HYDROLOGICAL MODEL – HEC - HMS

(Hydrologic Engineering Center- Hydrologic Modeling Systems)

FOR RUN-OFF COMPUTATION.

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OUTLINE

- FLOODING IN JAMAICA, CAUSES AND DAMAGES.
- HYDROLOGICAL MODELS FOR RUNOFF COMPUTATION.

  HYDROLOGIC ENGINEERING CENTER- HYDROLOGIC MODELING SYSTEMS (HEC – HMS) OVERVIEW AND USE.
- IMPACT OF CLIMATE CHANGE ON FLOODING.
- CASE STUDY ON THE HOPE RIVER WATERSHED.

What is Flood?

Flood is an overflow of an expanse of water that submerges land.

It is usually due to the **volume of water** within a body of water, such as a river or lake, exceeding the **total capacity of the body**, and as a result some of the water flows or sits outside of the normal perimeter of the body.

Flooding in Jamaica

Flooding is one of the important natural disasters affecting Jamaica causing loss of life and property.

MAIN CAUSES OF FLOODING

- Rainfall – high intensity rainfall associated with or without tropical storms or hurricane.
- Topography, Lithology.

CLIMATE

Jamaica has a tropical maritime (marine) climate. Mean daily temperature ranges from a seasonal low of 26 º C in February to a high of 28º C in August (33 º C in recent years).

Islandwide long term mean annual rainfall exhibits a characteristic pattern, with the primary maximum in October and the secondary in May. The main dry season lasts from December to April.

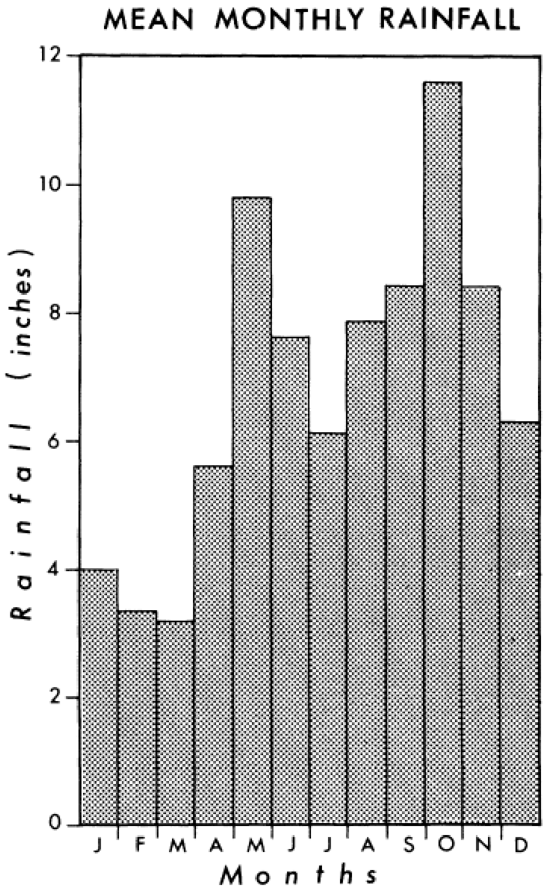
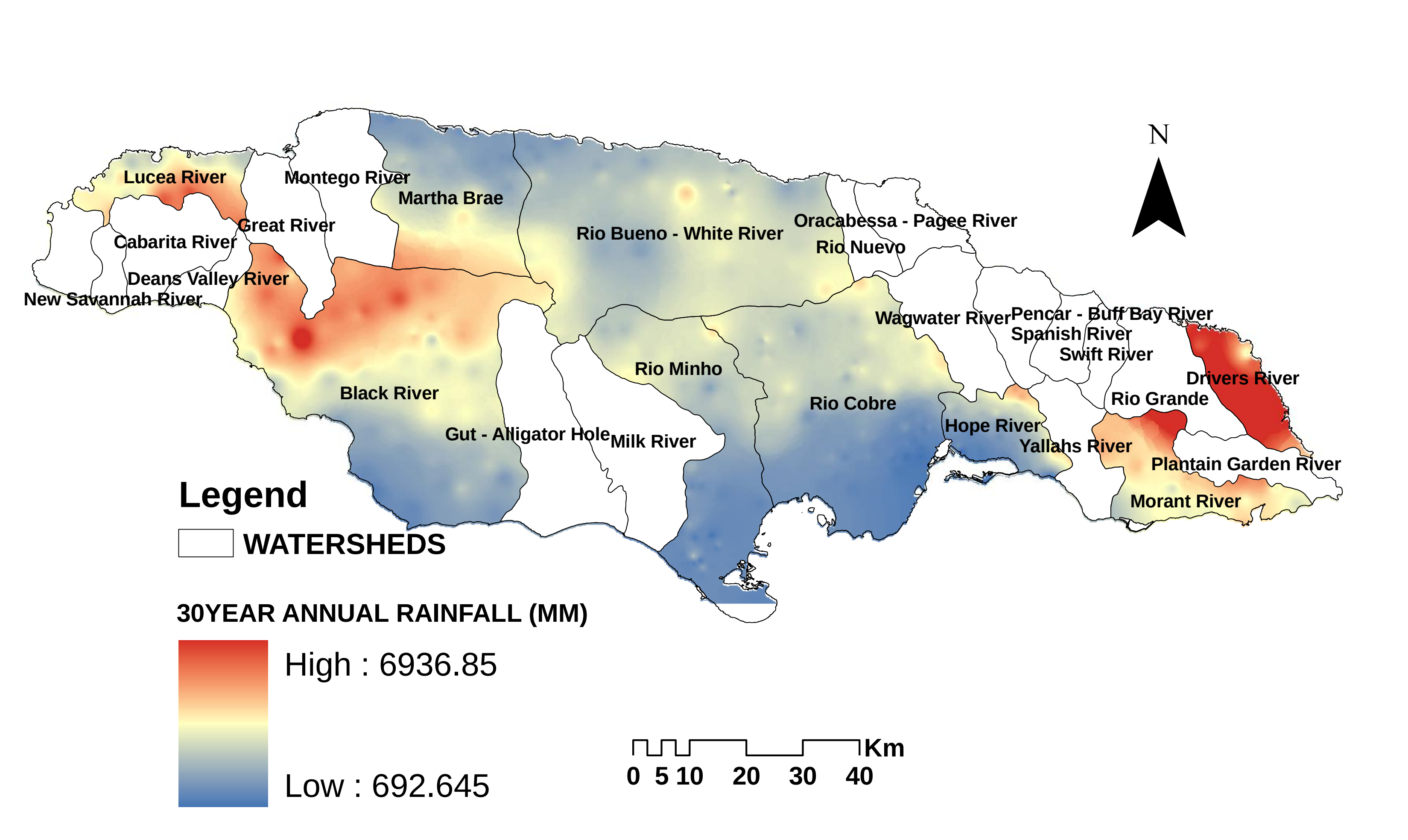


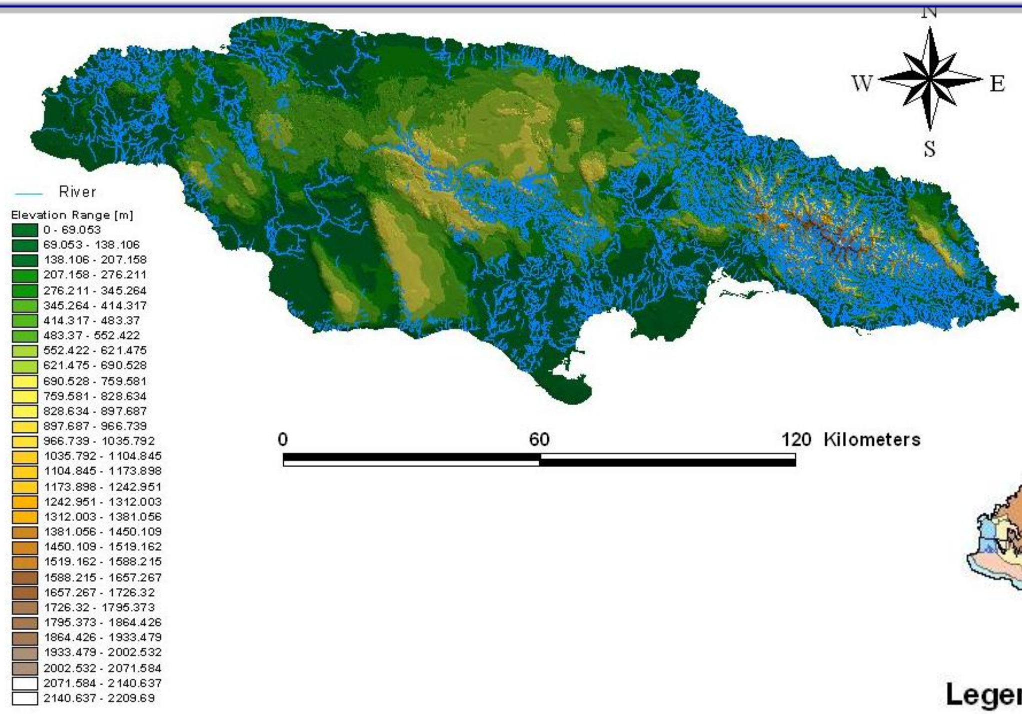
FIG. 4—Mean monthly rainfall. *Source:* Compiled from data obtained from Jamaica Meteorological Service.

WATERSHEDS IN JAMAICA AND THE 30YR MEAN ANNUAL RAINFALL

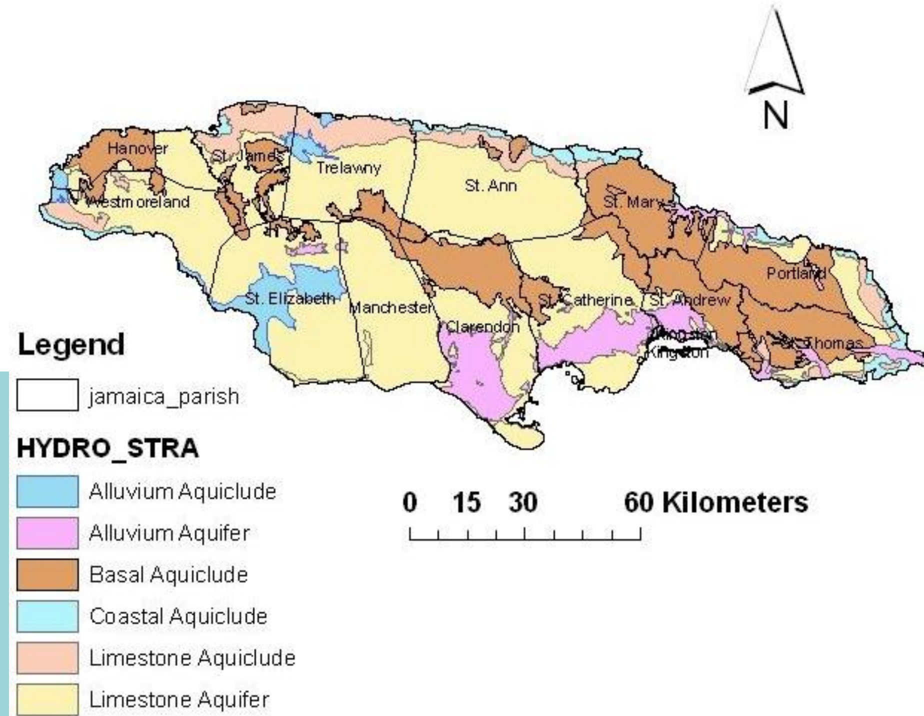


Data: Mona Geoinformatics Ltd. UWI Mona.

TOPOGRAPHY AND HYDROSTRATIGRAPHY OF JAMAICA



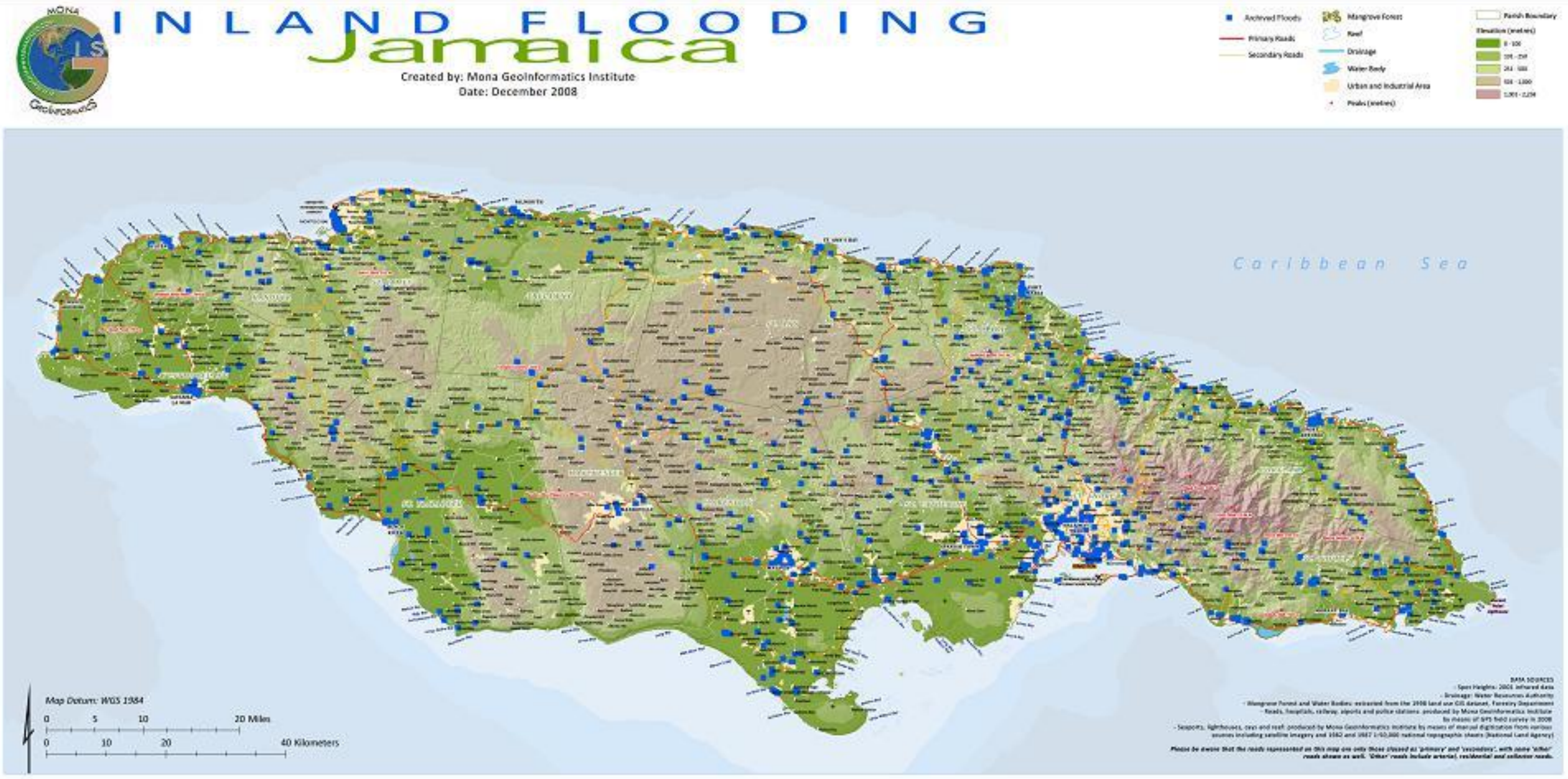
DEM of Jamaica showing the rivers.



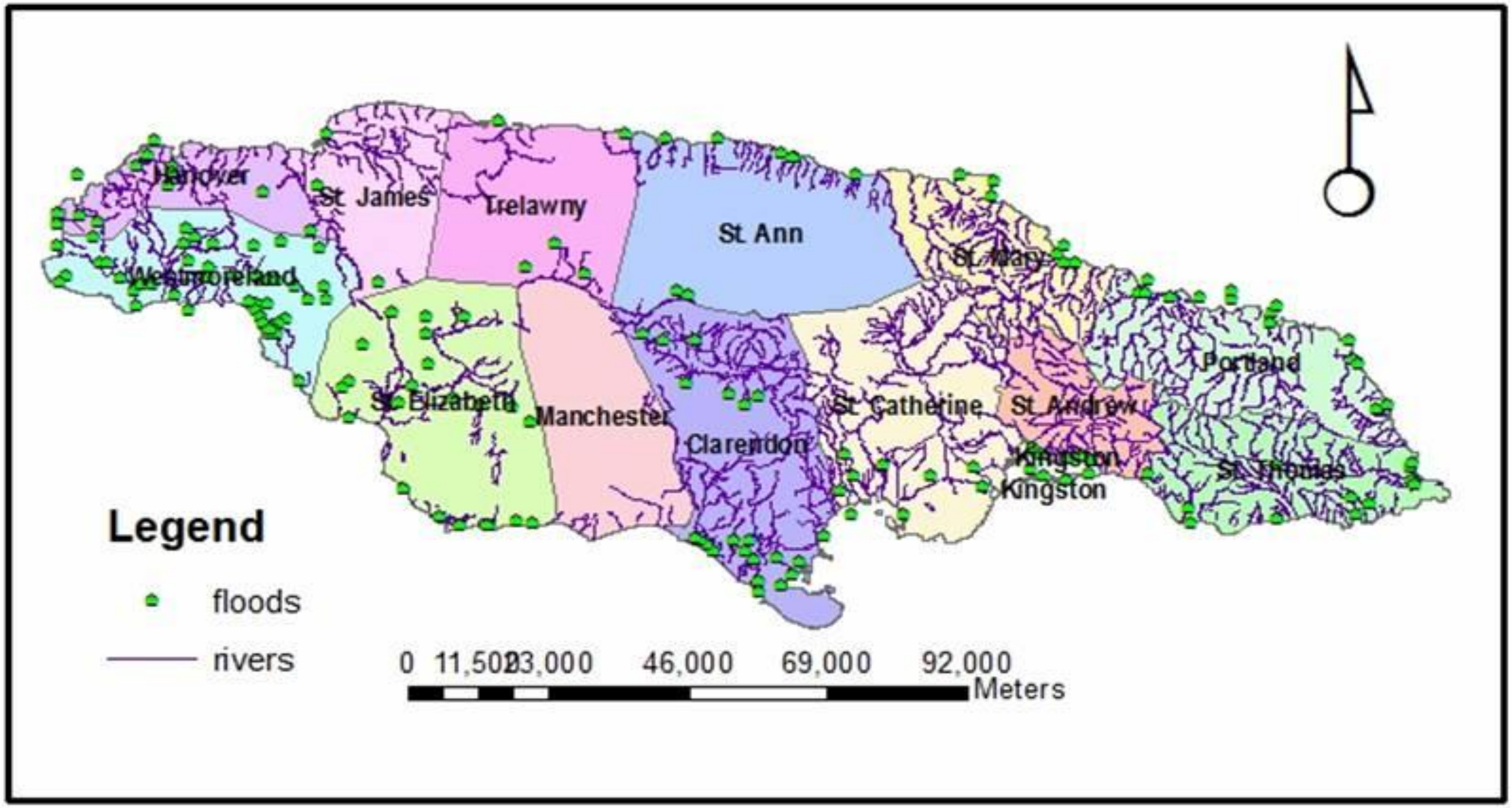
Hydrostratigraphy of Jamaica with the impermeable basal aquiclude (volcanics, volcanoclastics, shales, conglomerates) occurring in the highlands. Excess rainfall, steep topography leads to high erosion and downslope movement of debris during high rain associated with flooding.

Data: Water Resources Authority, Jamaica

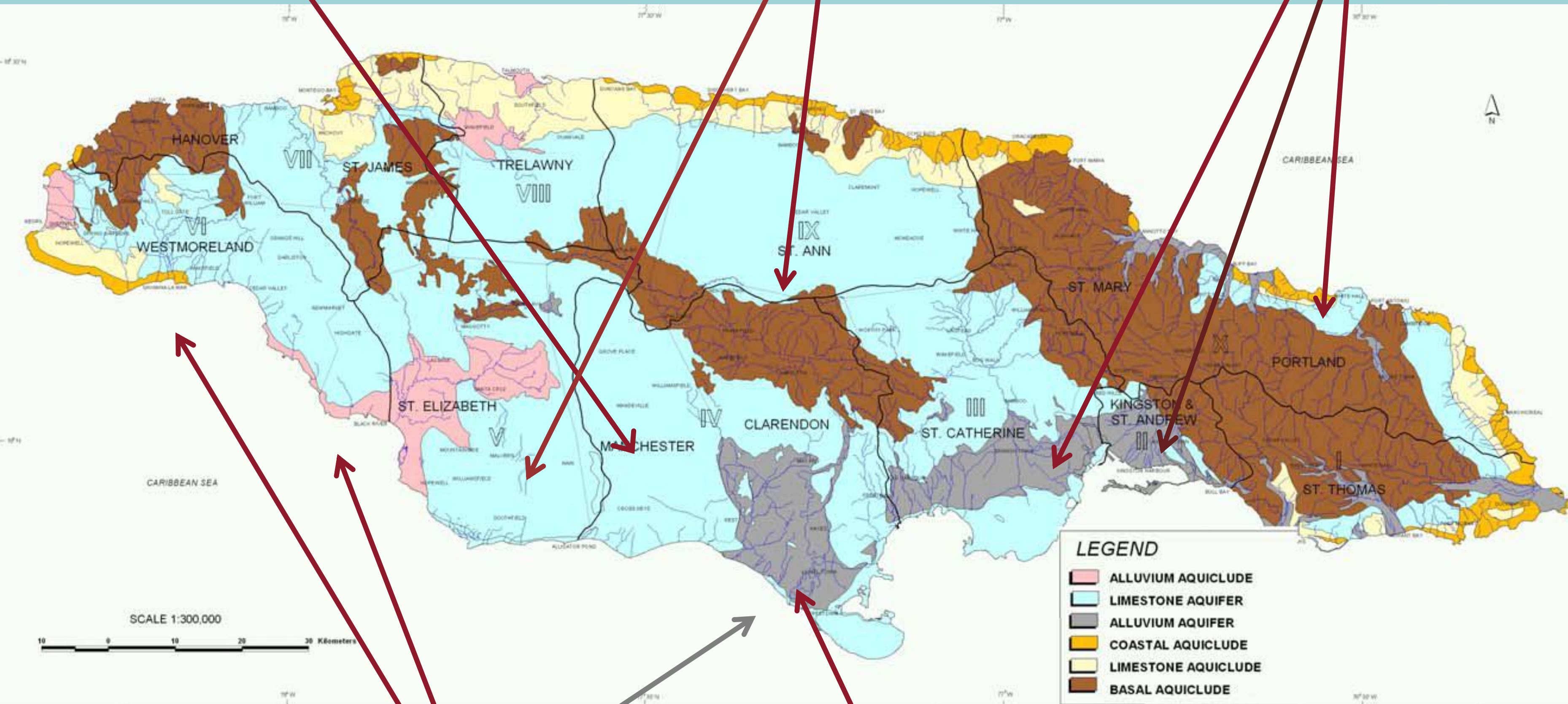
LOCATION OF FLOODING EVENTS AS REPORTED FROM NEWSPAPER ARCHIVES



REPORTED FLOOD EVENTS FROM OFFICE OF DISASTER PREPAREDNESS AND EMERGENCY MANAGEMENT (JAMAICA)



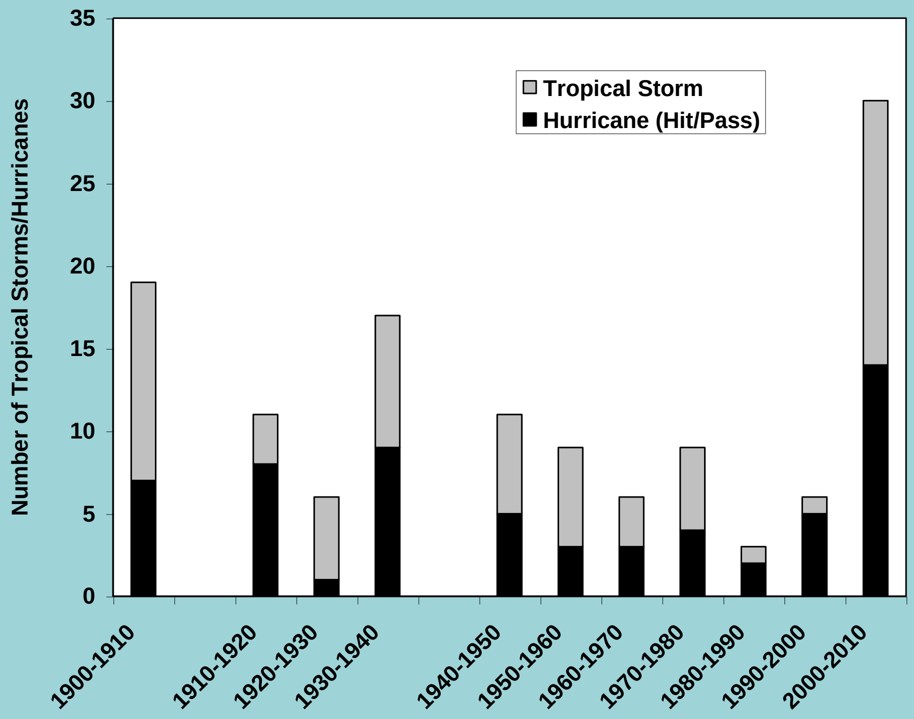
Groundwater induced • Depression • Riverine



Storm Surge • Urban Runoff

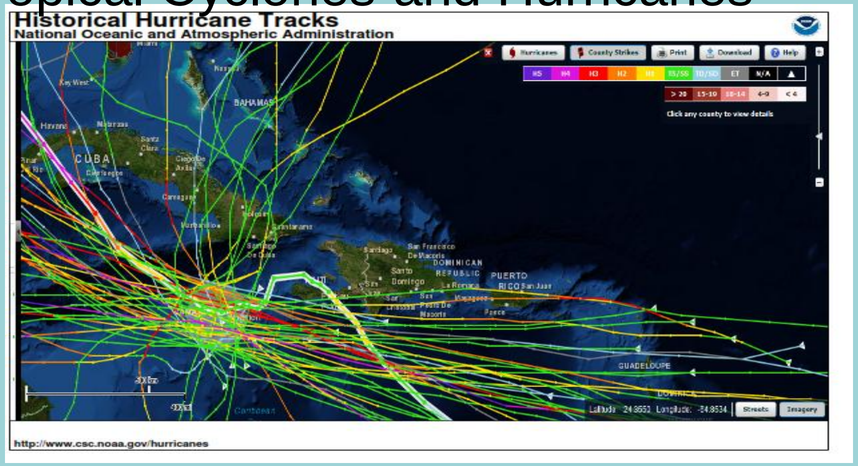
TYPES OF FLOODING IN JAMAICA

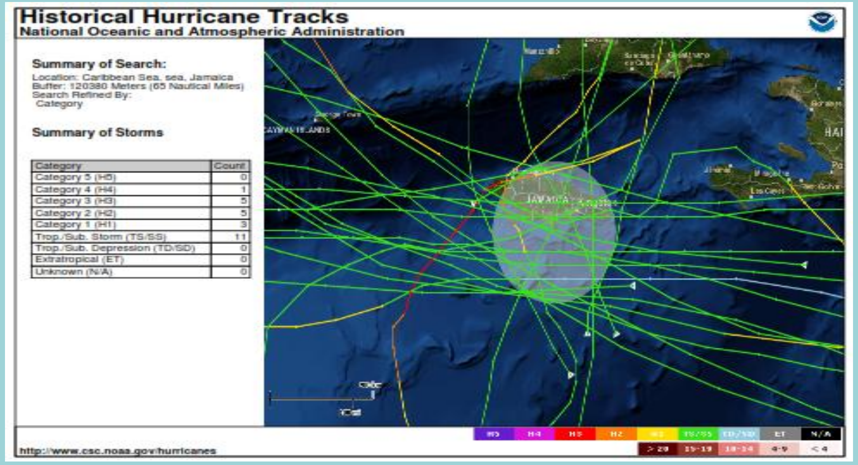
HURRICANES AND TROPICAL STORMS AFFECTING JAMAICA



Data from Metservice of Jamaica

Tropical Cyclones and Hurricanes





Data from 1857-2008, National Hurricane Center, USA

EFFECTS OF FLOODING IN DIFFERENT SECTIONS OF JAMAICA (NEWSPAPER AND INTENET ARCHIVES)

The remainder of a two storey house which was washed away by the Hope River at River View in Tavern, St Andrew during the passage of Tropical Storm Gustav on August 28, 2008.

Source: Brown (2008), *Jamaica Observer*, October 20

Flooding in Hope River Watershed- Tavern, Kingston > August 28, 2008. Tropical Storm Gustav

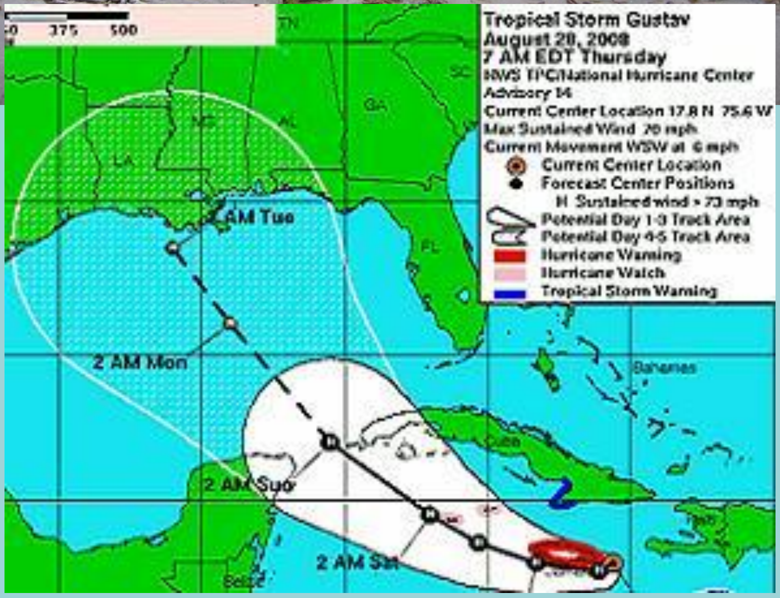
Flooding in Gordon Town, Kingston > August 28, 2008. Tropical Storm Gustav

Gordon Town, August 28, 2008. Tropical Storm Gustav

Flooding in Port Maria, Nov 23-24th , 2006 > Cold Front.

FLOODING WOES……….

Bridge over Hope River at Harbour View, Tropical Storm Gustav, August, 2008.



Kintyre, Kingston

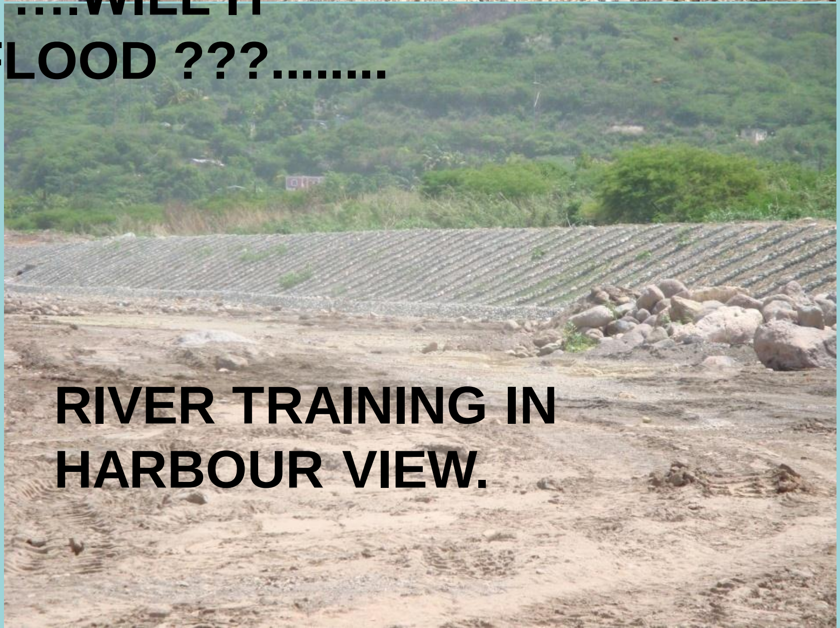
September, 2010.
Tropical Storm Nicole.

BRIDGE AT KINTRYE WHICH COLLAPSED FOLLOWING FLOODING , 2007, 2008, 2010

HOUSE RELOCATED FOLLOWING FLOODING, 2010

PRESENT SCENARIO ….WILL IT SUSTAIN ANOTHER FLOOD ???........

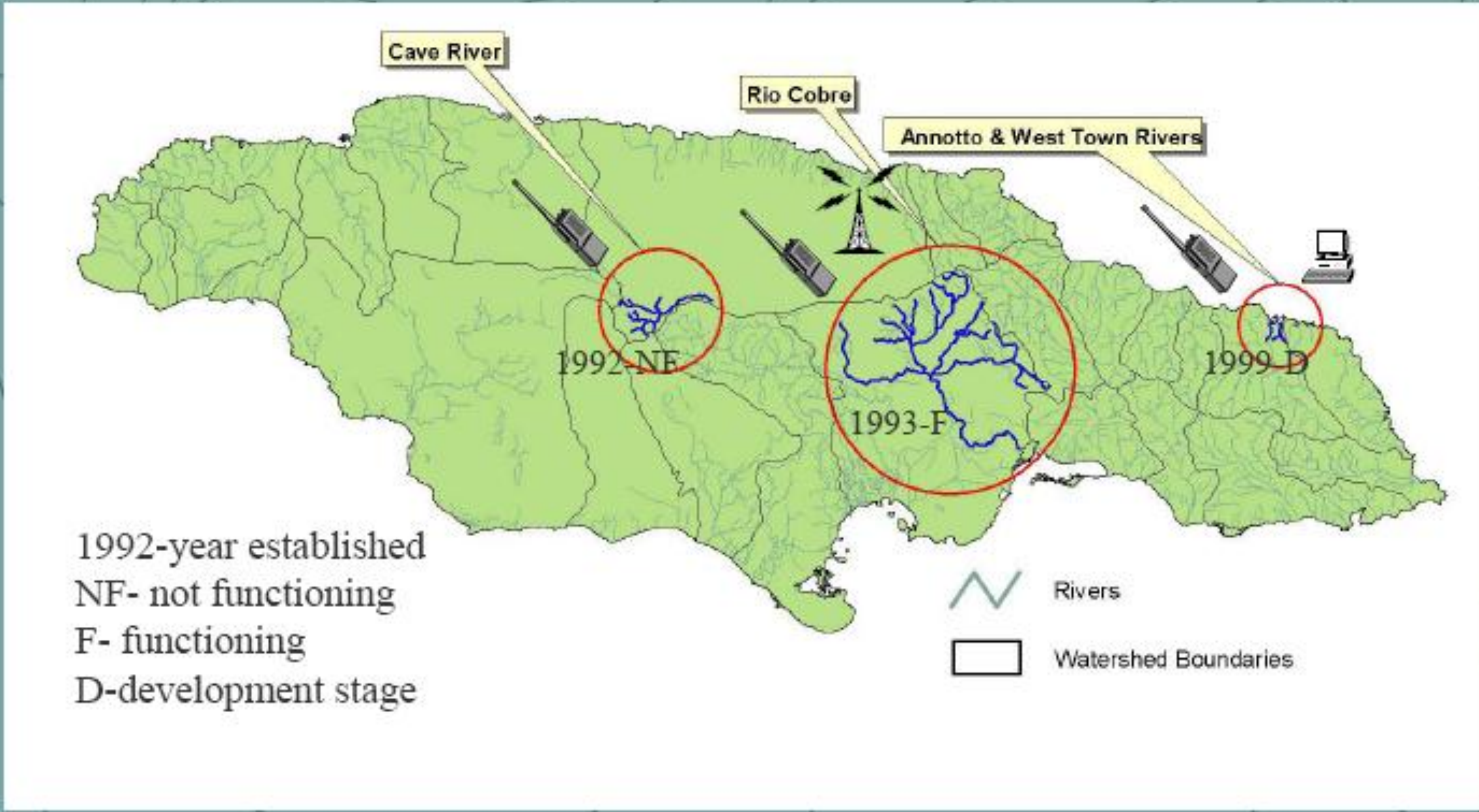
NEWLY CONSTRUCTED BRIDGE AT HARBOUR VIEW. POST NICOLE, 2010



RIVER TRAINING IN HARBOUR VIEW.

Existing early warning systems in Jamaica

TO BE NOTED : NO EXISTING EARLY WARNING SYSTEM FOR THE HOPE WATERSHED



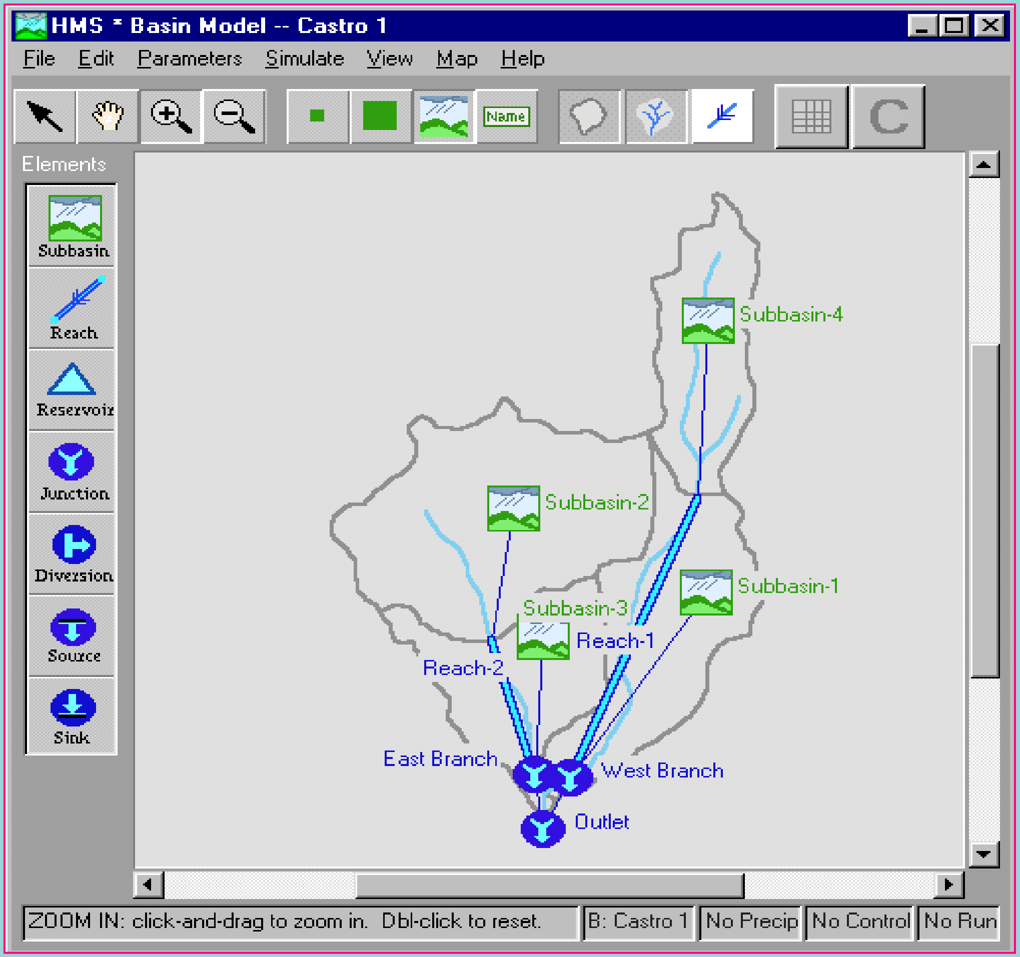
Source : Water Resources Authority of Jamaica

WHAT IS HYDRAULIC AND HYDROLOGIC MODELING

- HEC HMS-(Hydrologic Modeling System) is designed to simulate precipitation- runoff processes of dendritic water systems .
- HEC RAS- (River Analysis System) is a hydraulic model that calculates one-dimensional steady and unsteady flow. The inputs for this model are the hydrograph output from HMS.
- Integration of GIS

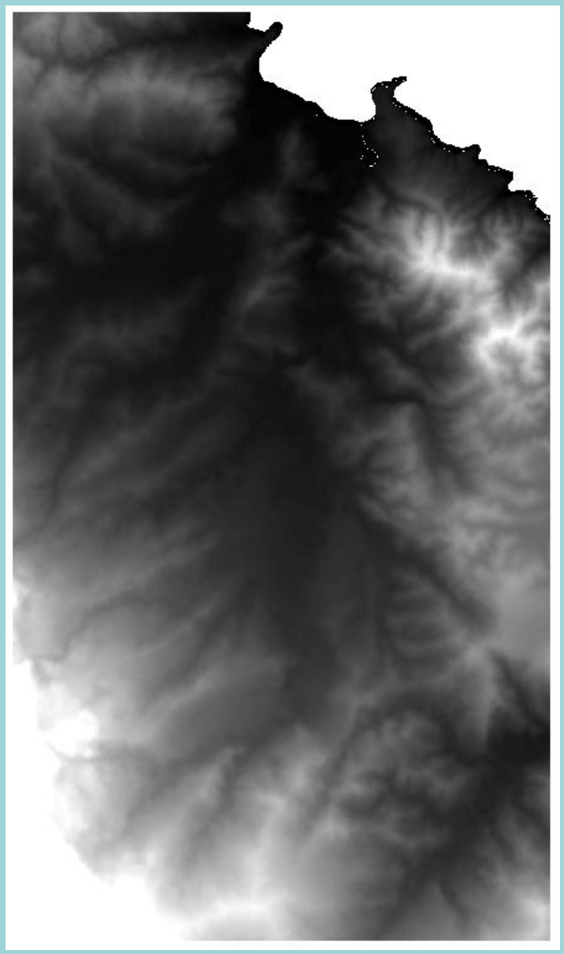
HEC-HMS

The Hydrologic Engineering Center's Hydrologic Modeling System (HMS)



MAIN ROLE: DEM (DIGITAL ELEVATION MODEL)

- Surface shape determines water behaviour
  - characterise surface using DEM
    - slope
    - aspect
    - (altitude)
  - delineate drainage system:
    - catchment boundary (watershed)
    - sub-catchments
    - stream network
  - quantify catchment variables
    - soil moisture, etc.
    - flow times... catchment response



- Other key catchment variables:
  - soils
    - type and association
    - derived characteristics
  - geology
    - type
    - derived characteristics
  - land use
    - vegetation cover
    - management practices
  - artificial drainage
    - storm drains/sewers/ bridges

HEC HMS – Data Structure

1
- METEROLOGICAL MODEL
- Climatological Data

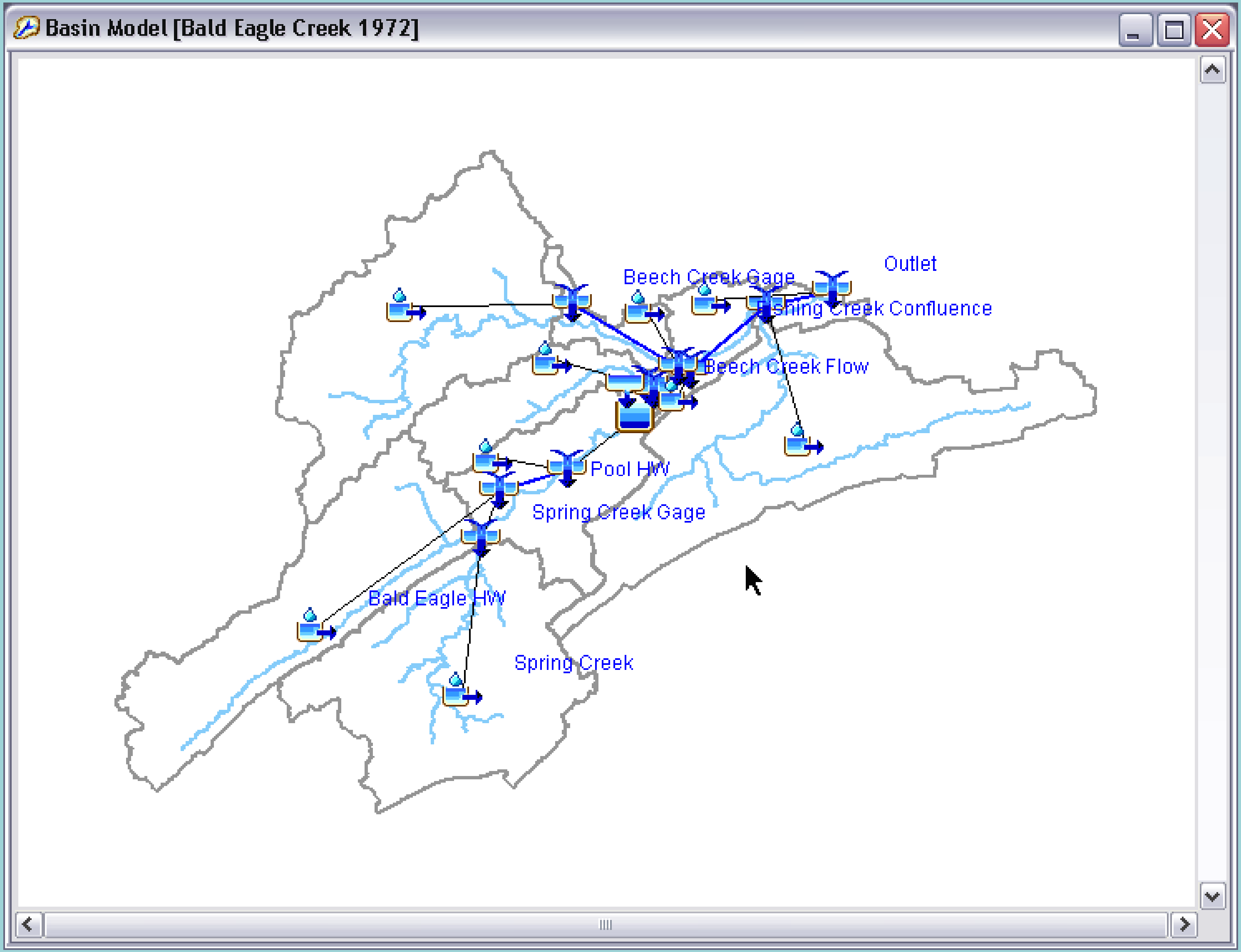
2
- BASIN MODEL
- Connectivity and Element Data

3
- CONTROL SPECIFICATIONS
- Simulation Duration & Time Steps

Main Components

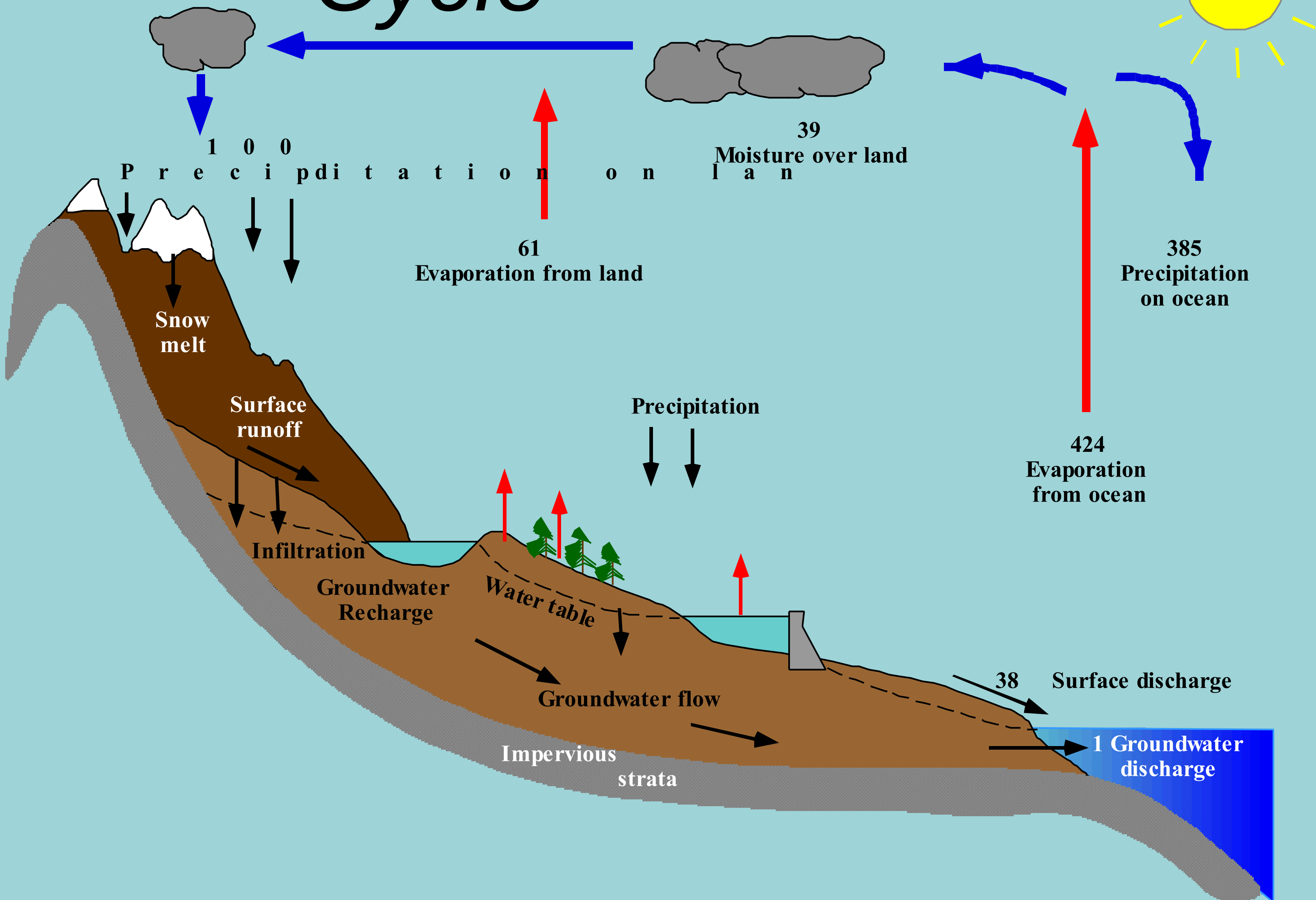
- Basin model gives the physical description of the watershed.
  - Subbasin: watershed catchments where rain falls.
  - Reach: rivers and streams.
  - Reservoir: dams and lakes.
  - Junction: confluence.
  - Diversion: bifurcations and withdrawls.
  - Source: springs and other model sinks.
  - Sink: outlets and terminal lakes.
- Meteorologic model describes atmospheric conditions over the watershed land surface.
  - Precipitation.
  - Potential evapotranspiration.
  - Snowmelt.
- Control specifications: Time control during a simulation run

Basin Map



Basin Model [Bald Eagle Creek 1972]
Beech Creek Gage
Outlet
Fishing Creek Confluence
Beech Creek Flow
Pool HW
Spring Creek Gage
Bald Eagle HW
Spring Creek

The Hydrologic Cycle



Uses of the HEC Program

Models the rainfall-runoff process in a watershed based on watershed physiographic data

- Offers a variety of modeling options in order to compute Unit Hydrograph for basin areas.
- Offers a variety of options for flood routing along streams.
- Capable of estimating parameters for calibration of each basin based on comparison of computed data to observed data

HEC-HMS Availability

Available Through HEC Vendors

Available at HEC Web Site:

http://www.wrc-hec.usace.army.mil

"Public Domain" Program

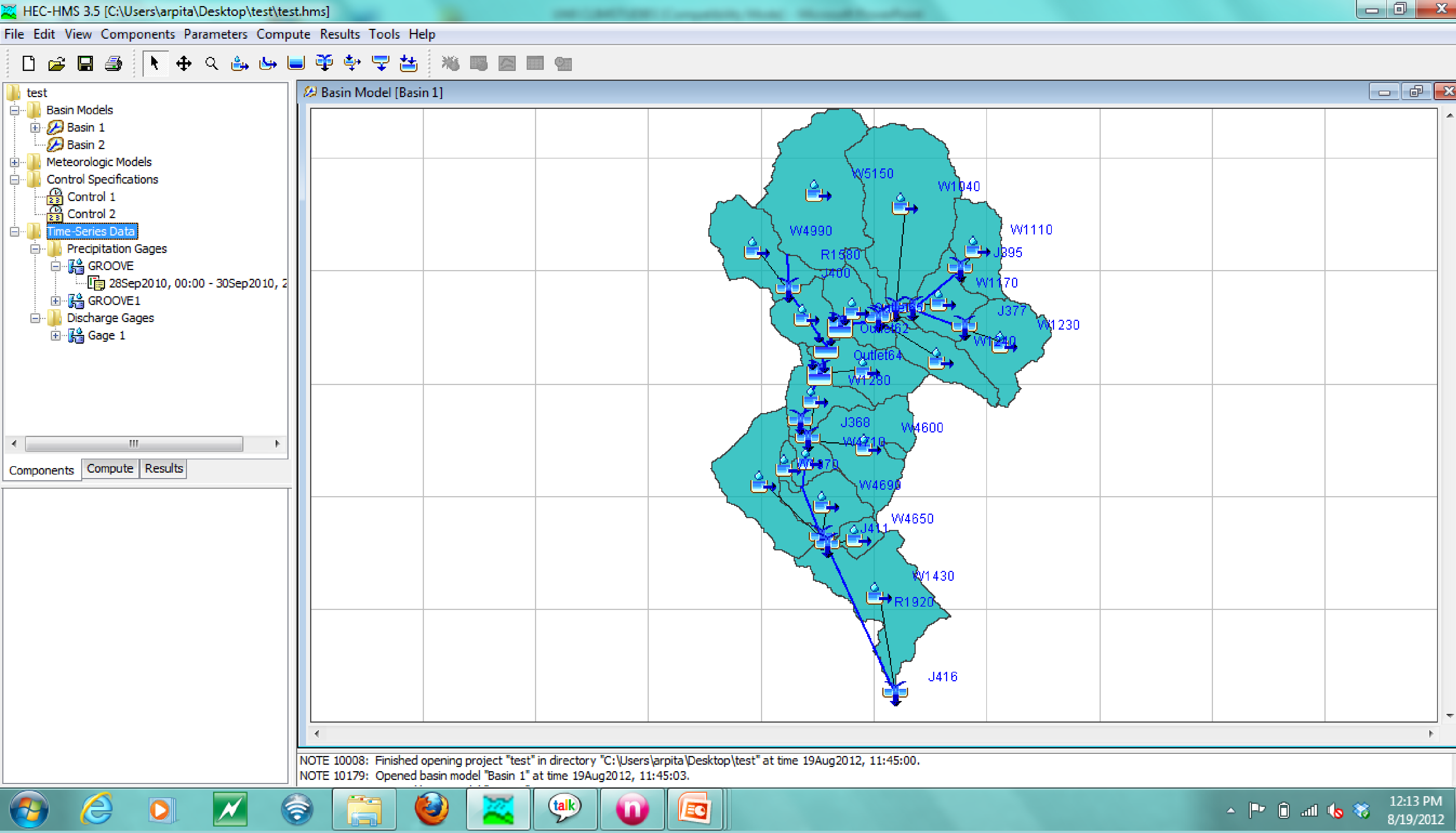
- No Copyright on Software
- No Copyright on HEC Documentation

Special Training Available

COMPONENTS OF HEC HMS

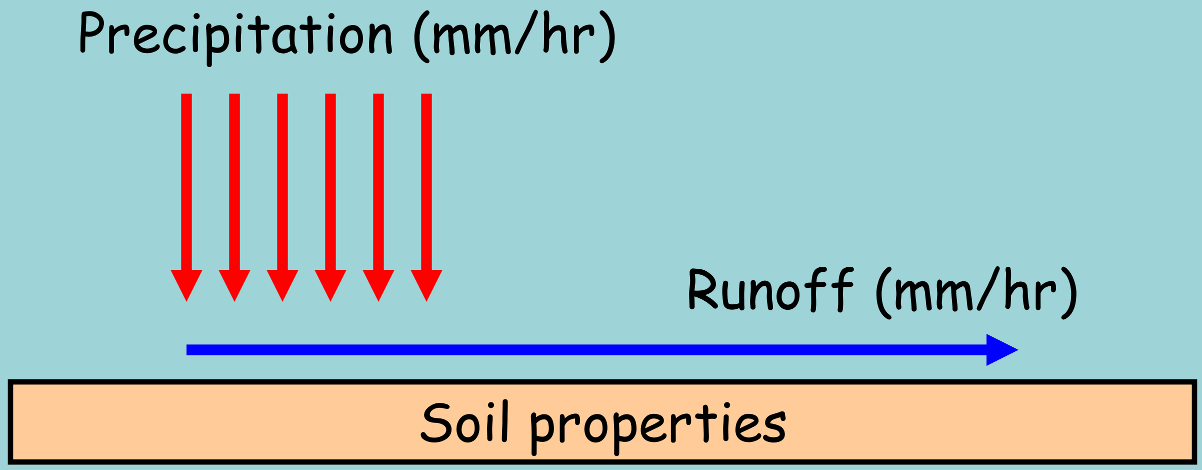
Three components

- *Basin model* - contains the elements of the basin, their connectivity, and runoff parameters
- *Meteorologic Model* - contains the rainfall and evapotranspiration data
- *Control Specifications* - contains the start/stop timing and calculation intervals for the run
- Time Series data: component where the actual rainfall , discharge data are entered in tables as per the control specified.



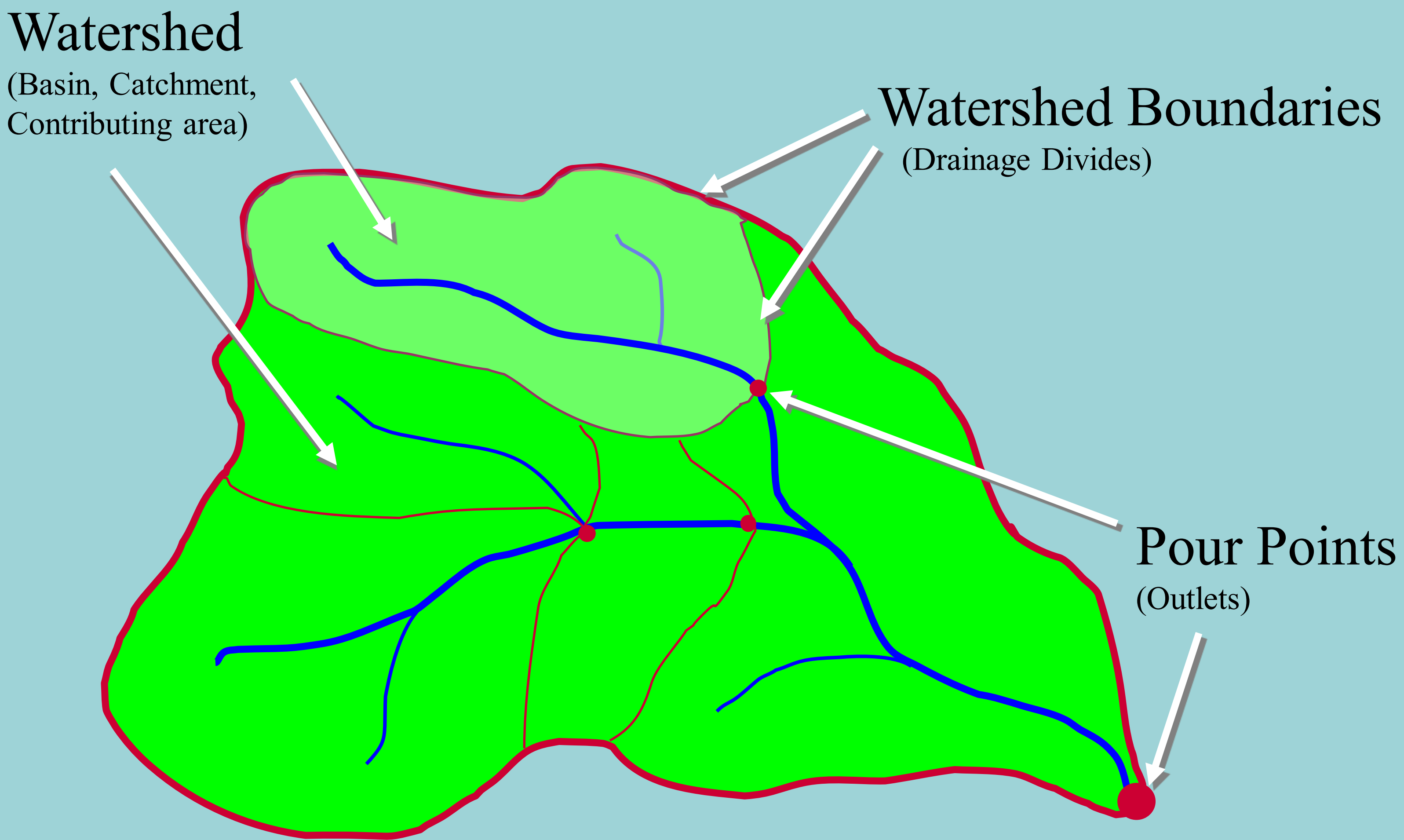
HEC-HMS SCREEN SHOT WITH BASIN MODEL, MET MODEL, CONTROL SPECIFICATION AND TIME SERIES DATA.

Watershed Abstractions



Runoff = f(precipitation, soil properties, moisture conditions)

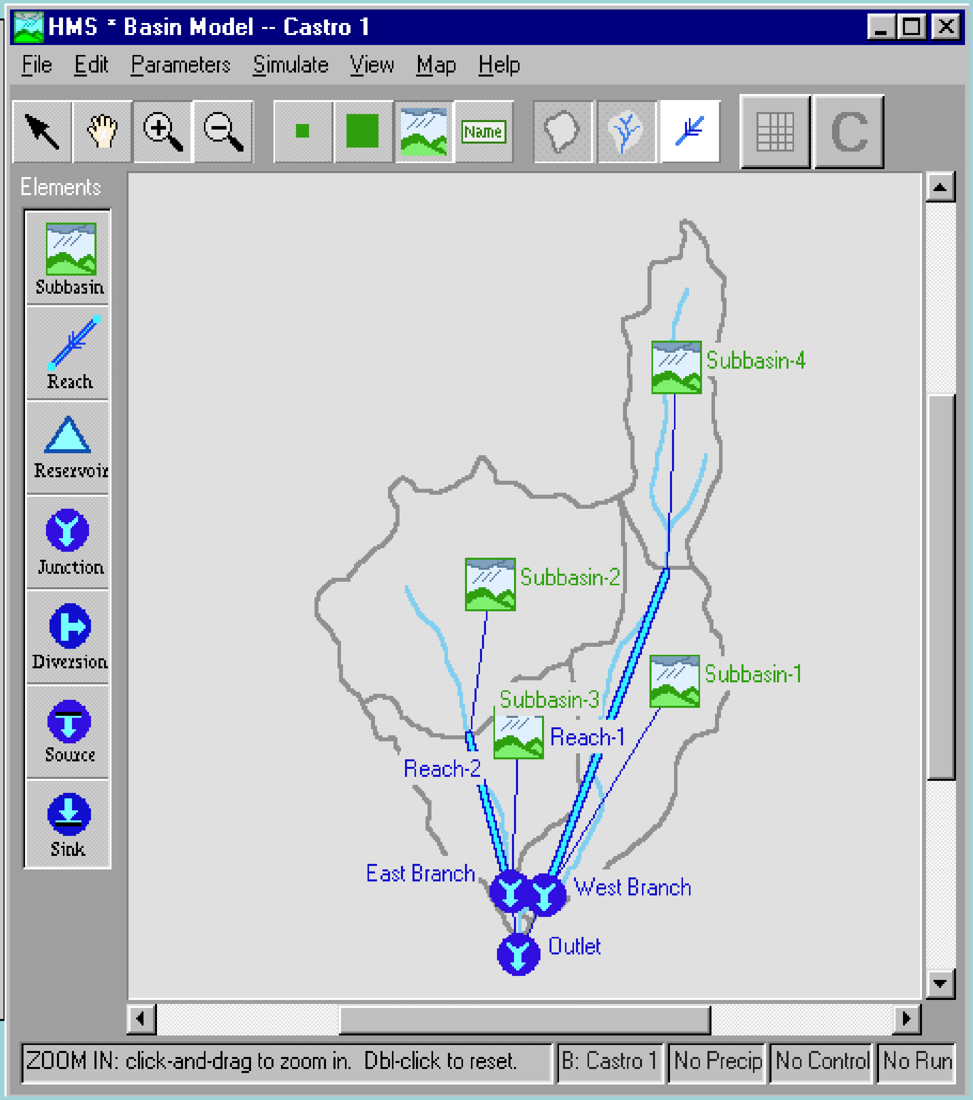
BASICS OF DRAINAGE SYSTEM….



Basin Model

Basin Model

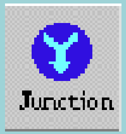
- Based on Graphical User Interface (GUI)
- Click on elements from left and drag into basin area
- Can import map files from GIS programs to use as background
- Actual locations of elements do not matter, just connectivity and runoff parameters



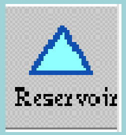
Basin Model Elements

- **subbasins-** contains data for subbasins (losses, UH transform, and baseflow)

- **reaches**- connects elements together and contains flood routing data



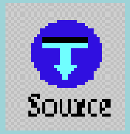
- **junctions**- connection point between elements



- **reservoirs**- stores runoff and releases runoff at a specified rate (storage-discharge relation)

Basin Model Elements

- **sinks**- has an inflow but no outflow



- **sources**- has an outflow but no inflow

- **diversions**- diverts a specified amount of runoff to an element based on a rating curve - used for detention storage elements or overflows

Loss Rate methods

Green & Ampt

Initial & constant

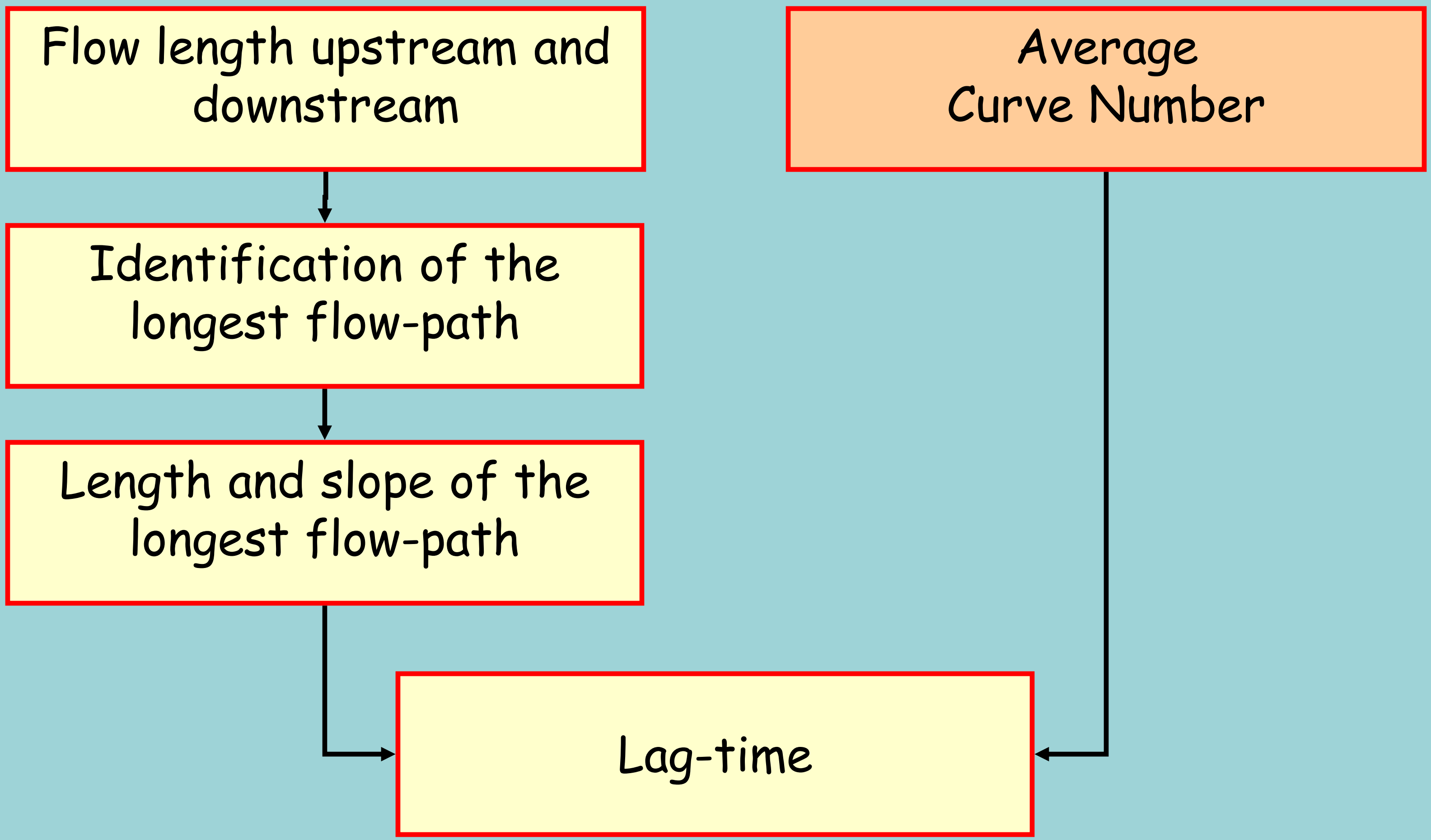
SCS curve no.

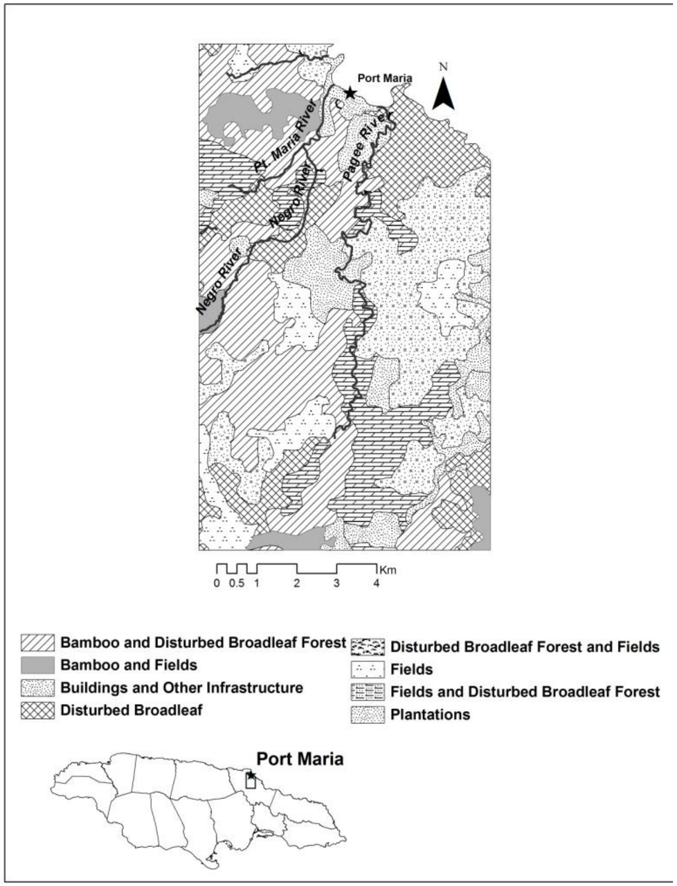
Gridded SCS curve no.

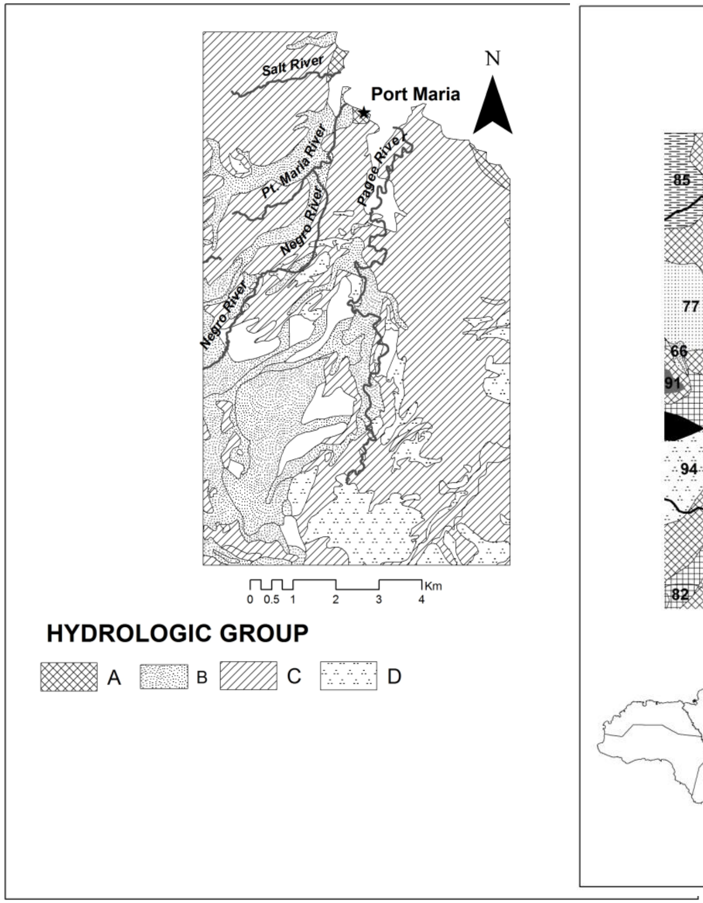
Deficit/Constant

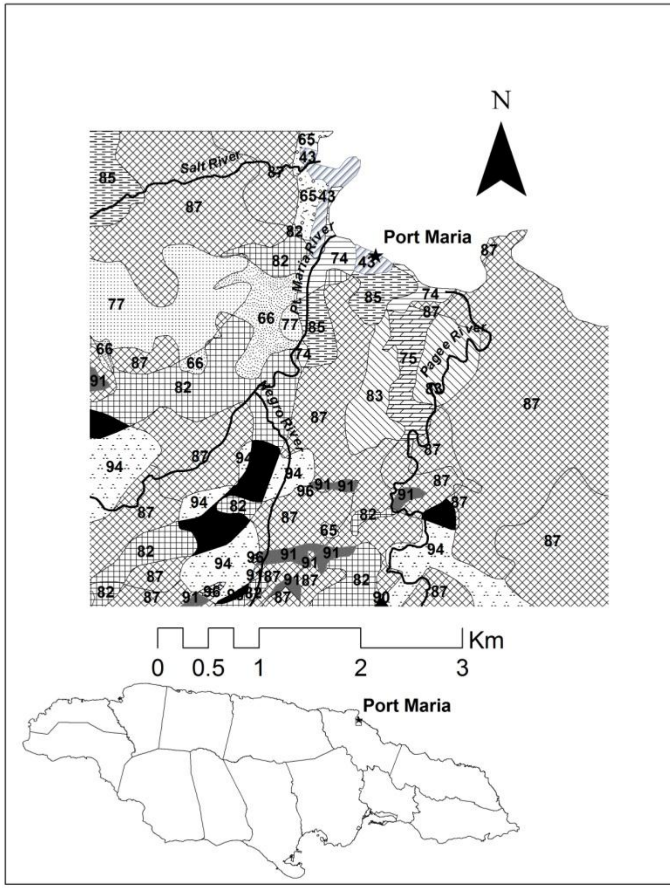
No loss rate

Watershed Lag-Time (SCS)









Identifying curve number for catchments using soil, landuse data in ARC GIS

Hydrologic Parameters

- Sub-basin lag-time according to the SCS formula:

$$t_p = \max\left(\frac{L_w^{0.8}\,[(1000/CN)-9]^{0.7}}{31.67\,S^{0.5}},\ 3.5\,\Delta t \right)$$

t_p: sub-basin lag-time (min)
L_W: length of sub-basin longest flow-path (ft)
CN: average Curve Number in sub-basin
S: slope of the sub-basin longest flow-path (%)
Δt: analysis time step (min)

Calculation of Basin Lag time

$$\text{Lag} = \frac{(L^{0.8} * (S+1)^{0.7})}{(1900 * Y^{0.5})}$$

Where: Lag = basin lag time (hours)

L = hydraulic length of the watershed (feet)

$$S = \frac{1000}{CN} - 10$$

CN values between 50 to 95 are appropriate to this equation.

Y = basin slope (%)

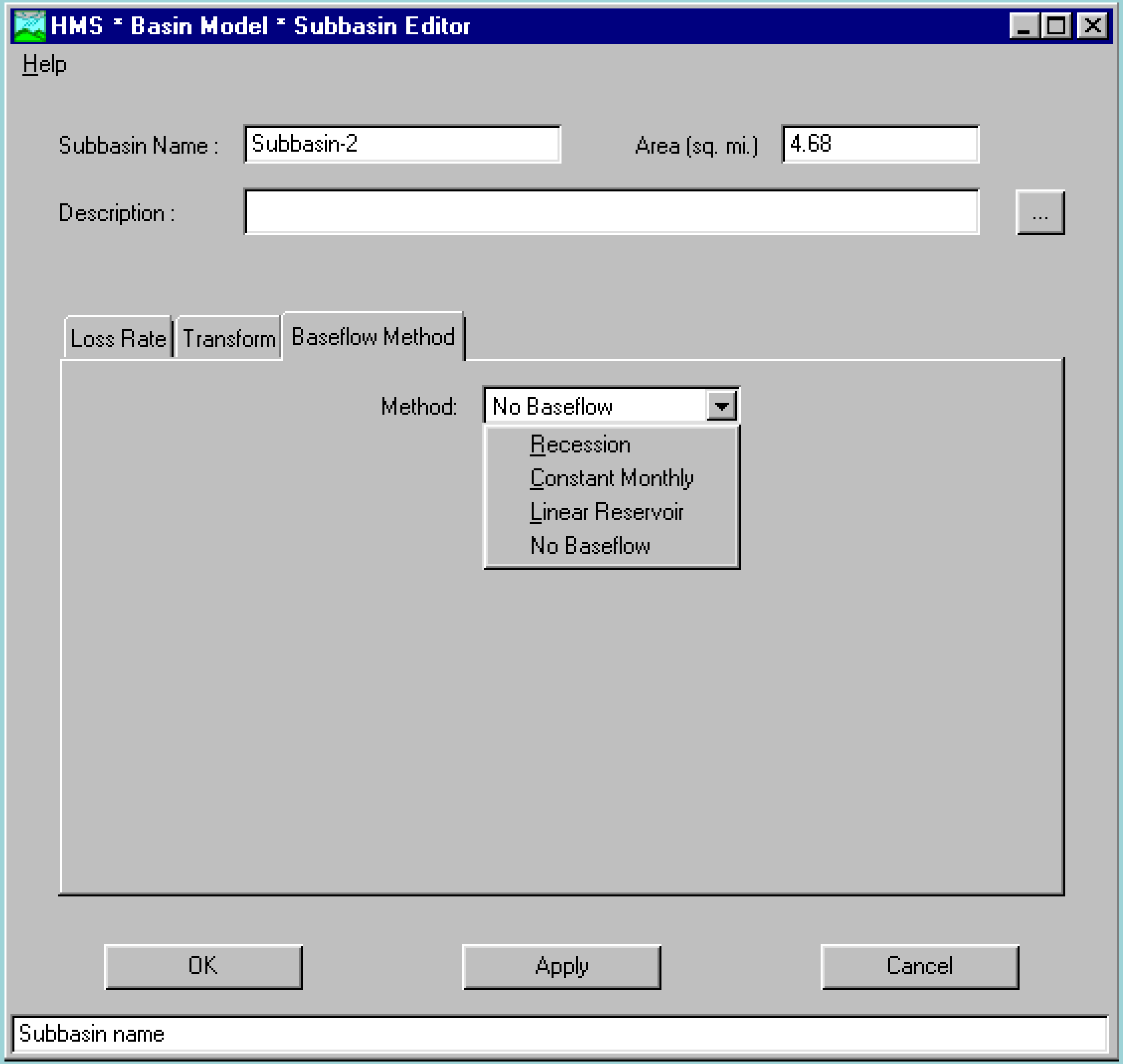
- Reach lag-time for Pure Lag routing:

$$t_{lag} = \frac{L_s}{60\ V_s}$$

t_{lag}: reach lag-time (min)
L_s: length of reach (m)
V_s: reach average velocity (m/s)

Baseflow Options

– recession
– constant monthly
– linear reservoir
– no baseflow



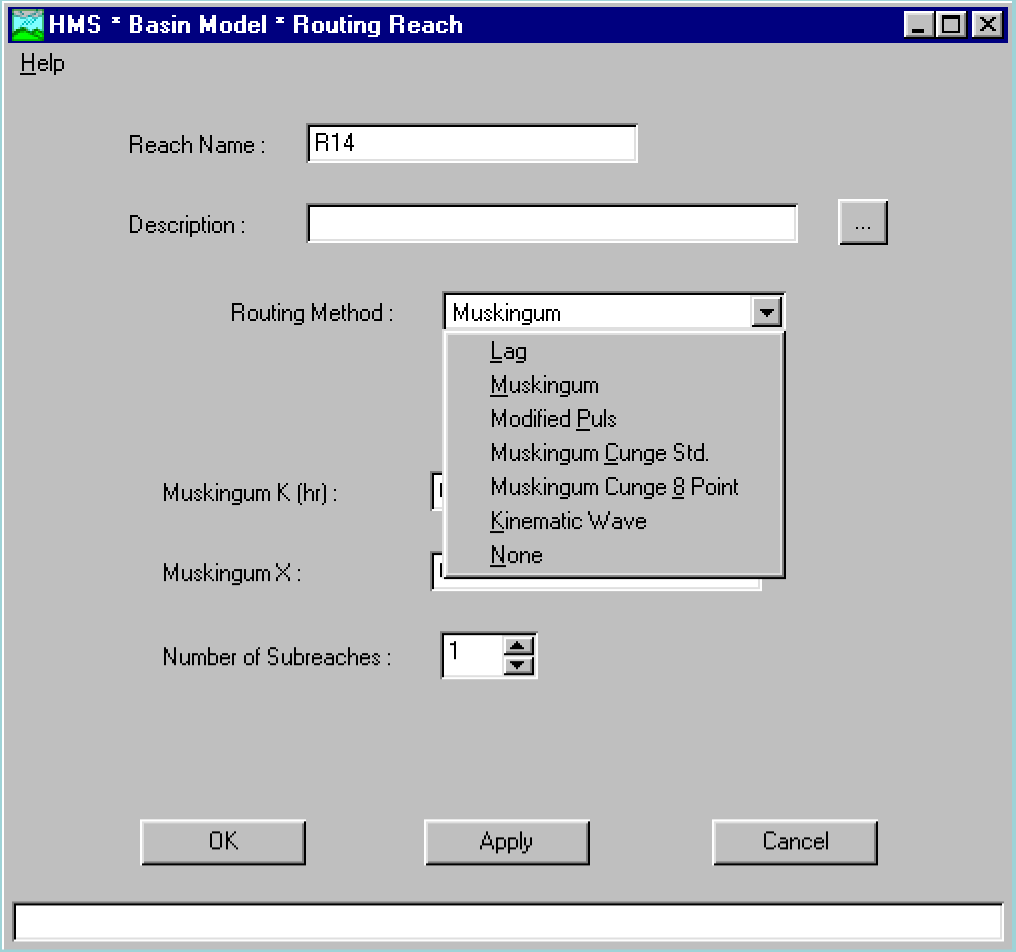
Stream Flow Routing

- Simulates Movement of Flood Wave Through Stream Reach
- Accounts for Storage and Flow Resistance
- Allows modeling of a watershed with sub-basins

Reach Routing

Flood routing methods:

- Simple Lag
- Modified Puls
- Muskingum
- Muskingum Cunge
- Kinematic Wave



Baseflow

- Three alternative models for baseflow
  - Constant, monthly-varying flow
  - Exponential recession model
  - Linear-reservoir volume accounting model

Baseflow

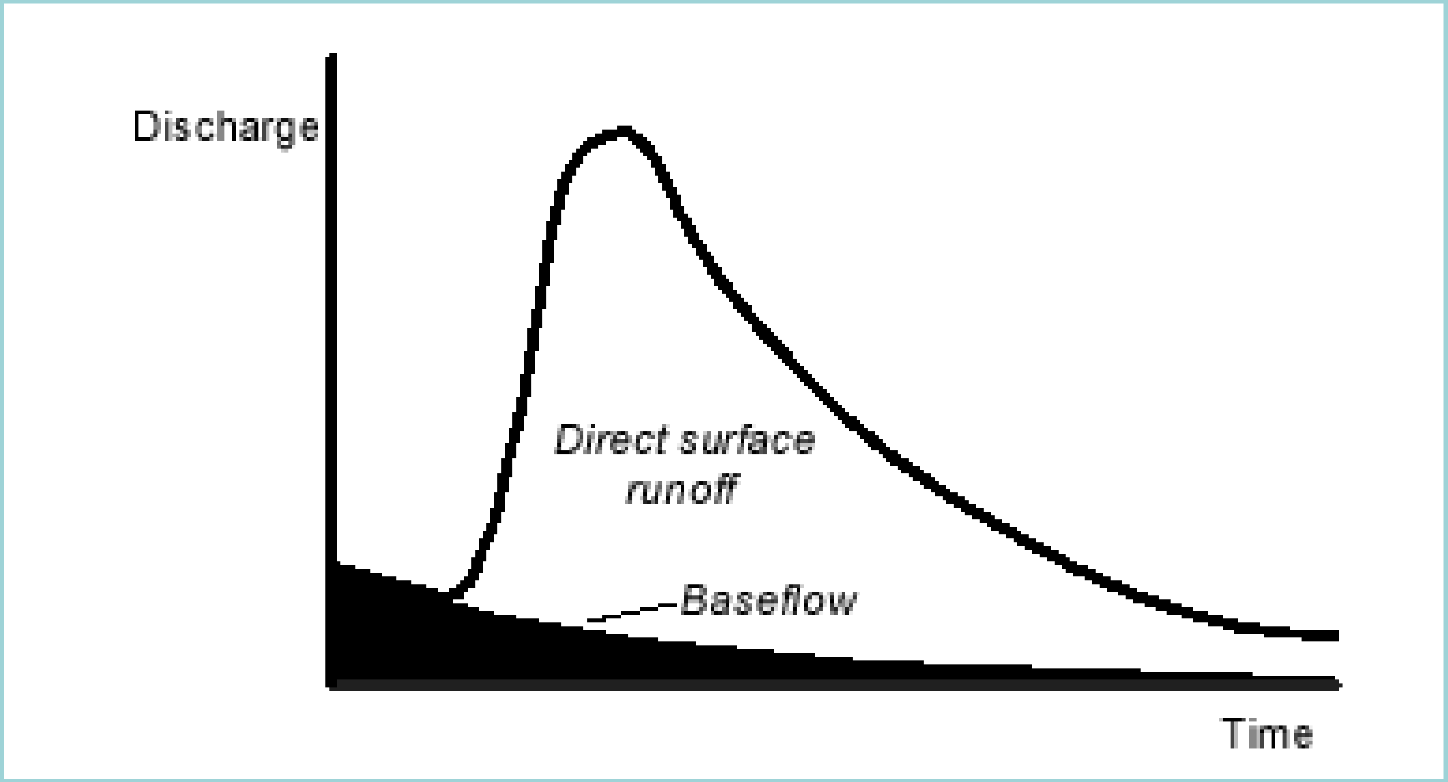
- Exponential recession model
  - Defines relationship of Qt (baseflow at time t) to an initial value of baseflow (Q_0) as:

    $$Q_t = Q_0 K^t$$

  - K is an exponential decay constant
    - Defined as ratio of baseflow at time t to baseflow one day earlier
  - Q_0 is the average flow before a storm begins

Baseflow

- Exponential recession model



Baseflow

- Exponential recession model
  - Typical values of K
    - 0.95 for Groundwater
    - 0.8 – 0.9 for Interflow
    - 0.3 – 0.8 for Surface Runoff
  - Can also be estimated from gaged flow data

Meteorologic Model

Meteorologic Model

Precipitation

user hyetograph

user gage weighting

inverse-distance gage weighting

gridded precipitation

frequency storm

standard project storm - Eastern U.S.

Evapotranspiration-ET

monthly average,

no evapotranspiration

Precipitation

Historical Rainfall Data

- Recording Gages
- Non-Recording Rainfall Gages

Design Storms

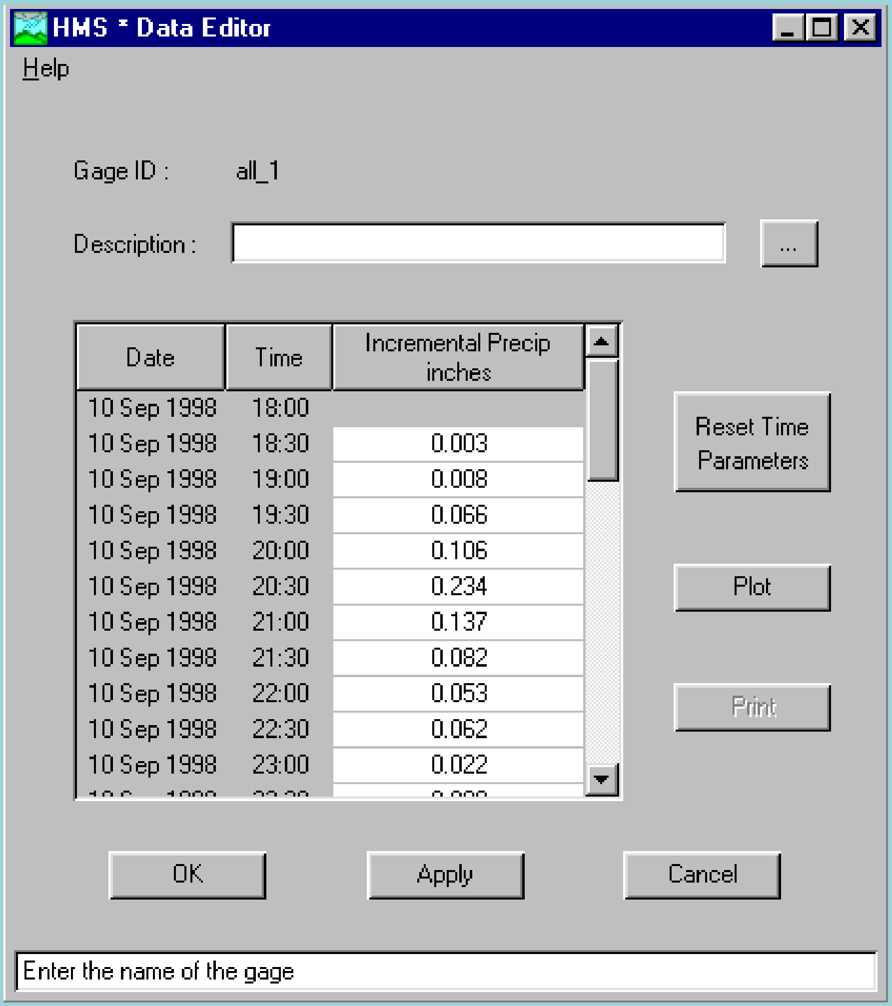
- Hypothetical Frequency Storms
- Corps Standard Project Storm
- Probable Maximum Precipitation

Gage Data

Gage Data (from project definition screen)

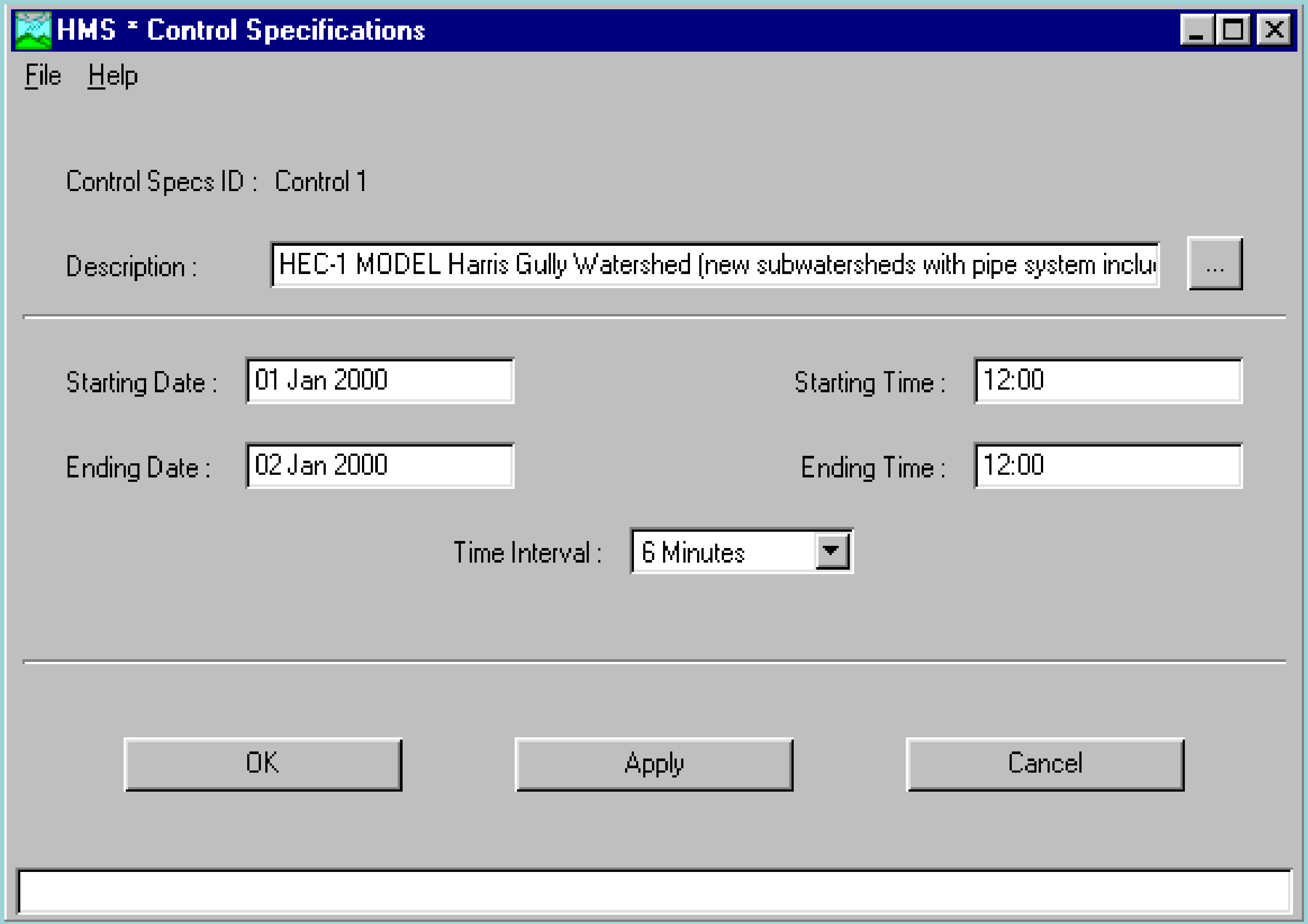
<u>Precipitation gages</u>- precipitation data for use with meteorologic models

<u>Stream gages</u>- observed level data to compare computed and actual results



Control Specifications

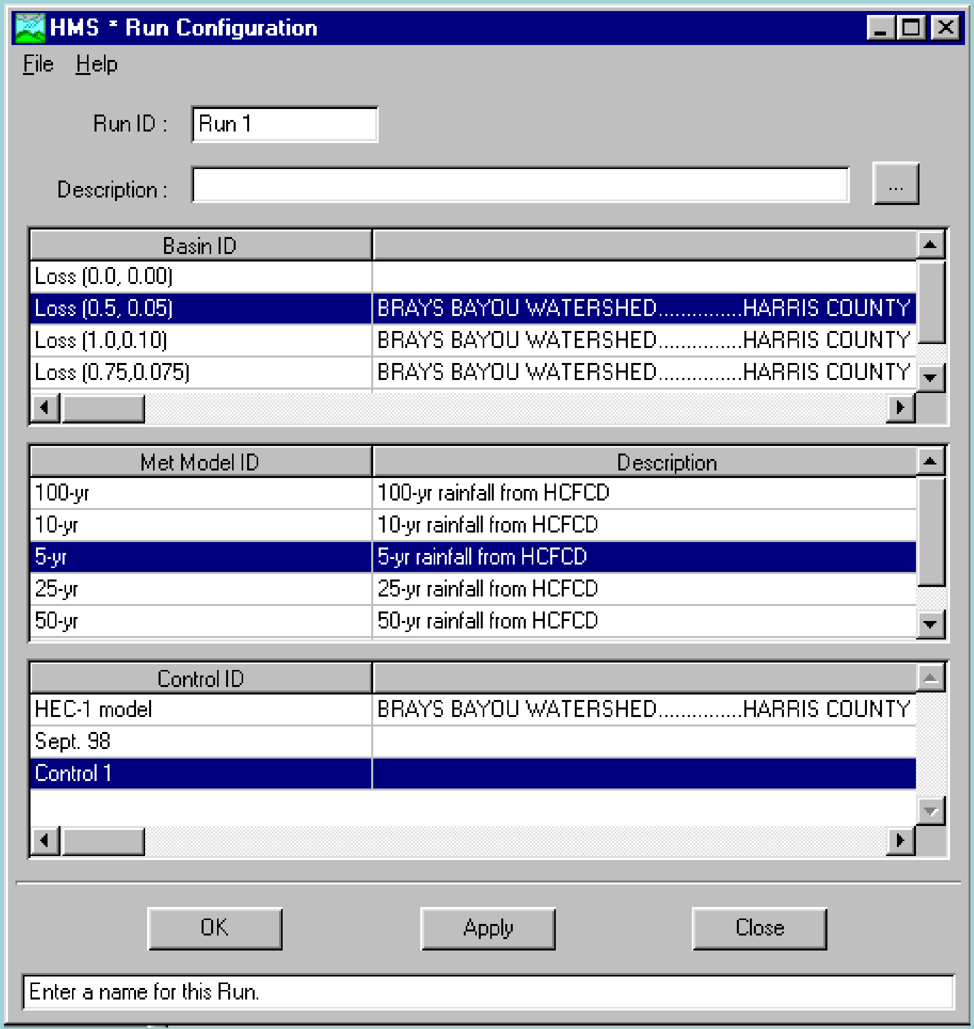
Control Specifications - Start/Stop/Time Interval



Running a project

<u>User selects the</u>

1. Basin model
2. Meteorologic model
3. Control ID for the HMS run



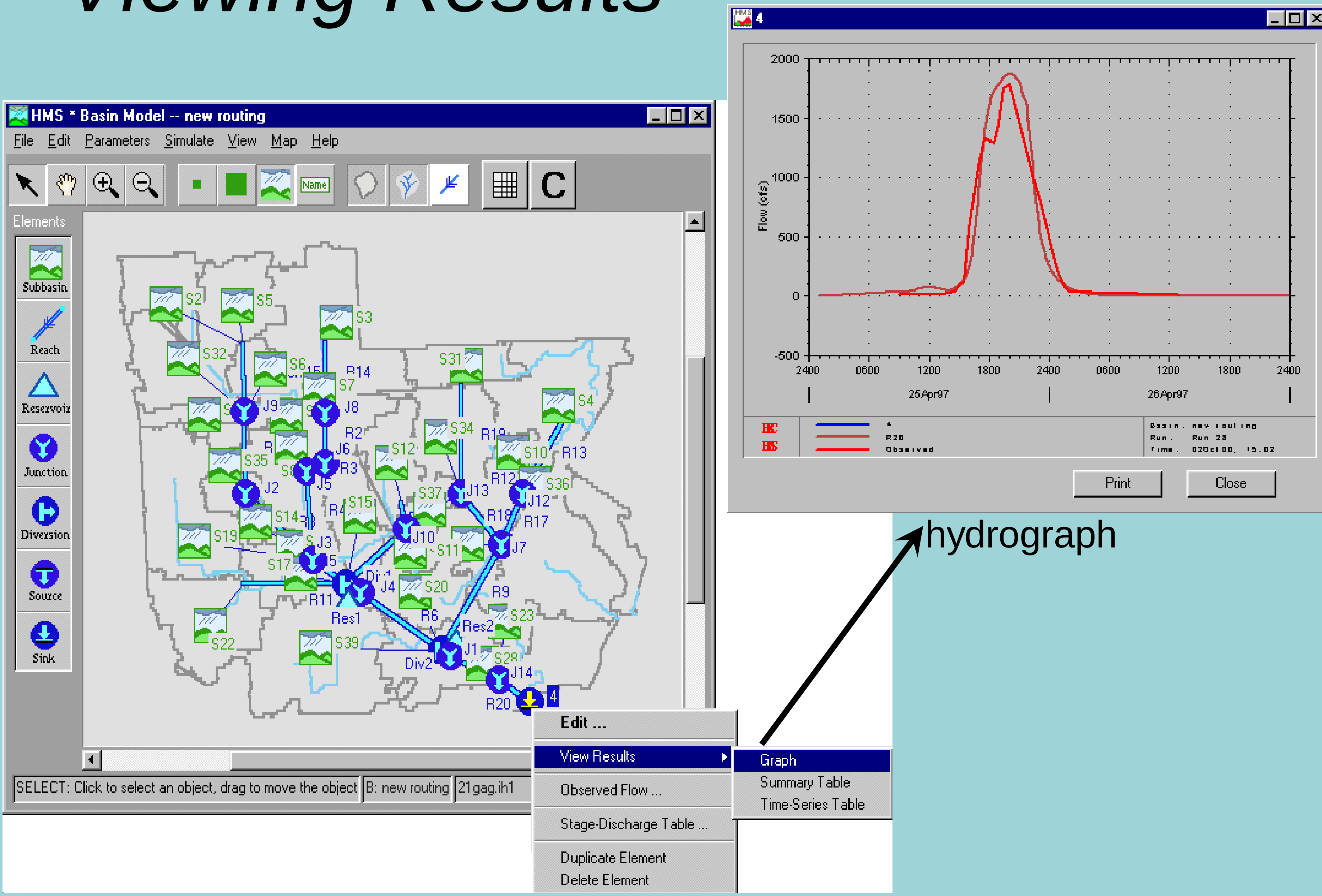
Viewing Results

- **To view the results**: right-click on any basin element, results will be for that point

- **Display of results**:
  - hydrograph- graphs outflow vs. time
  - summary table- gives the peak flow and time of peak
  - time-series table- tabular form of outflow vs. time

- **Comparing computed and actual results:** plot observed data on the same hydrograph to by selecting a discharge gage for an element

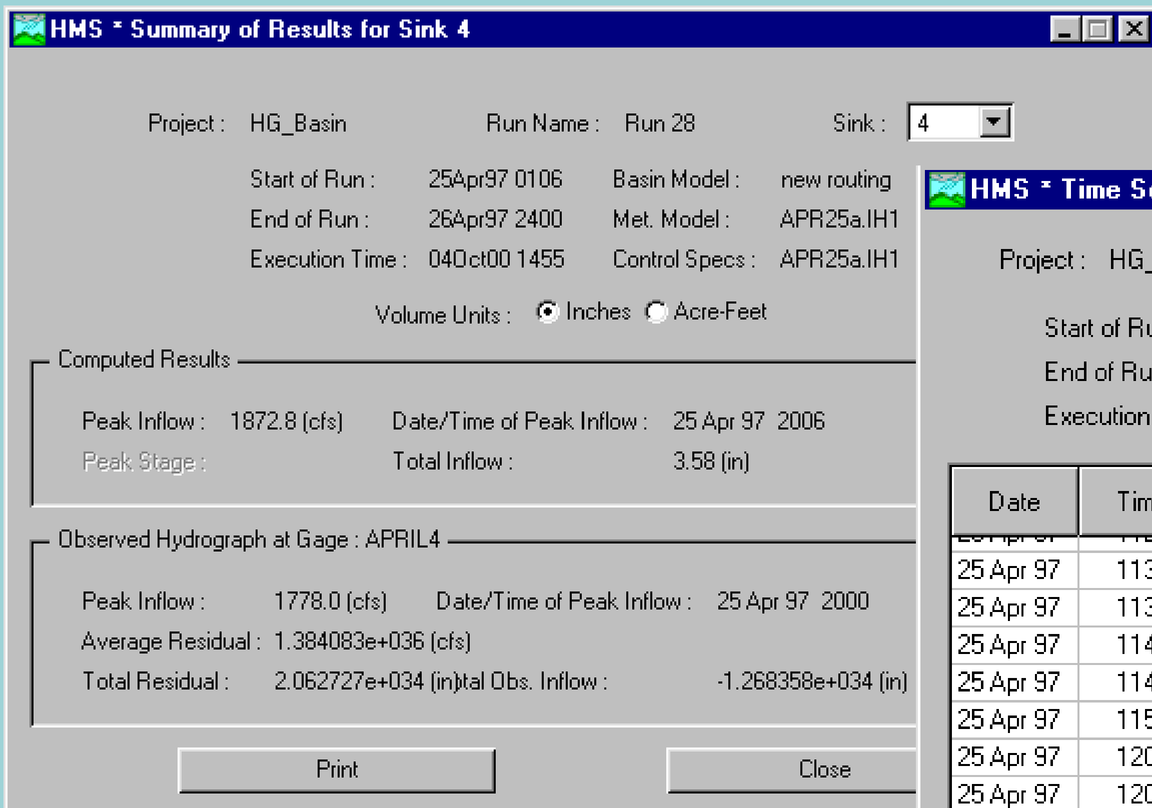
Viewing Results



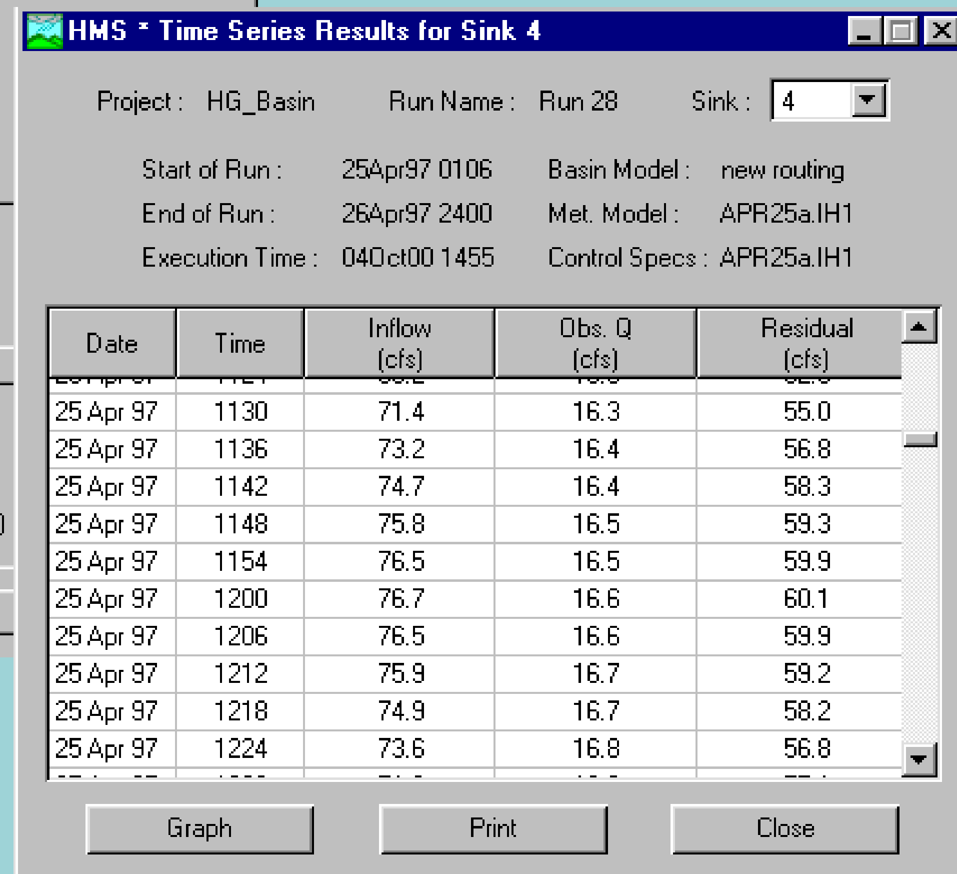
HEC-HMS Output

1. Tables
   - Summary
   - Detailed (Time Series)
2. Hyetograph Plots
3. Sub-Basin Hydrograph Plots
4. Routed Hydrograph Plots
5. Combined Hydrograph Plots
6. Recorded Hydrographs - comparison

Viewing Results



Summary table



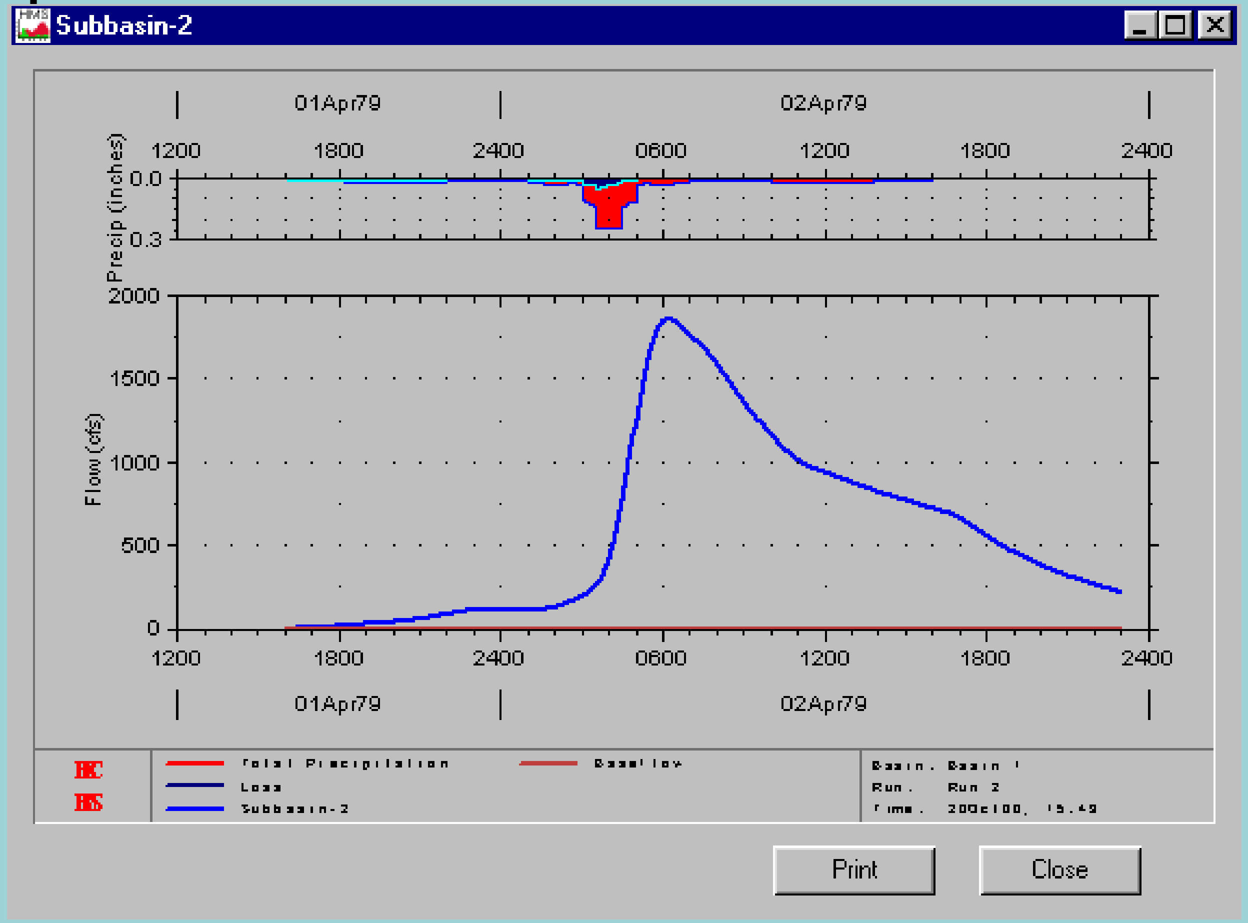
Date	Time	Inflow (cfs)	Obs. Q (cfs)	Residual (cfs)
25 Apr 97	1130	71.4	16.3	55.0
25 Apr 97	1136	73.2	16.4	56.8
25 Apr 97	1142	74.7	16.4	58.3
25 Apr 97	1148	75.8	16.5	59.3
25 Apr 97	1154	76.5	16.5	59.9
25 Apr 97	1200	76.7	16.6	60.1
25 Apr 97	1206	76.5	16.6	59.9
25 Apr 97	1212	75.9	16.7	59.2
25 Apr 97	1218	74.9	16.7	58.2
25 Apr 97	1224	73.6	16.8	56.8

Time series table

HEC-HMS Output

<u>Sub-Basin Plots</u>

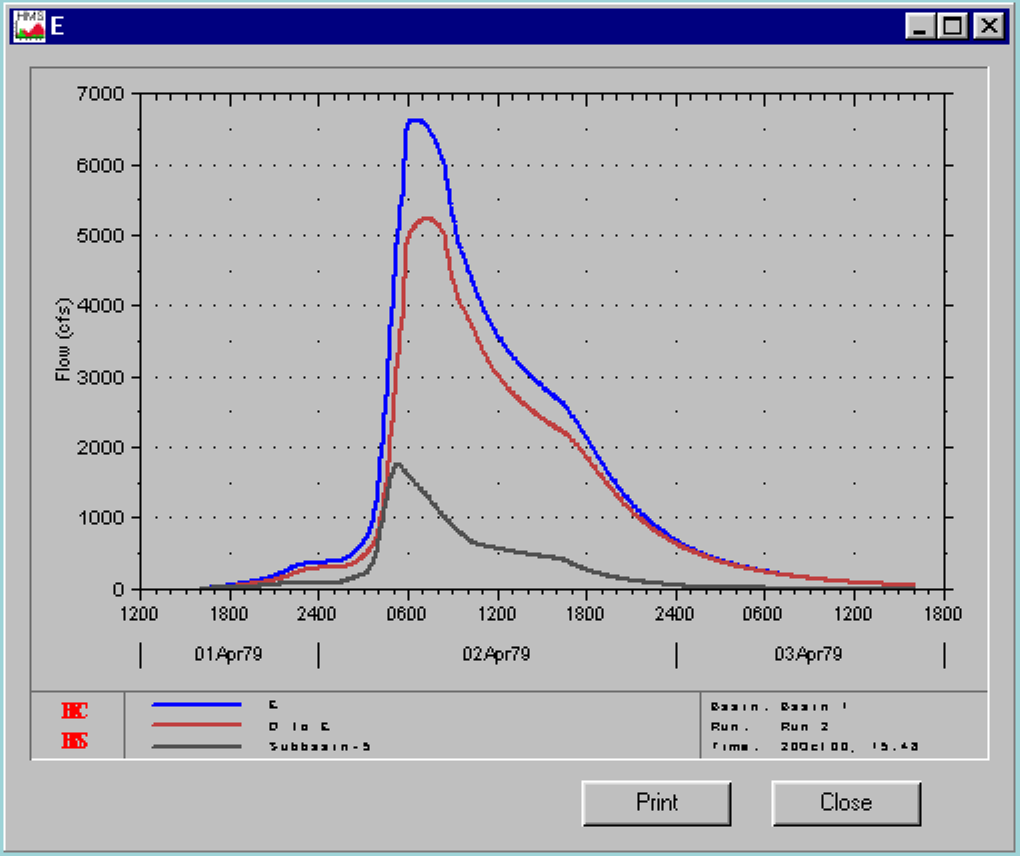
- Runoff Hydrograph
- Hyetograph
- Abstractions
- Base Flow



HEC-HMS Output

Junction Plots

Tributary Hydrographs
Combined Hydrograph
Recorded Hydrograph



Purpose of Calibration

Can Compute Sub-Basin Parameters

- Loss Function Parameters
- Unit Hydrograph Parameters

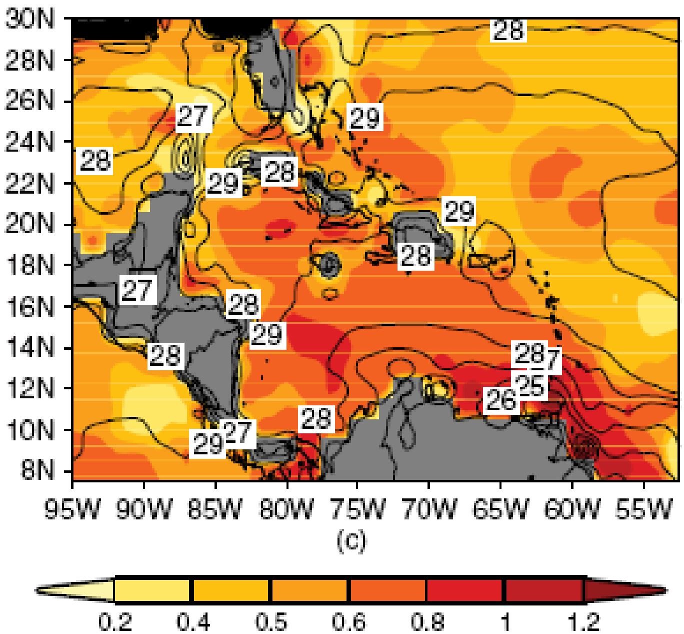
Can Compute Stream Flow Routing Parameters

Requires Gage Records

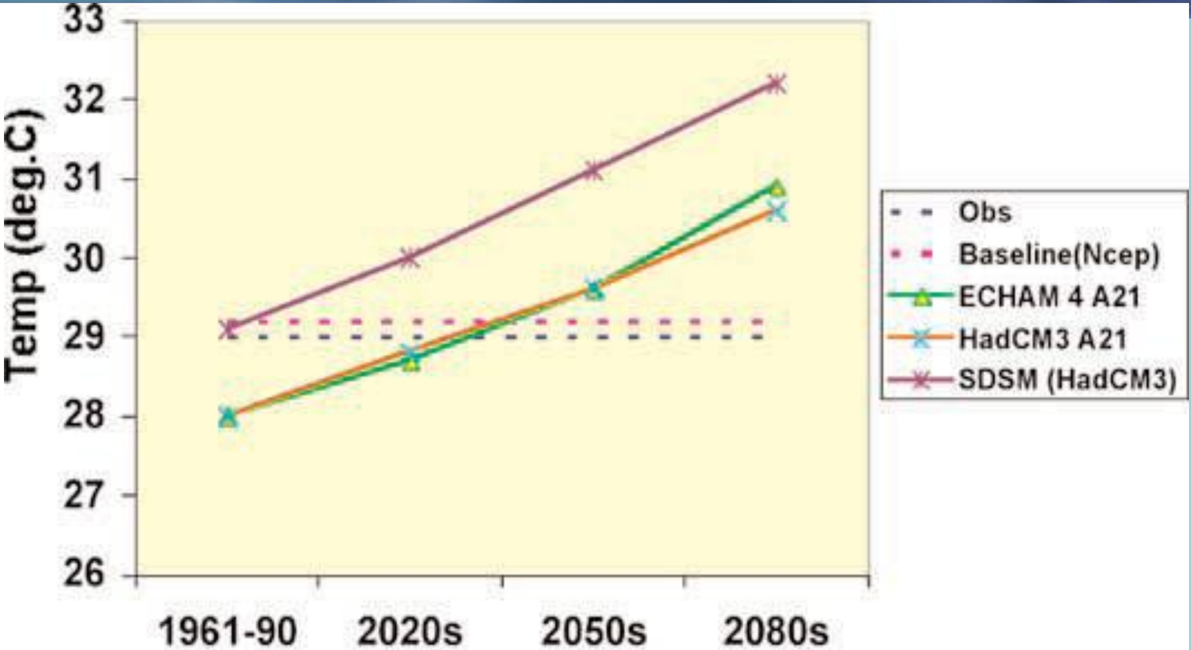
IMPACT OF CLIMATE CHANGE IN THE CARIBBEAN – JAMAICA.

- World's industrial powers (OECD) account for *20% world's population*, but are responsible for *>50 % of global emissions – the cause of global warming and resultant climate change*.
- Developing countries emit < *25 % of total GHG emissions*.
- Small Island States (SIDS) emit < *1% of global emissions*.
- SIDS have contributed little to the problem but are among the *most vulnerable* groups to GCC, and have *low adaptive capacity*.
  - Hence adaptation rather than mitigation is most appropriate course

CHANGE IN ANNUAL TEMPERATURE…SEA LEVEL RISE



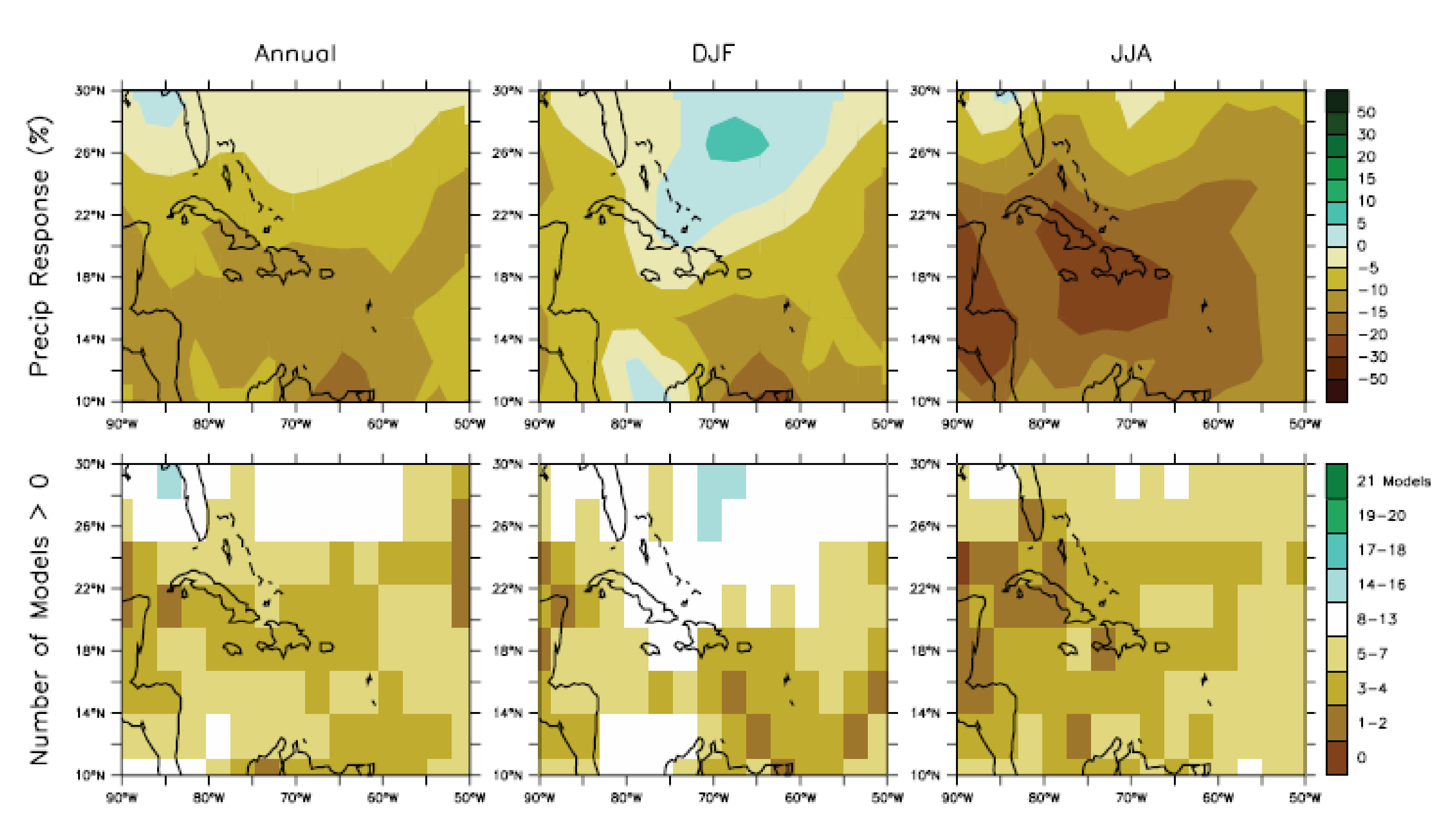
Temperature changes simulated across the Caribbean by Angeles et al., 2006



Observed and baseline (NCEP) temperatures and temperature scenarios at Worthy Park in Jamaica for present (1961-90), 2020s, 2050s and 2080s time slices, obtained by SDSM using HadCM3 with A2 emission scenario. Corresponding results for the Caribbean region given by HadCM3 and ECHAM4 are also shown.(Chen et al. 2008)

Global temperatures have increased by about 0.74˚C (0.56˚C to 0.92˚C) since the 19th century (IPCC, 2007).

CHANGES IN PRECIPITATION…



Precipitation changes over the Caribbean from the MMD-A1B simulations. Top row: Annual mean, DJF and JJA fractional precipitation change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Bottom row: number of models out of 21 that project increases in precipitation (From Christensen et al., 2007*).*

Effects of increase in temperature … on small island states.
Increase in frequency of hurricanes.

INCREASED IN FREQUENCY OF HURRICANES AND TROPICAL STORMS WILL LEAD TO AN INCREASE IN FLOODING….

- Flood risk modeling (HADCM2, HADCM3, UKMO, 1999) suggests that by 2080, numbers facing severe floods in the Caribbean, Indian and Pacific Ocean regions would be 200 times higher than if there were no SLR.

Increase in flooding due to high intensity rains from hurricanes and storms will affect the coastal areas of Jamaica.. Ocho Rios, Port Maria, parishes of St. Thomas , Kingston and Portland.

Major damages have been done by tropical storm Gustav and Nicole in Portland, St. Thomas , Kingston and St. Andrew.

Flooding along coastal areas affects tourism as well as the transportation to the major airports.

HOPE RIVER WATERSHED-CASE STUDY

The Hope River supplies water to Kingston and flows through the eastern section of the city and has been responsible for high levels of damage in the past. Damage is usually caused by fast-flowing torrents carrying debris of varying size.

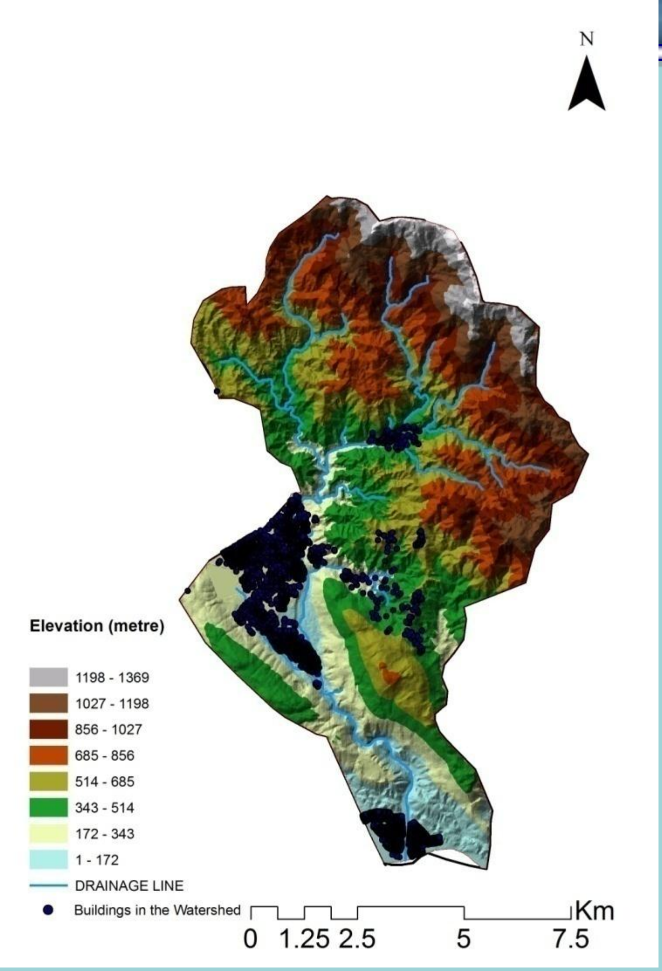
The Hope River Watershed had repeated occurrences of flooding and associated debris flows resulting from heavy rains associated with Tropical storms and hurricanes.

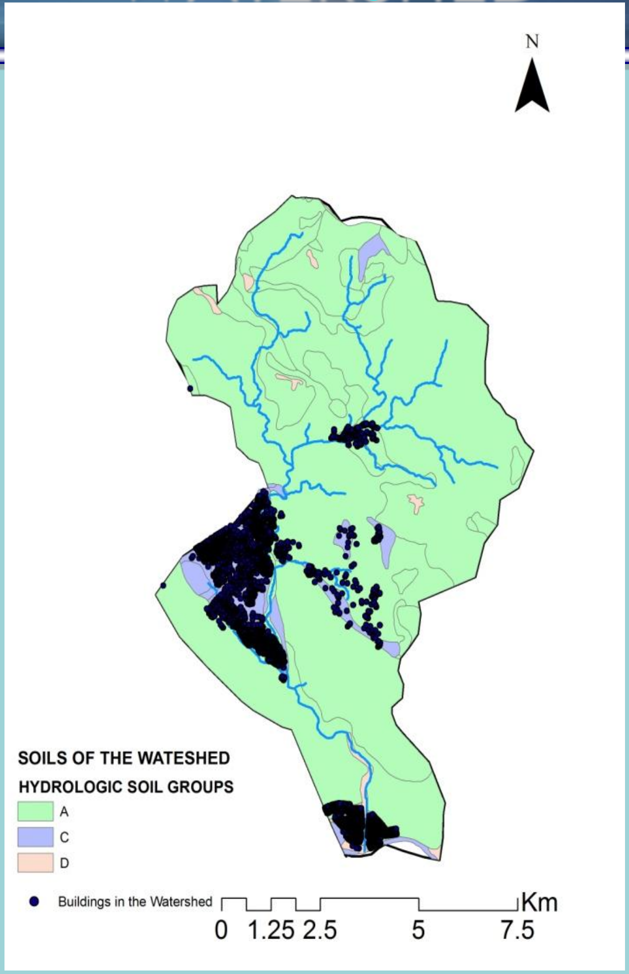
Damages have resulted in collapse of bridges (at Kintyre and Harbour view and houses along the flood plain from hurricane Gustav (2008), tropical storm Nicole (2010). These are some of the recent damages.

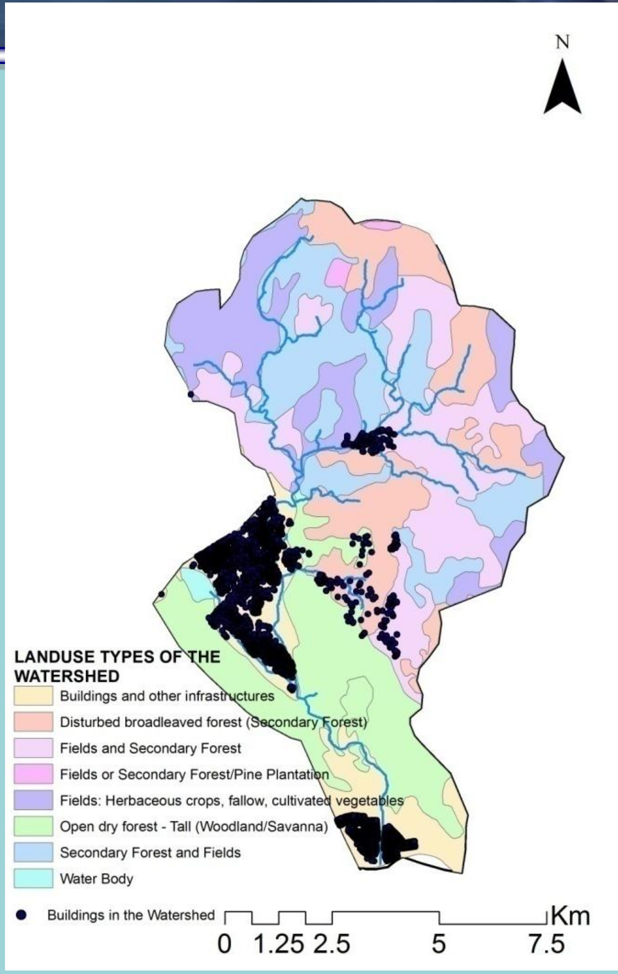
Aims of the study on Hope River Watershed

- **Assessment of damages done by flooding.**
- **Study on rainfall return periods and rainfall pattern for the watershed.**
- **Analysis of the flood return periods.**
- **Analysis of long term (1955-2010) discharge data from the Hope River.**
- **Flood plain maps for the watershed and highlighting vulnerable zones.**

ELEVATION, LANDUSE AND SOIL TYPE OF THE WATERSHED

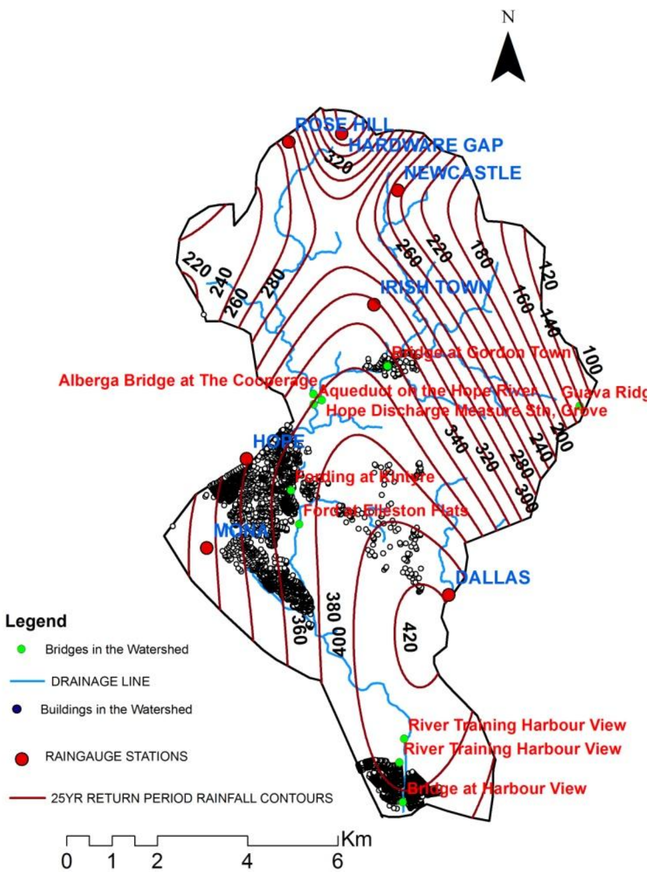


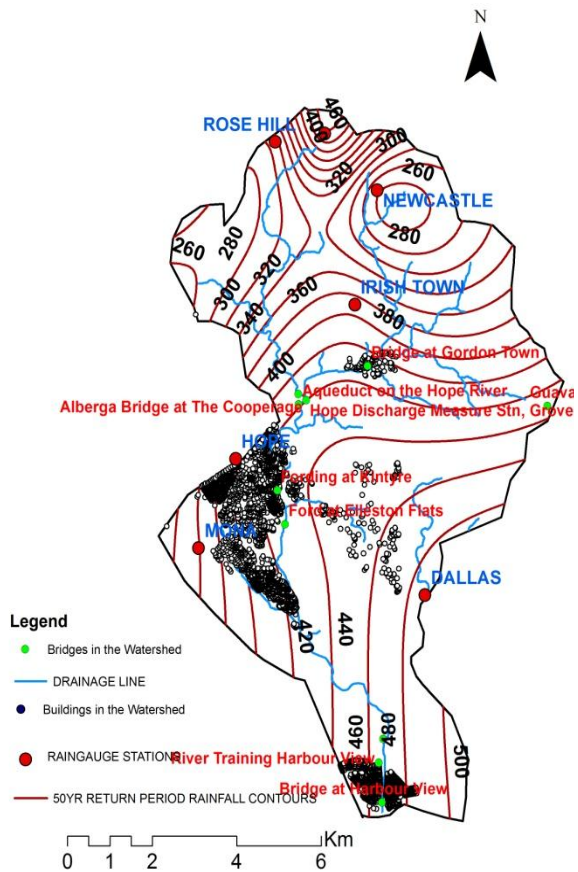


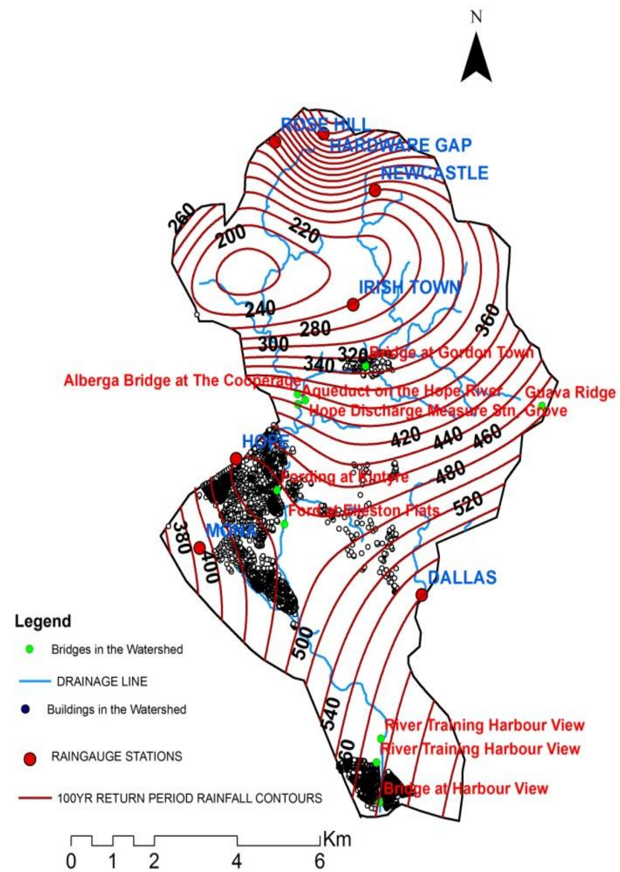


Elevation Map created from DEM of 6m horizontal and 1m vertical resolution. Note the buildings are located in the floodplains of the river and in the areas of low elevation. High elevation in the upper watersheds coupled with impermeable rocks results in less infiltration. Hence high run off and flooding in the downstream areas. Soil data shows buildings located in zones with moderate high runoff ie C.

Return Periods for Maximum 24hr rainfall for the watershed . (Data 1937-1985, Metservice of Jamaica)







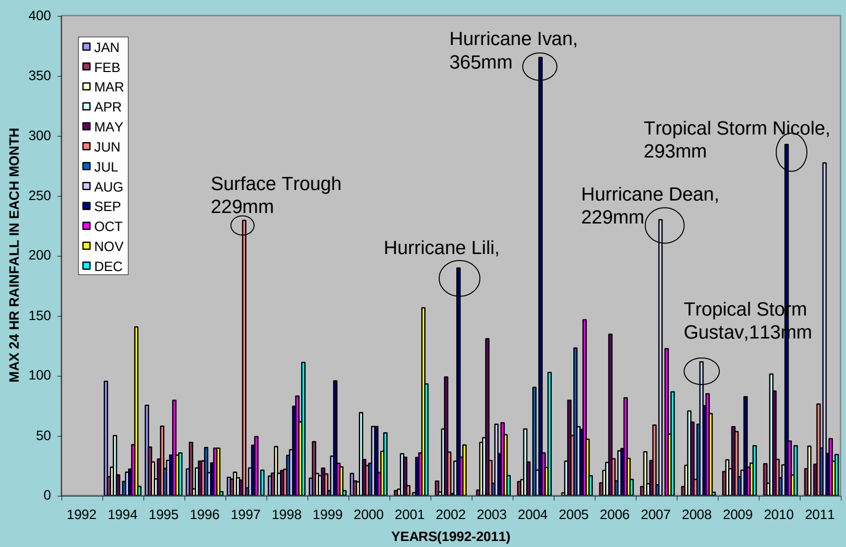
25yr return period rainfall contours (mm)

50yr return period rainfall contours (mm)

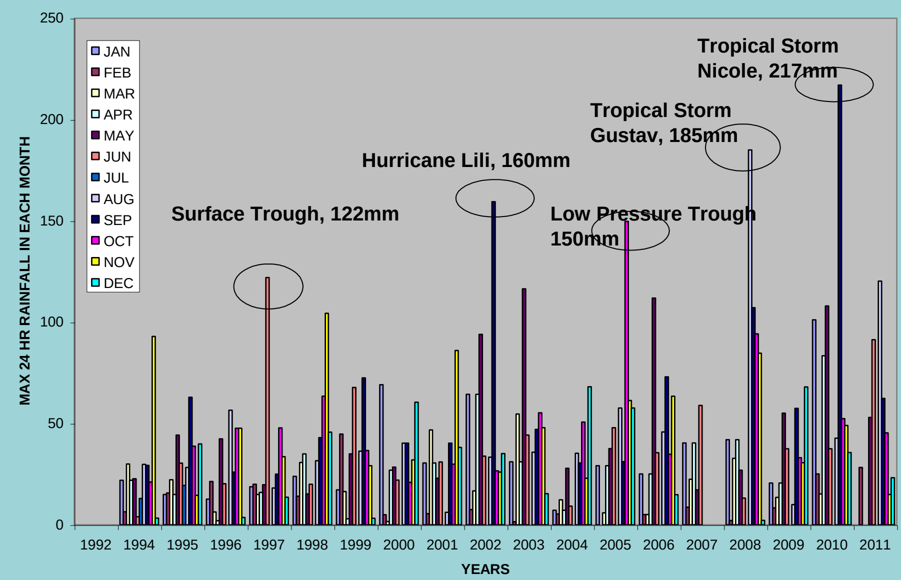
100yr return period rainfall contours (mm)

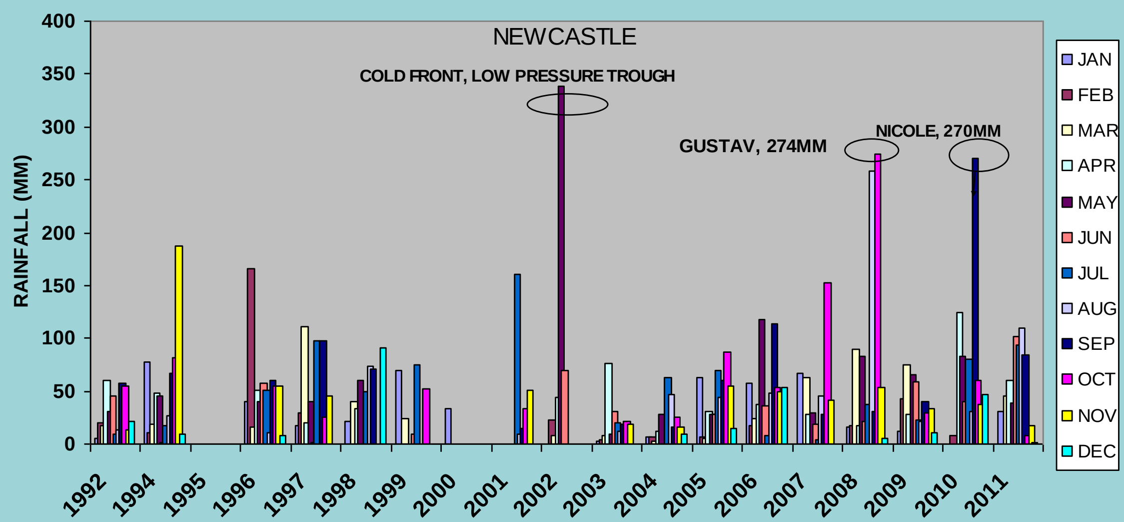
MAXIMUM RAINFALL FOR SOME STATIONS OF THE HOPE WATERSHED AND ASSOCIATED TROPICAL STORMS, HURRICANES AND TROUGHS.

IRISH TOWN

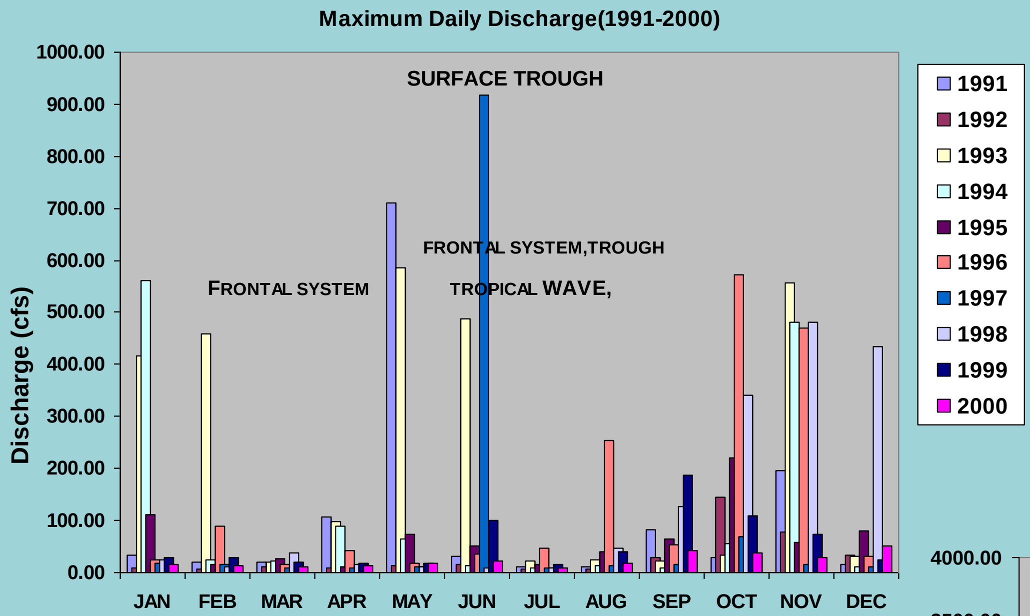


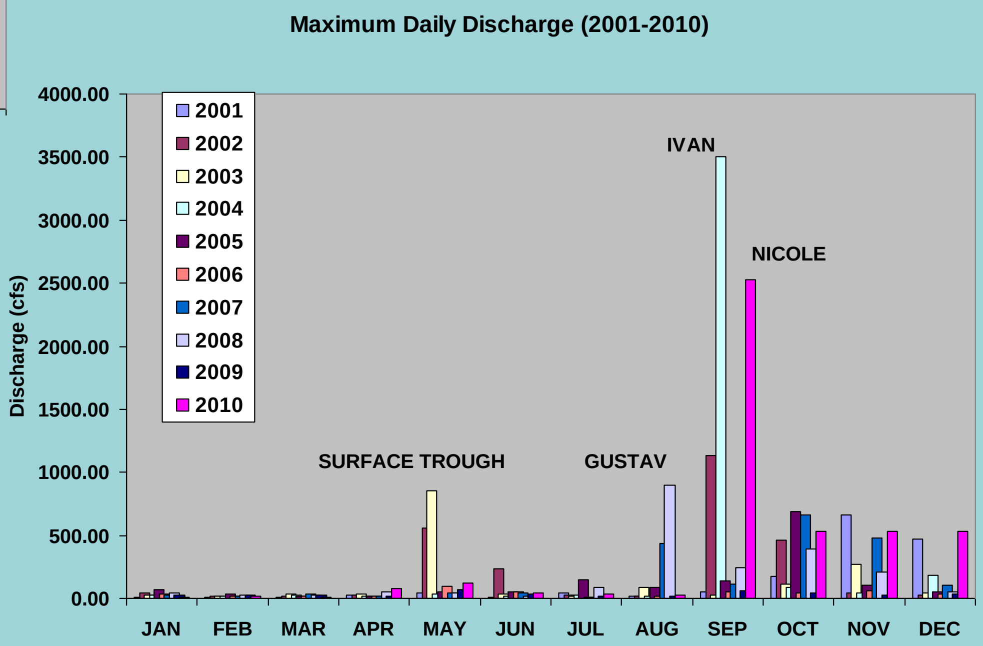
JACKS HILL



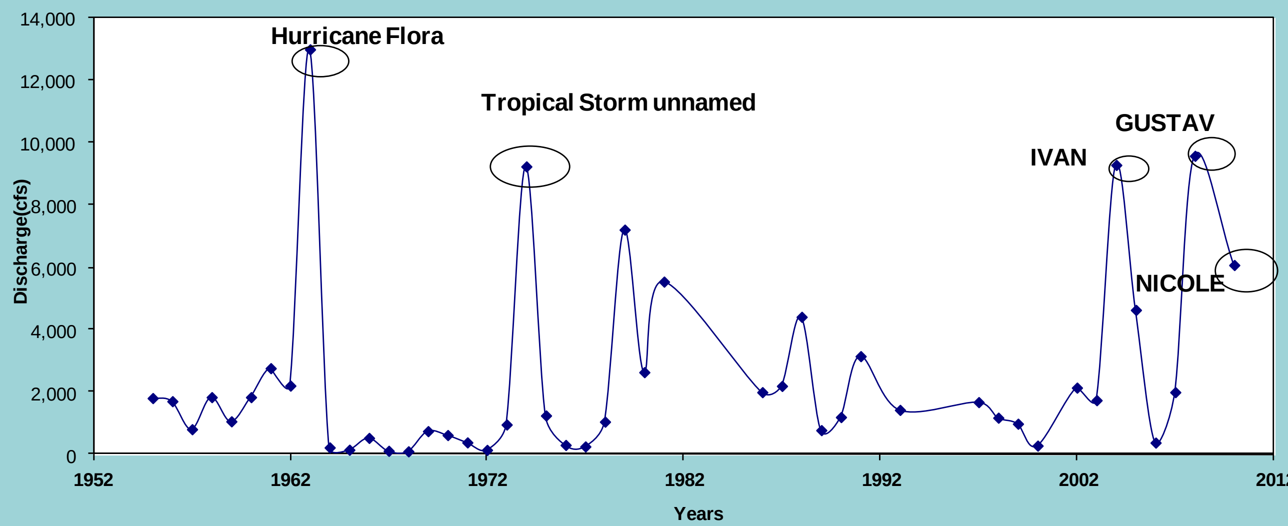


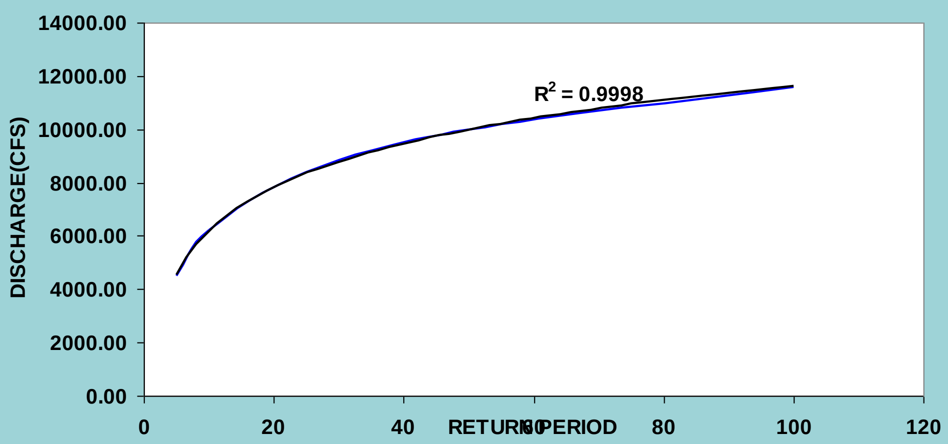
MAXIMUM PEAK DISCHARGES FOR THE HOPE RIVER MEASURED AT THE HOPE DISCHARGE STATION AT GROVE AND ASSOCIATED CAUSES.





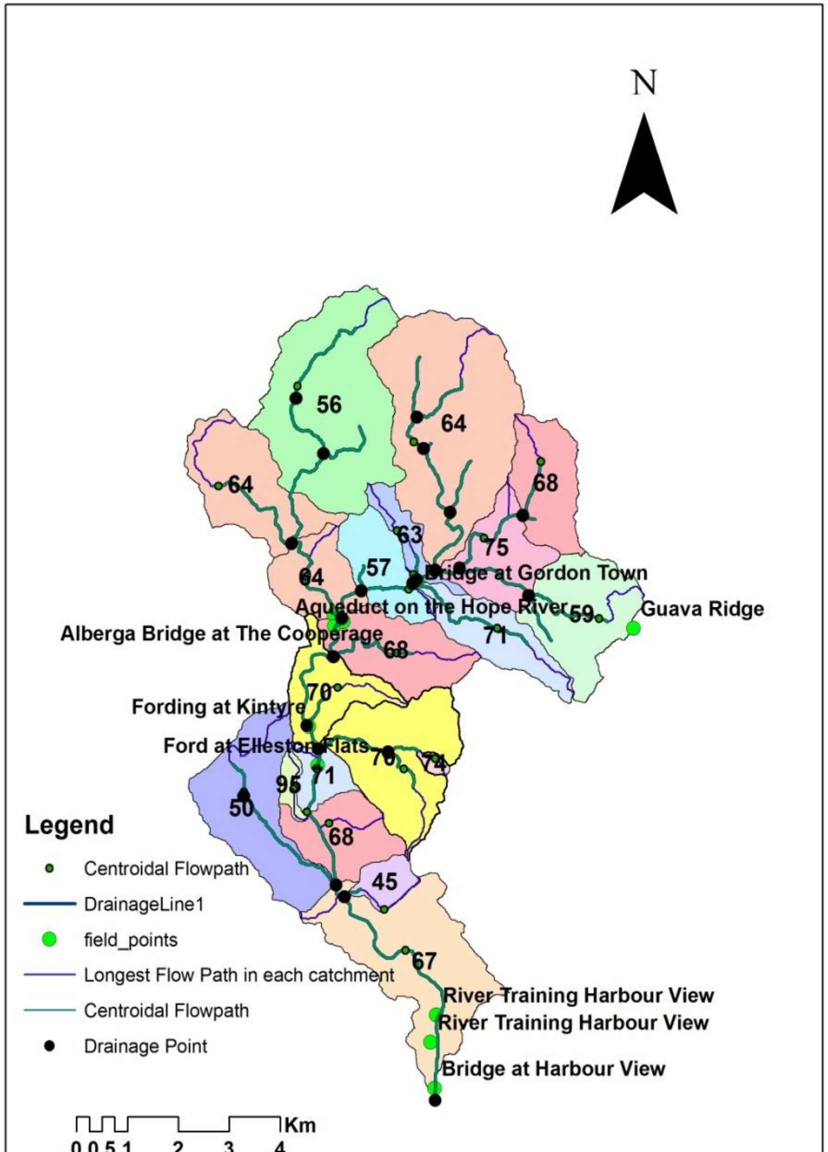
PEAK FLOOD DISCHARGES AND LONG TERM MAXIMUM DISCHARGE FROM HOPE DISCHARGE STATION. RETURN PERIOD OF FLOOD PEAK FLOWS USING GUMBEL METHOD (MOMENT OF MEANS)



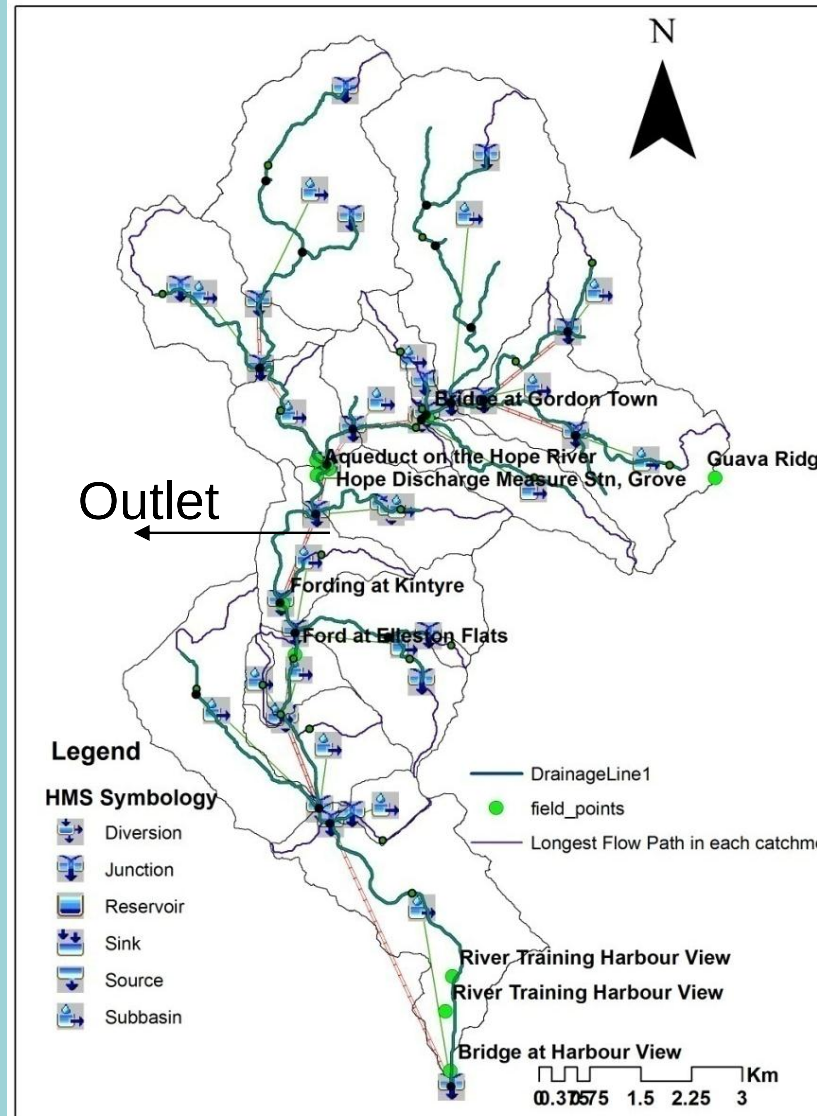


Return Period	Flow(cfs)
5	4495.73
10	6219.23
25	8382.22
50	9990.82
100	11599.65

Catchments, flowlengths, curve number for the watershed created in GEOHMS



Basin model with junctions, sub-basins, reaches and outlets as in HEC-HMS



SIMULATION OF THE RAINFALL – RUNOFF MODEL IN HEC HMS AND CALIBRATION WITH OBSERVED DISCHARGE DATA

HEC HMS was run with 2 meteorological model

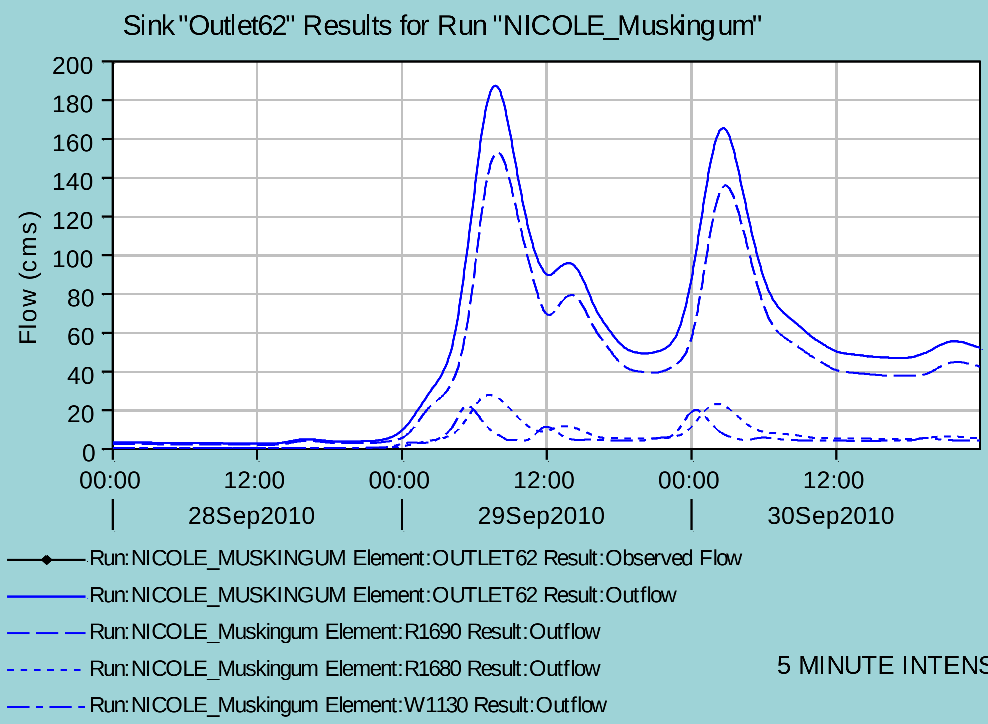
- 5 minute rainfall intensity data for Tropical Storm Nicole measured at the Hope discharge station
- 5 minute rainfall intensity data from raingauge at Hope discharge station for the month of June 2011.

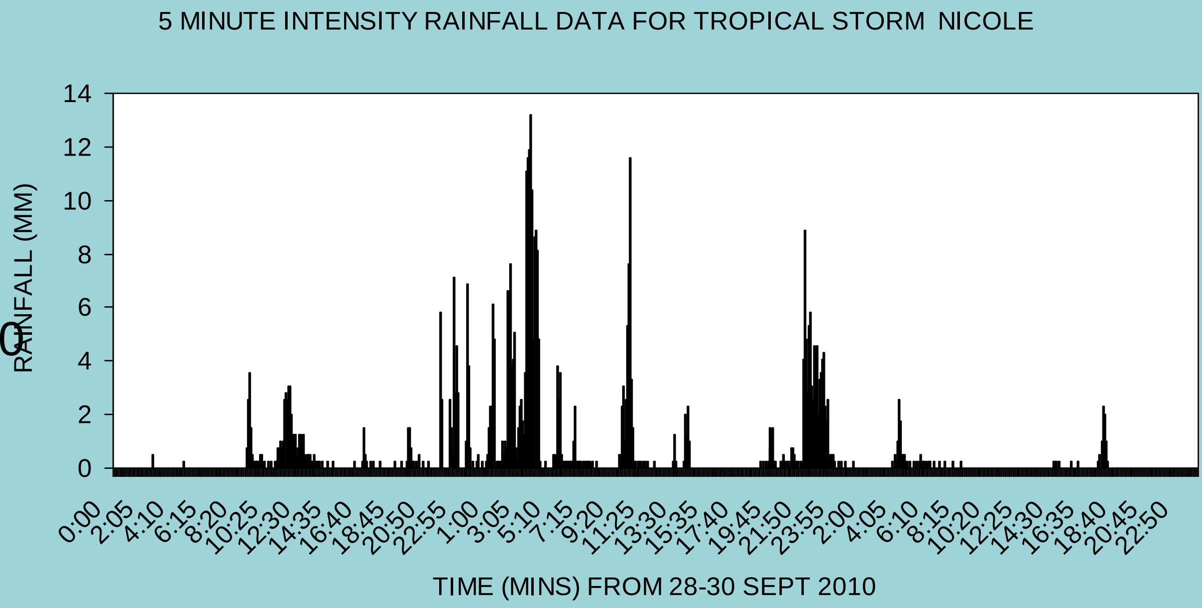
The SCS loss method and basin lag were used as other input data. Basin lag was determined using SCS formula:

TL =L^0.8(SCN+1)^0.7/1900*Y^0.5 where, L= length of the longest flowpath, SCN = (1000/CN -10) , Y = Slope .

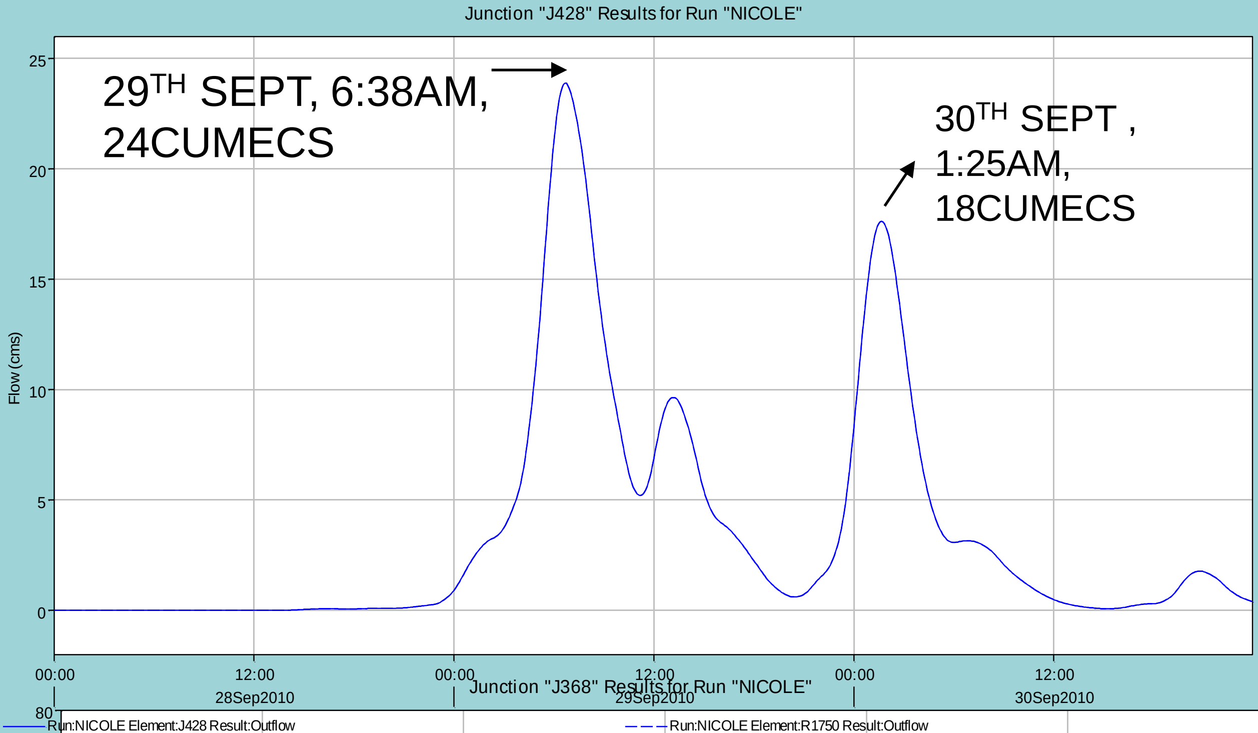
Model calibrated with observed discharge data from hope discharge station.

RESULTS FROM HEC HMS

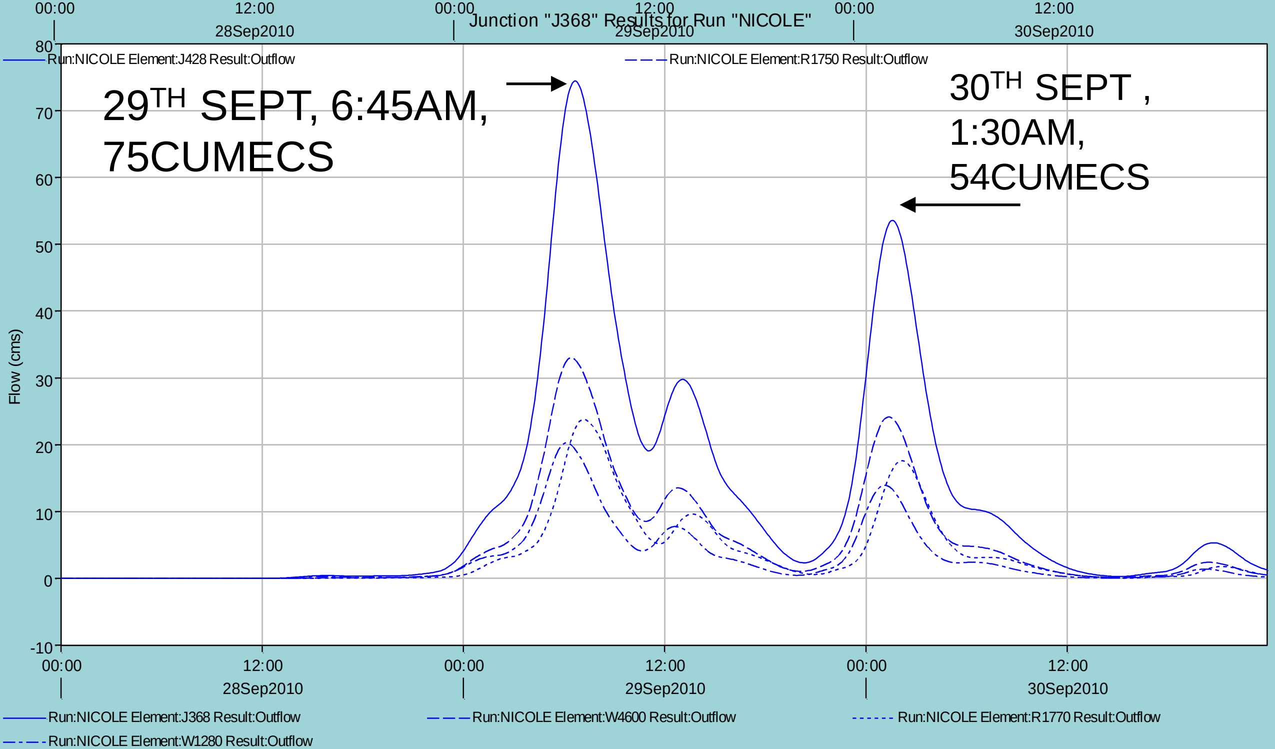




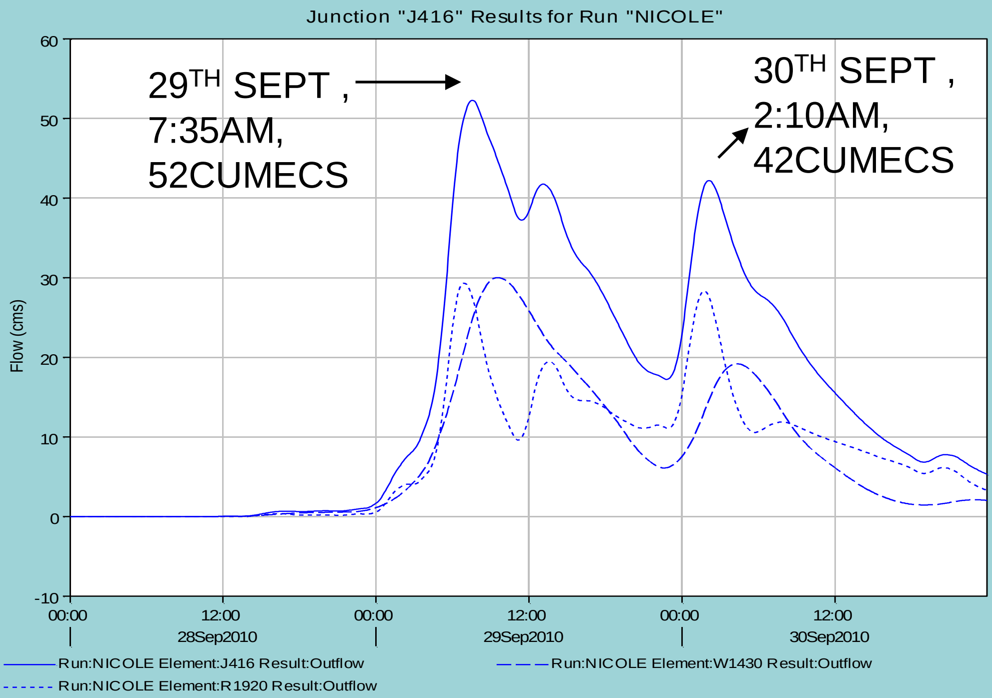
Peak rainfall =13.2MM AT 3:40 AM , 29TH SEPT

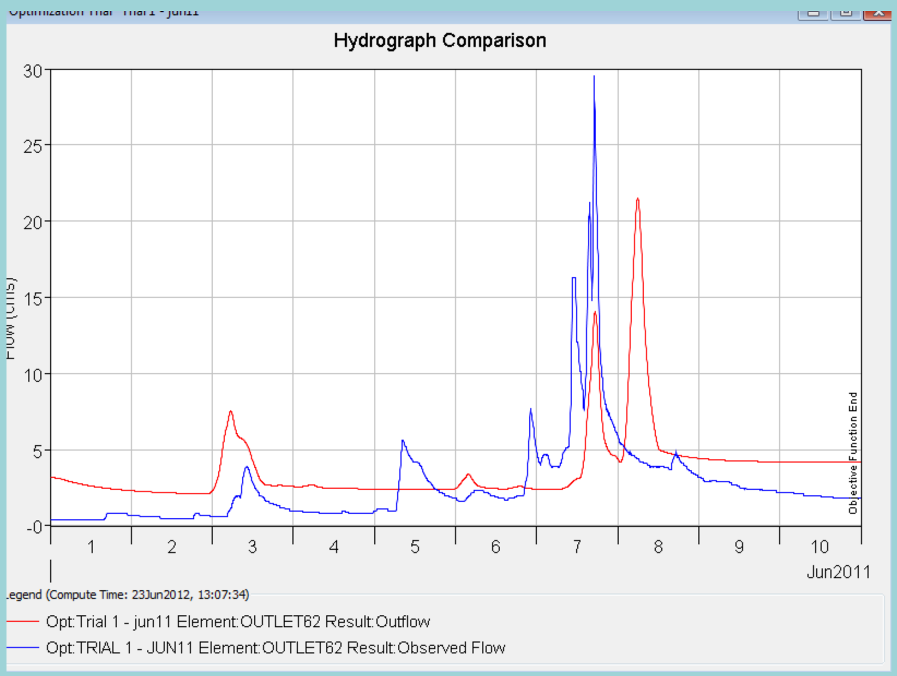


Simulated peak discharges at junction of flow nodes at the fording at Kintyre.



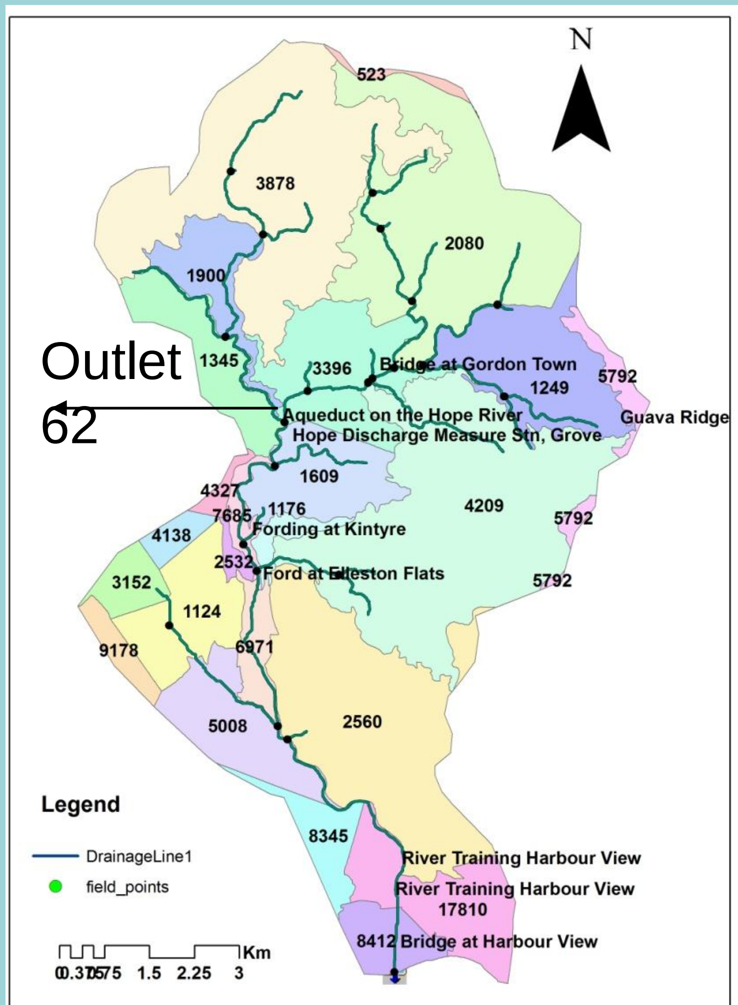
Simulated discharge at the junction of flow nodes immediate upstream (~ 330m) north of fording at Elleston Flats.





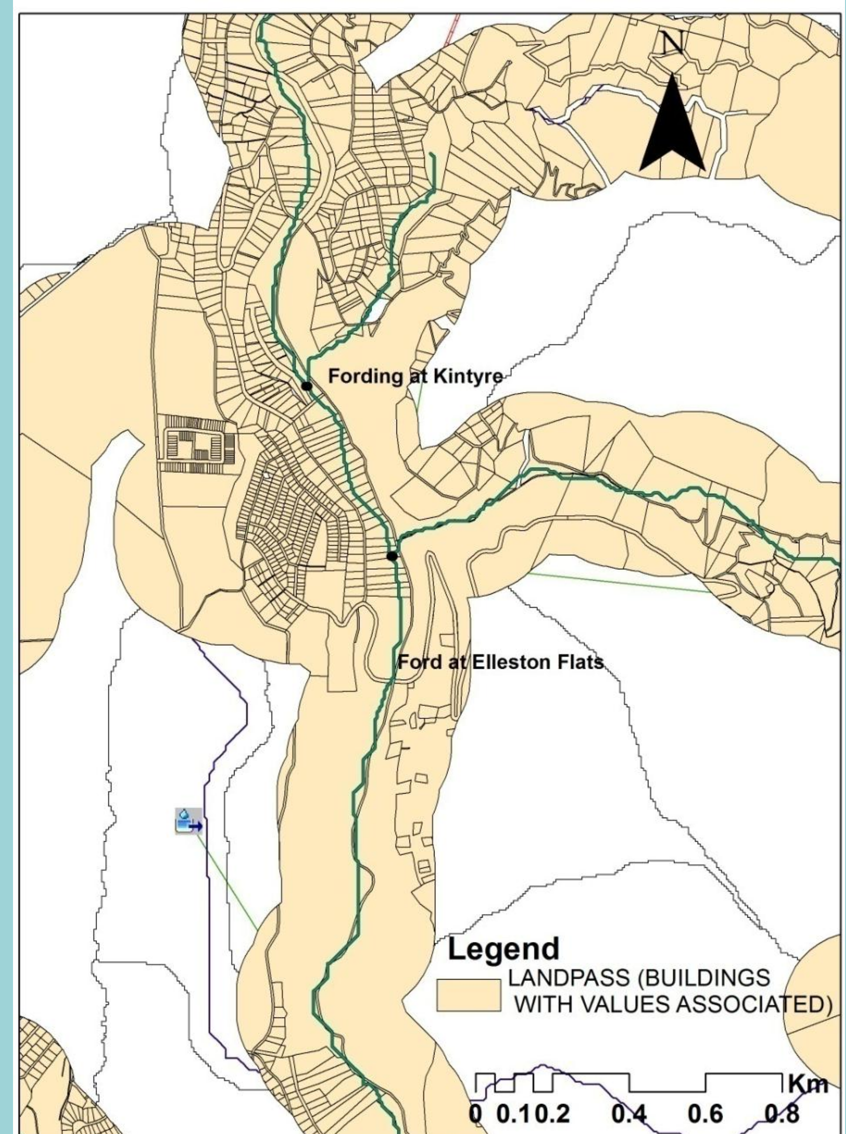
Simulated discharge at the junction node near the mouth of the river at harbour view.

Simulated vs observed hydrograph for the hope discharge station at grove which is marked as outlet 62 in the hec hms model. This is the outlet of flow from the sub-basins of the upper part of the watershed.



Population of the Hope River watershed. The vulnerable areas i.e., Kintyre, Elleston Flats/August Town which are in the high peak flow zone have a population of 1609, 1176, 2532 respectively. Population of Harbour View ranging from 8412-17810.

Outlet 62 = peak of 173CFS(Nicole).



Buildings within a distance of 200m from the river for two of the vulnerable communities. Approx range of value for houses left of Kintyre ~ 450000 to 550000

ACKNOWLEDGEMENTS

- ❖World Bank For Funding The Research Work
- ❖Institute of Sustainable Development, UWI Mona.
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THANK YOU