Quinto Congreso Nacional de Riego y Drenaje
COMEII-AURPAES 2019
Septiembre 2019 | Mazatlán, Sinaloa

AURPAES, S.C.

THE UNIVERSITY OF ARIZONA

A HYDROLOGIC ENGINEERING ANALYSIS OF A FAILED RANGELAND WATER CONTROL STRUCTURE ON THE BUENOS AIRES NATIONAL WILDLIFE REFUGE

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Fecha de presentación **19/septiembre/2019**
Mazatlán, Sinaloa, México

Outline

- Introduction
- Methods and Materials
- Results and Discussion
- Conclusions

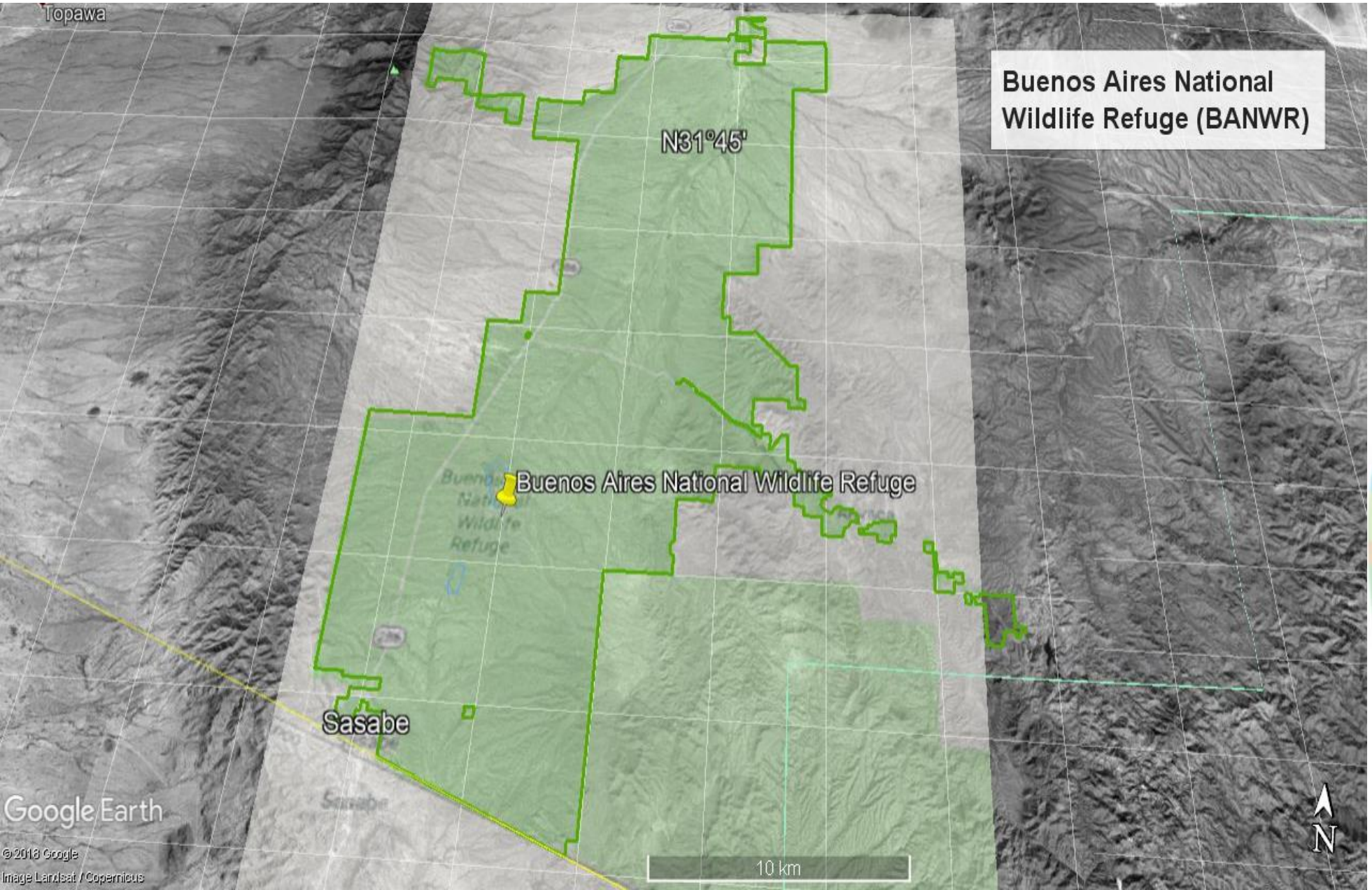
Introduction

- **Comprehensive watershed analysis including:**
  - **Characterization of selected study site watershed**
  - **Historical evaluation of selected study site watershed**
  - **Focus on spillway/weir at hydrological outlet of watershed using hydrologic engineering methods to determine conditions of structural failure**

History of Land Use

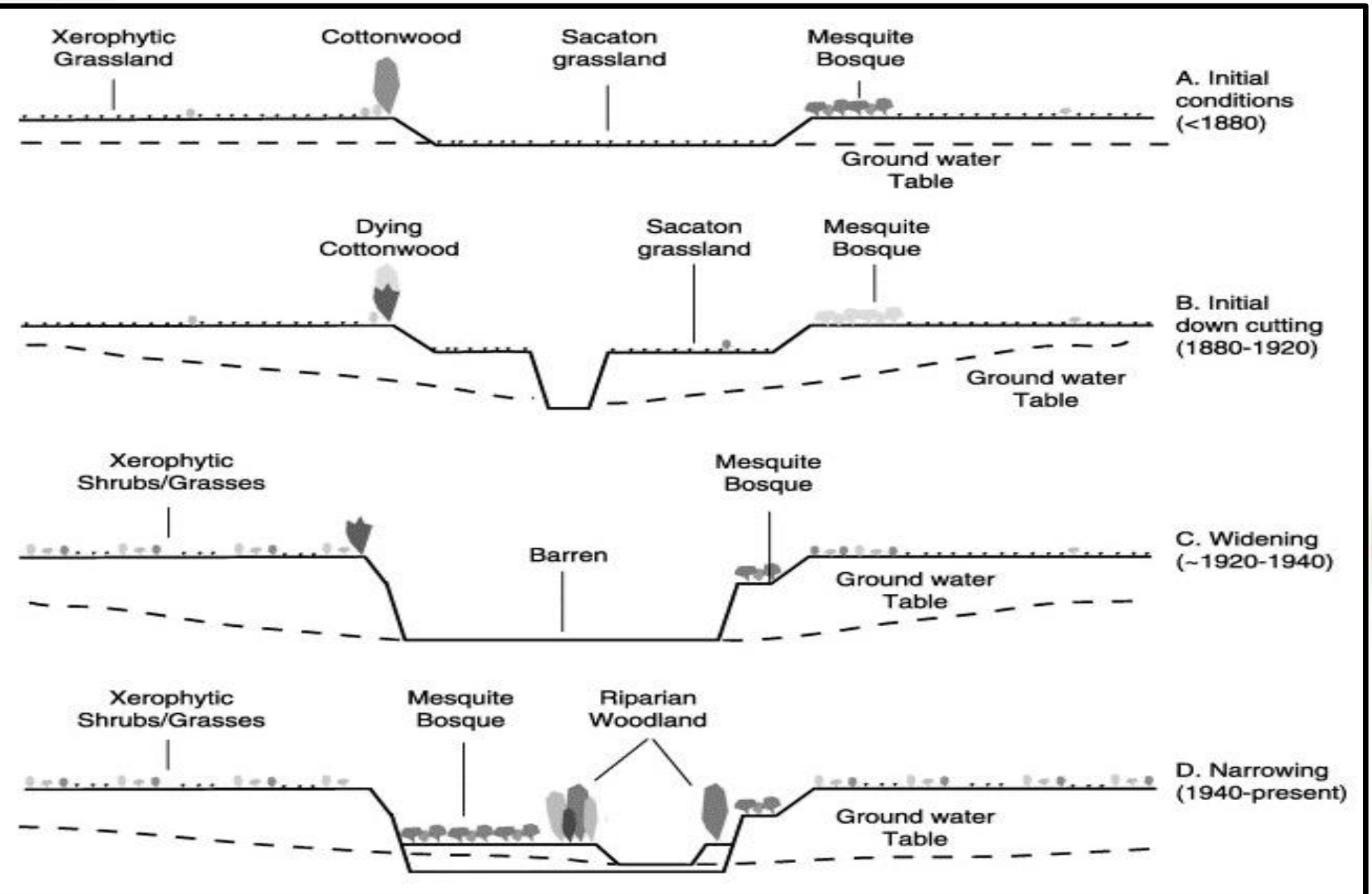
- Study conducted on present-day Buenos Aires National Wildlife Refuge (BANWR)
  - 47,500 [ha] in total
  - Once working cattle ranch
- Founded 1880s by Don Pedro Aguirre Jr. as Buenos Ayres Ranch
- First water retention structure, Aguirre Lake, est. circa 1883-1886
- Many ownership changes—name change to Buenos Aires Ranch in 1909
- Implementation of water control structures (ranch owners and Soil Conservation Service)
- U.S. Fish and Wildlife purchase in 1985 to establish wildlife reserve (BANWR)


Buenos Aires
National Wildlife Refuge
Visitor Information
Refuge Office


Topawa
N31°45'
Buenos Aires National Wildlife Refuge (BANWR)
Buenos Aires National Wildlife Refuge
Sasabe
Google Earth
© 2018 Google
Image Landsat / Copernicus
10 km
N

Focus of Study

- **Declining hydrologic connectivity on arid and semi-arid Southwestern rangelands**
- **Arroyo cutting/channelization of floodplains alters ground/surface water interactions**
- **Heavy grazing, intense flooding, failed/unmaintained water control structures**
- **Water control structures implemented across rangeland watersheds including:**
  - **Berms, water spreaders, spillways/weirs, flow control gates, stock tanks**


Xerophytic Grassland
Cottonwood
Sacaton grassland
Mesquite Bosque
A. Initial conditions (<1880)
Ground water Table
Dying Cottonwood
Sacaton grassland
Mesquite Bosque
B. Initial down cutting (1880-1920)
Ground water Table
Xerophytic Shrubs/Grasses
Mesquite Bosque
Barren
C. Widening (~1920-1940)
Ground water Table
Xerophytic Shrubs/Grasses
Mesquite Bosque
Riparian Woodland
D. Narrowing (1940-present)
Ground water Table

Objectives of Study

1. **Map watershed by pinpointing key water control structures and drainages/streamlines**

2. **Utilize historic/current aerial/ground-level imagery to characterize watershed**

3. **Conduct hydrologic engineering analysis of spillway to quantify maximum capacity and the storm magnitude generating large enough runoff to exceed that capacity**

Methods and Materials

1. **Geographic Information Systems (GIS) software (ArcMap 10.5.1 and Google Earth Pro)**

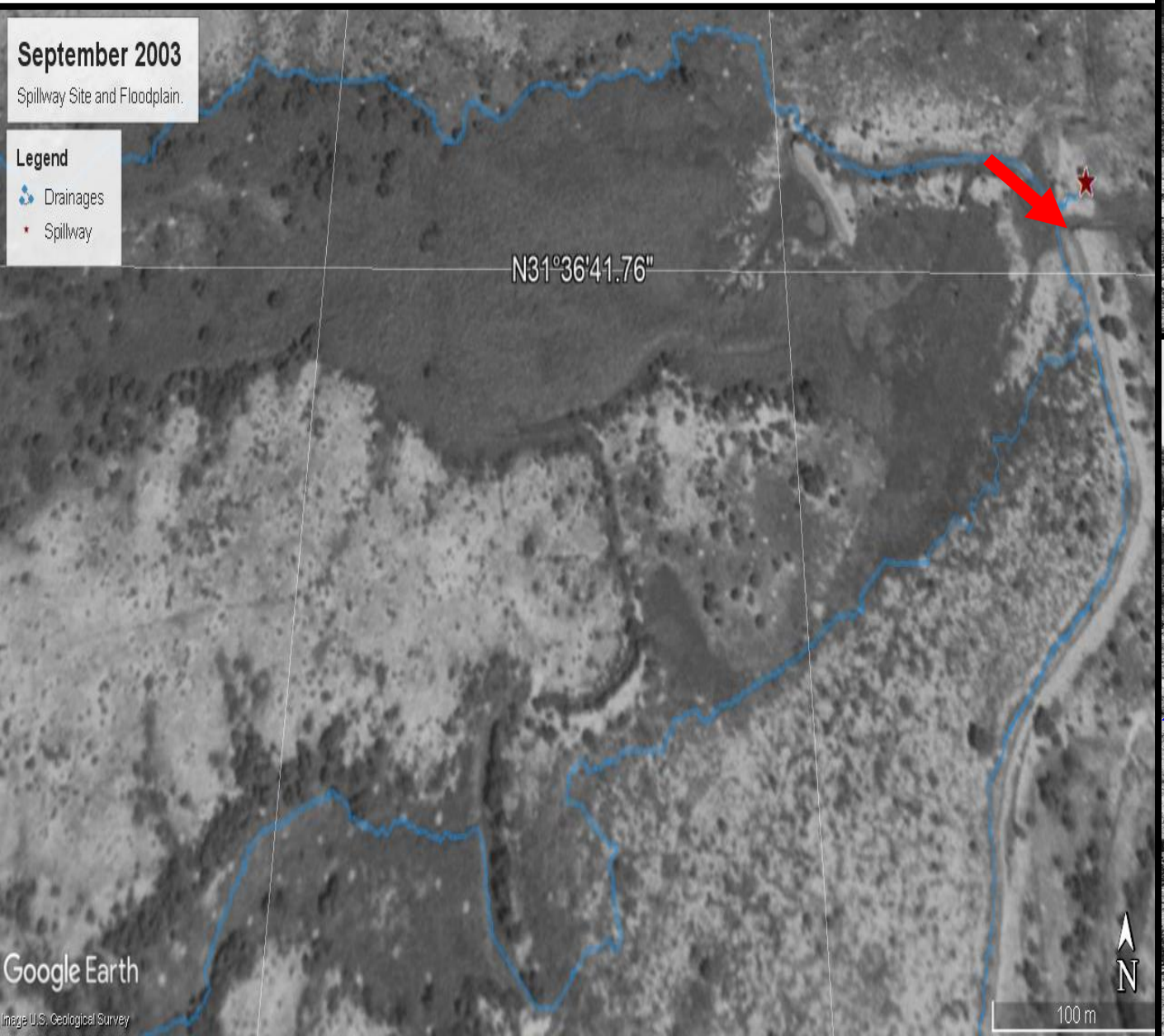
2. **Both historic and current aerial and ground-level imagery**

   (USGS Earth Explorer, Google Earth Pro, photos taken in person)

3. **Field visits to walk watershed hydrologic route and take measurements of spillway**

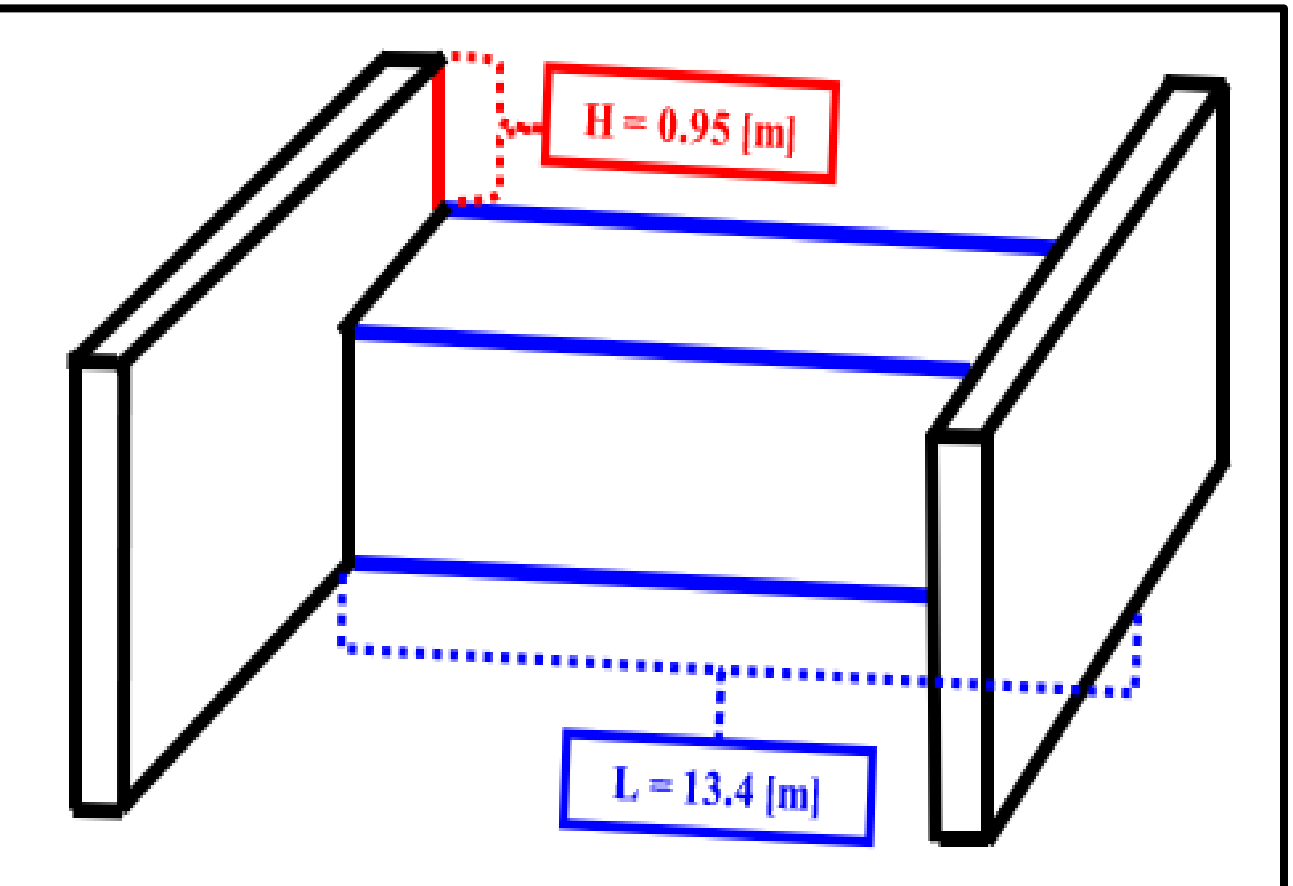
4. **Hydrologic engineering analysis via weir formula, Rational and Curve Number Methods**

Spillway Site



Spillway Capacity

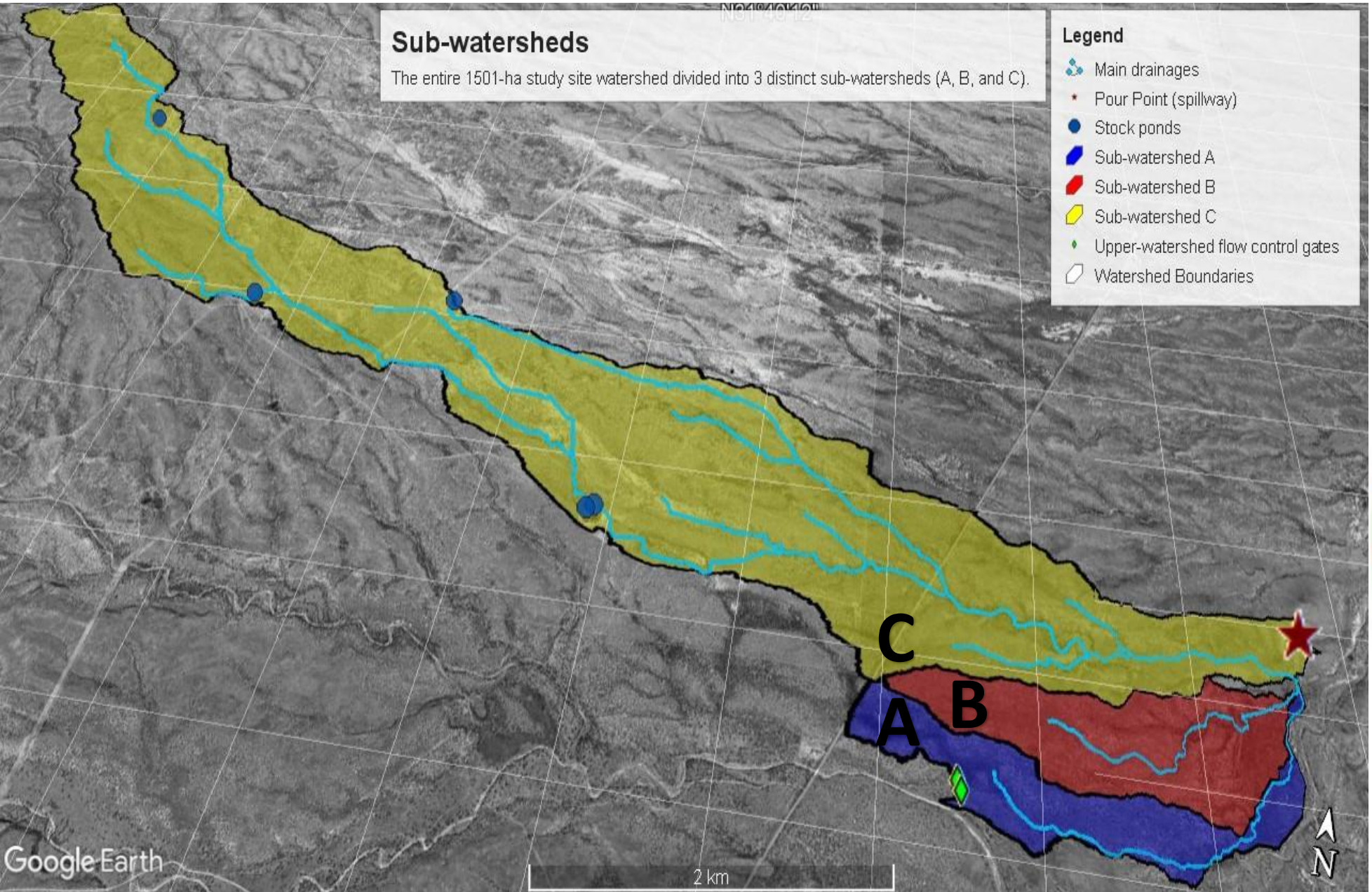
- **Spillway capacity calculated using standard weir formula:**



$$Q = CLH^{\frac{3}{2}}$$

where,

Q = discharge [m^3s^{-1}]
C = weir coefficient = 1.70
L = weir length [m]
H = hydraulic head [m]


Sub-watersheds
The entire 1501-ha study site watershed divided into 3 distinct sub-watersheds (A, B, and C).
Legend
Main drainages
Pour Point (spillway)
Stock ponds
Sub-watershed A
Sub-watershed B
Sub-watershed C
Upper-watershed flow control gates
Watershed Boundaries
C
B
A
Google Earth
2 km
N

Runoff Estimations (Rational Method)

- **The peak flow rate was calculated as:**

$$q_p = \frac{CiA}{360}$$

where,

q_p **= peak runoff [$m^3 s^{-1}$]**
C **= runoff coefficient**
i **= rainfall intensity [mm/hr]**
A **= drainage area [ha]**

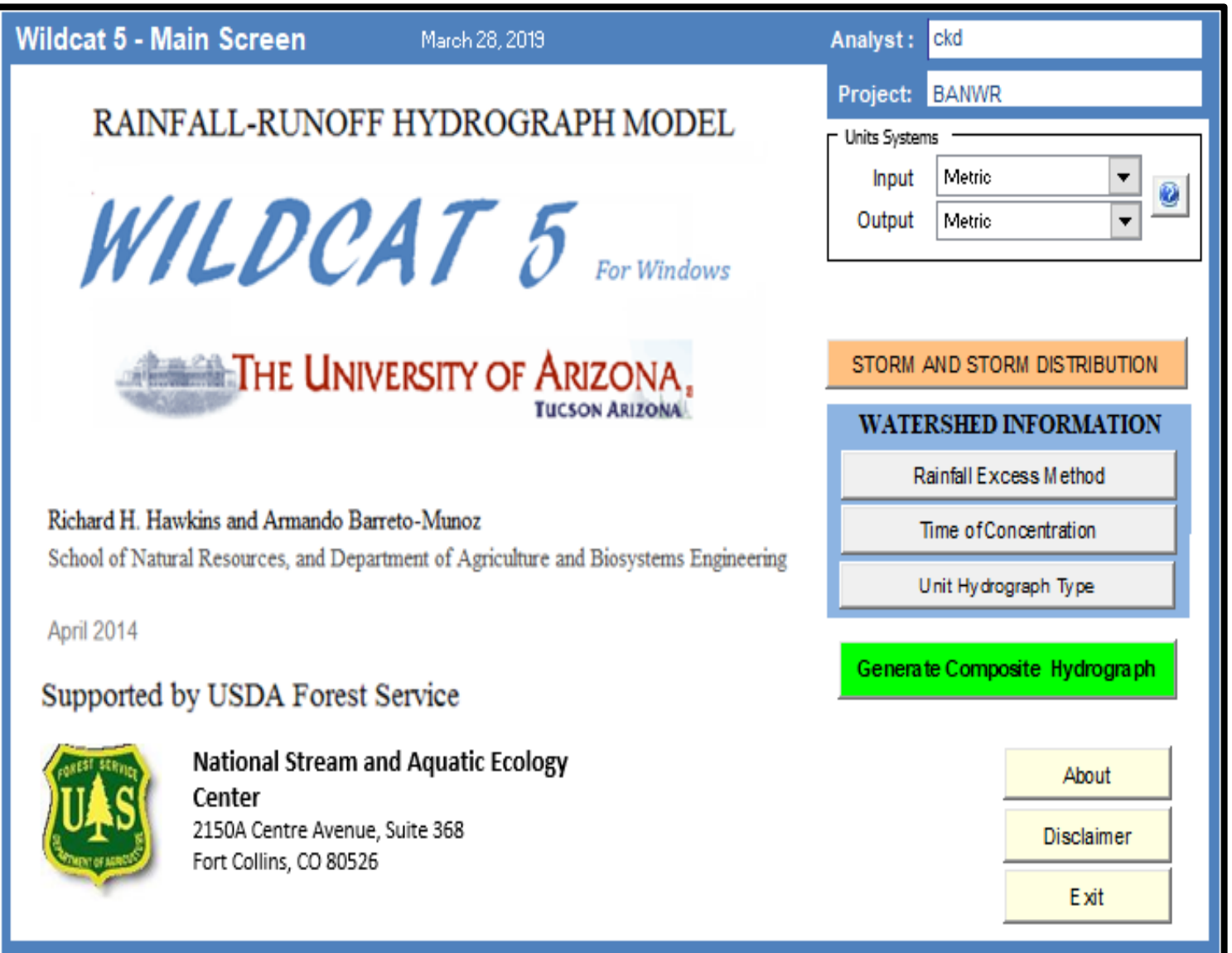
- **Runoff coefficients from USDA Web Soil Survey**

- **Rainfall intensities from NOAA**

- **Watershed areas:**

Sub-watershed A – 94.2 [ha]
Sub-watershed B – 122 [ha]
Sub-watershed C – 1285 [ha]
Entire watershed – 1501 [ha]

Design Storms (Curve Number Method)



- **Rainfall-runoff hydrograph modeling via add-on for Microsoft Excel called Wildcat5**
- **Assists watershed analysts in predicting peak flow/runoff volumes from single-event storms with Curve Number Method as basis**

Curve Number Method

- **CN Method is basis for estimation of runoff volume and generation of hydrograph:**

$$Q = \frac{(P-0.2S)^2}{P+0.8S}, \mathrm{P} > 0.2\mathrm{S}$$

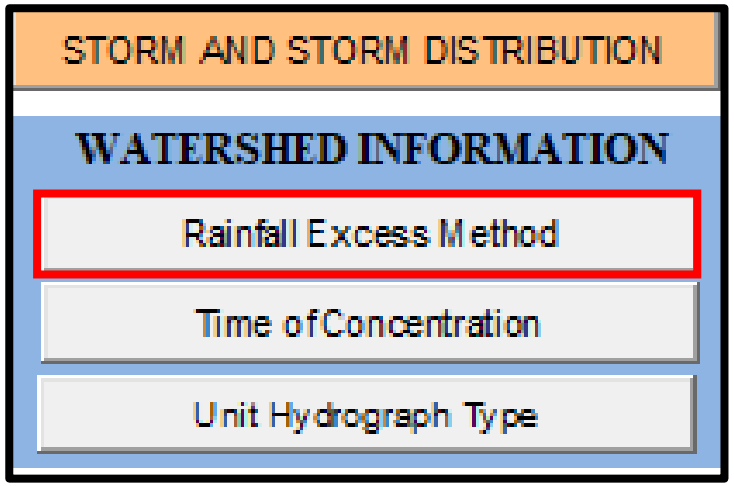
where,

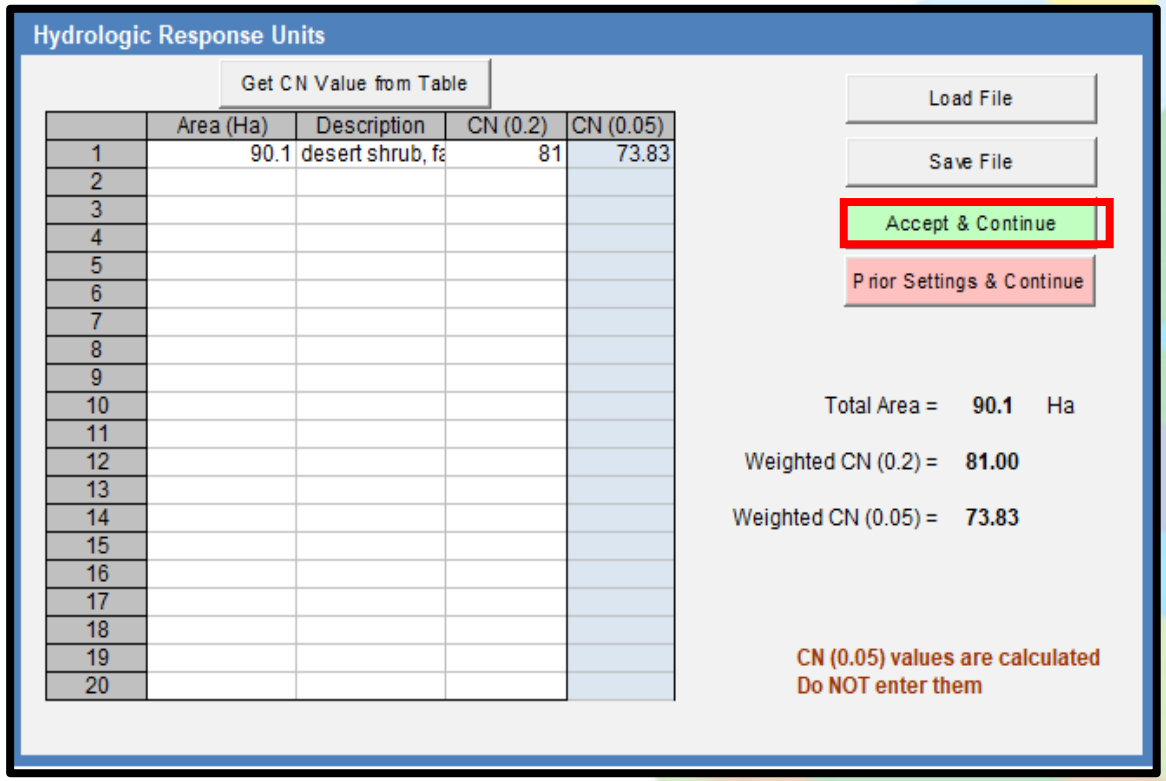
Q = runoff depth/volume [mm]
P = precipitation depth [mm]
S = soil water retention parameter [mm]

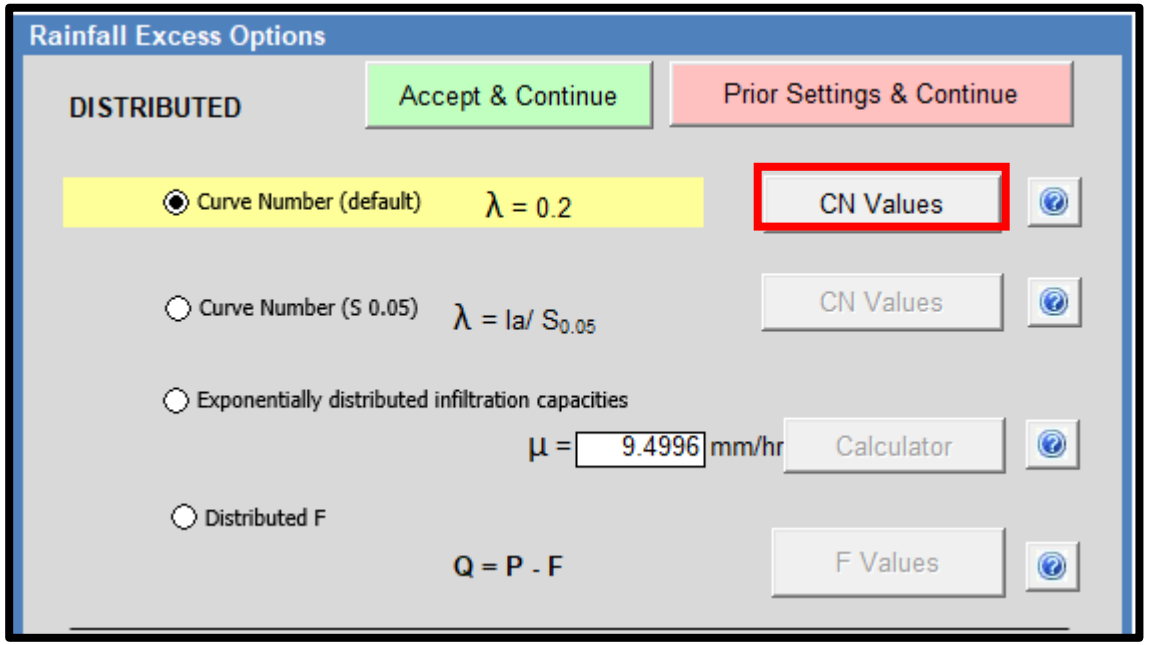
- **The soil water retention parameter is based on the CN and is found using:**

$$S = \frac{25400}{CN} - 254 \ (\mathrm{Q, P, S\ [mm]})$$

Wildcat5


STORM AND STORM DISTRIBUTION
WATERSHED INFORMATION
Rainfall Excess Method
Time of Concentration
Unit Hydrograph Type


Hydrologic Response Units
Get CN Value from Table
Load File
Save File
Accept & Continue
Prior Settings & Continue
Area (Ha)
Description
CN (0.2)
CN (0.05)
1 90.1 desert shrub, fa 81 73.83
Total Area = 90.1 Ha
Weighted CN (0.2) = 81.00
Weighted CN (0.05) = 73.83
CN (0.05) values are calculated
Do NOT enter them


Rainfall Excess Options
DISTRIBUTED
Accept & Continue
Prior Settings & Continue
Curve Number (default)
λ = 0.2
CN Values
Curve Number (S 0.05)
λ = Ia/ S0.05
CN Values
Exponentially distributed infiltration capacities
μ = 9.4996 mm/hr
Calculator
Distributed F
Q = P - F
F Values

STORM AND STORM DISTRIBUTION

WATERSHED INFORMATION

Rainfall Excess Method

Time of Concentration

Unit Hydrograph Type

STORM AND STORM DISTRIBUTION

WATERSHED INFORMATION

Rainfall Excess Method

Time of Concentration

Unit Hydrograph Type

Watershed Info & Time of Concentration

Watershed Identification: 1/4/2010

Area (Ha) 90.1 CN : 81.00

Time of Concentration / Lag Time

- Given value TC= 0.5 hr
- Calculate Tc: Kent's equation (SCS method) [1972] (most used)

Average Land Slope (%): 2.2

Length of Longest Channel (m): 3140

Calculated Tc (hr): 2.235

- SIMAS Equation TL [Centroid - Centroid Lag]

Width (m): 261

Average Land Slope (Percent): 0.6

Time Lag (hr): 0.792

Curve Numbers

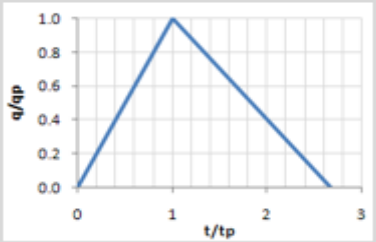
Accept & Continue

Prior Settings & Continue

Help

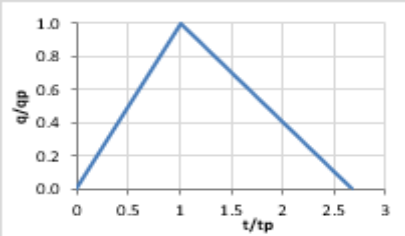
Unit Hydrograph

Simple Triangular Unit Hydrograph



HF = 484, tb/tp=2.67 (most used)

Variable Triangular UH



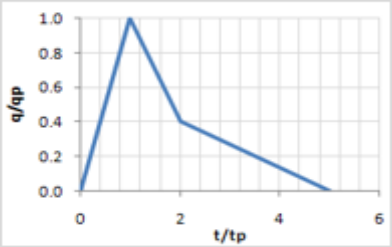
Variable hydrograph factor

tr/tp tb/tp HF

5/3 2.67 484 **Simple Triangular

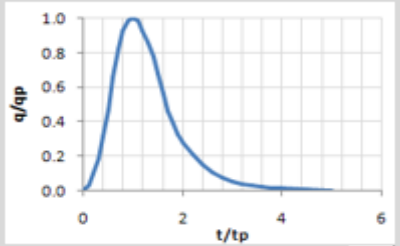
Accept & Continue

Broken Triangle



tb/tp =5

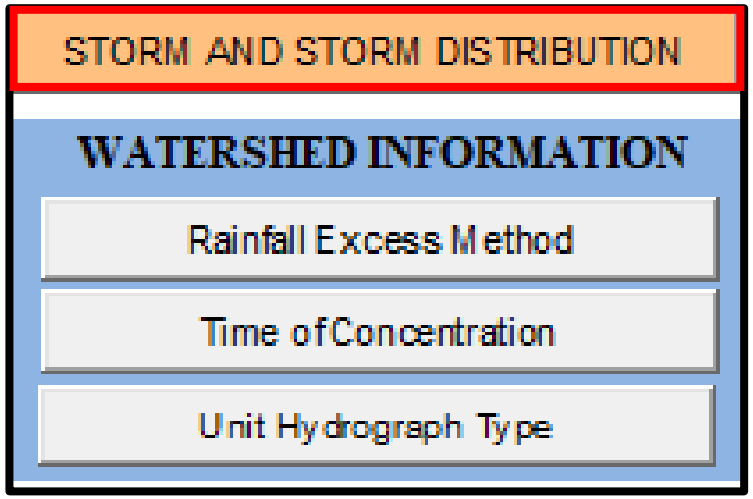
SCS Dimensionless Curvilinear

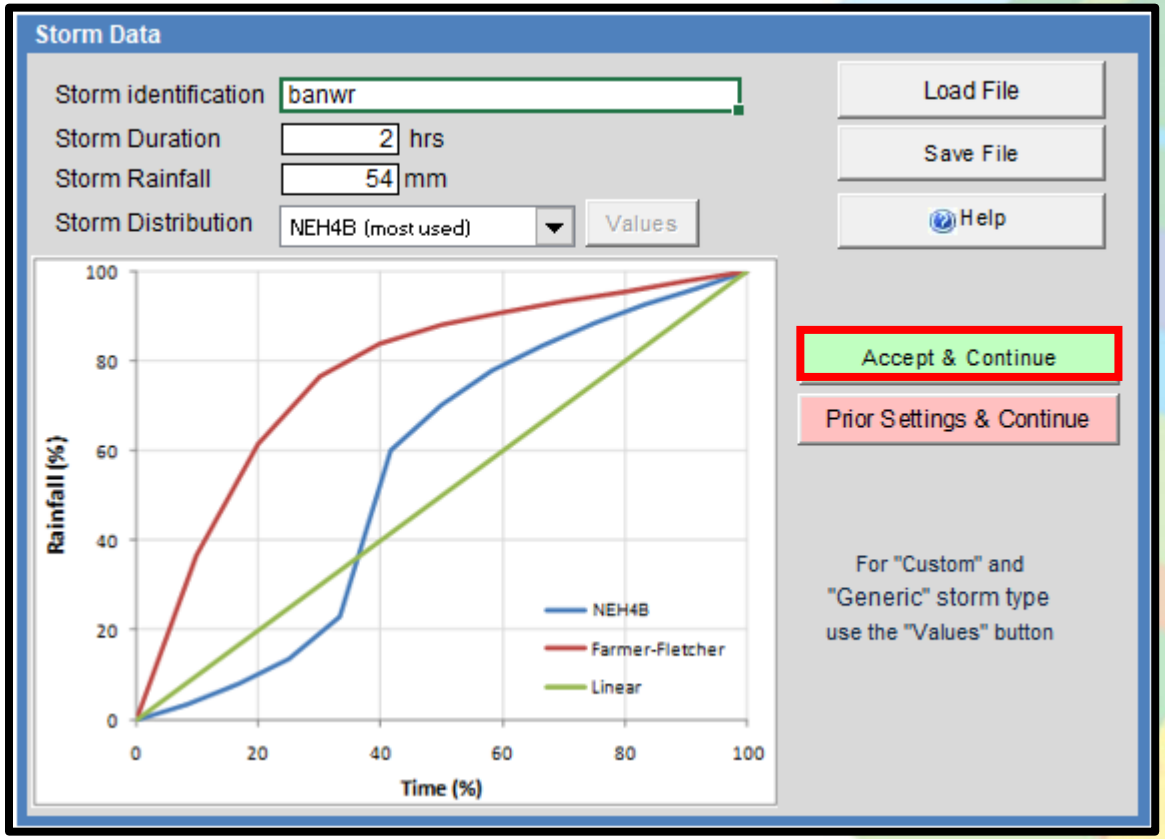


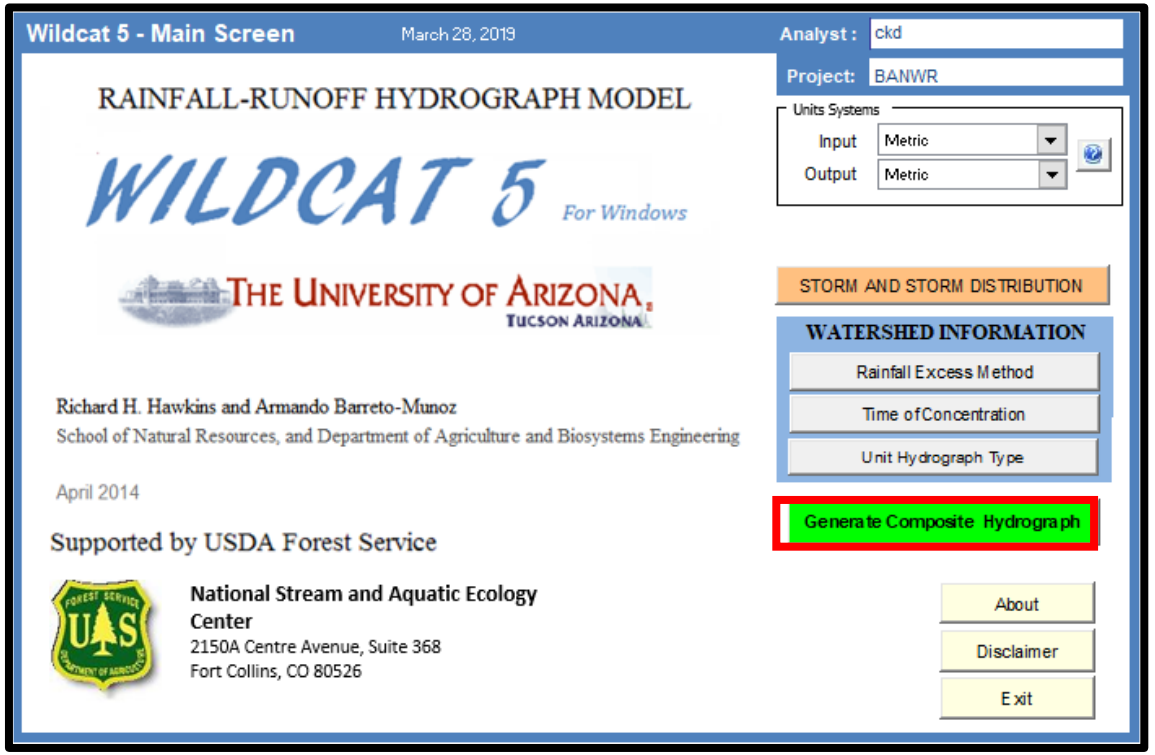
SCS

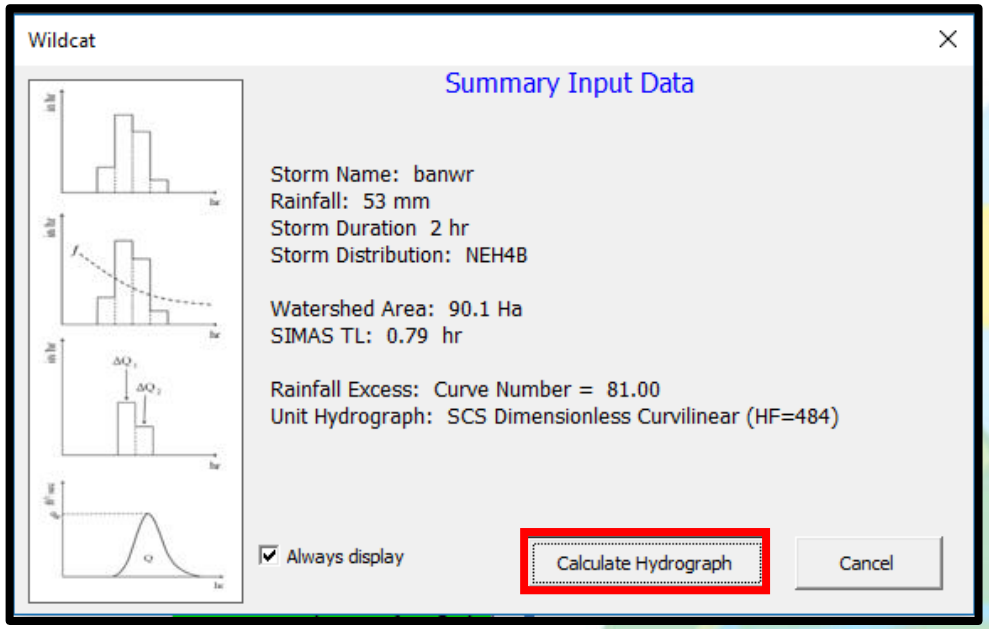
- **Storm *inputs* (duration and rainfall) were split into two categories: “flash floods” (2 and 6-hr) and “floods” (12 and 24-hr)**

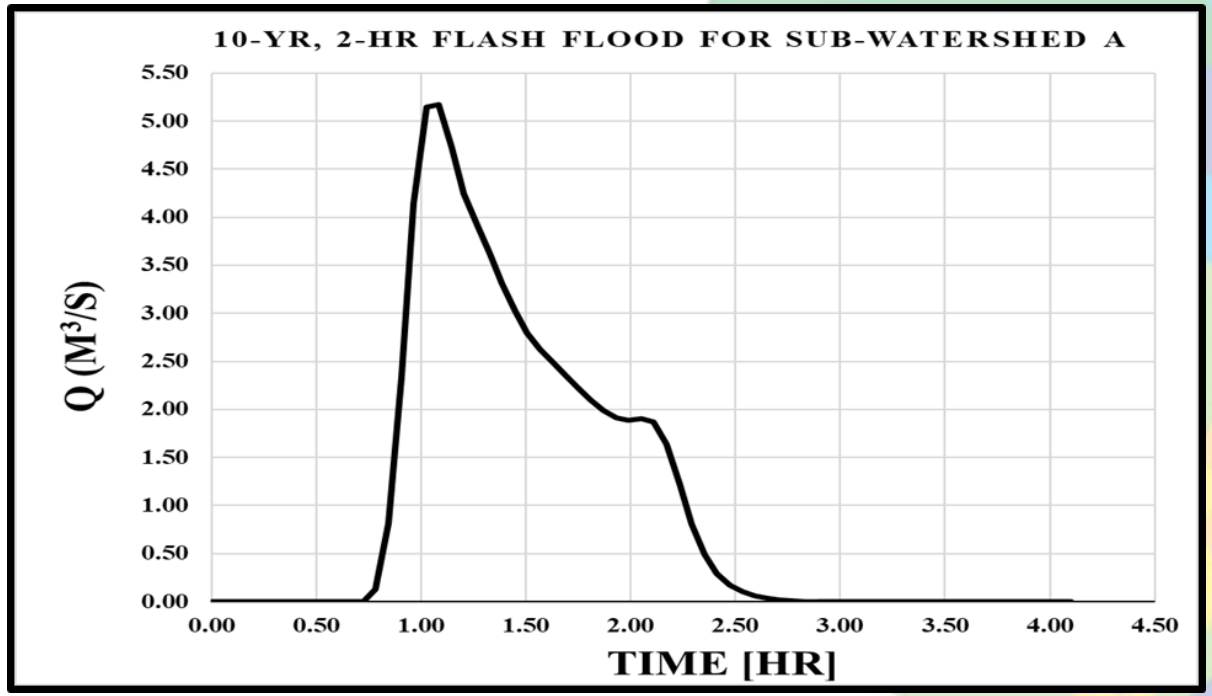
- **Recurrence intervals for the analysis were 10, 25, 60, and 80-year**

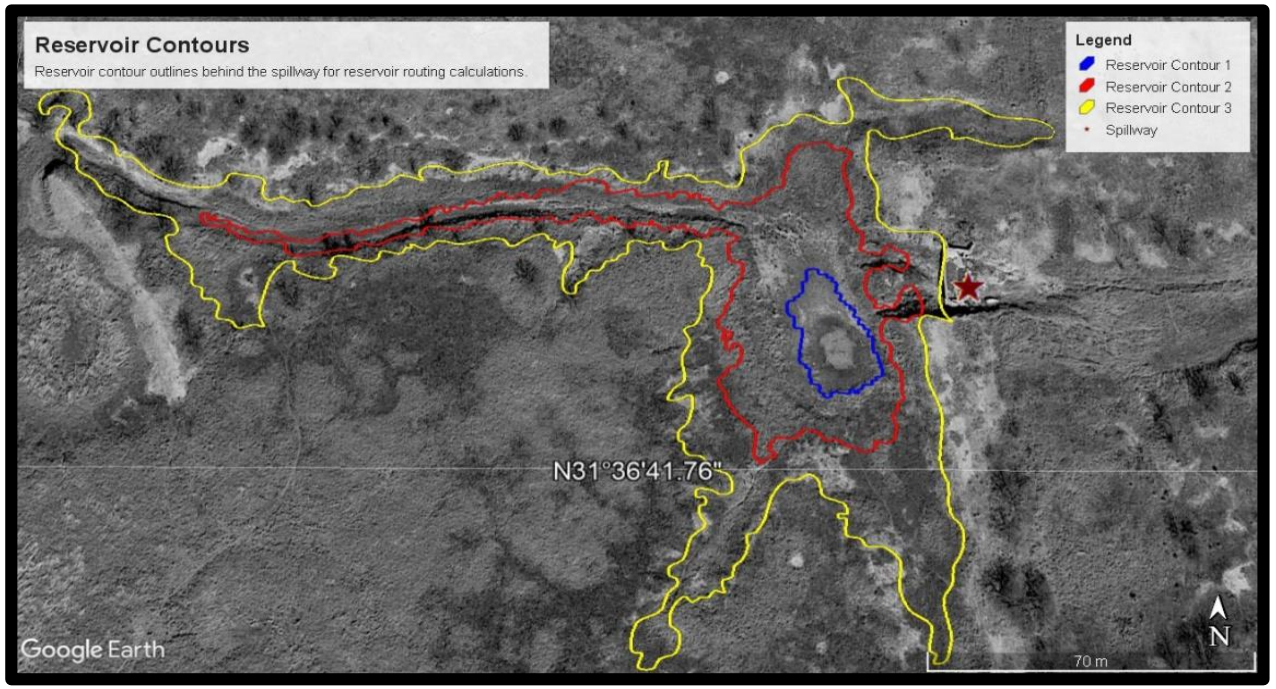


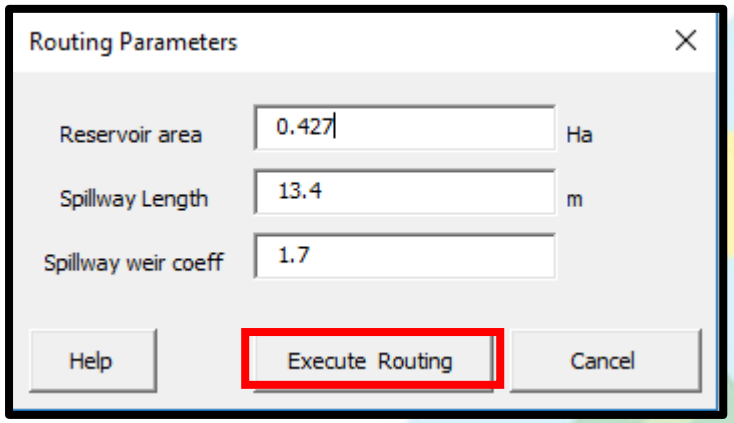


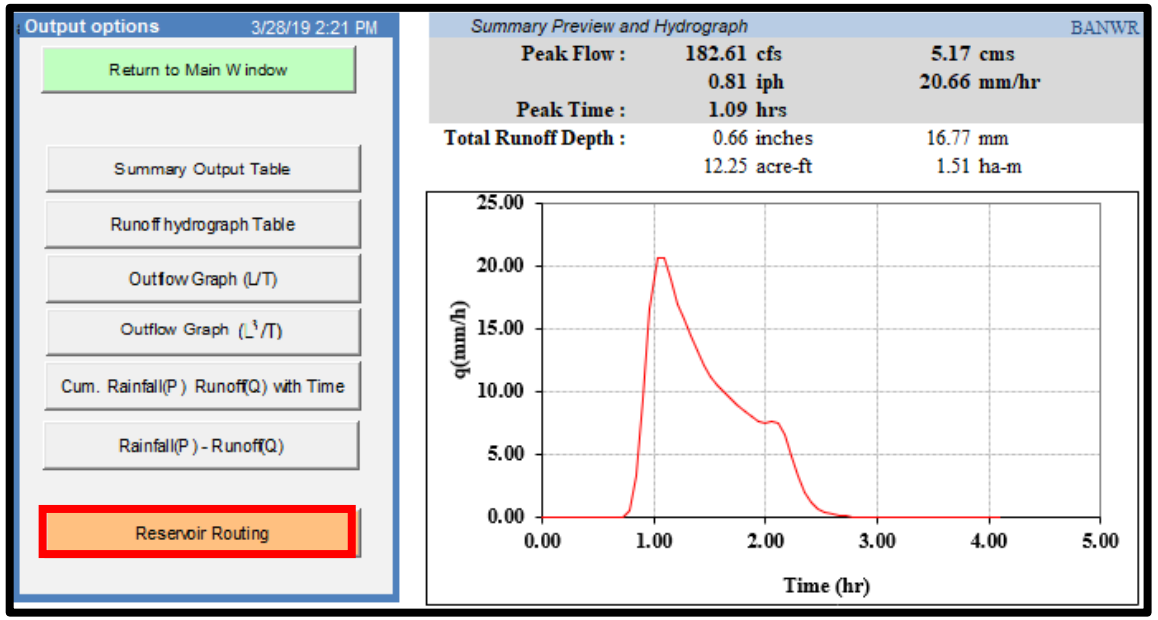

Wildcat 5 - Main Screen
March 28, 2019
Analyst : ckd
Project: BANWR
RAINFALL-RUNOFF HYDROGRAPH MODEL
WILDCAT 5
For Windows
THE UNIVERSITY OF ARIZONA
TUCSON ARIZONA
Units Systems
Input Metric
Output Metric
STORM AND STORM DISTRIBUTION
WATERSHED INFORMATION
Rainfall Excess Method
Time of Concentration
Unit Hydrograph Type
Generate Composite Hydrograph
Richard H. Hawkins and Armando Barreto-Munoz
School of Natural Resources, and Department of Agriculture and Biosystems Engineering
April 2014
Supported by USDA Forest Service
National Stream and Aquatic Ecology Center
2150A Centre Avenue, Suite 368
Fort Collins, CO 80526
About
Disclaimer
Exit

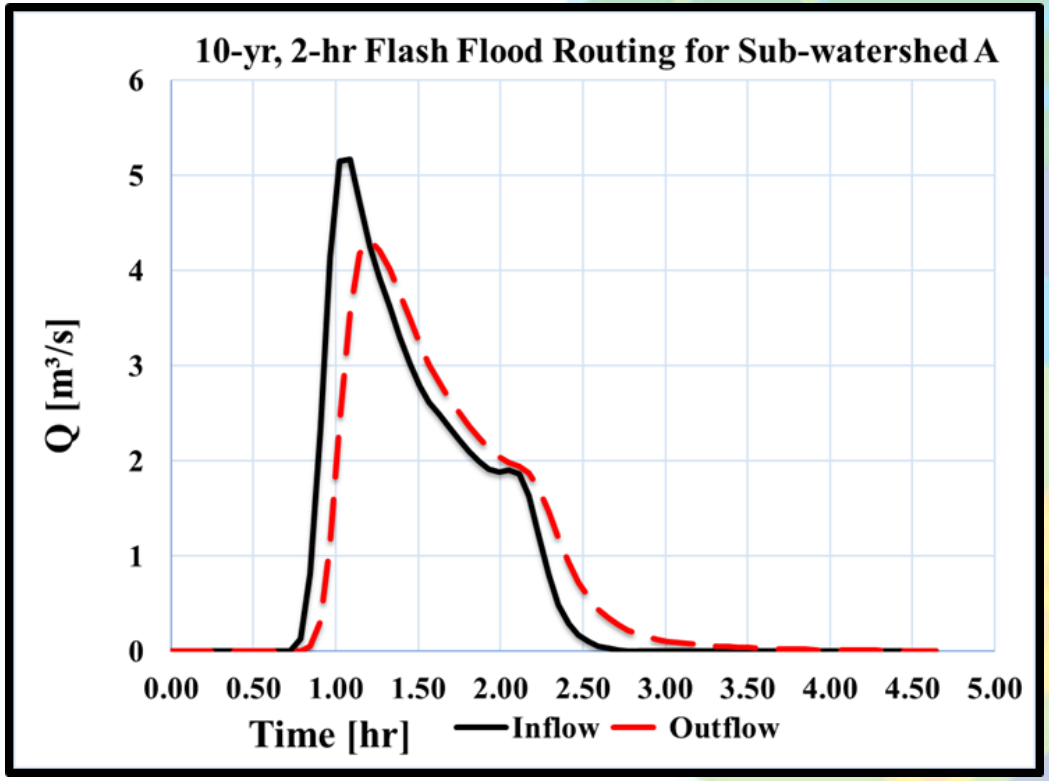

Wildcat
Summary Input Data
Storm Name: banwr
Rainfall: 53 mm
Storm Duration 2 hr
Storm Distribution: NEH4B
Watershed Area: 90.1 Ha
SIMAS TL: 0.79 hr
Rainfall Excess: Curve Number = 81.00
Unit Hydrograph: SCS Dimensionless Curvilinear (HF=484)
Always display
Calculate Hydrograph
Cancel


10-YR, 2-HR FLASH FLOOD FOR SUB-WATERSHED A
Q (M³/S)
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
TIME [HR]


Reservoir Contours
Reservoir contour outlines behind the spillway for reservoir routing calculations.
Legend
Reservoir Contour 1
Reservoir Contour 2
Reservoir Contour 3
Spillway
N31°36'41.76"
Google Earth
70 m
N


Routing Parameters
Reservoir area
0.427
Ha
Spillway Length
13.4
m
Spillway weir coeff
1.7
Help
Execute Routing
Cancel


Output options
3/28/19 2:21 PM
Return to Main Window
Summary Output Table
Runoff hydrograph Table
Outflow Graph (L/T)
Outflow Graph (L³/T)
Cum. Rainfall(P) Runoff(Q) with Time
Rainfall(P) - Runoff(Q)
Reservoir Routing
Summary Preview and Hydrograph
BANWR
Peak Flow : 182.61 cfs 5.17 cms
0.81 iph 20.66 mm/hr
Peak Time : 1.09 hrs
Total Runoff Depth : 0.66 inches 16.77 mm
12.25 acre-ft 1.51 ha-m
q(mm/h)
Time (hr)


10-yr, 2-hr Flash Flood Routing for Sub-watershed A
Q [m³/s]
Time [hr]
Inflow
Outflow

Results and Discussion

- **Spillway Capacity: Q = 21.1 [m^3s^{-1}]**

- **Rational Method:**

Table 1. Precipitation Intensity (mm/hr) and corresponding peak runoff rates (m^3s^{-1}) for Sub-watershed A | Latitude: 31.6042°, Longitude: -111.5129° | Elevation (USGS): 1063.3 m

	Storm Recurrence Interval [yr]					
	10	25	50	60	80	100
Intensity (mm/hr)	46.2	54.9	61.6	63.0	65.7	68.5
Peak runoff (m^3s^{-1})	3.24	3.85	4.32	4.42	4.61	4.80

Table 2. Precipitation Intensity Estimates (mm/hr) and corresponding peak runoff rates (m^3s^{-1}) for Sub-watershed B | Latitude: 31.6074°, Longitude: -111.5094° | Elevation (USGS): 1064.3 m

	Storm Recurrence Interval [yr]					
	10	25	50	60	80	100
Intensity (mm/hr)	61.1	72.8	81.6	83.2	86.5	89.8
Peak runoff (m^3s^{-1})	6.11	7.29	8.17	8.33	8.66	8.99

Table 3. Precipitation Intensity Estimates (mm/hr) and corresponding peak runoff rates (m^3s^{-1}) for Sub-watershed C | Latitude: 31.6596°, Longitude: -111.6144° | Elevation (USGS): 1232.3 m

	Storm Recurrence Interval [yr]					
	10	25	50	60	80	100
Intensity (mm/hr)	20.5	24.6	27.7	28.5	30.1	31.7
Peak runoff (m^3s^{-1})	22.8	27.4	30.9	31.8	33.6	35.4

Table 4. Precipitation Intensity Estimates (mm/hr) and corresponding peak runoff rates (m^3s^{-1}) for Entire 1501-ha Watershed | Latitude: 31.6596°, Longitude: -111.6144° | Elevation (USGS): 1232.3 m

	Storm Recurrence Interval [yr]					
	10	25	50	60	80	100
Intensity (mm/hr)	20.5	24.6	27.7	28.5	30.1	31.7
Peak runoff (m^3s^{-1})	26.4	31.6	35.6	36.7	38.8	40.8

CN Method/Wildcat5

Table 5. Precipitation Depth Estimates (mm) for Sub-watershed C | Latitude: 31.6596°, Longitude: -111.6144° | Elevation (USGS): 1232.3 m

Storm Duration [hr]	Storm Recurrence Interval [yr]			
	10	25	60	80
2	59	71	81.8	85.4
6	67	81	94.2	98.6
12	77	92	107.4	112.2
24	86	102	116.4	121.2

Table 6. Design Storm Peak Flows (m^3s^{-1}) for Sub-watershed C | Latitude: 31.6596°, Longitude: -111.6144° | Elevation (USGS): 1232.3 m

Storm Duration [hr]	Storm Recurrence Interval [yr]			
	10	25	60	80
2	104.8	153.6	200.7	217.0
6	74.5	105.4	136.0	146.3
12	56.8	76.1	96.4	102.8
24	35.7	46.5	56.4	59.7

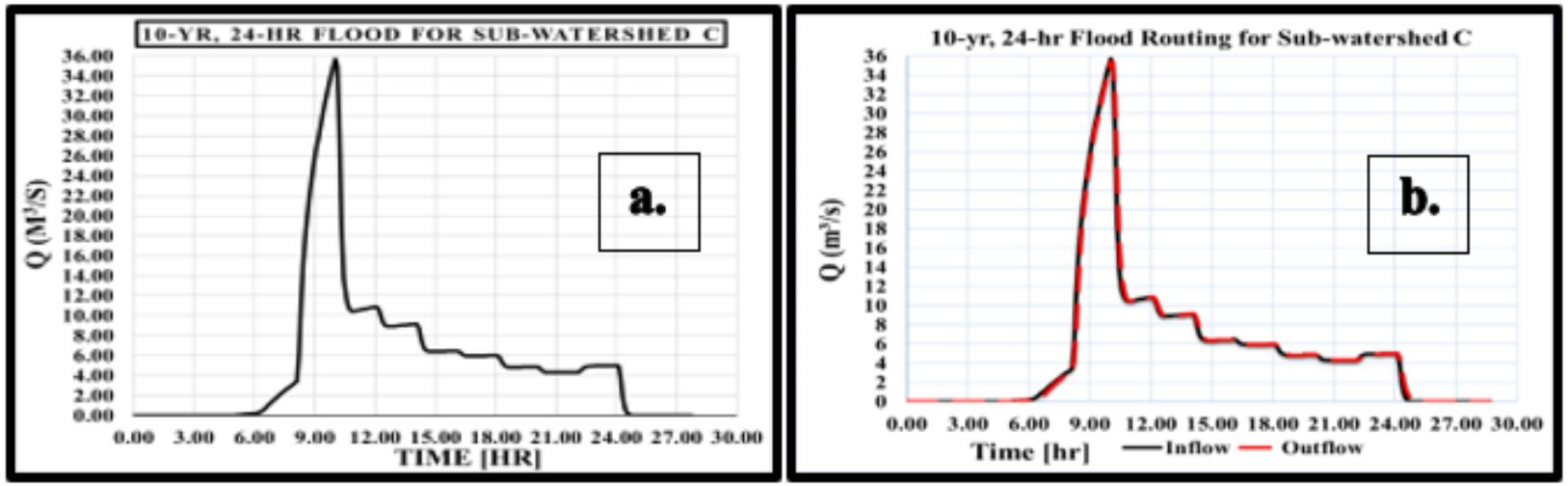


Figure 6. Design storm hydrographs producing peak "flood"-flow at spillway capacity threshold/limit a) 10-yr, 24-hr (35.7 [m^3s^{-1}]) and b) routed through reservoir (35.4 [m^3s^{-1}]) over Sub-watershed C.

Table 7. Precipitation Depth Estimates (mm) for Entire 1501-ha Watershed | Latitude: 31.6596°, Longitude: -111.6144° | Elevation (USGS): 1232.3 m

Storm Duration [hr]	Storm Recurrence Interval [yr]			
	10	25	60	80
2	59	71	81.8	85.4
6	67	81	94.2	98.6
12	77	92	107.4	112.2
24	86	102	116.4	121.2

Table 8. Design Storm Peak Flows (m^3s^{-1}) for Entire 1501-ha Watershed | Latitude: 31.6596°, Longitude: -111.6144° | Elevation (USGS): 1232.3 m

Storm Duration [hr]	Storm Recurrence Interval [yr]			
	10	25	60	80
2	118.1	174.8	229.7	248.6
6	83.4	120.8	158.1	170.9
12	64.5	87.2	111.3	118.9
24	42.0	54.6	66.2	70.0

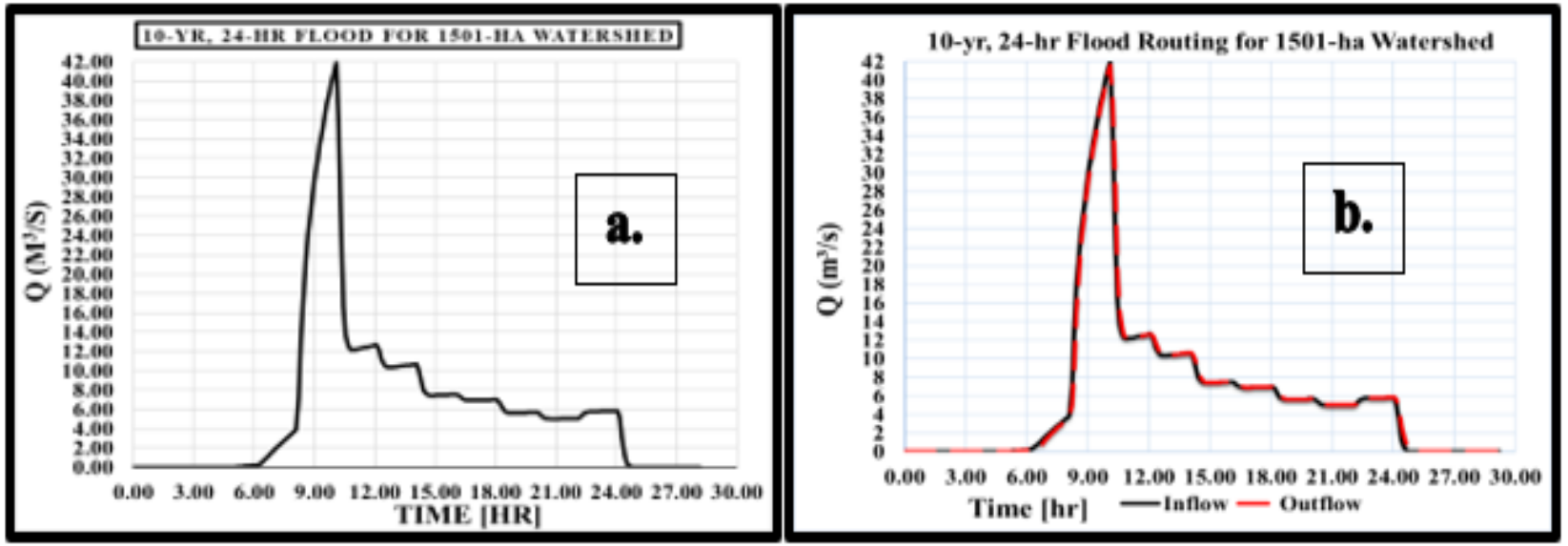


Figure 7. Design storm hydrographs producing peak "flood"-flow at spillway capacity threshold/limit a) 10-yr, 24-hr (42.0 [m^3s^{-1}]) and b) routed through reservoir (41.6 [m^3s^{-1}]) over Entire 1501-ha Watershed.

Conclusions

- **Spillway discharge capacity calculated as 21.1 [m^3/s].**
  - **Likely built within channel without similar capacity analysis presented**
- **Based on Rational Method and CN Method Results:**
  - **Spillway of adequate capacity for runoff volumes generated for 10-yr to 25-yr recurrence interval storms of variable durations and intensities IF spatial extent of rainfall limited to Sub-watersheds A and B.**
  - **Spillway capacity exceeded for runoff volumes generated for 10-yr or 25-yr recurrence interval storms of all durations and intensities evaluated IF rainfall occurred over Sub-watershed C and/or the Entire 1501-ha Watershed.**

GRACIAS

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COMEII-AURPAES 2019
Septiembre 2019 | Mazatlán, Sinaloa

AURPAES, S.C.

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Mary Nichols;
Kamel Didan

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didan@email.arizona.edu