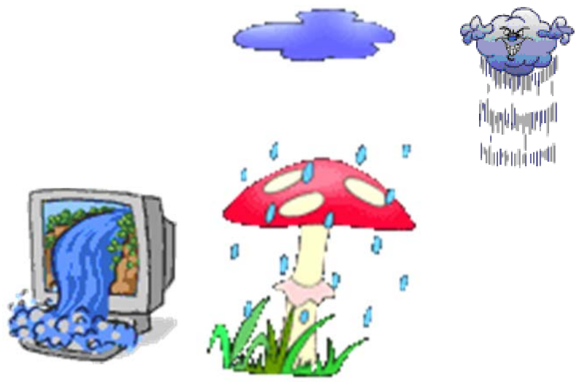
STORM WATER MANAGEMENT MODELING TECHNIQUES

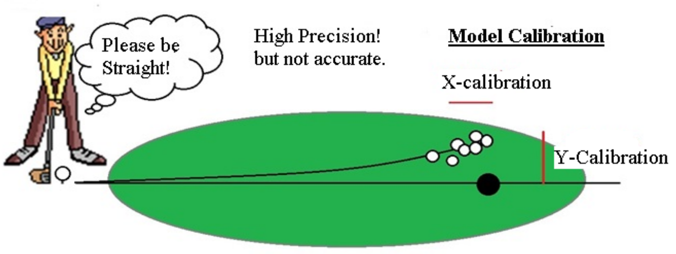


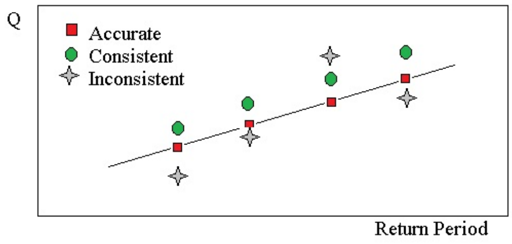
Dr. James C.Y. Guo, P.E.
Professor and Director, Civil Engineering, UC-Denver

Storm Water Simulation Models

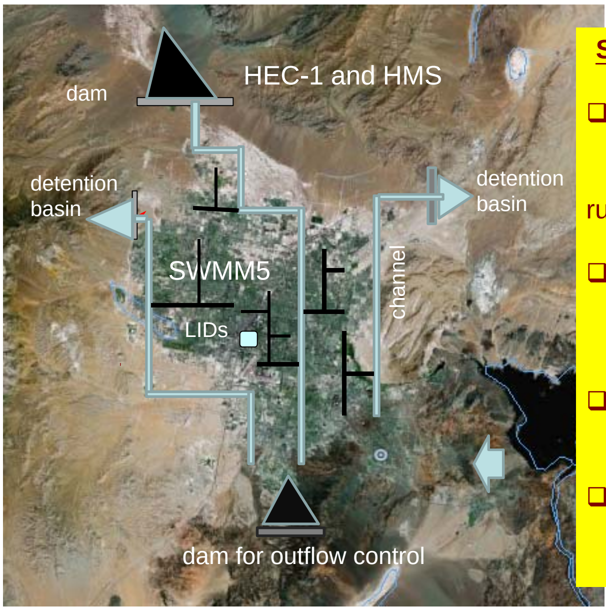
- **Physical Model -- Laboratory Data**
  Laboratory test -- shower + sprinkler man-made rainfall
  Major problem: scale effect in laboratory settings
- **Probabilistic Model -- Historical Data**
  Time-dependent vs Time-independent
  Homogeneous vs Non-homogeneous data
  Major problem: watershed continuous development
- **Empirical Model - Local Data**
  Regional analysis for a hydrologic zone ($Q = a A^b S^c$)
  Major problem: how to generalize the local empirical formula
- **Numerical Model - Numerical Data**
  A. Unit Hydrograph
  B. Kinematic Wave (KW) Overland Flow
  Numerical models provide consistent predictions among events and various watershed conditions, and can be calibrated for accurate predictions.

Why is SWMM acceptable? -- consistency





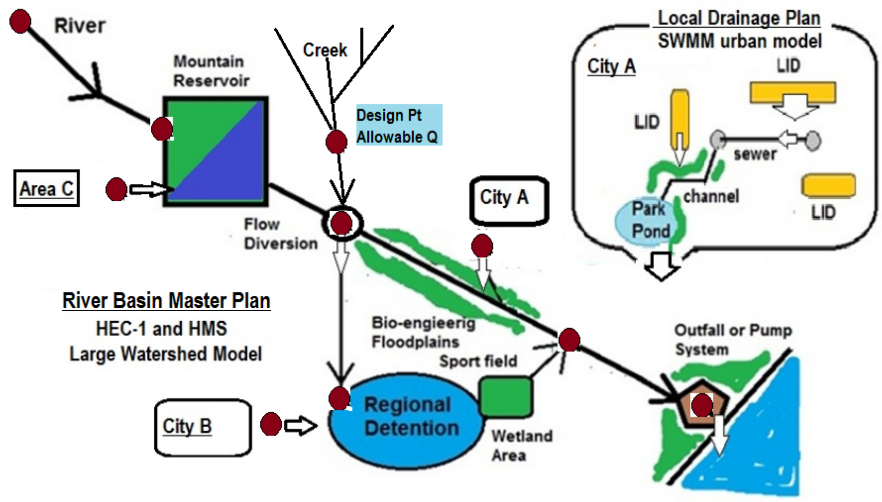
Levels of Details for Drainage Network Modeling



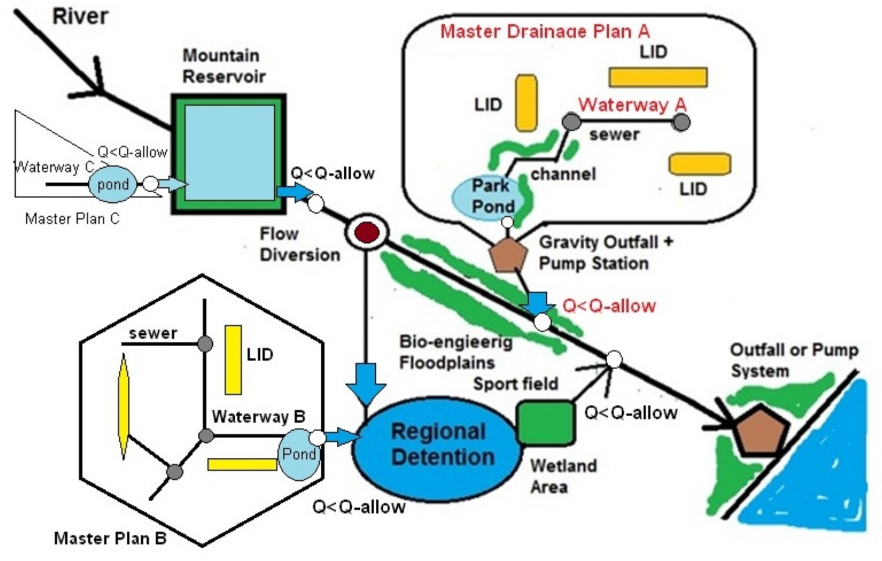
Selections of Models

- HEC-1 and HMS (>100 sq miles) regional off-site runoff
- SWMM5 (10 to 20 sq miles) in-city stormwater
- Rational Method (<100 acres)
- SWMM-LIDs (1 to 10 acres) on-site treatment

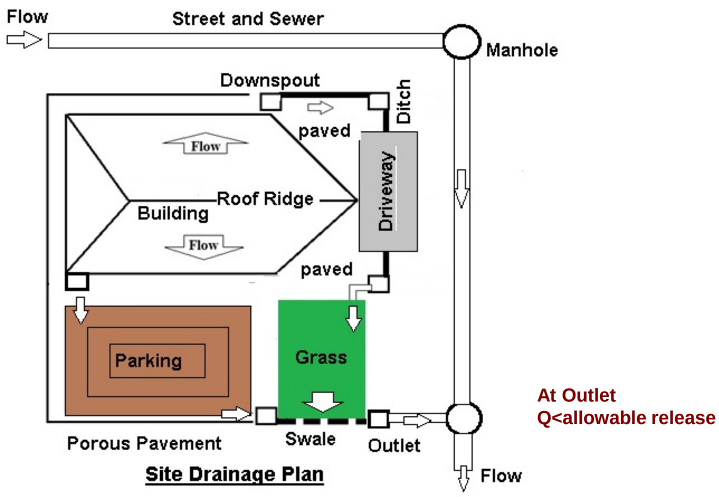
River Drainage Plan- Floodplain Delineation



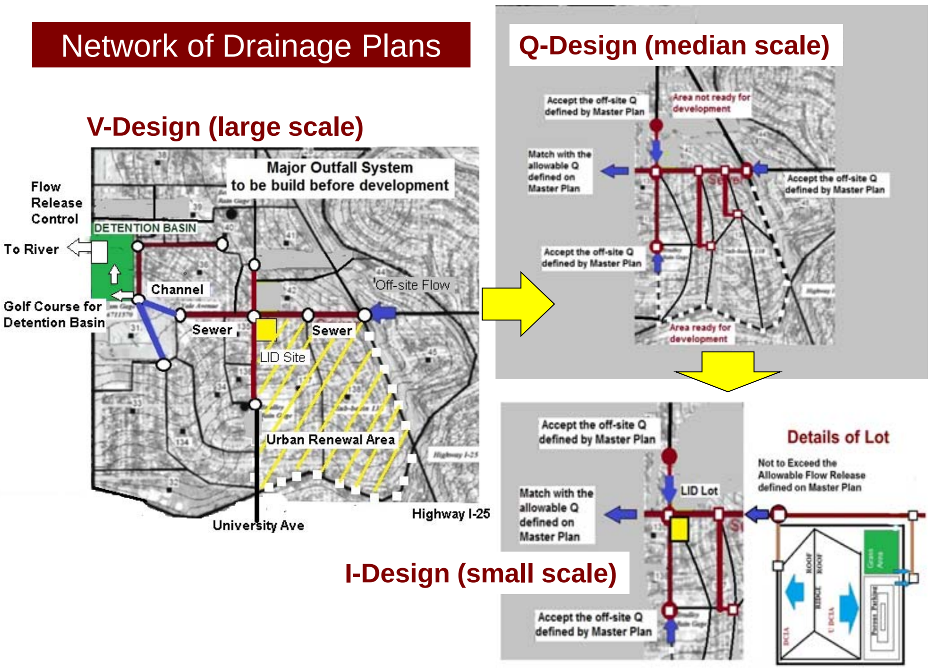
City Drainage Plans – Streets and Sewers



Site LID Drainage Plan – Lots <10 acres



Network of Drainage Plans

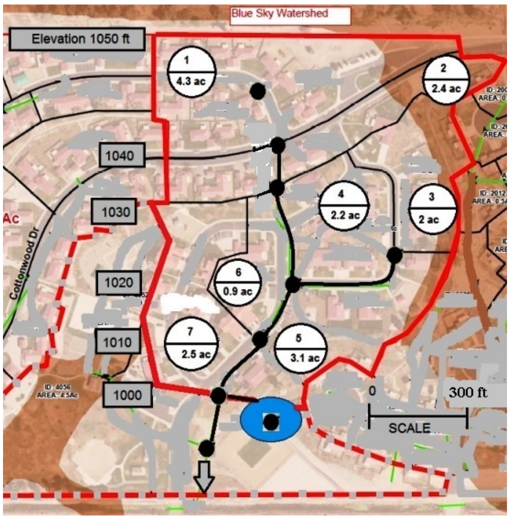


EPA Storm Water Management Model Version 5 (SWMM5)

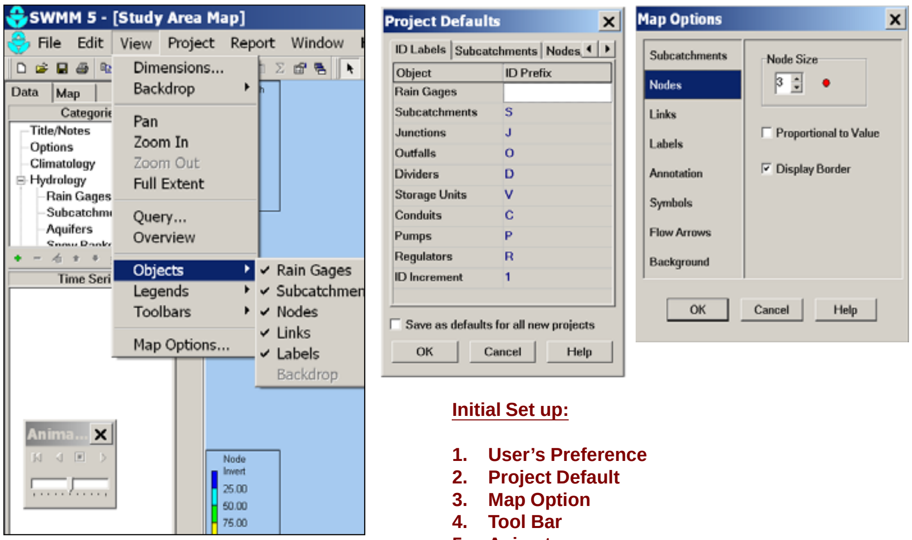
- SWMM 1 to 2 developed by Metcalf and Eddy, Inc. in 1971
- SWMM 3 maintained by the U of Florida at Gainesville
- Missouri River Division, COE added new features: Flow Diversion and Detention Storage into SWMM RUNOFF Sub-routing in 1974.
- To model hydraulic designs, the University of Florida added the EXTRAN BLOCK to convert SWMM3 into SWMM4.
- The Boyle Engineering Incorporation modified SWMM RUNOFF BLOCK into UDSWMM. UDFCD adopted UDSWMM and CUHP as the storm water numerical simulator in 1985.
- UDSWMM was modified by the University of Colorado Denver 1988, 1995, and 2000 to its last version: UDSWMM2000.
- In 2005, SWMM4 was converted into SWMM5 under the window operation.
- UDFCD adopted CUHP5 and SWMMM5 to replace the package of CUHP2000 and UDSWMM2000.
- In 2008, CUHP5 was revised into CUHP1.3.3 with the capability of LID cascading flows.

Workshop Watershed – 17 acres

Base-line model: Swales and Channels for pre- and post-developments
Hydro-Modification models: Street-culvert-diversion-sewer-detention
KW for planning and DW for design



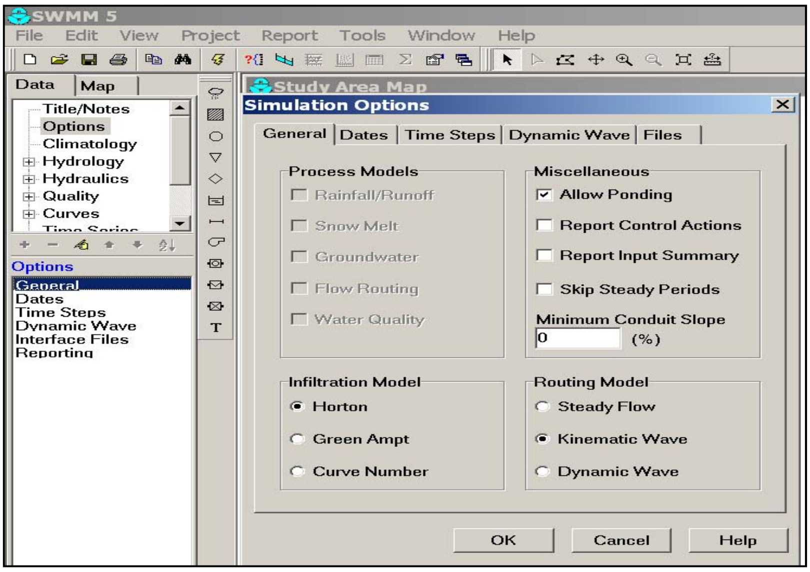
Initial Set Up for SWMM Model



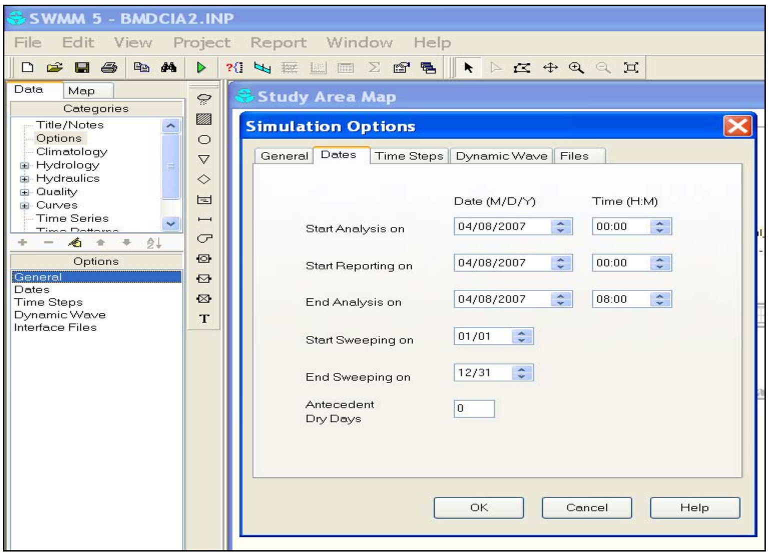
Initial Set up:

1. User's Preference
2. Project Default
3. Map Option
4. Tool Bar
5. Animator
6. Background Watershed Map

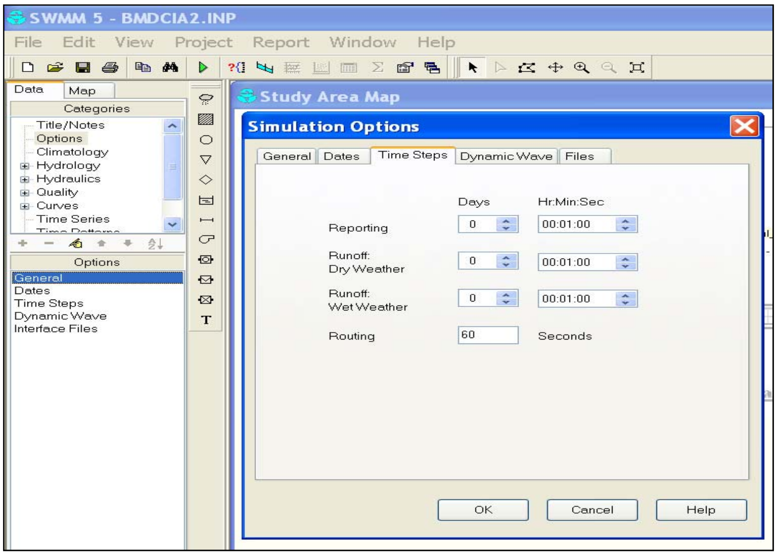
Simulation Options



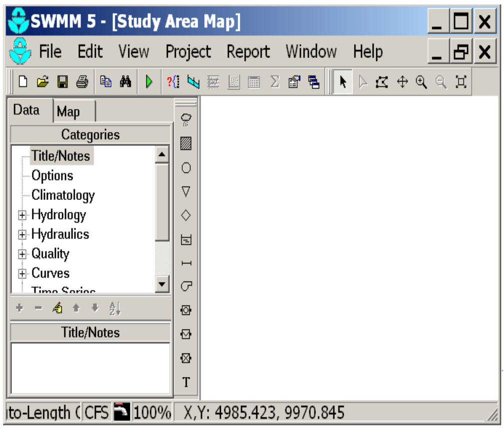
Start time and End time of Simulation



Selection of Time Intervals



Swmm5 Operations and Input Data Structure

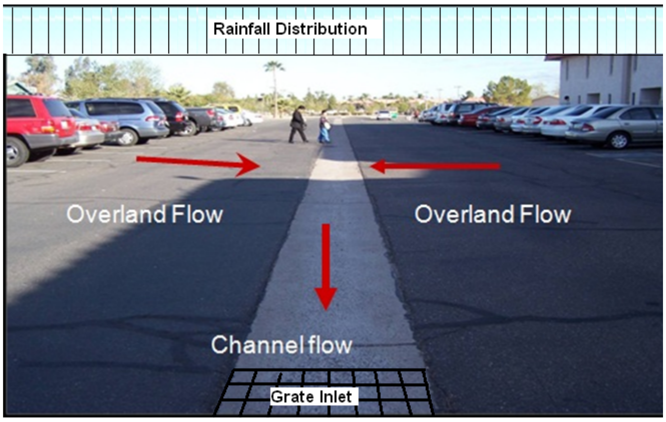


Data Inputs

- Title/Notes
- Options
  - KW or DW
  - Time step
  - External in-flows
- Climatology
  - Rain, Snow, Temp, Evap
- Hydrology
  - Sub-catchment
  - LID's
- Hydraulics
  - Link and Nodes
- Quality-
  - Surface Erosion
  - Street Sweeping
  - Snow melting

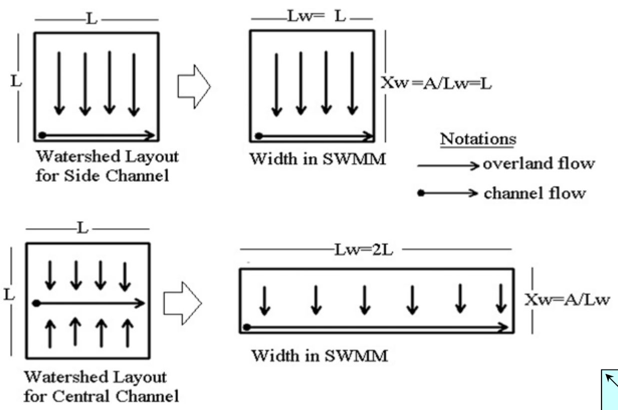
KW Sloping Planes

No significant flow acceleration, no backwater, flow friction equal to gravitation force, and single-valued rating curve

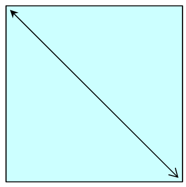


How can a nature watershed be converted into a rectangular KW sloping planes?

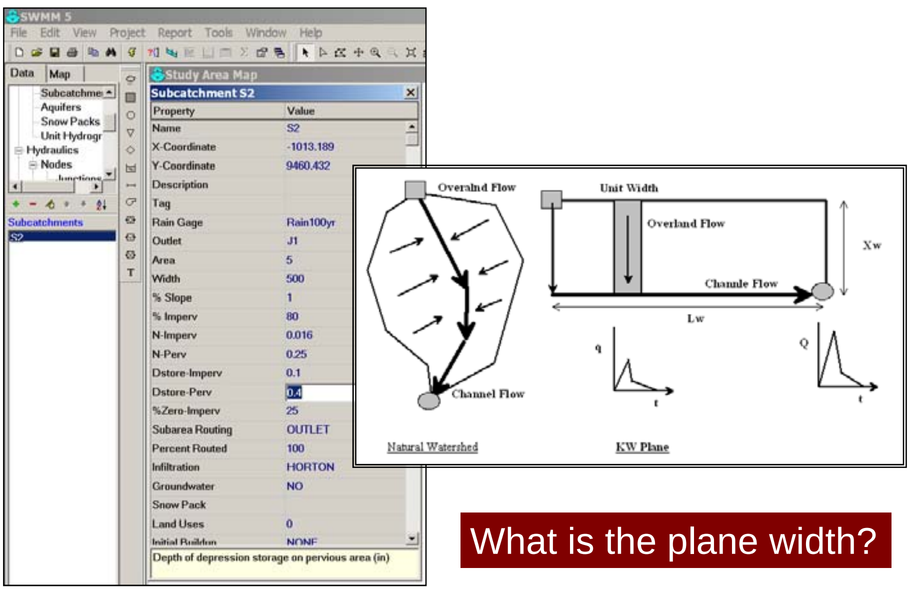
Square Watershed and KW Sloping Plane



The above are special cases.
What if the channel is diagonal?.
How to define the plane width: Lw ?

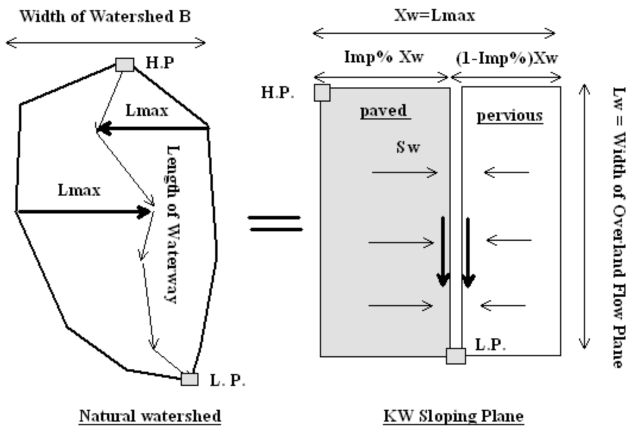


Watershed Parameters for Overland Flow



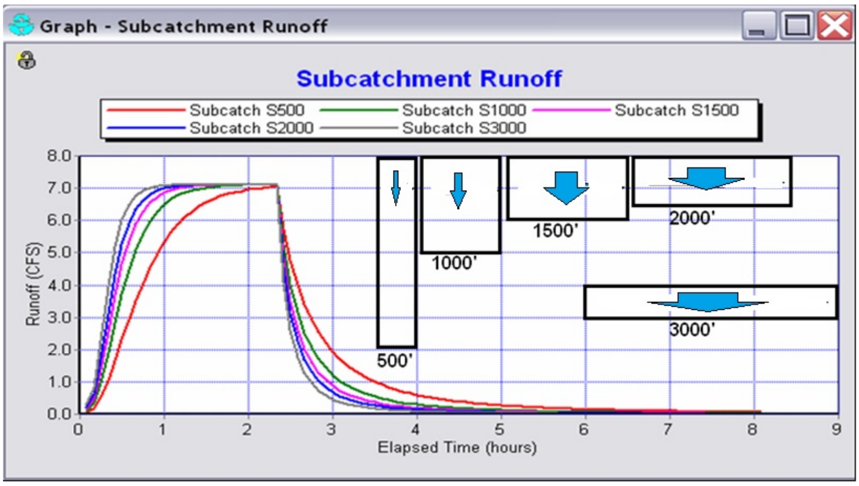
What is the plane width?

Various Recommended KW Plane Width
(two-flow path)



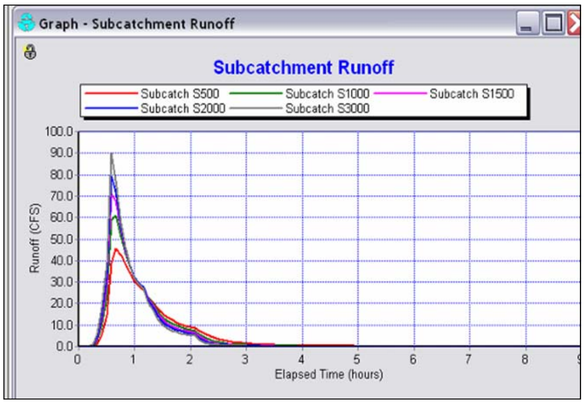
Empirical formulas:
(1) Lw= 2.2 L (2) Lw=1.67 L (3) Lw=2.0 L (4) Lw=A/Lmax

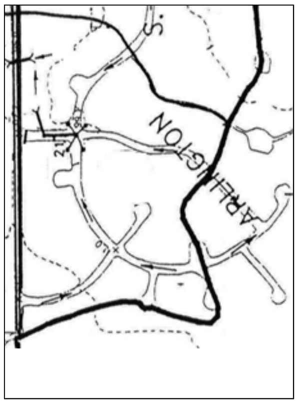
Sensitivity on Watershed Shape (uniform rainfall)



The unit watershed has A=21.76 acre, S=1%, and Imp=50%. Five waterway lengths were tested for Lw = 500, 1000, 1500, 2000, to 3000 ft. Under a uniform rainfall, the longer the waterway, L, the less the runoff. Which width is ought to be used to represent this natural watershed?

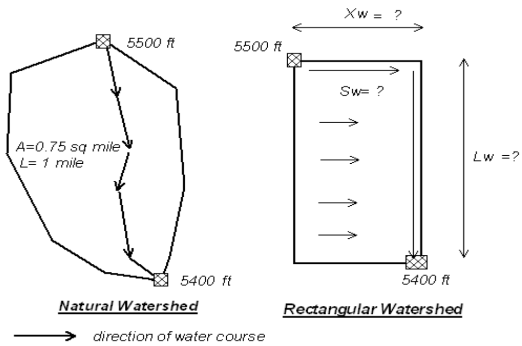
Sensitivity on KW Plane Width (Non-uniform Rainfall)





The unit catchment has: Area=21.76 ac, Imperviousness =50%. Slope =1%. The width of KW plane was tested for **Lw=500, 1000, 1500, 2000, to 3000 feet**. The peak flow varies from 45 to 90 cfs under a **non-uniform 100-yr rainfall**. **Which one shall be chosen for design?**

KW Shape Factor for Lw, Xw, and Sw



$X=A/L^2=B/L=0.75$ (width-length ratio)
$Y=L_w/L$
$Z=A_m/A=0.65$ (Am=larger half)
$S_o=0.019$
$X_w=A/L_w$
$S_oL=(X_w+L_w)S_w$

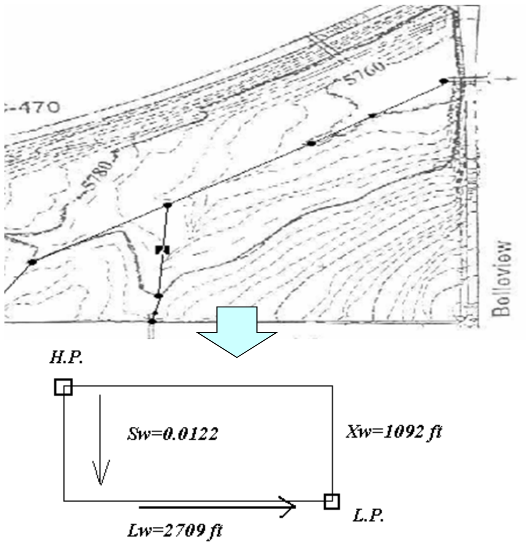
$$\frac{L_w}{L}=(1.5-Z)[2.286(\frac{A}{L^2})-0.286(\frac{A}{L^2})^2]=(1.5-0.65)(2.286\times0.75-0.286\times0.75^2)=1.55$$

$$Vertical\ \ Fall=S_oL=(X_w+L_w)S_w\ \ So,\ S_w=0.0093$$

Guo, James C.Y. and Urbonas, B. (2009) "*Conversion of Natural Watershed to Kinematic Wave Cascading Plane*", ASCE J. of Hydrologic Engineering, Vol 14, No. 8, August

Guo, James C. Y. Cheng, Jeff, Wright, L.(2012) "Field Test on Conversion of Natural Watershed into Kinematic Wave Rectangular Planes, ASCE J. of Hydrologic Engineering, Vol. 17, No. 8, August.

Example of KW Plane Width using KW Shape Factor

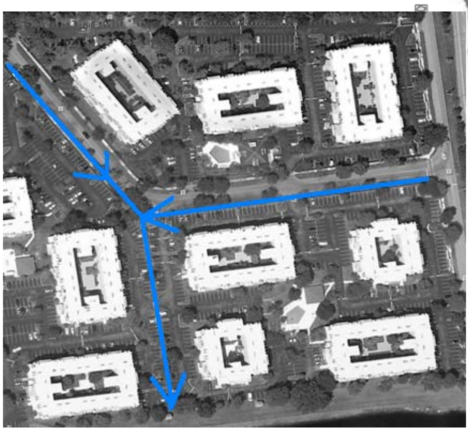


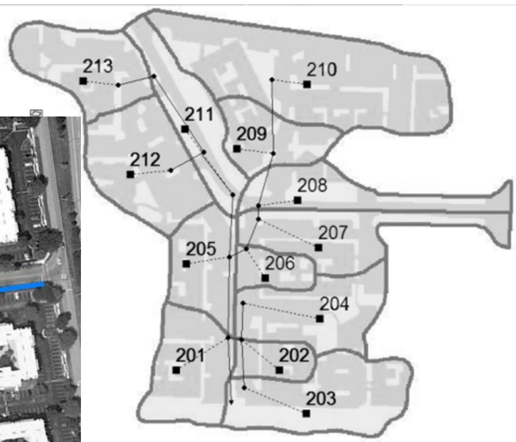
Area= 67.9 acres
L=2323 ft and Imp% =35
$X=A/L^2$ =0.55
Z=0.6
Y=Lw/L = 1.17
Lw = 2709 ft
Xw=1092 ft
So L =(Xw+Lw)Sw
Sw=1.22%

Do you see any problem?

Is there any limit on the overland flow length? What could be the impact on the model's accuracy?

Miami Watershed in Florida





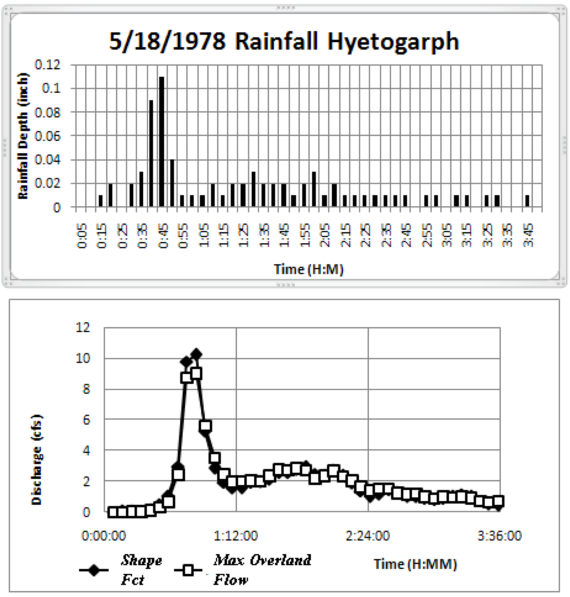
Miami Watershed in Florida, reported by Wayne Huber 2001

Comparison with a Calibrated Model

Subarea	Area	L	So	Z=Am/A	X=A/L^2	Y=Lw/L	So/Sw	Sw	Lw-Parabolic	Lw-MOLF
ID	acre	ft	%					%	ft	ft
1	1.157	198	3.1	1	1.29	1.23	2.28	1.36	244.0	254
2	0.352	176	3.5	1	0.50	0.53	1.46	2.39	93.4	87
3	1.412	416	2.9	1	0.36	0.39	1.30	2.22	161.4	148
4	1.236	359	2	1	0.42	0.45	1.38	1.45	162.4	150
5	0.842	152	2.7	1	1.59	1.45	2.55	1.06	220.9	241
6	0.395	196	3	1	0.45	0.48	1.41	2.13	94.7	88
7	1.204	647	1.8	1	0.13	0.14	1.03	1.75	91.2	81
8	1.006	674	2	1	0.10	0.11	0.99	2.01	73.4	65
9	0.761	263	3.1	1	0.48	0.51	1.45	2.14	135.4	126
10	2.798	696	2.1	1	0.25	0.28	1.18	1.78	193.8	175
11	1.049	513	1.4	1	0.17	0.19	1.09	1.29	99.6	89
12	1.452	565	1.3	1	0.20	0.22	1.12	1.16	124.7	112
13	1.079	324	2.8	1	0.45	0.48	1.41	1.99	156.4	145

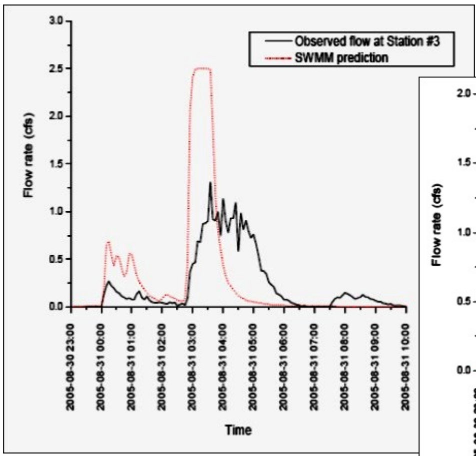
L_{MW} = plane width determined by maximum overland flow length method calibrated by several observed events

L_W = plane width determined by the watershed shape function with NO PRE-KNOWLEDGE about the watershed



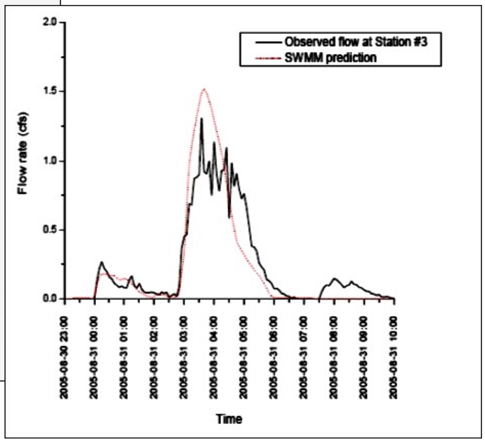
Comparison between KW Shape Function versus Max Overland Flow Method (Miami Watershed in Florida, reported by Wayne Huber 2001)

Calibration -- Current Practice with EPA SWMM5



Source: Fox Hollow Watershed, Centre County PA, 2006

No Guidance



A Calibrated Model

EPA SWMM Applicability

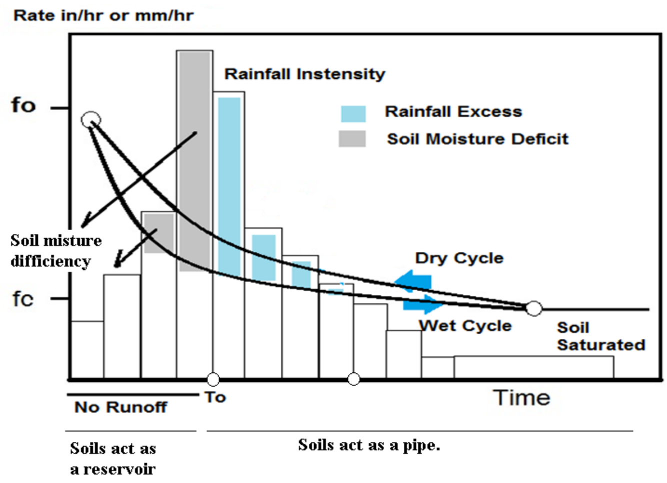
- Point-rainfall-depth model (<50 sq miles)
- Use a depth-area-reduction factor for larger watersheds
- Urban drainage system consisting of street, sewer, culvert, pump, and pond
- On-site LID's (sub-catchment <10 acres)
- KW for drainage planning (Qin=Qout, no backwater)
- DW for on-site hydraulic design (HGL and EGL)
- Single event for event simulation studies
- Long-term simulation for flow-frequency analyses
- Water quality simulation including surface erosion, snow melting, solids long street curbs, and street sweeping
- Graphic displays of flow, volume, and depth hydrographs
- Extensive text report on flow statistics
- User's Bulletin board for Q and A
- EPA SWMM engines for many 3-party peripherals.

High Roughness, n, for shallow water KW overland flow

Source	Ground Cover	n	Range
Crawford and Linsley (1966)[a]	Smooth Asphalt	0.012	
	Asphalt of concrete paving	0.014	
	Packed clay	0.03	
	Light turf	0.20	
	Dense turf	0.35	
	Dense shrubbery and forest litter	0.4	
Engman (1986)[b]	Concrete or asphalt	0.011	0.01-0.013
	Bare sand	0.01	0.01-0.016
	Graveled surface	0.02	0.012-0.03
	Bare clay-loam (eroded)	0.02	0.012-0.033
	Range (natural)	0.13	0.01-0.32
	Bluegrass sod	0.45	0.39-0.63
	Short grass prairie	0.15	0.10-0.20
	Bermuda grass	0.41	0.30-0.48

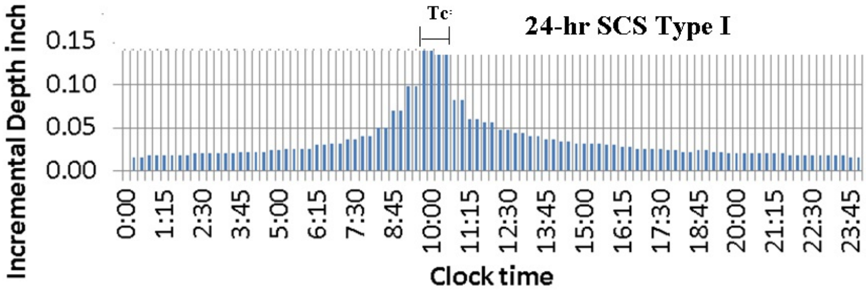
[a]Obtained by calibration of Stanford Watershed Model.
[b]Computed by Engman (1986) by kinematic wave and storage analysis of measured rainfall-runoff data.

Runoff Coeff= rainfall excess/total rainfall



SWMM reports values of C for all sub-catchments.

Rational method=KW Appraoch



1. Determine catchment's Area and Imp%
2. Determine the flow time, Tc, for the catchment
3. Calculate the most intense average I over a period of Tc
4. Accept runoff coeff from SWMM's Subcatchment report
5. Qp=CIA

Q and A Session

It will be intense, long days for this class.

FOR MORE INFORMATION

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WWW.UCDENVER.EDU/~Jguo -- Website
WWW.UDFCD.ORG -- Free Software
WWW.URBANWATERSHEDS.ORG – Training Classes

Porous Pavements in UC-Denver Campus