be specified by the user (default: 0.5%).

Manning's roughness is assigned for pervious portions and impervious portions of the subcatchment (Figure 6). (Recall that Stormnet allows modeling the mixing of different land covers within subcatchment based on percentage of area covered). Default values of 0.01 and 0.1 are used for impervious and pervious area, respectively. The default values are applied in this example.

Click the '?' help button to view a table of typical values of n for different surfaces (see Figure 7).

Assign Percent Pervious / Impervious

Use the "% imperv" field to control the percentage of impervious cover in the subcatchment (not including LIDs) – see Figure 8. Percentage pervious cover is calculated automatically for using in water balance and runoff calculations.



Figure 3: Non-linear reservoir routing or effective sheet flow runoff.

Subcatchment					0 🛞
Subcat. Id/Name:	Select a Sub	estehment	lighlight the Selected Su	bcatchment Reset Color to Defa	ult
SubCatchment Paramete	ers Infiltr	ation/Pollutants/Land Uses	Low Impact Design	Groundwater Flow Visualizatio	n Parameters
Property	Value	Property	Value	Property	Value
Name:	1	Description:	Description		
Rain Gage:	Select:	Apply selected Raingage	to the Subcatchements	that Do Not Have Raingage Assig	gned
Outlet:	Outlet node •	 Apply selected Outlet to a 	the Subcatchements tha	t Do Not Have Outlet Assigned	Hide Connection to this Outlet
Area (acres):	7.5	*Note: Press Enter to Update Lid Usage	%Occupied if it exists		
Width (ft):	500	Dstore-ImPerv (in)	0.05	Snow Pack	Select:
% Slope:	0.5	Dstore-Perv (in)	0.05	Curb Length (ft)	0
% imperv:	25	%Zero-Imperv	25	N-Perv Pattern	Select: 💌
N-Imperv	0.01	Subarea Routing	Select:	Dstore Pattern	Select: 💌
N-Perv	0.1	Percent Routed	100	Infil. Pattern	Select:
Save Subcatchment Data	Remove	Selected Subcatchment			

Figure 4: Subcatchment editor interface.

Subcatchment			
Subcat. Id/Name:	Sel	ect a Subca	tchment
SubCatchment Paramete	ers	Infiltrat	ion/Pollutants/Land Uses
Property	Value		Property
Name:	1		Description:
Rain Gage:	Select:	Ŧ	Apply selected Rain
Outlet:	Outlet r	node 🔻	Apply selected Outle
Area (acres):	7.5		Note: Press Enter to Update Lid
Width (ft):	895		Dstore-ImPer
% Slope:	0.5		Dstore-Perv (
% imperv:	25		%Zero-Imperv
N-Imperv	0.01		Subarea Rout
N-Perv	0.1		Percent Rout
Save Subcatchment Data	R	emove Se	lected Subcatchment

Figure 5: Input fields for subcatchment area, characteristic width, and slope.

Subcatchment			
	Sele	ect a Subca	atchment
Subcat. Id/Name:	1		•
SubCatchment Paramete	ers	Infiltrat	ion/Pollutants/Land Uses
Property	Value		Property
Name:	1		Description:
Rain Gage:	Select:	Ŧ	Apply selected Rain
Outlet:	Outlet n	ode 🔻	Apply selected Outle
Area (acres):	7.5		*Note: Press Enter to Update Lid
Width (ft):	895		Dstore-ImPer
% Slope:	0.5		Dstore-Perv (
% imperv:	25		%Zero-Imper
N-Imperv	0.01		Subarea Rou
N-Perv	0.1		Percent Rout
Save Subcatchment Data	Re	move Se	elected Subcatchment

Figure 6: Input fields for Manning's roughness.

	wanning strior overland	now over the imp
	portion of the subcatchme	ent. (<u>Typical Valu</u>
	Surface	n
	Smooth asphalt	0.011
	Smooth concrete	0.012
	Ordinary concrete lining	0.013
	Good wood	0.014
	Brick with cement mortar	0.014
	Vitrified clay	0.015
	Cast iron	0.015
	Corrugated metal pipes	0.024
	Cement rubble surface	0.024
	Fallow soils (no residue)	0.05
-Imperv	Cultivated soils	
	Residue cover < 20%	0.06
	Residue cover > 20%	0.17
	Range (natural)	0.13
	Grass	
	Short, prarie	0.15
	Dense	0.24
	Bermuda grass	0.41
	Woods	
	Light underbrush	0.40
	Dense underbrush	0.80

Figure 7: Typical values of Manning's roughness in the StormNET realtime help page.

Subcatchment			
	Sele	ect a Subca	atchment
Subcat. Id/Name:	1		•
SubCatchment Paramete	ers	Infiltrat	tion/Pollutants/Land Uses
Property	Value		Property
Name:	1		Description:
Rain Gage:	Select:	•	Apply selected Rain
	Outlet n	ode 🔻	
Outlet:			
	Select:	*	Apply selected Outle
Area (acres):	7.5		*Note: Press Enter to Update Lid
Width (ft):	895		Dstore-ImPer
% Slope:	0.5		Dstore-Perv (
% imperv:	25		%Zero-Imper
N-Imperv	0.01		Subarea Rou
N-Perv	0.1		Percent Rout
Save Subcatchment Data	Re	move Se	lected Subcatchment

Figure 8: Input field for percentage impervious cover.

Define Rain Input

StormNET enables automatic generation of spatially explicit rainfall time series based on 1) historical data, 2) future projections; and 3) design storm events or historical storm statistics.

In this example, we apply a pre-defined design storm as an illustration.

Users can interactively generate time series data based on a statistical temporal distribution for a design storm of a given depth, duration, and return period. Users may utilize a variety of standard deign storm distributions and use Intensity-Duration-Frequency curve information (if available). The results are automatically used as input into a Stormnet model.

Add a Rain Gage and Assign Storm Event (Rain Time-Series)

Modeling precipitation in StormNET requires 1) adding a rain gage to the model; 2) assigning the rain gage to a precipitation time-series; and 3) linking the subcatchment to the rain gage.

To add a rain gage to the model:

- Network Objects > Hydrology > Rain Gages > Right-click and select 'Start Drawing'
- Click in the map display to add a rain gage
- Select 'Stop Drawing' from Rain Gages submenu

To edit the rain gage:



- Click on the rain gage map icon; this opens the Rain Gage editor (see Figure 10) (or select 'Edit Rain Gage from the Rain Gage submenu)
- Define a rain data format (intensity, volume, or cumulative); in this example we use 'VOLUME'.
- Select the 2hr-Volume as the Series Name (default series) this is the time-series that will be used to compute precipitation input during simulation.
- Click 'Show Plot' to preview the rain time-series

Note: to edit the time-series:

• Network Objects > Time Series > Right-click and select 'Edit Time Series'; this opens the Time Series Editor interface (see Figure 11)

► Quality	
Curves	
Time Series	
Time Pa Edit Time Series	
 Geo Base Map 	
	 Quality Curves Time Series Time Pa Edit Time Series Geo Base Map

To link the rain gage to the subcatchment:

- Open the Subcatchment editor interface, SubCatchment Parameters subtab (see Figure 12).
- Select the rain gage ID from the drop-down menu next to 'Rain Gage'
- Save the changes



Figure 9: Rain gage added to the model.

Rain Gage								⊗
Raingage Properties	File Upload	Load from Server						
								_
Property		Value						
Id/Name:	Select:		~			Show Plot	i .	
			_					
X-Coordinate:	-84.549378	871:						
Y-Coordinate:	42.7216898	3306						
Description:	Description							
Tag:	tag							
Rain Format:	VOLUME	-						
Time Interval:	00:01	(hh:mm)						
Snow Catch Factor:	1.0							
Data Source:	TIMESERIES	s 🔻						
Series Name:	2hr-Volume		r					
_								
	Apply Select	ted Raingage to All S	ubcatchments					
	Cours	Domous						
	Save	Remove						

Figure 10: Rain Gage editor interface.

Time Series Editor		\odot	۲
Edit Mode:	Select Edit Mode: Edit 🛛 🗸		
Time Series Name: Description : Enter time series day Starting Time: Rain Duration(min): Distribution:	Select: 2hr-Volume ata O Use external data 12:00 AM O Total R 15 Time Ir Uniform Format	ta file Rainfall (in): 3.5 National Weather Service Data Server Interval (min) 1 at: Intensity Generate Time Series	
No dates means times are Add New Row Delete	e relative to start of simula e Last Row Clear Table	lation. e 2hr-Volume	
Id Date(M/D/Y) Tin	ne(H:M) Value		
1 mm/dd/yyyy 🗊 0:0	0		
2 mm/dd/yyyy 🗊 0:0	0.12		
3 mm/dd/yyyy 🗊 0:0	0.12		
4 mm/dd/yyyy 🗊 0:0	3 0.12		
5 mm/dd/yyyy 📰 0:0	4 0.12		
6 mm/dd/yyyy 📰 0:0	5 0.12		
7 mm/dd/yyyy 🗊 0:0	6 0.13	- 0.5	
8 mm/dd/yyyy 🗊 0:0	0.13		
9 mm/dd/yyyy 🗊 0:0	8 0.13	- 0 <mark>0 0.5 1 1.5 2</mark>	
10 mm/dd/yyyy 🗊 0:0	9 0.14		
		Hours	
Save Time Series	Delete Selected Time	e Series	

Figure 11: Time Series Editor interface for defining a storm event (rain time-series).

Subcatchment			
	Selec	t a Subcatchment	
Subcat. Id/Nam	e: 1		•
SubCatchment Par	ameters	Infiltration/Pol	lutants/Land Uses
Property	Value		Property
Name:	1		Description:
Rain Gage:	2	- 🗌 A	pply selected Rain
	Outlet no	de 🔻	
Outlet:			
	Select:	▼ 🗌 A	pply selected Outle

Figure 12: Linking a rain gage to a subcatchment.

Define Interception

Interception or depression storage is the amount of input water (precipitation and/or snowmelt) that can accumulate before runoff occurs – no runoff can occur until the subcatchment water depth is greater than the depression storage depth (refer to Figure 1).

Different depression storage depth can be specified for impervious and pervious subareas of the subcatchment.

To assign depth of depression storage depths:

- Open the Subcatchment editor interface, SubCatchment Parameters subtab.
- Update the input in 'Dstore-Imperv' (depth of depression storage in impervious subarea) see Figure 13). This example uses the default value
- Update the input in 'Dstore-Perv' (depth of depression storage in impervious subarea). This example uses 0.15 in

Refer to typical values of depth of depression storage in the realtime help page.

Subcatchment						
	Select a Subc	atchment		1.11		ed Outeestelu
Subcat. Id/Name:	-		L	j Higniign	t the Select	ed Subcatchr
SubCatchment Paramet	ters Infiltra	ition/Polluta	nts/Land Uses	Low Imp	act Design	Groundw
Property	Value		Property		Value	
Name:	1]	Description:		Description	
Rain Gage:	2 v		v selected Rainga	ige to the S	Subcatcher	nents that Do
	Outlet node type:					
Outlat	Outfalls -	- -				
Outlet:	Select:		selected Outlet	to the Sub	catchemen	ts that Do No
Area (acres):	7.5	*Note: Press I	Enter to Update Lid Us	age %Occupie	d if it exists	
Width (ft):	895]	Dstore-ImPerv	(in)	0.05	
% Slope:	0.5]	Dstore-Perv (in))	0.15	
% imperv:	25]	%Zero-Imperv		25	
N-Imperv	0.01]	Subarea Routin	g	Select: OUTLET	•
N-Perv	0.1]	Percent Routed	I	100	
Save Subcatchment Data	a Remove S	elected Subo	catchment			

Figure 13: Input fields for specifying depression storage depth in impervious and pervious subareas of the subcatchment.

Subcatchment			0	(\mathbf{x})
	Depth of depression the subcatchment	on storage on the pervious (inches or millimeters) (<u>Ty</u>	portion pical V	n of <u>alue</u>
	Typical Depression	Storage Values		
	Impervious surfaces	0.05 - 0.10 inches		
	Lawns	0.10 - 0.20 inches		
Dstore-Perv	Pasture	0.20 inches		
	Forest litter	0.30 inches		
	(Source: ASCE,(1992 Urban Stormwater Ma NY)), Design & Construction of nagement Systems, New York,		

Figure 14: Typical values of Manning's roughness in the StormNET realtime help page.

Define Infiltration Characteristics

Within pervious areas, StormNET models infiltration into unsaturated soils using one of the following methods: 1) the Horton method, 2) the Modified Horton method, 3) the Green and Ampt methods, 4) the SCS Curve Number method. Infiltration is not modeled within impervious subareas.

Here we will illustrate modeling infiltration with the SCS Curve Number method. The Curve Number method calculates runoff resulting from a given precipitation input and the hydrologic soil group, land use, and hydrologic condition. The difference between input precipitation and calculated runoff is the infiltration amount.

Assign Infiltration Method and Infiltration Parameters

Navigate to the Infiltration / Pollutants / Landuse subtab of the Subcatchment editor interface. The leftpanel is used to assign the infiltration method and infiltration parameters (Figure 15).

Select 'CURVE_NUMBER' from the drop-down menu next to 'Infil._Method'.

For this example, we will utilize the default values for curve number, conductivity, and drying time. Refer to the '?' (realtime help) for a table of typical values of curve number and saturated conductivity based on land use and hydrologic soil group Figure 17.

Note: users may examine the land use and soil type/soil properties at their site by mapping Big Data livelinked to the StormNET platform (not shown here; this is detailed in another tutorial):

- Navigate to VISUALIZATION (header menu) > Data Mapping > Draw Model area
- Follow the resulting interface to define a mapping area and which parameters to extract and display: DEM, soil, and/or land use and derived parameters, e.g., Curve Number

Alternatively, users may directly extract the Curve Number from Big Data :

- Navigate to: SIMULATE (header menu) > Add Spatial Data
- Click ' Get Spatial Data' in the interface that appears (see Figure 18)
- When the task is finished, notice that the Curve Number is updated in the Subcatchment editor interface (see Figure 19).

Subcatchment				() 🛞
-Select a Subcatchment- Subcat. Id/Name: 1	- Highlight	the Selected Subcat	chment Reset Colo	or to Default	
SubCatchment Parameters Infiltration/Pollutants/Land Uses Low Impact Design Groundwater Flow Visualization Parameters					
	*Note: Id's with data are part of	this subcatchment	*Note: Id's with data an	re part of this subcatchment	
Infil. Method HORION - Max. Infil. Rate (in/hr) 3.3 Min infil. Rate (in/hr) 0.5 Decay Constant 4 Drying Time 7 Max. Volume (ft3) 0	Land Use Residential_Low_Density Residential_High_Density Undeveloped Commerical Transportation Industrial Bare_Soil Civic	% of Area	Pollutant TSS TP TN Zinc Lead Copper	Ini. Buildup (lbs/ac)	
Save Subcatchment Data Remove Selected Sub	ocatchment				

Figure 15: Infiltration Data tab of the Subcatchment editor interface.

Subcat. Id/Nam	e:	Select	t a Subcato	chment
SubCatchment Para	ameters		Infiltratio	on/Pollutai
Infiltration Data He	elp ? CURVE	_NUME	BER 👻	ŗ
Curve Number Conductivity (in/hr) Drying Time	80 0.5 7]	

Figure 16: Example of selecting the Curve Number method for modeling infiltration within the subcatchment.

			SCS Urban Hydrology for Small Wat 1986. Consult the <u>Curve Number Ta</u>	tershe ble	eds, 2	nd Ed	., (IR-	5),		
			SCS Runoff Curve Numbers (Anteceder	nt moi	sture c	onditio	on II)			
Infiltration Data	Help?			Hydro	ologic	Soll G	roup	-		
			Land Use Description	A	В	C	D	This is t	he SCS curve number which is tabulated in the	ne publication
The Infiltration	Editor is used to energify	he method and its navemeters that model	Cultivated land	70	04	00	04	SCS Ur	ban Hydrology for Small Watersheds, 2nd Ed	., (1R-55),
the rate at which	rainfall infiltrates into the	upper soil zone of a subcatchment's	Without conservation treatment	60	74	00	91	June 19	86. Consult the <u>Curve Number Table</u> for a list	ang of value
nervious area T	he infiltration parameters of	enerd on which infiltration model is	vvitn conservation treatment	62	/1	/8	81	by soil g	roup, and the accompaning Soil Group Table	1
elected for the	subcatchment: Horton and	Modified Horton Green-Ampt and	Pasture or range land	00	70	00	00	NRCS H	ydrologic Soil Group Definitions	5
Modified Green	Ampt or Curve Number	The infiltration model is normally the	Poor condition	00	79	80	89	10.00		Saturated
lefault one set h	v project's Simulation Ont	ons or its Default Properties but can be	Good condition	39	61	14	80			Conductivit
verridden in th	e Editor	ons of no benash i rependes our can be	Weadow Qood condition	20	50	74	70	Group	Meaning	(in/hr)
			Good condition	30	00	/1	10		Low runoff potential. Water is transmitted freely through the soil. Group A	
Lindan Infi	0	Ourse Number	This stead associated	45	00	77	02	~	enile typically have less than 10 percent clay and	> 1.42
Horton Infil. Green-Ampt Infil. Curve Number		Thin stand, poor cover, no muich	45	00	70	03		more than 90 percent sand or gravel and have gravel		
Faiametei	Falalleter	Falancier	Good cover	25	22	10	11		or sand textures.	
Curve	Curve This is the SCS curve number which publication SCS Urban Hydrology fr 2nd Ed., (TR-55), June 1986. Consi	number which is tabulated in the	Open spaces, lawns, parks, golf courses, cemeteries, etc.				_	в	Moderately low runoff potential. Water transmission through the soil is unimpeded	0.57 - 1.42
Number		an Hydrology for Small Watersheds, ne 1986. Consult the <u>Curve Number</u>	Good condition: grass cover on 75% or more of the area	39	61	74	80		Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand	0.01 1.42
	Table for a listing of va accompaning Soil Grou	ues by soil group, and the <u>p Table</u> for the definitions of the	Fair condition: grass cover on 50 - 75% of the area	49	69	79	84		and have loamy sand or sandy loam textures.	
	various groups. Adjust	nents will be needed when a separate pervious	Commercial and business areas (85% impervious)	89	92	94	95	С	Water transmission through the soil is somewhat	0.06 - 0.57
	fractions and a Curve	Number is selected from a table	Industrial districts (72% impervious)	81	88	91	93		percent and 40 percent clay and less than 50 percen	it
	where the two land use	es are lumped together.	Residential ³						sand and have loam, silt loam, sandy clay loam, clay	V
		1 3	Average lot size (% Impervious ⁴)						loam, and silty clay loam textures.	
Conductivity	This property has been	deprecated and is no longer used.	1/8 ac or less (65)	77	85	90	92	100	High runoff potential.	and the second
			1/4 ac (38)	61	75	83	87	D	Water movement through the soil is restricted or very	< 0.06
Drying Time	The number of days it	takes a fully saturated soil to dry.	1/3 ac (30)	57	72	81	86		restricted. Group D soils typically have greater than	
	Typical values range b	etween 2 and 14 days.	1/2 ac (25)	54	70	80	85		clavey textures	1
			1 ac (20)	51	68	79	84		longey toxico.	1
			Paved parking lots, roofs, driveways, etc. ⁵	98	98	98	98	Source:	Hydrology National Engineering Handbook, Chapter 7, 1	Natural
			Streets and roads						Resources Conservation Service, U.S. Department of A	griculture,
			Paved with curbs and storm sewers ⁵	98	98	98	98		January 2009.	
			Gravel	76	85	89	91			
			Dia	72	00	07	20			

Figure 17: Realtime help page for Infiltration Data, including tables of typical values for curve number and saturated conductivity.



Figure 18: Steps for assigning infiltration parameters from Big Data live-linked to Stormnet.

Subcatchment				
Select a Subcatchmen Subcat. Id/Name: 1	t ▼			
SubCatchment Parameters Infiltration/Po	llutants/Land Uses			
Infiltration Data Help? *Note: Id's with data				
Infil. Method CURVE_NUMBER -	Land Use % of Ar Land Use			
Curve Number 82.90	Residential_Low			
Conductivity (in/hr) 0.5	Residential_High			
Drying Time 7	Undeveloped			
	Commerical			
	Transportation			
	Industrial			

Figure 19: Updated Curve Number in Subcatchment editor interface after extracting from Big Data server.

Define Evaporation

Evaporation can be specified as constant daily rate or as monthly averages throughout the year (e.g., for long-term simulation). Evaporation can also follow a time series (similar to rain time-series data), climate file, or users can apply the relatively simple temperature relationship (Hargreaves approach) with automated, instant extraction of maximum and minimum air temperature from:

- the global CFSR climate generator database (about 38km resolution) containing temperature for the period 1979 to 2018.
- the NOAA PRISM database containing seamless USA-wide temperature datasets, from 1981 to 6 months ago, at 4km-resolution (with 800m coming soon).

In this example, a constant evaporation rate is applied throughout the half-day simulation of a single (design) storm event is utilized to compute evaporation during simulation.

Assign Evaporation Rate

Navigate to: Network Objects > Climatology > Edit Climatology. This opens the Climatology editor interface (Figure 20).

The default subtab is 'Temperature' where users can

specify/import temperature data which can be used to compute evaporation. Click on the 'Evaporation' subtab and

assign a constant daily evaporation rate of 0.05in./day (see Figure 21).



Climatology						0 🛞
Temperature	Evaporation	Wind Speed	Snow Melt	Areal Depletion	Adjustments	
Source of Temperature	Data:					
🖲 No Data 🔿 Time	Series 🔘 Select or U	Jpload External Climat	e File			
Save Cancel						

Figure 20: Climatology editor interface.

Climatology					
Temperature	Evaporation	Wind Speed			
Source of Evaporation Rates: Constant Value					
Daily Evaporation (in/day): 0.05					
Month Value					
Monthly soil recovery pattern (optional):					
Evaporate only during Dry Periods					
Save Cancel					

Figure 21: Assigning a constant daily evaporation rate to be applied throughout simulation.

Define Subcatchment Outlet

The outlet of a subcatchment is the location/network feature that receives the runoff. The outlet can be a node (e.g., a junction, divider, or storage unit), an outfall (special node), or another subcatchment.

In this example, an outfall is utilized. An outfall represents the 'end-point'; water at an outfall essentially leaves the model network. Outfalls can represent free outflow (i.e., water leaves freely with no tailwater effects), or they can involve user defined tailwater effects (e.g., fixed stage, temporally variable elevations, etc.

Add an Outfall and Assign as Subcatchment Outlet

First, add an Outfall to the bottom-right corner of the subcatchment (Figure 22):

- Network Objects > Hydrology > Nodes > Outfalls > Start Drawing
- Click on the map to add the Outfall node
- Select 'Stop Drawing' in the Outfalls submenu

Next, edit the Outfall in the Outfall Editor (Figure 23):



Hydraulics

• We will use the default Type: 'FREE' (free outflow)

Note that invert elevation (Invert El) is, by default, zero. To add an invert elevation based on DEM:

- SIMULATE (header menu) > Add DEM (Figure 24)
- After a few moments, the extracted DEM at the outfall location will be used to compute the invert elevation.
- The invert elevation is computed based on a DEM offset (DEM minus offset equals invert elevation. The offset used here is 5ft (Figure 25).
- Note the updated value in the Outfall Editor interface.

Now link the Outfall to the Subcatchment as its outlet:

- Navigate to Subcatchment Editor interface, SubCatchment Parameters interface
- Select 'Outfalls' from the Outlet node type drop-down menu, and select Outfall 3 (ID from this example) see Figure 26.
- Click Save. Notice the linkage is now represented in the map display (Figure 27)



Figure 22: Rain gage added to the model at bottom-right corner of subcatchment (essentially the configuration shown in Figure 3).

Outfall Editor			()	۲
Property	Val	ue			
ld:	Select: 3	•			
X-Coordinate:	-84.550048480				
Y-Coordinate:	42.7202787384				
Description:	Description				
Tag:	Outfall				
Inflows:	NO	Ed	lit		
Treatment:	NO	Ed	lit		
Invert EI (ft):	0				
DEM (ft):	0				
DEM Offset (ft):	10				
Max Depth (ft):	5				
Tide Gate:	NO	*			
Route To:					
Type:	FREE	•			
Save	e Remo	ve			

Figure 23: Outfall Editor interface.



Figure 24: Utilizing the 'Add DEM' tool to assign invert elevations based on DEM to the nodes in the model.

Outfall Editor			⊘ ⊗
Property	Valu	le	
ld:	Select: 3	•	
X-Coordinate:	-84.6361362822		
Y-Coordinate:	42.6794686313		
Description:	Description		
Tag:	Outfall		
Inflows:	NO	Edit	
Treatment:	NO	Edit	
Invert EI (ft):	830.1		
DEM (ft):	835.10		
DEM Offset (ft):	5		
Max Depth (ft):	5		
Tide Gate:	NO	•	
Route To:			
Туре:	FREE	*	
Sav	e Remo	ve	

Figure 25: Updates to the Outfall Editor interface after utilizing the 'Add DEM' tool.

Subcatchment					0 😣
Subcat. Id/Name:	Select a 1	Subcatchment	Highlight the Selected	Subcatchment Reset Cold	or to Default
SubCatchment Paramet	ers In	filtration/Pollutants/Land Uses	Low Impact Design	Groundwater Flow Vis	sualization Parameters
Property	Value	Property	Value	Property	Value
Name:	1	Description:	Description		
Rain Gage:	Select: 2	 Apply selected Raing 	gage to the Subcatchemer	- nts that Do Not Have Rainga	ge Assigned
Outlet:	Outfalls Select: 3	•··· 👻 🗌 Apply selected Outle	t to the Subcatchements	that Do Not Have Outlet Ass	igned Hide Connection to this Outlet
Area (acres):	7.5	*Note: Press Enter to Update Lid U	Isage %Occupied if it exists		
Width (ft):	895	Dstore-ImPer	v (in) 0.05	Snow Pack	Select: 👻
% Slope:	0.5	Dstore-Perv (i	n) 0.05	Curb Length (ff	t) 0
% imperv:	25	%Zero-Imperv	25	N-Perv Pattern	Select: 👻
N-Imperv	0.01	Subarea Rout	ing OUTLET V	Dstore Pattern	Select:
N-Perv	0.1	Percent Route	ed 100	Infil. Pattern	Select: 💌
Save Subcatchment Data	a Remo	ve Selected Subcatchment			

Figure 26: Assigning the outfall node as the subcatchment outlet.



Figure 27: Map display after assigning the outfall node as the subcatchment outlet.

Simulate Water Balance, Runoff Depth, and Runoff Hydrograph

StormNET simulates / solves the water balance, runoff depth, and runoff outflow at each time-step of over a simulation spanning a specified length (simulation period).

Assign Simulation Length (Start and End Date & Time)

- Navigate to: Network Objects > Options > Dates subtab of Simulation Options subtab
- The simulation length is by default: 48 hours, but our storm event is 2hr
- Reduce the simulation length to 6 hours by making the End Analysis Time: 6:00pm of the same date as Start Analysis (see Figure 28).

Run Simulation

All aspects of setup and parameterization of relevant hydrological processes has been completed, as the model is ready for simulation, i.e., solving the subcatchment water balance (runoff depth) and simulating the runoff hydrograph for 2-hour storm event.

- Navigate to: SIMULATE (header menu) > Run Simulation (Figure 29).
- When the simulation is complete, a summary update report will appear. Also shown is a map display editor that allows users to explore the model outputs or inputs at different times (see Figure 30). Map-based visualization is covered in detail in other tutorials.

Simulation Options				📀 😒
General	Dates	Time Steps	Dynamic Wave	
	Date (M/D/Y)	Time (H·M)		
Start Analysis on	1/1/2020	12:00 AM (
Start Reporting on	1/1/2020	12:00 AM 🕒		
End Analysis on	1/1/2020	06:00 AM 🕒		
Start sweeping on	01/01			
End sweeping on	12/31			
Antecedent day days	0			
Save Cancel				

Figure 28: Adjusting the simulation length: 'Start Analysis on' and 'End Analysis on' options.

FILE	SIMULATE	REPORT VISUALIZATION	GALLERY TUTORIAL	SUPPORT SIGN UP ACCOUNT
Pan: Mi	Add DEM	D P Set Projectic Unit		
	Add Spatial Data	Aug		Y 5 15
	Run Simulation	Lummun P		
	Stop Analysis		A	A Deta ch
2.0	111 6 6			

Figure 29: Run Simulation.



Figure 30: Status Report and Map Visualization interface, post-simulation.

Visualizing Runoff

There are a number of ways to map, chart, visualize, and analyze the results of the StormNET model. For this example, we are interested in visualizing the runoff hydrograph (time-series) for the simple subcatchment.

To view the runoff hydrograph (runoff time-series):

- Navigate to: VISUALIZATIONS (header menu) > Simulation > Basic Model > Time Series
- In the interface that appears, select 'Subcatchment' as Object Type, 'Runoff' as Parameter (see
- Double-click in the subcatchment and then click the '+' next to Feature ID
- Click 'Show Timeseries Plot'

A graph of runoff over simulation time will appear (see Figure 32). Note that peak runoff occurs at about the same time as peak precipitation.

The user can change the parameter to be plotted, e.g., to "losses" (evaporation, infiltration, storage).

ILE SIMULATE REPORT	VISUALIZATION GALLERY TUTORIAL SUPPORT SIGN UP ACCOUNT
'an <mark>: Michigan, US/∼ </mark>	Design
	Run off Quantity Advanced 3D CAD Time Series
K'AJ	Water Budget
	Timeseries Plot Selection Make Timeseries Plot Select Object Type Subcatchment Select Parameter Runoff Double Click On Map to Select Object and Click + button. Click - to remove last item from list Feature ID 1 Show Timeseries Plot

Figure 31: Creating a runoff hydrograph.



Figure 32: Runoff Hydrograph and a "Losses Hydrograph" for the subcatchment.

Sensitivity Analysis (Design Experimentation/Optimization)

StormNET's integrated modeling and design environment enables users to experiment with different scenarios/configurations/parameters and almost instantly visualize the impact of their modifications. This is critical for model sensitivity analysis (i.e., how different parameters/processes control the water dynamics) and model optimization (how the system is best configured to meet compliance requirements).

In this example, it is interesting to consider how runoff routing and degree of imperviousness impacts the subcatchment runoff hydrograph.

Route Runoff to the Pervious Subarea

Let's first look at the impact of routing runoff from the impervious subarea to the pervious subarea (as opposed to routing impervious directly to the subcatchment outlet, as was done earlier).

- Navigate to the Subcatchment editor interface, SubCatchment Parameters subtab
- Choose 'PERVIOUS' from the drop-down menu next to Subarea Routing (Figure 33).
- Run Simulation (SIMULATE > Run Simulation)
- View the subcatchment runoff time-series (VISUALIZATIONS > Simulation > Basic Model > Time Series)

The resulting time-series is shown in Figure 34. Note that the peak flow is reducing, and the onset of runoff (and its peak flow) is delayed relative to the 'baseline' case where runoff from the impervious areas is routed directly to the subcatchment outlet. This is because the runoff routing allows for more infiltration of water in the pervious area that would have otherwise contributed to direct runoff to the subcatchment outlet.

Model a Completely Impervious Subcatchment

Now let's consider the case of an 100% impervious subcatchment.

- Navigate to the Subcatchment editor interface, SubCatchment Parameters subtab
- Change '% imperv' to 100 (Figure 35)
- Choose 'OUTLET' from the drop-down menu next to Subarea Routing
- Run Simulation
- View the subcatchment runoff time-series

The resulting time-series is shown in Figure 36. Note that the peak runoff is much higher than in the case of a mixed subcatchment (25% impervious, 75% pervious). This is expected, as there is no longer any infiltration in the model (now converted to runoff).

Model a Completely Pervious Subcatchment

Finally, consider the case of an 100% pervious subcatchment.

- Navigate to the Subcatchment editor interface, SubCatchment Parameters subtab
- Change '% imperv' to 0 (Figure 37Figure 35)
- Run Simulation
- View the subcatchment runoff time-series

The resulting time-series is shown in Figure 38. Note that the peak runoff is significantly less than in the case of a mixed subcatchment (25% impervious, 75% pervious) or impervious subcatchment. Also, the timing of the onset of runoff to the outlet and its peak flow is delayed (as was seen before in the runoff routing example). Again, this is expected, as the entire subcatchment area is available for more infiltration (and therefore less runoff).

SubCatchment Param	eters	Infiltration/Pollutants/Land Uses Low Impact Design G		
Property	Value		Property	Value
Name:	1		Description:	Description
Rain Gage:	2	- [Apply selected Raingage to	the Subcatchements t
Outlet:	Outlet node Outfalls Select: 3	type: •	Apply selected Outlet to the	e Subcatchements that
Area (acres):	7.5	*No	ote: Press Enter to Update Lid Usage %0	ccupied if it exists
Width (ft):	895		Dstore-ImPerv (in)	0.05
% Slope:	0.5		Dstore-Perv (in)	0.15
% imperv:	25		%Zero-Imperv	25
				Select:
N-Imperv	0.01		Subarea Routing	PERVIOUS 💌
N-Perv	0.1		Percent Routed	100
Save Subcatchment Da	ita Rer	nove Selec	sted Subcatchment	

Figure 33: Routing runoff from the impervious subarea to the pervious subarea.



Figure 34: Runoff hydrograph for the case of <u>runoff routing</u> from impervious subarea into pervious subarea.

п

Property	Value	Property	Value				
Name:	1	Description:	Description				
Rain Gage:	Select:	 Apply selected Raingage t 	o the Subcatchem				
	Outlet node type: Outfalls	•					
Outlet:	Select:						
Area (acres):	7.5	7.5 *Note: Press Enter to Update Lid Usage %Occupied if it e					
Width (ft):	895	Dstore-ImPerv (in)	0.05				
% Slope:	0.5	Dstore-Perv (in)	0.15				
% imperv:	100	%Zero-Imperv	25				
N-Imperv	0.01	Subarea Routing	Select: OUTLET				
N-Perv	0.1	Percent Routed	100				

Figure 35: Assigning the subcatchment as 100% impervious cover.



Figure 36: Runoff hydrograph for the case of <u>100% impervious</u> cover in the subcatchment.

SubCatchment Paramet	Infiltration/Poll			
Property	Valu	e		
Name:	1			
Rain Gage:	Select: 2		•	
Outlet:	Outlet n Outfal Select: 3	ode type: I IS	•	
Area (acres):	7.5		_	Note: Pr
Width (ft):	895			
% Slope:	0.5			
% imperv:	0			
N-Imperv	0.01			_
N-Perv	0.1			
Save Subcatchment Data		Remove	Sel	ected S

Figure 37: Assigning the subcatchment as 100% pervious cover.



Figure 38: Runoff hydrograph for the case of <u>100% pervious</u> cover in the subcatchment.