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B.S. Engineering Science, Humboldt State University, Arcata, CA 1970.
MSCE, San Jose State University, San Jose, CA 1971.
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About 40 years working in the area of wet weather flows; effects, sources, and control of stormwater. About 100 publications, including several books.

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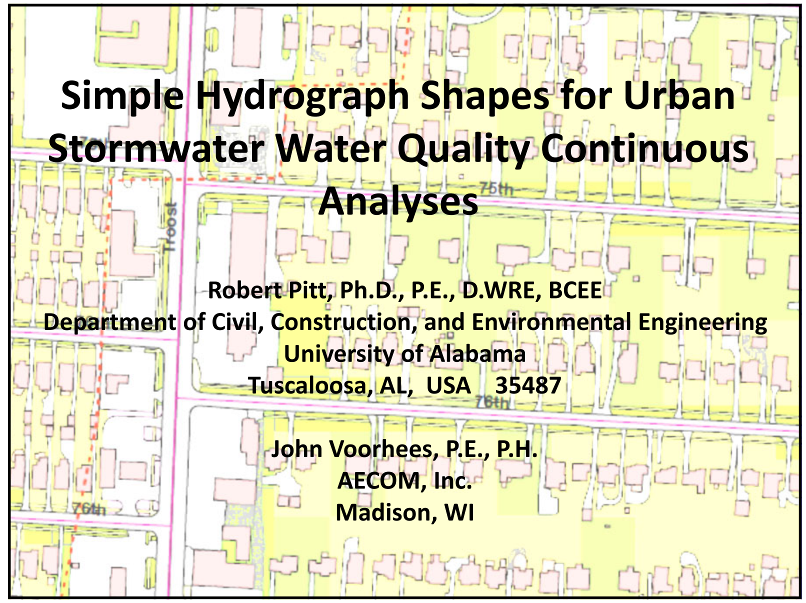

Simple Hydrograph Shapes for Urban Stormwater Water Quality Continuous Analyses

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Presentation Topics

- Observed Urban Area Hydrographs
- Modeling Hydrographs in Urban Areas
- Calculated WinTR-55 Hydrographs
- Hydrograph Characteristics used in WinSLAMM
- Analyses of Observed Urban Hydrograph Shapes

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Observed Urban Hydrographs

Evaluated about 550 different urban area hydrographs from 8 watersheds (1, 1a, 2, and 3 rain distributions and B soils to pavement)

Location	Land use	area (acres)	directly connected impervious	# of events monitored
Bellevue, WA				
Surrey Downs	Resid, med. den.	95	17 %	196
Lake Hills	Resid, med. den.	102	17	201
San Jose, CA				
Keyes	Resid, med. den.	92	30	6
Tropicana	Resid, med. den.	195	25	8
Toronto, Ontario				
Thistledowns	Resid, med. den.	96	21	35
Emery	Industrial	381	42	60
Tuscaloosa, AL				
City Hall	Institutional/com	0.9	100	31
BamaBelle	Commercial	0.9	68	17

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Observed Runoff Characteristics

	Monitored rains (in, range)	Observed Rv (avg and range)	Observed CN (range)	peak/avg flow ratio (avg and range)
Bellevue, WA				
Surrey Downs	0.03 - 4.38	0.18 (0.01 - 0.60)	64 - 100	4.4 (1 - 14)
Lake Hills	0.02 - 3.69	0.21 (0.01 - 0.49)	73 - 100	5.4 (1.1 - 19)
San Jose, CA				
Keyes	0.01 - 1.06	0.10 (0.01 - 0.28)	88 - 100	3.2 (2.4 - 3.7)
Tropicana	0.01 - 1.08	0.59 (0.17 - 1.6)	95 - 100	3.8 (2.7 - 4.9)
Toronto, Ontario				
Thistledowns	0.03 - 1.01	0.17 (0.02 - 0.37)	84 - 99	4.0 (1.4 - 12)
Emery	0.03 - 1.0	0.23 (0.05 - 0.58)	87 - 99	3.1 (1.3 - 8.3)
Tuscaloosa, AL				
City Hall	0.02 - 3.2	0.6 (0.09 - 0.80)	95 - 99	4.2 (1.1 - 8)
BamaBelle	0.1 - 1.9	0.8 (0.3 - 1.0)	94 - 100	5.5 (1.8 - 9.4)

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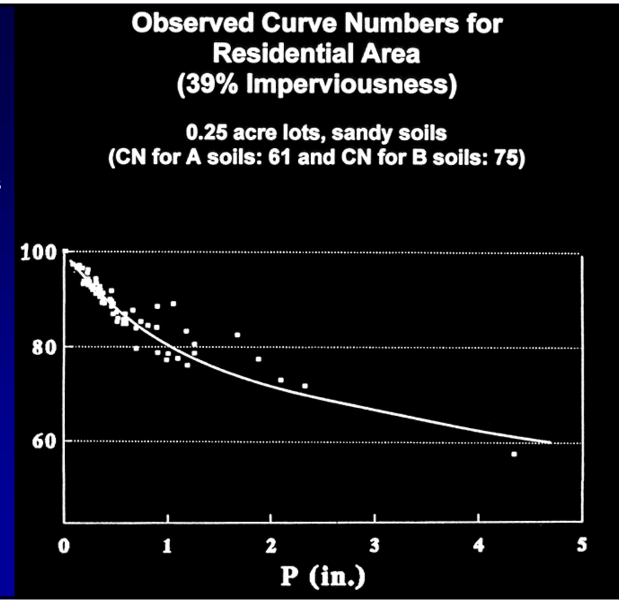
Typical plot of calculated curve numbers for actual site monitoring. This date is from the Univ. of Florida's rainfall-runoff database that contains historical SCS and COE monitoring data that was used to develop TR-55. Obviously, the CN method is only applicable for the large drainage design storms for which it was intended!



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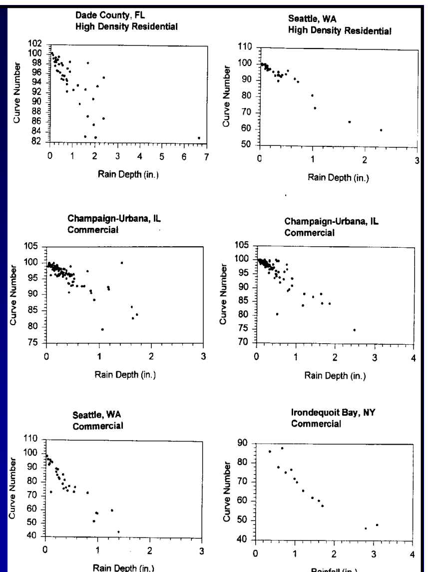
This type of plot, with very high curve number values for small events and more "reasonable" values with large events, is consistent with all monitoring locations. This is another example showing several of these plots for monitoring locations at high density residential areas from some of the EPA's NURP projects (1983). The effect is most extreme for areas having less impervious cover.

This is solely an effect of the algebraic simplifications of the CN method (mostly due to the Ia/S = 0.2 assumption) which is reasonable for drainage design storms, but not for smaller events.

"Average" or best-fit outfall conditions are usually used to calibrate models, resulting in reasonable long-term calculations, but with significant errors when determining the sources (and control benefits) in the watershed area.



Pitt, et al. 2002

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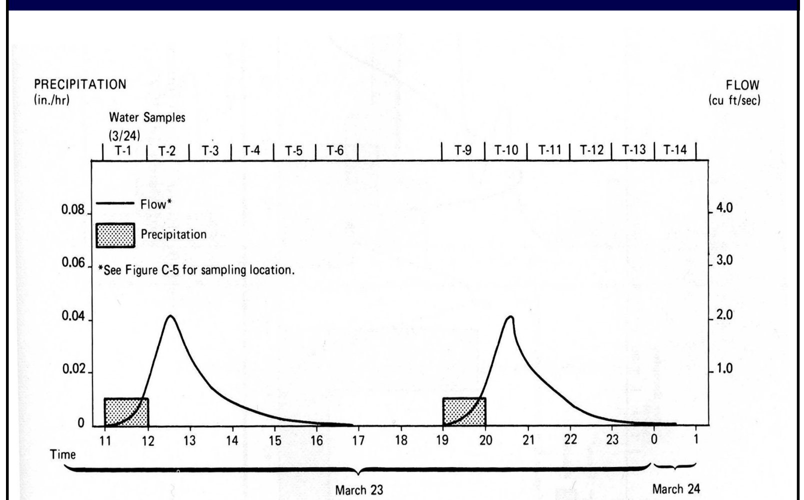
Rains Ranged from Small and Simple:



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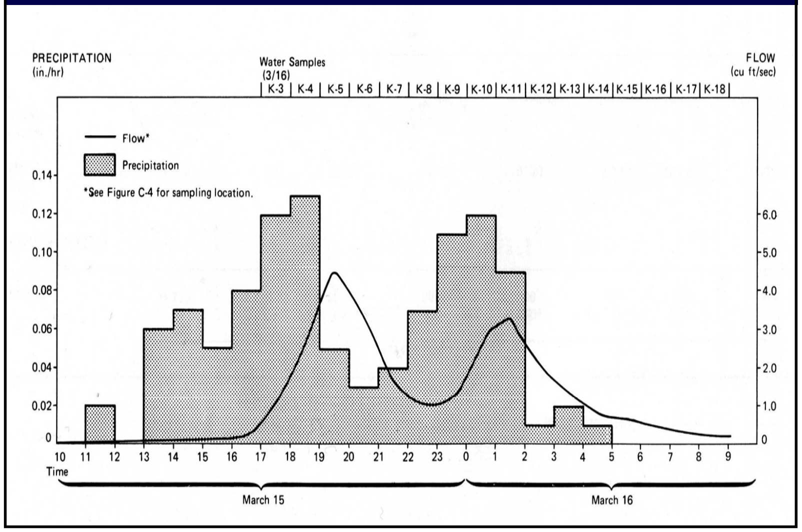
To Complex:



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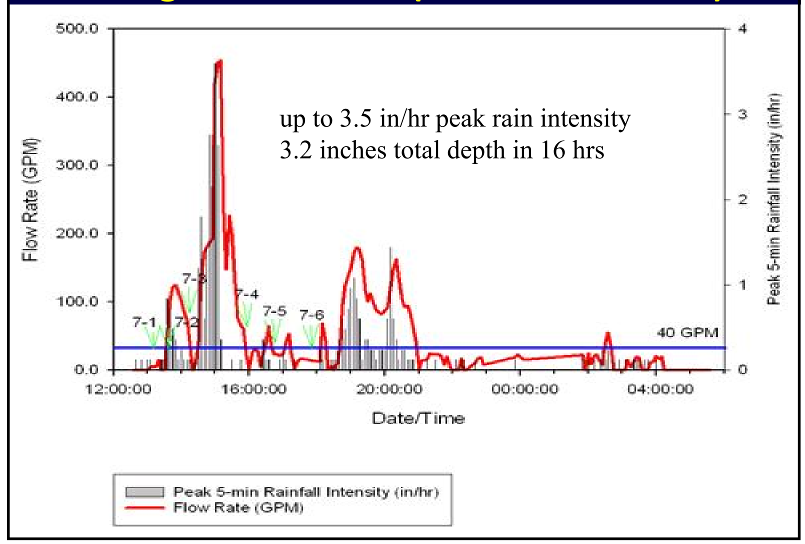
To Large and Intense (Hurricane Katrina):



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SWMM 5 Unit hydrographs and aggregate storm hydrograph (Bend, OR, 2008)

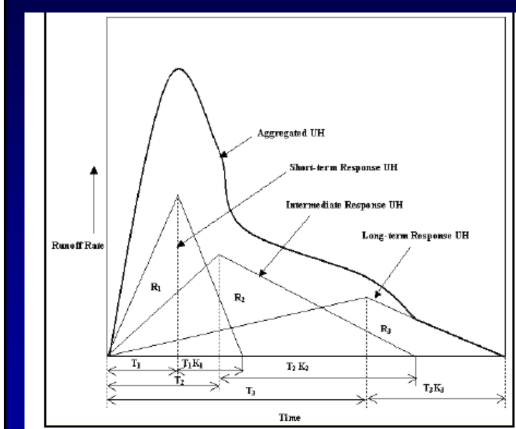
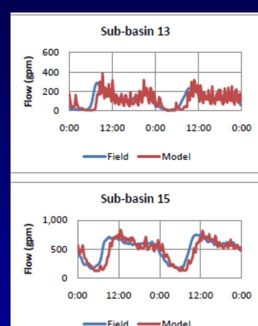


Figure 4. SWMM Unit Hydrograph Description



Examples of excellent calibrations with local data

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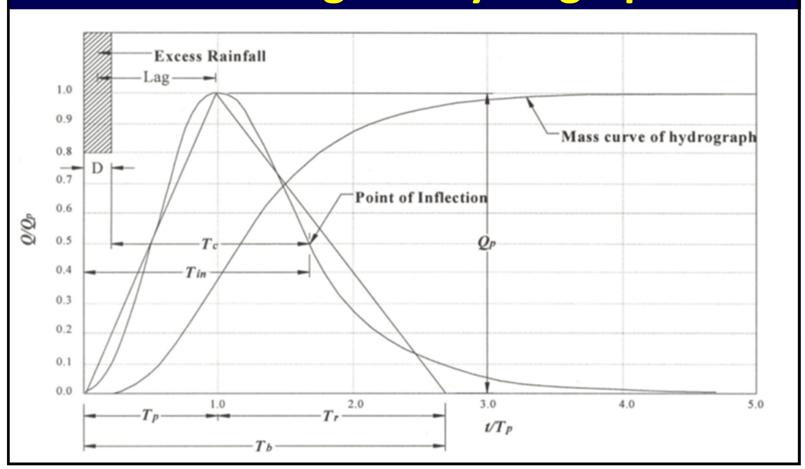
NRCS Dimensionless Unit Hydrograph and Triangular Hydrograph



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WinTR-55 Calculated Hydrographs

	WinTR55 using actual CN value and 1 inch rains	
	Peak/avg flow rate ratios	Runoff/rain duration ratios
Bellevue, WA		
Surrey Downs	1.7	0.71
Lake Hills	2.5	0.75
San Jose, CA		
Keyes	5.8	0.67
Tropicana	8.3	0.92
Toronto, Ontario		
Thistledowns	9.7	0.58
Emery	9.5	0.58
Tuscaloosa, AL		
City Hall	6.4	0.09

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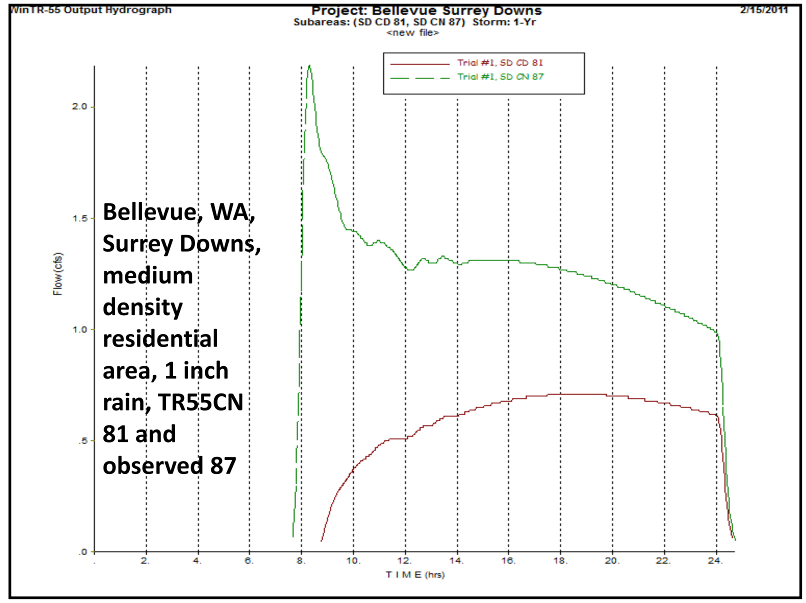

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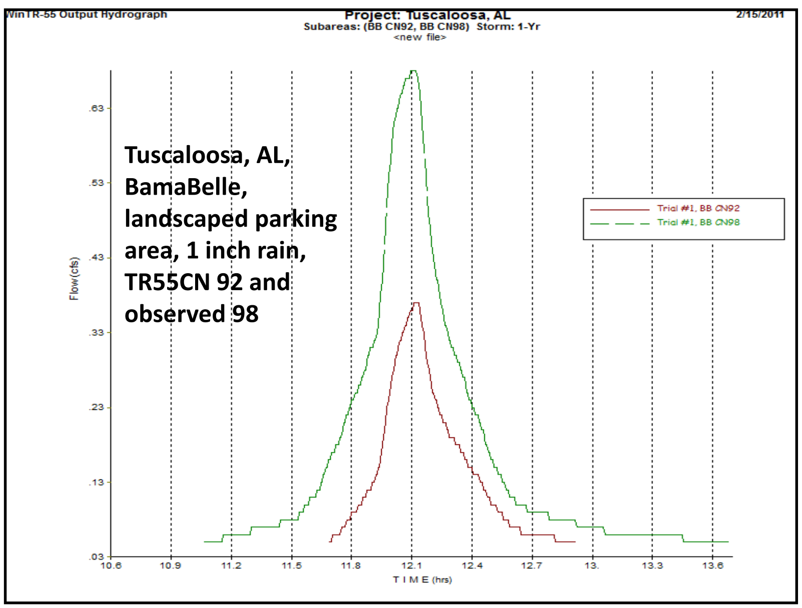

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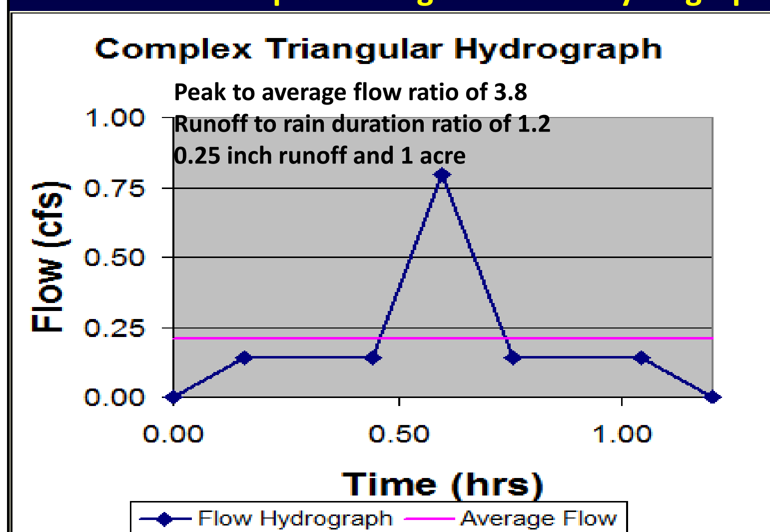
WinSLAMM Complex Triangular Storm Hydrograph



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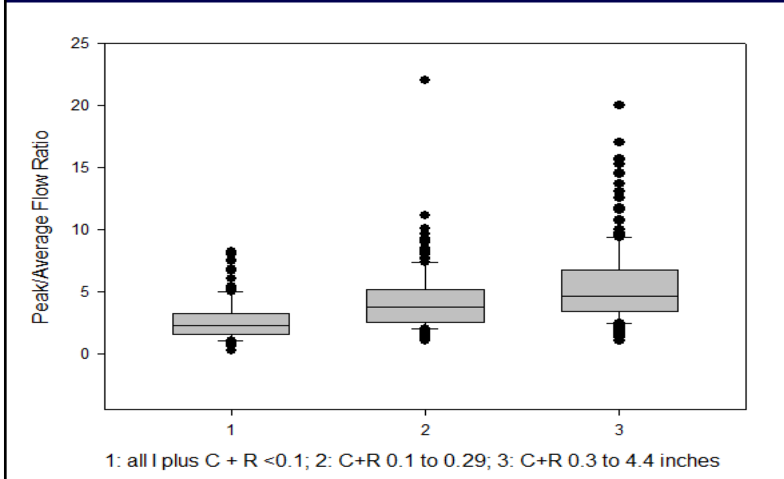
Observed Peak to Average Flow Ratios

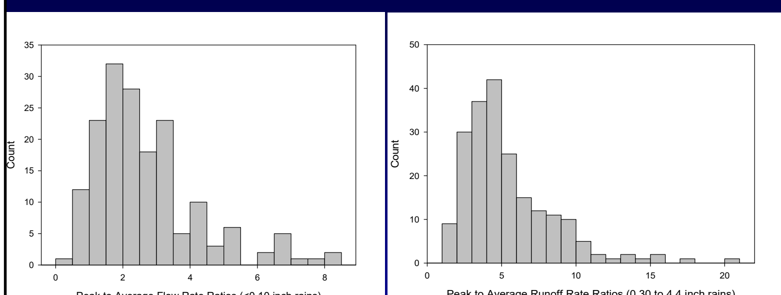
(non-parametric Kruskal-Wallis one way ANOVA on ranks)



Peak to Average Flow Rate Ratios

	<0.10 in (<2.5 mm) rains	0.10 to 0.29 in (2.5 to 7.4 mm) rains	0.30 to 4.4 in (7.5 to 120 mm) rains
Number of Observations	172	172	206
Minimum	1.0	1.0	1.1
Maximum	8.3	22	20
Average	2.7	4.2	5.4
COV	0.55	0.65	0.66

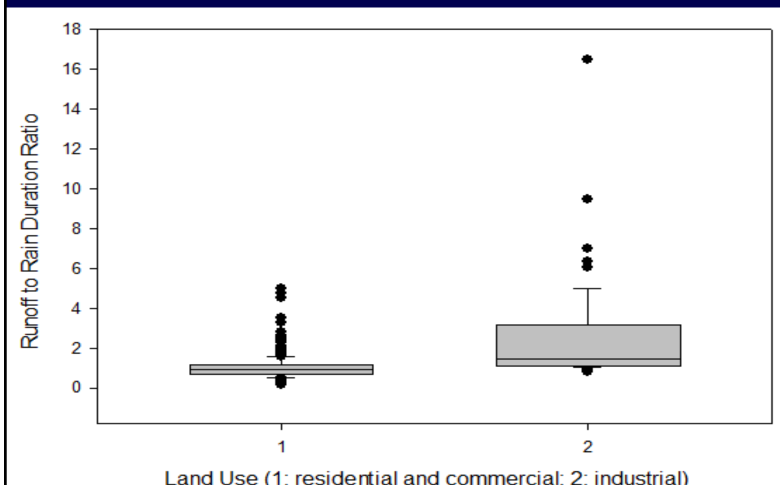
Peak to Average Runoff Rate Ratios



The variation in each rain/land use group can be described using a Monte Carlo stochastic modeling approach for long-tem continuous simulations.

Observed Runoff to Rain Duration Ratios

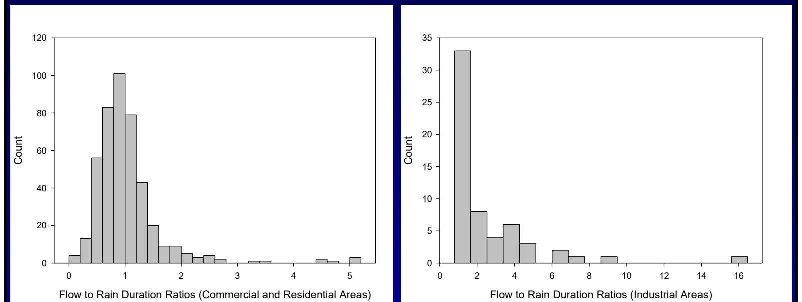
(non-parametric Kruskal-Wallis one way ANOVA on ranks)



Runoff to Rain Duration Ratios

	Residential and Commercial Areas	Industrial Areas
Number of observations	447	60
Minimum	0.16	0.78
Maximum	5.0	16
Average	1.0	2.5
COV	0.63	1.0

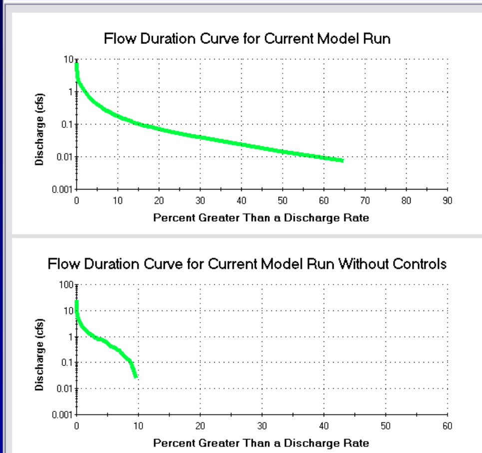
Runoff to Rain Duration Ratios



Again, the variation in each land use group can be described using a Monte Carlo stochastic modeling approach for long-tem continuous simulations.

WinSLAMM Flow-Duration Analyses for Examining Different Control Scenarios

Flow Duration Curves



Flow Duration Data

Discharge Greater Than Percent	Flow Rate (cfs) for Current Model Run	Flow Rate (cfs) Without Controls
0	7.611	24.70
0.1	4.216	7.113
1	1.621	2.248
3	0.6926	0.8892
5	0.4110	0.5434
10	0.1751	0
20	0.06850	0
30	0.03805	0
40	0.02283	0
50	0.007611	0
60	0.007611	0
70	0	0
80	0	0
90	0	0
100	0	0

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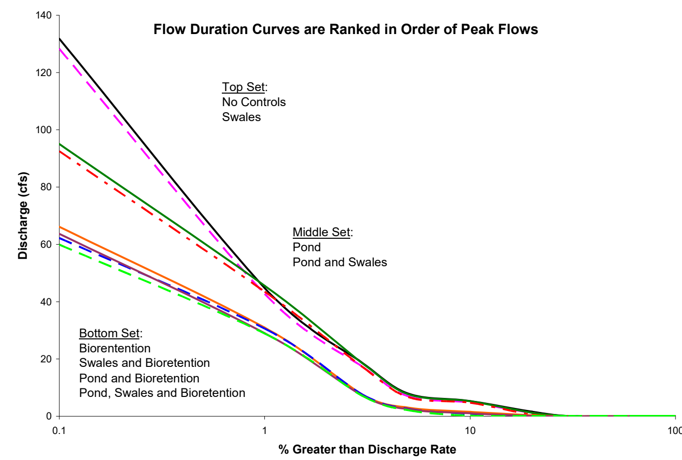
Flow-Duration Curves for Different Stormwater Conservation Design Practices



Conclusions

- Uncalibrated, or partially calibrated runoff models (such as only for annual runoff volume) likely greatly distort the actual hydrograph shapes in urban areas, especially for small to moderate-sized events.
- Smaller events are under-represented and larger events are over-predicted to balance long-term flows.
- Greatly affects flow-duration analyses for habitat assessment.

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Conclusions

- Simple models cannot match the hydrograph shape and commonly use the same mechanisms for all rains.
- More complex models can be appropriately calibrated to represent a wide range of rains and watershed conditions.
- However, if uncalibrated (and use "traditional" model parameters representative of drainage design), even these better models will distort the flow-duration relationship (usually by greatly over-predicting the peak to average runoff ratio, especially for the smaller rains).

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Conclusions

- WinSLAMM uses a complex triangular storm hydrograph that can be modified based on relatively simple data evaluations (peak to average flow ratio, runoff to rain duration ratio, and storm runoff volume).
- This flexibility allows a good match to observed conditions for the storms of most interest in water quality and habitat evaluations.
- Planned model improvements will include stochastic elements to better describe remaining variability.

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