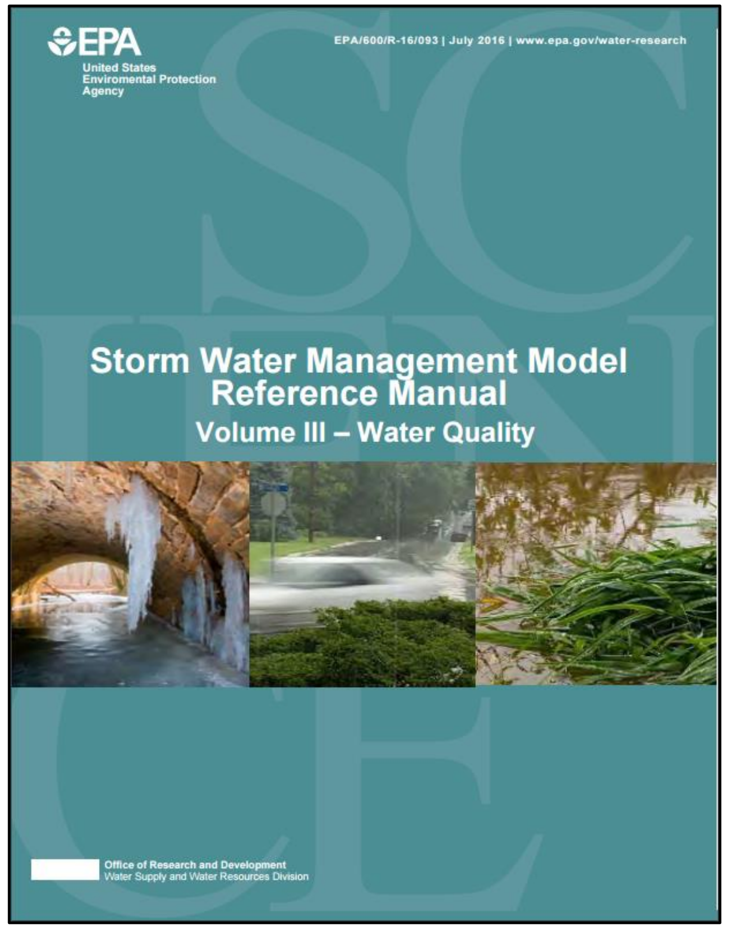
Stormwater
Modeling Committee
ASCE | EWRI

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

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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

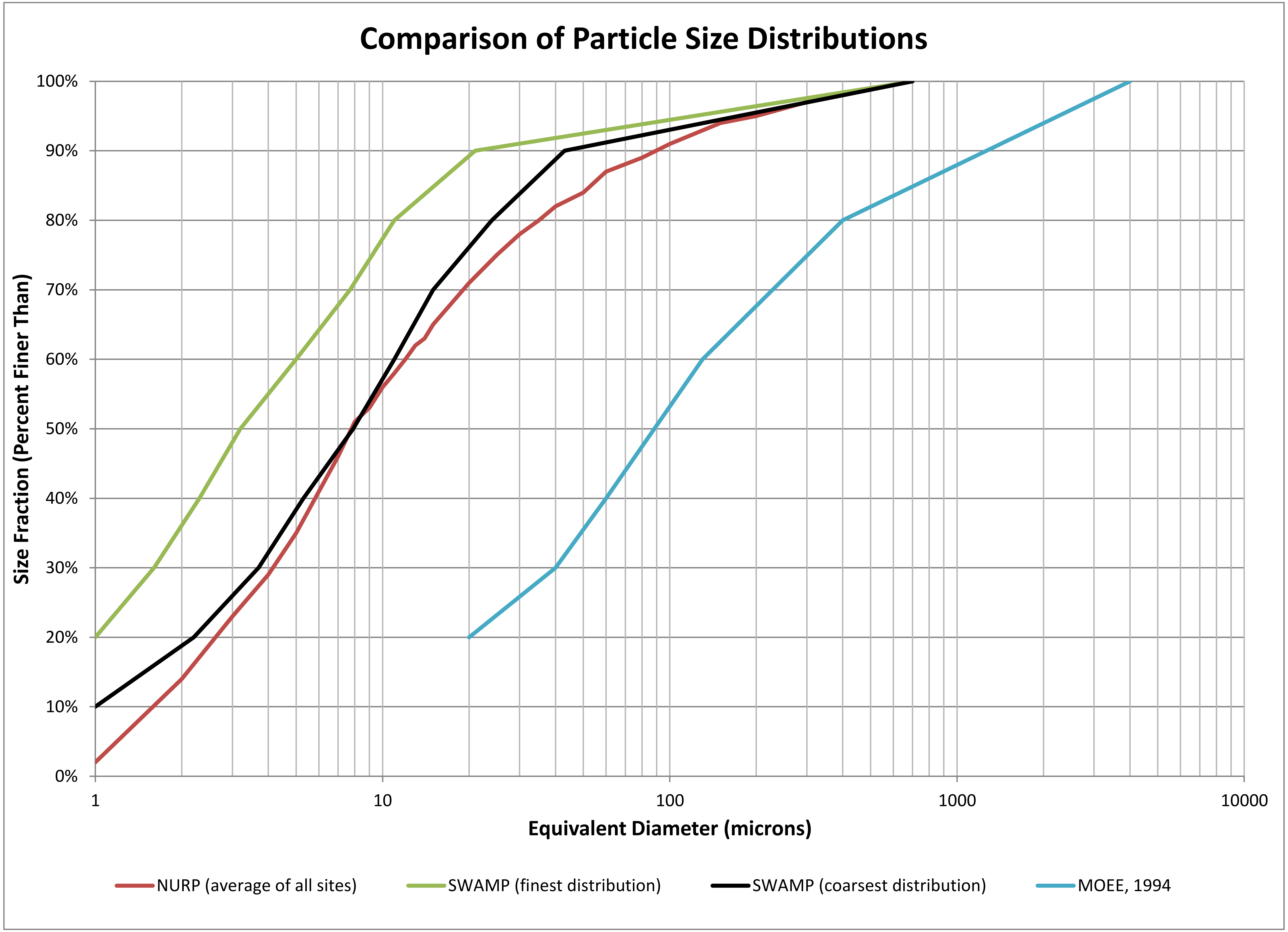
- Pollutant
  - Affects feeding, respiration, spawning of fish
  - Restricts light (increases turbidity)
  - Siltation/clogging of hydraulic structures
  - Preferential settling of largest particles
- Medium for transporting pollutants
  - Fine-textured material (clay, organics)
  - Likely to be transported 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) Range	Equiv. Diameter (µm) Mean	Average Velocity (m/s)	Average Velocity (ft/hr)	Density (kg/m^3)	Bulk Density Dry (kg/m^3)
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 > 63µm > coarse silt



Comparison of Particle Size Distributions
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Size Fraction (Percent Finer Than)
1
10
100
1000
10000
Equivalent Diameter (microns)
NURP (average of all sites)
SWAMP (finest distribution)
SWAMP (coarsest distribution)
MOEE, 1994

Typical Urban Runoff Event Mean Concentrations

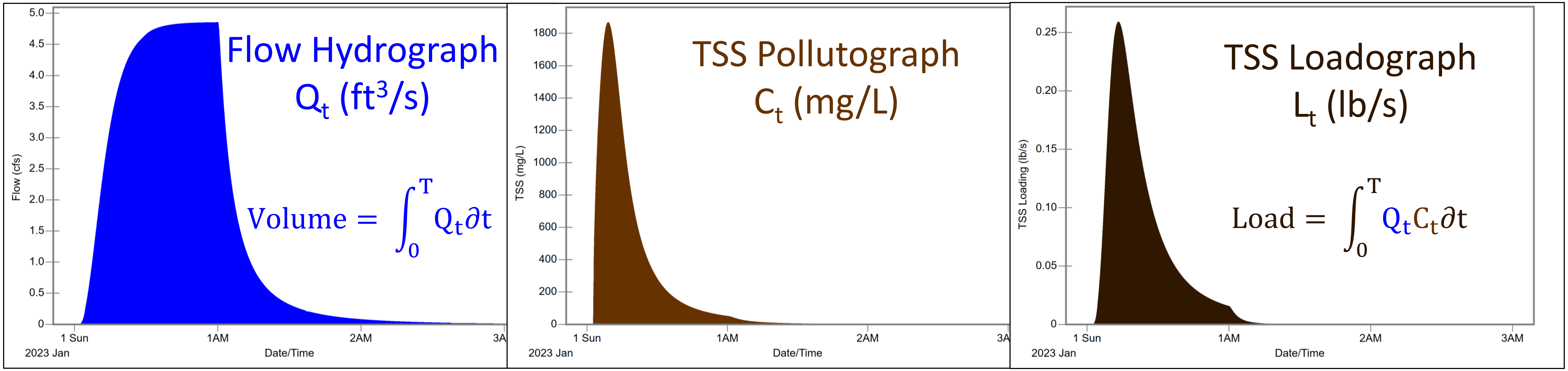
Constituent	Units	Mean EMC
Total Suspended Solids	mg/L	78.4
Biological Oxygen Demand*		14.1
Chemical Oxygen Demand*		52.8
Total Phosphorous		0.32
Soluble Phosphorous		0.13
Total Kjeldahl Nitrogen		1.73
Nitrite and Nitrate		0.66
Copper	µg/L	13.4
Lead		67.5
Zinc		162
Fecal Coliform*	colonies/100 mL	15,038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

Source: Center for Watershed Protection (CWP), Impacts of Impervious Cover on Aquatic Systems, Watershed Protection Research Monograph No.1, Center for Watershed Protection, Ellicott City, MD, March 2003.

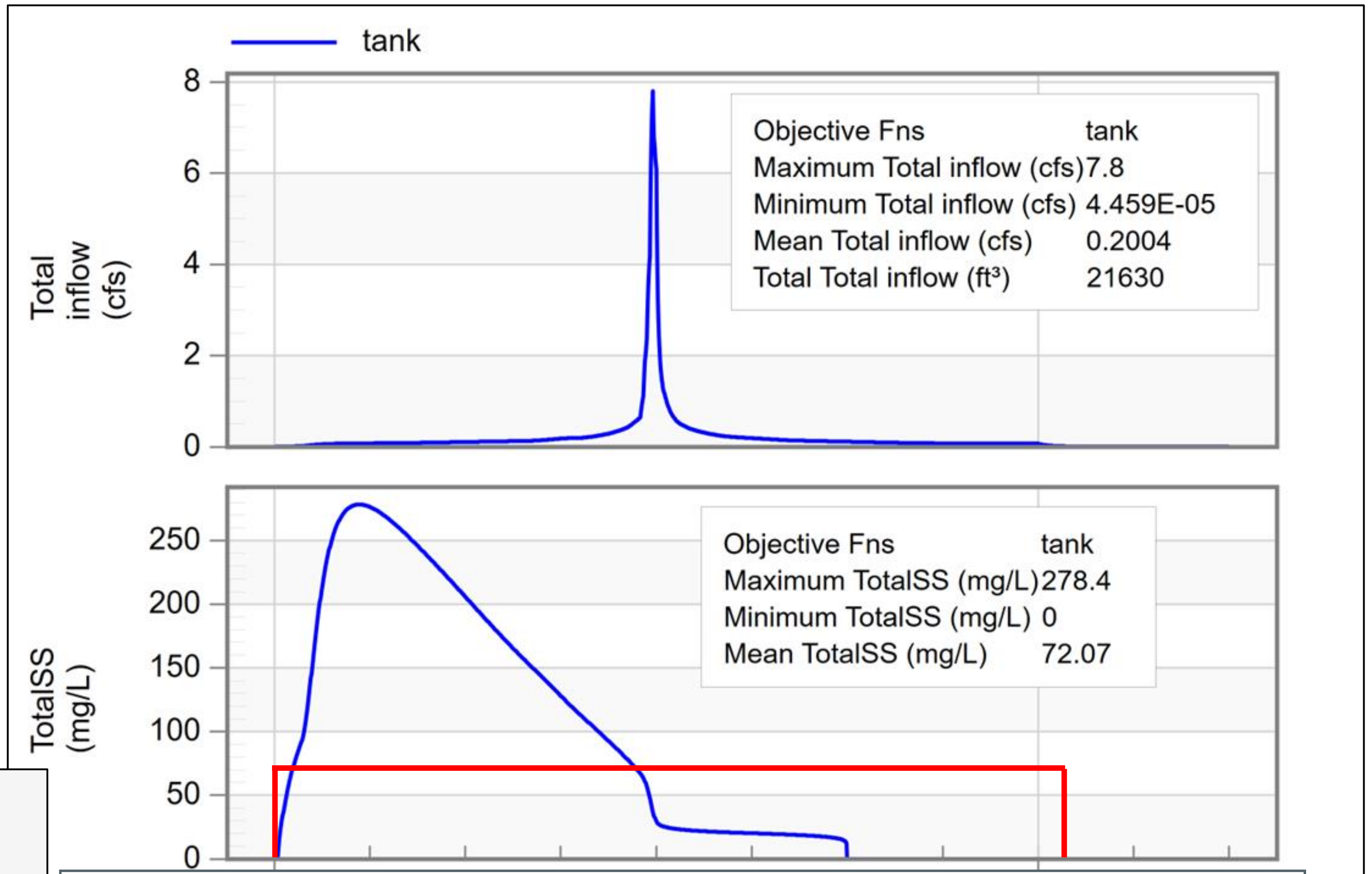
Quantifying Quantity and Quality

- 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



EMC = 23 lb ÷ 21,630 ft^3 = 71 mg/L

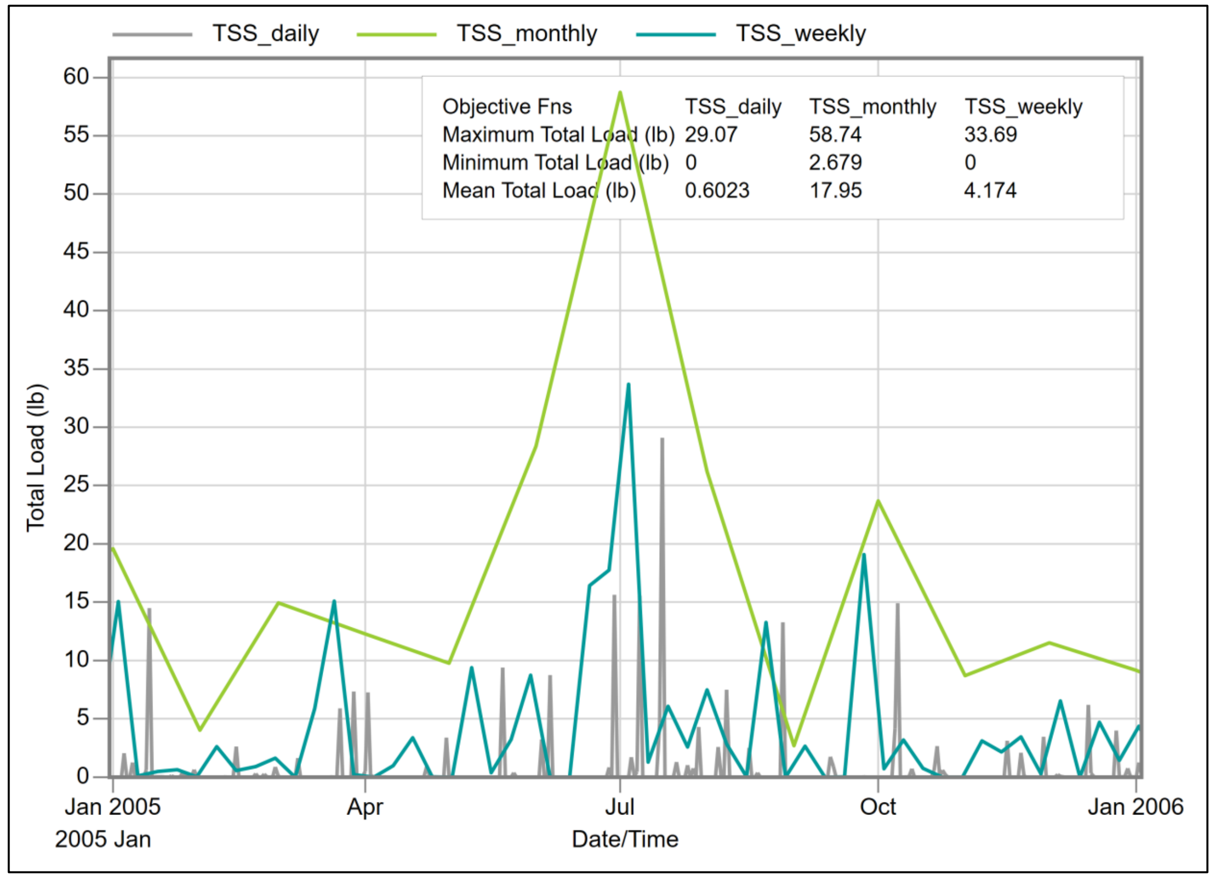
```
***************************
Subcatchment Washoff Summary
***************************

------------------------------------
                             TotalSS
Subcatchment                     lbs
------------------------------------
IntoTank                      23.044
------------------------------------
System                        23.044
```

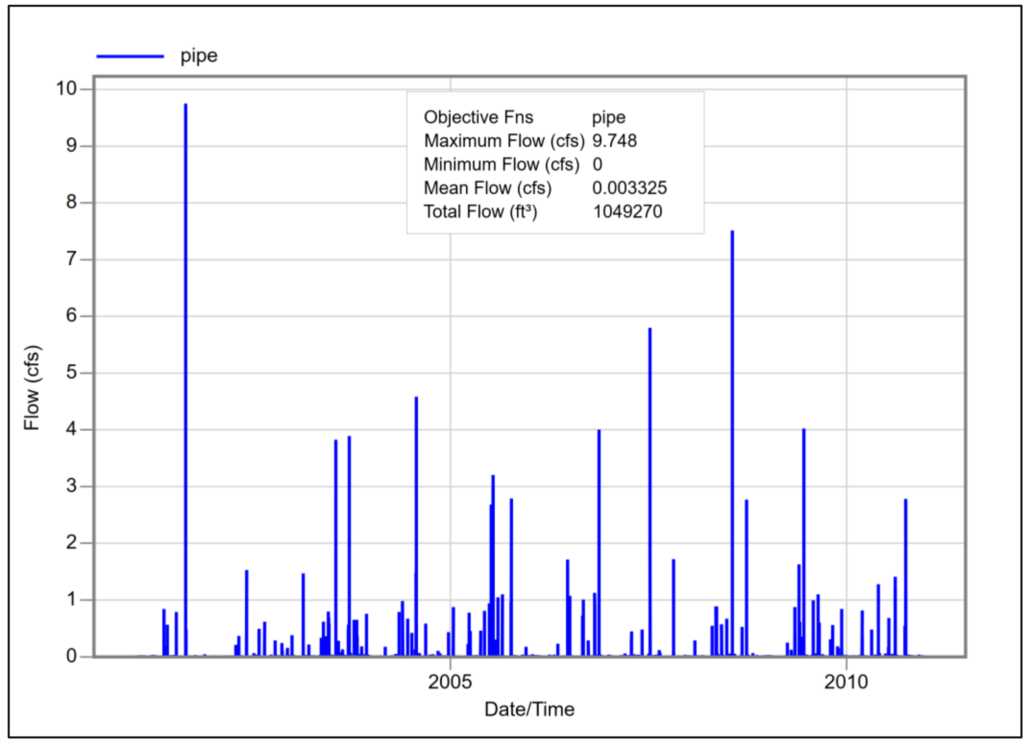
- For continuous simulation, parse the timeseries into runoff-producing, pollutant-generating events
  - Example: rainfall minimum interevent time = 12hr, pollutant threshold = 0 mg/L)
  - Top 10 Total Suspended Solids “events”…

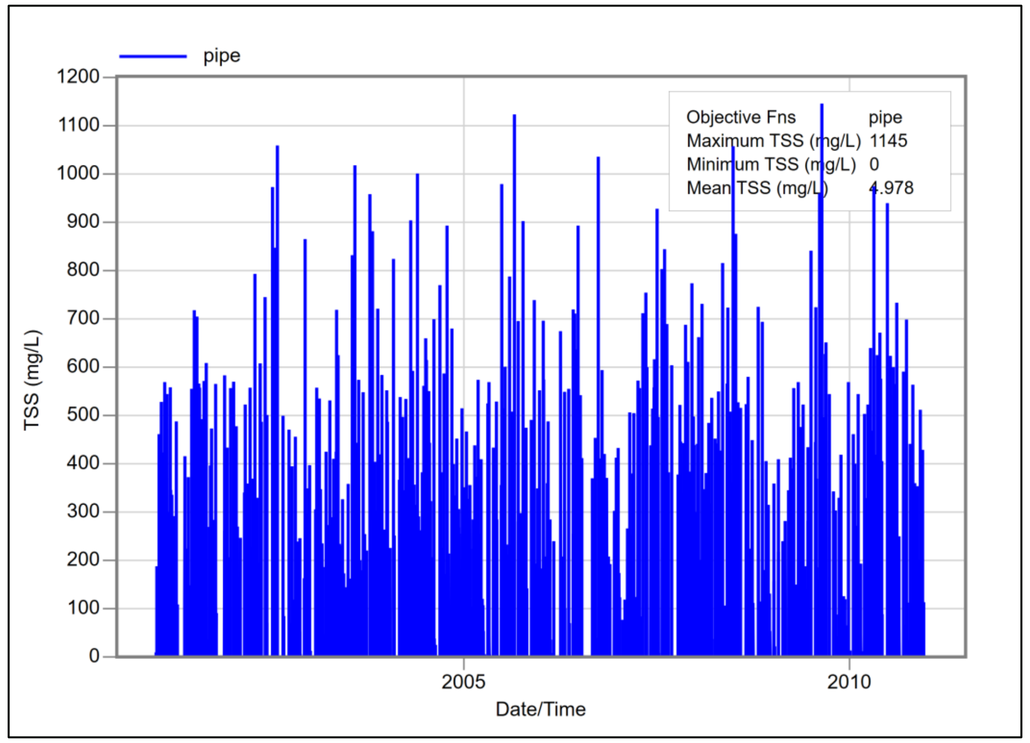
Start Date/Time	Duration (hr)	Flow Volume (ft3)	TSS Mean (mg/L)	TSS Load (kg)	Event Mean Conc. (mg/L)
01-Jan-2011 11:15	2.75	39.1	92.6	0.3	255.7
24-Dec-2008 15:05	4	88.5	83.1	0.6	235.9
09-Dec-2009 12:10	3.17	92.8	71.4	0.5	189.2
01-Feb-1986 16:10	4.92	54.9	45.7	0.3	163.1
27-Feb-2009 11:20	2.25	40.4	79.5	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

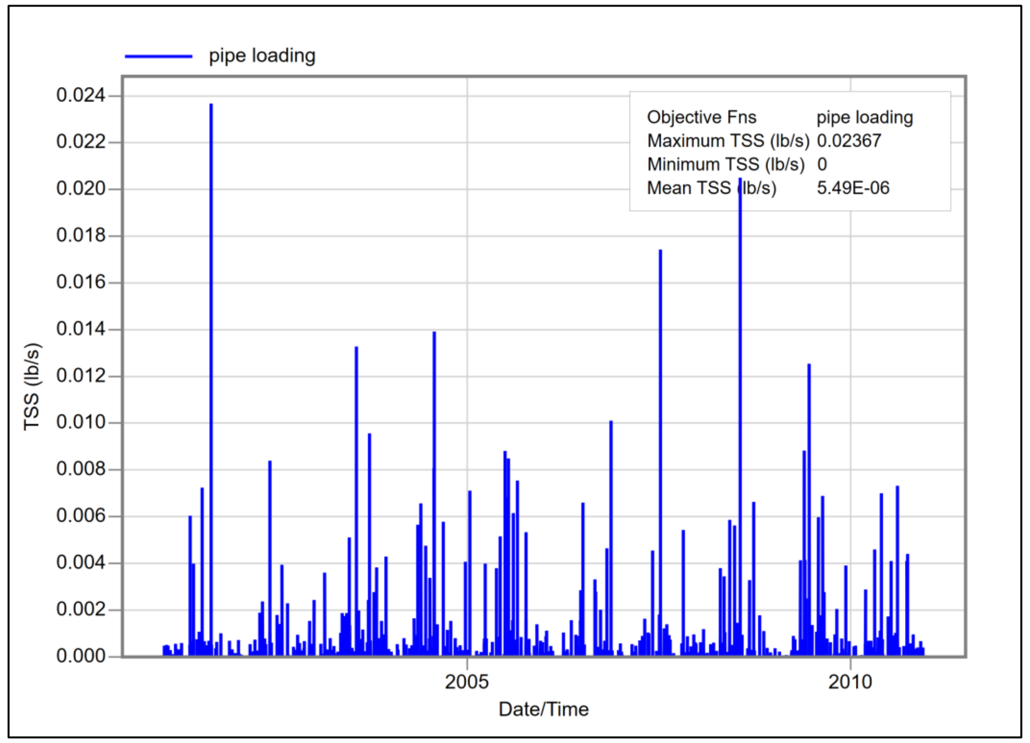
- Load: Pollutant mass passing a given point over a given period of time
- Load = Concentration × Flowrate
- And since concentrations and flows are highly variable in stormwater systems, so too is load
- Always know the concentration averaging and load accumulation periods







$$\text{Load} = \int_0^T Q_t C_t \partial t$$



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SWMM5 Water Quality Processes

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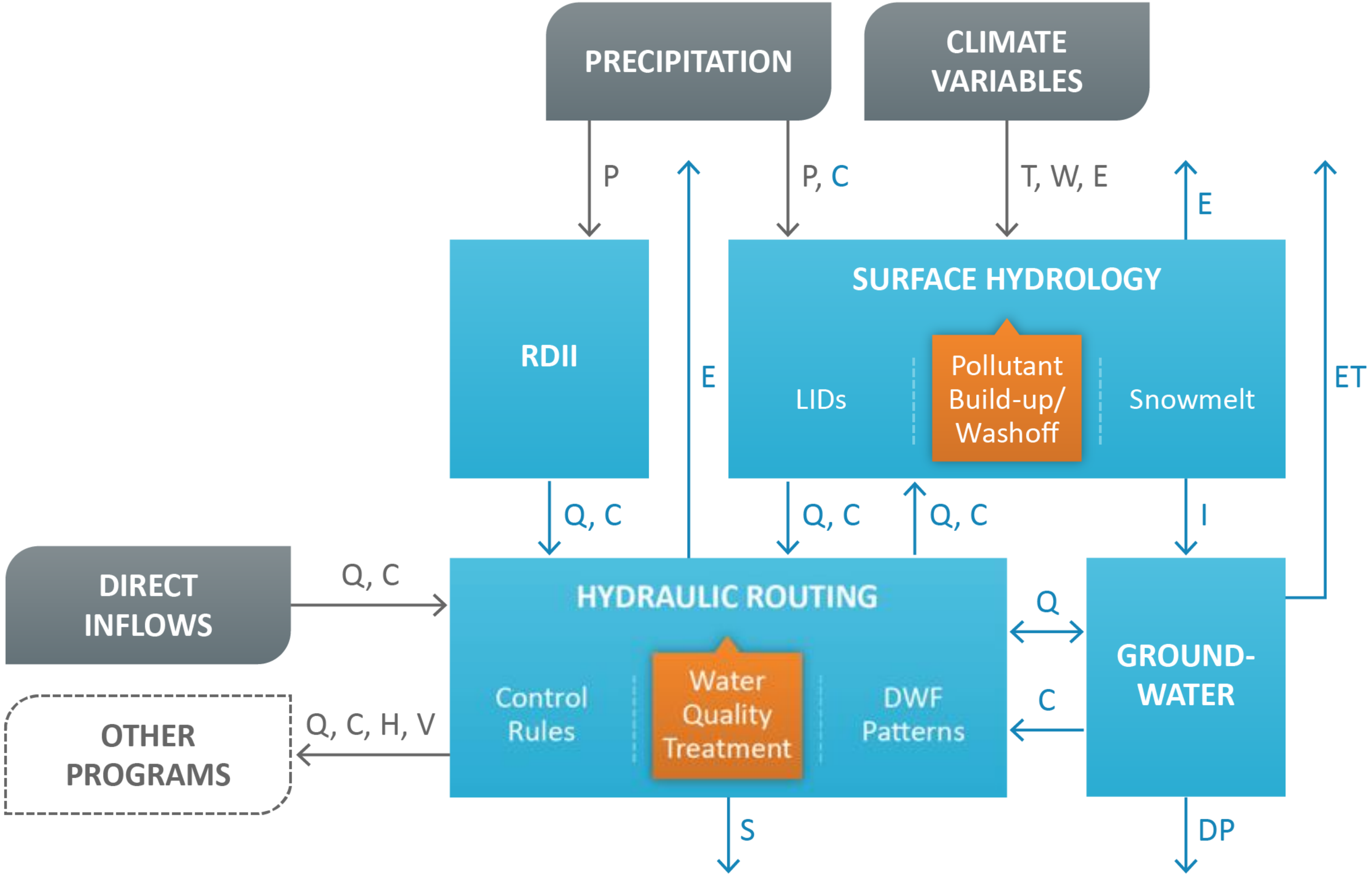
SWMM Process Schematic



Input Function

SWMM Process

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

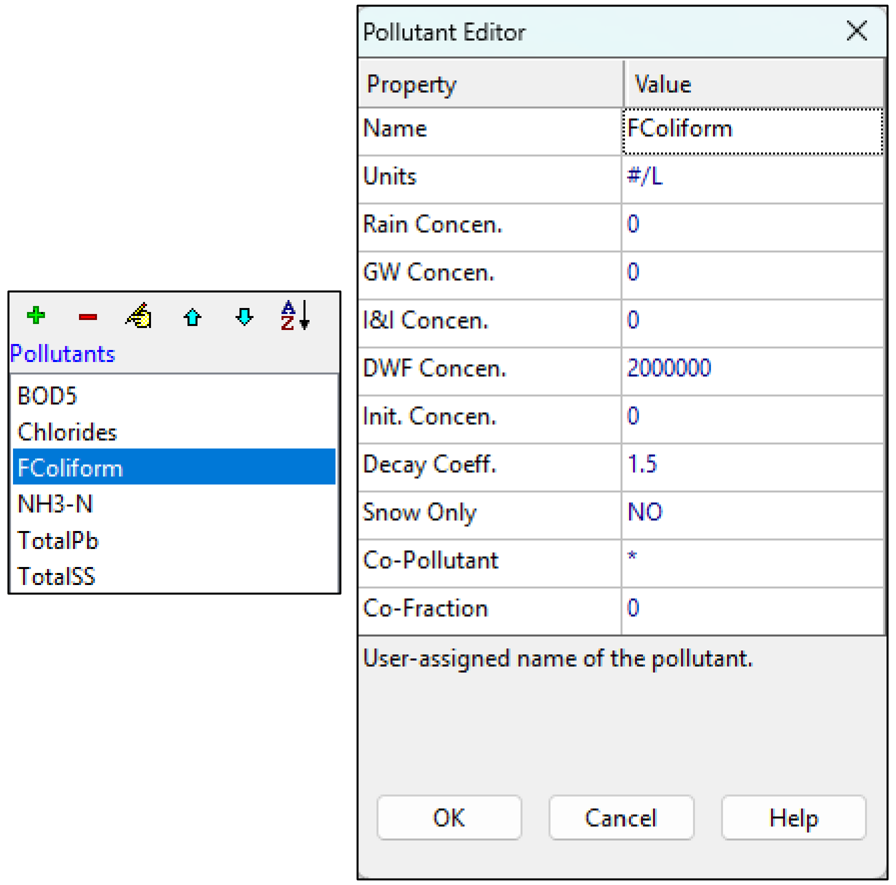
1. Identify the pollutants to be analyzed
2. Define the land uses that generate these pollutants
3. Assign one or a mixture of land uses to each subcatchment
4. Set the buildup, washoff and street cleaning parameters for each land use
5. Define pollutant removal functions for nodes within the drainage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



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

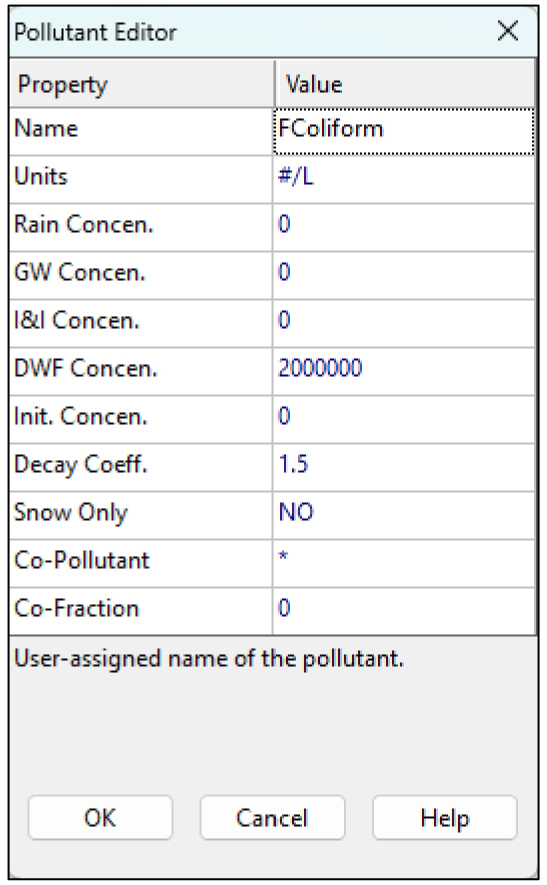
Matt Gamache[1*], Mitch Heineman[1], Derek Etkin[1], Zachary Eichenwald[1], Jamie Lefkowitz[1], Paul Keohan[2], and Ron Miner[1]

[1]CDM Smith, Cambridge, Massachusetts
[2]Boston 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
E. coli (#/100 mL)	0	0	3,800,000
Enterococcus (#/100 mL)	0	0	500,000

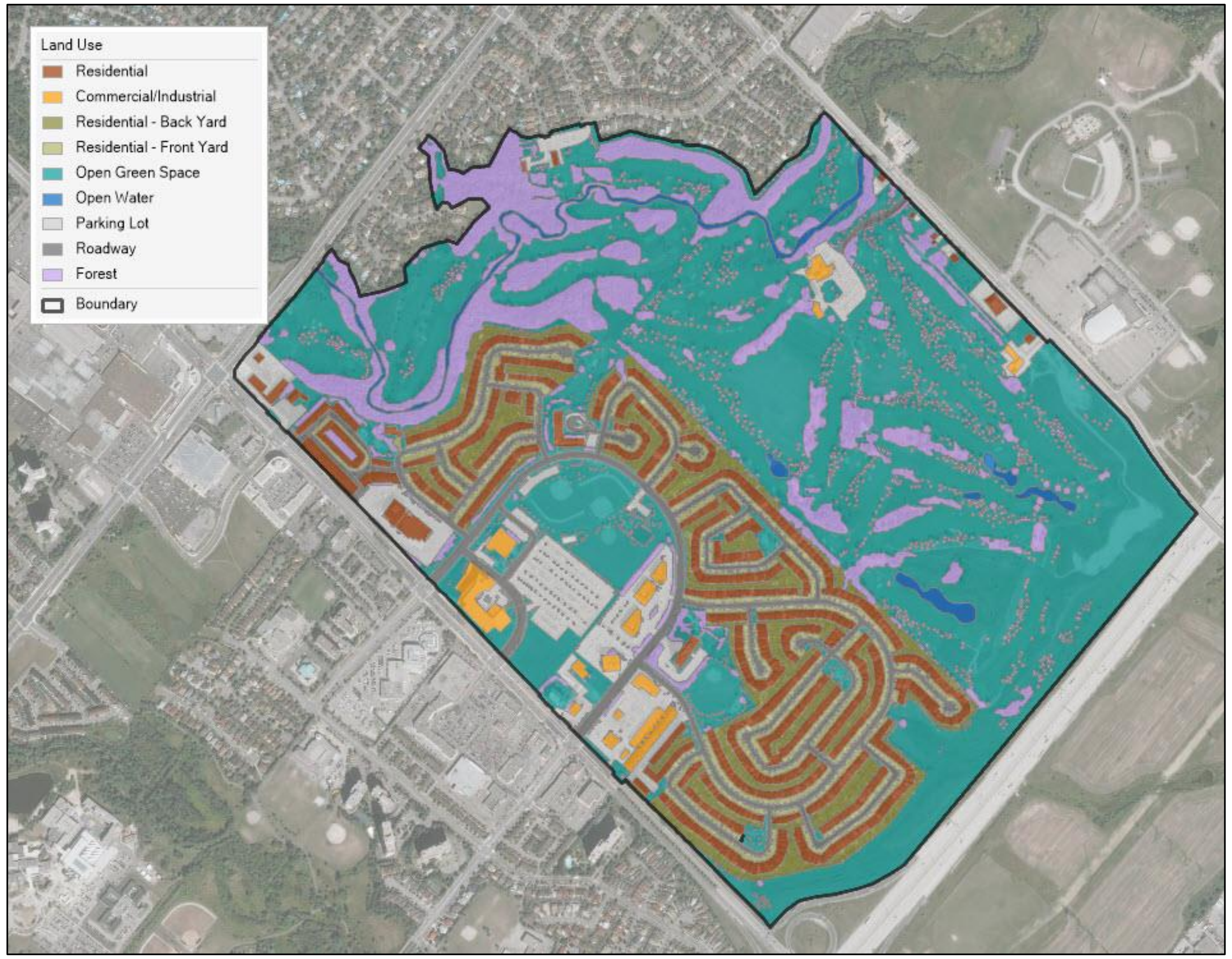
Pollutant Input Parameters (continued)

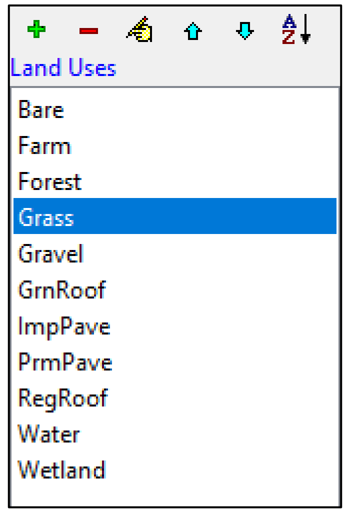
- (optional) Decay coefficient: A first-order reaction coefficient (in units of 1/days) used to compute the rate at which the constituent decays due to reaction or other processes once it enters the conveyance portion of a SWMM model
- Snow Only: Enter YES if pollutant buildup occurs only when there 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)

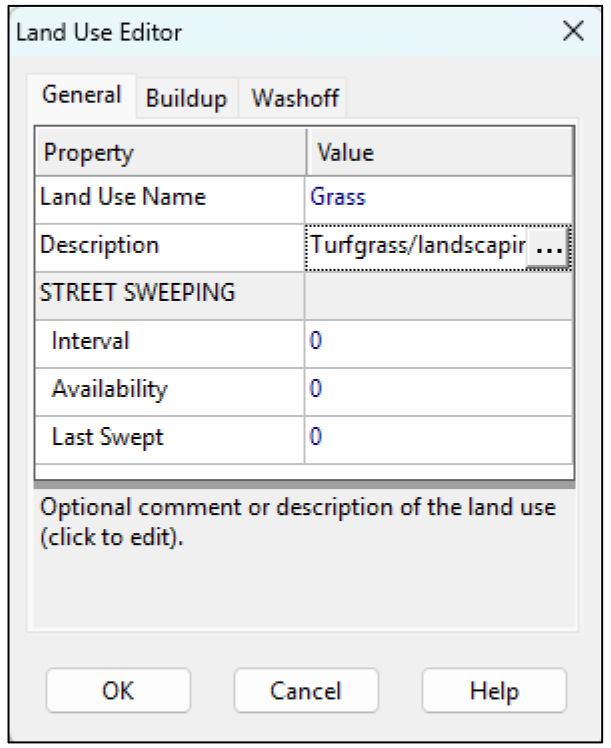


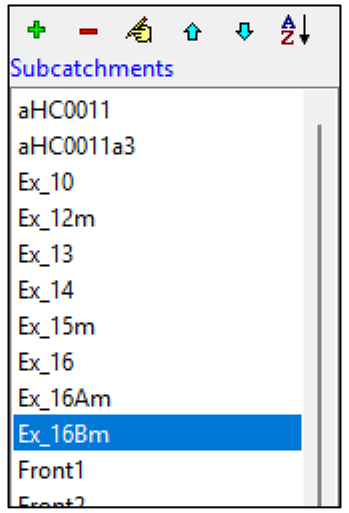
Pollutant Land Uses

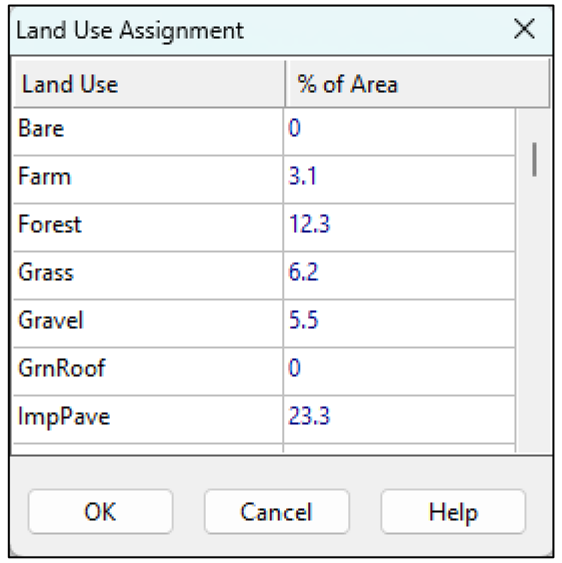
- Pollutants associated with runoff are generated by specific land uses assigned to subcatchments
  - Usually based on zoning type, but can use the same surface cover material categories that are generally used to create a Hydrology model
- Note: check your land use percentages – SWMM5 doesn't check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





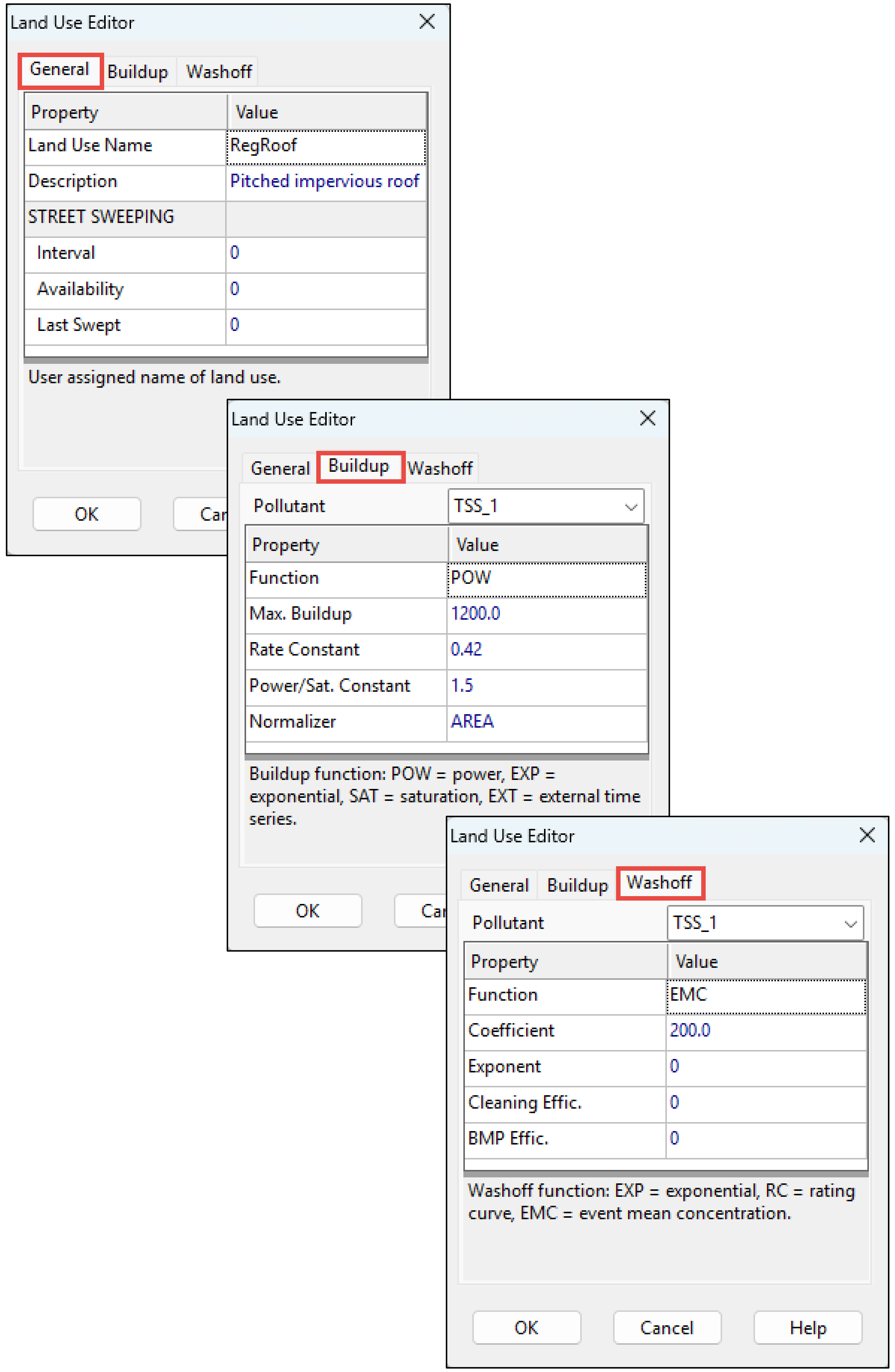






Pollutant Land Uses (continued)

- 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



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Surface Buildup and Washoff

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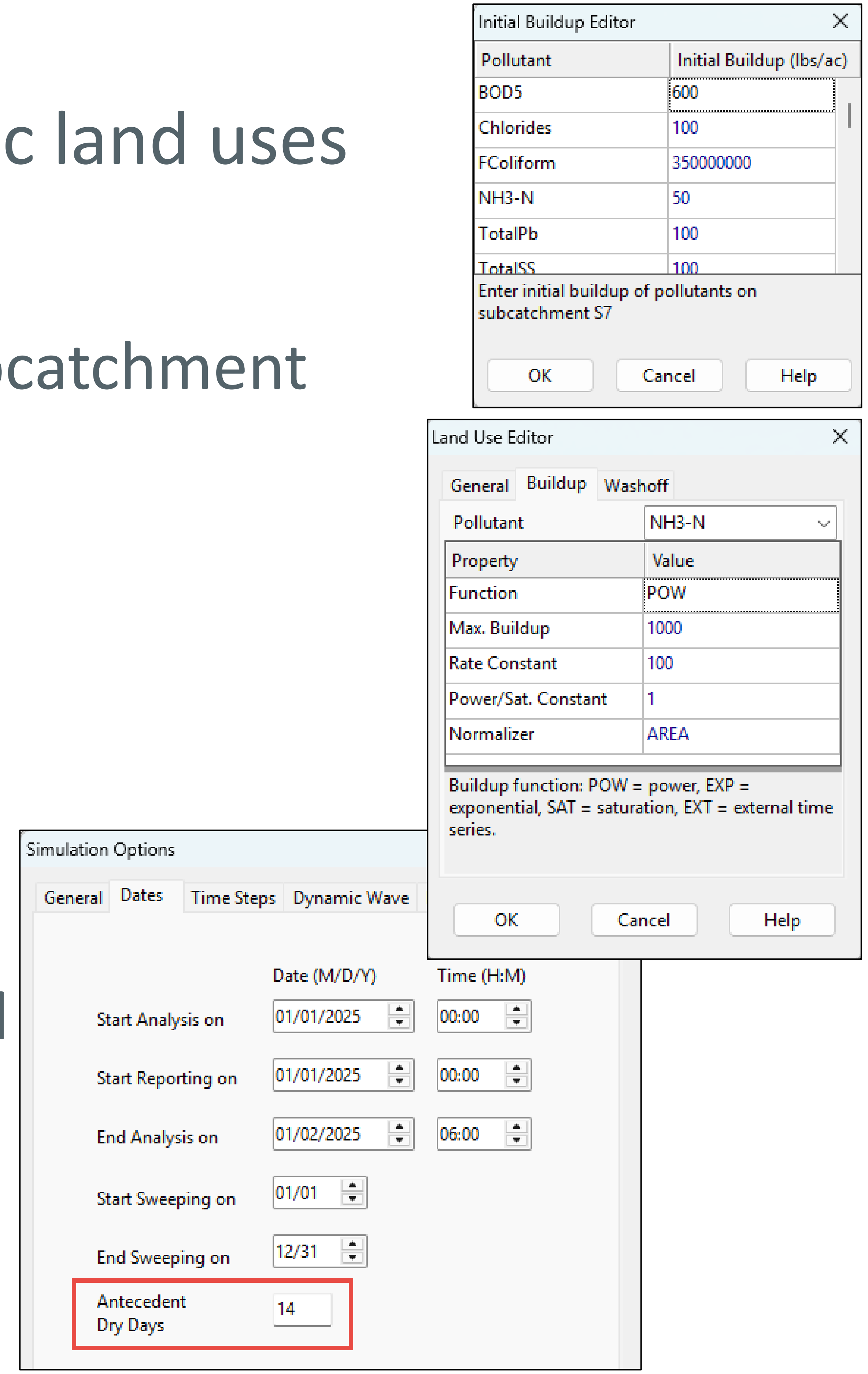
Dry Weather Buildup on Subcatchments

- 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)



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)

Runoff Quantity Continuity	Volume acre-feet	Depth inches
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	

Runoff Quality Continuity	TotalSS lbs
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

Flow Routing Continuity	Volume acre-feet	Volume 10^6 gal
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	

Quality Routing Continuity	TotalSS lbs
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	$B = Min(C_1, C_2 t^{C_3})$
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

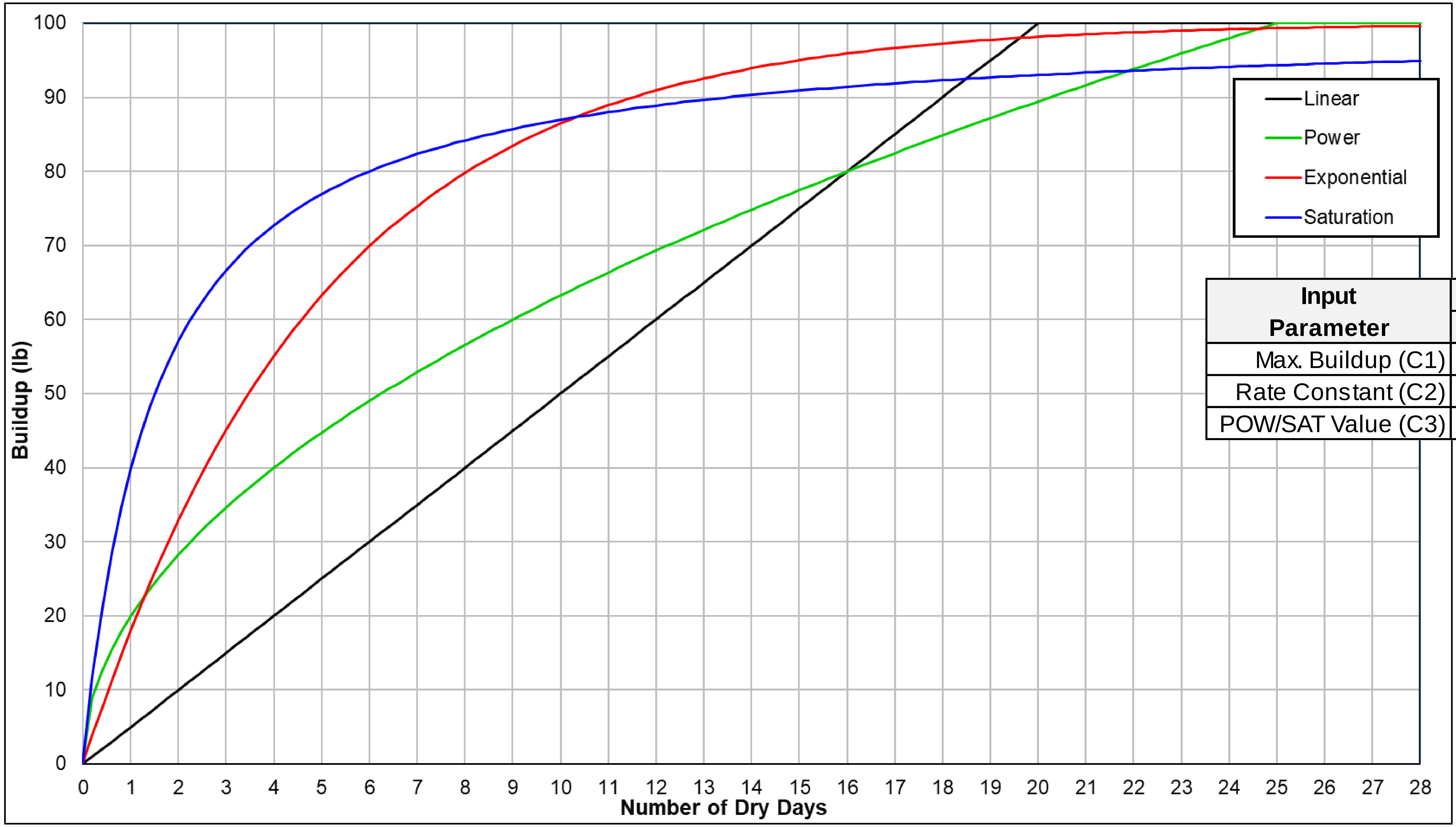
C_3(POW) = buildup time exponent

C_3(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…

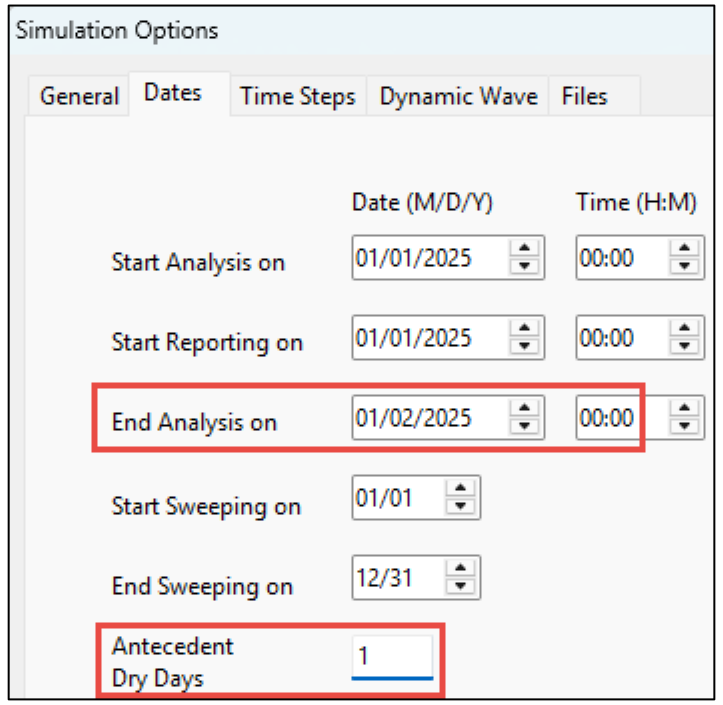


Input Parameter	Buildup Function			
	Linear	Power	Exponential	Saturation
Max. Buildup (C1)	100 lb	100 lb	100 lb	100 lb
Rate Constant (C2)	5	20	0.2 1/day	n/a
POW/SAT Value (C3)	1	0.5	n/a	1.5 days

C_1 = maximum buildup
C_2 = buildup rate constant
C_3 (POW) = buildup time exponent
C_3 (SAT) = half-saturation constant

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)



1 dry day before and
1 dry day after simulation start

Runoff Quality Continuity	TotalSS lbs
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

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

10 dry days

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

11 dry days

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

14 dry days

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

99 dry days

Runoff Quality Continuity	TotalSS lbs
Initial Buildup	100.000
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	100.000
Continuity Error (%)	0.000

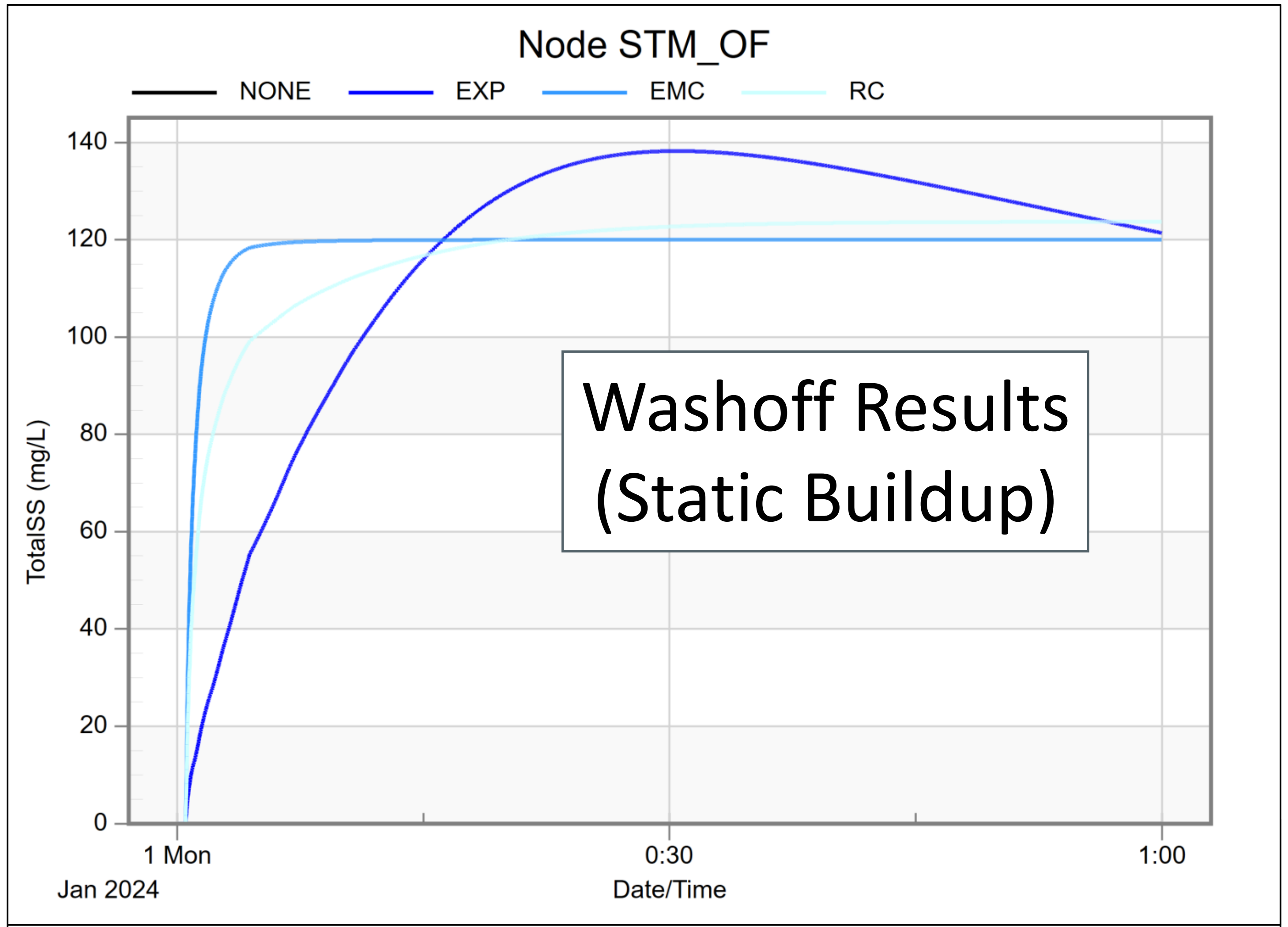
Important Note

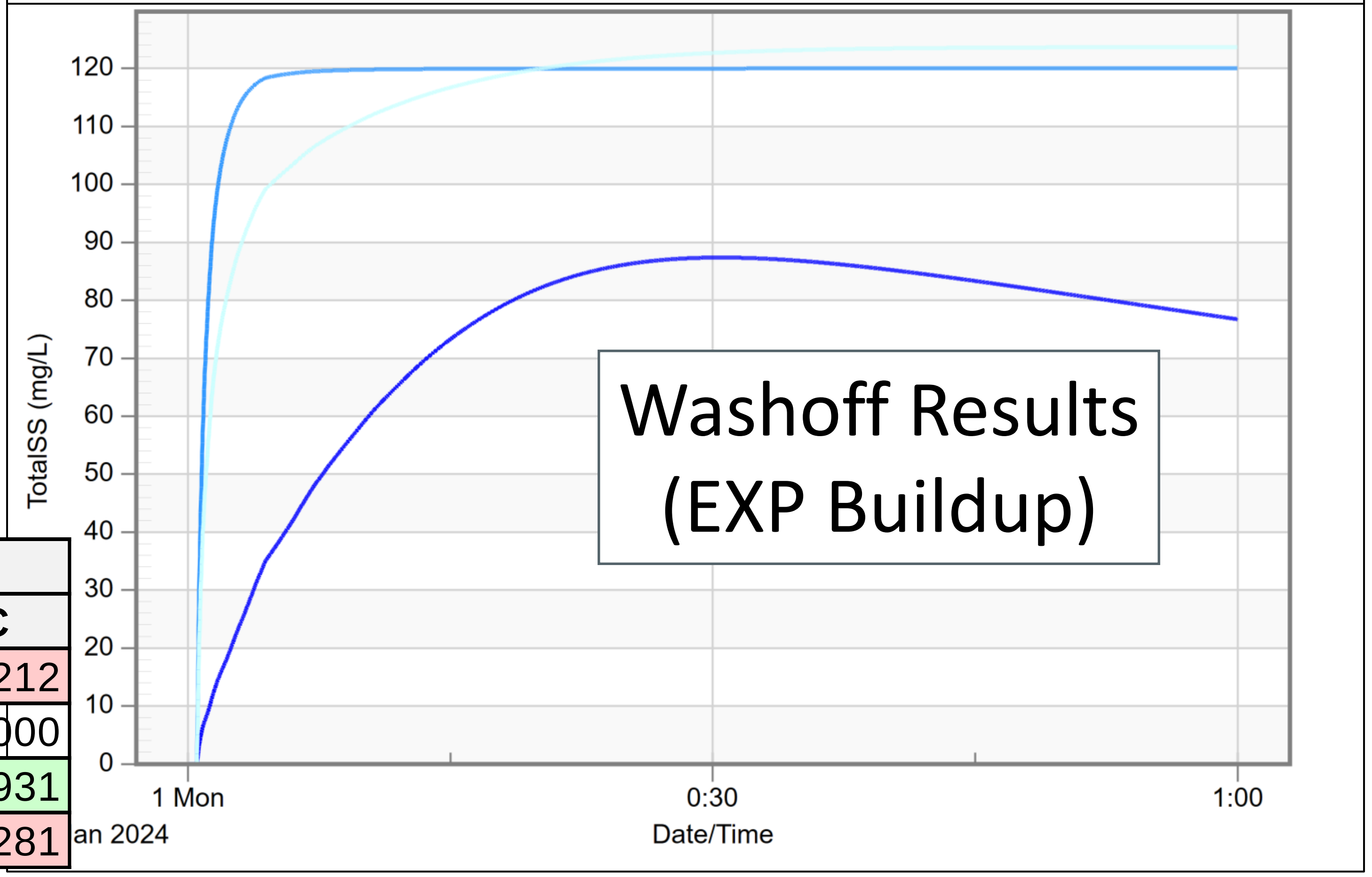
SWMM5 Washoff Functions

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

CHI

- 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

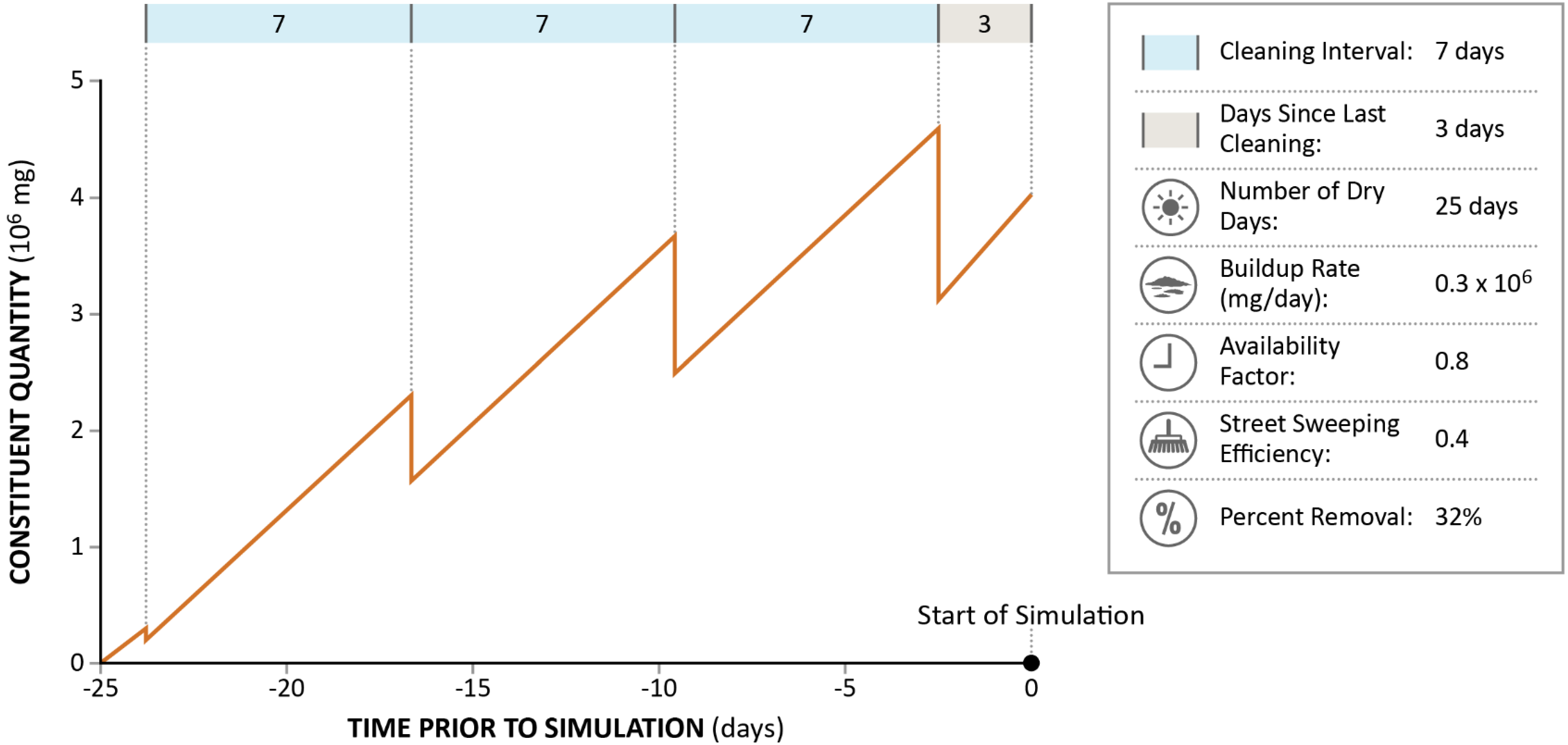
Pollutant: TotalSS

Property	Value
Function	EMC
Coefficient	120
Exponent	0.0
Cleaning Effic.	55
BMP Effic.	0.0

Street cleaning removal efficiency (percent) for the pollutant.

```
**************************        TotalSS
Runoff Quality Continuity             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…

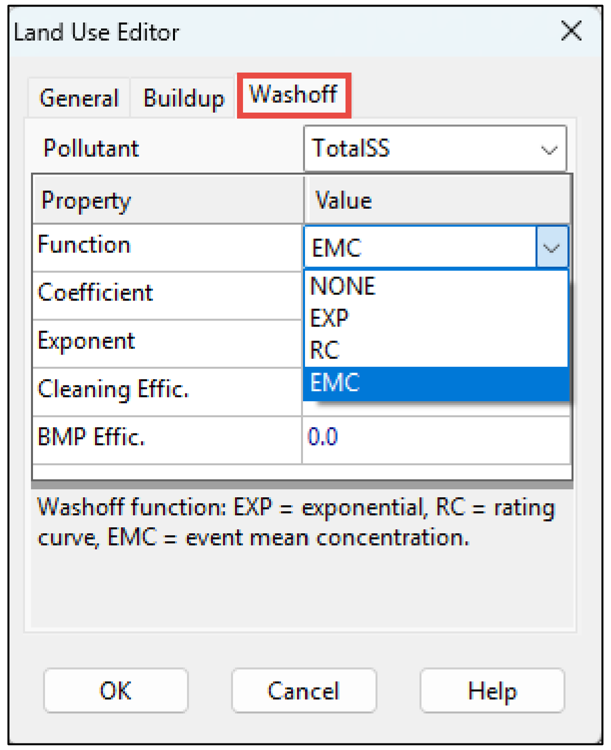
Daily Pollutant Build-Up Ranges

Land Use	BOD5[1] (lbs/Ac/Day)	SUS-SOL[2] (lbs/Ac/Day)	SET-SOL[3] (lbs/Ac/Day)	TDS[4] (lbs/Ac/Day)	NH3[5] (lbs/Ac/Day)	NO3[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

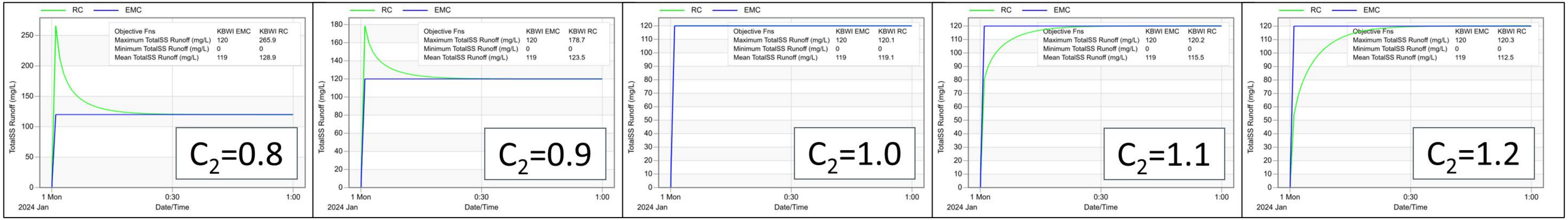
$$\boxed{W = C_1 Q}$$

- 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

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

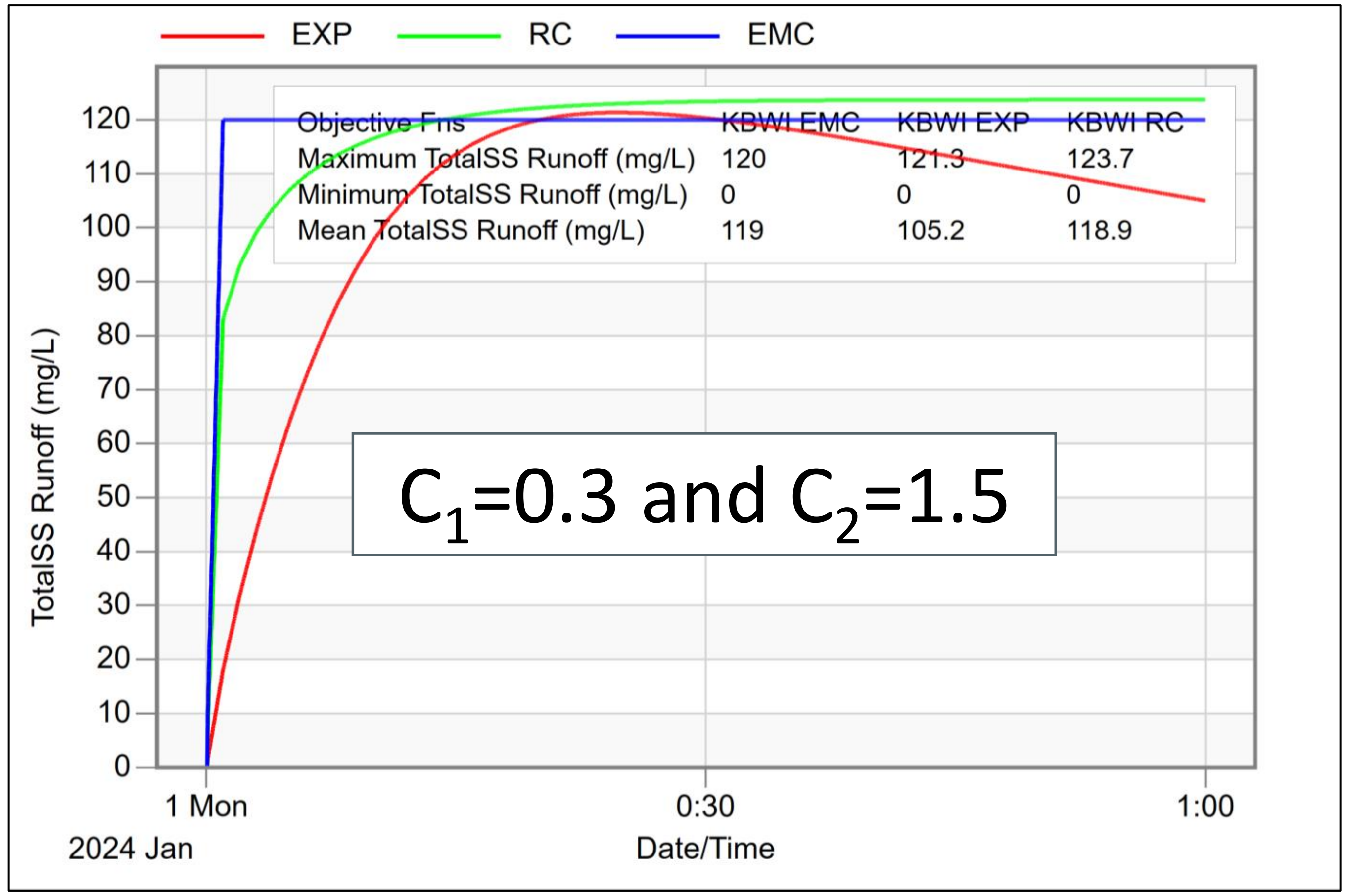
- Empirically described, but physics also suggests the mass loading rate of particulate pollutants is proportional to flow rate raised to some power
- Just like EMC washoff, RC washoff is not a function of Buildup load, but…
  - If washoff is supply-limited (i.e., Buildup load ≤ Washoff load), then washoff continues until the buildup amount is depleted
  - If unlimited supply for washoff (i.e., Buildup load ≥ 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):

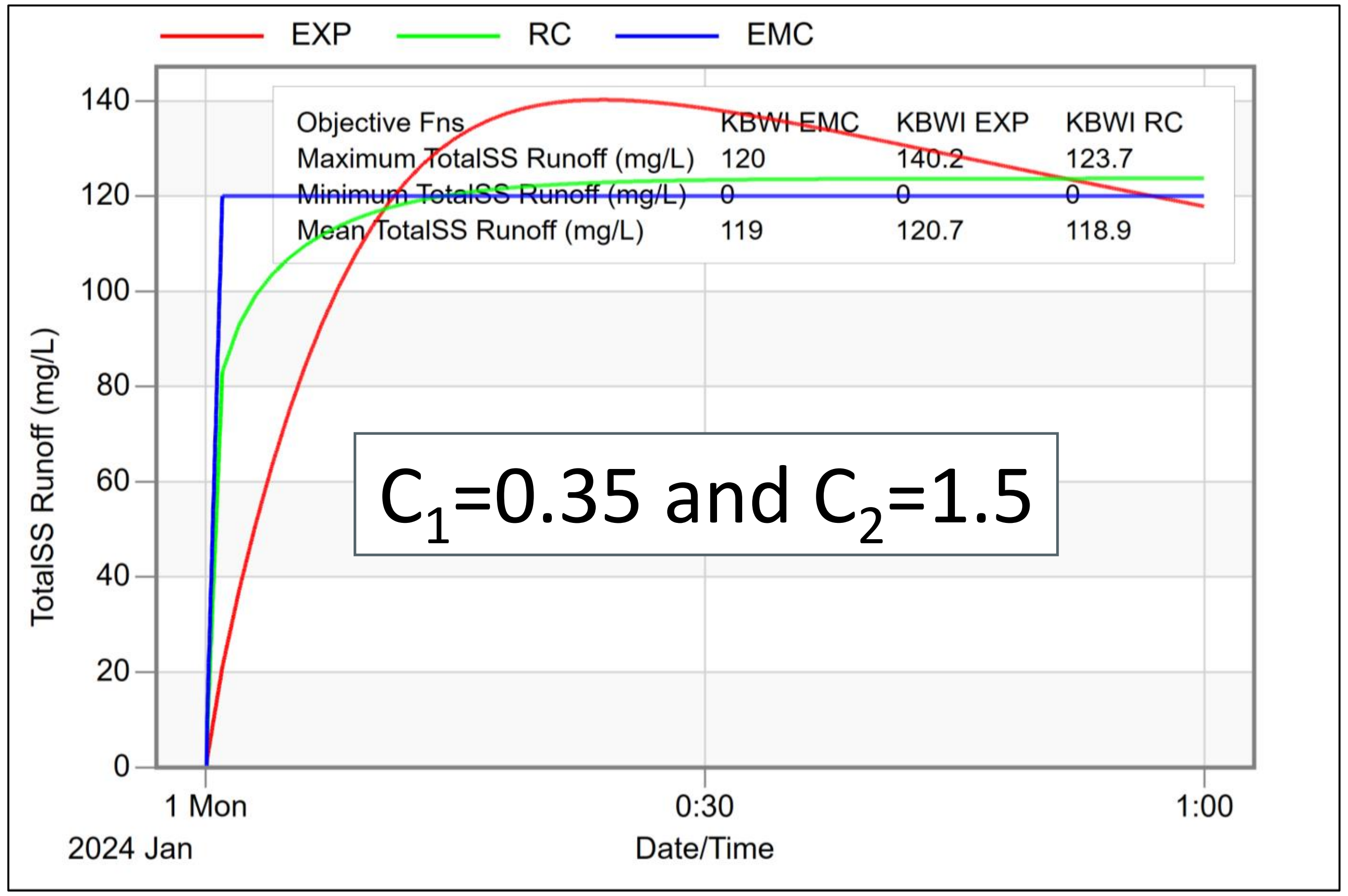


EXP Washoff

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

- 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):

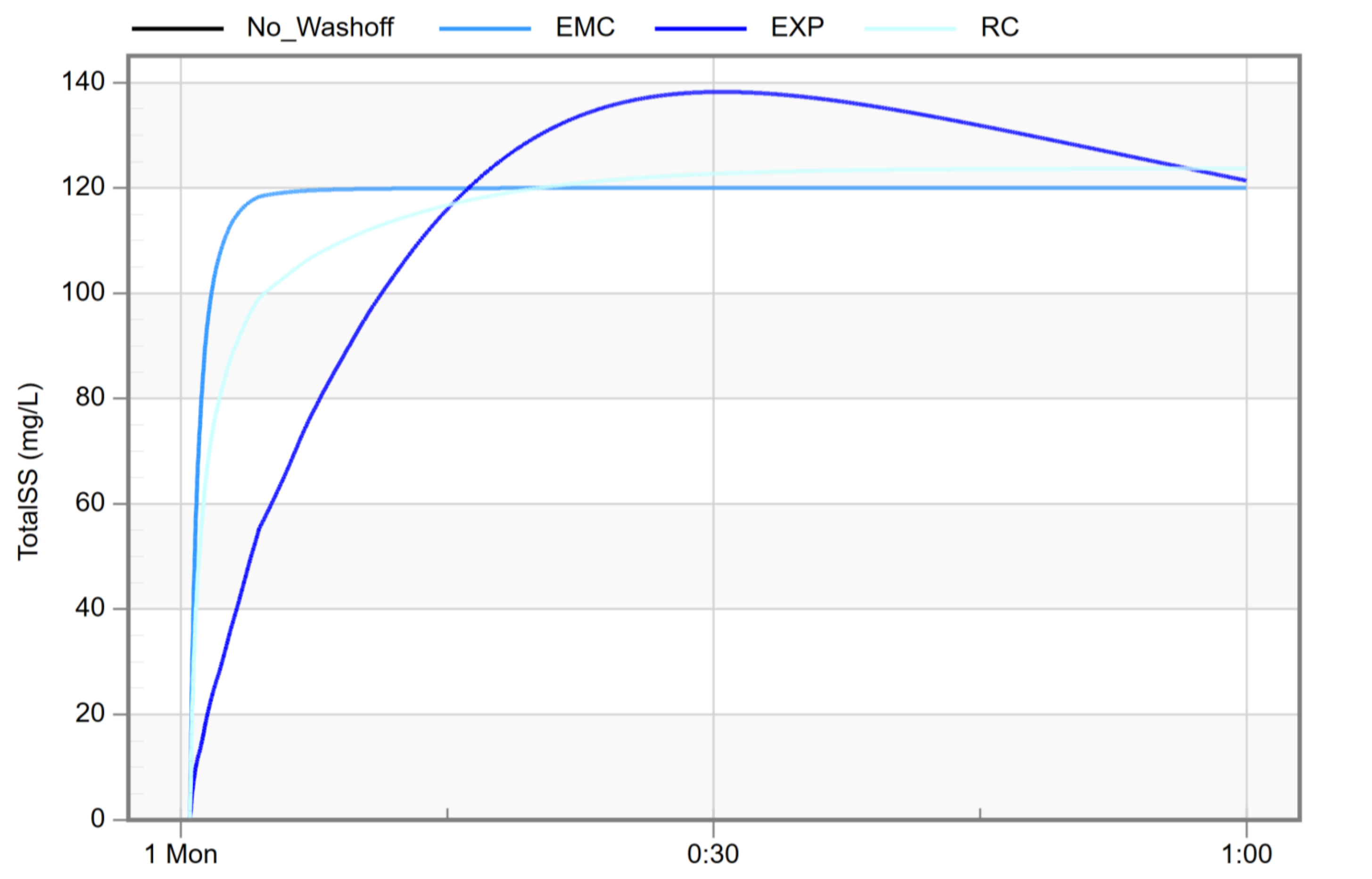




Comparison of Washoff Functions

- 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

```
[WASHOFF]
;;Land Use   Pollutant  Func C1     C2   SweepRmvl  BmpRmvl
Subcatch1    TotalSS    NONE   99   99  0          0
Subcatch2    TotalSS    EMC   120  9.9  0          0
Subcatch3    TotalSS    RC   3500  1.1  0          0
Subcatch4    TotalSS    EXP  0.35  1.5  0          0
```



NONE

General | Buildup | Washoff

Pollutant	TotalSS
Attributes	
Function	NONE
Coefficient	99
Exponent	99
Cleaning Effic.	0
BMP Effic.	0

EMC

General | Buildup | Washoff

Pollutant	TotalSS
Attributes	
Function	EMC
Coefficient	120
Exponent	9.9
Cleaning Effic.	0
BMP Effic.	0

RC

General | Buildup | Washoff

Pollutant	TotalSS
Attributes	
Function	RC
Coefficient	3500
Exponent	1.1
Cleaning Effic.	0
BMP Effic.	0

EXP

General | Buildup | Washoff

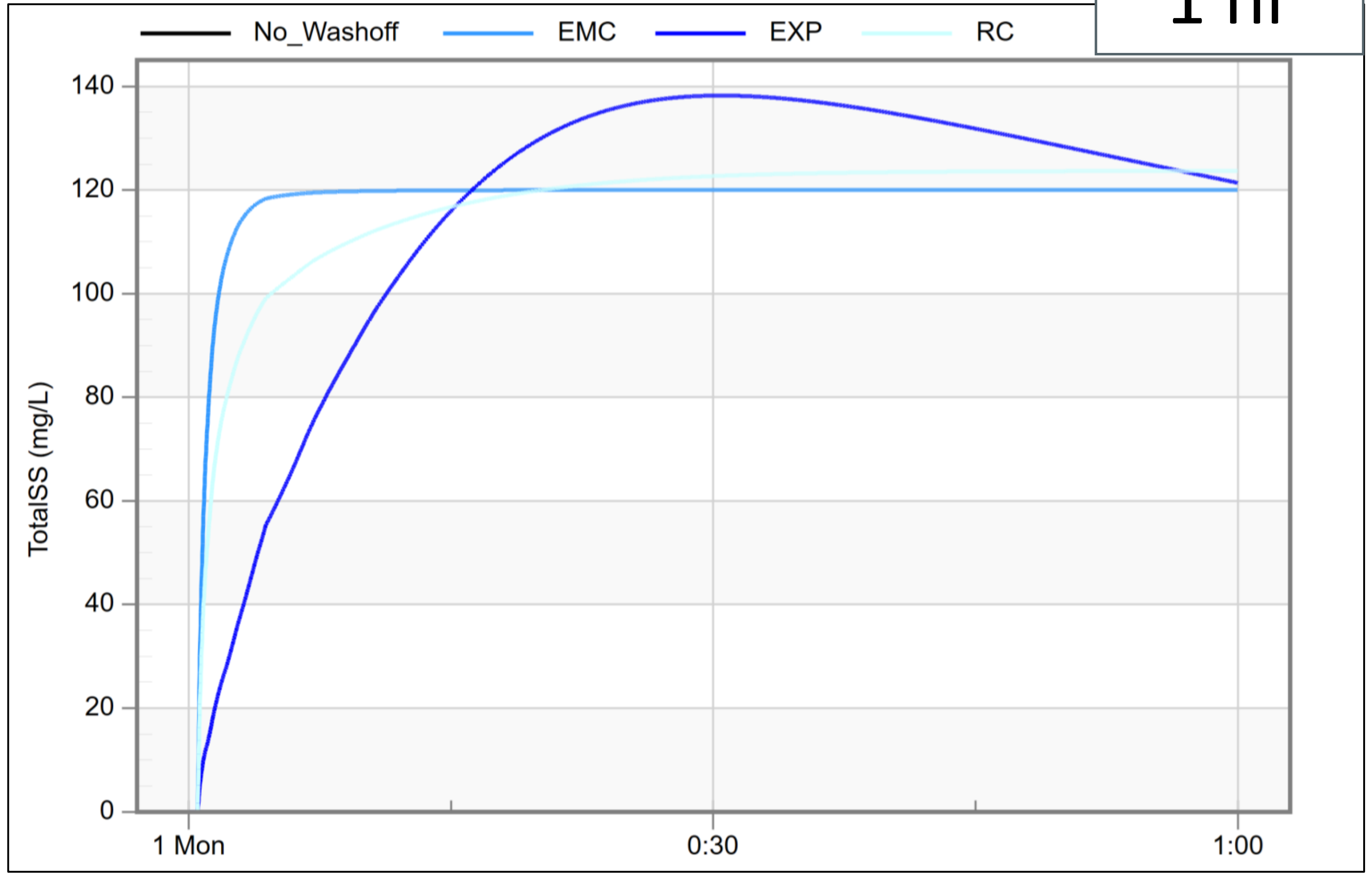
Pollutant	TotalSS
Attributes	
Function	EXP
Coefficient	0.35
Exponent	1.5
Cleaning Effic.	0
BMP Effic.	0

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)

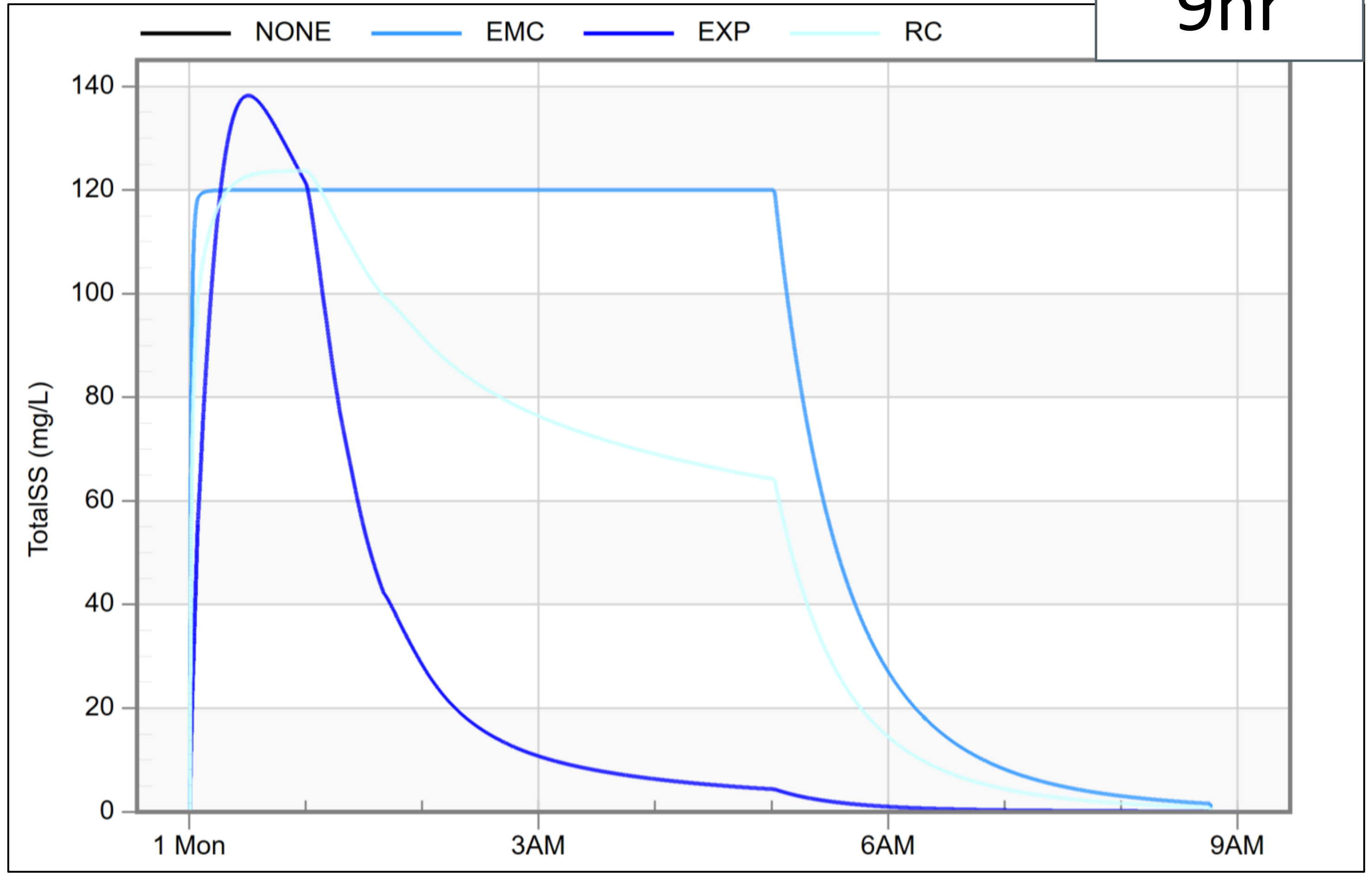
- 1hr vs 9hr simulation (runoff ends at 5am)

1 hr



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

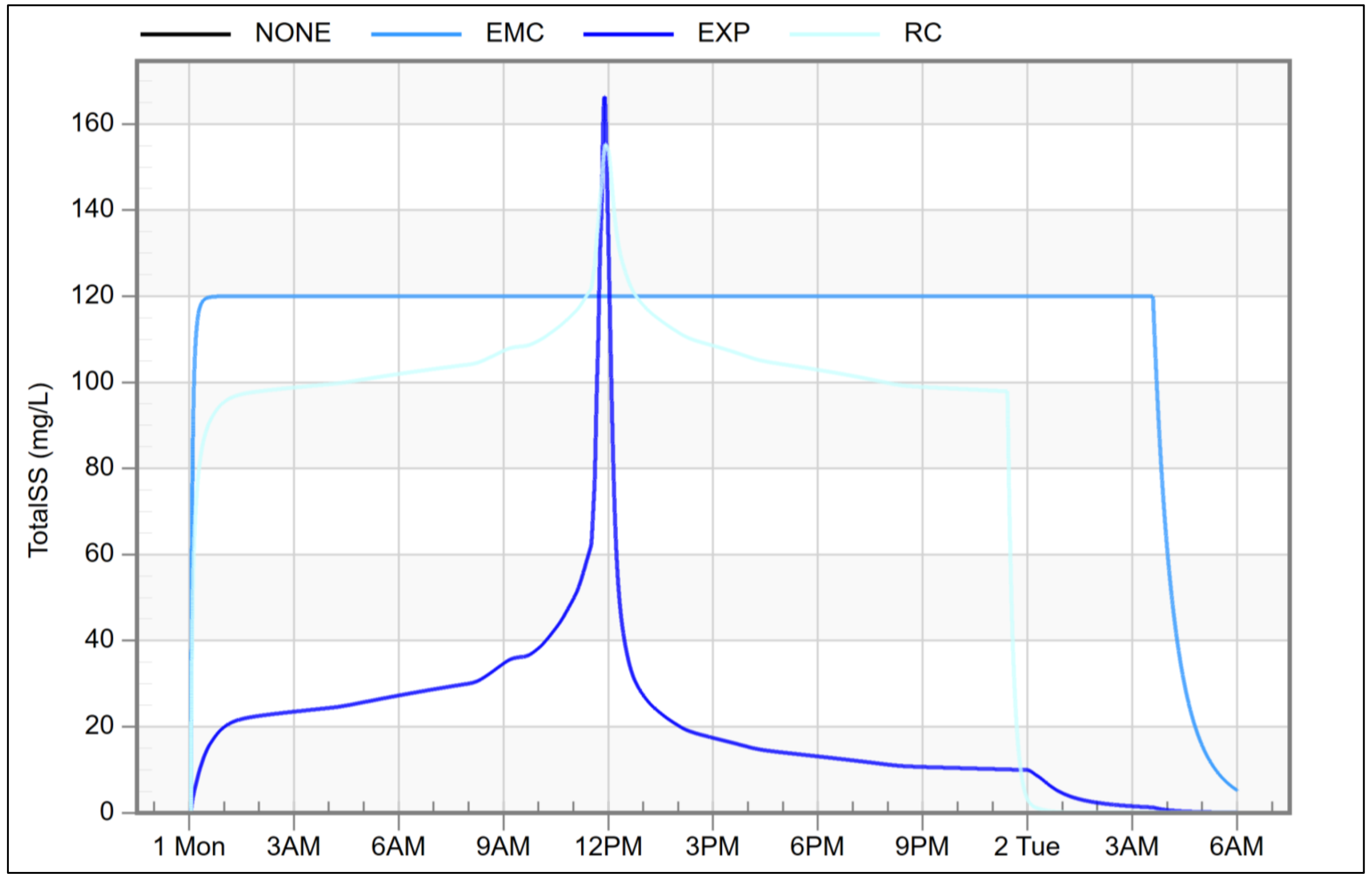
9hr

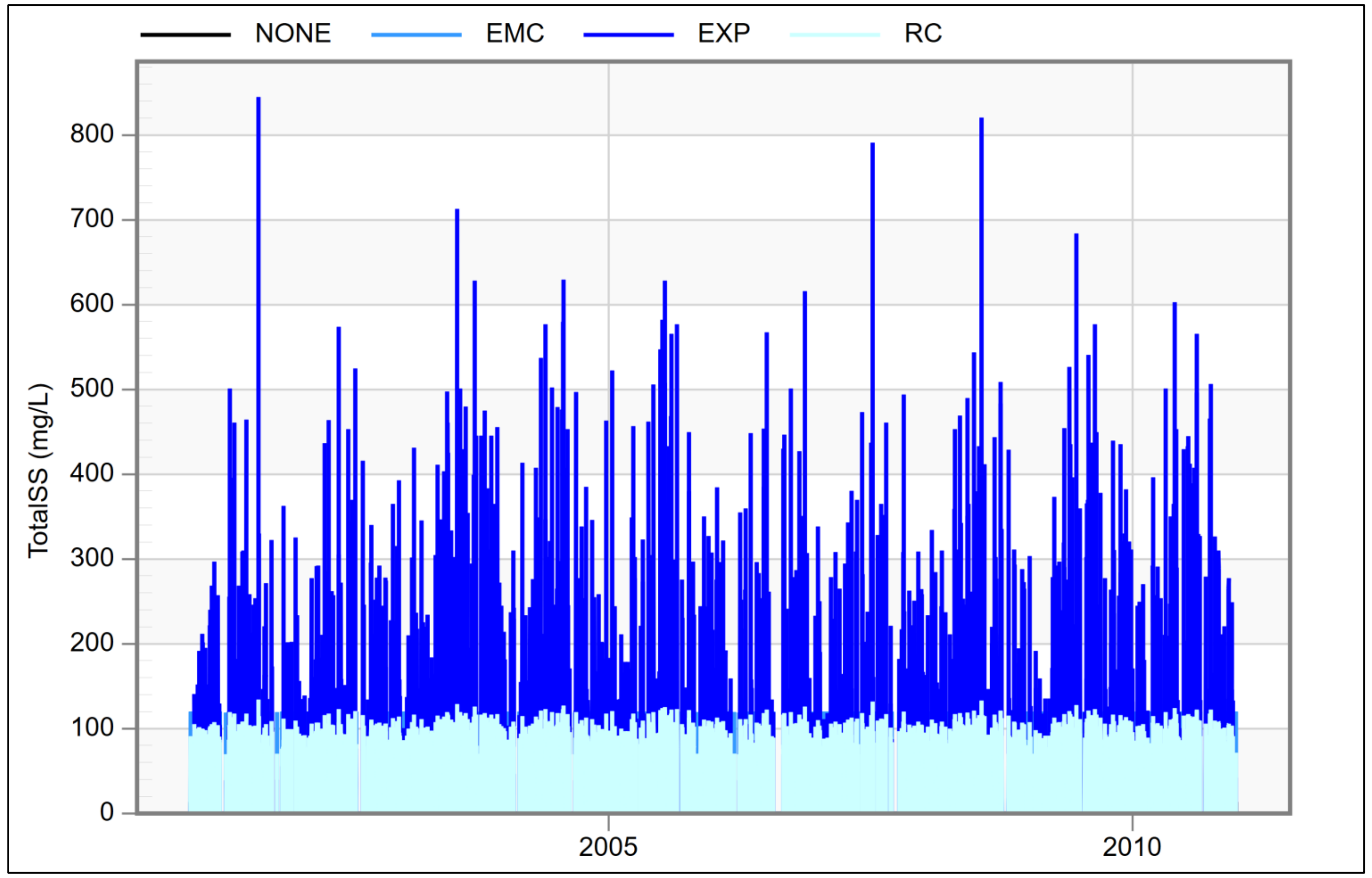


Runoff Quality Continuity	TotalSS (lb)			
	NONE	EMC	EXP	RC
Initial Buildup	100.000	100.000	100.000	100.000
Surface Buildup	0.000	0.000	0.000	0.000
Wet Deposition	0.000	0.000	0.000	0.000
Sweeping Removal	0.000	0.000	0.000	0.000
Infiltration Loss	0.000	0.000	0.000	0.000
BMP Removal	0.000	0.000	0.000	0.000
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



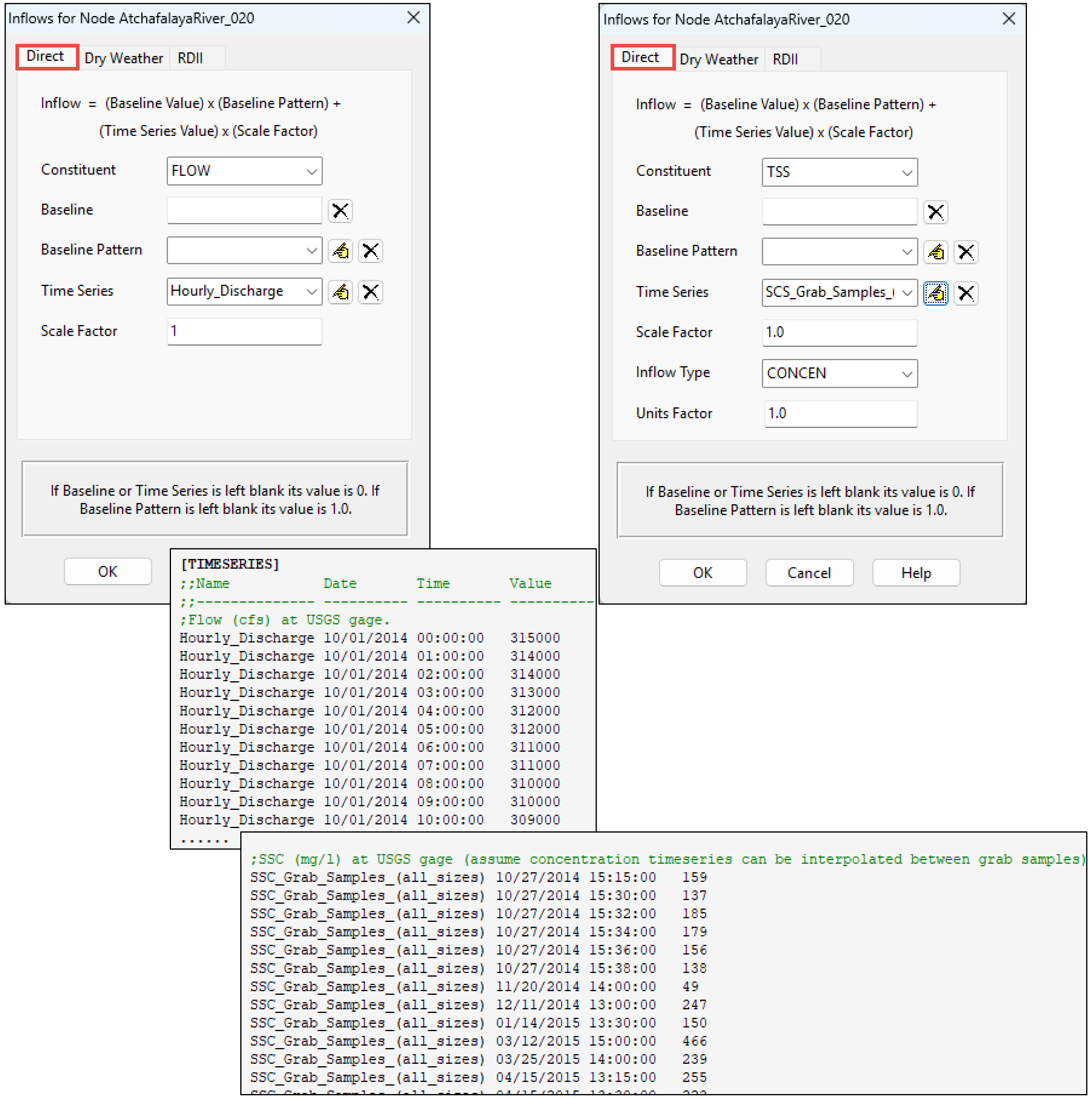


Runoff Quality Continuity	TotalSS (lb)			
	NONE	EMC	EXP	RC
Initial Buildup	235.000	235.000	235.000	235.000
Surface Buildup	4.798	4.798	4.798	4.798
Wet Deposition	0.000	0.000	0.000	0.000
Sweeping Removal	0.000	0.000	0.000	0.000
Infiltration Loss	0.000	0.000	0.000	0.000
BMP Removal	0.000	0.000	0.000	0.000
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



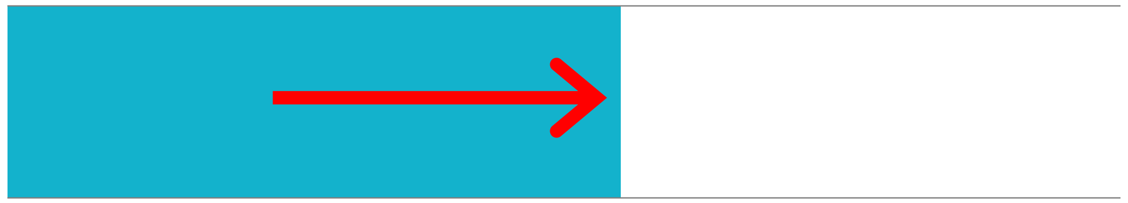
Stormwater
Modeling Committee
ASCE | EWRI

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

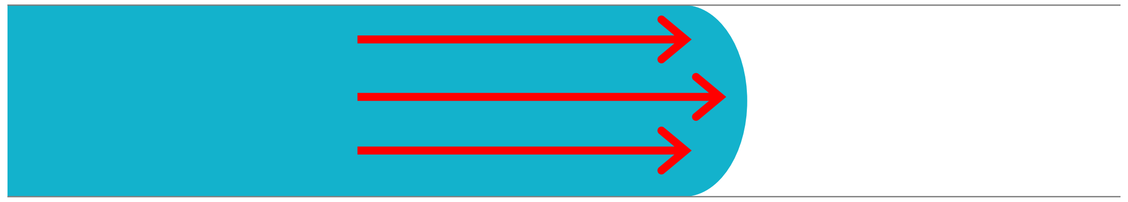
Routing and Treatment

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.

$$\frac{\partial c}{\partial t} = -\overset{\text{advection term}}{\overset{\downarrow}{\frac{\partial (uc)}{\partial x}}} + \overset{\text{dispersion tern}}{\overset{\downarrow}{\frac{\partial}{\partial x}\left(D\frac{\partial c}{\partial x}\right)}} + \overset{\substack{\text{reaction}\\\text{rate term}}}{\overset{\downarrow}{r(c)}}$$

Where:

c = constituent concentration [M/L^3]
u = longitudinal velocity [L/T]
D = longitudinal dispersion coefficient [L^2/T]
x = longitudinal distance [L]
t = time [T]
r(c) = reaction rate [M/L^{3}T]

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

Order of calculation

Hydraulic routing

↓

Node concentration

↓

Node treatment

↓

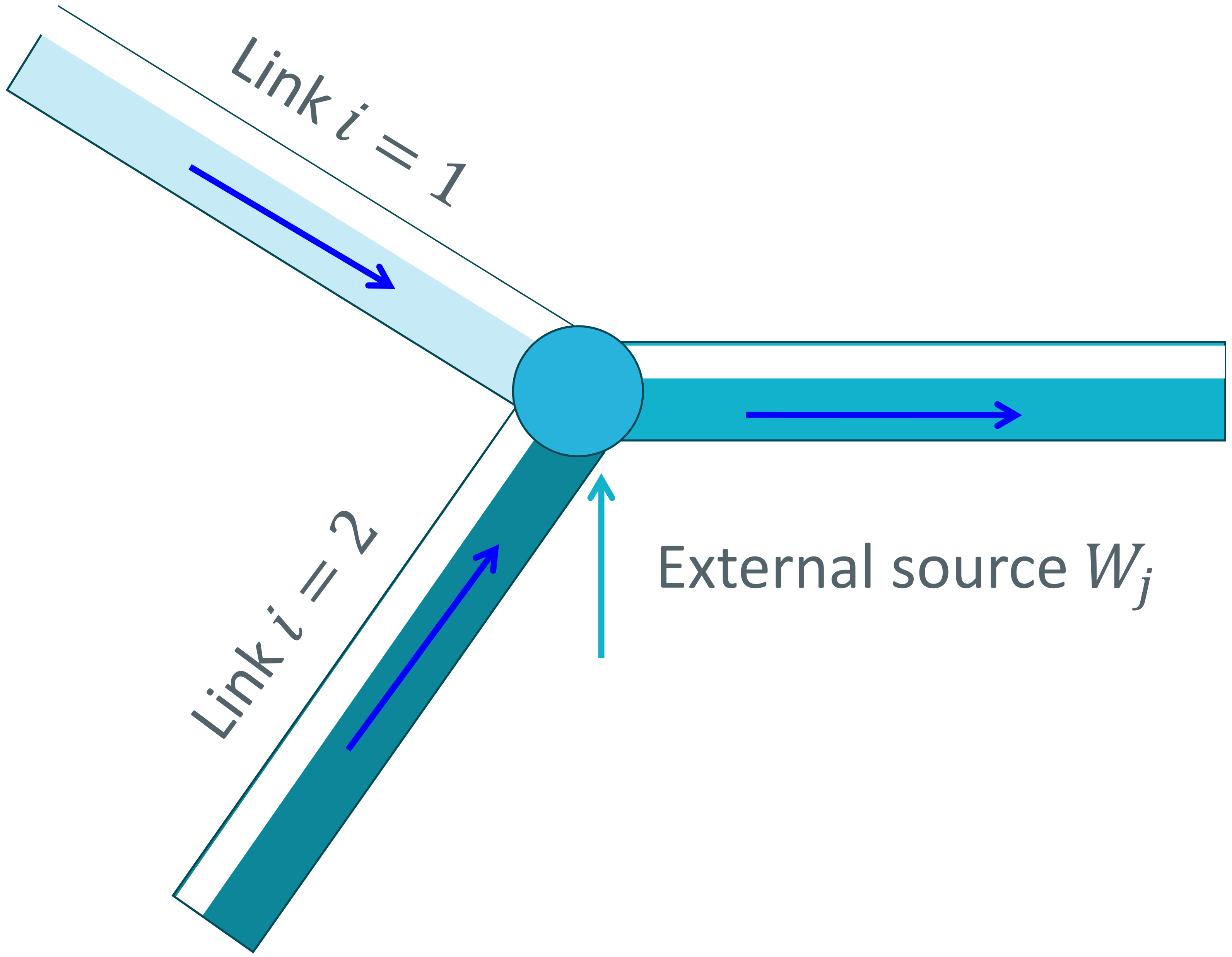
Link concentration

Instantaneous Complete Mixing at Junctions

- Non-storage nodes have no volume

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

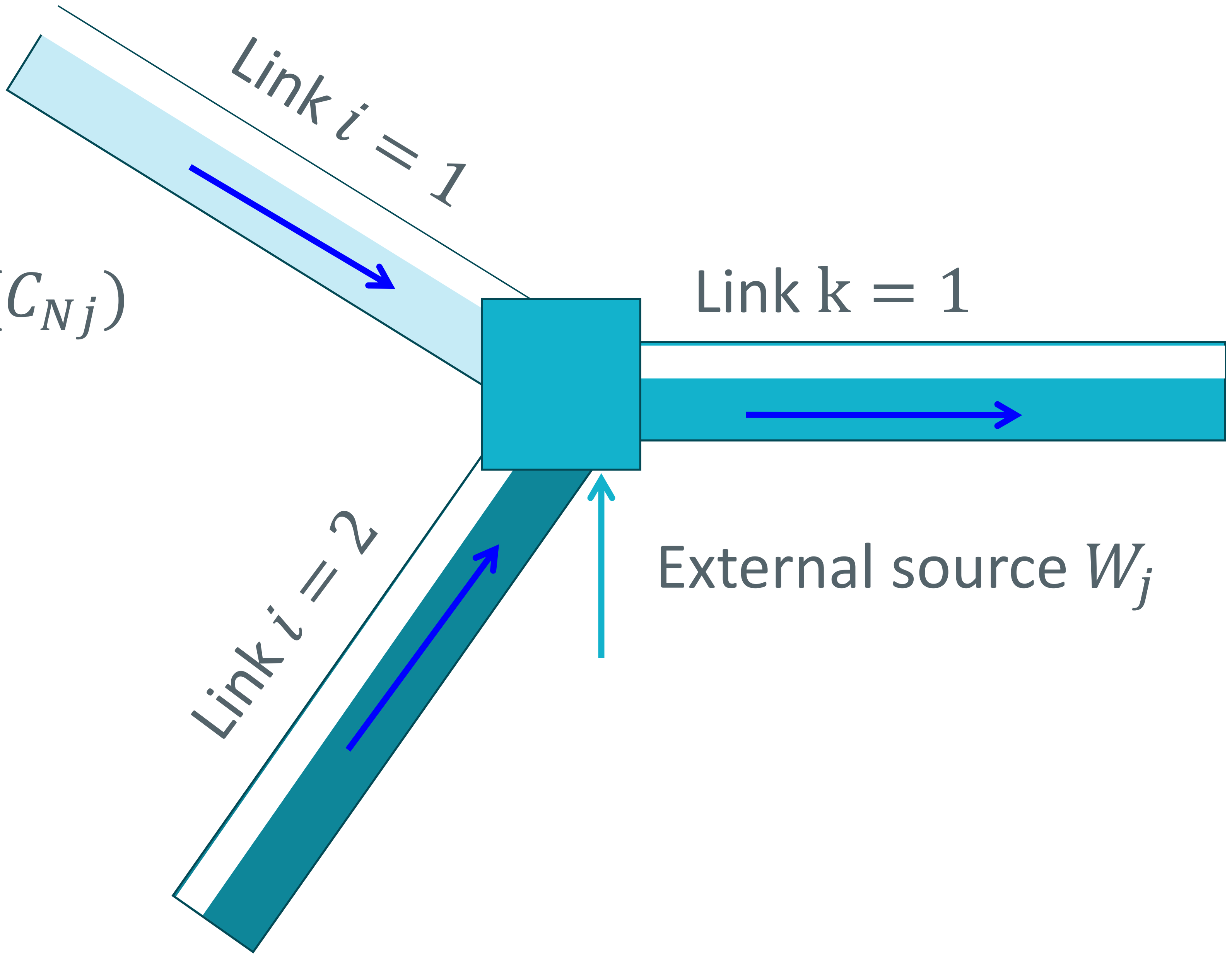
- Where:
  - C_{Nj} = concentration at node j
  - C_{L2i} = concentration at the end of link i
  - q_{2i} = flow rate at the end of link i
  - W_j = mass flow rate of the external source of constituent
  - Q_j = flow rate of the external source



Complete Mixing in Storage Junctions

- Storage units have volume property

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



- 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

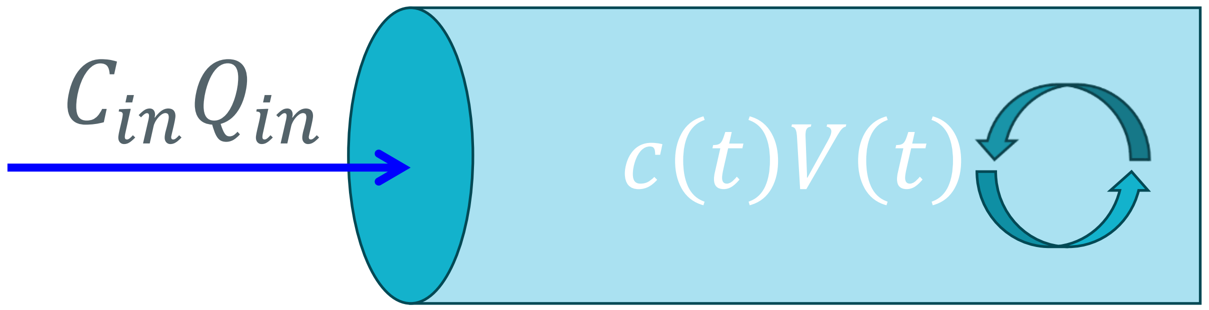
$$\frac{d(Vc)}{dt} = C_{in}Q_{in} - cQ_{out} - VK_1c$$

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

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

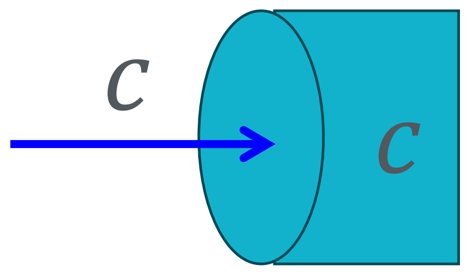


Where:

- $c(t+\Delta t)$ = 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

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

Where:

c = nodal pollutant concentration after treatment is applied
C_{in} = pollutant concentration in the node's inflow stream
$c(\ldots)$ = concentration-based treatment function
$r(\ldots)$ = removal-based treatment function
$\boldsymbol{C}$ = vector of nodal pollutant concentrations before treatment is applied
$\boldsymbol{R}$ = vector of fractional removals resulting from treatment
$\boldsymbol{H}$ = 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 = value or expression`) or as a fractional removal (`R = 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 `FLOW / AREA`)

Treatment Expressions

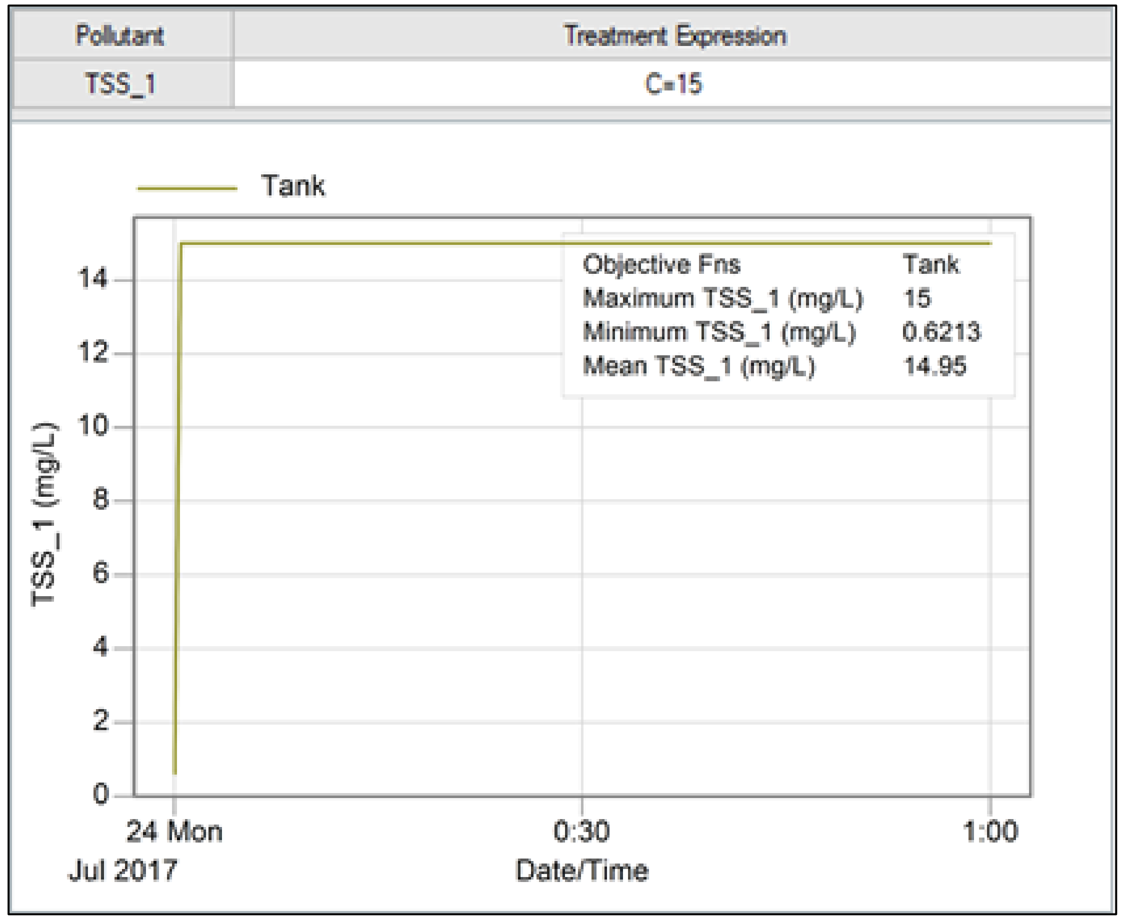
- A treatment expression can use
  - Variables
  - Functions
  - Numbers
  - Standard operators +,-,*,/,^
  - Pollutant names
  - Any level of nested parentheses
- Names of variables and functions are case-insensitive

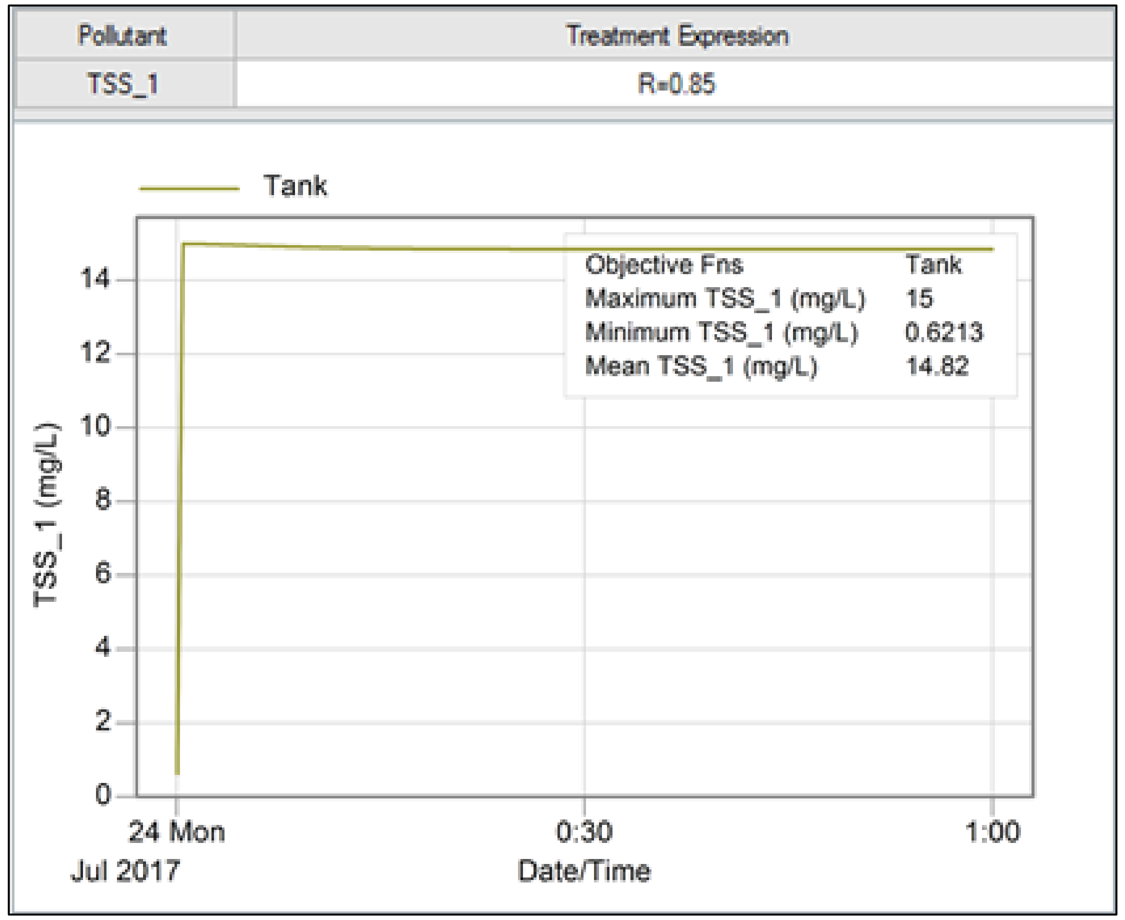
Variable	Description
FLOW	Flow rate into the node in user defined flow units
DEPTH	Average water depth in the node over the time step (ft or m)
AREA	Average surface area of the node over the time step (ft2 or m2)
DT	Current routing time step (seconds)
HRT	Hydraulic residence time of water in a storage 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

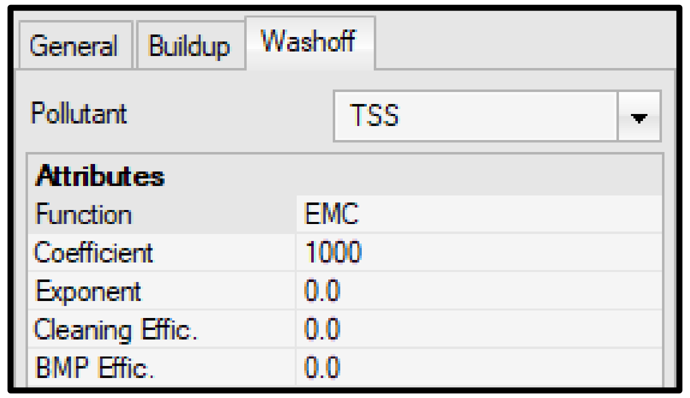
- Simple EMC/Constant removal (e.g., inflow = 100 mg/L and desired outflow = 15 mg/L): `C = 15` or `R = 0.85` (see examples below)
- Correlated removal, where pollutant treatment is proportional to the removal of another pollutant (e.g., if 50% of TSS1 removal): `R = 0.5 * R_TSS1`

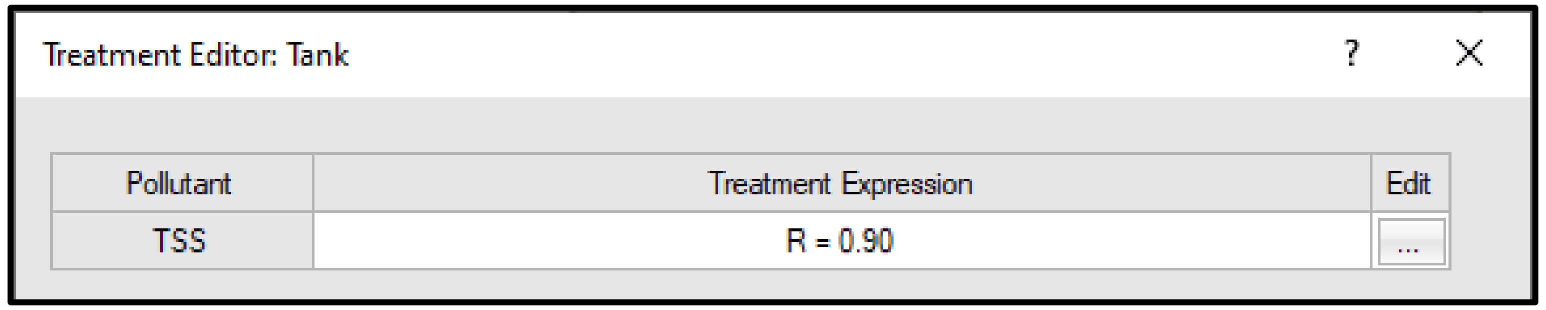




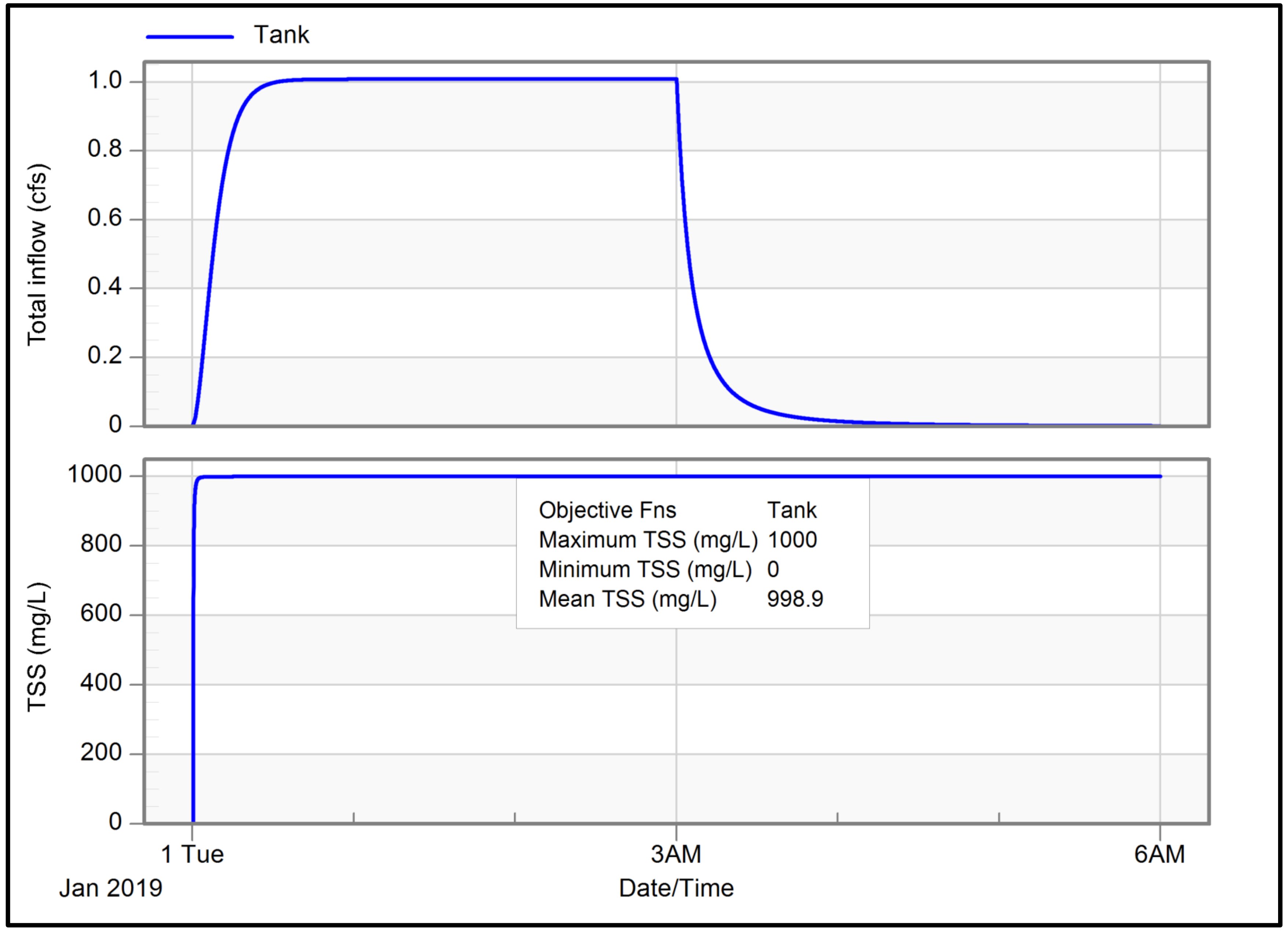
Example – No Treatment vs Fixed Removal

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

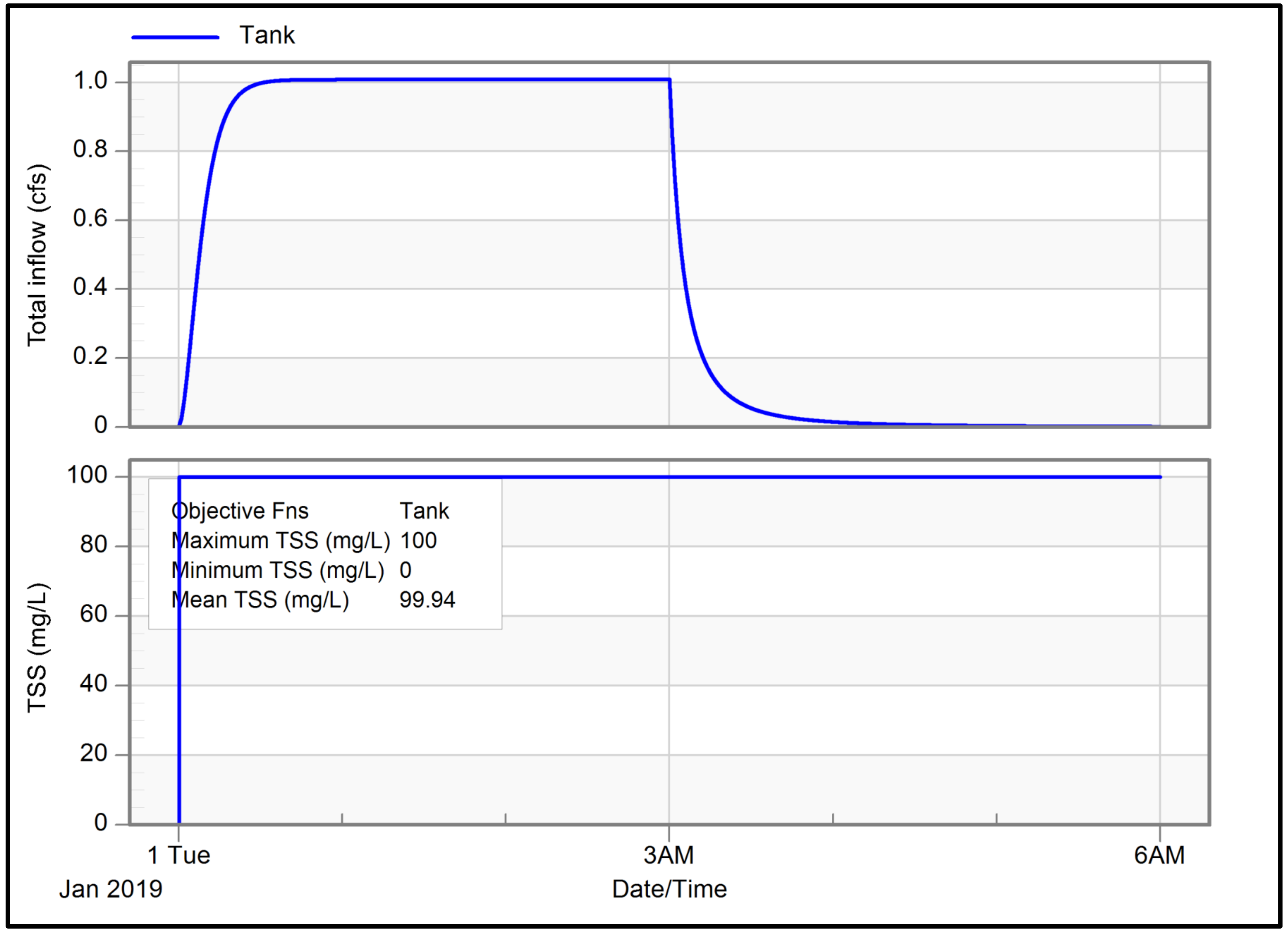




$C_{In} = 1000$ mg/L
$C_{Out} = 1000$ mg/L



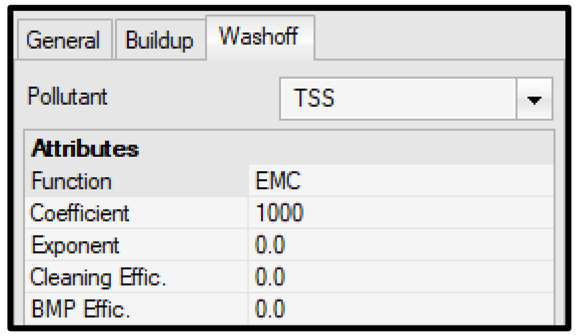
$C_{In} = 1000$ mg/L
$C_{Out} = C_{In} \times (1\text{-}R) = 100$ mg/L

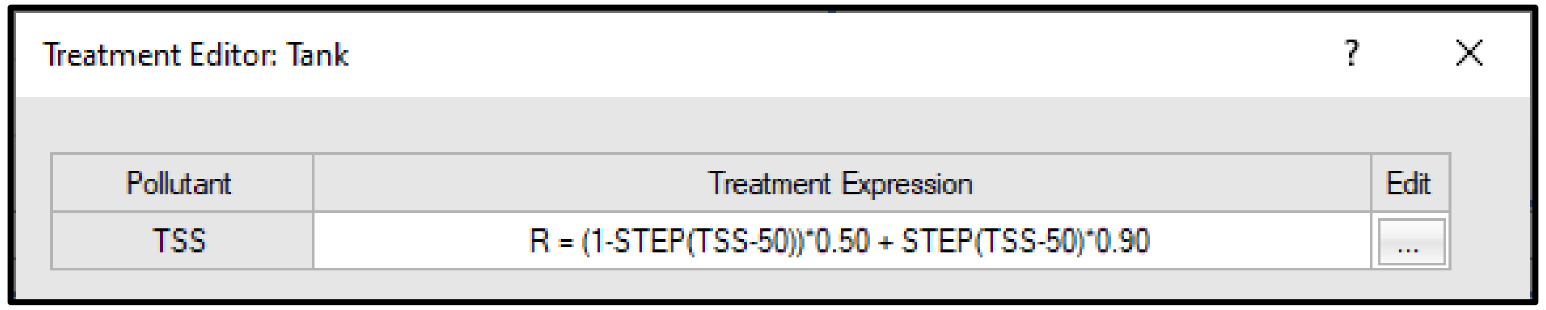


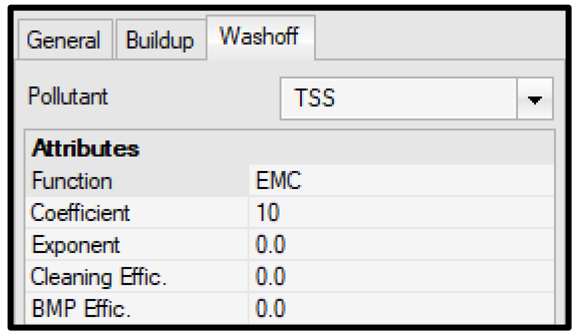
Detailed Treatment Expressions

- 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-STEP(TSS-50))*0.50 + STEP(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 (1^{st} order)
  - N^{th} order reaction kinetics
  - Particulate settling by gravity

Example – Step Function Removal





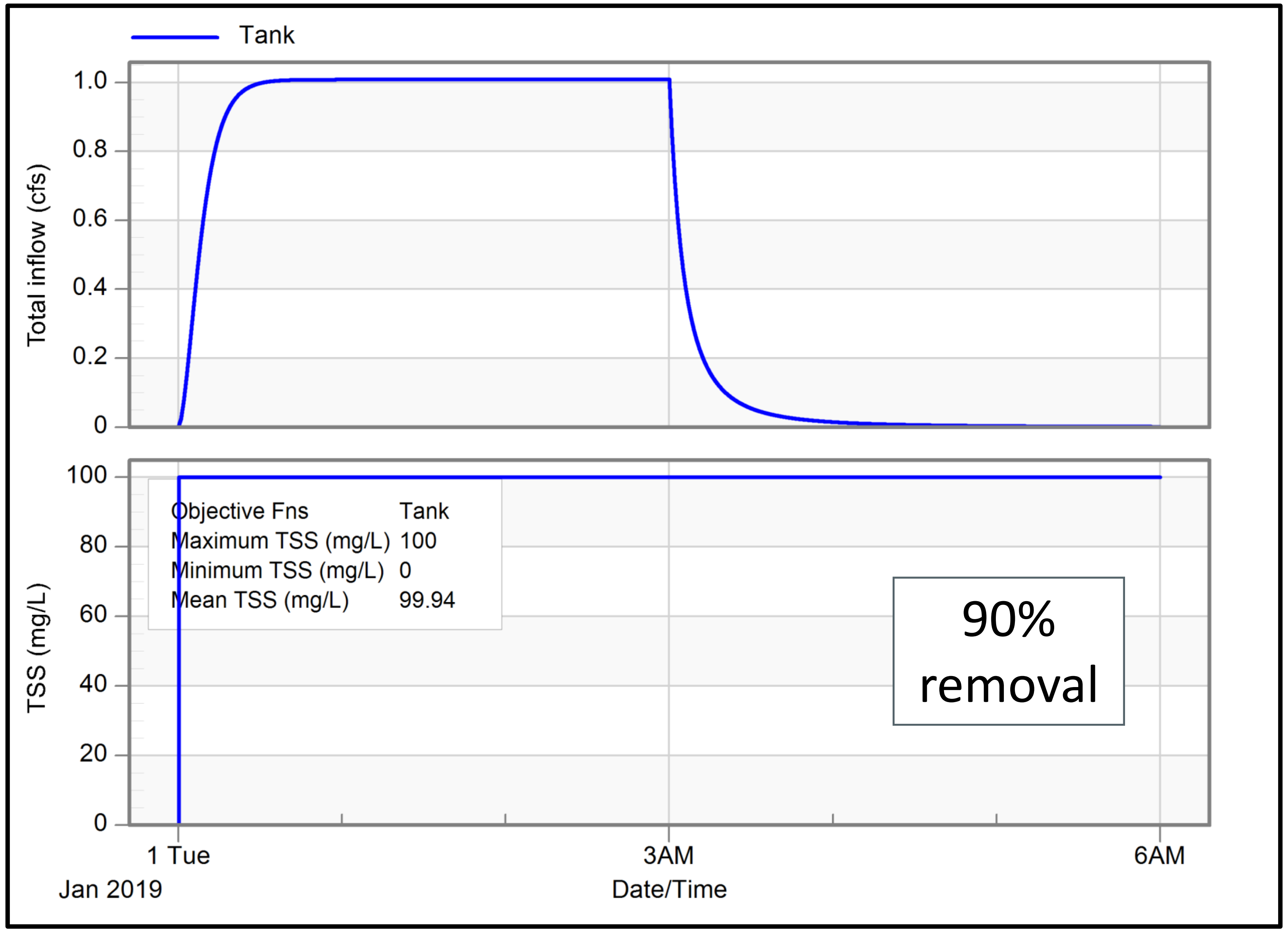


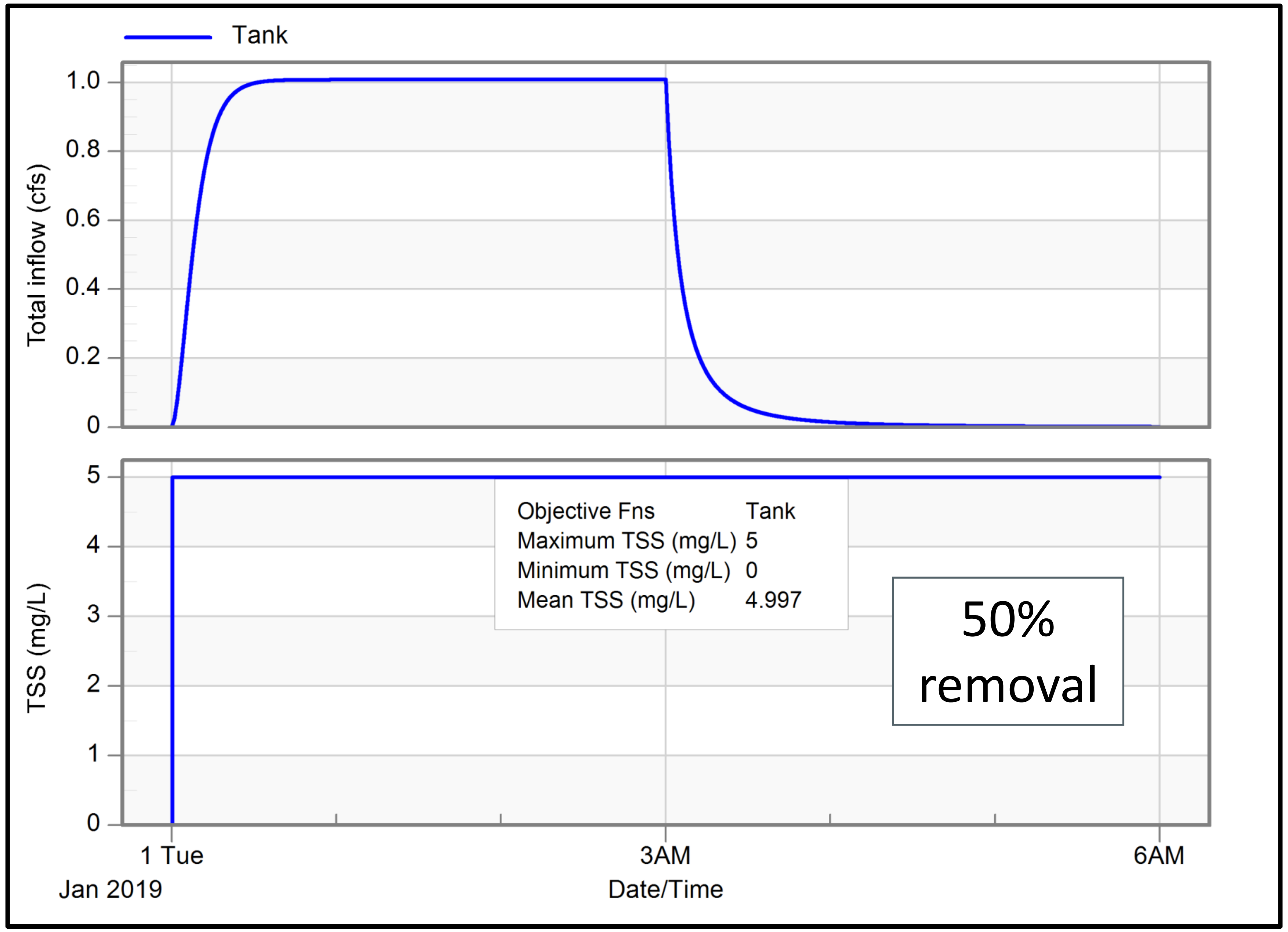
C_{In} = 1000 mg/L

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

C_{In} = 10 mg/L

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

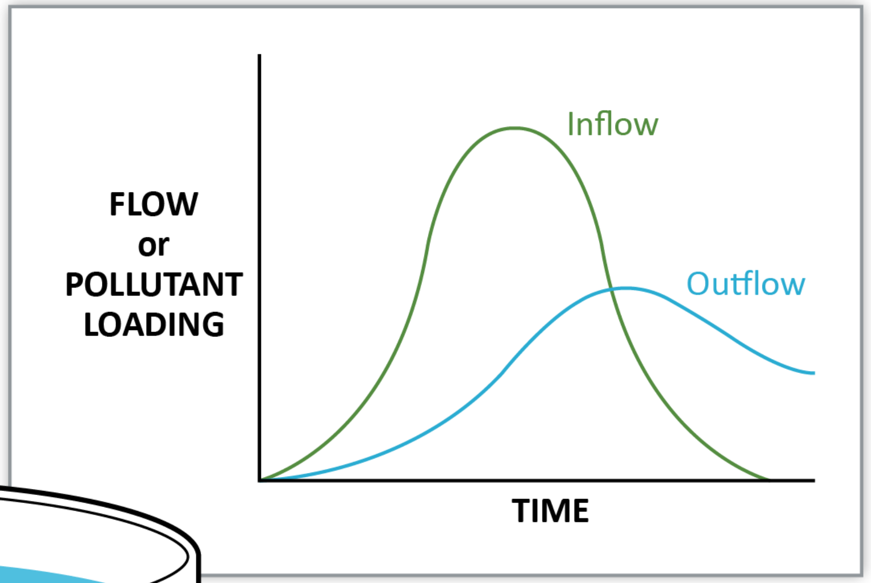


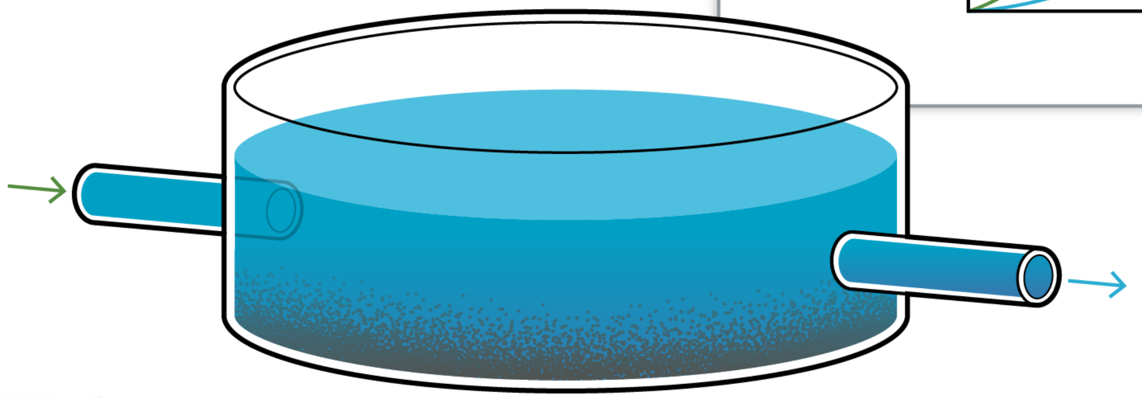


SWMM Sediment Modeling

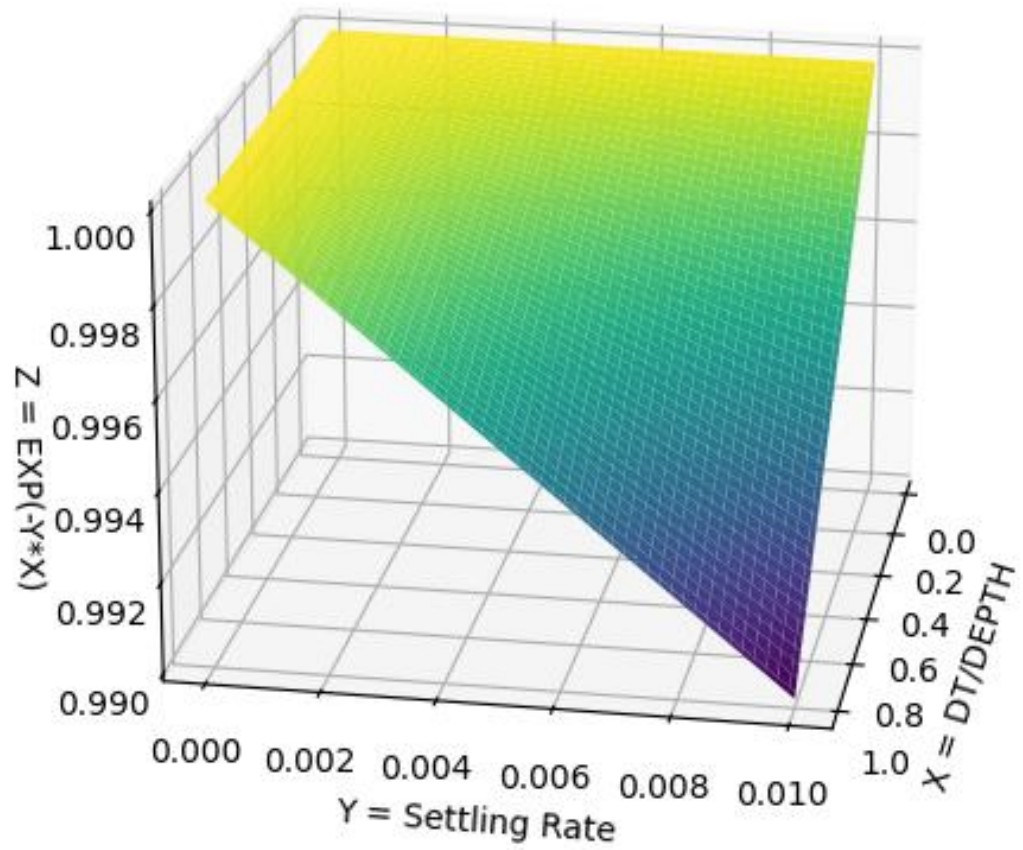
Settling Ponds – Gravity Settling

- 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 (m/s)	Average Velocity (ft/hr)	Equiv. Size µm
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%
Enhanced 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
Normal 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
Basic 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

Quality Routing Continuity	TSS_1 kg	TSS_2 kg	TSS_3 kg	TSS_4 kg	TSS_5 kg	TSS_6 kg
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

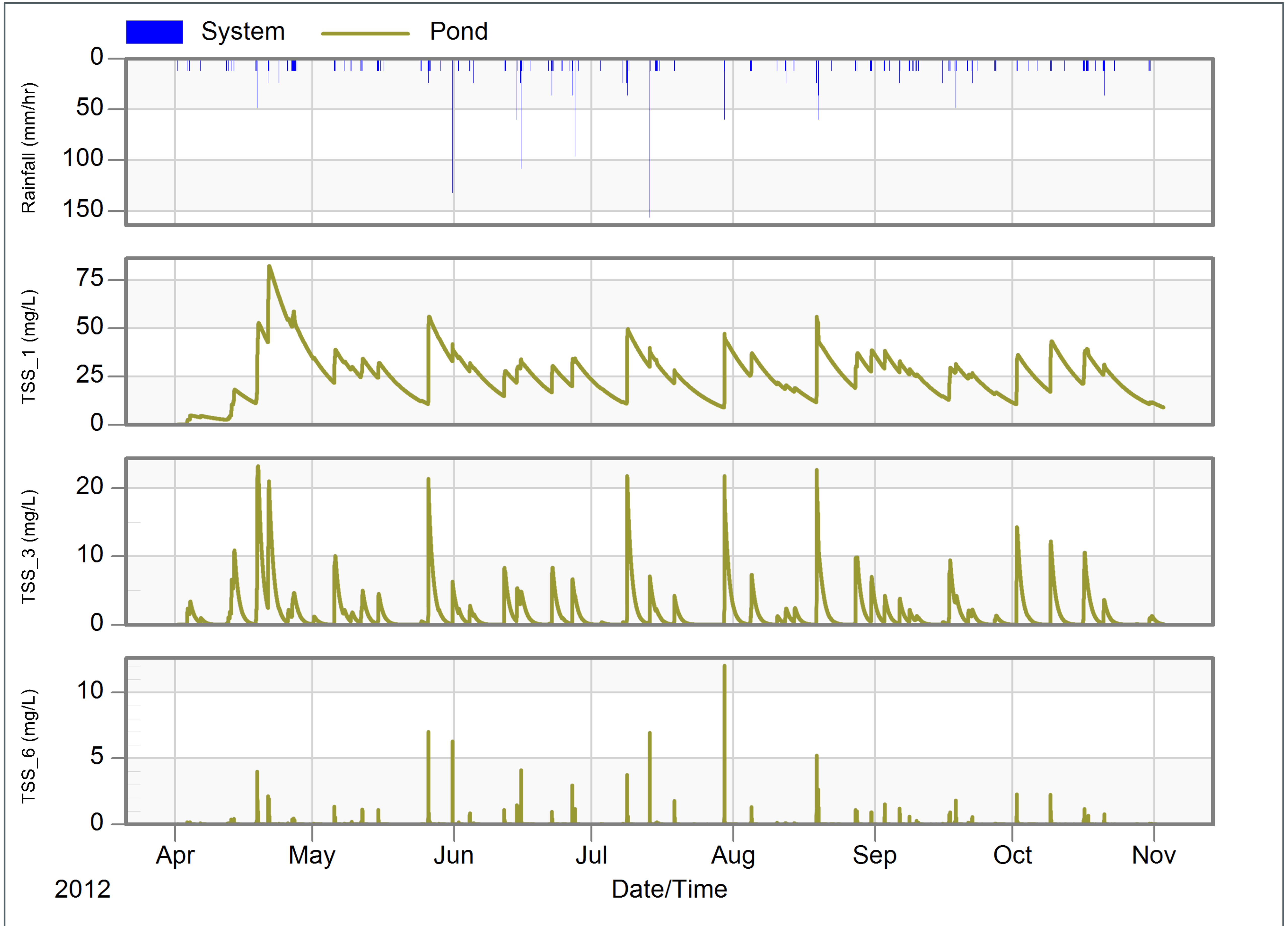
Outfall load (increasing load is transported through the system as particle size decreases)

Particulate Settling Results

Smallest 20% mass fraction

Middlest 20% mass fraction

Largest 20% mass fraction

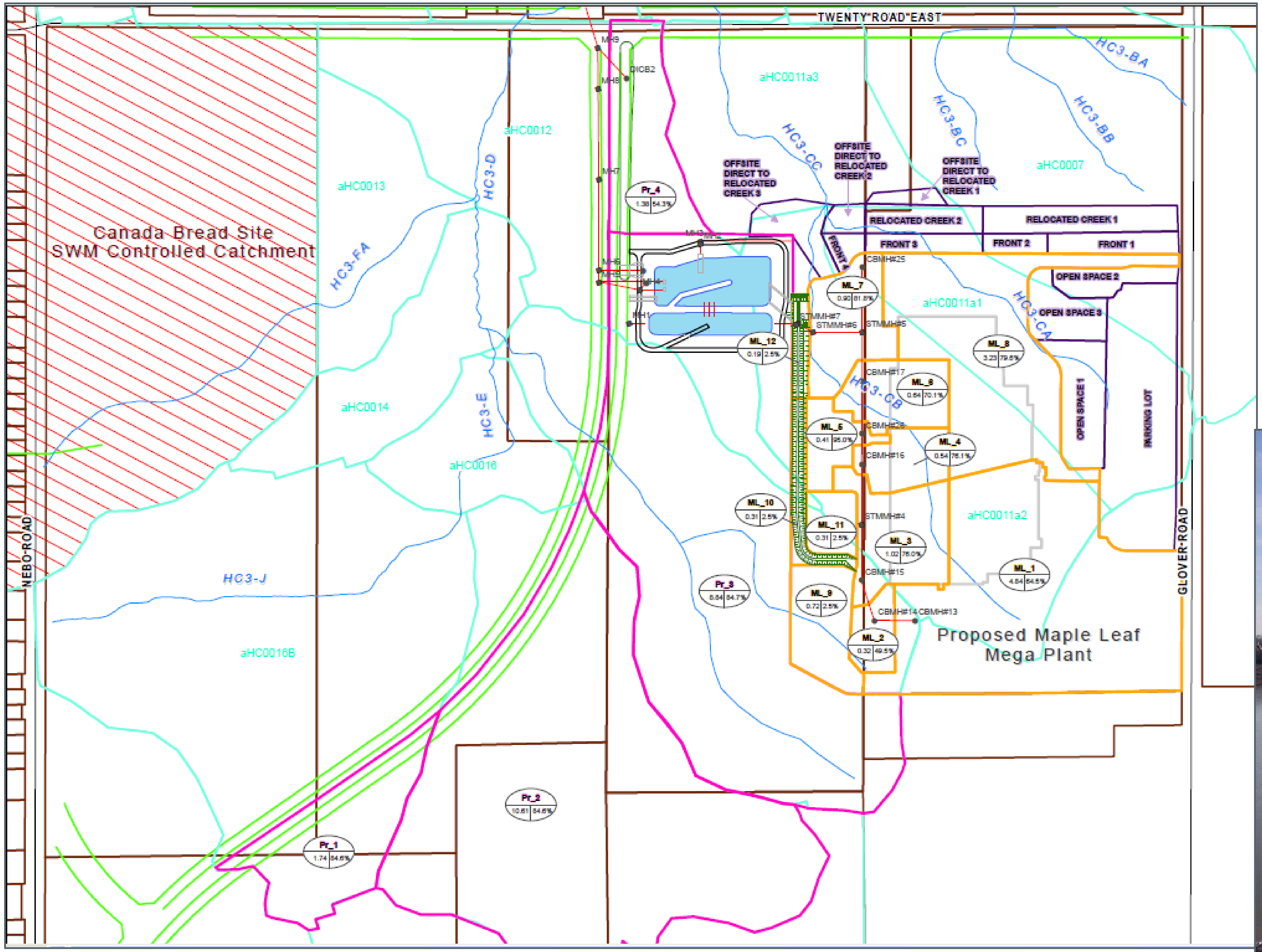


TSS Loading Summary

Event/Particle Characteristic	TSS Loading and Accumulation by Particle Size						Total TSS Loading
Mass Fraction (% Finer Than):	0-20%	20-30%	30-40%	40-60%	60-80%	80-100%	
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 m^3/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 m^3/ha/yr
- 10-yr sediment volume = 940 m^3 (available decant volume = 1,230 m^3)

Example Project Details…



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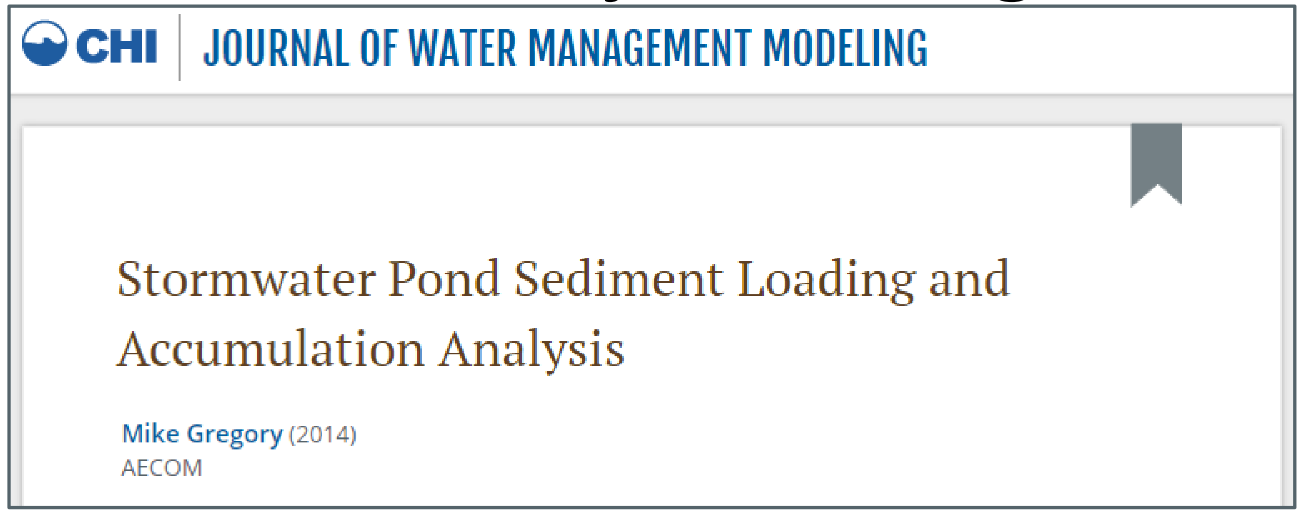

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EWRI Congress 2025, EPA SWMM5 Workshop -- LID Modeling

Thank you for your attention… any questions?

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