

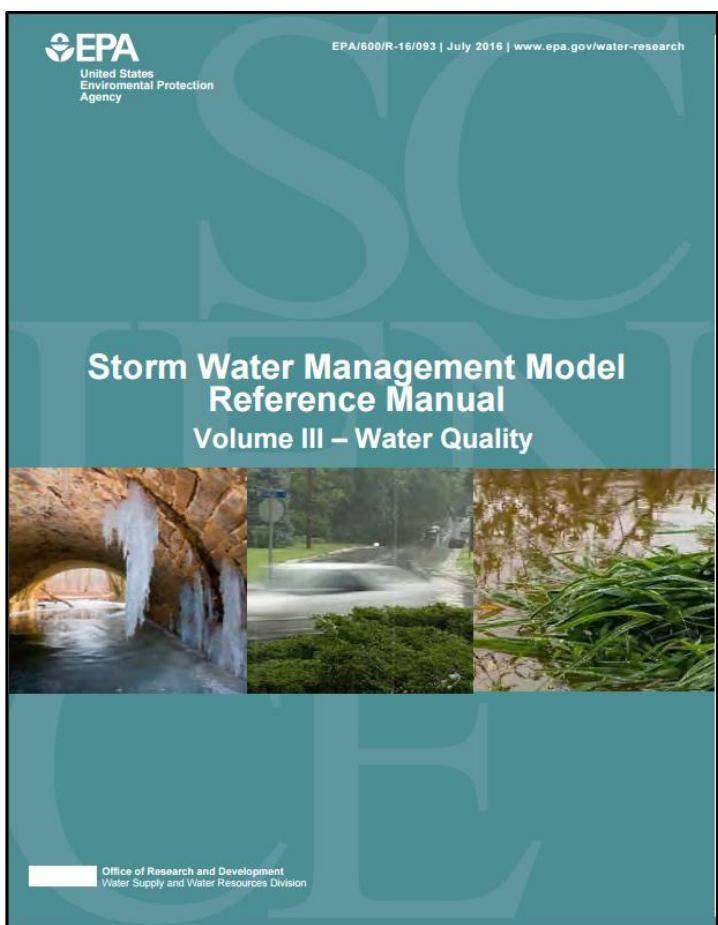
Water Quality Modeling



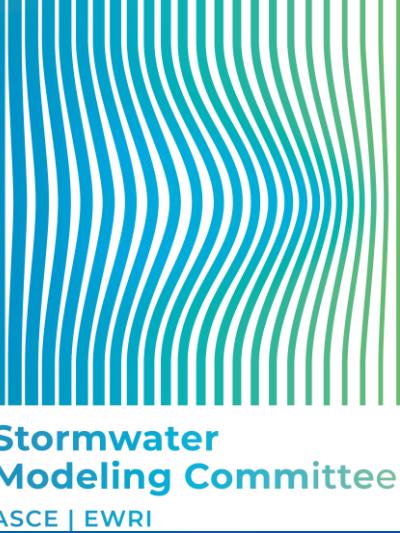
EWRI Congress 2025
EPA SWMM5 Technical Workshop
Anchorage AK, May 18, 2025

Outline

- Urban runoff quality
- SWMM5 water quality processes
- Surface buildup and washoff
- Routing and treatment



Reference Manual
Volume III – Water Quality
(at www.epa.gov)



EWRI Congress 2025, EPA SWMM5 Workshop -- Water Quality Modeling

Urban Runoff Quality

Common Pollutants in Stormwater

- Sediment: more on this later...
- Nutrients: various forms of Nitrogen and Phosphorus, more later...
- Metals: cadmium, copper, lead, mercury, zinc
- Pathogens: fecal coliform/streptococci & other bacteria, viruses, microorganisms
- Dissolved oxygen and biological/chemical/sediment oxygen demand
- Chlorides: dissolved salts from deicing activities and water softeners
- Toxicants: pesticides, herbicides, plasticizers, solvents, household cleaners
- Not simulated in SWMM5: oil/grease and other floatables, temperature, pH, turbidity, color, alkalinity, specific conductance, etc.

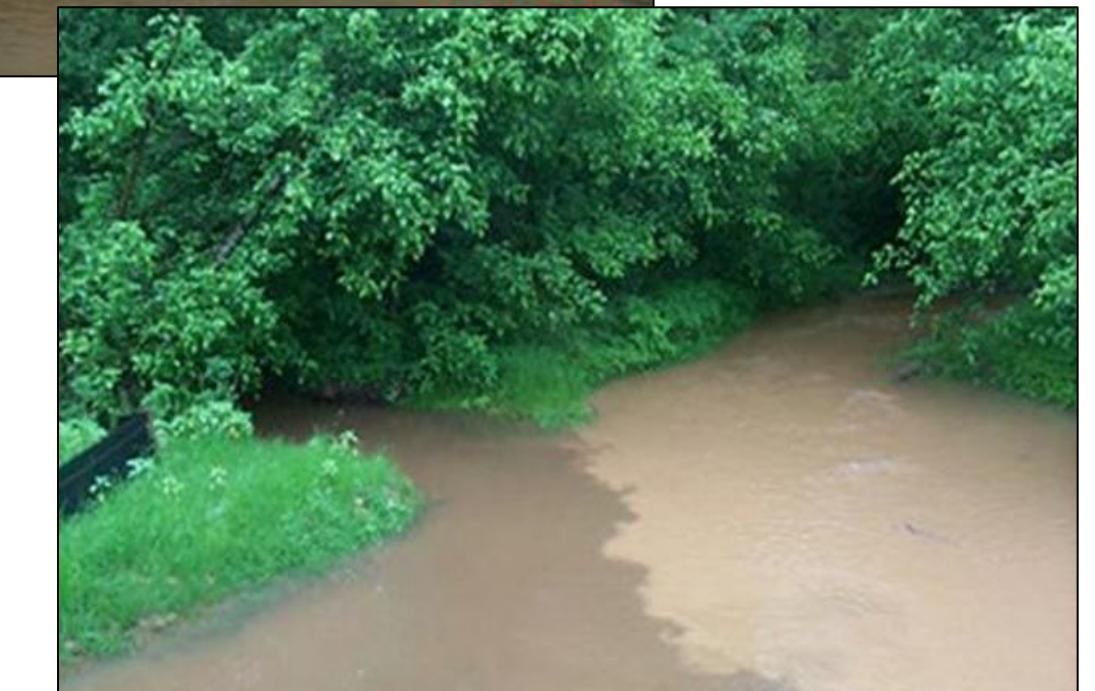
Substances in Flowing Water

- Buoyant materials on surface
- Dispersed materials in water
 - Solids held in suspension by turbulence
 - Colloidal/dissolved material in chemical solution
- Bed material on the bottom
- Sources of sediments/solids
 - Urban “dirt”
 - Streambank erosion
 - Construction/earthmoving activities
 - Channel/land use modifications



Sediment

- Pollutant
 - Affects feeding, respiration, spawning of fish
 - Restricts light (increases turbidity)
 - Siltation/clogging of hydraulic structures
 - Preferential settling of largest particles
- Medium for transporting pollutants
 - Fine-textured material (clay, organics)
 - Likely to be transported in suspension
 - Able to adsorb/absorb constituents
 - Preferential transport of finest particles
- Treatment processes require low turbidity to operate efficiently



TSS – One Size Does Not Describe All

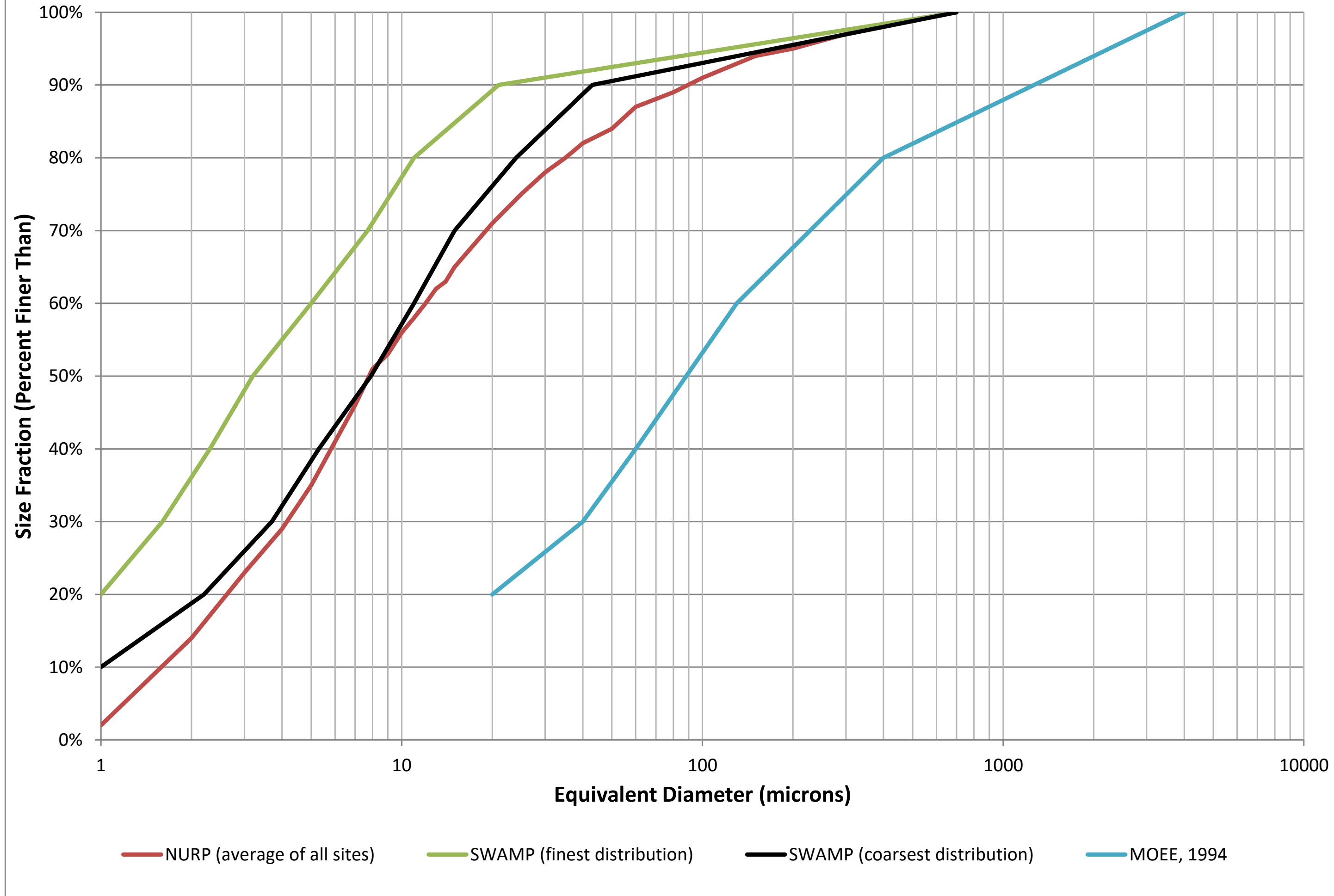
- Total Suspended Solids comprise a bunch of particle sizes (e.g., d₅₀ or PSD)
- According to NURP (U.S. EPA, 1983), particle size distribution of dirty water is:

Mass Fraction	Equiv. Diameter (μm)		Average Velocity		Density (kg/m^3)	Bulk Density Dry (kg/m^3)
	Range	Mean	(m/s)	(ft/hr)		
0-20%	<3	1.5	0.0000025	0.03	2,200	200
20-30%	3-5	4	0.0000130	0.15	2,425	400
30-40%	5-7	6	0.0000254	0.30	2,425	400
40-60%	7-17	12	0.0001270	1.50	2,575	1,200
60-80%	17-35	26	0.0005927	7.00	2,650	1,800
80-100%	>35	103	0.0055033	65.00	2,650	1,800

- Size and hydraulic residence times are critical
 - Preferential settling of large particles (bedload)
 - Preferential transport of small particles (washload)
 - very fine sand > 63 μm > coarse silt



Comparison of Particle Size Distributions



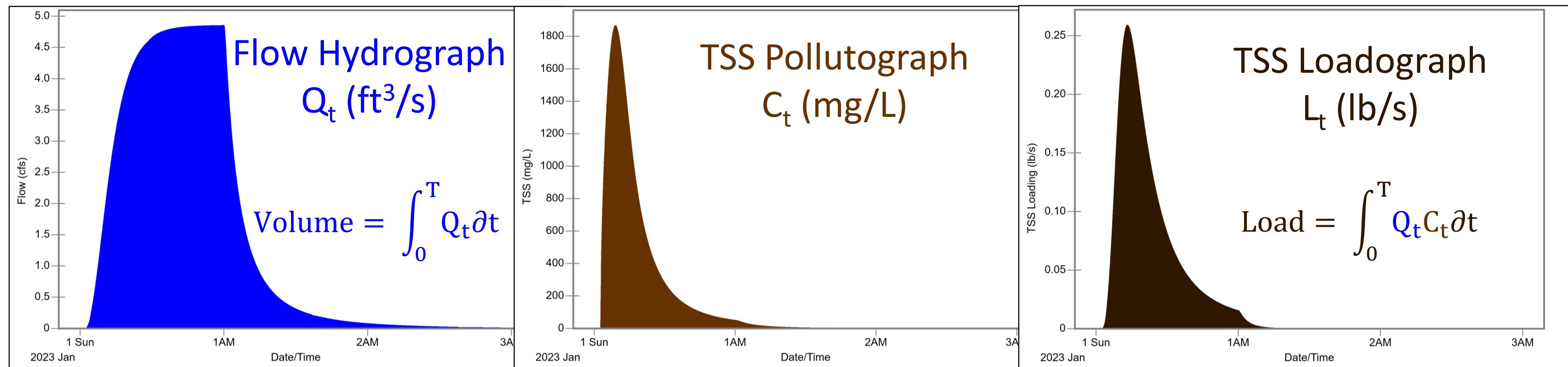
Typical Urban Runoff Event Mean Concentrations

Constituent	Units	Mean EMC
Total Suspended Solids	mg/L	78.4
Biological Oxygen Demand*		14.1
Chemical Oxygen Demand*		52.8
Total Phosphorous		0.32
Soluble Phosphorous		0.13
Total Kjeldahl Nitrogen		1.73
Nitrite and Nitrate	µg/L	0.66
Copper		13.4
Lead		67.5
Zinc	colonies/100 mL	162
Fecal Coliform*		15,038
Fecal Streptococci*		35,351

* Temperature is not accounted for in SWMM Water Quality modeling and therefore Biological and Chemical Oxygen Demand may not be modeled accurately

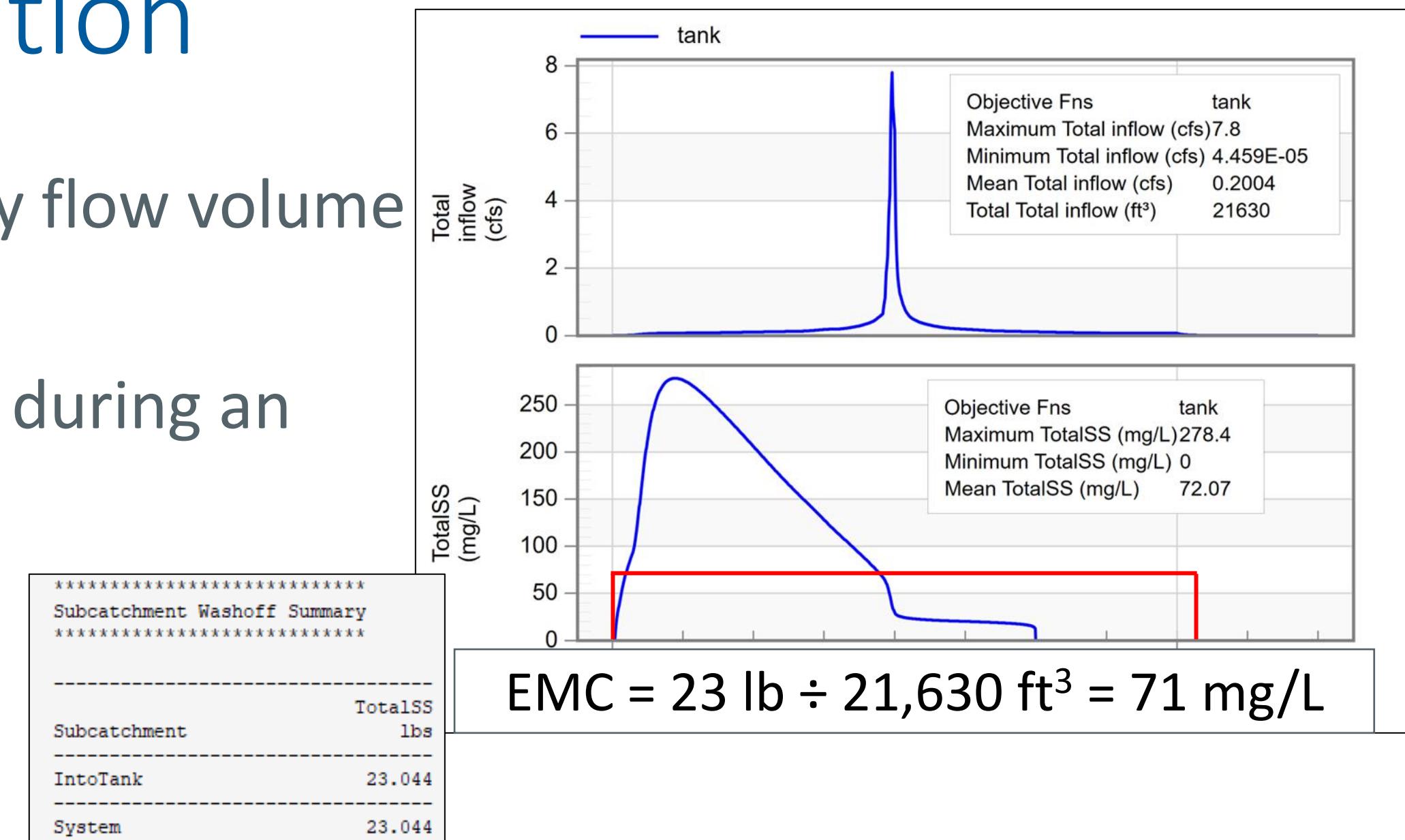
Quantifying Quantity and Quality

- Hyetograph: rainfall timeseries
- Hydrograph: water quantity flow rate, Q_t
- Pollutograph: pollutant concentration, C_t
- Loadograph: pollutant mass loading rate, $L_t = Q_t \times C_t$



Event Mean Concentration

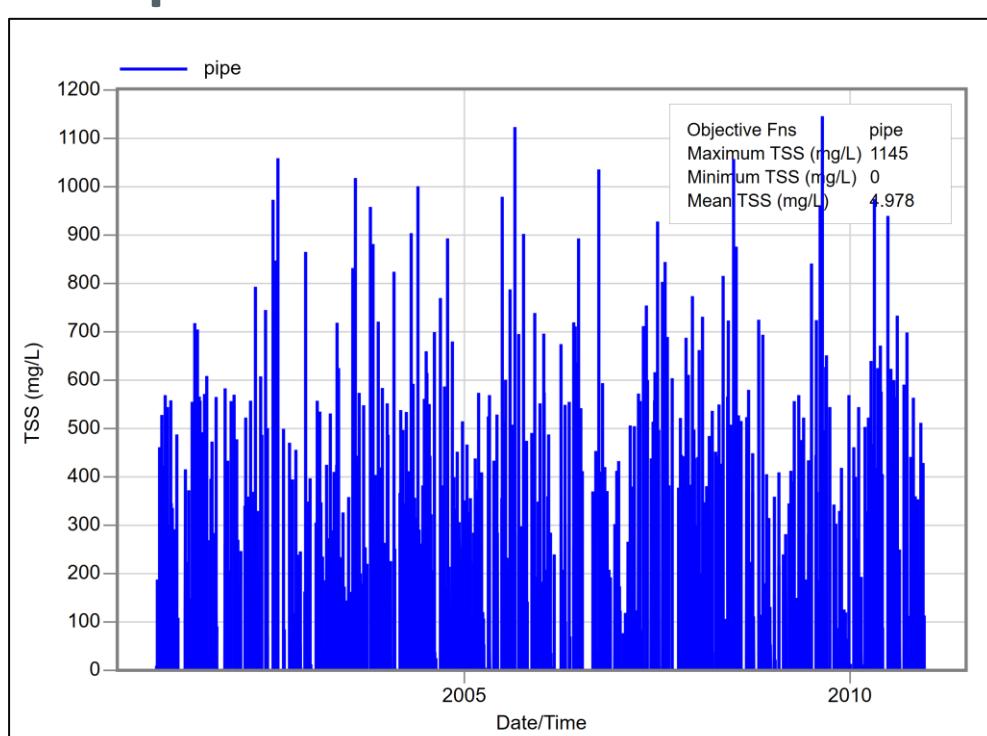
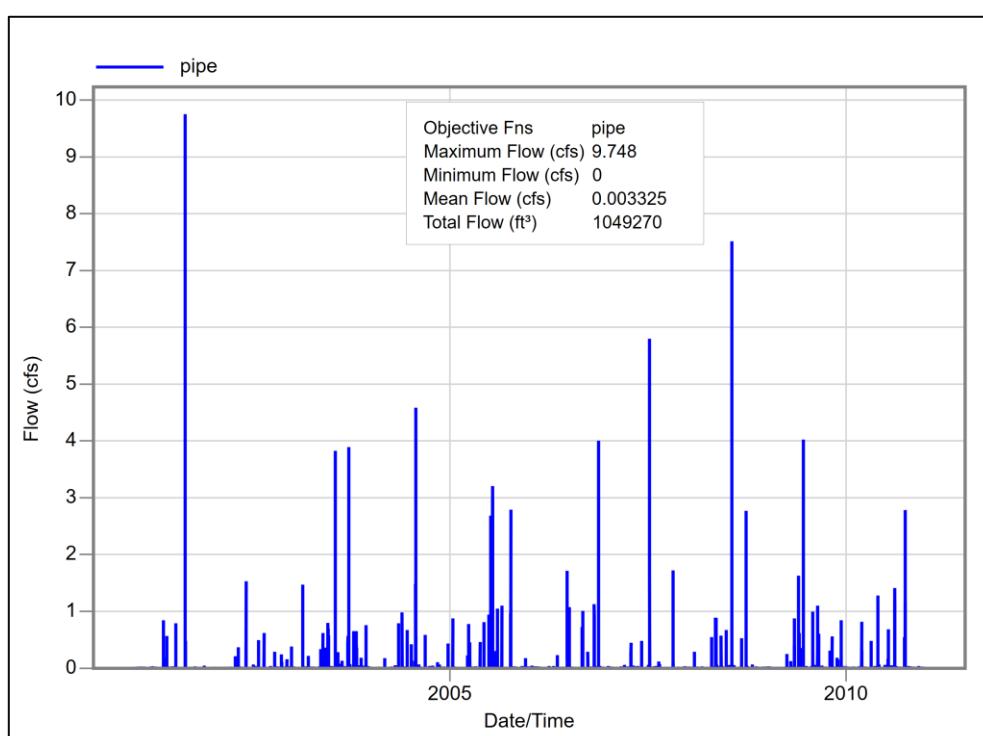
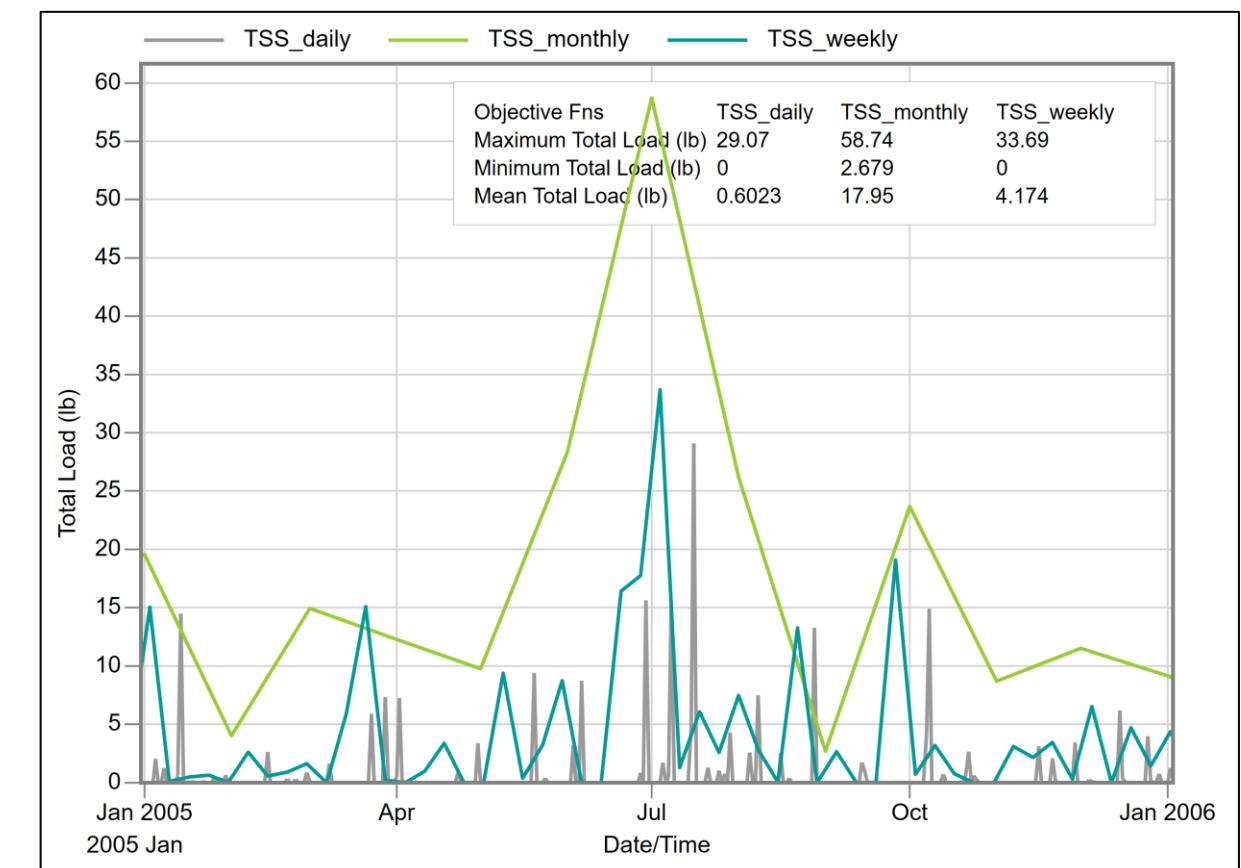
- EMC: Total pollutant load divided by flow volume over the event duration
- Concentrations can vary very much during an event, EMC is the overall average
- Handy unit conversions:
 - 28.317 L per ft³
 - 453592.4 mg per lb
- For continuous simulation, parse the timeseries into runoff-producing, pollutant-generating events
 - Example: rainfall minimum interevent time = 12hr, pollutant threshold = 0 mg/L)
 - Top 10 Total Suspended Solids “events”...



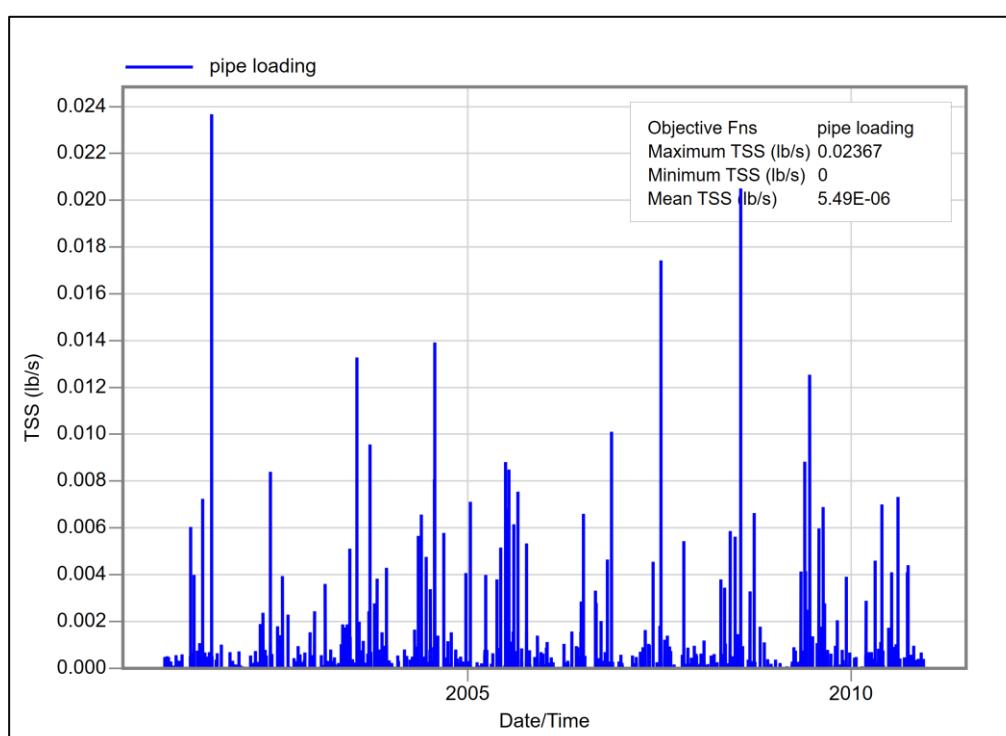
Start Date/Time	Duration (hr)	Flow Volume (ft ³)	TSS Mean (mg/L)	TSS Load (kg)	Event Mean Conc. (mg/L)
01-Jan-2011 11:15	2.75	39.1	92.6	0.3	255.7
24-Dec-2008 15:05	4	88.5	83.1	0.6	235.9
09-Dec-2009 12:10	3.17	92.8	71.4	0.5	189.2
01-Feb-1986 16:10	4.92	54.9	45.7	0.3	163.1
27-Feb-2009 11:20	2.25	40.4	79.5	0.2	155.6
12-Jan-2018 10:50	12.92	129.1	22.9	0.4	116.8
16-Dec-2000 11:15	2.33	38.5	52.4	0.1	115.3
28-Jan-2013 13:15	2.08	22.1	42.0	0.1	106.9
30-Nov-2014 22:15	2.33	49.6	54.9	0.1	102.0
18-May-1966 20:20	1.92	41.8	66.0	0.1	100.8

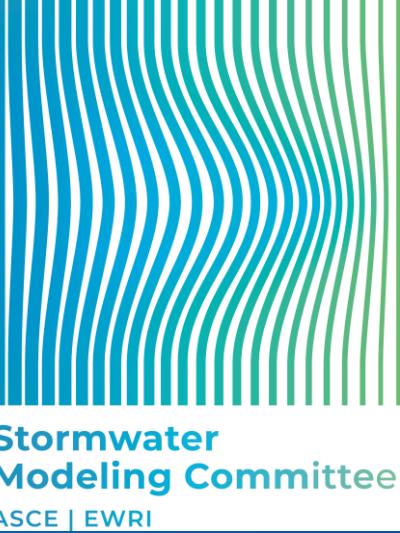
Pollutant Load

- Load: Pollutant mass passing a given point over a given period of time
- Load = Concentration × Flowrate
- And since concentrations and flows are highly variable in stormwater systems, so too is load
- Always know the concentration averaging and load accumulation periods



Load = $\int_0^T Q_t C_t \partial t$

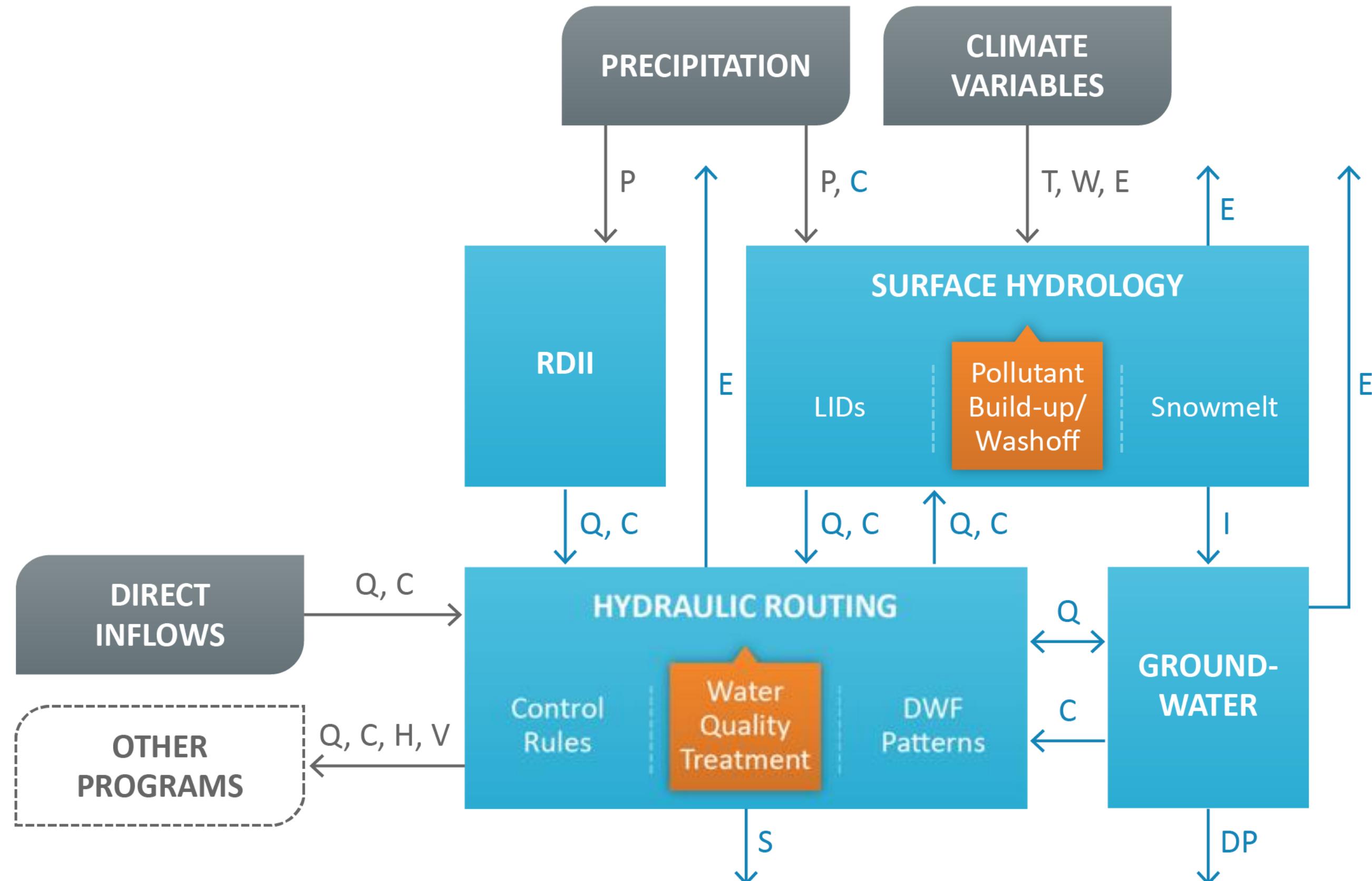




EWRI Congress 2025, EPA SWMM5 Workshop -- Water Quality Modeling

SWMM5 Water Quality Processes

SWMM Process Schematic



Legend:

- Input Function (Gray Box)
- SWMM Process (Blue Box)

Definitions:

- C** = Concentration
- DP** = Deep Percolation
- E** = Evaporation
- ET** = Evapotranspiration
- H** = Head/Depth
- I** = Infiltration
- P** = Precipitation
- Q** = Flow
- RDII** = Rainfall Dependent Infiltration & Inflow
- S** = Seepage
- T** = Temperature
- V** = Velocity
- W** = Wind Speed

Water Quality Processes

- Pollutant loads/concentrations come from...
 - “Buildup” during dry weather and “washoff” during rainfall
 - Other contributions such as wet deposition (i.e., with the rainfall), groundwater, sanitary sewer flows, external inflows, etc.
- Pollutants move through the hydraulic network...
 - Dispersed/diluted within storage facilities (in SWMM5 nodes)
 - Routed through the conveyance system (in SWMM5 links)
- Pollutant loads/concentrations can be reduced due to...
 - Street cleaning practices before washoff into the hydraulic network
 - Treatment or natural processes within the hydraulic network

SWMM5.2 Input File Sections

May contain water quality input parameters

Hydrology

[RAINGAGES]	rain gage information
[EVAPORATION]	evaporation data
[TEMPERATURE]	air temperature and snow melt data
[ADJUSTMENTS]	monthly adjustments applied to climate variables
[SUBCATCHMENTS]	basic subcatchment information
[SUBAREAS]	subcatchment impervious/pervious sub-area data
[INFILTRATION]	subcatchment infiltration parameters
[LID_CONTROLS]	low impact development control information
[LID_USAGE]	assignment of LID controls to subcatchments
[AQUIFERS]	groundwater aquifer parameters
[GROUNDWATER]	subcatchment groundwater parameters
[GWF]	groundwater flow expressions
[SNOWPACKS]	subcatchment snow pack parameters

Hydraulics

[JUNCTIONS]	junction node information
[OUTFALLS]	outfall node information
[DIVIDERS]	flow divider node information
[STORAGE]	storage node information
[CONDUITS]	conduit link information
[PUMPS]	pump link information
[ORIFICES]	orifice link information
[WEIRS]	weir link information
[OUTLETS]	outlet link information
[XSECTIONS]	conduit, orifice, and weir cross-section geometry
[TRANSECTS]	transect geometry for conduits with irregular cross-sections
[STREETS]	cross-section geometry for street conduits
[INLETS]	design data for storm drain inlets
[INLET_USAGE]	assignment of inlets to street and channel conduits
[LOSSES]	conduit entrance/exit losses and flap valves
[CONTROLS]	rules that control pump and regulator operation
[CURVES]	x-y tabular data referenced in other sections

Job Control

[TITLE]	project title
[OPTIONS]	analysis options
[REPORT]	output reporting instructions
[FILES]	interface file options

H&H

[INFLOWS]	external hydrograph/pollutograph inflow at nodes
[TIMESERIES]	timeseries data referenced in other sections
[PATTERNS]	periodic multipliers referenced in other sections

Water Quality

[POLLUTANTS]	pollutant information
[LANDUSES]	land use categories
[COVERAGES]	assignment of land uses to subcatchments
[LOADINGS]	initial pollutant loads on subcatchments
[BUILDUP]	buildup functions for pollutants and land uses
[WASHOFF]	washoff functions for pollutants and land uses
[TREATMENT]	pollutant removal functions at conveyance system nodes

Wastewater

[DWF]	baseline dry weather sanitary inflow at nodes
[RDII]	rainfall-dependent I/I information at nodes
[HYDROGRAPHS]	unit hydrograph data used to construct RDII inflows

Mapping Data

[MAP]	X,Y coordinates of the map's bounding rectangle
[POLYGONS]	X,Y coordinates for each vertex of subcatchment polygons
[COORDINATES]	X,Y coordinates for nodes
[VERTICES]	X,Y coordinates for each interior vertex of polyline links
[LABELS]	X,Y coordinates and text of labels
[SYMBOLS]	X,Y coordinates for rain gages
[BACKDROP]	X,Y coordinates of the bounding rectangle and backdrop image file name

SWMM5 Water Quality Capabilities

- Dry-weather pollutant buildup over different land uses
- Pollutant washoff from specific land uses during rainfall
- Direct contribution from rainfall deposition
- Reduction in dry-weather buildup due to street sweeping
- Estimation of dry-weather sanitary flows and user-specified external inflows
- Routing of water quality constituents through the drainage system
- Reduction in constituent concentration through treatment in storage units or natural processes in pipes/channels

Typical SWMM Water Quality Set Up

1. Identify the pollutants to be analyzed
2. Define the land uses that generate these pollutants
3. Assign one or a mixture of land uses to each subcatchment
4. Set the buildup, washoff and street cleaning parameters for each land use
5. Define pollutant removal functions for nodes within the drainage system that contain storage/treatment facilities

Water Quality Units

Parameter	US	SI
Concentration	mg/L	
	µg/L	
	Count/L	
Decay Constant		1/days
Pollutant Buildup	lbs/length	kg/length
	lbs/acre	kg/ha
Street Cleaning Interval		days

Pollutant Input Parameters

- Pollutant name
- Concentration units (i.e., milligrams/liter, micrograms/liter, or counts/liter for microorganisms)
- (optional) Concentration by source (used for Wet Deposition)
 - Rainfall: Pollutant concentration in Subcatchment rainfall
 - Groundwater: Concentration in defined Aquifers
 - I&I: Concentration in rainfall-dependent infiltration/inflow
 - DWF: Concentration in dry weather flow (in sanitary sewers), can be overridden by editing the node's Inflows property
 - Initial: Initial concentration throughout the conveyance system
 - See Table 2-6 in Vol. 3 Ref. Manual (& Table 7 from CDM Smith)

Pollutant Editor

Property	Value
Name	FColiform
Units	#/L
Rain Concen.	0
GW Concen.	0
I&I Concen.	0
DWF Concen.	2000000
Init. Concen.	0
Decay Coeff.	1.5
Snow Only	NO
Co-Pollutant	*
Co-Fraction	0

User-assigned name of the pollutant.

Pollutants

- BOD₅
- Chlorides
- FColiform**
- NH₃-N
- TotalPb
- TotalSS

OK Cancel Help

I Love That Dirty Water - Modeling Water Quality in the Boston Drainage System

Matt Gamache^{1*}, Mitch Heineman¹, Derek Etkin¹, Zachary Eichenwald¹, Jamie Lefkowitz¹, Paul Keohan², and Ron Miner¹

¹CDM Smith, Cambridge, Massachusetts

²Boston Water and Sewer Commission, Boston, Massachusetts

Constituent	Rainfall	Groundwater	Illicit
TSS (mg/L)	6	0	302
BOD ₅ (mg/L)	7	0	320
COD (mg/L)	12	0	691
TKN (mg/L)	0.14	0.1	51
Nitrate plus nitrite (mg/L)	0.17	0.51	0.98
NH ₃ (mg/L)	0.12	0.02	38
Total phosphorus (mg/L)	0.007	0.008	7.1
Orthophosphate	0.007	0.008	3.3
Total copper (µg/L)	0.5	1	90
Total zinc (µg/L)	2.5	2	193
Fecal coliform (#/100 mL)	0	0	7,100,000
<i>E. coli</i> (#/100 mL)	0	0	3,800,000
<i>Enterococcus</i> (#/100 mL)	0	0	500,000

Pollutant Input Parameters (continued)

- (optional) Decay coefficient: A first-order reaction coefficient (in units of 1/days) used to compute the rate at which the constituent decays due to reaction or other processes once it enters the conveyance portion of a SWMM model
- Snow Only: Enter YES if pollutant buildup occurs only when there is snow cover (e.g., chlorides), the default value is NO
- (optional) Co-pollutant designation:
 - Co-Pollutant: Name of another pollutant whose runoff concentration adds to the current pollutant's runoff concentration
 - Co-Fraction: Fraction of the co-pollutant's runoff concentration that contributes to the current pollutant's runoff concentration (i.e., the concentration is linearly related by a constant fraction)

Pollutant Editor	
Property	Value
Name	FColiform
Units	#/L
Rain Concen.	0
GW Concen.	0
I&I Concen.	0
DWF Concen.	2000000
Init. Concen.	0
Decay Coeff.	1.5
Snow Only	NO
Co-Pollutant	*
Co-Fraction	0

User-assigned name of the pollutant.

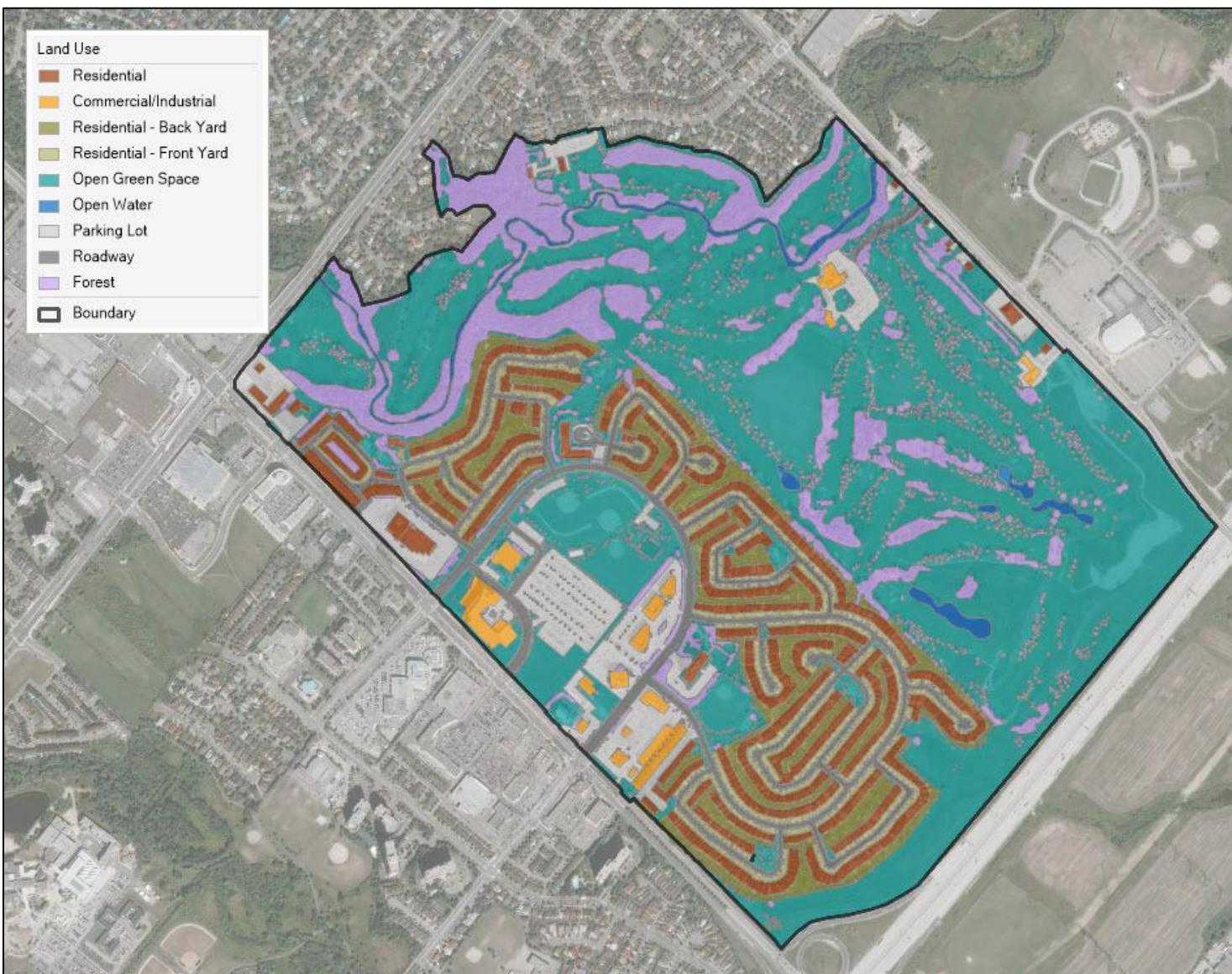
OK Cancel Help

Pollutant Land Uses

- Pollutants associated with runoff are generated by specific land uses assigned to subcatchments
 - Usually based on zoning type, but can use the same surface cover material categories that are generally used to create a Hydrology model
- Note: check your land use percentages – SWMM5 doesn't check if the total coverage is >100%

Land Use Editor

General		Buildup		Washoff																											
<table border="1"> <thead> <tr> <th>Property</th> <th>Value</th> </tr> </thead> <tbody> <tr> <td>Land Use Name</td> <td>Grass</td> </tr> <tr> <td>Description</td> <td>Turfgrass/landscaping...</td> </tr> <tr> <td>STREET SWEEPING</td> <td></td> </tr> <tr> <td>Interval</td> <td>0</td> </tr> <tr> <td>Availability</td> <td>0</td> </tr> <tr> <td>Last Swept</td> <td>0</td> </tr> </tbody> </table> <p>Optional comment or description of the land use (click to edit).</p>						Property	Value	Land Use Name	Grass	Description	Turfgrass/landscaping...	STREET SWEEPING		Interval	0	Availability	0	Last Swept	0												
Property	Value																														
Land Use Name	Grass																														
Description	Turfgrass/landscaping...																														
STREET SWEEPING																															
Interval	0																														
Availability	0																														
Last Swept	0																														
<table border="1"> <thead> <tr> <th colspan="2">Subcatchments</th> </tr> </thead> <tbody> <tr> <td>aHC0011</td> <td></td> </tr> <tr> <td>aHC0011a3</td> <td></td> </tr> <tr> <td>Ex_10</td> <td></td> </tr> <tr> <td>Ex_12m</td> <td></td> </tr> <tr> <td>Ex_13</td> <td></td> </tr> <tr> <td>Ex_14</td> <td></td> </tr> <tr> <td>Ex_15m</td> <td></td> </tr> <tr> <td>Ex_16</td> <td></td> </tr> <tr> <td>Ex_16Am</td> <td></td> </tr> <tr> <td>Ex_16Bm</td> <td></td> </tr> <tr> <td>Front1</td> <td></td> </tr> <tr> <td>Front2</td> <td></td> </tr> </tbody> </table>						Subcatchments		aHC0011		aHC0011a3		Ex_10		Ex_12m		Ex_13		Ex_14		Ex_15m		Ex_16		Ex_16Am		Ex_16Bm		Front1		Front2	
Subcatchments																															
aHC0011																															
aHC0011a3																															
Ex_10																															
Ex_12m																															
Ex_13																															
Ex_14																															
Ex_15m																															
Ex_16																															
Ex_16Am																															
Ex_16Bm																															
Front1																															
Front2																															
<table border="1"> <thead> <tr> <th>Land Use</th> <th>% of Area</th> </tr> </thead> <tbody> <tr> <td>Bare</td> <td>0</td> </tr> <tr> <td>Farm</td> <td>3.1</td> </tr> <tr> <td>Forest</td> <td>12.3</td> </tr> <tr> <td>Grass</td> <td>6.2</td> </tr> <tr> <td>Gravel</td> <td>5.5</td> </tr> <tr> <td>GrnRoof</td> <td>0</td> </tr> <tr> <td>ImpPave</td> <td>23.3</td> </tr> </tbody> </table>						Land Use	% of Area	Bare	0	Farm	3.1	Forest	12.3	Grass	6.2	Gravel	5.5	GrnRoof	0	ImpPave	23.3										
Land Use	% of Area																														
Bare	0																														
Farm	3.1																														
Forest	12.3																														
Grass	6.2																														
Gravel	5.5																														
GrnRoof	0																														
ImpPave	23.3																														
<input type="button" value="OK"/> <input type="button" value="Cancel"/> <input type="button" value="Help"/>																															



Pollutant Land Uses (continued)

- Accounts for spatial variation within subcatchments, distinguishing pollutant source areas by...
 - Zoning (coarse spatial resolution)
 - Surface cover (high level of detail)
- Affects water quality parameters for each pollutant:
 - Operations (street sweeping activities)
 - Pollutant buildup/washoff rates
 - BMP efficiency
- Land use designations do not affect runoff quantity

Land Use Editor

General	
Property	Value
Land Use Name	RegRoof
Description	Pitched impervious roof
STREET SWEEPING	
Interval	0
Availability	0
Last Swept	0

User assigned name of land use.

Land Use Editor

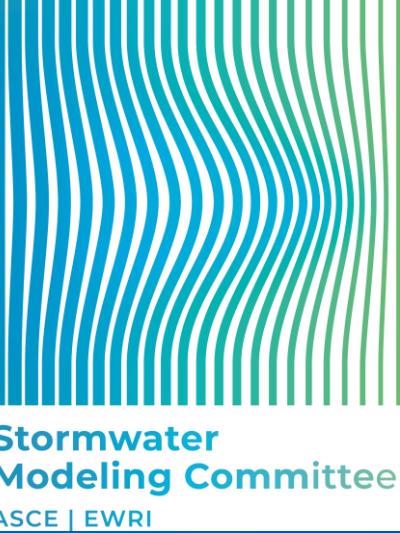
Buildup	
Pollutant	TSS_1
Property	Value
Function	POW
Max. Buildup	1200.0
Rate Constant	0.42
Power/Sat. Constant	1.5
Normalizer	AREA

Buildup function: POW = power, EXP = exponential, SAT = saturation, EXT = external time series.

Land Use Editor

Washoff	
Pollutant	TSS_1
Property	Value
Function	EMC
Coefficient	200.0
Exponent	0
Cleaning Effic.	0
BMP Effic.	0

Washoff function: EXP = exponential, RC = rating curve, EMC = event mean concentration.



EWRI Congress 2025, EPA SWMM5 Workshop -- Water Quality Modeling

Surface Buildup and Washoff

Dry Weather Buildup on Subcatchments

- Buildup functions derived from empirical data for specific land uses
- Static initial buildup:
 - Initial pollutant buildup (mass per area) over the entire subcatchment
 - Specified in the [LOADINGS] section of the input file
 - If dynamic buildup is not used, there is no further buildup/washoff once the initial load is depleted
- Dynamic buildup:
 - Initial pollutant build-up based on pollutant function and number of antecedent dry days (prior to simulation start)
 - If static buildup is used, initial dynamic buildup is overruled
 - After simulation start, dynamic buildup occurs during dry periods (according to the selected pollutant function)

Initial Buildup Editor

Pollutant	Initial Buildup (lbs/ac)
BOD5	600
Chlorides	100
FColiform	350000000
NH3-N	50
TotalPb	100
TotalSS	100

Enter initial buildup of pollutants on subcatchment S7

OK Cancel Help

Land Use Editor

General		Buildup	Washoff
Pollutant	NH3-N		
Property	Value		
Function	POW		
Max. Buildup	1000		
Rate Constant	100		
Power/Sat. Constant	1		
Normalizer	AREA		

Buildup function: POW = power, EXP = exponential, SAT = saturation, EXT = external time series.

OK Cancel Help

Simulation Options

General		Dates	Time Steps	Dynamic Wave
Date (M/D/Y)	Time (H:M)			
Start Analysis on	01/01/2025	00:00	00:00	00:00
Start Reporting on	01/01/2025	00:00	00:00	00:00
End Analysis on	01/02/2025	06:00	06:00	06:00
Start Sweeping on	01/01			
End Sweeping on	12/31			
Antecedent Dry Days	14			

Tracking Buildup Loads

- During wet weather, built-up pollutants are washed into the hydraulic network along with the surface runoff
- Components of buildup loads are summarized (for all subcatchments) in the Runoff Quality Continuity table
 - Initial Buildup: Dry weather load prior to the simulation start
 - Surface Buildup: Dry weather load during periods of no rain
 - Surface Runoff: Portion of buildup load that enters the hydraulic network
 - Remaining Buildup: Portion of buildup load that stays behind
- Surface Runoff is discharged into the hydraulic network (and included as the “Wet Weather Inflow” in the Quality Routing Continuity summary table)

	Volume	Depth
	acre-feet	inches
Runoff Quantity Continuity		
Total Precipitation	487.998	450.460
Evaporation Loss	29.630	27.351
Infiltration Loss	243.296	224.581
Surface Runoff	215.083	198.538
Final Storage	0.000	0.000
Continuity Error (%)	-0.002	

	TotalSS	lbs
Runoff Quality Continuity		
Initial Buildup	131.040	
Surface Buildup	62402.976	
Wet Deposition	0.000	
Sweeping Removal	0.000	
Infiltration Loss	0.000	
BMP Removal	0.000	
Surface Runoff	62019.642	
Remaining Buildup	514.374	
Continuity Error (%)	0.000	

	Volume	Volume
	acre-feet	10^6 gal
Flow Routing Continuity		
Dry Weather Inflow	0.000	0.000
Wet Weather Inflow	215.083	70.088
Groundwater Inflow	0.000	0.000
RDII Inflow	0.000	0.000
External Inflow	0.000	0.000
External Outflow	215.083	70.088
Flooding Loss	0.000	0.000
Evaporation Loss	0.000	0.000
Exfiltration Loss	0.000	0.000
Initial Stored Volume	0.000	0.000
Final Stored Volume	0.000	0.000
Continuity Error (%)	-0.000	

	TotalSS	lbs
Quality Routing Continuity		
Dry Weather Inflow	0.000	
Wet Weather Inflow	62019.642	
Groundwater Inflow	0.000	
RDII Inflow	0.000	

Buildup Load Examples

- 1-hour simulation with 1-hour rainfall duration
 - Initial Buildup is a function of the number of antecedent dry days
 - There is no Surface Buildup in both cases (there is no dry period)

*****		AquaCrud
Runoff Quality Continuity		lbs
Initial Buildup	0.000	
Surface Buildup	0.000	
Wet Deposition	0.000	
Sweeping Removal	0.000	
Infiltration Loss	0.000	
BMP Removal	0.000	
Surface Runoff	0.000	
Remaining Buildup	0.000	
Continuity Error (%)	0.000	

0 dry days before start

*****		AquaCrud
Runoff Quality Continuity		lbs
Initial Buildup	54.040	
Surface Buildup	0.000	
Wet Deposition	0.000	
Sweeping Removal	0.000	
Infiltration Loss	0.000	
BMP Removal	0.000	
Surface Runoff	30.430	
Remaining Buildup	23.610	
Continuity Error (%)	0.000	

7 dry days before start

- 12-hour simulation (1 hour of rainfall followed by 11 hours of no rain)

*****		AquaCrud
Runoff Quality Continuity		lbs
Initial Buildup	0.000	
Surface Buildup	54.040	
Wet Deposition	0.000	
Sweeping Removal	0.000	
Infiltration Loss	0.000	
BMP Removal	0.000	
Surface Runoff	0.000	
Remaining Buildup	54.040	
Continuity Error (%)	0.000	

0 dry days before start

*****		AquaCrud
Runoff Quality Continuity		lbs
Initial Buildup	54.040	
Surface Buildup	31.787	
Wet Deposition	0.000	
Sweeping Removal	0.000	
Infiltration Loss	0.000	
BMP Removal	0.000	
Surface Runoff	31.787	
Remaining Buildup	54.040	
Continuity Error (%)	0.000	

7 dry days before start

SWMM5 Pollutant Buildup

Dynamic Buildup Function	Equation
Power Function	$B = \text{Min}(C_1, C_2 t^{C_3})$
Exponential Function	$B = C_1(1 - e^{-C_2 t})$
Saturation Function	$B = \frac{C_1 t}{C_2 + t}$
External Time Series	Uses a time series to describe the rate of buildup

B = pollutant buildup

C_1 = maximum buildup possible
(mass per unit area or curb length)

C_2 = buildup rate constant

$C_3(\text{POW})$ = buildup time exponent

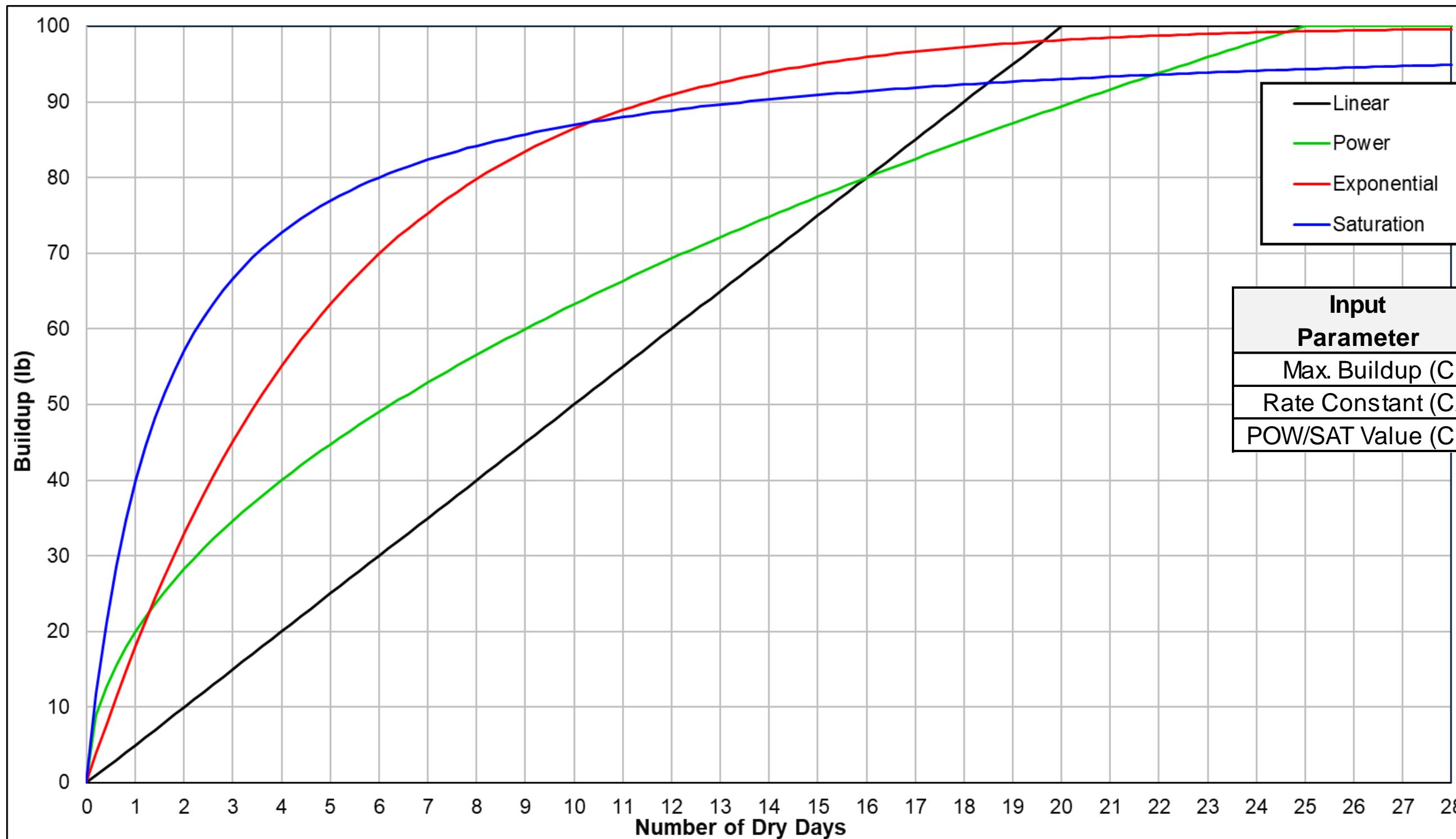
$C_3(\text{SAT})$ = half-saturation constant

(days to reach half of max. buildup)

t = time

Comparison of Dynamic Buildup Functions

- SWMM5 does not save buildup as a timeseries, but you can track the Initial Buildup for various antecedent dry day periods...



Another Buildup Load Example

- Static initial buildup (100 lb max.) with dynamic buildup using a Linear function
- Set number of dry days before start = days of simulation with no rainfall (so that the Initial Buildup and Surface Buildup totals are the same)

Simulation Options

	General	Dates	Time Steps	Dynamic Wave	Files
Date (M/D/Y)	01/01/2025	Time (H:M)	00:00		
Start Analysis on	01/01/2025	Start Reporting on	00:00		
End Analysis on	01/02/2025	00:00			
Start Sweeping on	01/01				
End Sweeping on	12/31				
Antecedent Dry Days	1				

1 dry day before and
1 dry day after simulation start

TotalSS	lbs
Runoff Quality Continuity	

Initial Buildup	5.000
Surface Buildup	5.000
Wet Deposition	0.000
Sweeping Removal	0.000
Infiltration Loss	0.000
BMP Removal	0.000
Surface Runoff	0.000
Remaining Buildup	10.000
Continuity Error (%)	0.000

5 dry days

TotalSS		TotalSS
Runoff Quality Continuity	lbs	Runoff Quality Continuity
-----		-----
Initial Buildup	25.000	Initial Buildup
Surface Buildup	25.000	Surface Buildup
Wet Deposition	0.000	Wet Deposition
Sweeping Removal	0.000	Sweeping Removal
Infiltration Loss	0.000	Infiltration Loss
BMP Removal	0.000	BMP Removal
Surface Runoff	0.000	Surface Runoff
Remaining Buildup	50.000	Remaining Buildup
Continuity Error (%)	0.000	Continuity Error (%)

10 dry days

TotalSS		TotalSS
Runoff Quality Continuity	lbs	Runoff Quality Continuity
-----		-----
Initial Buildup	50.000	Initial Buildup
Surface Buildup	50.000	Surface Buildup
Wet Deposition	0.000	Wet Deposition
Sweeping Removal	0.000	Sweeping Removal
Infiltration Loss	0.000	Infiltration Loss
BMP Removal	0.000	BMP Removal
Surface Runoff	0.000	Surface Runoff
Remaining Buildup	100.000	Remaining Buildup
Continuity Error (%)	0.000	Continuity Error (%)

11 dry days

TotalSS		TotalSS
Runoff Quality Continuity	lbs	Runoff Quality Continuity
-----		-----
Initial Buildup	55.000	Initial Buildup
Surface Buildup	45.000	Surface Buildup
Wet Deposition	0.000	Wet Deposition
Sweeping Removal	0.000	Sweeping Removal
Infiltration Loss	0.000	Infiltration Loss
BMP Removal	0.000	BMP Removal
Surface Runoff	0.000	Surface Runoff
Remaining Buildup	100.000	Remaining Buildup
Continuity Error (%)	0.000	Continuity Error (%)

14 dry days

TotalSS		TotalSS
Runoff Quality Continuity	lbs	Runoff Quality Continuity
-----		-----
Initial Buildup	70.000	Initial Buildup
Surface Buildup	30.000	Surface Buildup
Wet Deposition	0.000	Wet Deposition
Sweeping Removal	0.000	Sweeping Removal
Infiltration Loss	0.000	Infiltration Loss
BMP Removal	0.000	BMP Removal
Surface Runoff	0.000	Surface Runoff
Remaining Buildup	100.000	Remaining Buildup
Continuity Error (%)	0.000	Continuity Error (%)

99 dry days

TotalSS		TotalSS
Runoff Quality Continuity	lbs	Runoff Quality Continuity
-----		-----
Initial Buildup	100.000	Initial Buildup
Surface Buildup	0.000	Surface Buildup
Wet Deposition	0.000	Wet Deposition
Sweeping Removal	0.000	Sweeping Removal
Infiltration Loss	0.000	Infiltration Loss
BMP Removal	0.000	BMP Removal
Surface Runoff	0.000	Surface Runoff
Remaining Buildup	100.000	Remaining Buildup
Continuity Error (%)	0.000	Continuity Error (%)

Important Note

SWMM5 Washoff Functions

- NONE: No washoff of subcatchment buildup
- EXP: Exponential washoff function
- EMC: Event Mean Concentration washoff function
- RC: Rating Curve washoff function

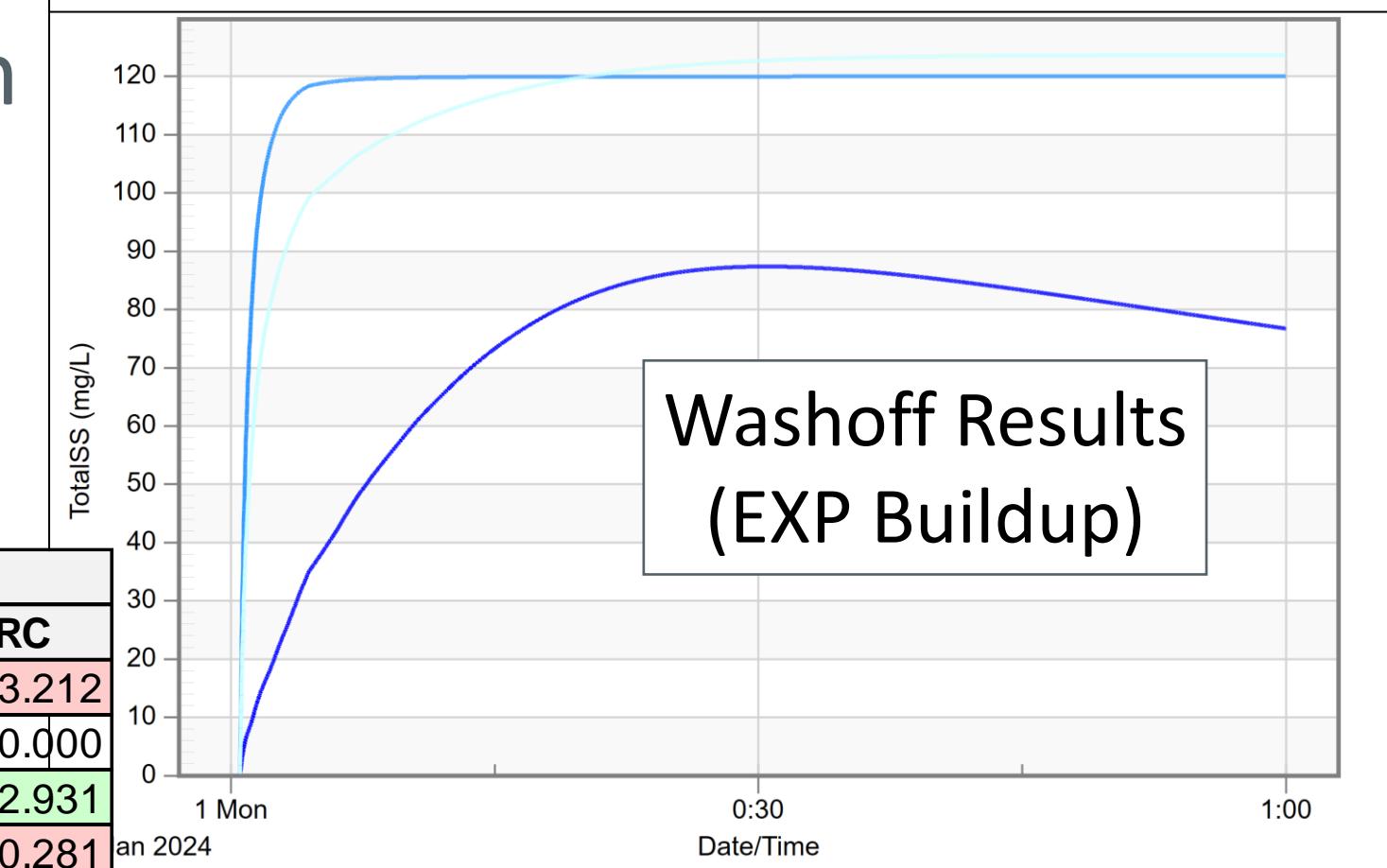
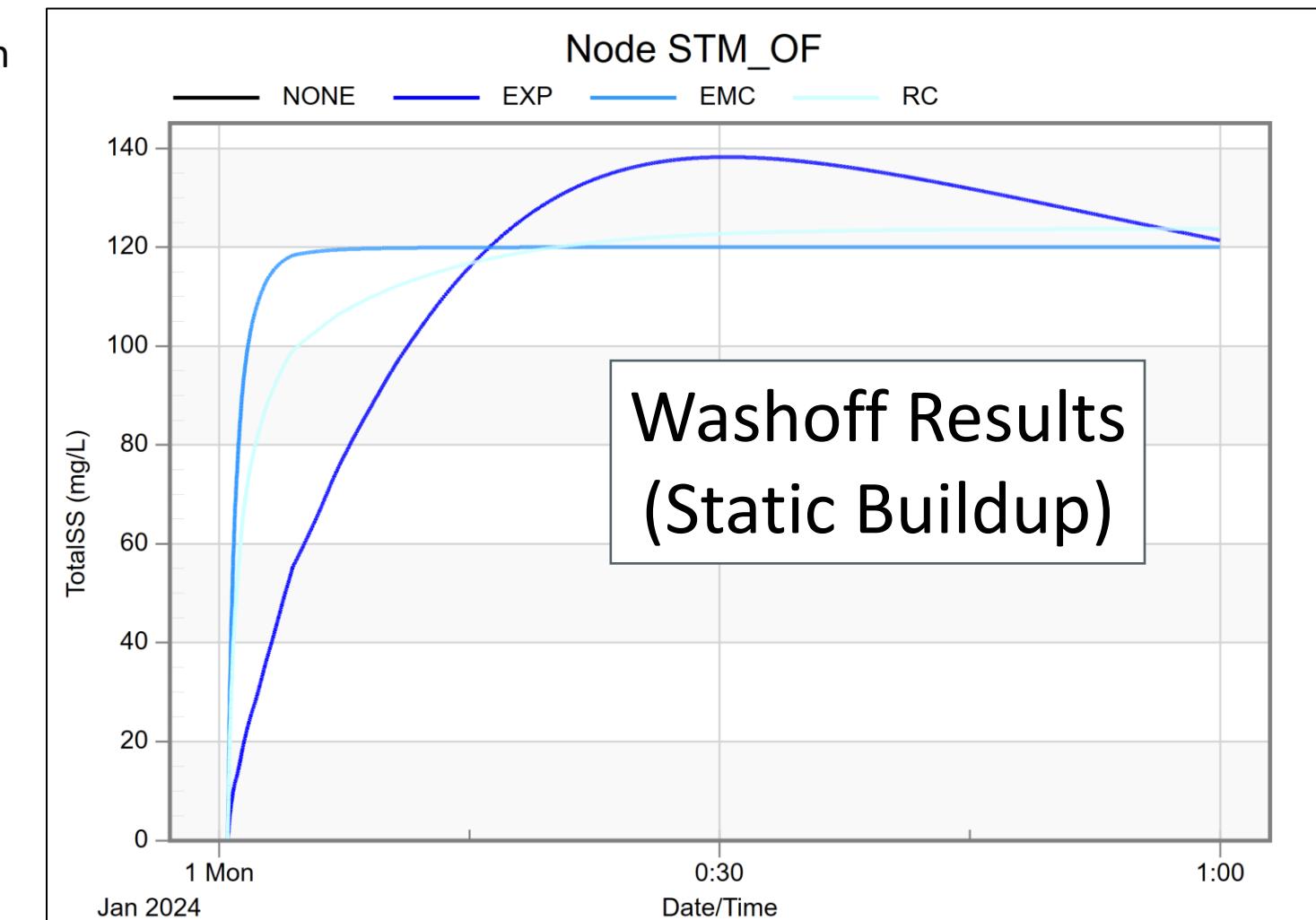
- When using dynamic buildup functions with dynamic washoff functions...
- The Surface Runoff load (i.e., pollutants that are washed off into the hydraulic network) is only affected by the **Exponential washoff function**
- Initial Buildup loads will still be computed for the other washoff functions, indicating the maximum pollutant load that could be removed

**Washoff Results
(Static Buildup)**

Runoff Quality Continuity	TotalSS (lb)			
	NONE	EMC	EXP	RC
Initial Buildup	100.000	100.000	100.000	100.000
Surface Buildup	0.000	0.000	0.000	0.000
Surface Runoff	0.000	22.487	24.175	22.931
Remaining Buildup	100.000	77.513	75.825	77.069

**Washoff Results
(EXP Buildup)**

Runoff Quality Continuity	TotalSS (lb)			
	NONE	EMC	EXP	RC
Initial Buildup	63.212	63.212	63.212	63.212
Surface Buildup	0.000	0.000	0.000	0.000
Surface Runoff	0.000	22.487	15.282	22.931
Remaining Buildup	63.212	40.725	47.930	40.281



Street Sweeping Removal

- Reduces the dynamic buildup of pollutants (before and after the start of simulation)
- Parameters required for street sweeping include:
 - Interval: Days between sweeping
 - Availability: Fraction of buildup that is available for removed by sweeping
 - Last Swept: Days since the last sweeping at the start of the simulation
 - Cleaning Effic.: Street cleaning removal efficiency (percent) for the pollutant
- Runoff Quality Continuity table includes the total Sweeping Removal load



Street sweeping operations dates (Simulation Options)

Start Sweeping on	01/01
End Sweeping on	12/31

Land Use Editor

General	Buildup	Washoff
Property	Value	
Land Use Name	Airport	
Description		
STREET SWEEPING		
Interval	5	
Availability	0.9	
Last Swept	21	

User assigned name of land use.

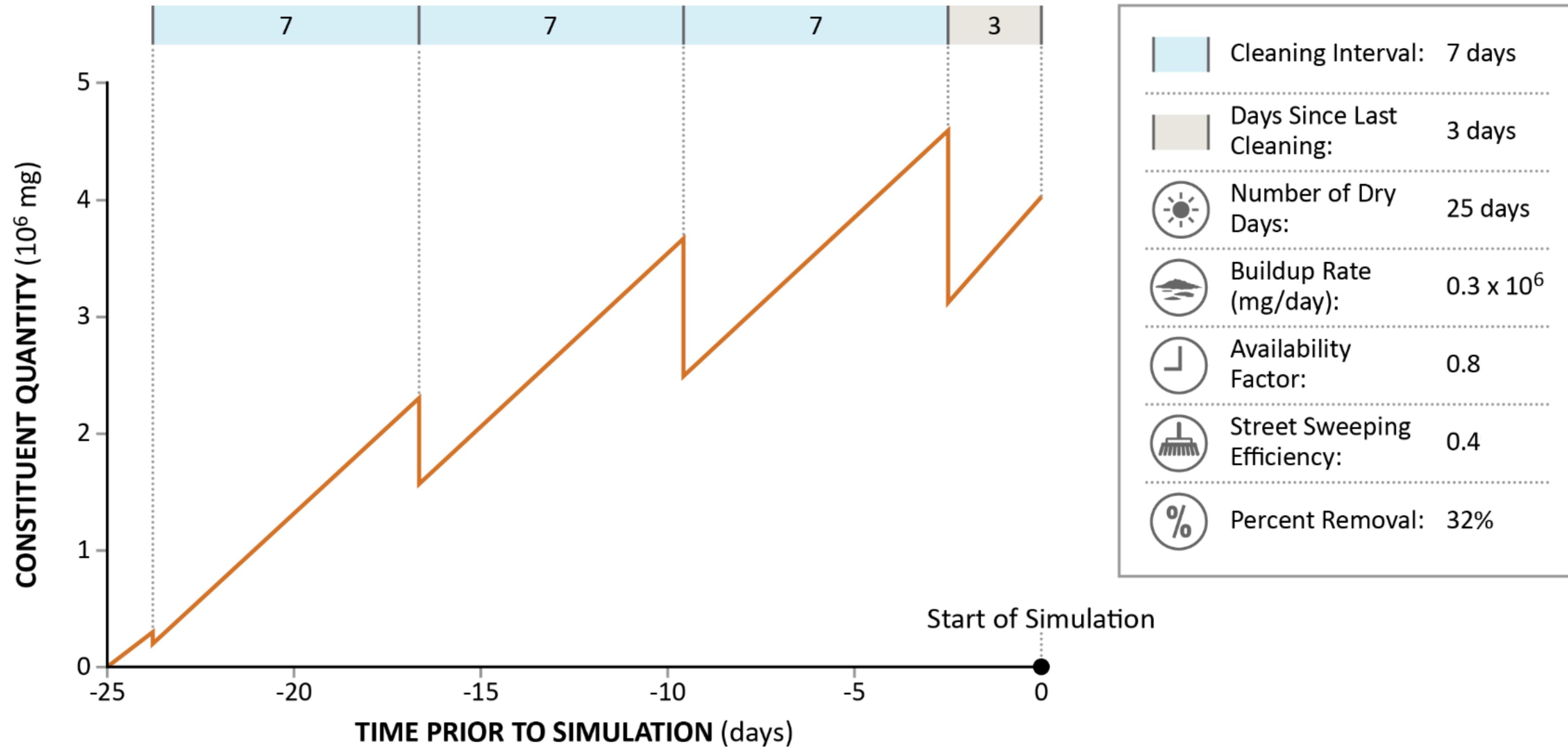
Land Use Editor

General	Buildup	Washoff
Pollutant	TotalSS	
Property	Value	
Function	EMC	
Coefficient	120	
Exponent	0.0	
Cleaning Effic.	55	
BMP Effic.	0.0	

Street cleaning removal efficiency (percent) for the pollutant.

Runoff Quality Continuity		TotalSS lbs
Initial Buildup	420.000
Surface Buildup	1680.000
Wet Deposition	0.000
Sweeping Removal	1585.791

Example Linear Buildup and Street Sweeping



Guidance

- Several helpful tables in Chapter 3 of the Vol. 3 Reference Manual
 - And local examples in practice...

Anchorage Stormwater Manual

Volume 1—Management and Design Criteria

Daily Pollutant Build-Up Ranges

Land Use	BOD ¹ (lbs/Ac/Day)	SUS-SOL ² (lbs/Ac/Day)	SET-SOL ³ (lbs/Ac/Day)	TDS ⁴ (lbs/Ac/Day)	NH ₃ ⁵ (lbs/Ac/Day)	NO ₃ ⁶ (lbs/Ac/Day)	TOT-P ⁷ (lbs/Ac/Day)	GRS-OIL ⁸ (lbs/Ac/Day)	FE-COL ⁹ (BILLION MPN/Ac/Day)
Commercial	0.33-0.43	4.9-5.0	0.004-0.005	0.8-1.3	0.005-0.010	0.002-0.006	0.007-0.25	0.20-0.23	0.009-0.15
Industrial	0.35-0.60	7.5-7.5	0.0075-0.01	1.0-2.0	0.005-0.010	0.0005- 0.003	0.0053-0.10	0.30-0.34	0.002-0.01
Multiple-Family Residential	0.12-0.34	0.50-1.6	0.001-0.005	0.40-1.3	0.005-0.015	0.0012- 0.0015	0.0035-0.08	0.06-0.10	0.0008-0.007
High-Density Residential	0.10-0.49	0.20-1.0	0.003-0.004	0.3-0.8	0.002-0.016	0.001-0.002	0.002-0.15	0.03-0.04	0.002-0.002
Low-Density Residential	0.05-0.10	0.15-0.7	0.001-0.002	0.25-0.3	0.002-0.005	0.0005- 0.001	0.0014-0.02	0.01-0.02	0.001-0.0015
Cleared and Pervious	0.02-0.05	0.10-0.5	0.001-0.001	0.2-0.3	0.002- 0.0005	0.0001- 0.0005	0.0007-0.01	0.001-0.002	0.001-0.001
Bogs and Marshes	0.01-0.02	0.0-0.0	0.0-0.0	0.1-0.2	0.0001- 0.0002	0.0001- 0.0001	0.0007- 0.0007	0.0-0.0001	0.0001-0.001
Lowland Forest	0.01-0.01	0.0-0.0	0.0-0.0	0.1-0.1	0.0001- 0.0002	0.0001- 0.0001	0.0007- 0.0007	0.0-0.0001	0.0001-0.001
Upland Forest	0.01-0.01	0.0-0.0	0.0-0.0	0.1-0.1	0.0001- 0.0002	0.0001- 0.0001	0.0007- 0.0007	0.0-0.0001	0.0001-0.001
Natural Pervious	0.01-0.01	0.0-0.0	0.0-0.0	0.01-0.1	0.0001- 0.0002	0.0001- 0.0001	0.0007- 0.0007	0.0-0.0001	0.0001-0.001

(1) BOD₅ – Biological Oxygen Demand (5) NH₃ – Ammonia Nitrogen (9) FE-COL – Fecal Coliform

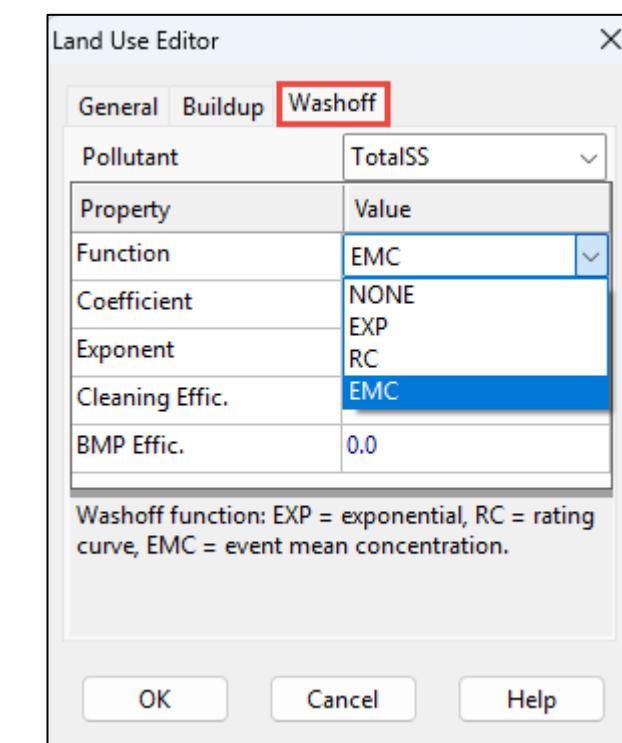
(2) SUS-SOL – Suspended Solids (6) NO₃ – Nitrate Nitrogen

(3) SET-SOL – Settleable Solids (7) TOT-P – Total Phosphorus

(4) TDS – Total Dissolved Solids (8) GRS-OIL – Grease and Oil

Wet Weather Washoff from Subcatchments

- Washoff functions are also derived from empirical data for specific land uses
- Physically-based methods are preferable (e.g., based on erosion detachment and sediment transport), but simplistic functions are useful and you probably don't have any calibration data anyway
- SWMM5 Washoff Functions
 - NONE: No washoff of subcatchment buildup
 - EXP: Exponential washoff function
 - EMC: Event Mean Concentration washoff function
 - RC: Rating Curve washoff function



SWMM5 Pollutant Washoff

Washoff Function	Equation
Exponential Washoff	$W = C_1 q^{C_2} B$
Rating Curve Washoff	$W = C_1 Q^{C_2}$
Event Mean Concentration	Special case of rating curve method with $C_2 = 1$

B = pollutant buildup

W = pollutant washoff

C_1 = washoff coefficient

C_2 = washoff exponent

q = runoff rate (in/hr) over subcatchment

Q = runoff rate (cfs) over land use area

EMC Washoff

$$W = C_1 Q$$

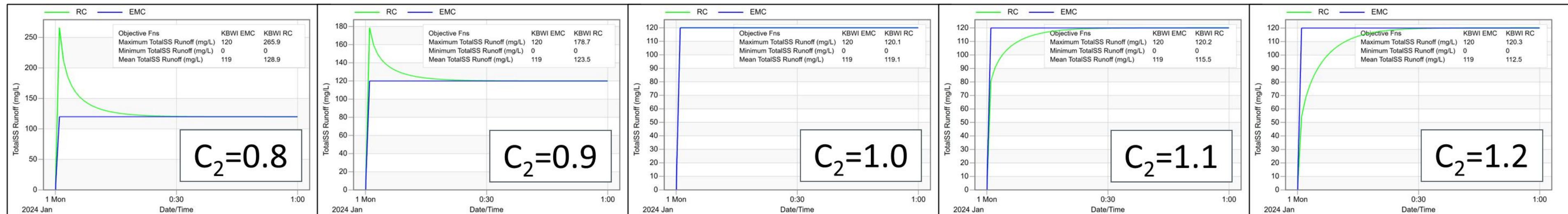
- Most popular method, despite being the least accurate
- EMC values are very commonly available (see Vol.3 Ref. Manual and <https://bmpdatabase.org/national-stormwater-quality-database>)
- Washoff is only a function of the subcatchment runoff and EMC
 - Concentration [mg/L] is constant during the storm (i.e., it equals the EMC while there is subcatchment runoff AND buildup load available)
 - Loading rate [lb/s or mg/s] varies with the runoff rate
- And remember that SWMM5 sometimes forces variables to zero
 - Subcatchment runoff = 0 when computed runoff in next timestep < 0.001 cfs
 - Conduit velocity = 0 when computed conduit depth in next timestep < 0.01 ft
 - etc.



RC Washoff

$$W = C_1 Q^{C_2}$$

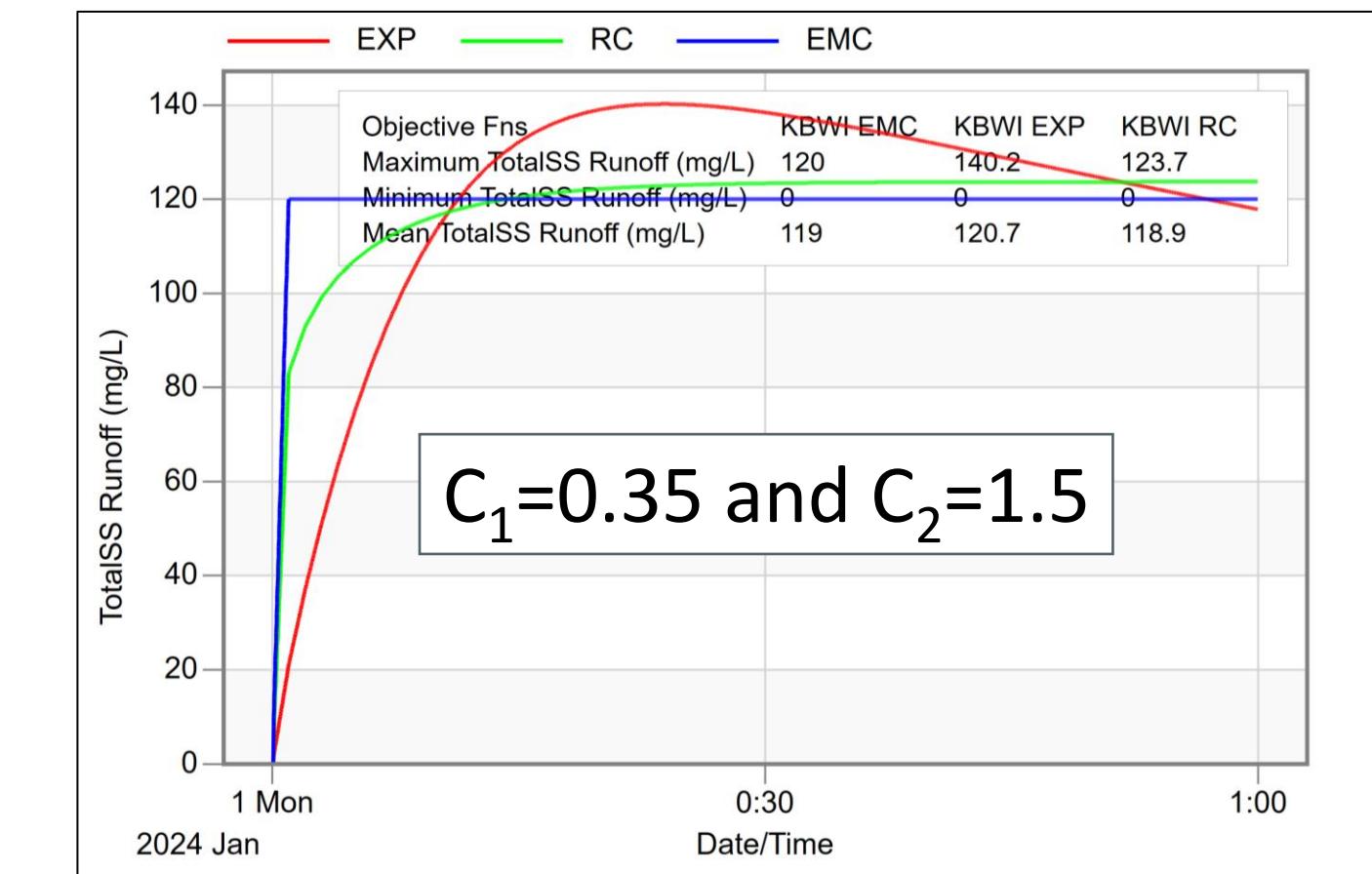
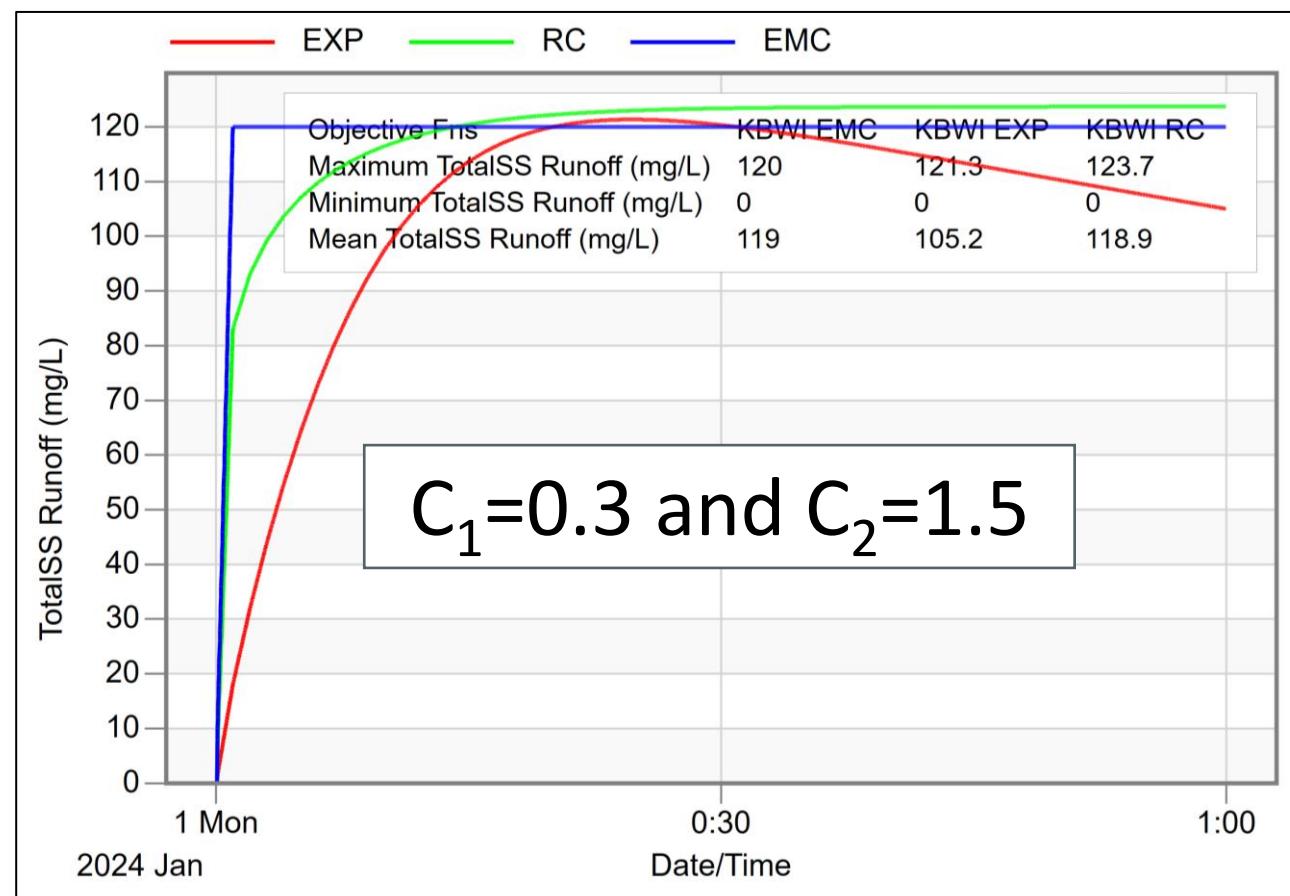
- Empirically described, but physics also suggests the mass loading rate of particulate pollutants is proportional to flow rate raised to some power
- Just like EMC washoff, RC washoff is not a function of Buildup load, but...
 - If washoff is supply-limited (i.e., Buildup load \leq Washoff load), then washoff continues until the buildup amount is depleted
 - If unlimited supply for washoff (i.e., Buildup load \geq Washoff load), then washoff continues until the runoff runs out
- Parameter sensitivity (hold C_1 constant and vary C_2 exponent for one simple case):



EXP Washoff

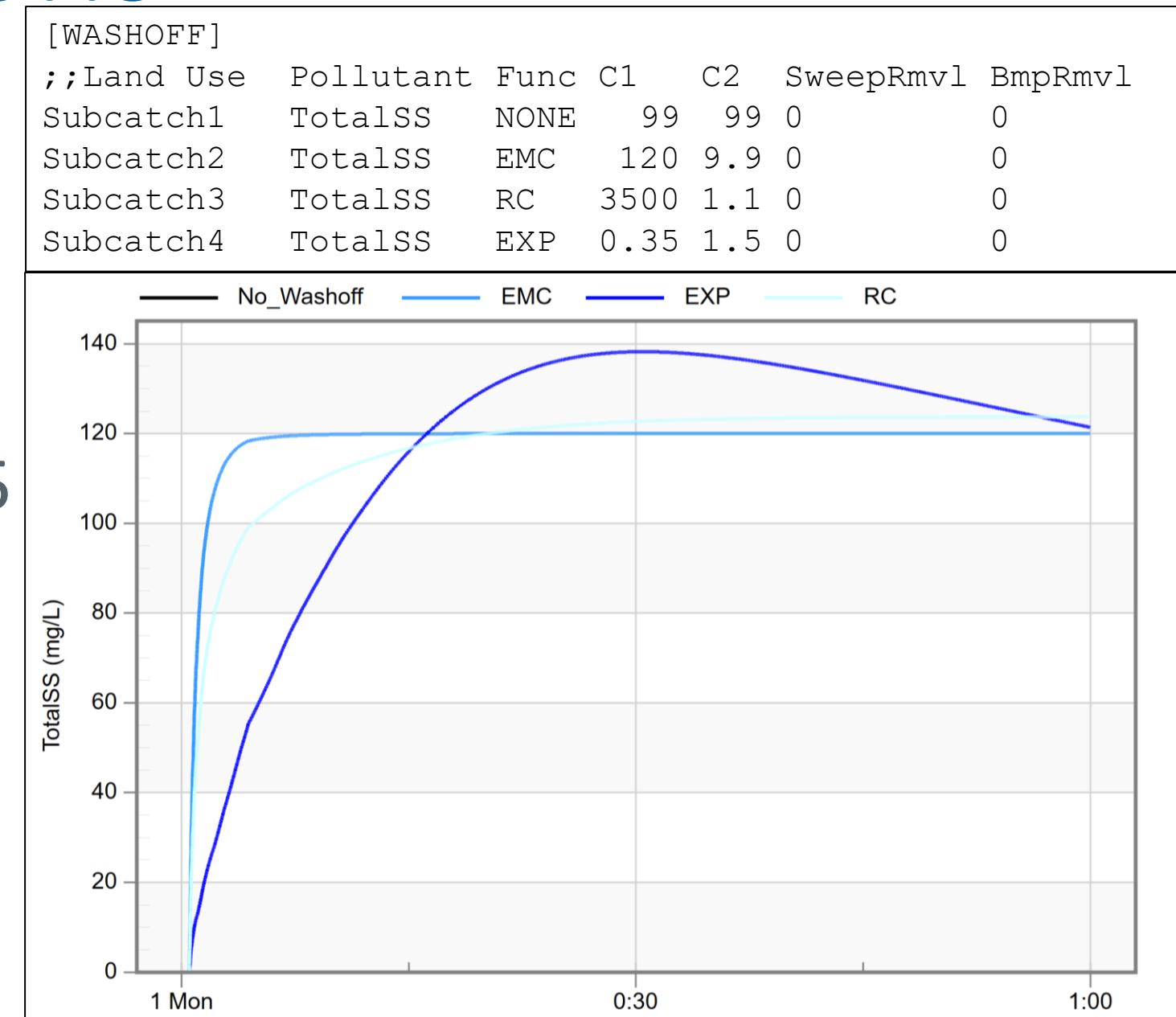
$$W = C_1 q^{C_2} B$$

- Finally, a function that is dependent on buildup, originally based on the work of Sartor & Boyd (1972) and included in SWMM1 and all subsequent versions
- That is, the washoff loading rate is proportional to the product of unit-area runoff raised to some power AND to the product of the remaining buildup load
- Parameter sensitivity (vary C_1 with fixed C_2 exponent for one simple case):



Comparison of Washoff Functions

- Compare washoff function types
 - All use static initial buildup (100 lb max.)
 - Run for 1 hour of rainfall (no dry period after)
 - Input: “99” means parameter not used by SWMM5
- Compare for various rainfall conditions
 - 1 hour of rainfall followed by 8 hours of no rain
 - 100-year/24-hour design storm event
 - Continuous simulation for a 10-year period

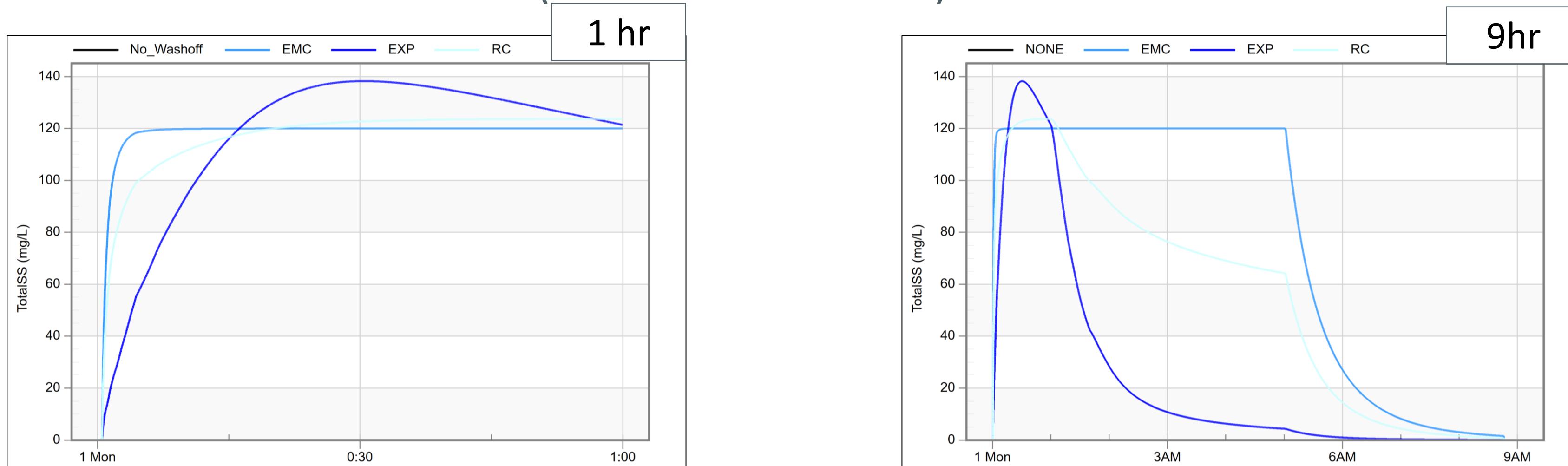


NONE		EMC		RC		EXP	
General	Buildup	General	Buildup	General	Buildup	General	Buildup
Pollutant	TotalSS	Pollutant	TotalSS	Pollutant	TotalSS	Pollutant	TotalSS
Attributes		Attributes		Attributes		Attributes	
Function	NONE	Function	EMC	Function	RC	Function	EXP
Coefficient	99	Coefficient	120	Coefficient	3500	Coefficient	0.35
Exponent	99	Exponent	9.9	Exponent	1.1	Exponent	1.5
Cleaning Effic.	0						
BMP Effic.	0						

Runoff Quality Continuity	TotalSS (lb)			
	NONE	EMC	EXP	RC
Initial Buildup	100.000	100.000	100.000	100.000
Surface Buildup	0.000	0.000	0.000	0.000
Wet Deposition	0.000	0.000	0.000	0.000
Sweeping Removal	0.000	0.000	0.000	0.000
Infiltration Loss	0.000	0.000	0.000	0.000
BMP Removal	0.000	0.000	0.000	0.000
Surface Runoff	0.000	22.487	24.175	22.931
Remaining Buildup	100.000	77.513	75.825	77.069
Continuity Error (%)	0.000	0.000	0.000	0.000

Comparison of Washoff Functions (continued)

- 1hr vs 9hr simulation (runoff ends at 5am)

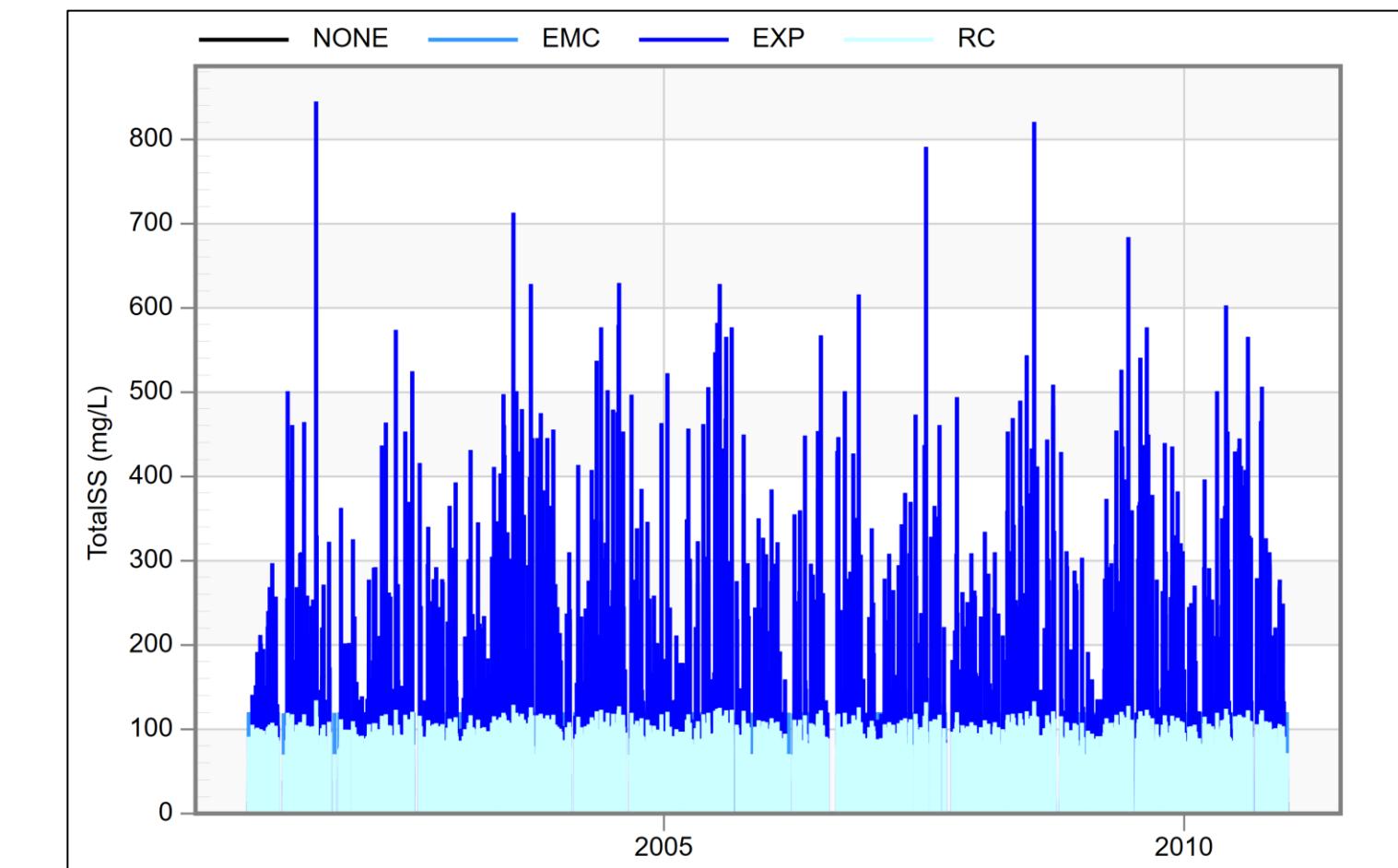
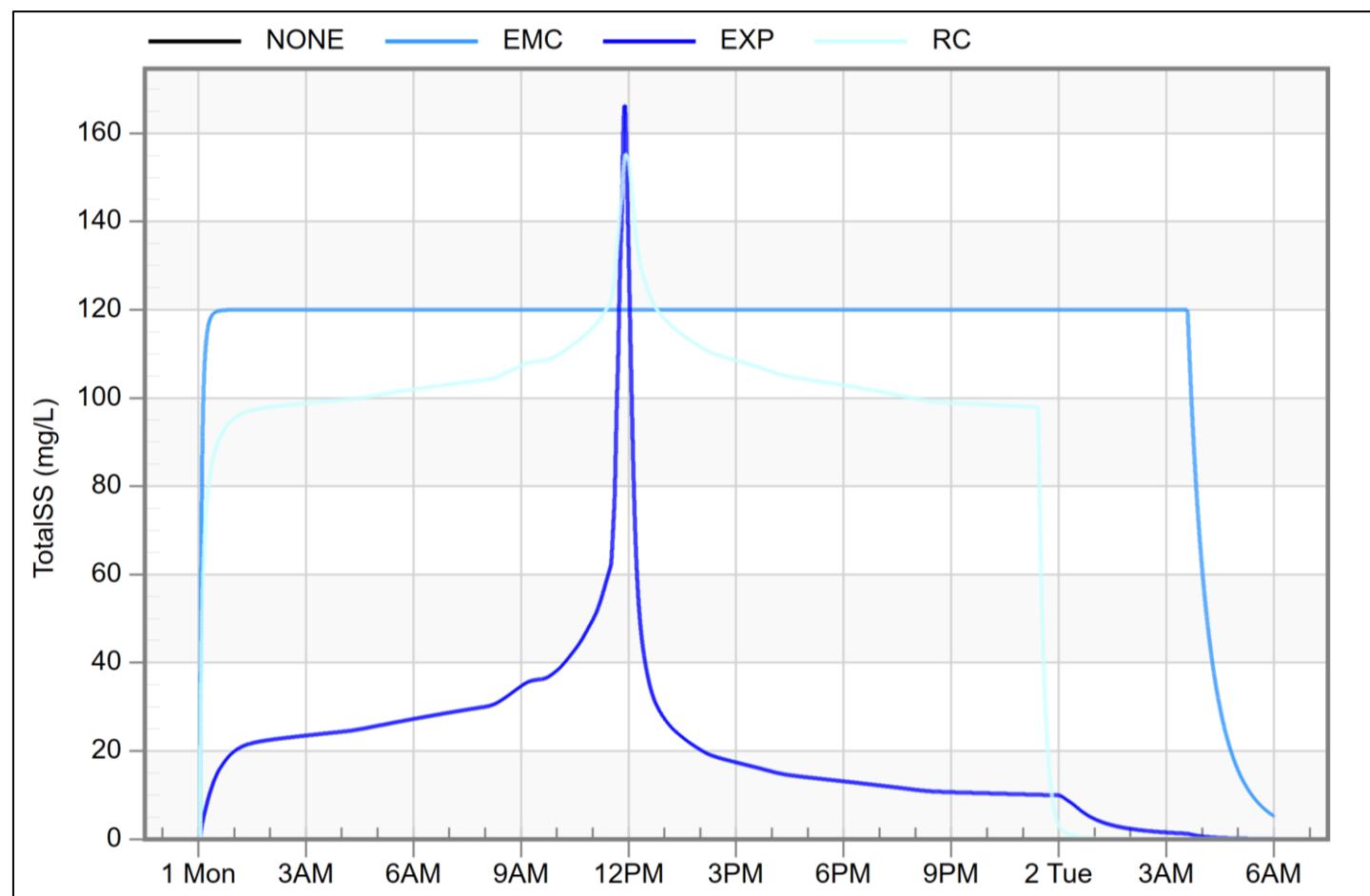


Runoff Quality Continuity	TotalSS (lb)			
	NONE	EMC	EXP	RC
Initial Buildup	100.000	100.000	100.000	100.000
Surface Buildup	0.000	0.000	0.000	0.000
Wet Deposition	0.000	0.000	0.000	0.000
Sweeping Removal	0.000	0.000	0.000	0.000
Infiltration Loss	0.000	0.000	0.000	0.000
BMP Removal	0.000	0.000	0.000	0.000
Surface Runoff	0.000	22.487	24.175	22.931
Remaining Buildup	100.000	77.513	75.825	77.069
Continuity Error (%)	0.000	0.000	0.000	0.000

Runoff Quality Continuity	TotalSS (lb)			
	NONE	EMC	EXP	RC
Initial Buildup	100.000	100.000	100.000	100.000
Surface Buildup	0.000	0.000	0.000	0.000
Wet Deposition	0.000	0.000	0.000	0.000
Sweeping Removal	0.000	0.000	0.000	0.000
Infiltration Loss	0.000	0.000	0.000	0.000
BMP Removal	0.000	0.000	0.000	0.000
Surface Runoff	0.000	27.103	26.547	27.013
Remaining Buildup	100.000	72.897	73.453	72.987
Continuity Error (%)	0.000	0.000	0.000	0.000

Comparison of Washoff Functions (continued)

- 100-year/24-hour design storm event vs 10-year continuous simulation



Runoff Quality Continuity	TotalSS (lb)			
	NONE	EMC	EXP	RC
Initial Buildup	235.000	235.000	235.000	235.000
Surface Buildup	4.798	4.798	4.798	4.798
Wet Deposition	0.000	0.000	0.000	0.000
Sweeping Removal	0.000	0.000	0.000	0.000
Infiltration Loss	0.000	0.000	0.000	0.000
BMP Removal	0.000	0.000	0.000	0.000
Surface Runoff	0.000	227.687	130.547	235.065
Remaining Buildup	239.798	12.110	109.251	4.733
Continuity Error (%)	0.000	0.000	0.000	0.000

Runoff Quality Continuity	TotalSS (lb)			
	NONE	EMC	EXP	RC
Initial Buildup	235.000	235.000	235.000	235.000
Surface Buildup	1765.000	13635.660	26854.878	11815.355
Wet Deposition	0.000	0.000	0.000	0.000
Sweeping Removal	0.000	0.000	0.000	0.000
Infiltration Loss	0.000	0.000	0.000	0.000
BMP Removal	0.000	0.000	0.000	0.000
Surface Runoff	0.000	11870.660	25089.878	10050.355
Remaining Buildup	2000.000	2000.000	2000.000	2000.000
Continuity Error (%)	0.000	0.000	0.000	0.000

Hydraulic Inputs for Water Quality

- Other ways to add to (or bypass) surface washoff loads and concentrations
 - Included in Baseflow
 - Included in Dry Weather Flow (DWF)
 - As a Direct Inflow while there is runoff
 - As a Timeseries
 - Any combination of the above

Inflows for Node AtchafalayaRiver_020

Direct Dry Weather RDII

Inflow = (Baseline Value) x (Baseline Pattern) +
(Time Series Value) x (Scale Factor)

Constituent	FLOW
Baseline	<input type="text"/>
Baseline Pattern	<input type="text"/>
Time Series	Hourly_Discharge
Scale Factor	1

If Baseline or Time Series is left blank its value is 0. If Baseline Pattern is left blank its value is 1.0.

[TIMESERIES]

Name	Date	Time	Value
Hourly_Discharge	10/01/2014	00:00:00	315000
Hourly_Discharge	10/01/2014	01:00:00	314000
Hourly_Discharge	10/01/2014	02:00:00	314000
Hourly_Discharge	10/01/2014	03:00:00	313000
Hourly_Discharge	10/01/2014	04:00:00	312000
Hourly_Discharge	10/01/2014	05:00:00	312000
Hourly_Discharge	10/01/2014	06:00:00	311000
Hourly_Discharge	10/01/2014	07:00:00	311000
Hourly_Discharge	10/01/2014	08:00:00	310000
Hourly_Discharge	10/01/2014	09:00:00	310000
Hourly_Discharge	10/01/2014	10:00:00	309000
.....			

Inflows for Node AtchafalayaRiver_020

Direct Dry Weather RDII

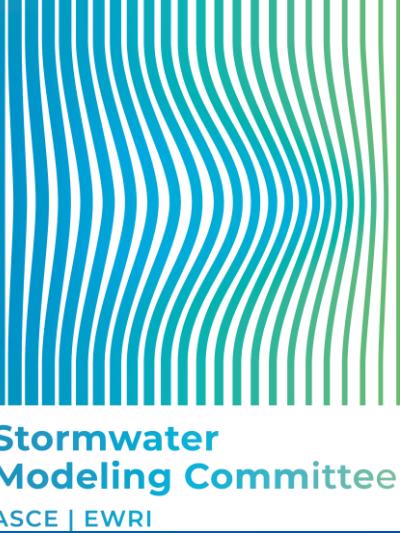
Inflow = (Baseline Value) x (Baseline Pattern) +
(Time Series Value) x (Scale Factor)

Constituent	TSS
Baseline	<input type="text"/>
Baseline Pattern	<input type="text"/>
Time Series	SCS_Grab_Samples_I
Scale Factor	1.0
Inflow Type	CONCEN
Units Factor	1.0

If Baseline or Time Series is left blank its value is 0. If Baseline Pattern is left blank its value is 1.0.

[TIMESERIES]

Name	Date	Time	Value
SSC_Grab_Samples_(all_sizes)	10/27/2014	15:15:00	159
SSC_Grab_Samples_(all_sizes)	10/27/2014	15:30:00	137
SSC_Grab_Samples_(all_sizes)	10/27/2014	15:32:00	185
SSC_Grab_Samples_(all_sizes)	10/27/2014	15:34:00	179
SSC_Grab_Samples_(all_sizes)	10/27/2014	15:36:00	156
SSC_Grab_Samples_(all_sizes)	10/27/2014	15:38:00	138
SSC_Grab_Samples_(all_sizes)	11/20/2014	14:00:00	49
SSC_Grab_Samples_(all_sizes)	12/11/2014	13:00:00	247
SSC_Grab_Samples_(all_sizes)	01/14/2015	13:30:00	150
SSC_Grab_Samples_(all_sizes)	03/12/2015	15:00:00	466
SSC_Grab_Samples_(all_sizes)	03/25/2015	14:00:00	239
SSC_Grab_Samples_(all_sizes)	04/15/2015	13:15:00	255
SSC_Grab_Samples_(all_sizes)	04/15/2015	13:20:00	222

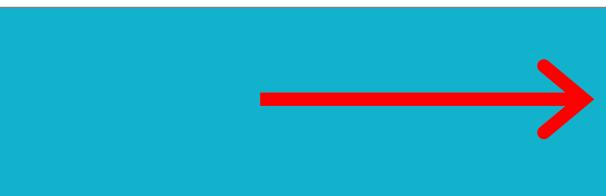


EWRI Congress 2025, EPA SWMM5 Workshop -- Water Quality Modeling

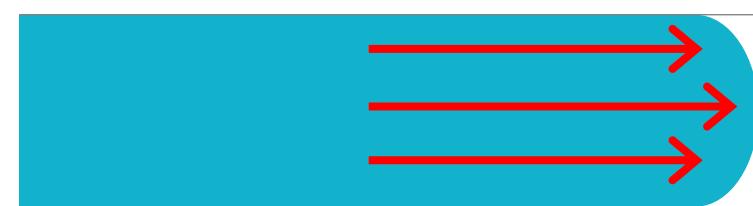
Routing and Treatment

Advection, Dispersion, Reaction

- Advection: transport of a substance driven by the bulk movement of water

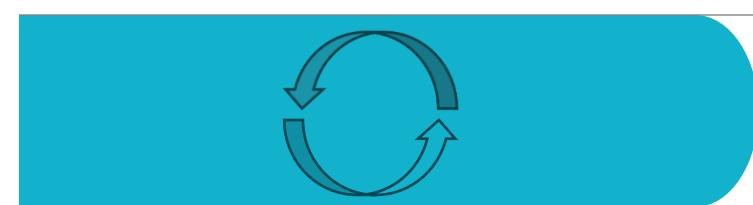


- Dispersion: spreading of a substance caused by velocity variations within the flow



- Reaction: chemical, biological, or physical processes that alter the concentration of a substance over time

- SWMM5: “mass reacted” is the pollutant load removed from the water column



1-D Advection Dispersion Equation

- Used to represent solute transport in a moving fluid
- Assumes uniform flow, constant coefficients, no sorption, etc.

$$\frac{\partial c}{\partial t} = - \frac{\partial (uc)}{\partial x} + \frac{\partial}{\partial x} \left(D \frac{\partial c}{\partial x} \right) + r(c)$$

advection term dispersion term reaction
↓ ↓ rate term
↓

Where:

c = constituent concentration [M/L³]

u = longitudinal velocity [L/T]

D = longitudinal dispersion coefficient [L²/T]

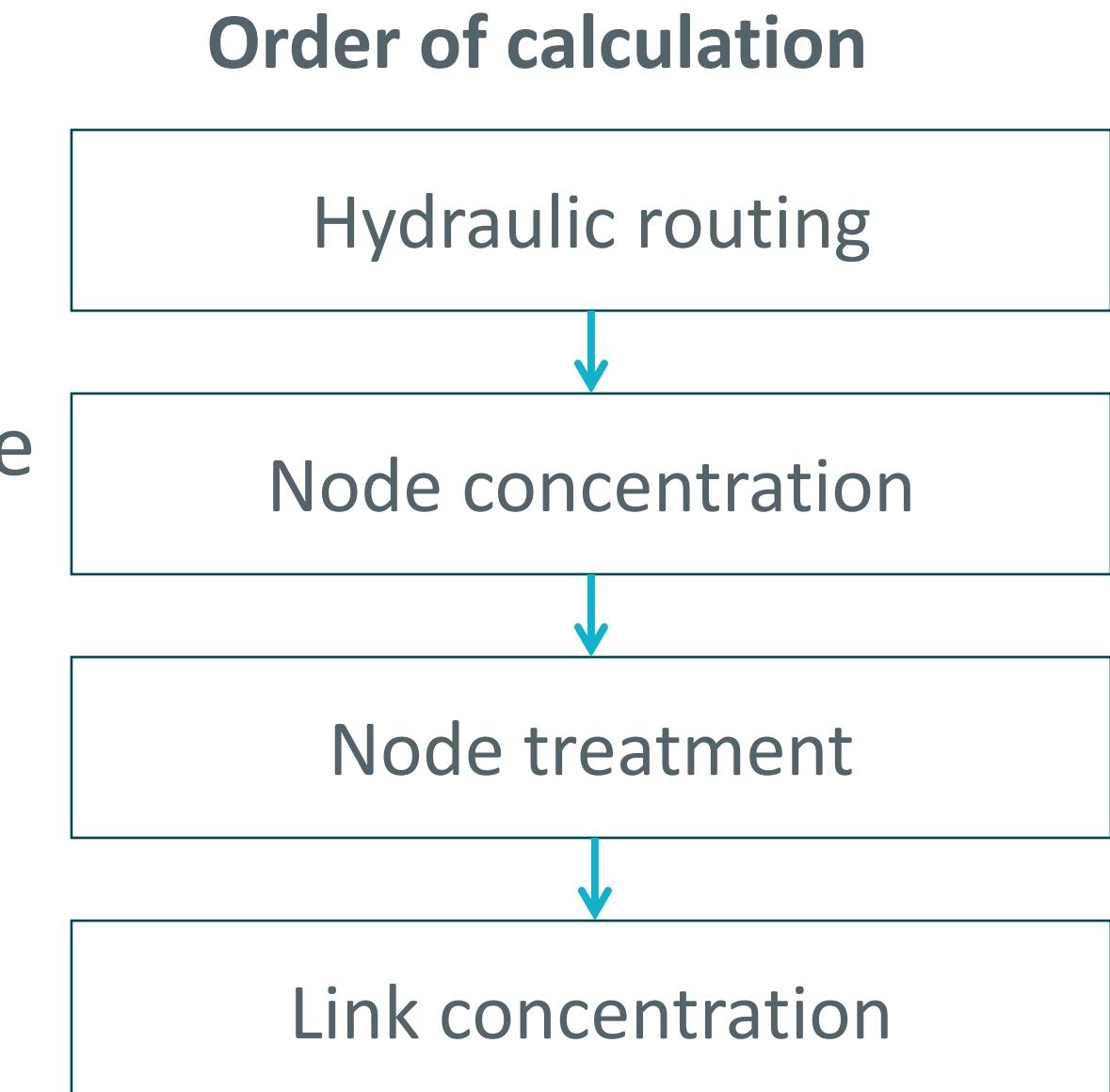
x = longitudinal distance [L]

t = time [T]

$r(c)$ = reaction rate [M/L³T]

SWMM5 Assumptions & Limitations

- Routing is performed after the hydraulic computation at each routing step, with the assumption that it does not influence the hydraulic results
- Routing within conduit links and storage nodes assumes behavior as a continuously-stirred tank reactor
- In non-storage nodes, the quality of water exiting the node is simply the mixture concentration of all water entering the node
- Concentration remains unchanged through links with no volume (pumps, orifices, weirs, outlets, and dummy conduits)
- Plug flow reactor assumption might be more realistic, however differences will be small if the travel/residence time is on the same order as the routing time step

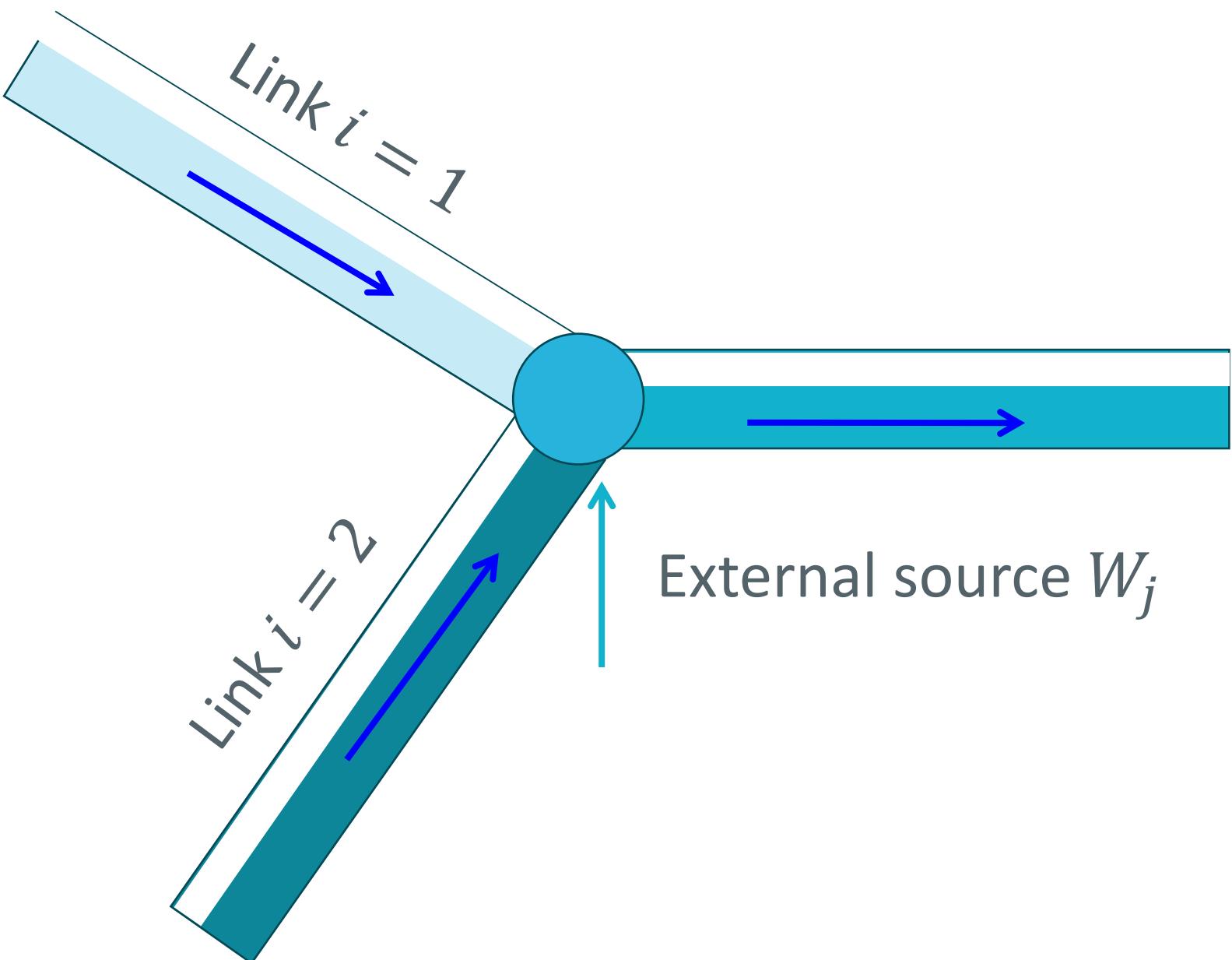


Instantaneous Complete Mixing at Junctions

- Non-storage nodes have no volume

$$C_{Nj} = \frac{\sum_{i \rightarrow j} C_{L2i} q_{2i} + W_j}{\sum_{i \rightarrow j} q_{2i} + Q_j}$$

- Where:
 - C_{Nj} = concentration at node j
 - C_{L2i} = concentration at the end of link i
 - q_{2i} = flow rate at the end of link i
 - W_j = mass flow rate of the external source of constituent
 - Q_j = flow rate of the external source



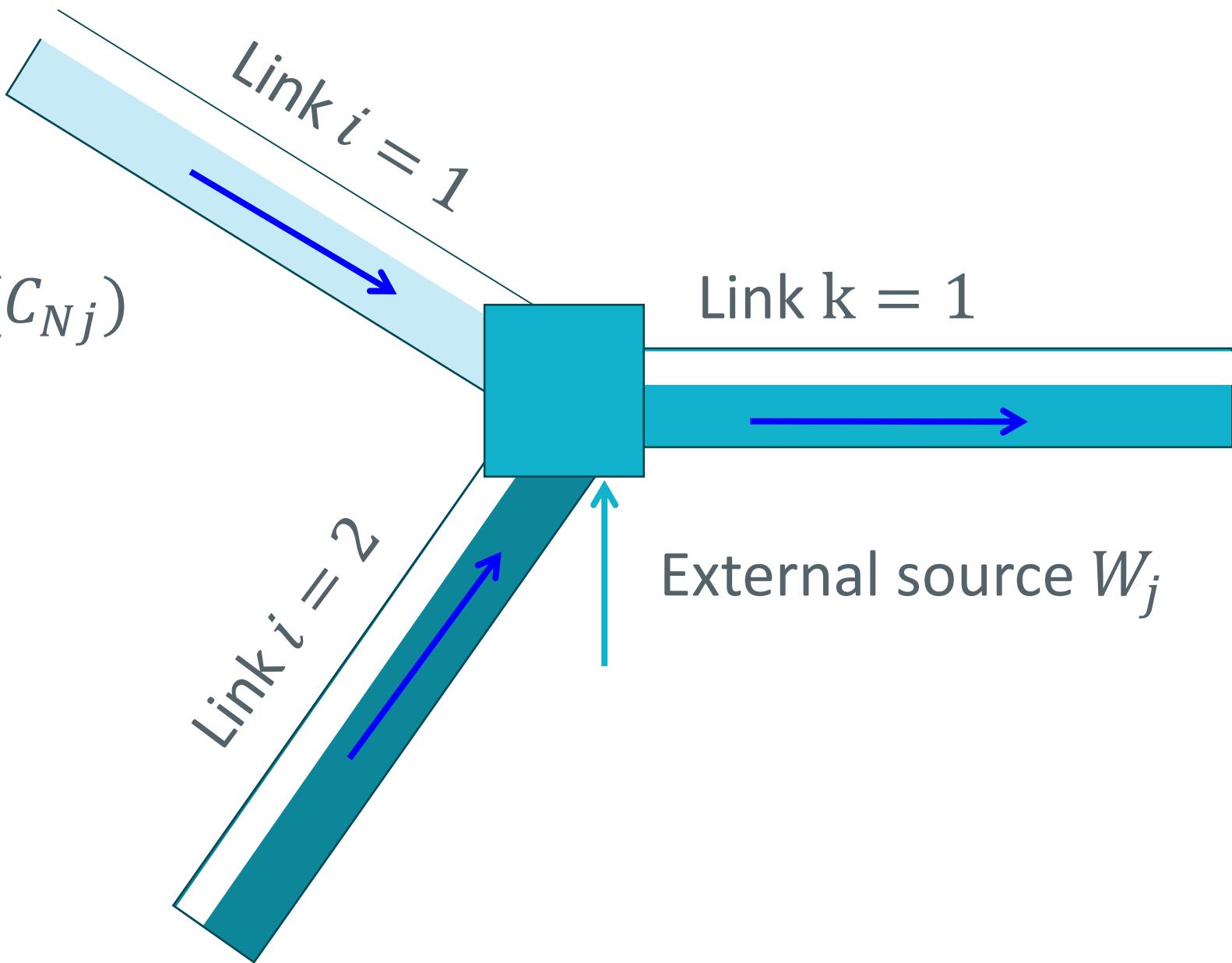
Complete Mixing in Storage Junctions

- Storage units have volume property

$$\frac{d(V_{Nj}C_{Nj})}{dt} = \sum_{i \rightarrow j} C_{L2i}q_{2i} - \sum_{j \rightarrow k} C_{Nj}q_{1k} + W_j - V_{Nj}r(C_{Nj})$$

- Where:

- V_{Nj} = volume of water storage at node j
- C_{Nj} = concentration at node j
- C_{L2i} = concentration at the end of link i
- q_{2i} = flow rate at the end of link i
- q_{1k} = flow rate at the start of link k
- W_j = mass flow rate of the external source of constituent
- r = reaction rate in the storage



Quality Routing Assumes Complete Mixing

Tanks in series
model

$$\frac{d(Vc)}{dt} = C_{in}Q_{in} - cQ_{out} - VK_1c$$

Where:

V = reactor volume

C_{in} = influent pollutant concentration

c = effluent and reactor pollutant concentration

Q_{in} = volumetric inflow rate

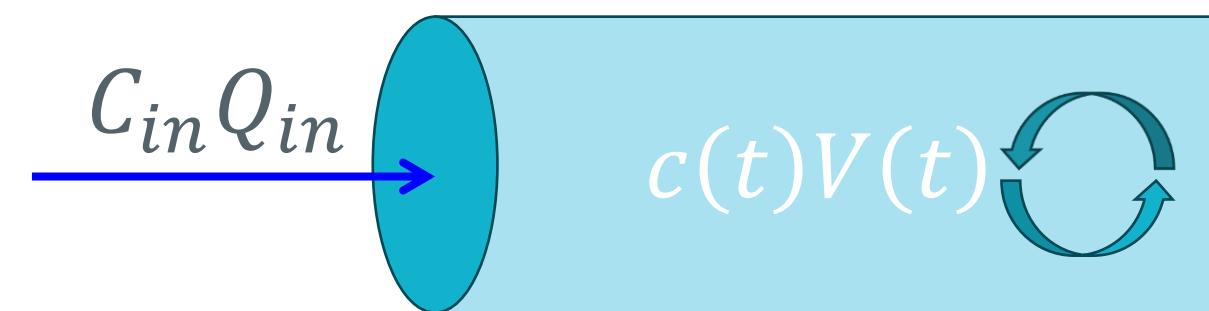
Q_{out} = volumetric outflow rate

t = time

K_1 = decay coefficient

SWMM 5 Solution

$$c(t + \Delta t) = \frac{c(t)V(t)e^{-K_1\Delta t} + C_{in}Q_{in}\Delta t}{V(t) + Q_{in}\Delta t}$$

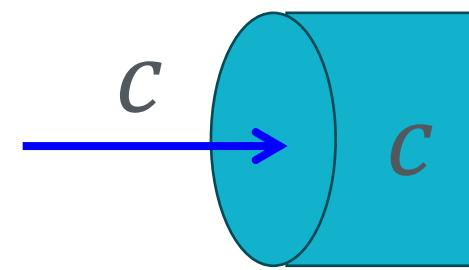


Where:

- $c(t + \Delta t)$ = reactor concentration at end of routing step Δt
- $c(t)$ = reactor concentration at start of routing step
- $V(t)$ = reactor volume at start of the routing step
- C_{in} = node inflow concentration
- Q_{in} = net inflow rate

Routing for Links without Volume

- Node concentrations are calculated first during the routing process
- Links with no volume property include:
 - Pumps
 - Orifices
 - Weirs
 - Outlets
 - Dummy conduits
- In these cases, link concentration is equal to that of the upstream node



Treatment Expressions

- Treatment expressions can be applied at any node, either concentration-based or removal-based, and depending on a range of hydraulic variables

$$c(t + \Delta t) = c(\mathbf{C}, \mathbf{R}, \mathbf{H}) \quad c(t + \Delta t) = (1 - r(\mathbf{C}, \mathbf{R}, \mathbf{H}))C_{in}(t + \Delta t)$$

Where:

c = nodal pollutant concentration after treatment is applied

C_{in} = pollutant concentration in the node's inflow stream

$c(\dots)$ = concentration-based treatment function

$r(\dots)$ = removal-based treatment function

\mathbf{C} = vector of nodal pollutant concentrations before treatment is applied

\mathbf{R} = vector of fractional removals resulting from treatment

\mathbf{H} = vector of hydraulic variables at the current time step

Water Quality Treatment

- After computing the water quality routing of pollutants, treatment operations are calculated for each pollutant at each node during each time step
- Treatment expressions can be applied at any node, either as a concentration remaining after treatment ($C = \text{value or expression}$) or as a fractional removal ($R = \text{value or expression}$)
- With non-storage nodes (i.e., junctions and outfalls), treatment results are dependent on the pollutant concentration and flow rate
- For storage nodes, treatment results are also dependent on the depth, nodal surface area, routing time step, and hydraulic residence time within the node (or some combination, such as loading rate $\text{FLOW} / \text{AREA}$)

Treatment Expressions

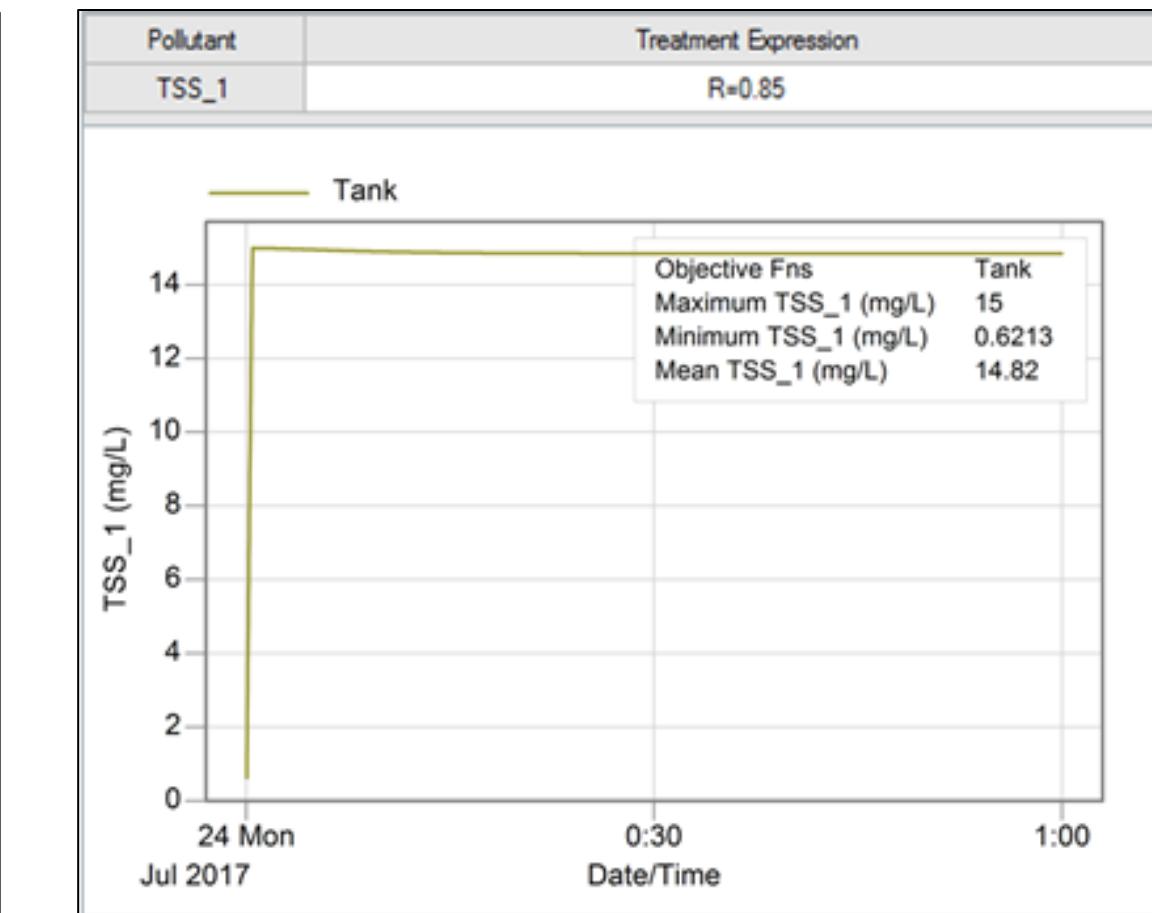
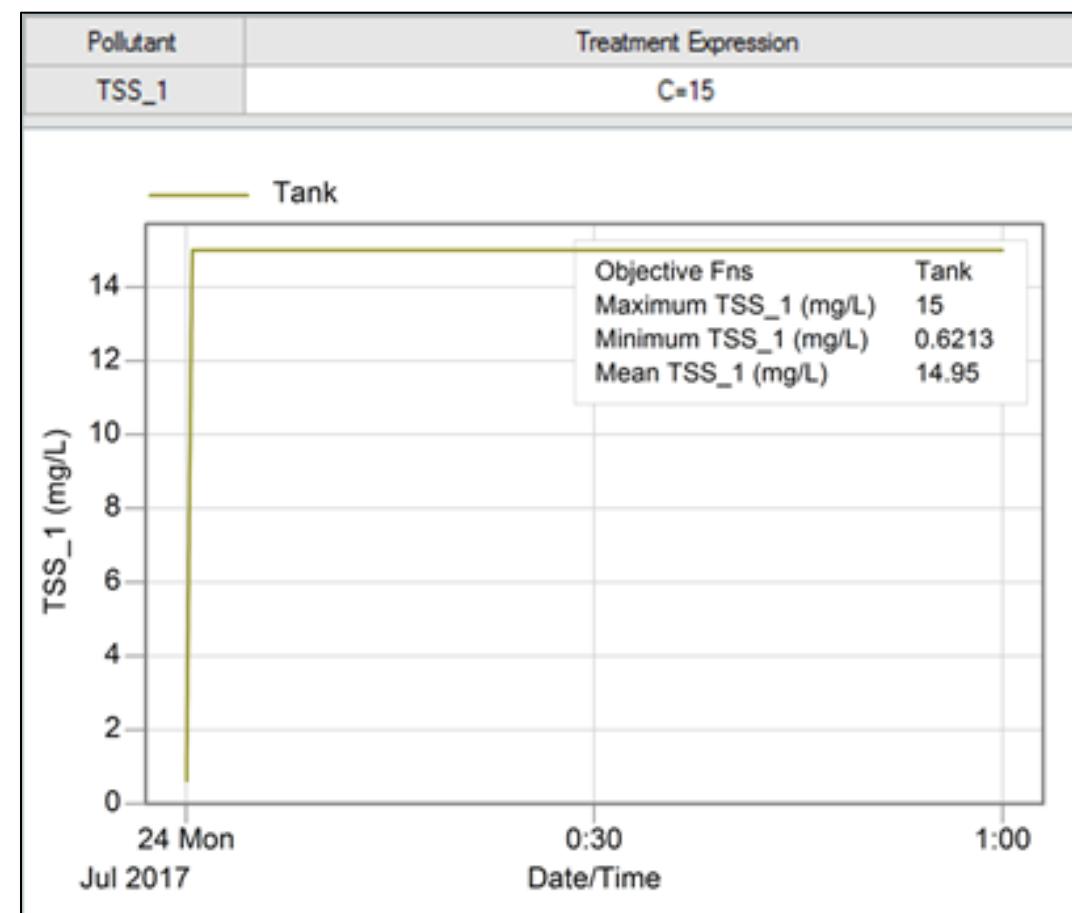
- A treatment expression can use
 - Variables
 - Functions
 - Numbers
 - Standard operators +,-,*,,/,,^
 - Pollutant names
 - Any level of nested parentheses
- Names of variables and functions are case-insensitive

Variable	Description
FLOW	Flow rate into the node in user defined flow units
DEPTH	Average water depth in the node over the time step (ft or m)
AREA	Average surface area of the node over the time step (ft ² or m ²)
DT	Current routing time step (seconds)
HRT	Hydraulic residence time of water in a storage node (hours)

Function	Description
ABS	Returns the absolute value of a double-precision floating number
ACOS	Returns the angle (in radians) whose cosine is the specified number
ACOT	Returns the inverse cotangent (arccotangent) of a number
ASIN	Returns the angle (in radians) whose sine is the specified number
ATAN	Returns the angle (in radians) whose tangent is the specified number
COS	Returns the cosine of the specified angle (measured in radians)
COT	Returns the cotangent of the specified angle (measured in radians)
COSH	Returns the hyperbolic cosine of a number
COTH	Returns the hyperbolic cotangent of a number
EXP	Returns e raised to the specified power
LOG	Returns the logarithm base e of a specified number
LOG10	Returns the base 10 logarithm of a specified number
SGN	Returns the sign (-1 = negative, 0, or 1 = positive) of a number
SIN	Returns the sine of the specified angle (measured in radians)
SINH	Returns the hyperbolic sine of a number
SQRT	Returns the square root of a specified number
STEP	Returns 1 if the number is positive, or 0 if it is negative or 0
TAN	Returns the tangent of the specified angle (measured in radians)
TANH	Returns the hyperbolic tangent of a number

Simple Treatment Expressions

- Simple EMC/Constant removal (e.g., inflow = 100 mg/L and desired outflow = 15 mg/L): $C = 15$ or $R = 0.85$ (see examples below)
- Correlated removal, where pollutant treatment is proportional to the removal of another pollutant (e.g., if 50% of TSS1 removal): $R = 0.5 * R_{_TSS1}$



Example – No Treatment vs Fixed Removal

- No treatment ($C_{in} = C_{out}$)

$$C_{in} = 1000 \text{ mg/L}$$

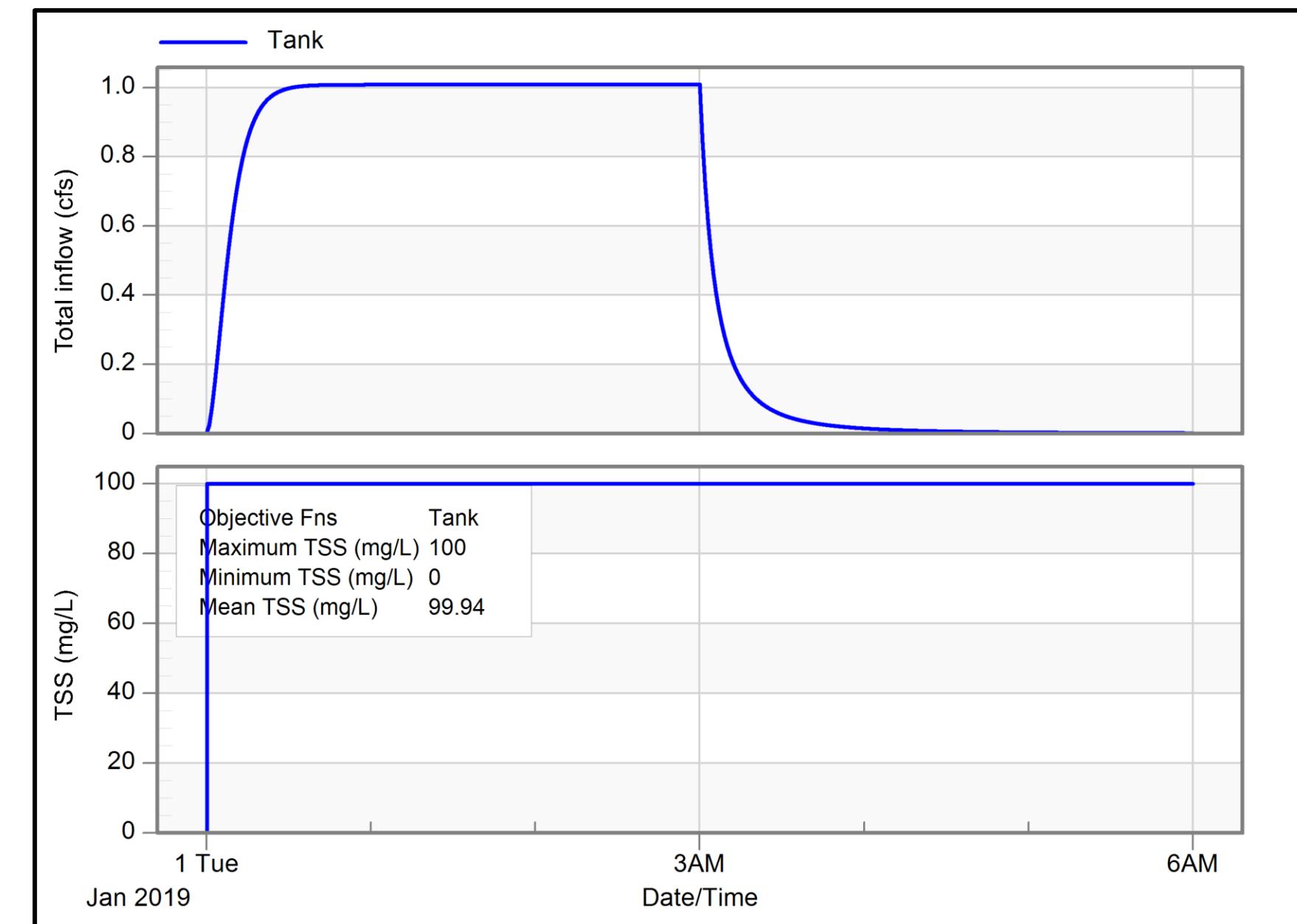
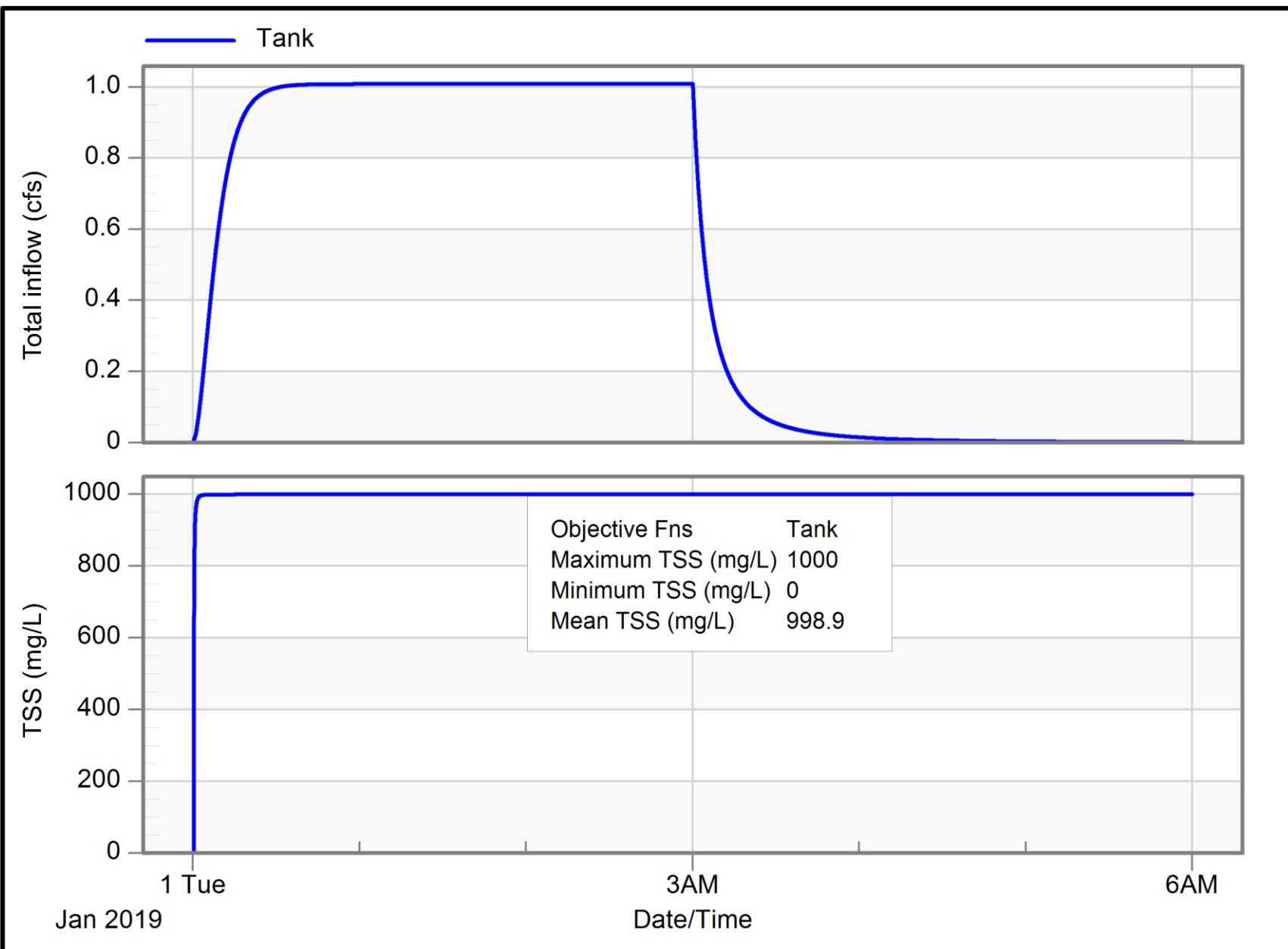
$$C_{out} = 1000 \text{ mg/L}$$

General		Buildup	Washoff
Pollutant	TSS		
Attributes			
Function	EMC		
Coefficient	1000		
Exponent	0.0		
Cleaning Effic.	0.0		
BMP Effic.	0.0		

Treatment Editor: Tank	
Pollutant	Treatment Expression
TSS	R = 0.90

$$C_{in} = 1000 \text{ mg/L}$$

$$C_{out} = C_{in} \times (1-R) = 100 \text{ mg/L}$$



Detailed Treatment Expressions

- Represent removal based on influent concentration using STEP (expression) function:
 - If expression is positive, then value = 1; or
 - If expression is negative or 0, then value = 0
- Example expression 1 : $R = (1 - \text{STEP}(\text{TSS} - 50)) * 0.50 + \text{STEP}(\text{TSS} - 50) * 0.90$
 - If inflow concentration > 50 mg/L then 90% TSS removal
 - If inflow concentration < 50 mg/L then 50% TSS removal
- Other removal mechanisms are available
 - k-C* model (1st order)
 - Nth order reaction kinetics
 - Particulate settling by gravity

Example – Step Function Removal

General Buildup Washoff

Pollutant TSS

Attributes

Function	EMC
Coefficient	1000
Exponent	0.0
Cleaning Effic.	0.0
BMP Effic.	0.0

$$C_{In} = 1000 \text{ mg/L}$$

$$C_{Out} = C_{In} \times (1-R) = 100 \text{ mg/L}$$

Treatment Editor: Tank

Pollutant	Treatment Expression
TSS	R = (1-STEP(TSS-50))*0.50 + STEP(TSS-50)*0.90

General Buildup Washoff

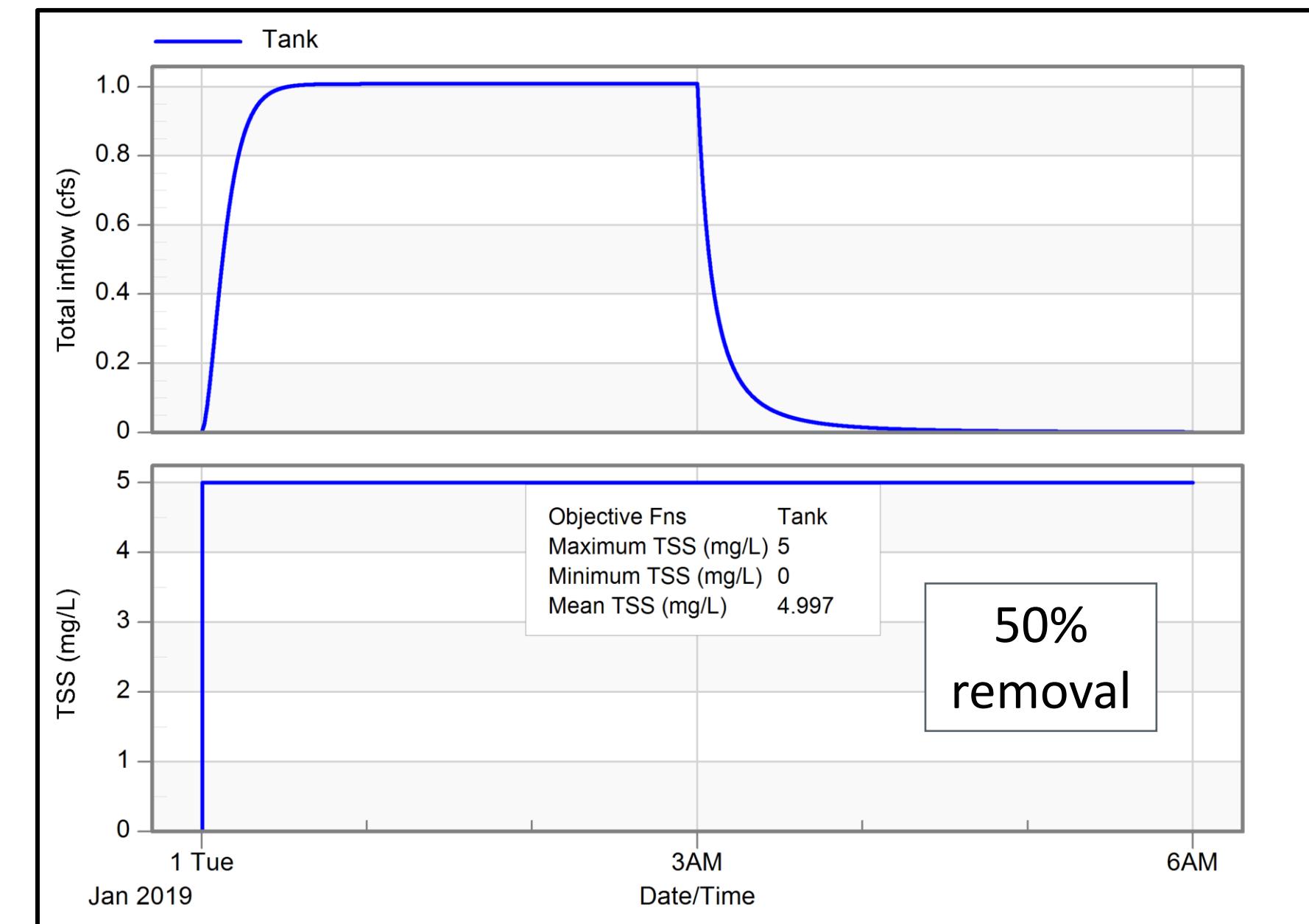
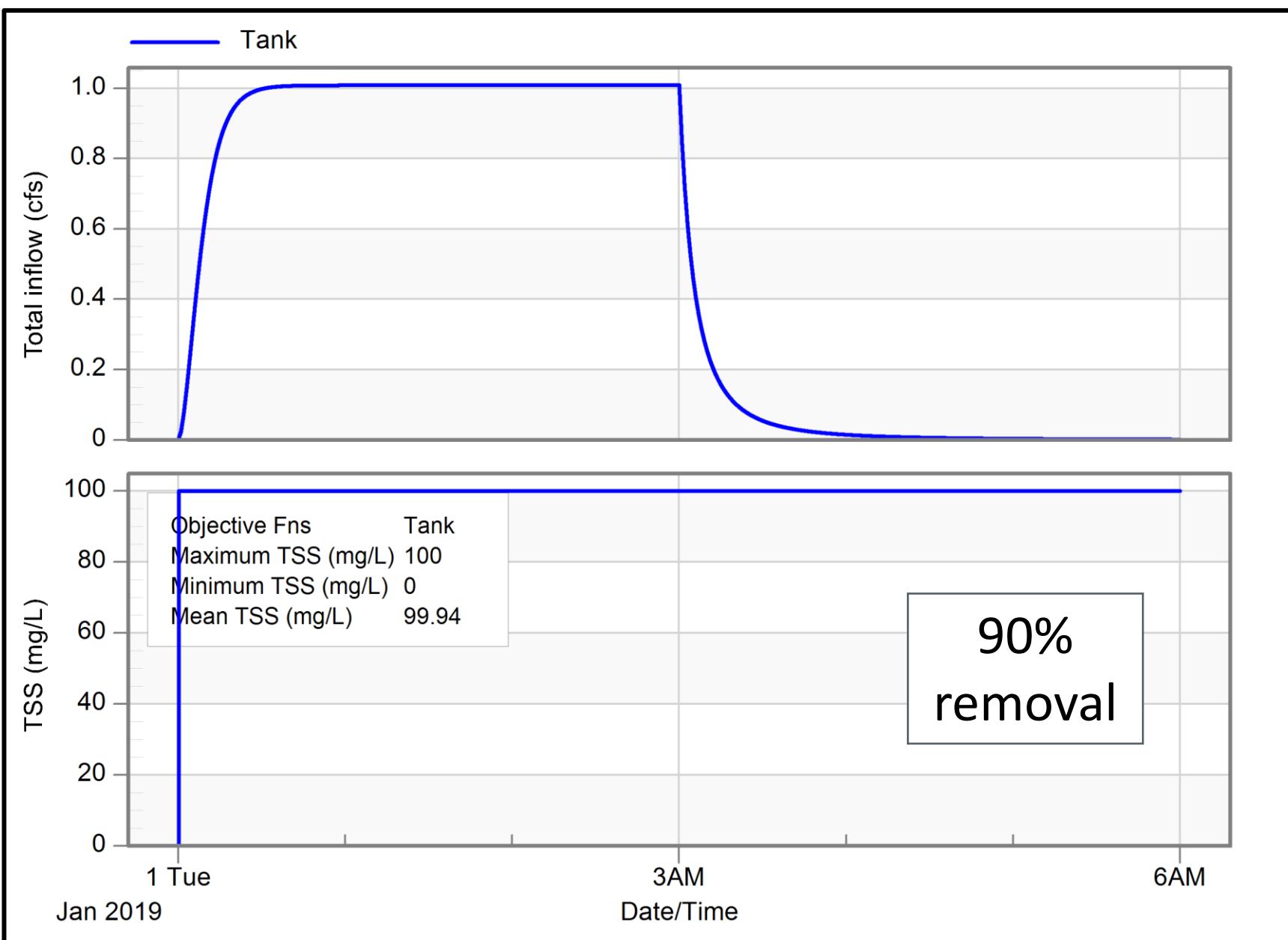
Pollutant TSS

Attributes

Function	EMC
Coefficient	10
Exponent	0.0
Cleaning Effic.	0.0
BMP Effic.	0.0

$$C_{In} = 10 \text{ mg/L}$$

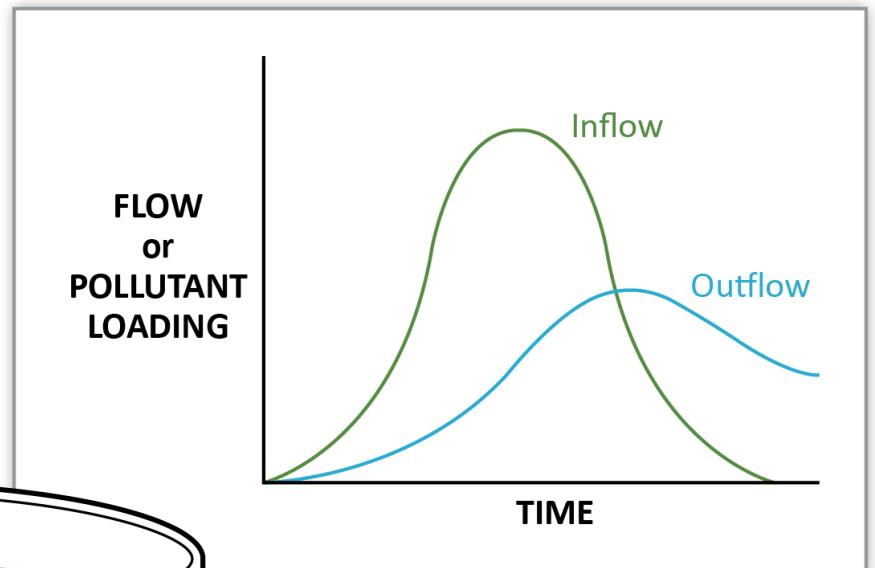
$$C_{Out} = C_{In} \times (1-R) = 5 \text{ mg/L}$$



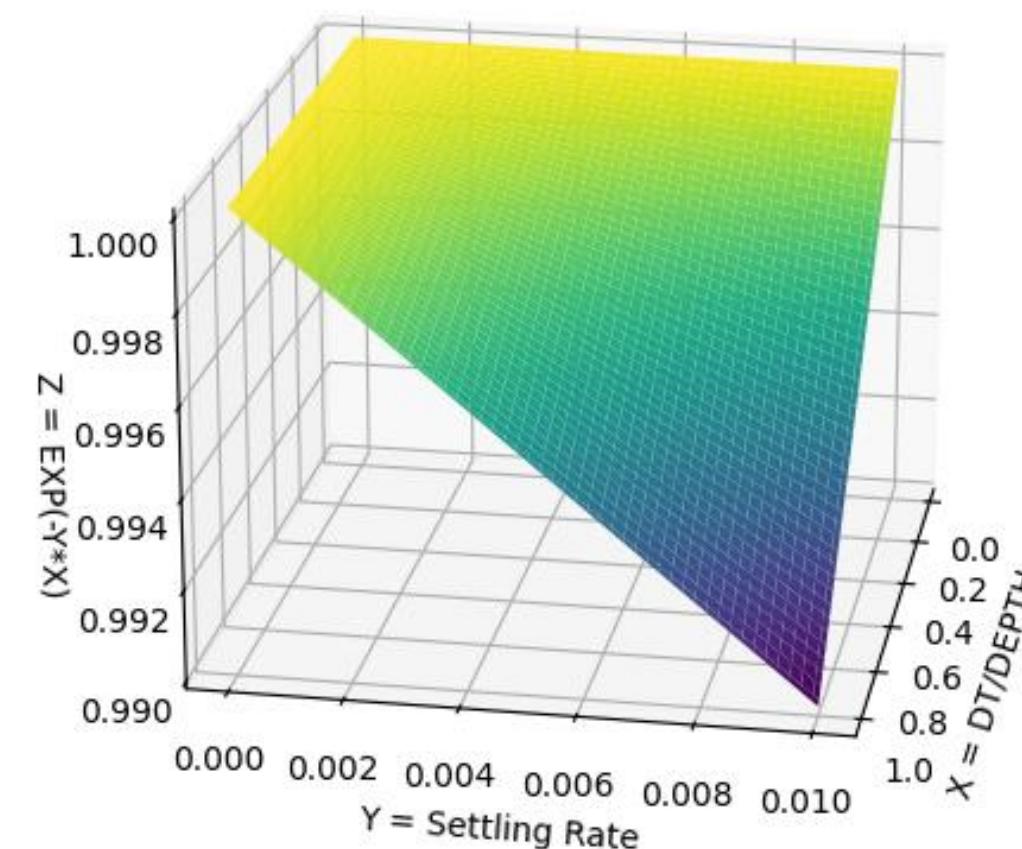
SWMM Sediment Modeling

Settling Ponds – Gravity Settling

- To represent the deposition of particulates in the pond:
 - Develop treatment expression for each suspended solids mass fraction
 - Defines rate of settling as function of time and depth of water in the pond



Mass Fraction	Average Velocity		Equiv. Size μm
	(m/s)	(ft/hr)	
20%	0.0000015	0.02	2
30%	0.0000124	0.15	4
40%	0.0000279	0.33	6
60%	0.0001235	1.46	12
80%	0.0006073	7.17	26
100%	0.0070788	83.61	103



Pond Design – Water Quality Treatment Volume

- Storage volume requirements are often quantified as a function of contributing area imperviousness
 - Technical basis: presumed TSS removal on an average annual basis (e.g., Ontario guidelines)
- City of Calgary Stormwater Management and Design Manual (2011)

The selection and design of stormwater BMPs must incorporate both water quantity and water quality concerns. Current stormwater quality criteria for the City of Calgary requires the removal of a minimum of 85% total suspended solids (TSS) for particle sizes greater than, or equal to, 50 µm. As time goes on, additional pollutant loading criteria might be established that will identify additional pollutant controls required. If a single BMP is unable to fully meet these criteria, a combination of BMPs in series could be required.

Table 3.2 Water Quality Storage Requirements based on Receiving Waters^{1, 2}

Protection Level	SWMP Type	Storage Volume (m ³ /ha) for Impervious Level			
		35%	55%	70%	85%
<i>Enhanced</i> 80% long-term S.S. removal	Infiltration	25	30	35	40
	Wetlands	80	105	120	140
	Hybrid Wet Pond/Wetland	110	150	175	195
	Wet Pond	140	190	225	250
<i>Normal</i> 70% long-term S.S. removal	Infiltration	20	20	25	30
	Wetlands	60	70	80	90
	Hybrid Wet Pond/Wetland	75	90	105	120
	Wet Pond	90	110	130	150
<i>Basic</i> 60% long-term S.S. removal	Infiltration	20	20	20	20
	Wetlands	60	60	60	60
	Hybrid Wet Pond/Wetland	60	70	75	80
	Wet Pond	60	75	85	95
	Dry Pond (Continuous Flow)	90	150	200	240

Water Quality – Particulate Settling Parameters

- To represent the deposition of particulates in the pond...
 - Develop treatment expression for each TSS mass fraction
 - Defines rate of settling as function of time and depth of water in the pond

[TREATMENT]		
:;Node	Pollutant	Function
:;		
Pond	TSS_1	C = TSS_1 * EXP (-0.00000254/DEPTH*DT)
Pond	TSS_2	C = TSS_2 * EXP (-0.00001300/DEPTH*DT)
Pond	TSS_3	C = TSS_3 * EXP (-0.00002540/DEPTH*DT)
Pond	TSS_4	C = TSS_4 * EXP (-0.00012700/DEPTH*DT)
Pond	TSS_5	C = TSS_5 * EXP (-0.00059267/DEPTH*DT)
Pond	TSS_6	C = TSS_6 * EXP (-0.00550333/DEPTH*DT)

- TSS mass that settles out is removed from water column
 - Note: SWMM does not reduce available storage volume in the pond (generally okay if less than 1% of permanent pool volume)

Particulate Settling Results

	TSS_1 kg	TSS_2 kg	TSS_3 kg	TSS_4 kg	TSS_5 kg	TSS_6 kg
Quality Routing Continuity						
Dry Weather Inflow	0.000	0.000	0.000	0.000	0.000	0.000
Wet Weather Inflow	725.439	697.458	697.458	725.439	725.439	725.439
Groundwater Inflow	0.000	0.000	0.000	0.000	0.000	0.000
RDII Inflow	0.000	0.000	0.000	0.000	0.000	0.000
External Inflow	0.000	0.000	0.000	0.000	0.000	0.000
External Outflow	571.452	500.037	476.743	436.307	406.438	377.646
Flooding Loss	0.000	0.000	0.000	0.000	0.000	0.000
Exfiltration Loss	0.000	0.000	0.000	0.000	0.000	0.000
Mass Reacted	147.612	191.172	214.706	283.674	313.563	342.228
Initial Stored Mass	0.000	0.000	0.000	0.000	0.000	0.000
Final Stored Mass	1.514	1.504	1.503	1.502	1.499	1.495
Continuity Error (%)	0.670	0.680	0.646	0.545	0.543	0.561

Mass reacted (increasing load is removed as particle size increases)

Mass reacted includes both treatment and reactions. It may be negative if the reaction results in pollutant growth (e.g., bacteria).

Outfall Loading Summary

Outfall Node	Flow Freq. Pcnt.	Avg. Flow CMS	Max. Flow CMS	Total Volume 10^6 ltr	Total TSS_1 kg	Total TSS_2 kg	Total TSS_3 kg	Total TSS_4 kg	Total TSS_5 kg	Total TSS_6 kg
Hopewell_OF1	9.91	0.000	0.013	0.478	52.373	52.373	52.373	52.373	52.373	52.373
Hopewell_OF2	100.00	0.048	0.100	892.070	53.729	53.450	53.125	50.697	42.904	21.962
Hopewell_OF3	6.75	0.000	0.012	0.220	22.958	22.958	22.958	22.958	22.958	22.958
Hopewell_OF4	100.00	0.050	0.120	929.462	134.044	134.044	134.044	134.044	134.044	134.044
Randall_OF1	27.57	0.000	0.010	1.947	102.389	60.190	49.869	39.585	37.435	36.996
Wetland_OF1	13.10	0.000	0.006	0.629	57.845	57.845	57.845	57.845	57.845	57.845
Hwy7_OF1	6.05	0.001	0.042	0.981	116.299	89.464	76.832	47.155	27.247	19.843
Hwy7_OF2	1.86	0.000	0.014	0.134	17.729	15.744	15.744	17.729	17.729	17.729
System	33.16	0.100	0.281	1825.920	557.366	486.069	462.790	422.386	392.536	363.750

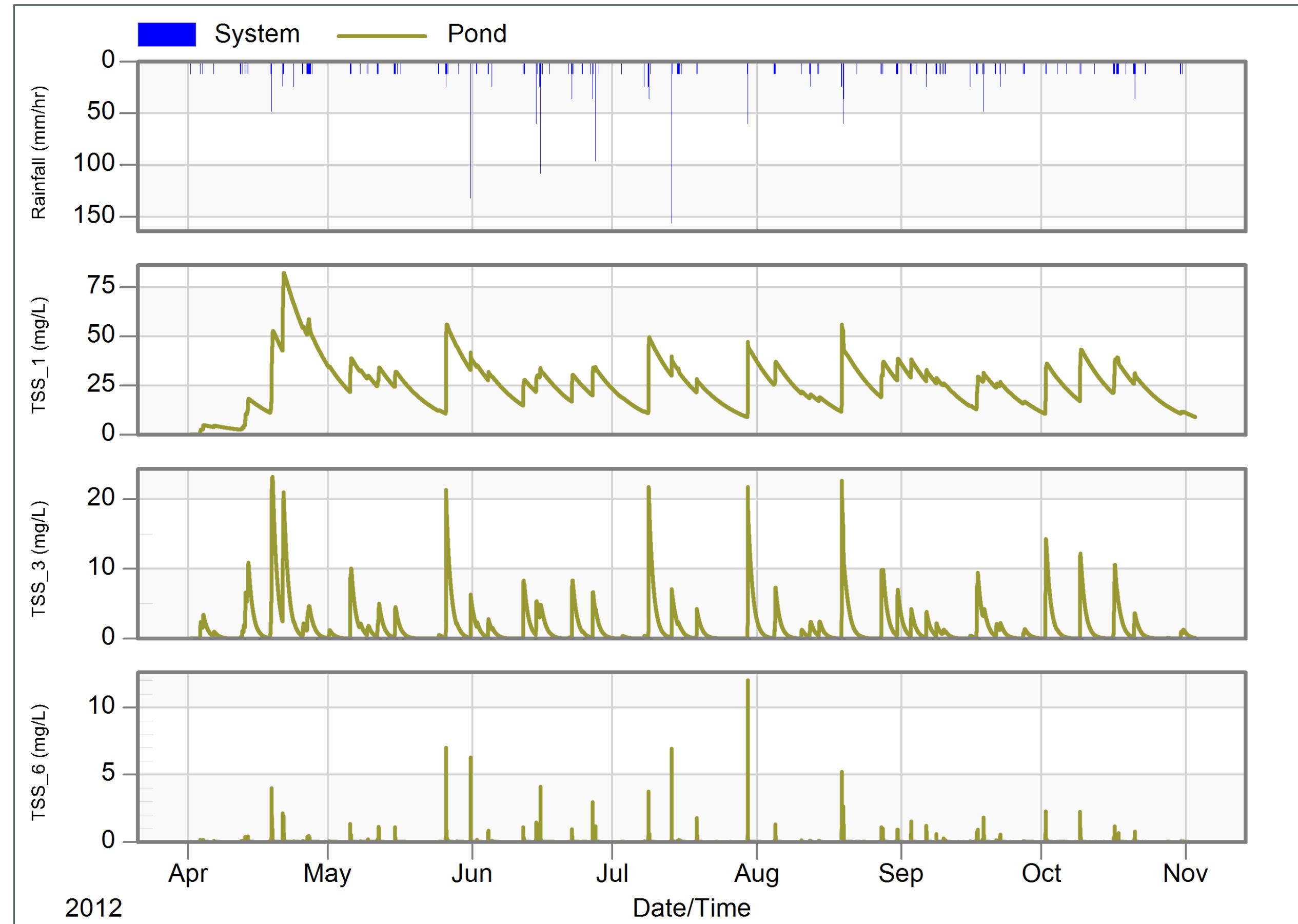
Outfall load (increasing load is transported through the system as particle size decreases)

Particulate Settling Results

Smallest 20% mass fraction

Middlest 20% mass fraction

Largest 20% mass fraction

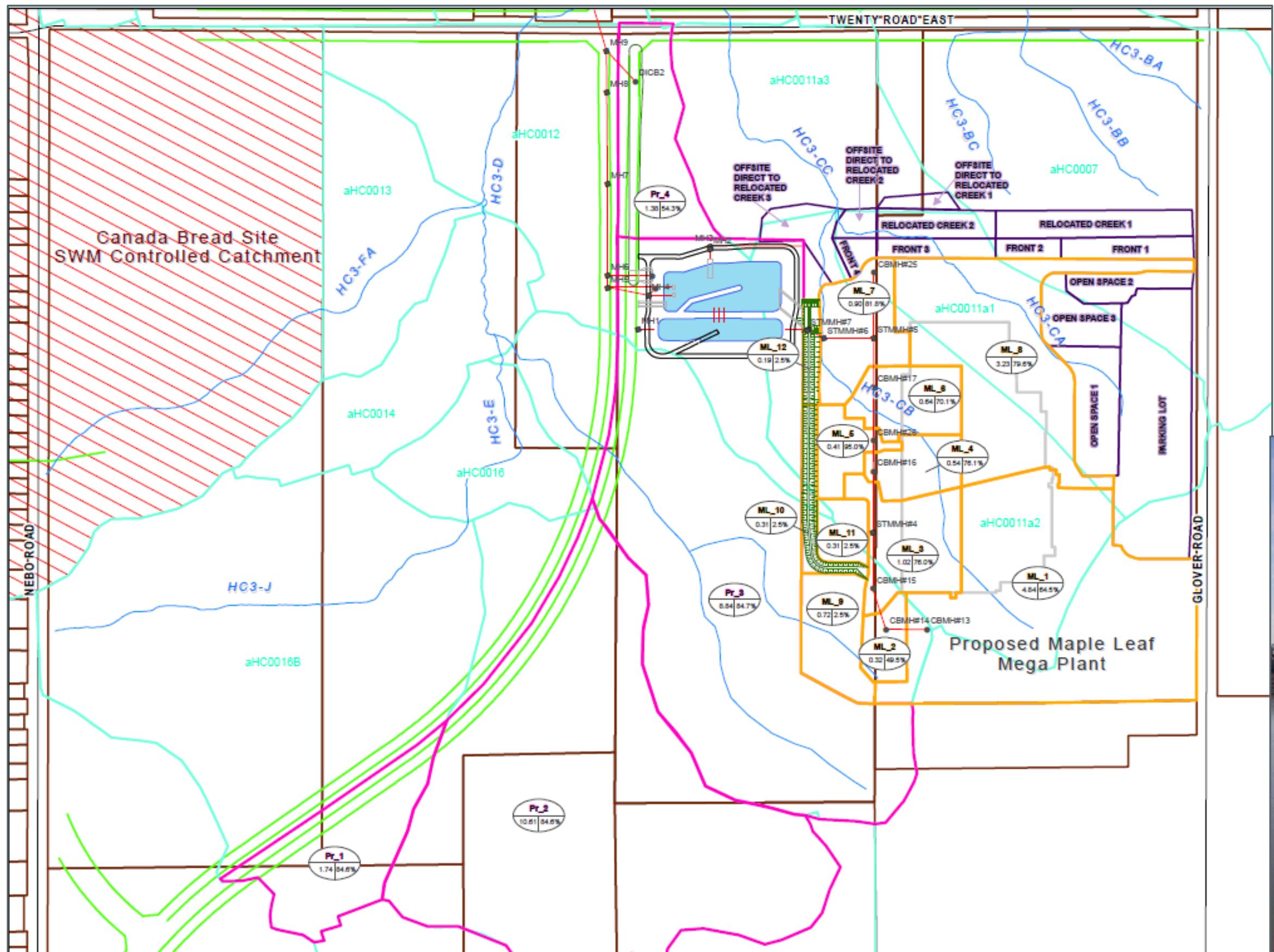


TSS Loading Summary

Event/Particle Characteristic	TSS Loading and Accumulation by Particle Size						Total TSS Loading
	0-20%	20-30%	30-40%	40-60%	60-80%	80-100%	
Mass Fraction (% Finer Than):							
Equivalent Particle Size:	<3 µm	3-5 µm	5-7 µm	7-17 µm	17-35 µm	>35 µm	
Mean Equivalent Diameter:	1.5 µm	4 µm	6 µm	12 µm	26 µm	103 µm	
Equiv. Particle Density (kg/m ³):	2,200	2,425	2,425	2,575	2,650	2,650	
Equiv. Dry Bulk Density (kg/m ³):	200	400	400	1,200	1,800	1,800	
Average Rainfall Year (April - October)							
Surface Washoff Load (kg)	6,765.0	3,011.4	3,011.4	6,765.0	6,765.0	6,765.0	33,082.8
Pond Discharge Load (kg)	2,535.4	510.3	374.0	350.1	69.3	5.2	3,844.2
Removal Efficiency	62.5%	83.1%	87.6%	94.8%	99.0%	99.9%	88.4%
Load Remaining in Pond (kg)	4,229.6	2,501.2	2,637.5	6,414.8	6,695.6	6,759.8	29,238.5
Volume Remaining in Pond (m ³)	21.15	6.25	6.59	5.35	3.72	3.76	46.82

- Sediment accumulation rate of 1.3 m³/ha/yr (April thru October)
- Snowmelt and hydrologic conditions during winter months not modeled
 - Winter road operations introduces additional TSS loading
 - Estimated annual sediment accumulation rate of 2.6 m³/ha/yr
- 10-yr sediment volume = 940 m³ (available decant volume = 1,230 m³)

Example Project Details...



www.chijournal.org/C378

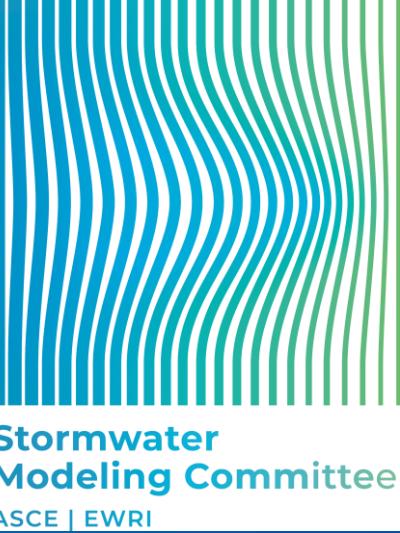
CHI JOURNAL OF WATER MANAGEMENT MODELING

Stormwater Pond Sediment Loading and Accumulation Analysis

Mike Gregory (2014)
AECOM

Under construction January 2013





EWRI Congress 2025, EPA SWMM5 Workshop -- Water Quality Modeling

Thank you for your attention...
any questions?

Mike Gregory, P.Eng., PE mike@chiwater.com