Highly Flexible Rainfall-Runoff Model Using Multiple Spreadsheets

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Keywords: Rainfall-runoff Modeling, Spreadsheets, Dimensionless Hyetograph, Dimensionless Hydrograph

This contribution presents a highly flexible spreadsheet model for rainfall-runoff processes. The model uses dimensionless equations for both hyetograph and hydrograph. These dimensionless equations help to generalize the model to handle various types of storms and also various hydrograph shapes. The model uses SCS-CN method as a loss model. This allows studying the land use and land cover (LULC) changes easily and straightforwardly. The circular reference option in Excel provides quick and immediate results for investigating the effect of storm pattern; stochastic storms, storm duration, hydrograph shape, and LULC changes. The model results are presented in colorful figures with a very nice graphical interface that helps the analysis of the results.

The model has been tested with well know software such as HEC-HEMS and is applied on a real case study in the Kingdom of Saudi Arabia.

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Outline

- Research Objective.
- The RARUSM Model.
- Storms in Saudi Arabia.
- Modelling Storms Using Dimensionless Equations.
- Rainfall Storm Models in RARUSM.
- Generalized Runoff Hydrograph Model in RARUSM.
- Case Study.
- Conclusions.
- Future Work.

Research Objective

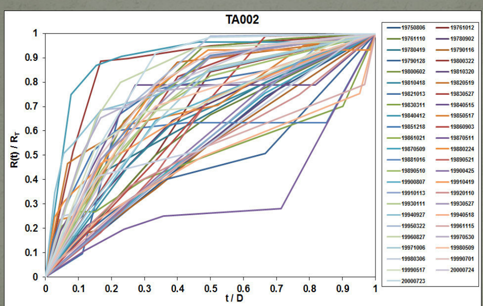
- Development of a spreadsheet rainfall-runoff model that is highly flexible that has the following features:

1. User friendly software.
2. Handy to adjust input parameters.
3. Get immediate output results while changing input.
4. Using the built in graphical interface in the spreadsheet.
5. All calculations are visible in the sheets.

The RARUSM Model.

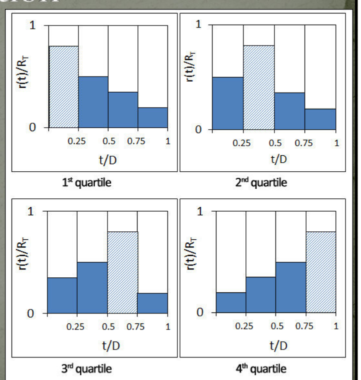
- It is a rainfall-runoff model.
- It uses dimensionless equation for the rainfall model
- It uses dimensionless equation for the hydrograph shape.
- It uses the timing equations of the SCS method.
- It uses the SCS-CN model for estimation of infiltration losses.
- It calculates the convulsion integral to transfer the unit hydrograph to the storm hydrograph in a tabular form.

Dimensionless cumulative mass curves of storms in station TA002

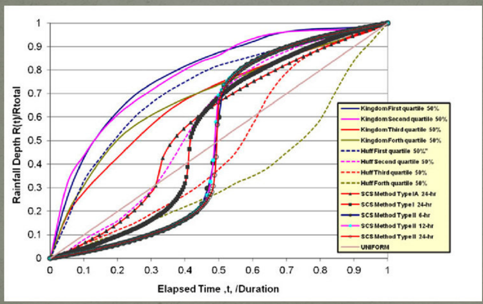


Storm Classification

- Storm Pattern:
- 1st quartile: the maximum intensity is located from the beginning of the storm up to 25% of the storm duration,
- the 2nd quartile: the maximum intensity is located between 25% to 50% of the storm duration,
- 3rd quartile, the maximum intensity is located between 50% to 75% of the storm duration, and
- the 4th quartile, the maximum intensity is located between 75% to 100% of the storm duration.



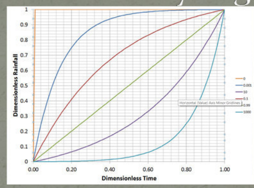
Dimensionless cumulative hyetographs for KSA compared with Huff (1967) and SCS Types I, II and IA

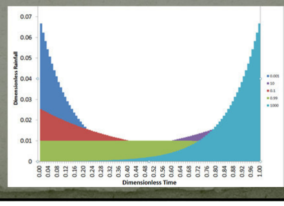


Dimensionless Cumulative Hyetograph

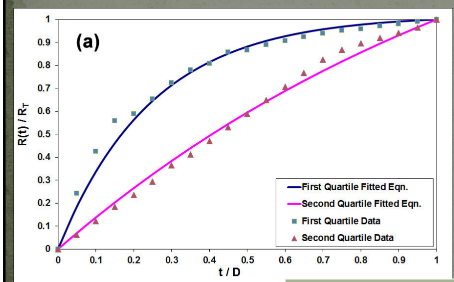
$$\frac{R(t)}{R_T} = \frac{1-a^{(\frac{t}{D}).b}}{1-a}$$

Where, R(t) is the cumulative rainfall depth at each elapsed time, t,
R_T is the total rainfall
t is the elapsed time since the storm begins,
D is the storm duration, and
a and b are the fitting parameters.





Makkah Al-Mukaramah Region DL Hyetograph



Storm type	a	b
First quartile (current study)	0.022	1
Second quartile (current study)	0.410	1

SCS Model Equations

$$\boxed{S_{\max}(mm) = 10\left[\frac{2540}{CN} - 25.4\right]}$$

$$\boxed{R_s = \frac{\left[P - 0.2S_{\max}\right]^2}{\left[P + 0.8S_{\max}\right]}}$$

$$F = (P - 0.2S_{\max}) - R_s$$

Timing in The Hydrograph

$$T_L = \frac{L^{0.8}(2540 - 22.86CN)^{0.7}}{14104CN^{0.7}Y^{0.5}}$$

in which t_l = catchment lag in hours; L = hydraulic length (length measured along principal watercourse) in meters; CN = runoff curve number; and Y = average catchment land slope in meters per meter. In U.S. customary units, the formula is:

$$T_p = D/2 + T_L$$

Where T_p = time to peak (hours)
D = duration of excess rainfall (hr)
T_L = time of lag (hr)

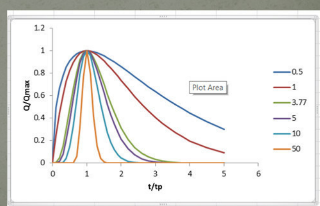
$$T_c = T_L / 0.6$$

$$D = 0.133T_c$$

Dimensionless Hydrograph

$$Q(t) = Q_{\max}\left[\left(\frac{t}{t_p}\right)\exp\left(1 - \frac{t}{t_p}\right)\right]^K$$

$$K = 6.5\left(\frac{Q_{\max}t_p}{V}\right)$$



Where, Q_{max} is the maximum inflow,
t_p is the time to peak of the inflow hydrograph, and
K is the shape factor of the hydrograph,
V is the volume of the inflow hydrograph, for the SCS-unit hydrograph, the value of K is 3.77.

(Haan, 1970);

Unit Hydrograph (1 mm)Peak Value

$$q = C\frac{A}{T_p}$$

$$C = 0.0021$$

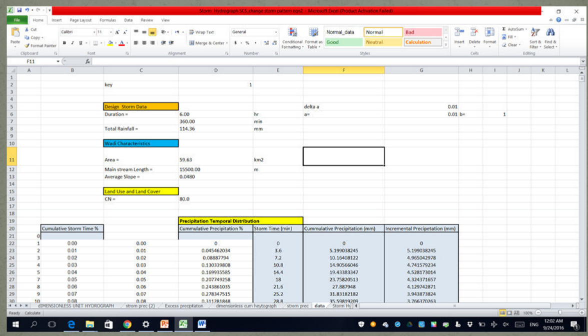
where

q = runoff rate in m^3/s

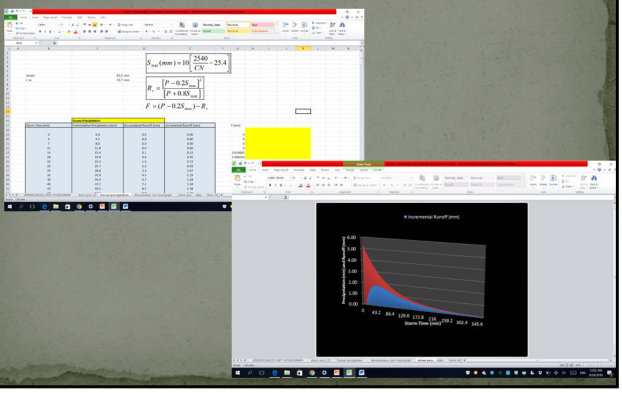
A = watershed area in ha. km2=100 ha

T_p = time of peak in hours

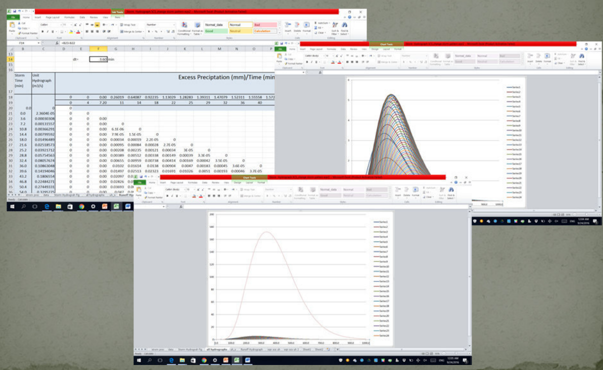
Input data sheet



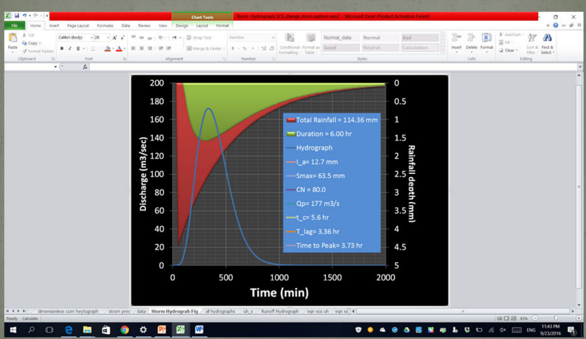
Excess rainfall calculation



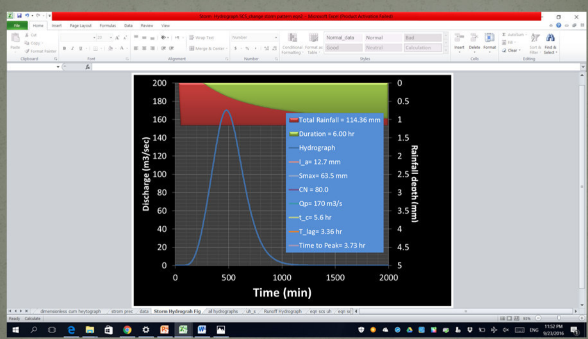
Convulsion table form UH to SH

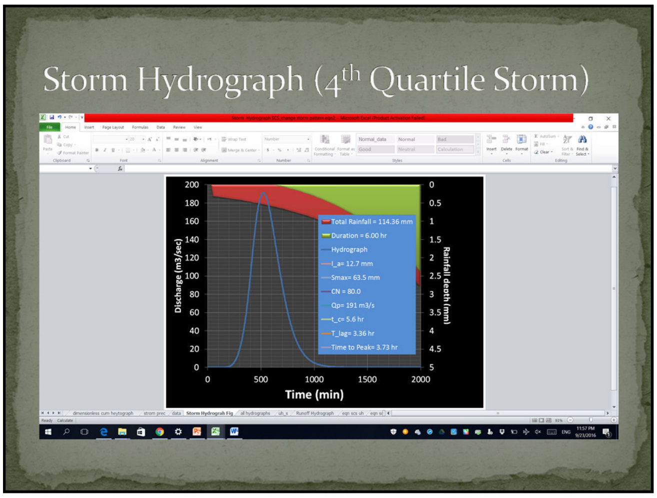


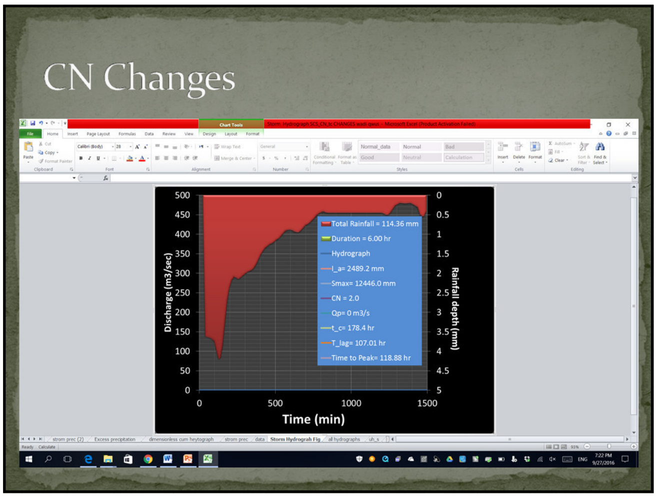
Storm Hydrograph (1th Quartile Storm)

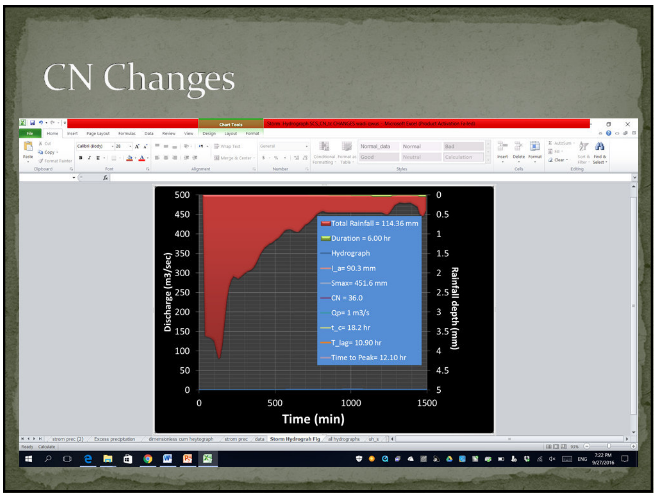


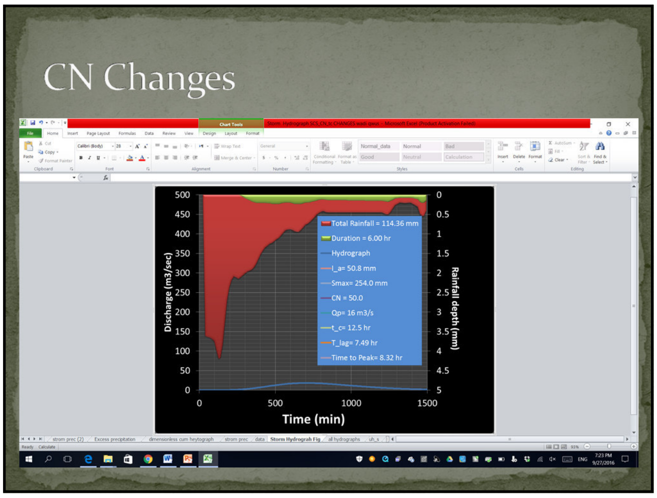
Storm Hydrograph (Uniform Storm)

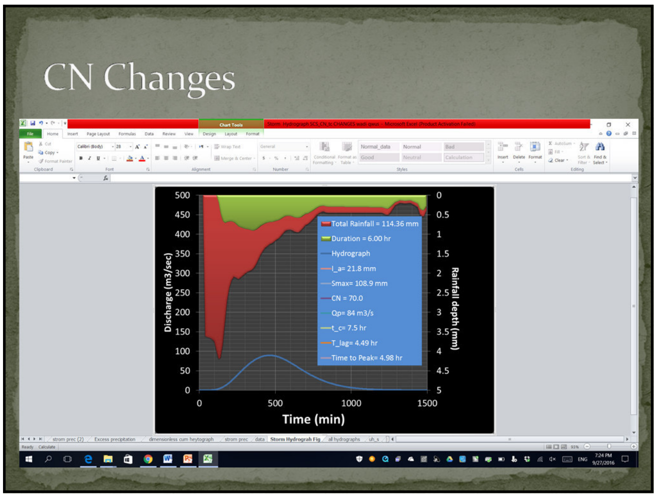


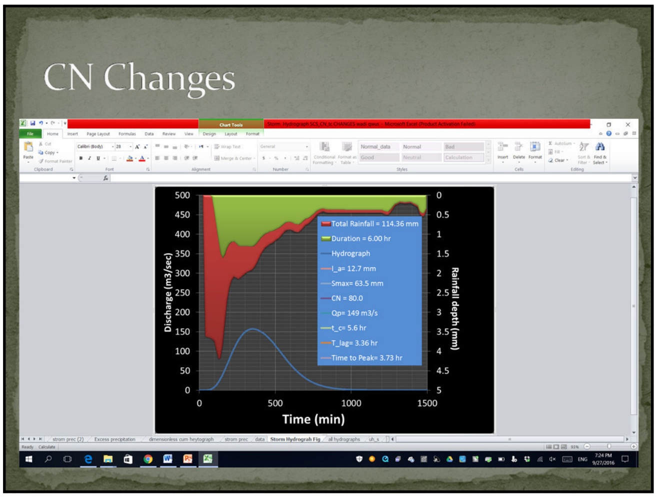

Storm Hydrograph (4th Quartile Storm)
Discharge (m3/sec)
Rainfall depth (mm)
Time (min)
Total Rainfall = 114.36 mm
Duration = 6.00 hr
Hydrograph
I_a= 12.7 mm
Smax= 63.5 mm
CN = 80.0
Qp= 191 m3/s
t_c= 5.6 hr
T_lag= 3.36 hr
Time to Peak= 3.73 hr

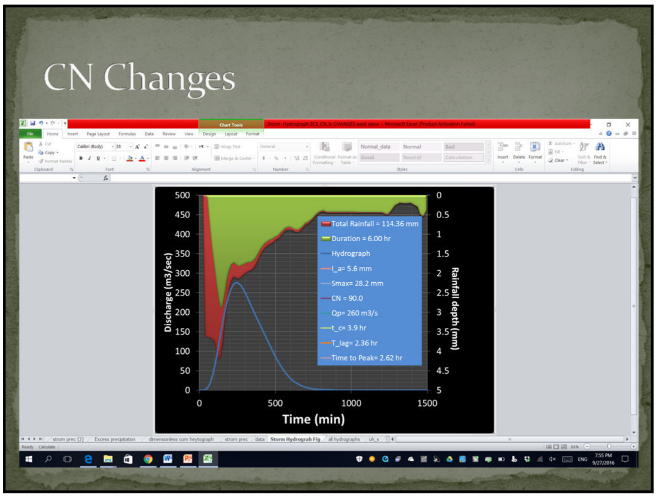

CN Changes
Discharge (m3/sec)
Rainfall depth (mm)
Time (min)
Total Rainfall = 114.36 mm
Duration = 6.00 hr
Hydrograph
I_a= 2489.2 mm
Smax= 12446.0 mm
CN = 2.0
Qp= 0 m3/s
t_c= 178.4 hr
T_lag= 107.01 hr
Time to Peak= 118.88 hr

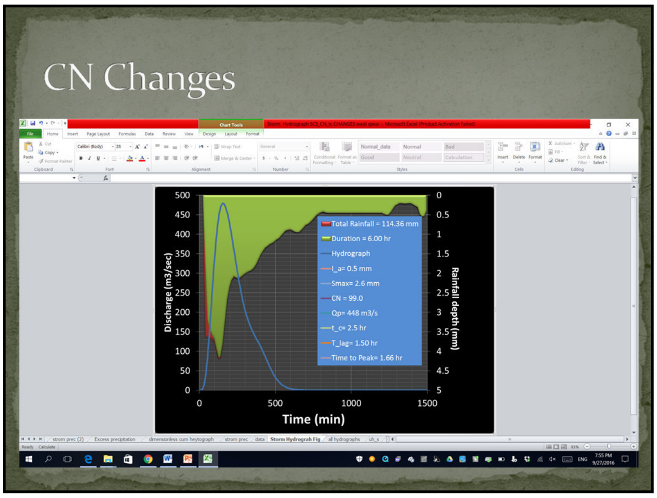

CN Changes
Discharge (m3/sec)
Rainfall depth (mm)
Time (min)
Total Rainfall = 114.36 mm
Duration = 6.00 hr
Hydrograph
I_a= 90.3 mm
Smax= 451.6 mm
CN = 36.0
Qp= 1 m3/s
t_c= 18.2 hr
T_lag= 10.90 hr
Time to Peak= 12.10 hr

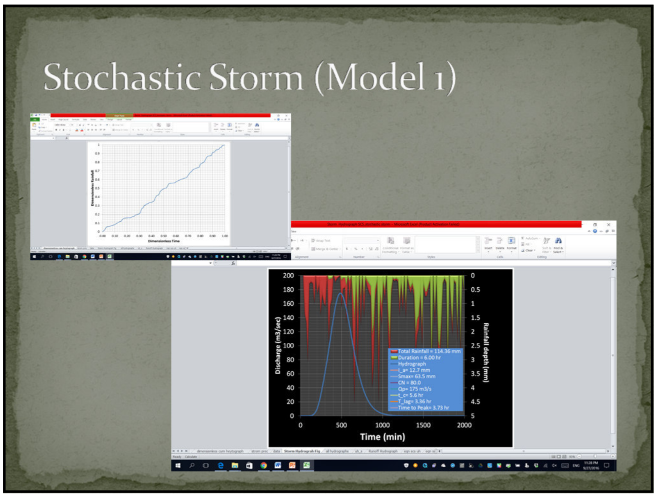

CN Changes
Discharge (m3/sec)
Rainfall depth (mm)
Time (min)
Total Rainfall = 114.36 mm
Duration = 6.00 hr
Hydrograph
I_a= 50.8 mm
Smax= 254.0 mm
CN = 50.0
Qp= 16 m3/s
t_c= 12.5 hr
T_lag= 7.49 hr
Time to Peak= 8.32 hr

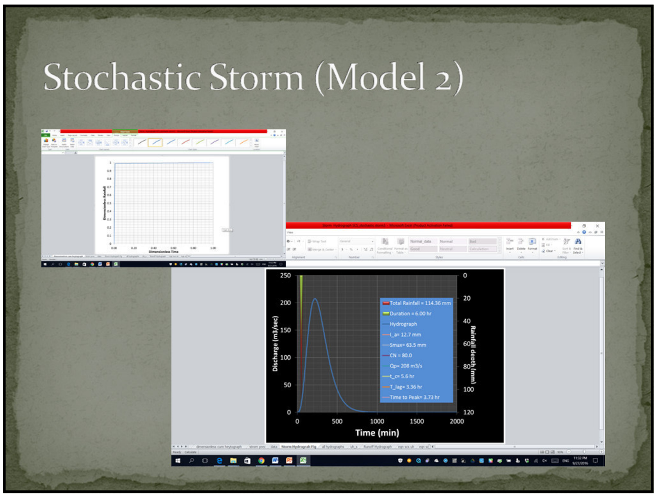

CN Changes
Discharge (m3/sec)
Rainfall depth (mm)
Time (min)
Total Rainfall = 114.36 mm
Duration = 6.00 hr
Hydrograph
I_a= 21.8 mm
Smax= 108.9 mm
CN = 70.0
Qp= 84 m3/s
t_c= 7.5 hr
T_lag= 4.49 hr
Time to Peak= 4.98 hr

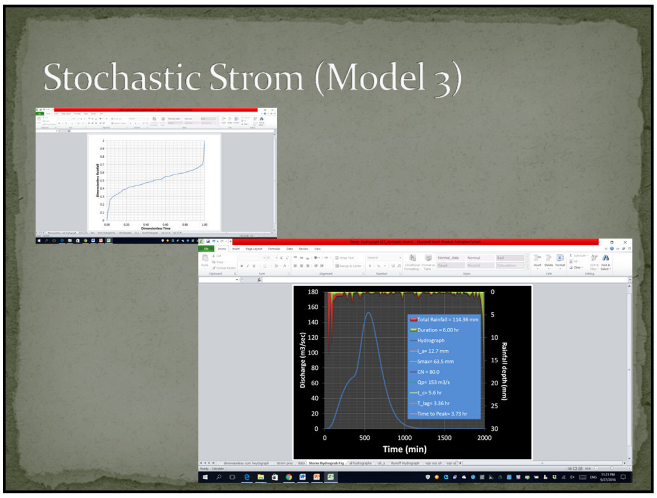

CN Changes
Discharge (m3/sec)
Rainfall depth (mm)
Time (min)
Total Rainfall = 114.36 mm
Duration = 6.00 hr
Hydrograph
I_a= 12.7 mm
Smax= 63.5 mm
CN = 80.0
Qp= 149 m3/s
t_c= 5.6 hr
T_lag= 3.36 hr
Time to Peak= 3.73 hr

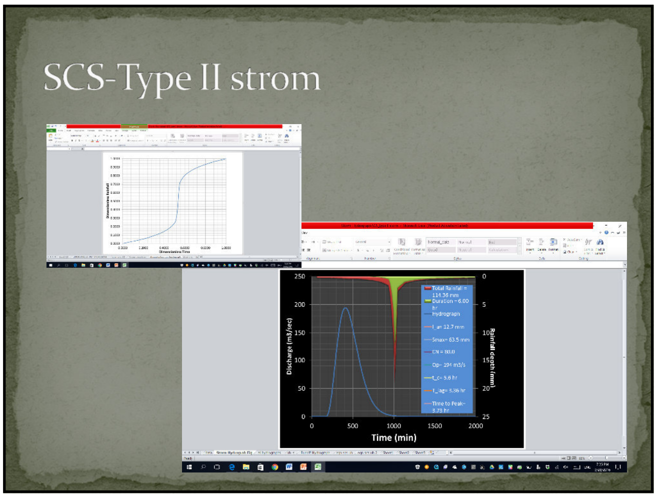

CN Changes
Total Rainfall = 114.36 mm
Duration = 6.00 hr
Hydrograph
I_a= 5.6 mm
Smax= 28.2 mm
CN = 90.0
Qp= 260 m3/s
t_c= 3.9 hr
T_lag= 2.36 hr
Time to Peak= 2.62 hr
Discharge (m3/sec)
Rainfall depth (mm)
Time (min)


CN Changes
Total Rainfall = 114.36 mm
Duration = 6.00 hr
Hydrograph
I_a= 0.5 mm
Smax= 2.6 mm
CN = 99.0
Qp= 448 m3/s
t_c= 2.5 hr
T_lag= 1.50 hr
Time to Peak= 1.66 hr
Discharge (m3/sec)
Rainfall depth (mm)
Time (min)

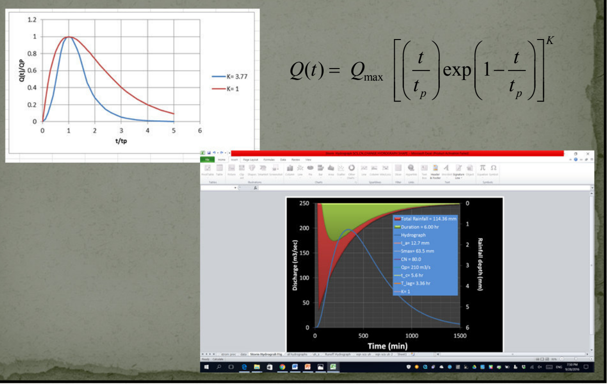

Stochastic Storm (Model 1)
Time (min)


Stochastic Storm (Model 2)
Time (min)


Stochastic Strom (Model 3)
Time (min)

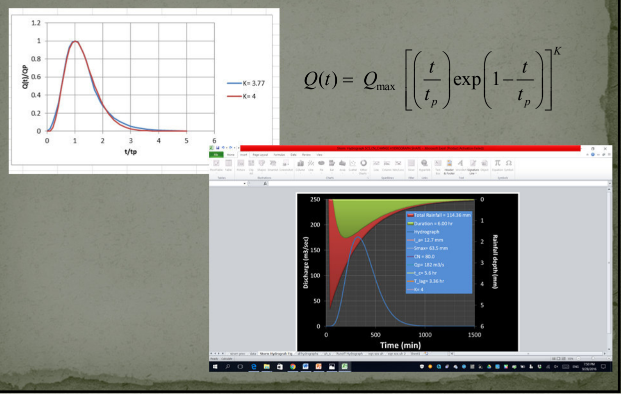

SCS-Type II strom
Time (min)

Dimensionless Hydrograph Shape K=1



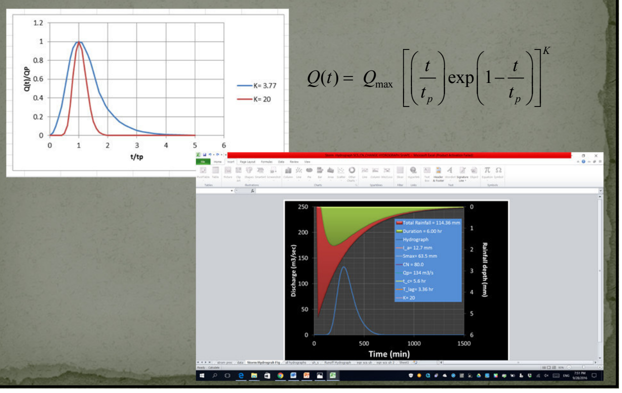
$$Q(t) = Q_{\max}\left[\left(\frac{t}{t_p}\right)\exp\left(1-\frac{t}{t_p}\right)\right]^K$$

Dimensionless Hydrograph Shape K=4



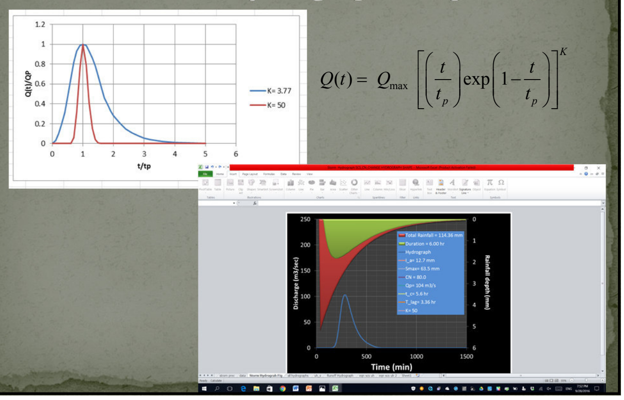
$$Q(t) = Q_{\max}\left[\left(\frac{t}{t_p}\right)\exp\left(1-\frac{t}{t_p}\right)\right]^K$$

Dimensionless Hydrograph Shape K=20



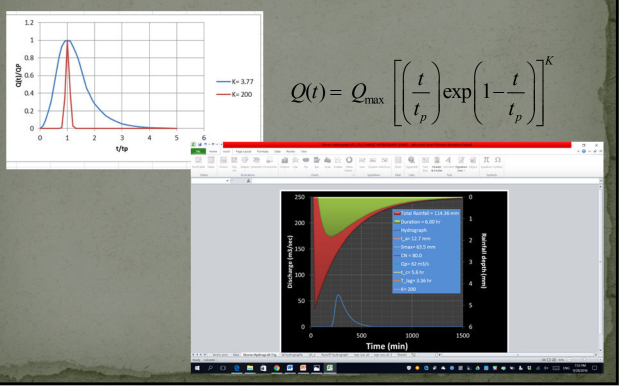
$$Q(t) = Q_{\max}\left[\left(\frac{t}{t_p}\right)\exp\left(1-\frac{t}{t_p}\right)\right]^K$$

Dimensionless Hydrograph Shape K=50



$$Q(t) = Q_{\max}\left[\left(\frac{t}{t_p}\right)\exp\left(1-\frac{t}{t_p}\right)\right]^K$$

Dimensionless Hydrograph Shape K=200

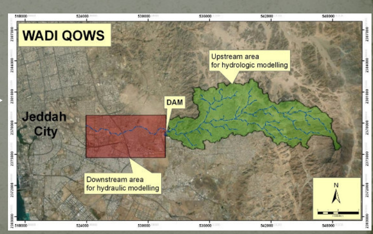


$$Q(t) = Q_{\max}\left[\left(\frac{t}{t_p}\right)\exp\left(1-\frac{t}{t_p}\right)\right]^K$$

Case Study: Wadi Qows in Jeddah

The study area consists of two parts, which are:

- Upper stream area (63.36 km²)
- Down stream area (33.5 km²)

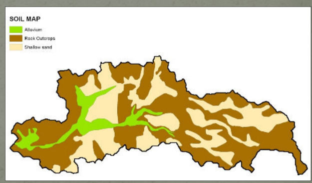


Coordinate of the location:

- Latitude : 21.5° north
- Longitude : 39.3° east

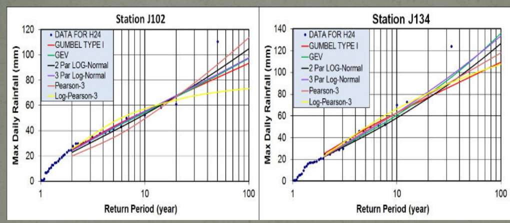
Kuswantoro , 2013

Soil type	Area (m^2)	% of total
Shallow sand	21,573,283	34.0
Rock Outcrops	36,413,577	57.5
Alluvium	5,370,950	8.5
Total =	63,357,810	100.0

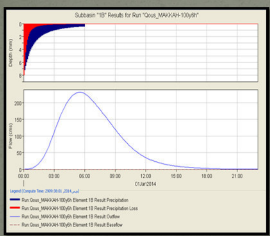


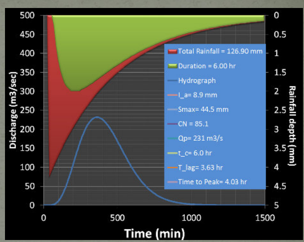
Obtained from Elfeki et al. (2011)

Statistical rainfall analysis for stations J102, and J134.



Comparison between RARUSM and HECHMS





	Qp (m^3/s)	Volume (1000 m^3)
HECHMS	231.6	5430.3
RARUSM	231	5414

Conclusions

- RARUSM Model is highly flexible rainfall-runoff spreadsheet model since it uses dimensionless equations.
- Its capability has been shown in this presentation.
- It produces almost identical results to HECHMS, however, it is more handy and easy to run various scenarios.
- The circular reference option in Excel allows to present continues changes in the runoff hydrograph due to changes in CN, storm pattern parameters, stochastic storms, and dimensionless hydrograph shape.

Future Work

- Automation of some items in the model.
- Make it as a software .
- Make it more user friendly.
- Introducing uncertainty aspects in the model input and the corresponding model output.
- Make continuous variation of other parameters like rainfall intensity, duration, etc.
- Finding out the most suitable hydrograph shape for arid environment.