Cause, Assessment & Management of Flood Hazards associated with Landfalling Tropical Cyclones & Heavy Rain

by

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Outlines

Part 1 :

Cause & Impact of Landfalling Tropical Cyclones

Part 2 :

Case Assessment of the Failure of ‘New Orleans Flood Protection System’ from Hurricane Katrina

Part 3:

Management & Mitigation of Flood Hazards associated with Landfalling Tropical Cyclones

Part 4:

Tutorial- Simulation models for planning, forecast and assessment

Part 4

Tutorial- Simulation models for planning, forecast and assessment

- **Simulation Models for River Flooding:**

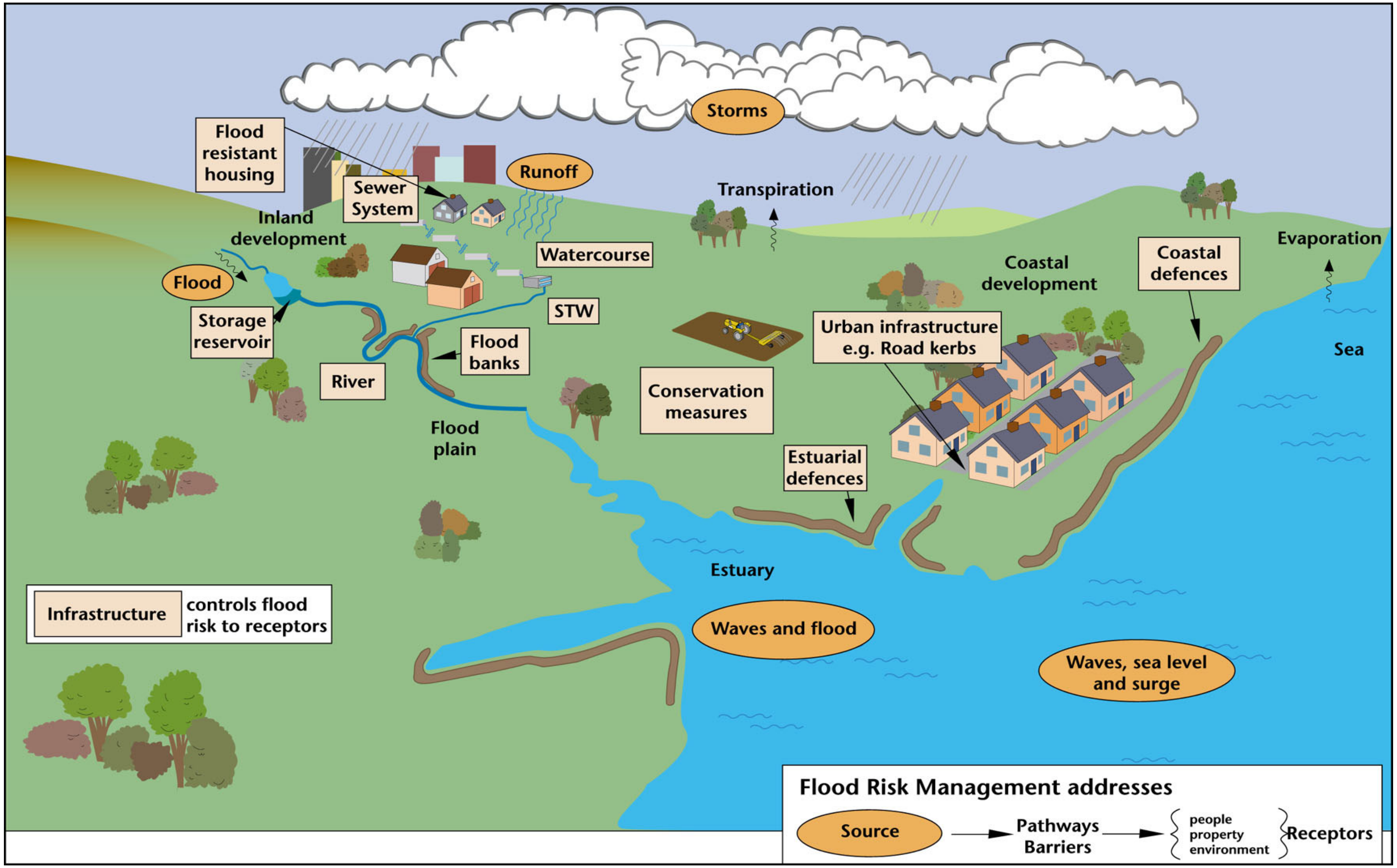
  River floods over stream banks & floodplains

- **Simualtion Models for Coastal Flooding:**

  Storm surges along coastal & estuarine areas

  Combined or joint floods from the coastal & river sources

The coastal and river flooding



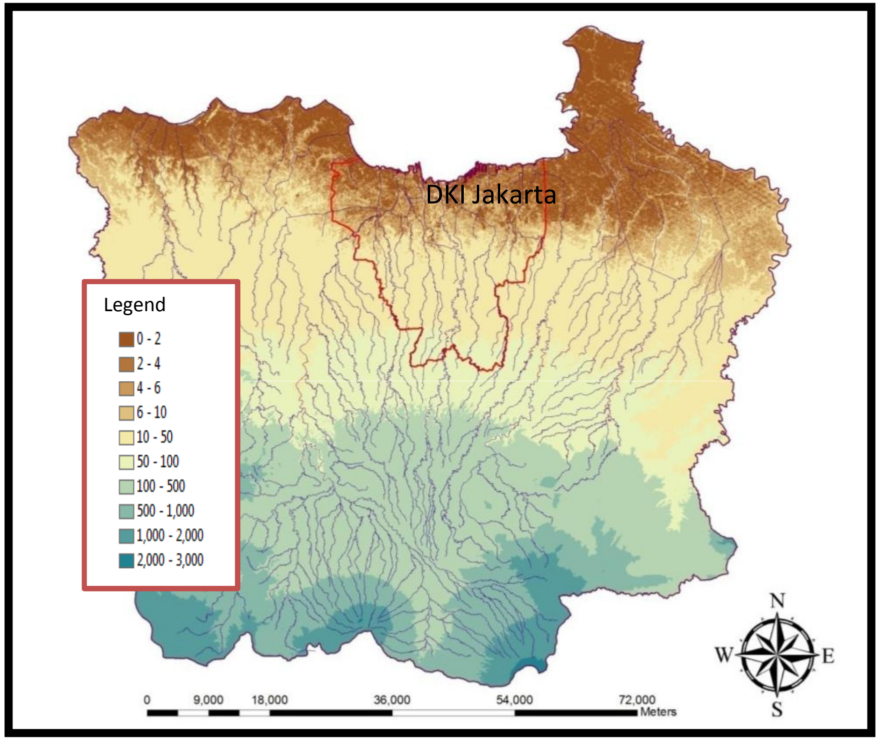
Source: UK Foresight project on Flooding and Coastal Defence 2004

Prof Colin Thorne, University of Nottingham

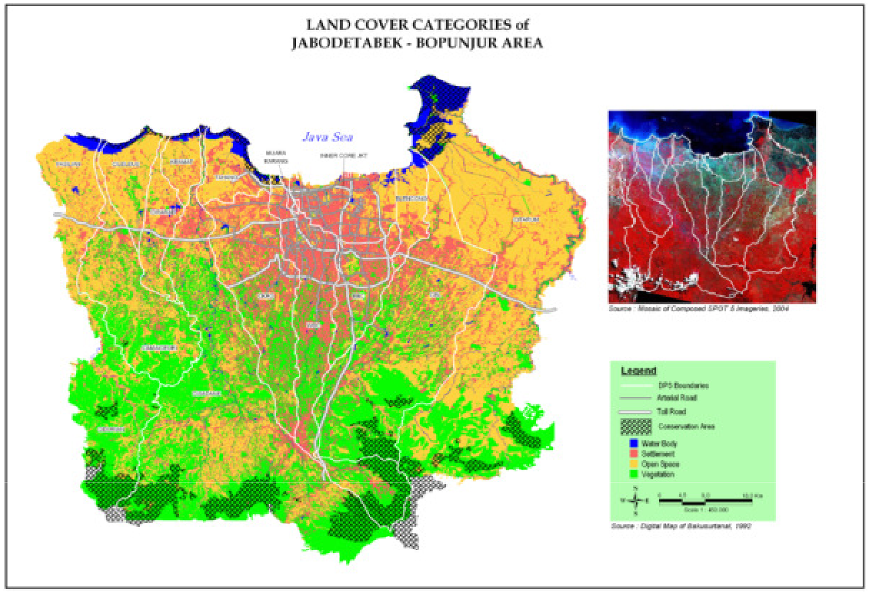
Simulation models for river flooding
Database Inventories

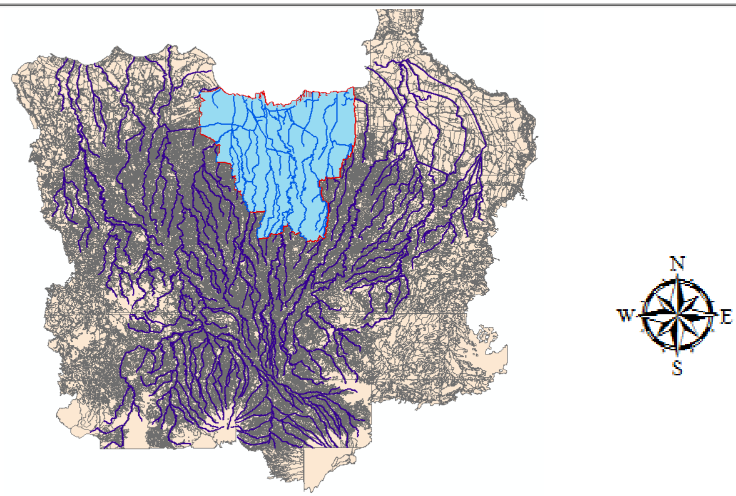
- **DEM** (Digital Elevation Model)**/DTM** (Digital Terrain Model) through public domain sources such as SRTM, digitization of topographic maps, LiDAR (Light Detection and Ranging) mapping, land surveys, etc.
- **Survey data** of watersheds & drainage channels, gates, bridges, and stream crossing structures

Digital Elevation Model (DEM), Land Cover & Drainage Network of Jabodetabek



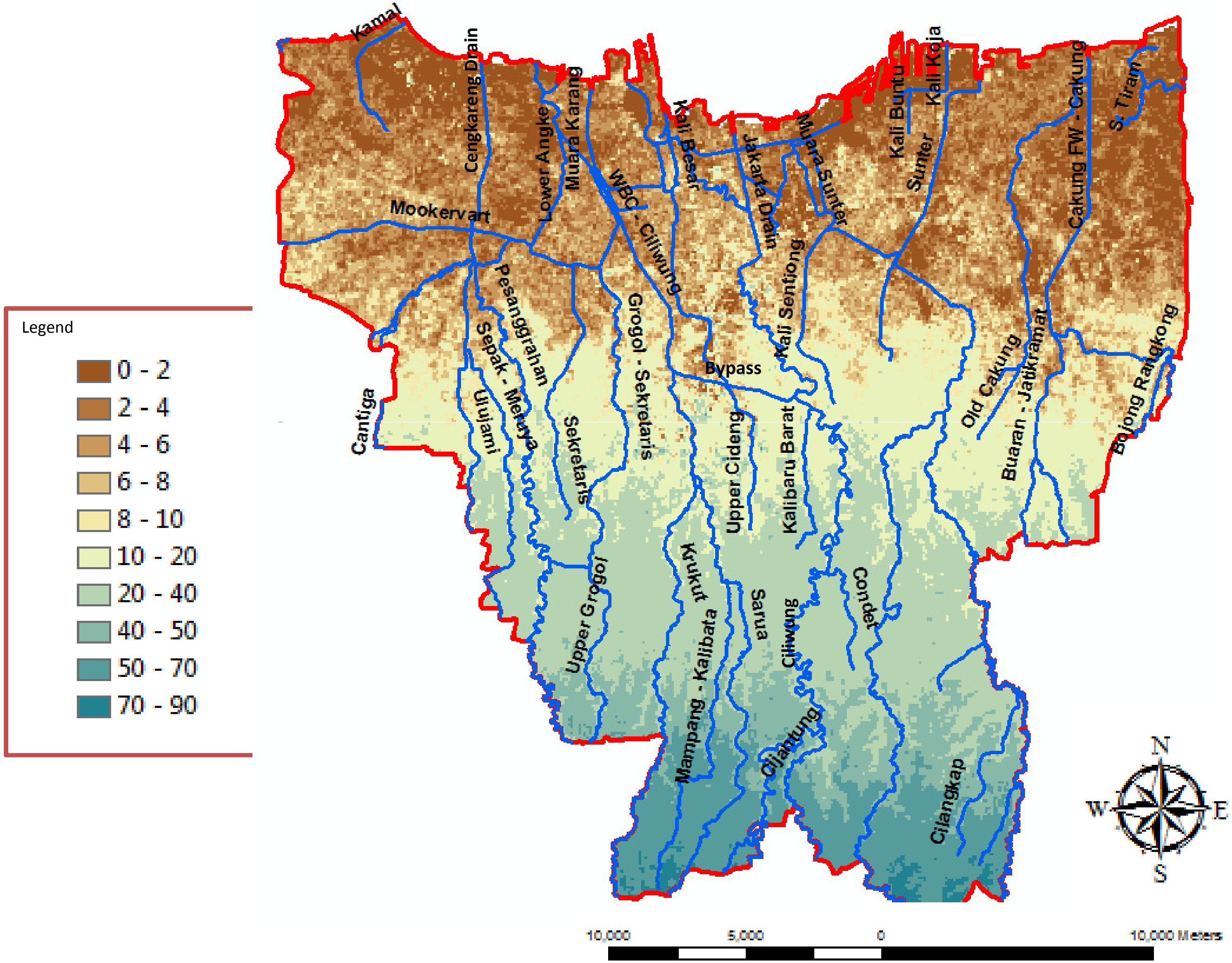
DEM of Jabodetabek
(Source: SRTM, Dec 2009)



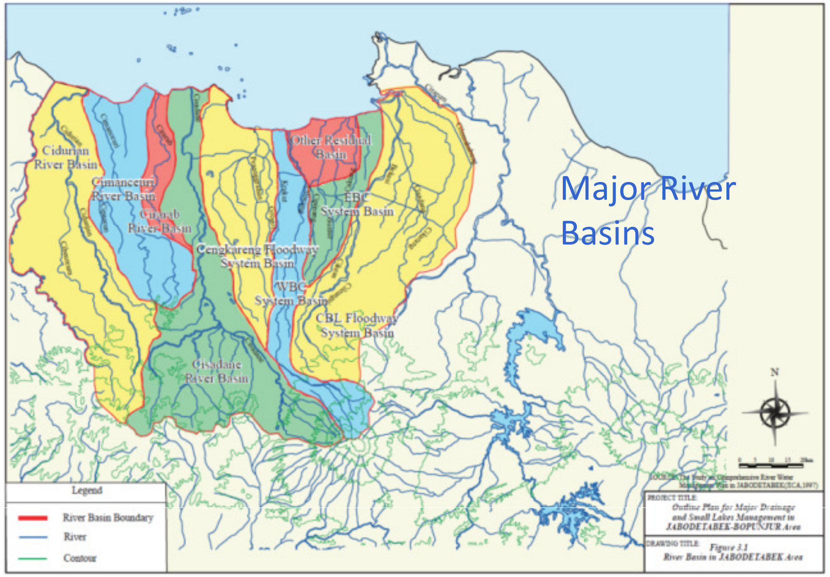


Land-use and River Network

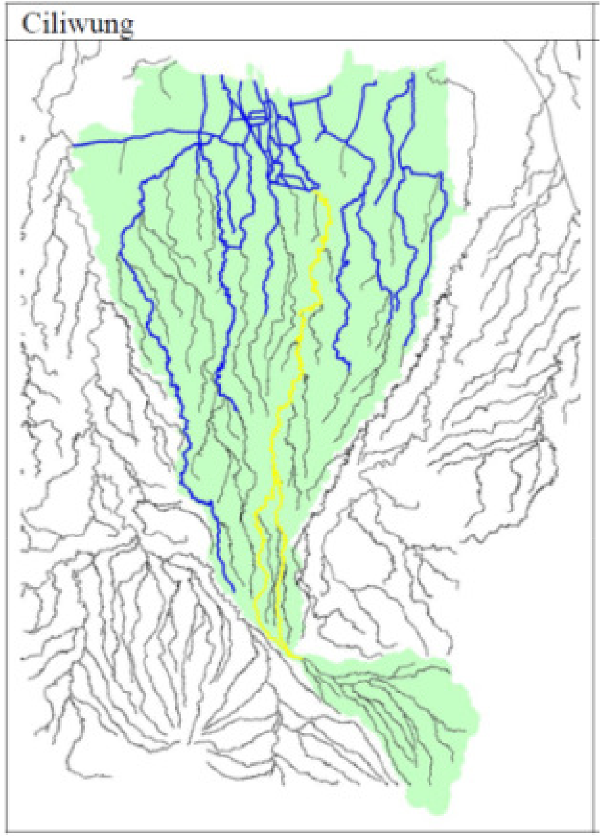
DEM and Rivers Draining DKI Jakarta



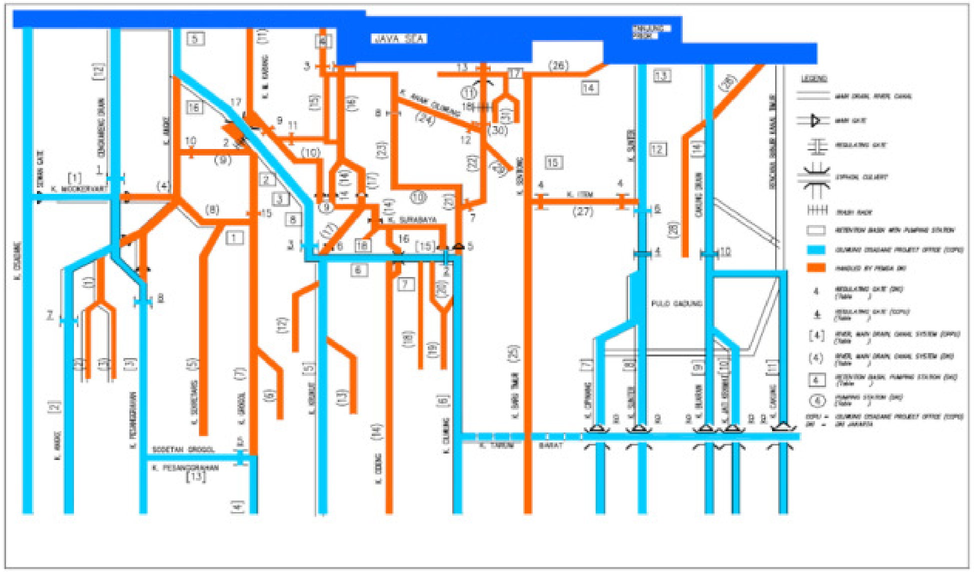
Jakarta River Drainage Network



Major River Basins



Ciliwung Draining Central Jakarta



Schematic of Jakarta River Network

Simulation models for river flooding

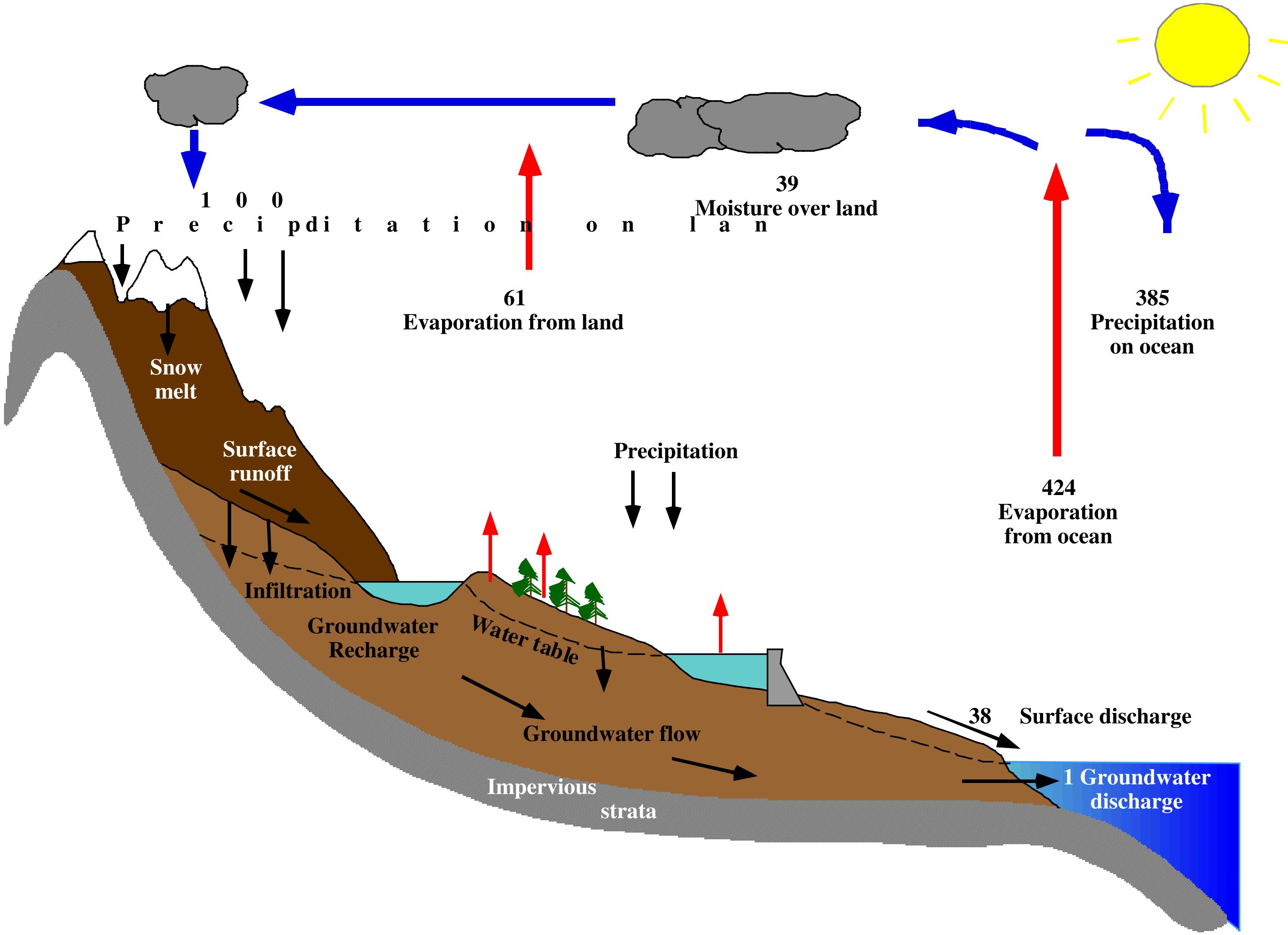
Hydrologic Models

- **HEC- HMS** (Hydrologic Modeling System)

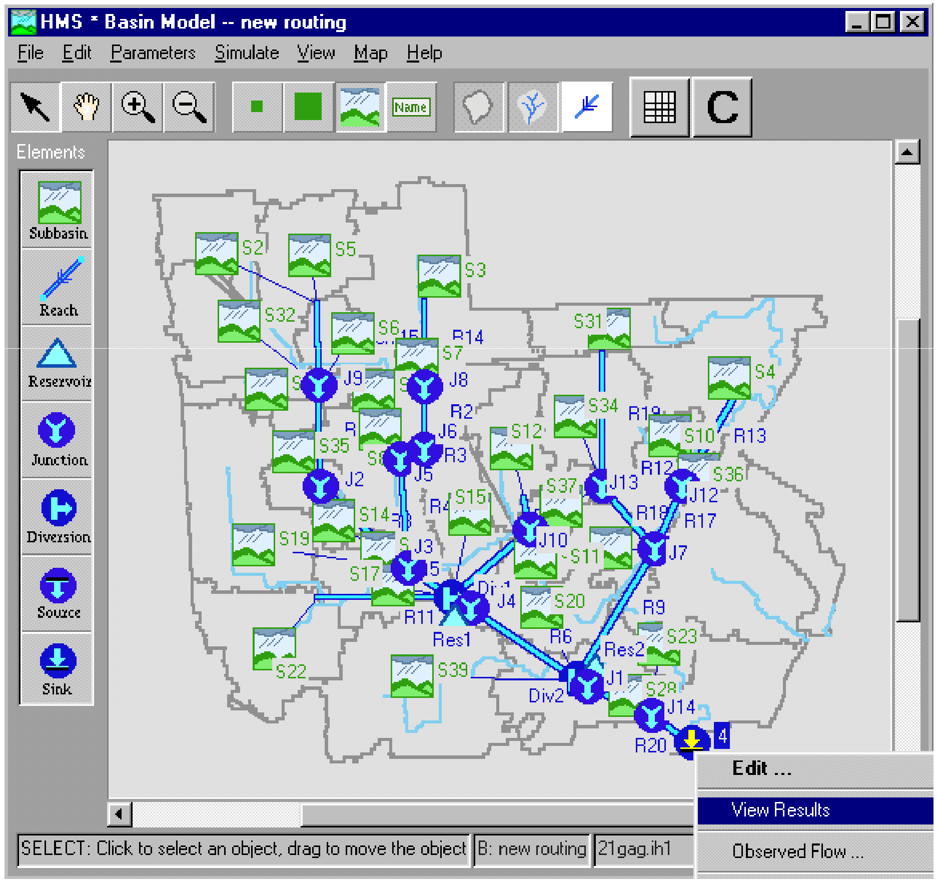
  by US Army COE's Hydrologic Engineering Center, for simulation of rainfall-runoff processes.
- **HEC Geo HMS**, with GIS interface
- SWMM (Storm Water Management Model)

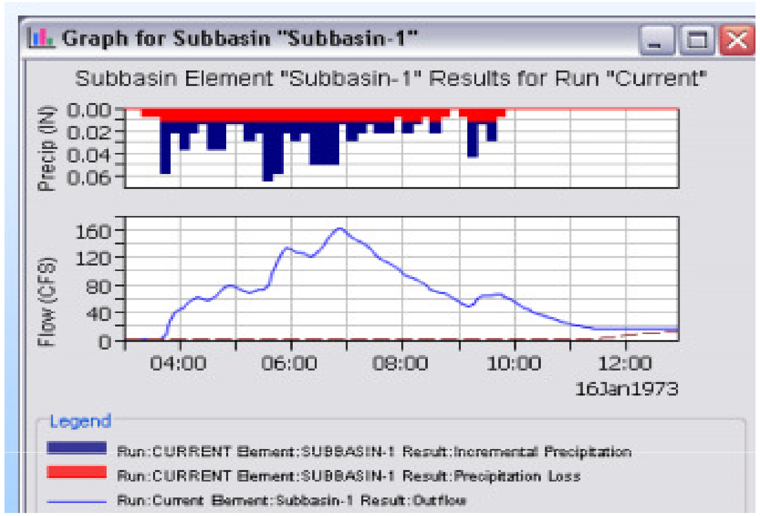
  by US EPA in 1969-71, for event based water quantity & quality simulation
- Others: NRCS's WinTR-20 & WinTR-50; US FHS's WSPRO

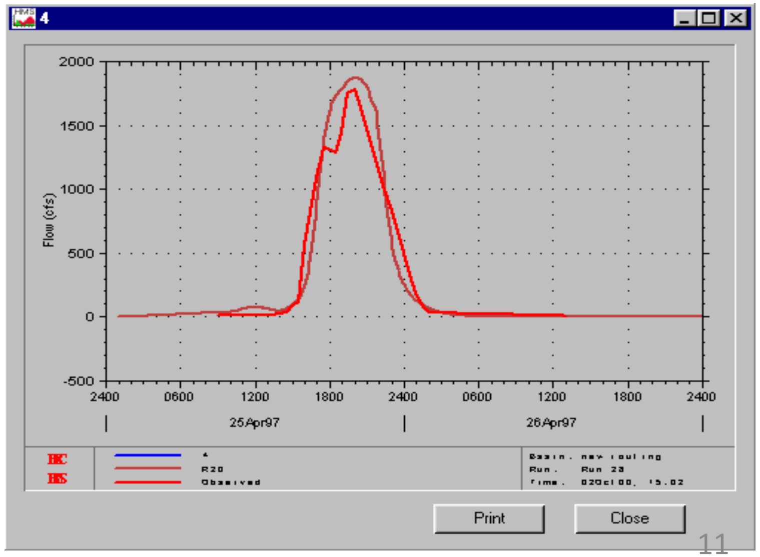
Hydrologic cycle- rainfall to runoff



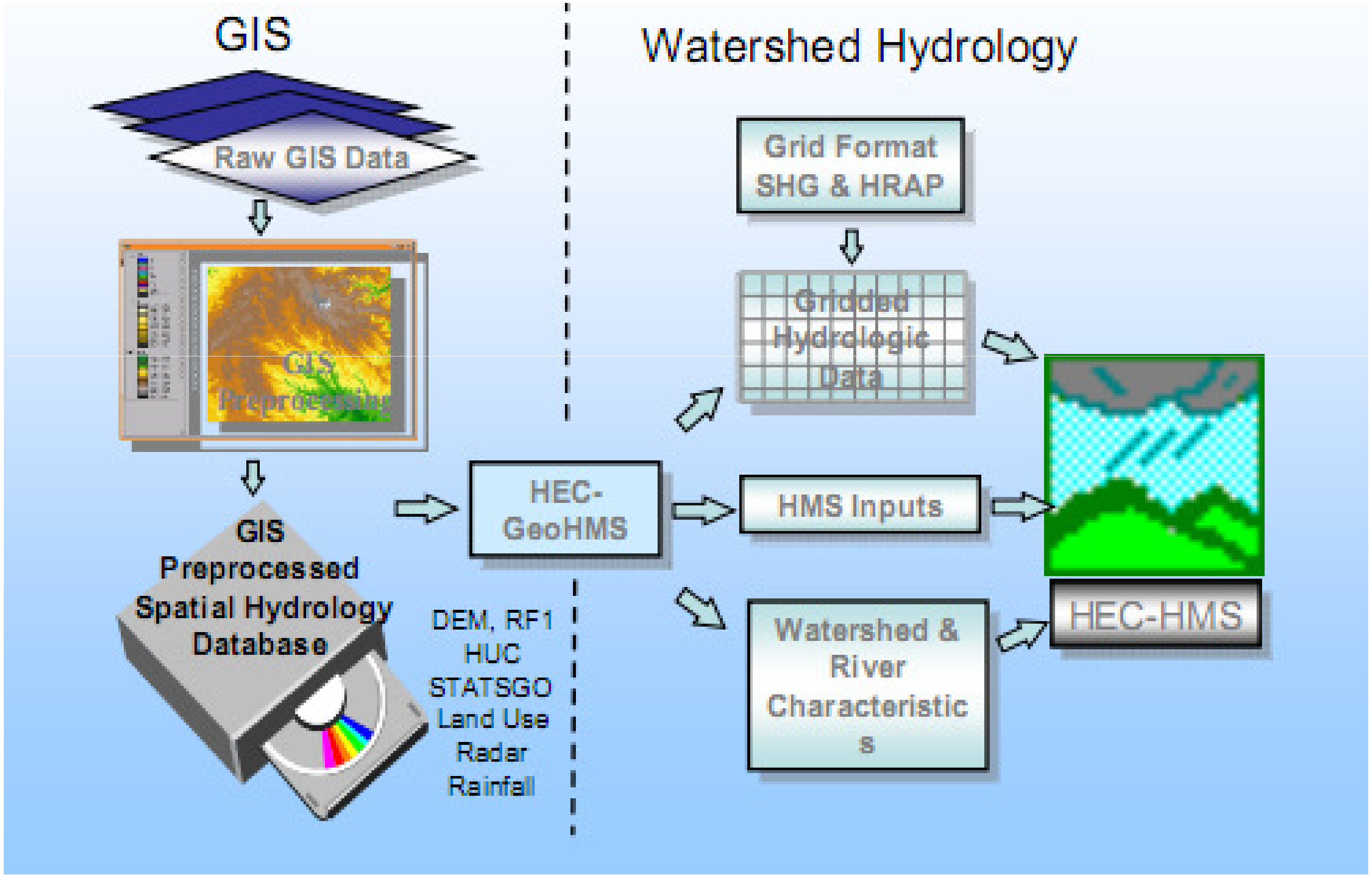
HEC HMS
Drainage network & rainfall-runoff simulation



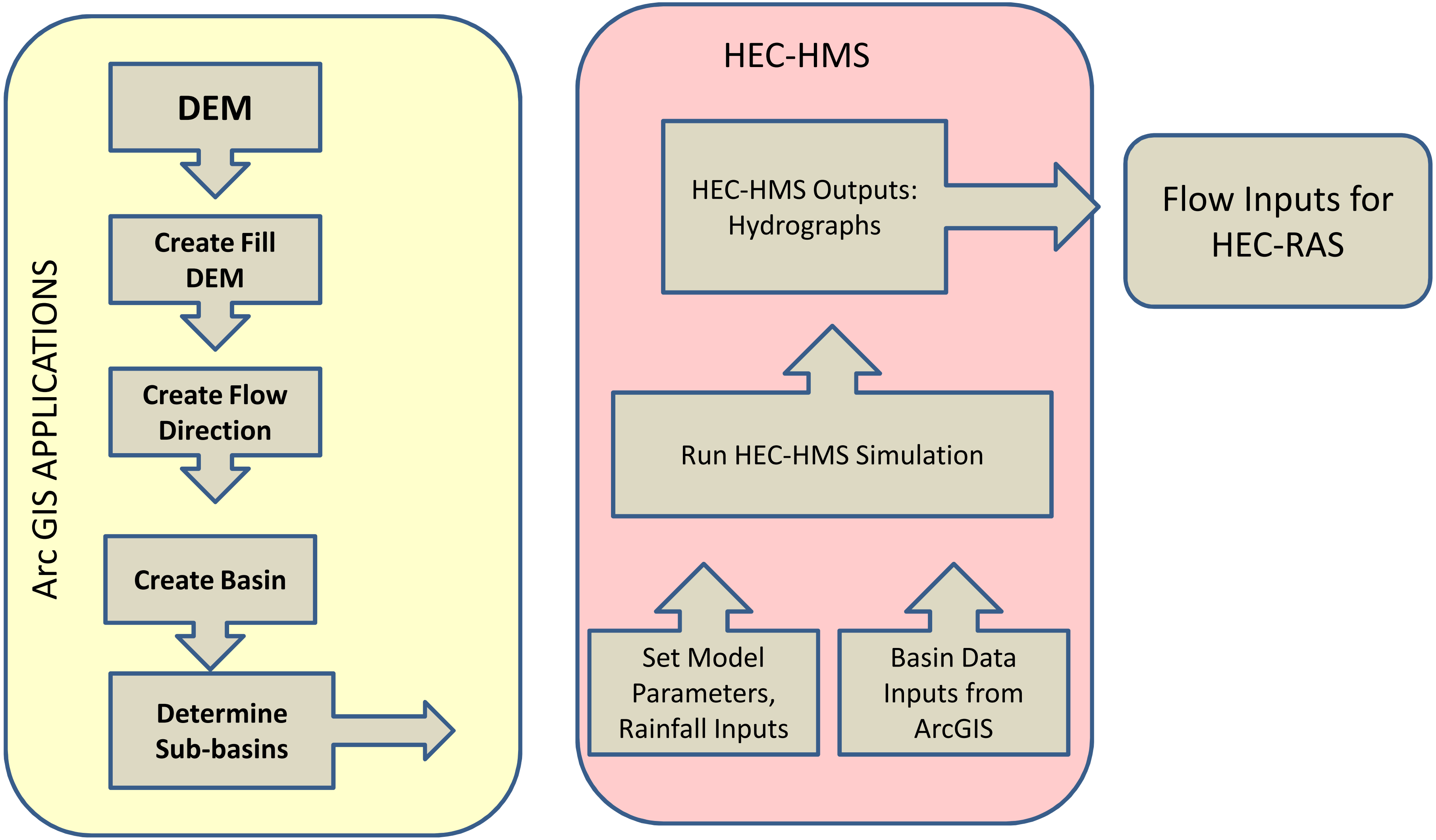




HEC Geo HMS (with GIS pre-processing)



Hydrologic Model with Arc GIS interface



- **Watershed Characteristics Component:**

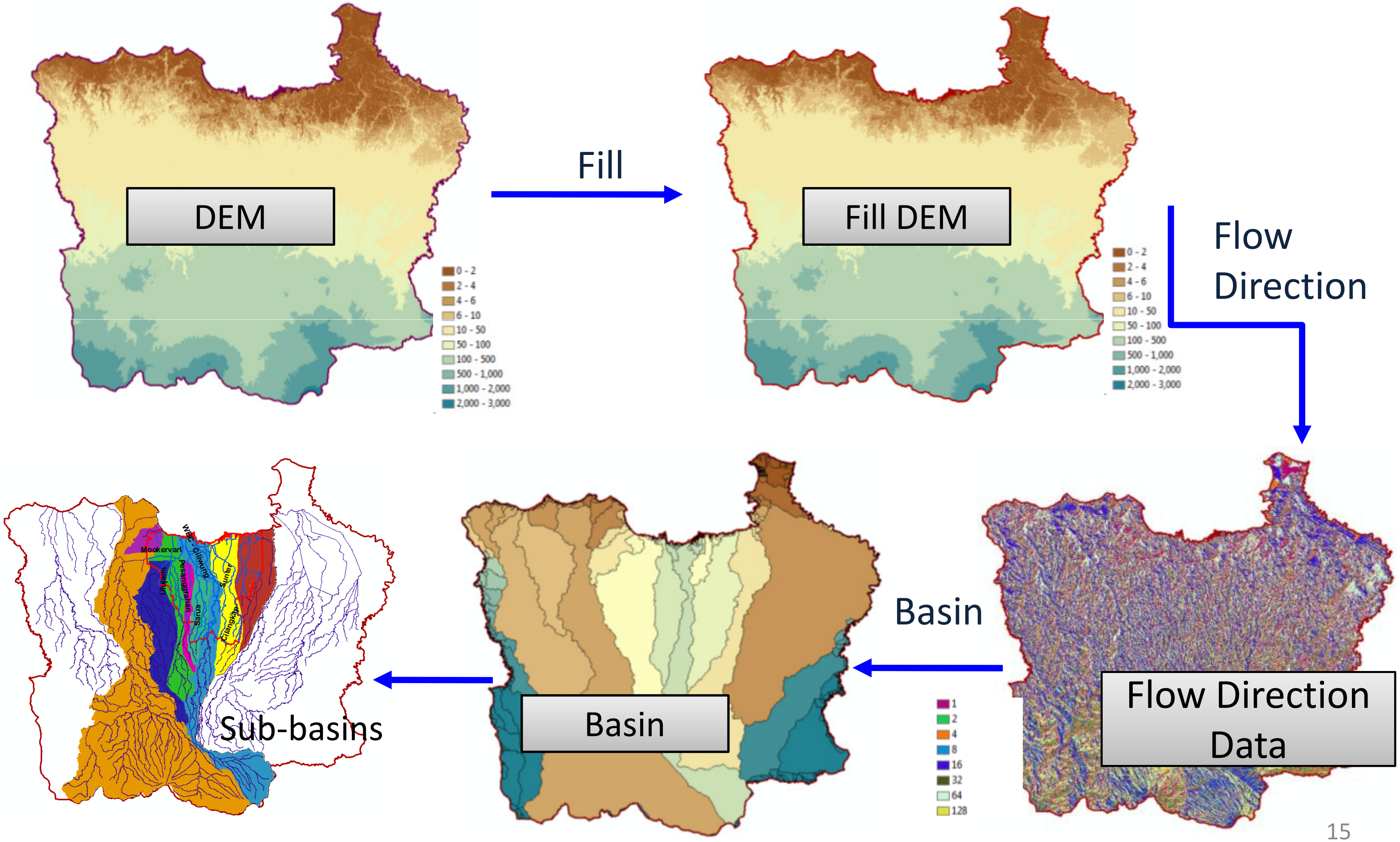
  Process DEM/DTM databases into stream networks & sub-catchment boundaries using GIS tools.

  Generate watershed characteristics (area, slope, LU, imperviousness, roughness, soil losses, etc) from available DEM/DTM, GIS land use data, etc.

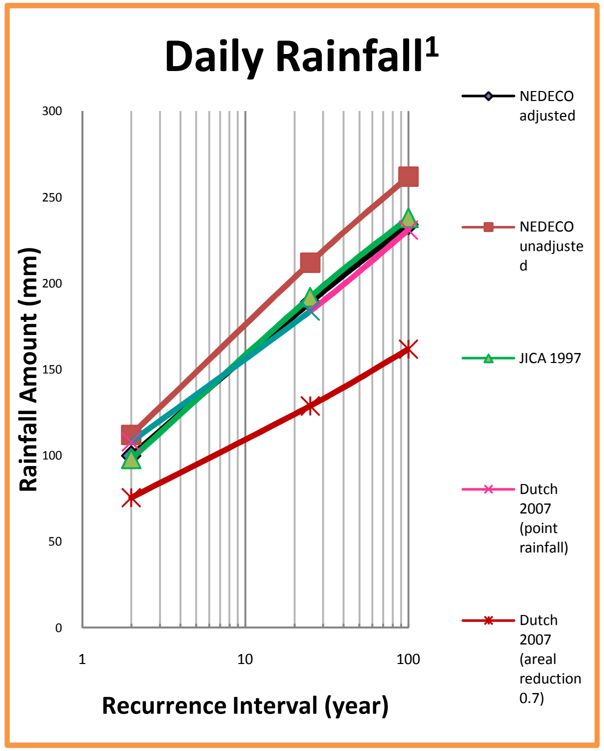
- **Flood Plain Characteristics Component:** Generate river channel and flood plain sections, roughness and slopes from DEM & survey drawings (using GIS tools)

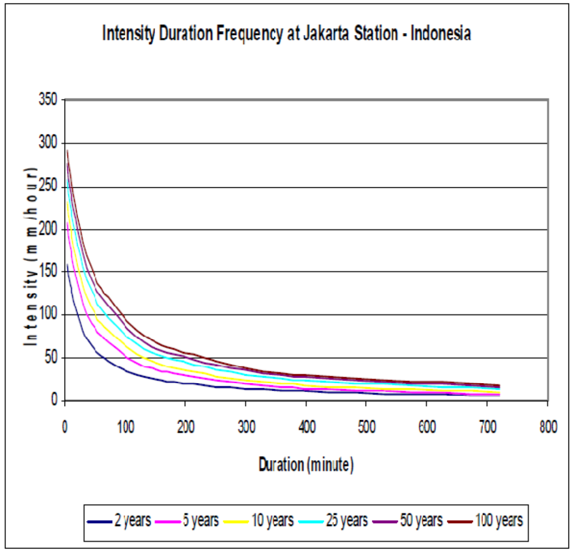
Hydrologic Model

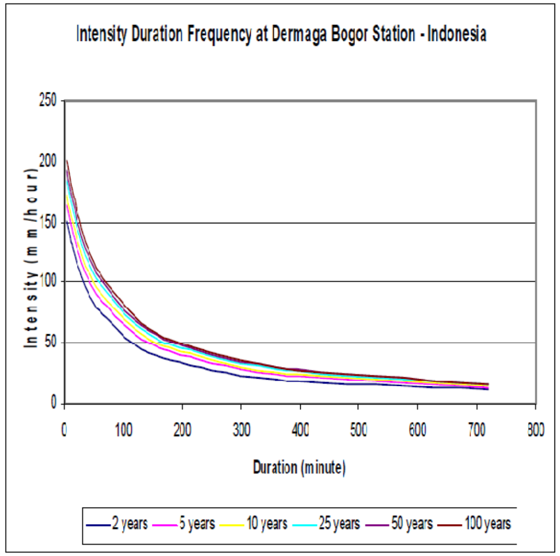
ArcGIS Applications

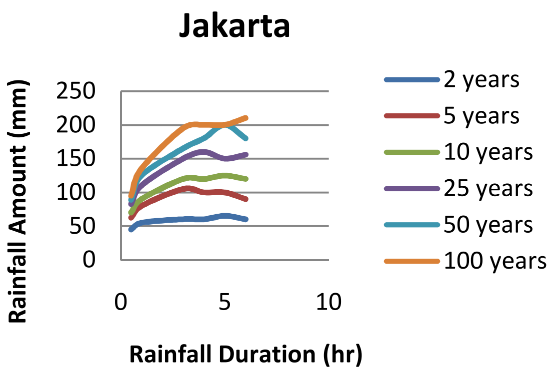


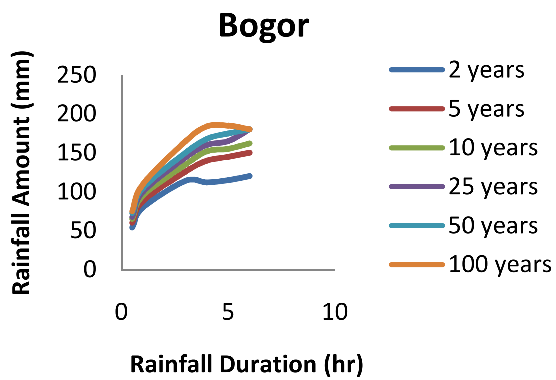
- **Rainfall Analysis Component** : Generate design rainfall (intensity-duration-frequency) of various return period of various probability from available rainfall databases





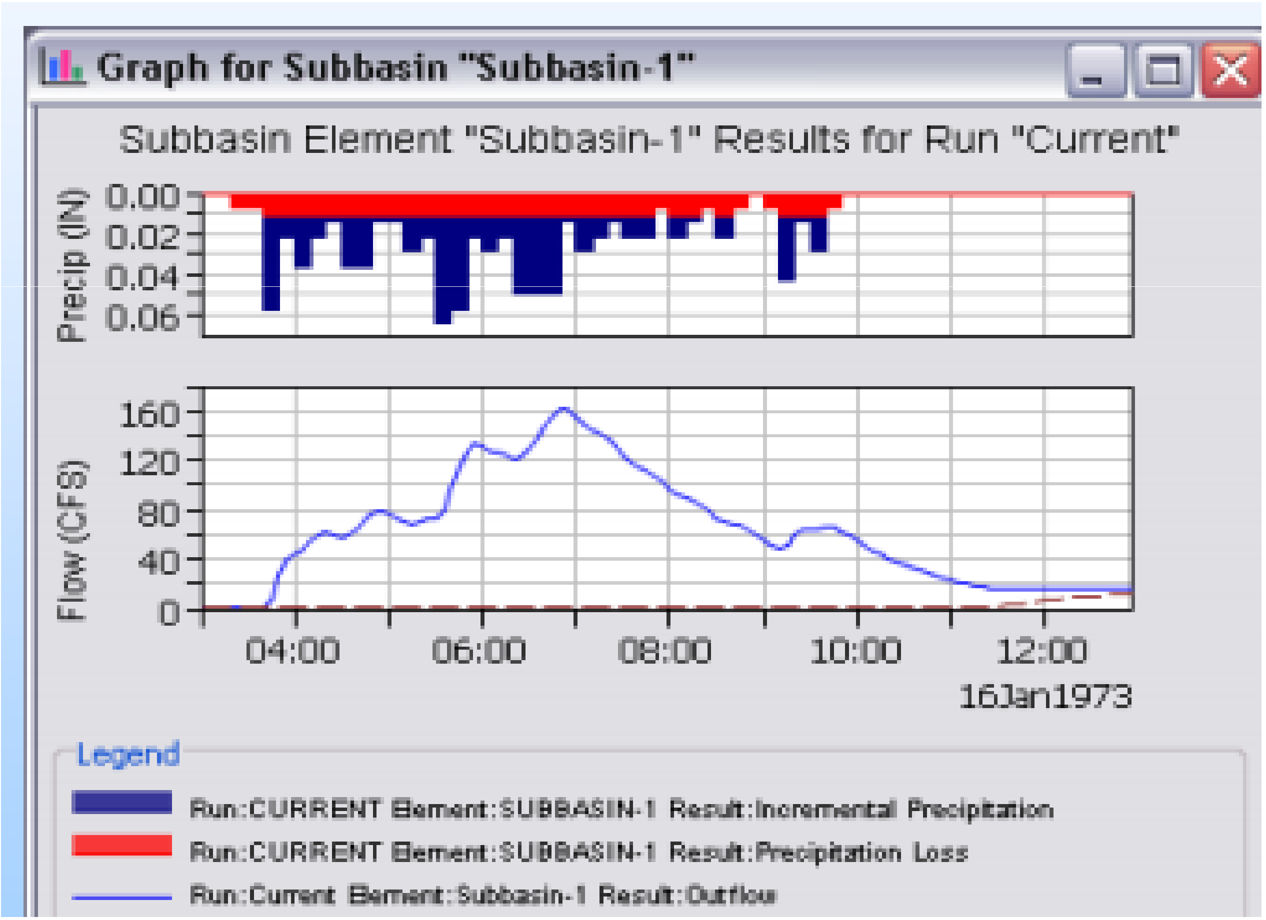






Source:
1. Annual Daily Rainfall from Report by DKI Jakarta Government
2. IDF Curve from Asian Pacific FRIEND Intensity Duration Frequency (IDF) Analysis for the Asia Pacific Region (Nov 2008)

- **Rainfall-Runoff Component:** Generate flood hydrographs & discharges using input data generated from the preceding components



Simulation models for river flooding

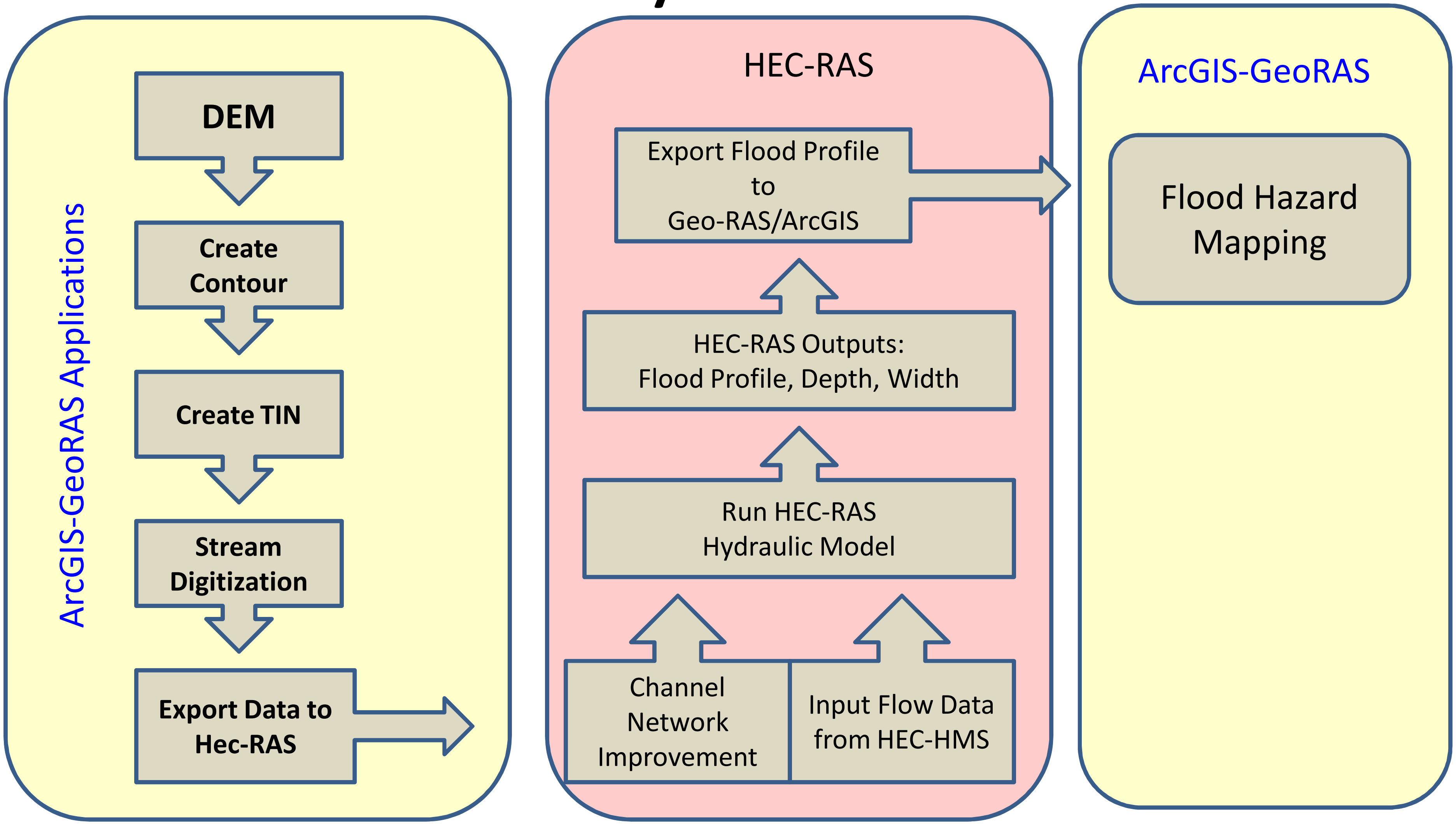
Floodplain Hydraulics Models

- **HEC- RAS** (River Analysis System)

  by US Army COE's Hydrologic Engineering Center, in 1995 for simulation of water surface profiles along a stream and for floodplain management.

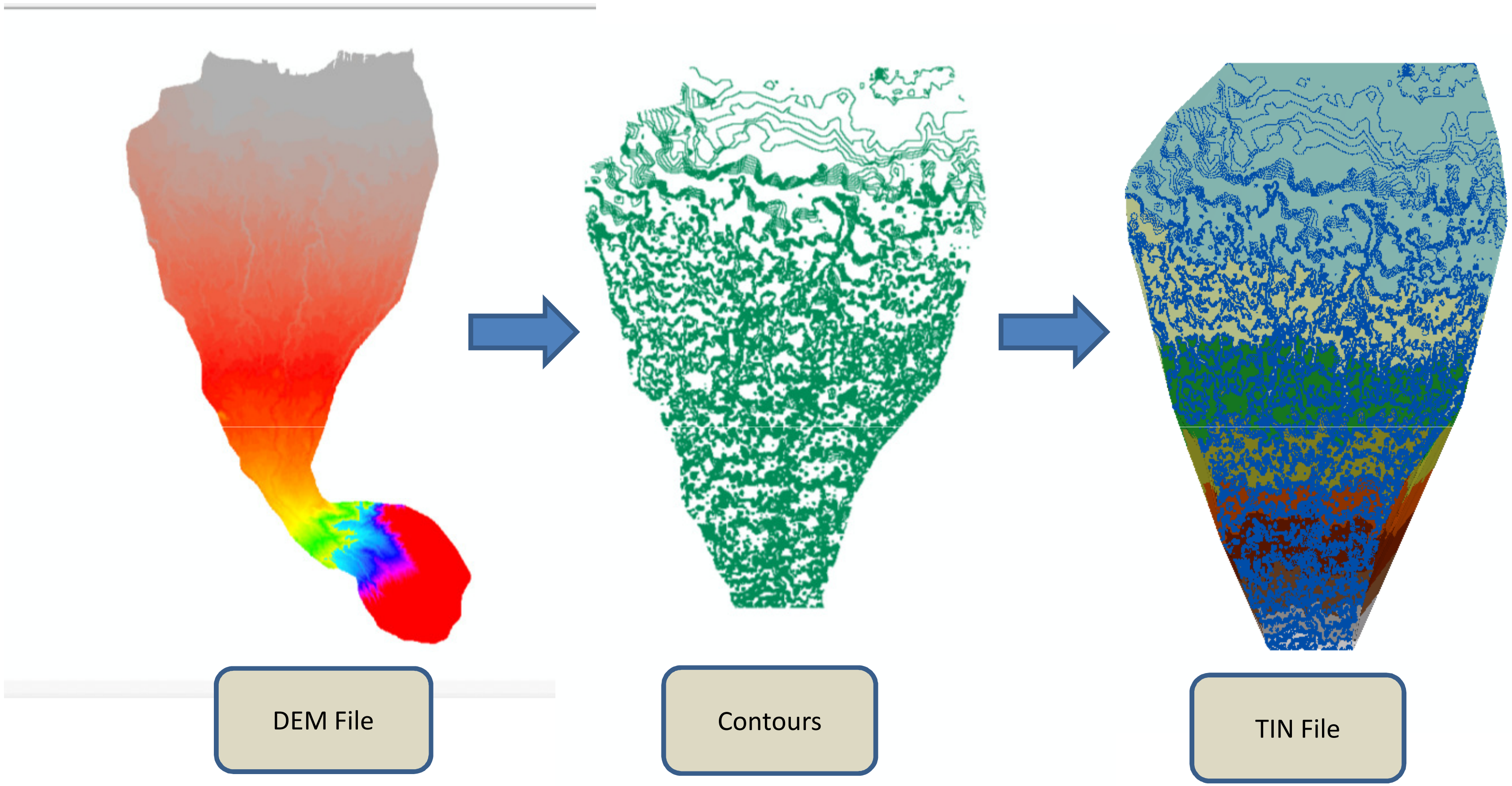
- **HEC Geo RAS**, with GIS interface
- Others: FLO-2D, MIKE series

Arc GIS- Hydraulic Model

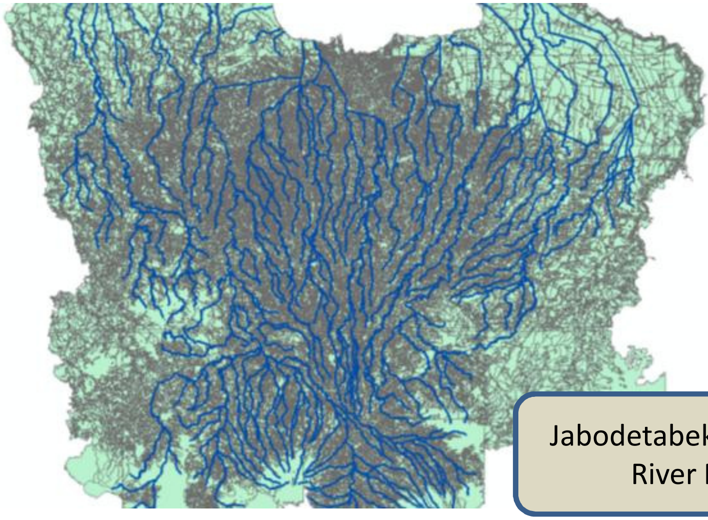


Hydraulic Model

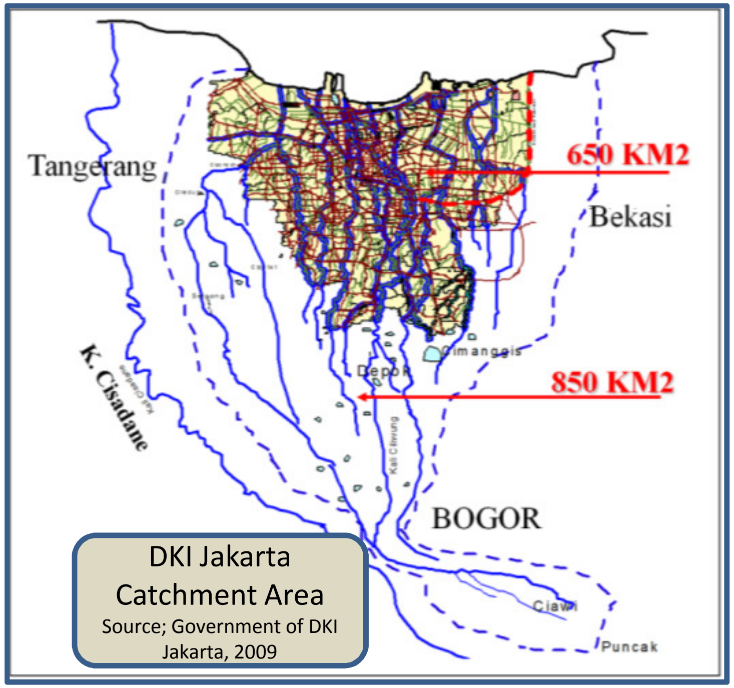
Geo RAS- Arc GIS Applications



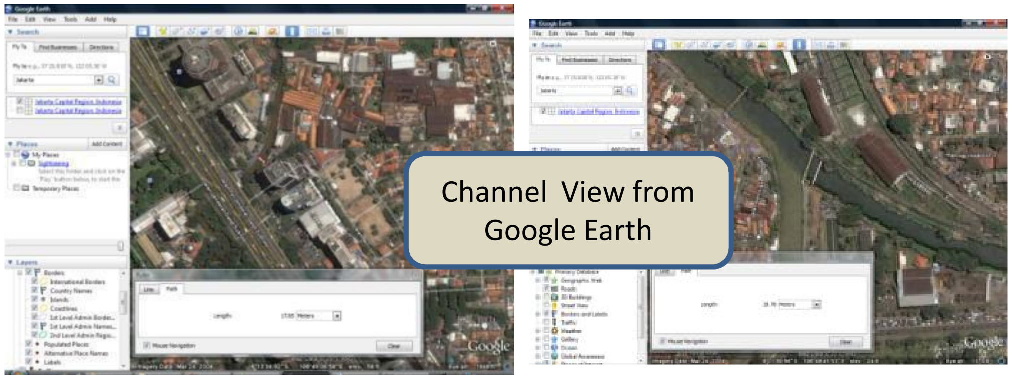
Hydraulic Model
Stream Digitization



Jabodetabek Land Use and River Network



DKI Jakarta Catchment Area
Source; Government of DKI Jakarta, 2009

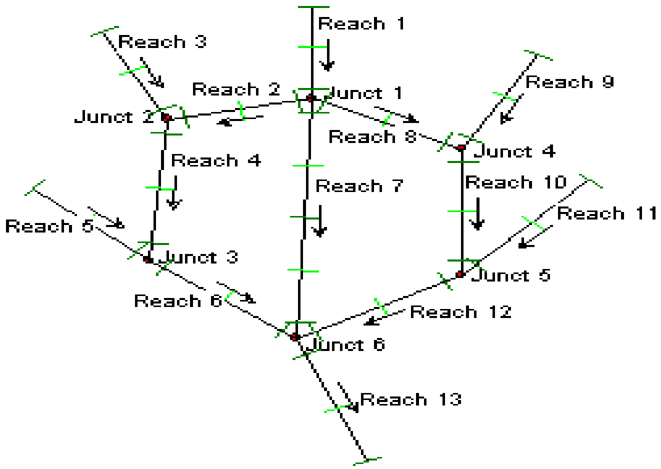


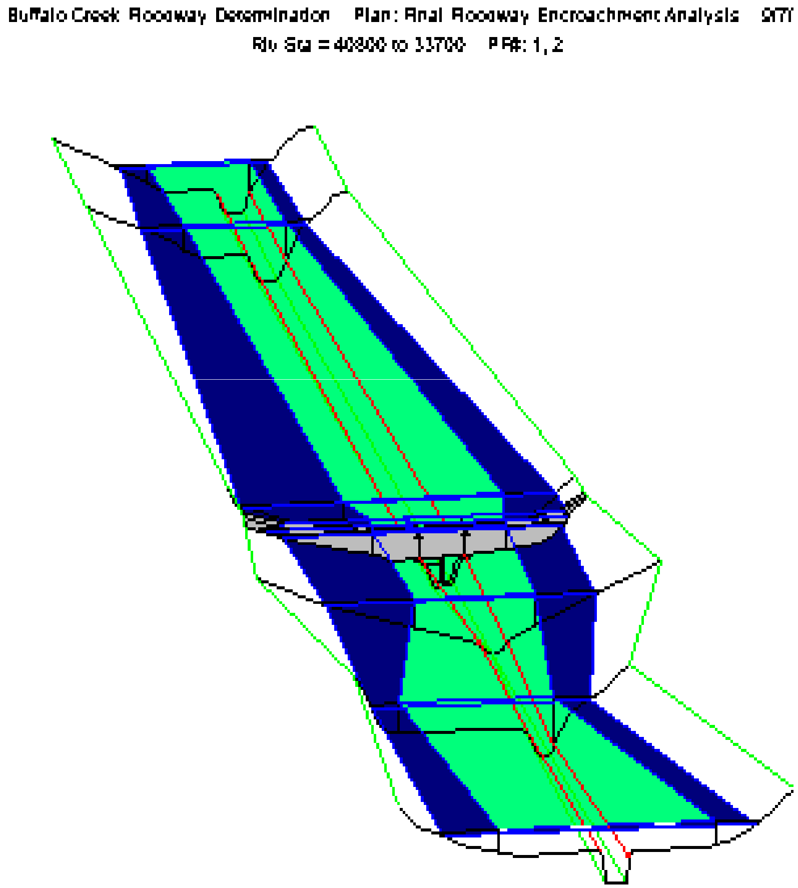
Channel View from Google Earth

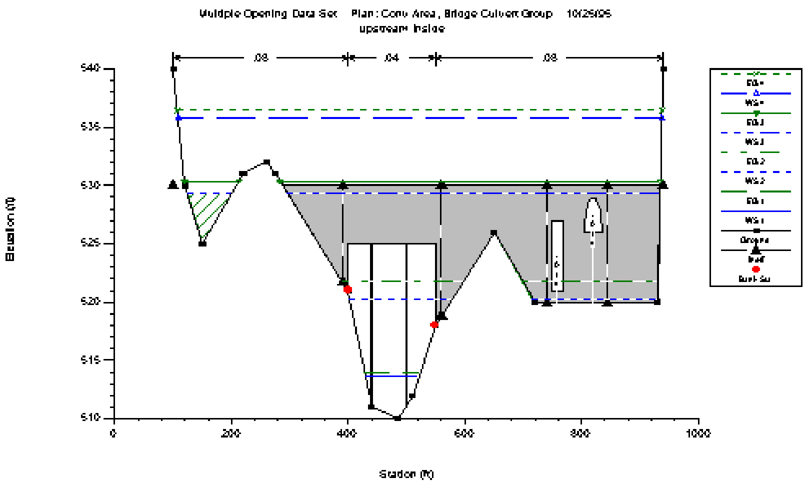
Schematic Rivers Draining DKI Jakarta
Source; Government of DKI Jakarta, 2009

- **Hydraulics Component :** Incorporate a suite of 1D/2D hydrodynamic models, to generate flood level and velocity at various return periods (risk levels), based on flood discharges generated from the rainfall-runoff module

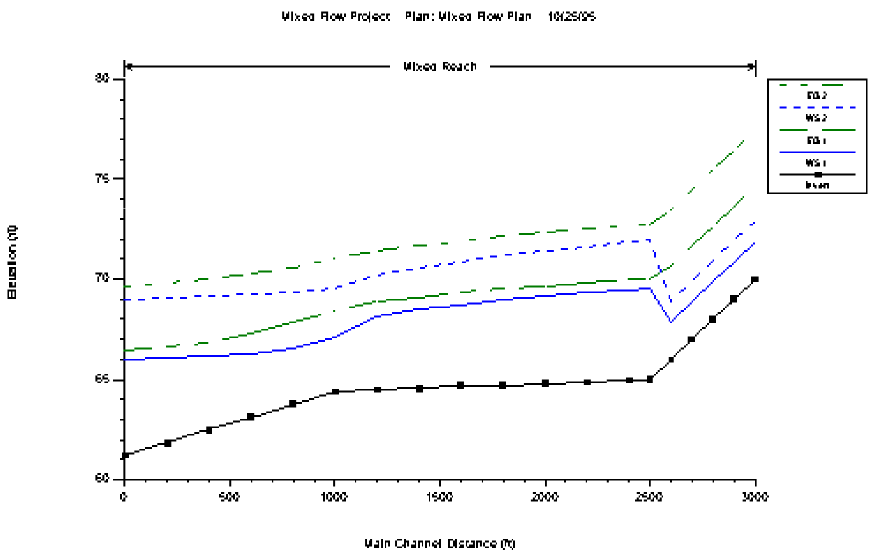
Typical drainage network, channel profiles & cross sections used in HEC RAS

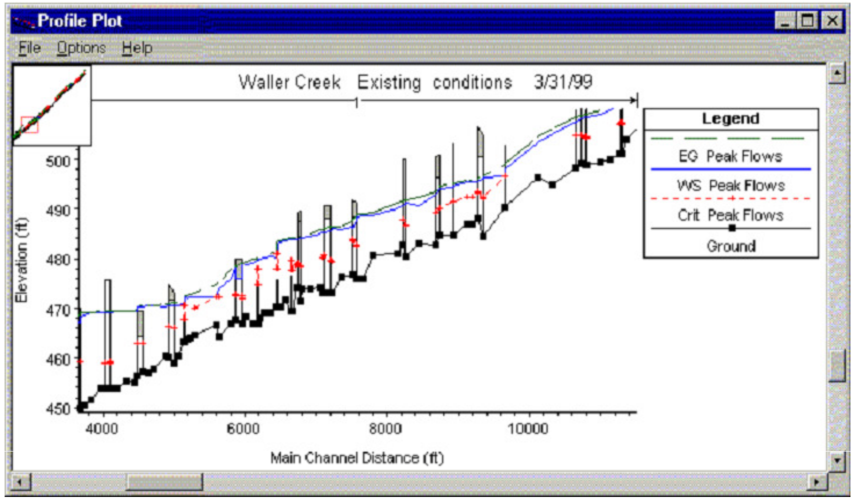


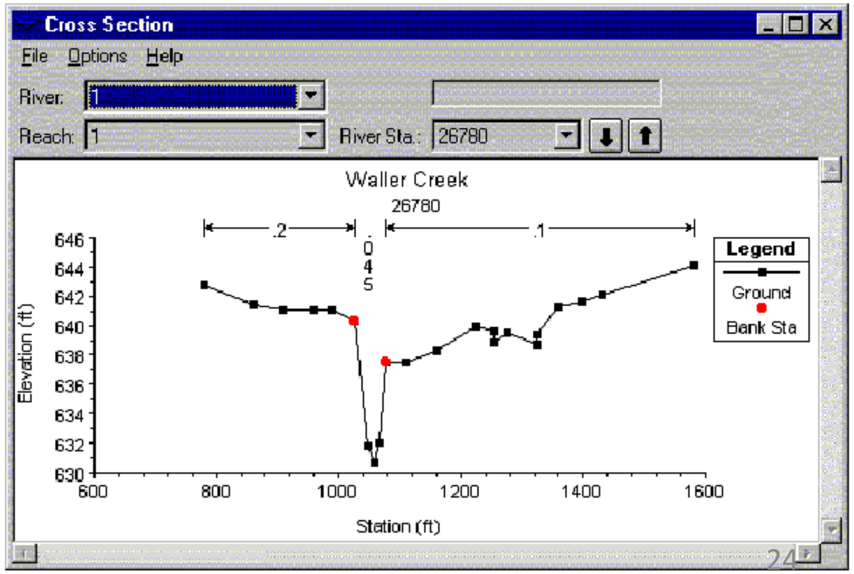




Typical flood stage profiles & channel sections

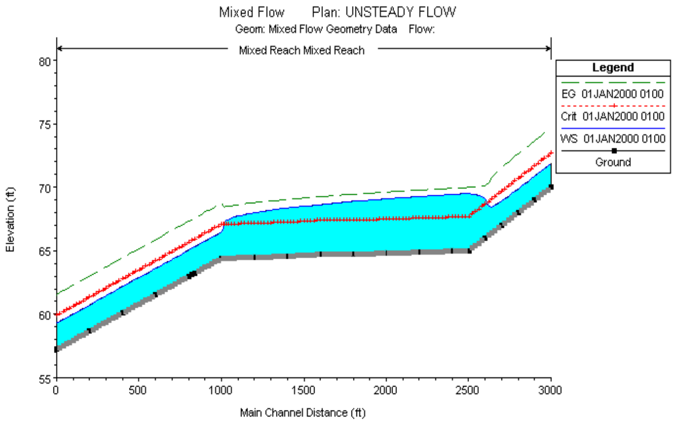


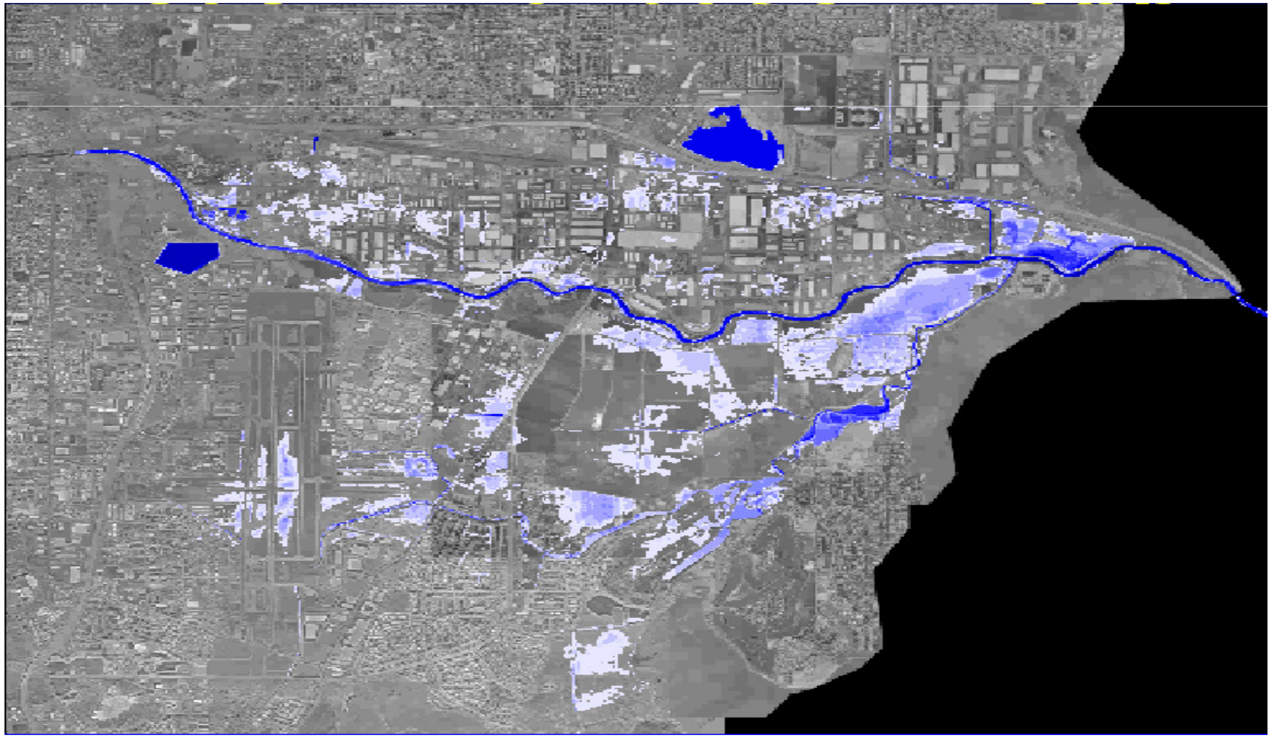




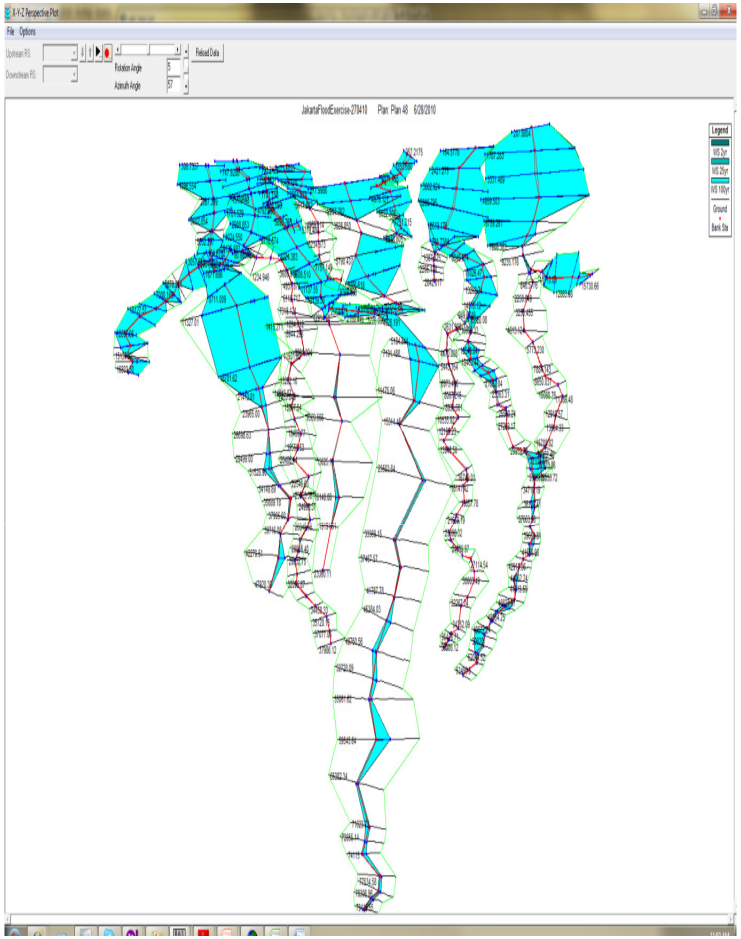
- **Flood Inundation Component :** Generate flood inundation maps and tabular outputs of extent of flooding at various locations (flood depth, velocity, duration, etc) using data from hydraulic models, at various return periods (risk levels)

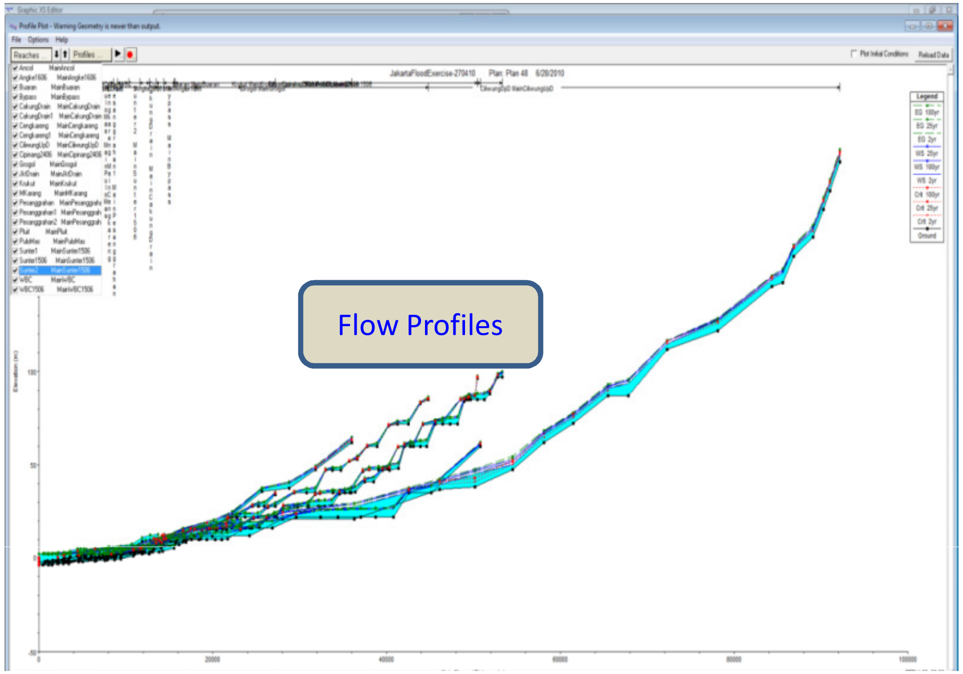
Simulation of Flood stages & inundation





Hydraulic Model- HEC-RAS Outputs





Steady Flow Data - steady250610-vLe

File Options Help

Enter/Edit Number of Profiles (25000 max): 3 Reach Boundary Conditions ... Apply Data

Locations of Flow Data Changes

River: Pesanggrahan2 Add Multiple...

Reach: MainPesanggrahan River Sta.: 4024.550 Add A Flow Change Location

Flow Change Location

	River	Reach	RS	2yr	25yr	100yr
1	Ancol	MainAncol	8848.805	19.5	32.6	40.8
2	Angke1606	MainAngke1606	16803.30	190.1	312	388.6
3	Buaran	MainBuaran	18353.72	9.6	16.1	20.1
4	Bypass	MainBypass	4026.191	369.1	765.1	1015
5	CakungDrain	MainCakungDrain	15730.66	62.9	105.4	132.1
6	CakungDrain1	MainCakungDrain	9235.176	106.4	177.5	222.6
7	Cengkareng	MainCengkareng	7671.686	83.7	139.2	176.7
8	Cengkareng1	MainCengkareng	6904.638	267.2	438.5	546.1
9	CiliwungUpD	MainCiliwungUpD	79415.55	341.4	639.9	832.3
10	Cipinang2406	MainCipinang2406	36308.12	8.7	14.9	18.8
11	Grogol	MainGrogol	37986.12	14.5	24.5	30.7
12	JktDrain	MainJktDrain	13964.71	100	100	100
13	JktDrain	MainJktDrain	277.9986	100	100	100
14	Krukut	MainKrukut	23360.11	43.1	78	100.3
15	MKarang	MainMKarang	5319.480	103.9	107.4	109.4
16	Pesanggrahan	MainPesanggraha	47920.38	82.1	139.4	175.5
17	Pesanggrahan1	MainPesanggraha	6487.636	162.2	273.9	344.1
18	Pesanggrahan2	MainPesanggraha	4024.550	356.9	587.8	729.7
19	Pluit	MainPluit	9763.686	5.6	9.7	12.2
20	PuloMas	MainPuloMas	2842.017	8	13.2	16.6
21	Sunter1	MainSunter1506	6613.176	162.2	273.9	344.1
22	Sunter1506	MainSunter1506	53490.5	40.4	68.7	86.6
23	Sunter2	MainSunter1506	14515.12	145.8	246.4	309.6
24	WBC	MainWBC	12914.50	330.5	747.3	1029.6
25	WBC1506	MainWBC1506	3131.173	528.1	1103.1	1483.4

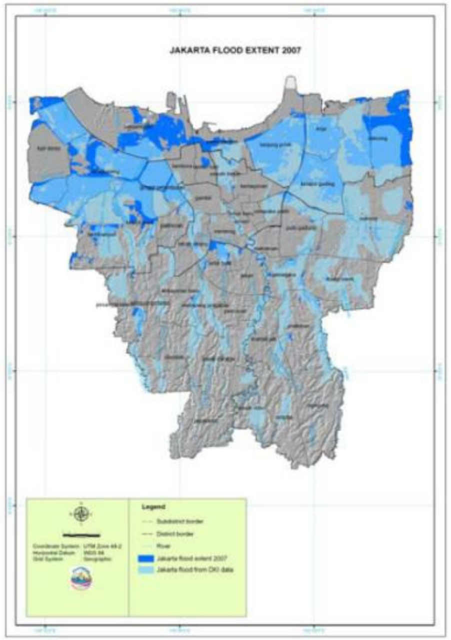
Flow Data Inputs from Hec-HMS

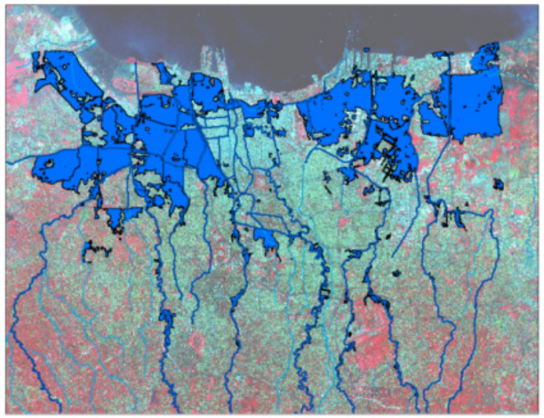
GeoRAS/ArcGIS Inundation Mapping historic & simulated flood hazard maps

1996 Flood

2002 Flood

2007 Flood





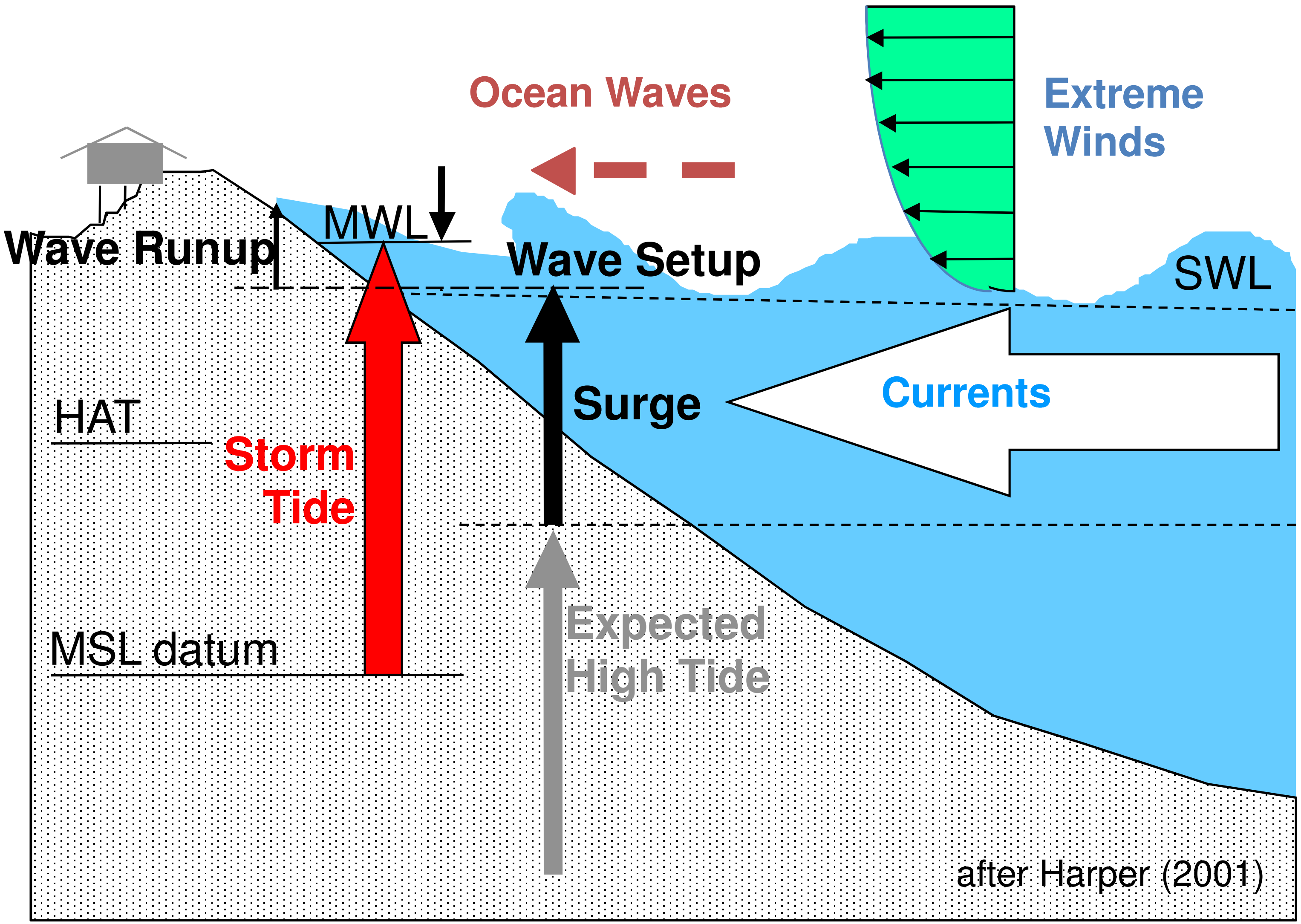
1996 and 2002 Flood Data

Region	Flood 1996				Flood 2002			
	Flooded Area	Flooded Duration	Ave. Depth	Damage (Rp. mil)	Flooded Area	Flooded Duration	Ave. Depth	Damage (Rp. mil)
Jakarta-Central	n.a.	6 hr	20-100 cm	2,000	890	24-72 hr	20-110 cm	781,772
Jakarta-North	n.a.	6 hr	20-150 cm	6,600	4,149	24-189 hr	20-200 cm	4,104,389
Jakarta-West	n.a.	6 hr	20-150 cm	2,000	2,482	24-189 hr	20-180 cm	3,923,389
Jakarta-South	n.a.	6 hr	20-200 cm	500	731	24-48 hr	20-160 cm	470,010
Jakarta-East	n.a.	6 hr	20-150 cm	15,000	454	24-189 hr	20-180 cm	607,935
DKI Jakarta				26,100	8,706			9,887,495
Kab. Tangerang					n.a.	24-120 hr	50-250 cm	100,000
Kodya Tangerang					n.a.	24-144 hr	100-250 cm	75,000
Kab. Bekasi					n.a.	n.a.	50-250 cm	100,000
Kodya Bekasi					n.a.	n.a.	50-250 cm	50,000
TOTAL				26,100				325,000
GDP per capita				*2.49*				*9.10*
Damage/GDPpC				*10,462*				*35,726*

Simulation models for coastal flooding

- SLOSH or 'Sea, Lake, and Overland Surge from Hurricane' is a computerized model developed by the National Weather Service (NWS), U.S. A., to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes.
- It accounts for astronomical tides, but doesn't include rainfall amounts, river flows, or wind-driven waves.
- Simulation models on waves & wave run-up include SMS (Surface Water Modeling System) by the U.S. ACE WES. and CHAMP (Coastal Hazard Analysis Modeling Program) by the FEMA of U.S.A.
- Other empirical formulae and design manuals are available for estimation of wind-driven water waves and wave run-up

Tropical Cyclone



Wind generated waves

Empirical formula for

Estimating Deepwater Significant Wave Ht, Ho,

based on hurricane characteristics

$$H_o = 16.5\ e\ (R\Delta p/100)\ [1+(0.208\ V_f / U_m^{0.5})]$$

R- radius of max. wind

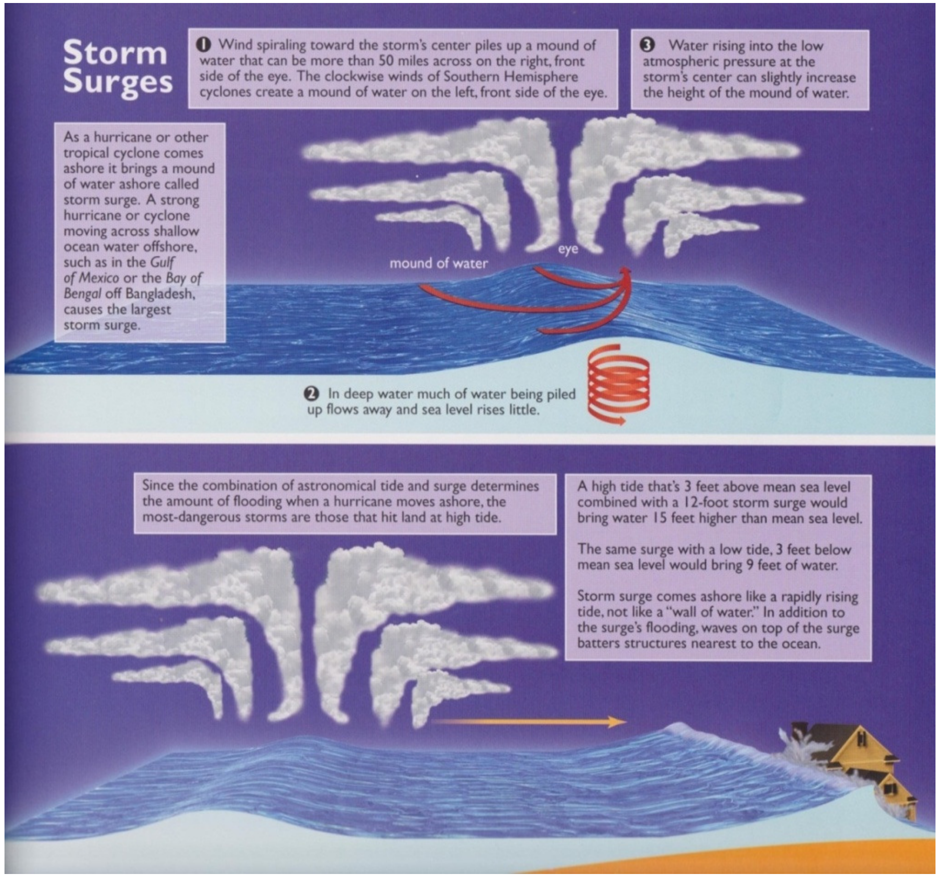
Δp- diff pressure between normal & central pressure

V_f - forward speed of translation

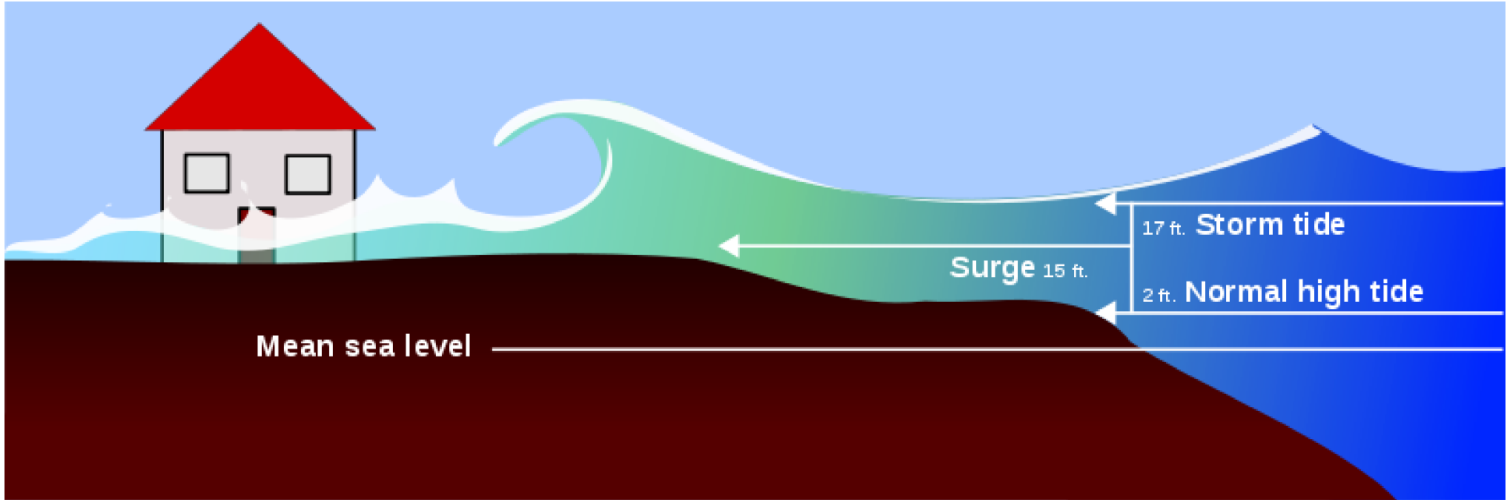
U_m- max wind speed

Factors influencing magnitude of storm surges

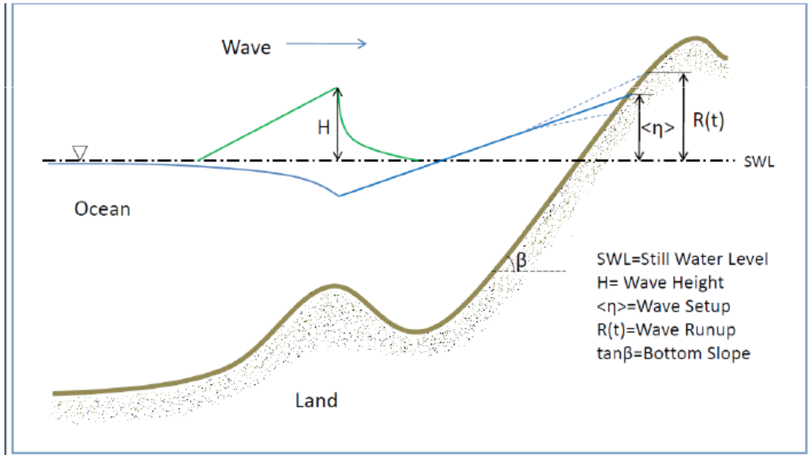
- **Storm intensity-** central pressure deficit of the storm controls wind velocity & stress over ocean surface, and inverse barometric effects
- **Storm size** (radius from eye to max wind)
- Translational speed
- **Angle of approach** to coastline
- **Landfall location** & its **bottom slope**



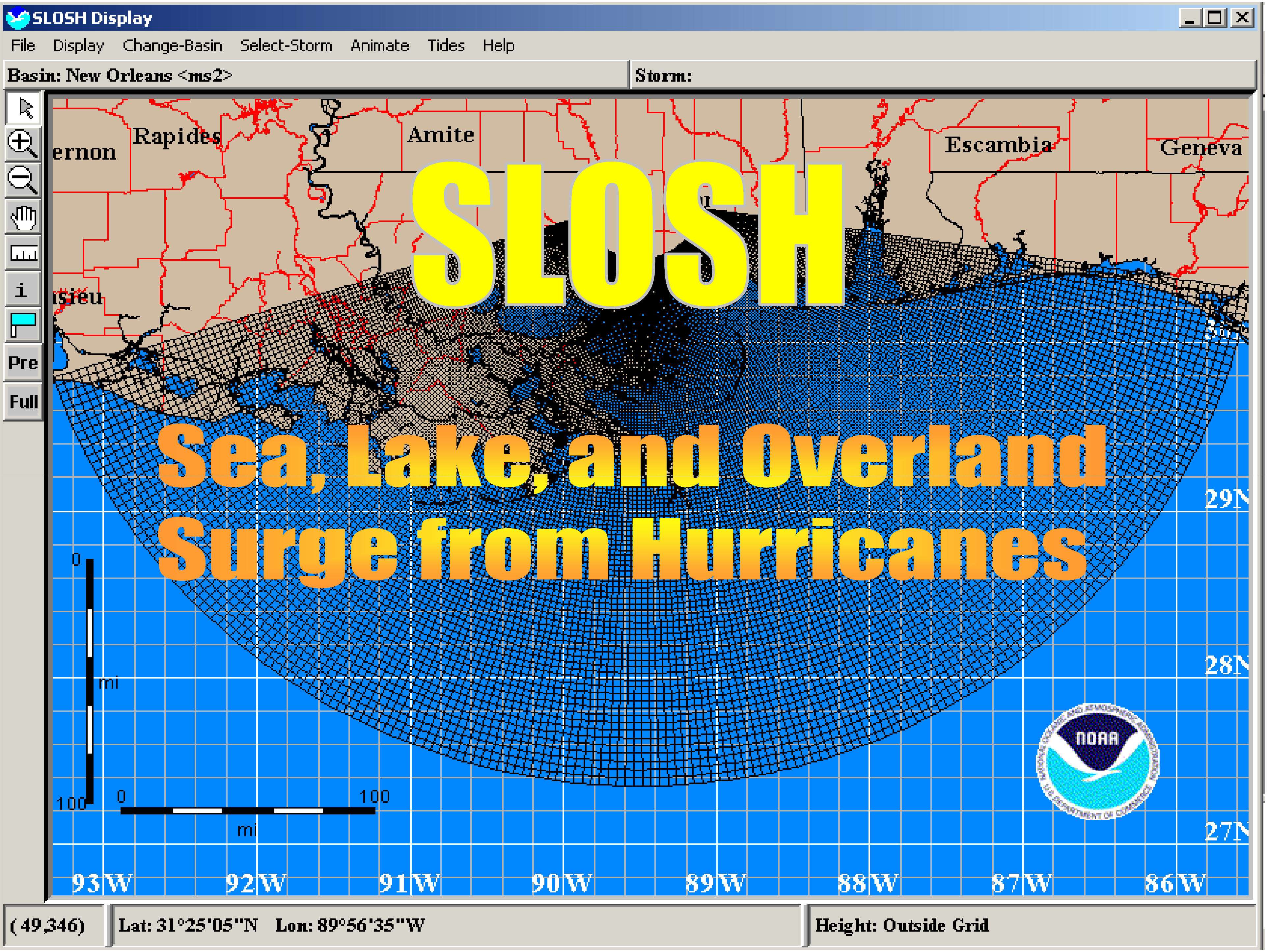
•Source: Hurricanes-causes, effects & future, by Leatherman & Williams, Voyageur Press, 2008



- Storm surge is caused by sustained winds over the ocean water surface, and low pressure of the cyclone
- It's also influenced by waves, tides, topography, and bathymetric and setting of the coastal zone
- Storm tide is the sum of storm surge & astronomical tide



Hurricane winds generate waves in the ocean. As these waves propagate into shallow water, wave heights increase due to a process called "shoaling". As the wave heights increase, the waves eventually break and impart their momentum to the water, causing onshore flow near the surface and offshore flow or "undertow" near the bottom, and an overall elevation in water level at the coast ("wave setup" – the rise in the water surface caused by breaking waves, and "wave runup" - the rush of wave water up a slope or structure).


SLOSH Display
File Display Change-Basin Select-Storm Animate Tides Help
Basin: New Orleans <ms2>
Storm:
SLOSH
Sea, Lake, and Overland
Surge from Hurricanes
Rapides
ernon
Amite
Escambia
Geneva
Pre
Full
29N
28N
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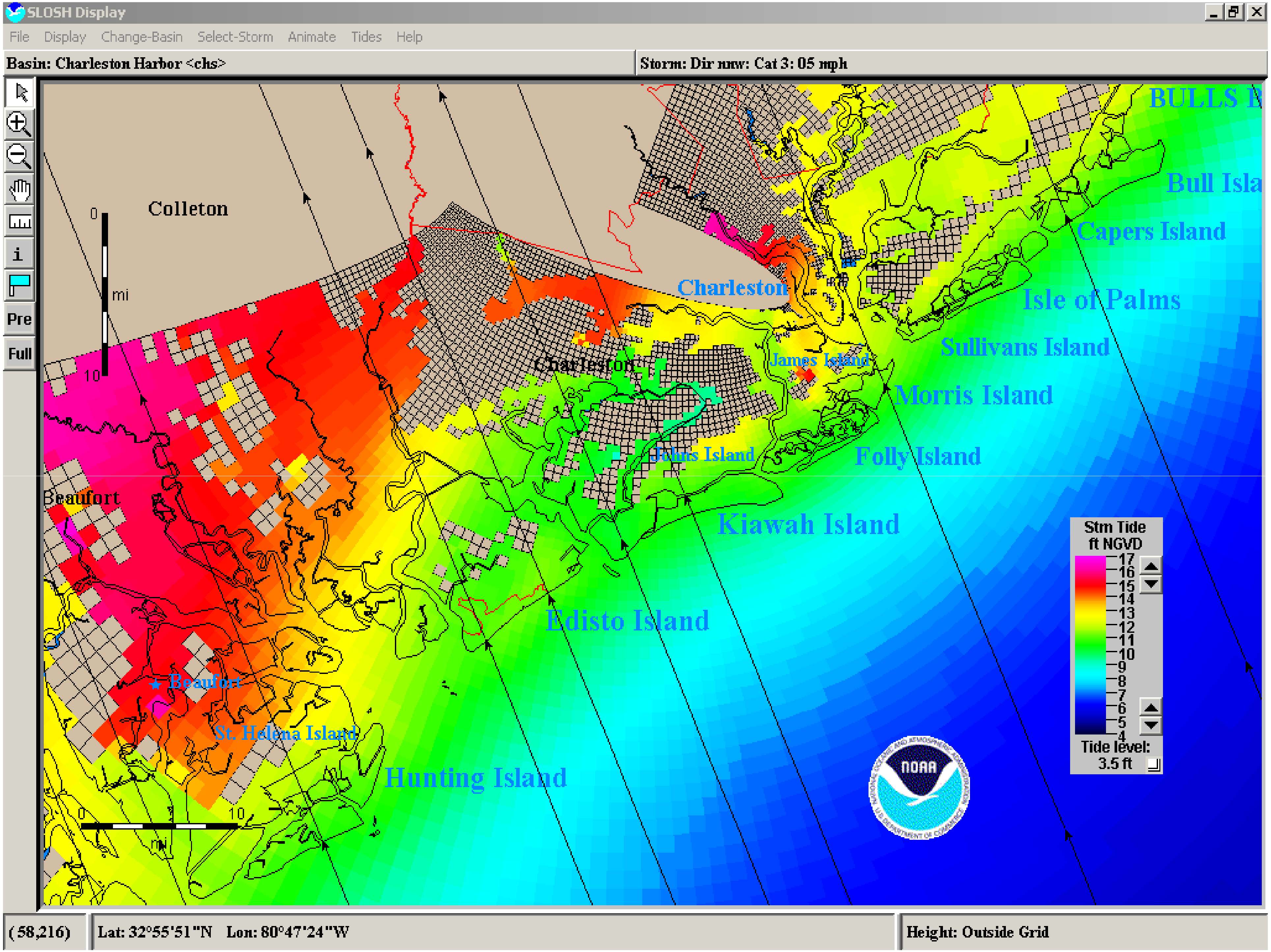
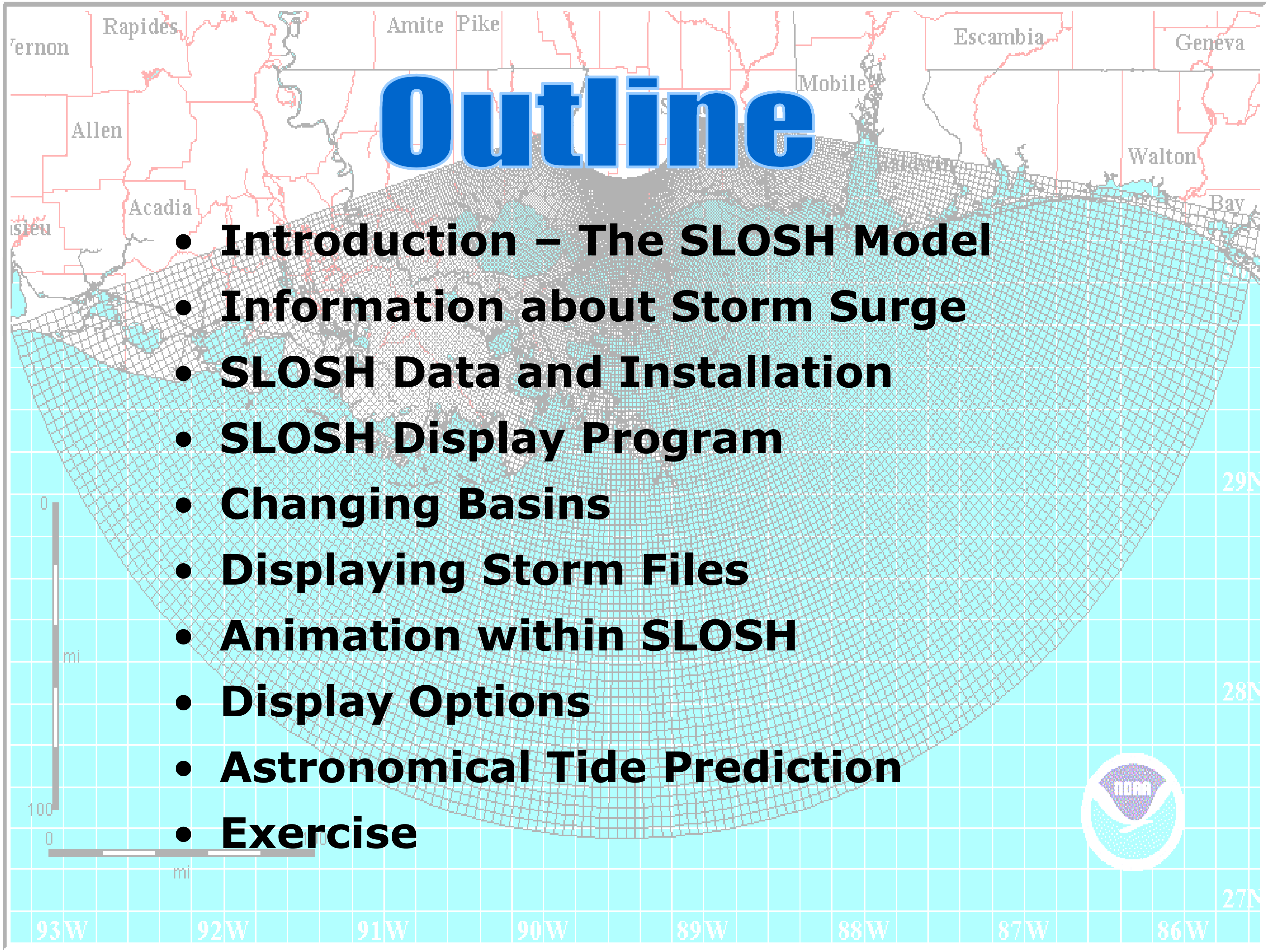
mi
93W
92W
91W
90W
89W
88W
87W
86W
NOAA
(49,346)
Lat: 31°25'05"N Lon: 89°56'35"W
Height: Outside Grid

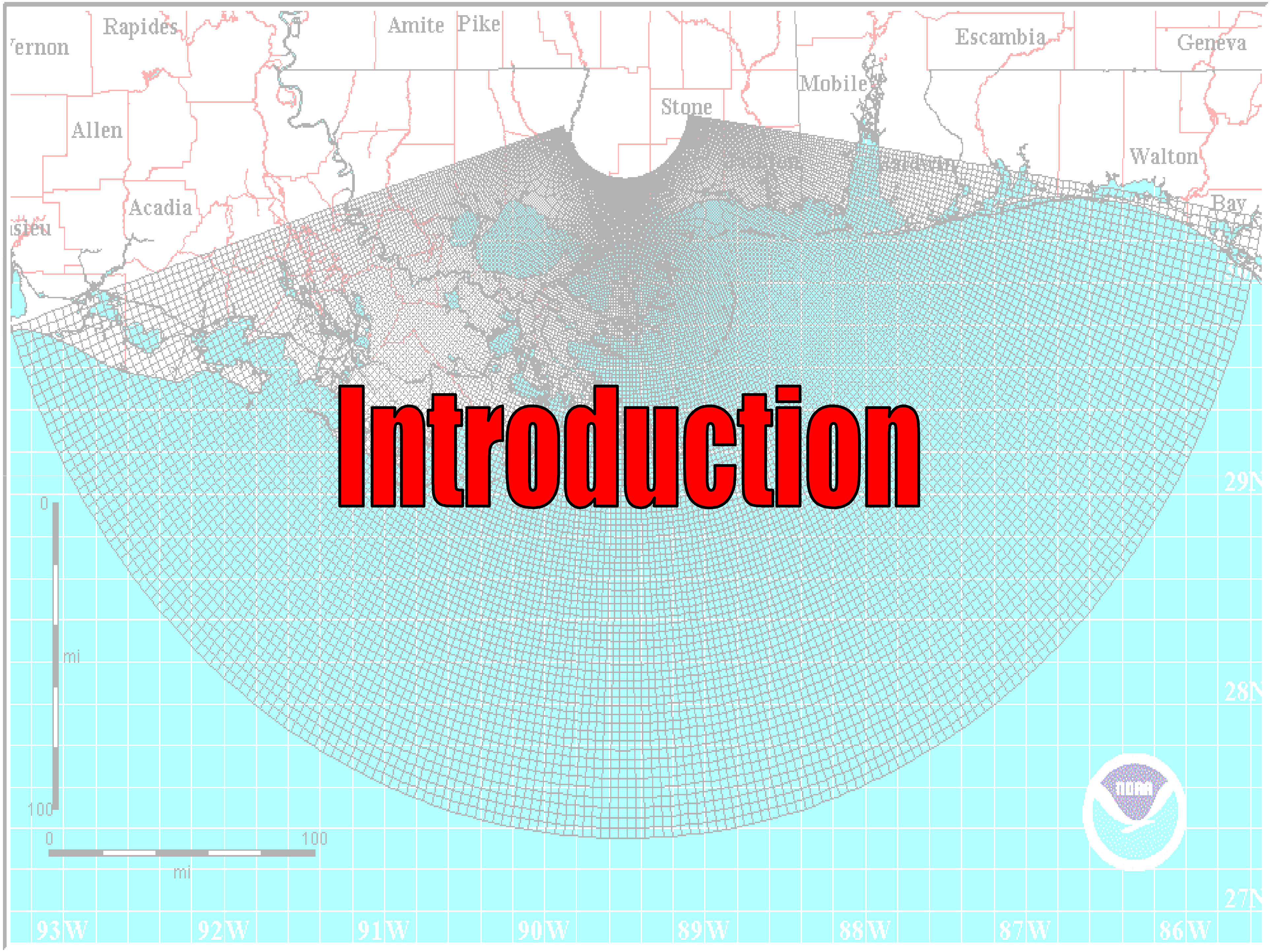

SLOSH Display
File Display Change-Basin Select-Storm Animate Tides Help
Basin: Charleston Harbor <chs>
Storm: Dir nnw: Cat 3: 05 mph
Pre
Full
Colleton
Charleston
Charleston
Beaufort
Beaufort
BULLS B
Bull Isla
Capers Island
Isle of Palms
Sullivans Island
James Island
Morris Island
Folly Island
Johns Island
Kiawah Island
Edisto Island
St. Helena Island
Hunting Island
Stm Tide
ft NGVD
17 16 15 14 13 12 11 10 9 8 7 6 5 4
Tide level:
3.5 ft
NOAA
(58,216)
Lat: 32°55'51"N Lon: 80°47'24"W
Height: Outside Grid

Outline

- Introduction – The SLOSH Model
- Information about Storm Surge
- SLOSH Data and Installation
- SLOSH Display Program
- Changing Basins
- Displaying Storm Files
- Animation within SLOSH
- Display Options
- Astronomical Tide Prediction
- Exercise



Introduction

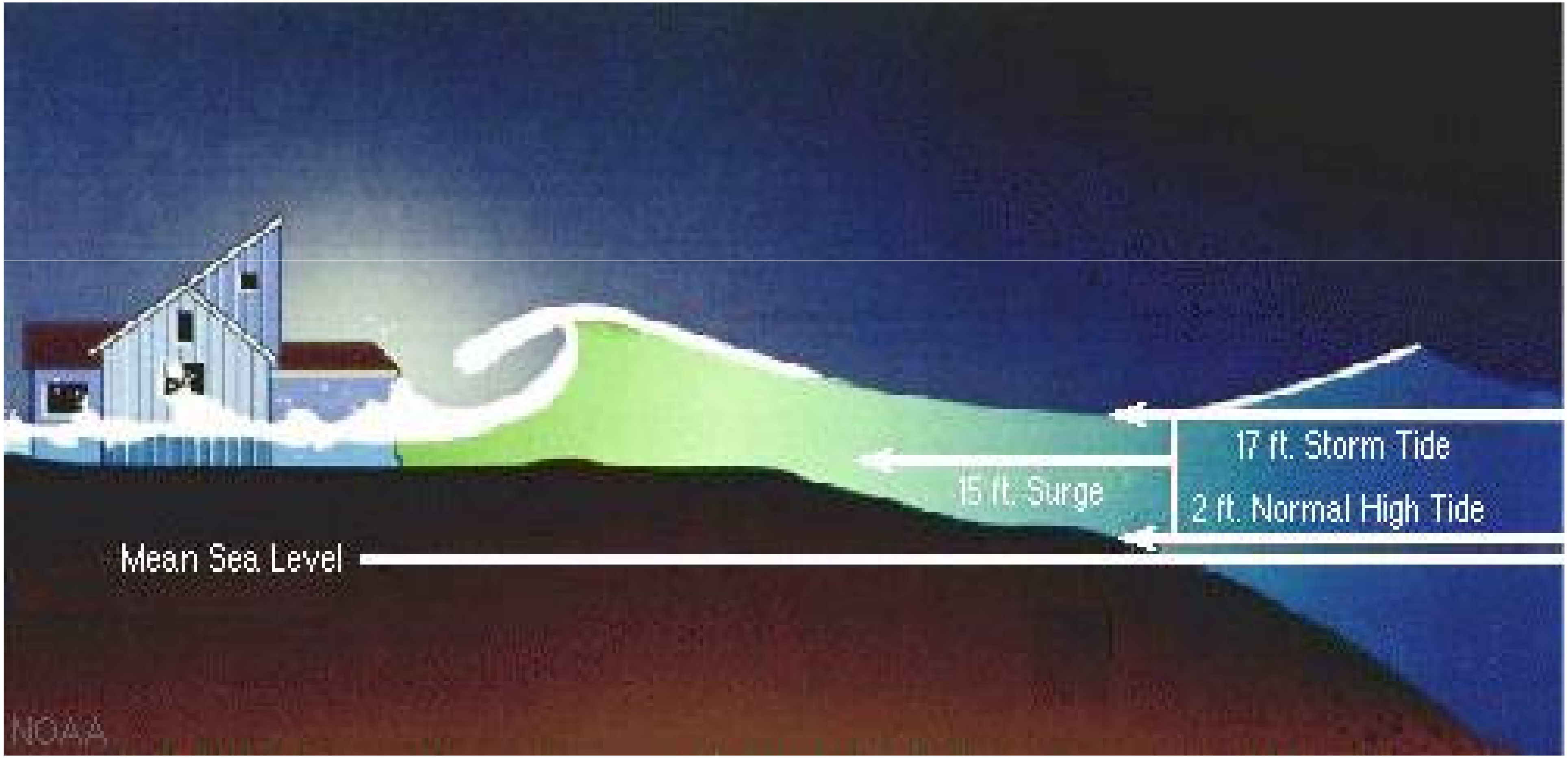


What is SLOSH?

- **Sea, Lake, and Overland Surge from Hurricanes**
- **A computerized model developed by the National Weather Service (NWS) to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes.**

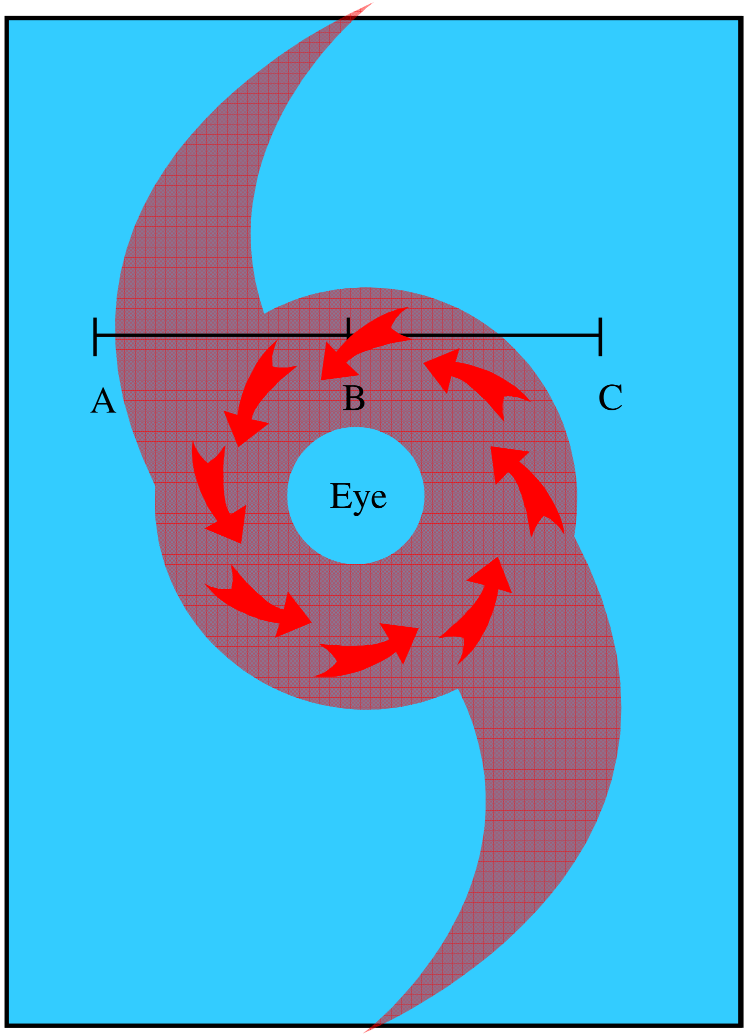
Source: http://www.nhc.noaa.gov/HAW2/english/storm_surge.shtml

Storm Surge

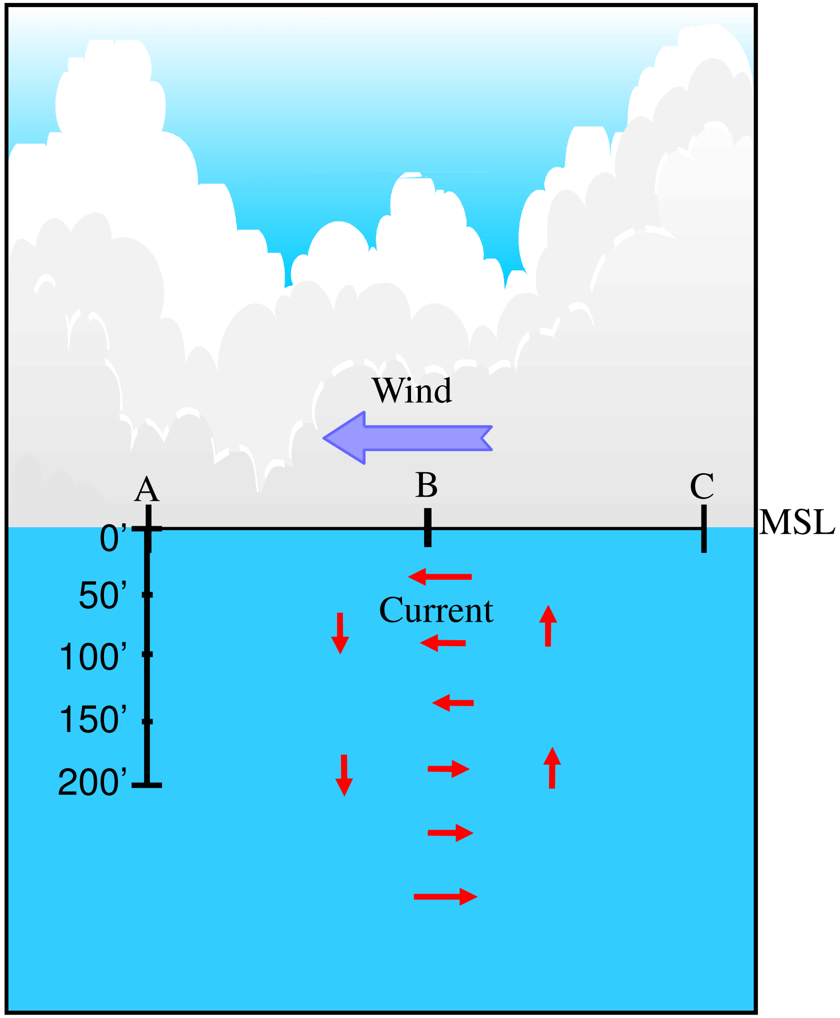

17 ft. Storm Tide
15 ft. Surge
2 ft. Normal High Tide
Mean Sea Level
NOAA

Deep Water

a. Top View of Sea Surface

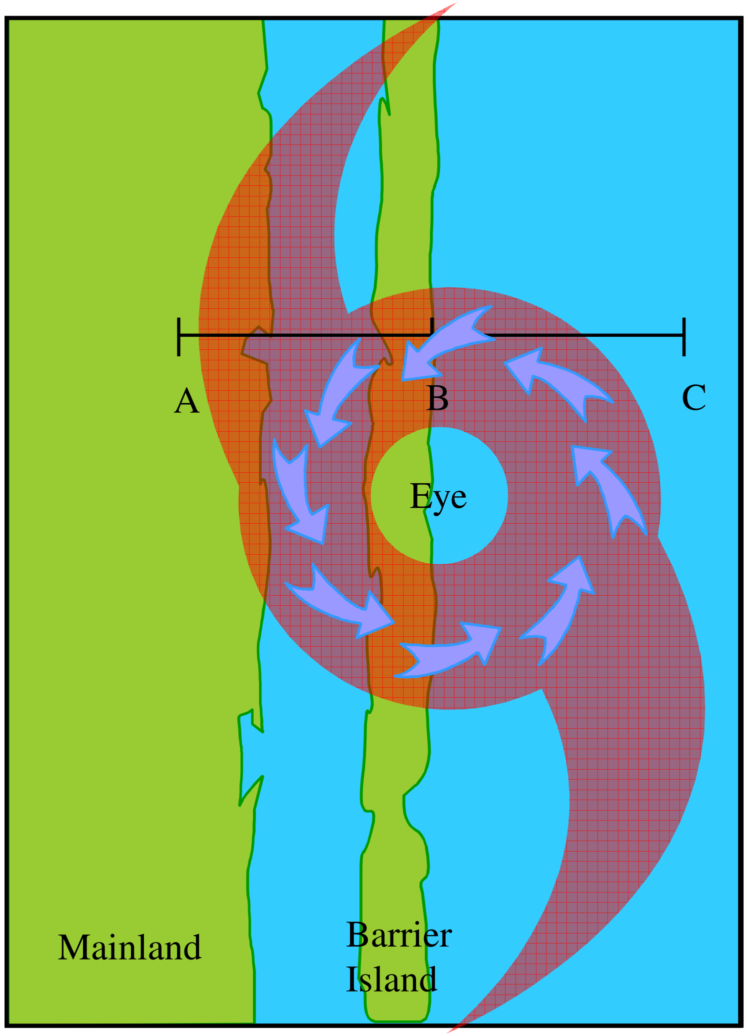


b. Side View of Cross Section "ABC"

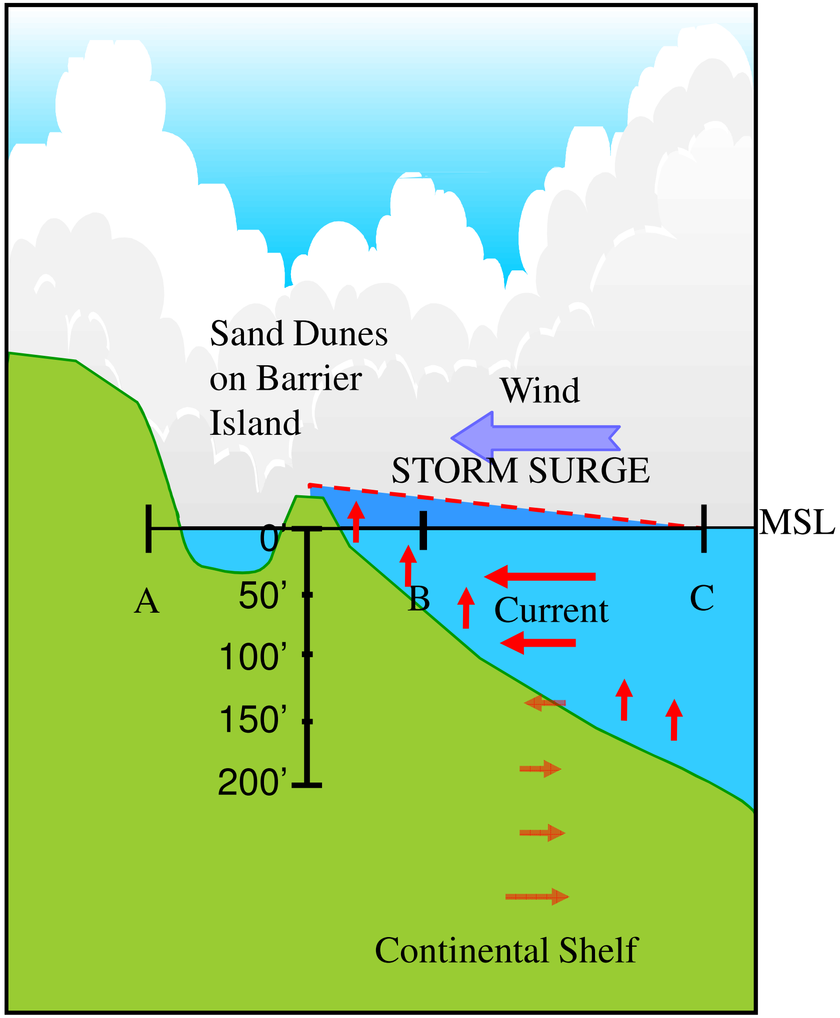


Landfall

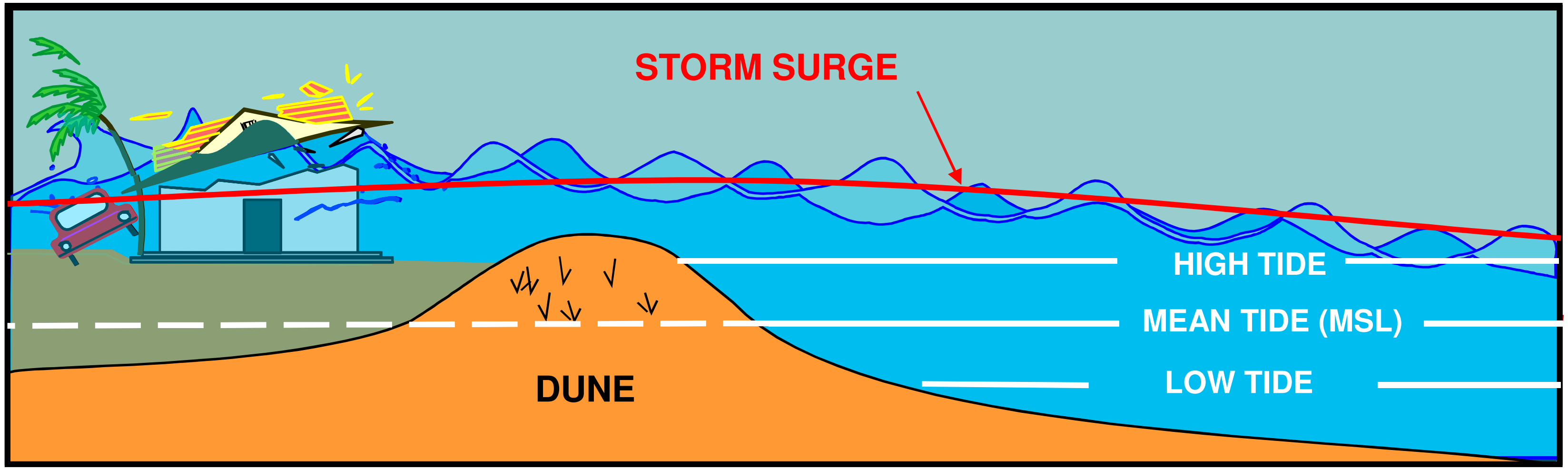
a. Top View of Sea Surface and Land



b. Side View of Cross Section "ABC"

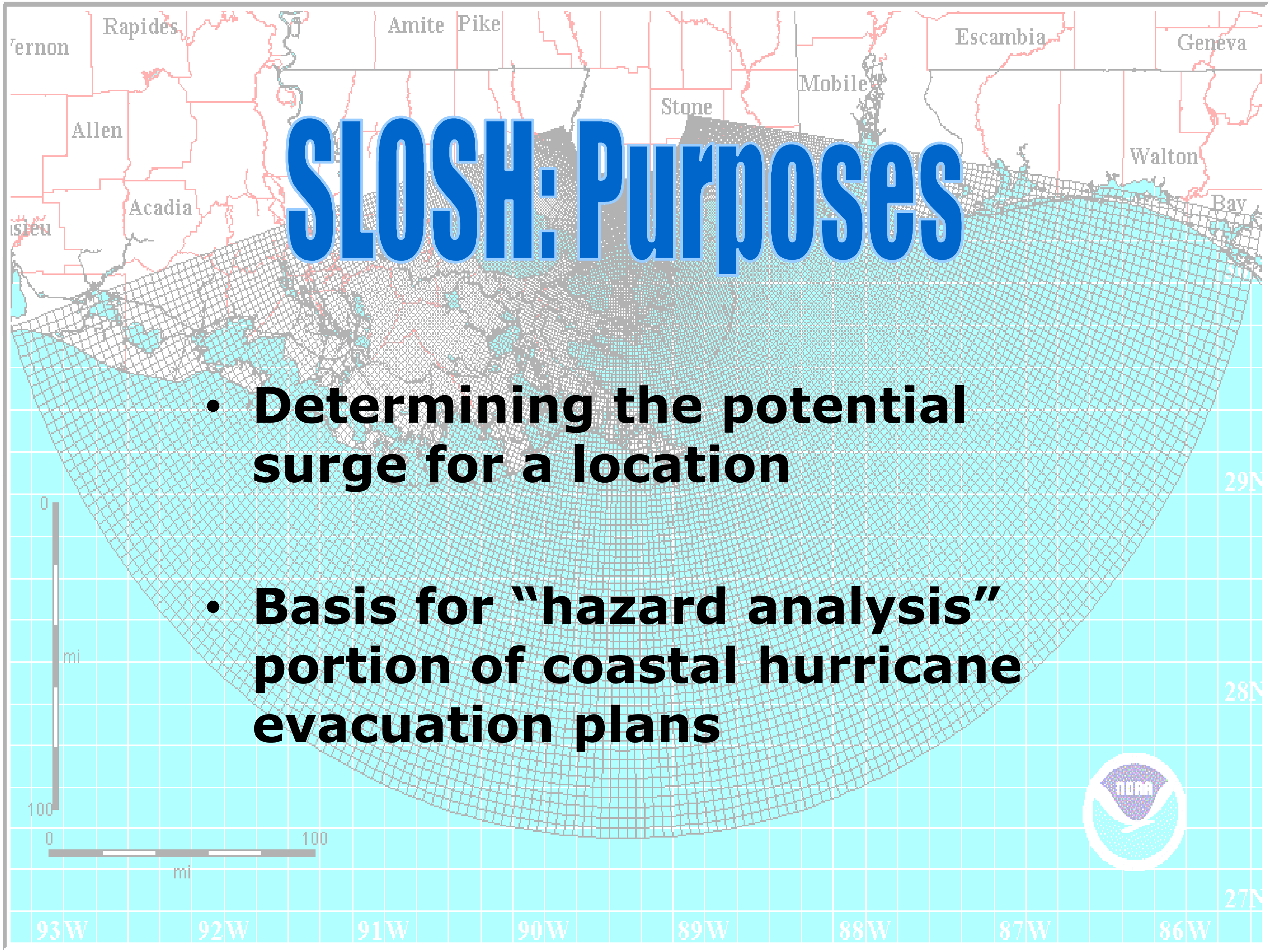


Tide with Storm Surge

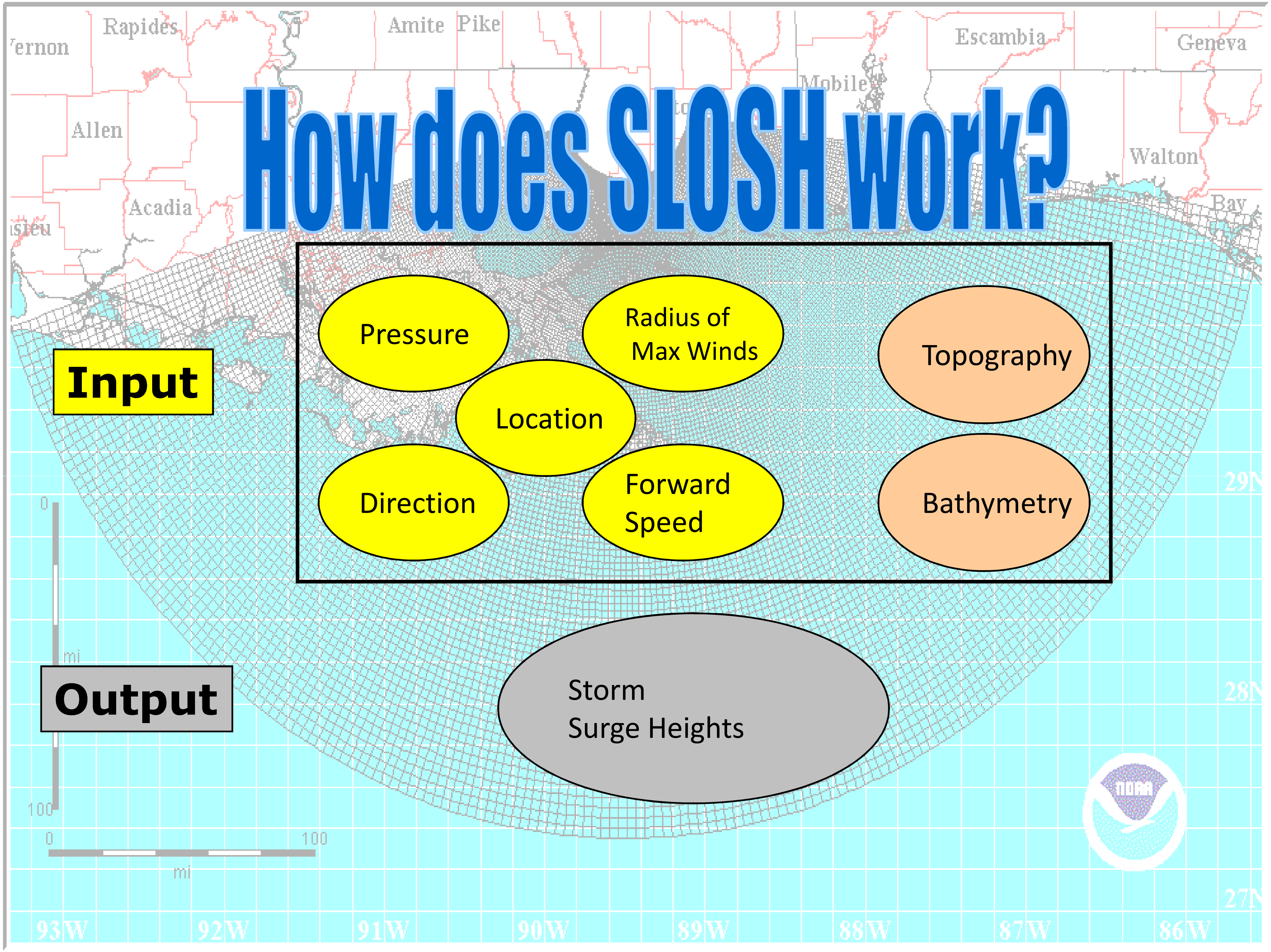


SLOSH: Purposes

- Determining the potential surge for a location
- Basis for "hazard analysis" portion of coastal hurricane evacuation plans



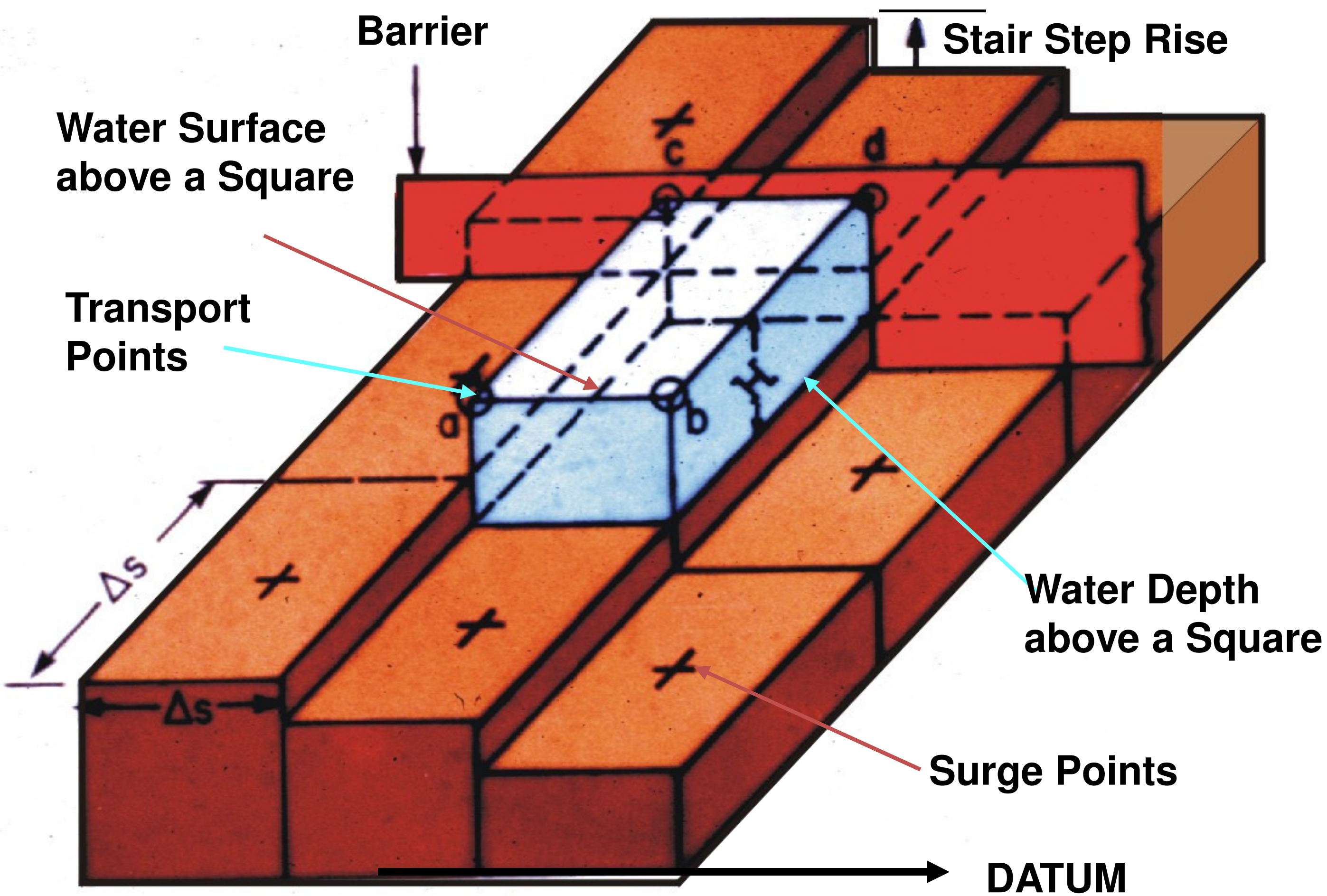
How does SLOSH work?



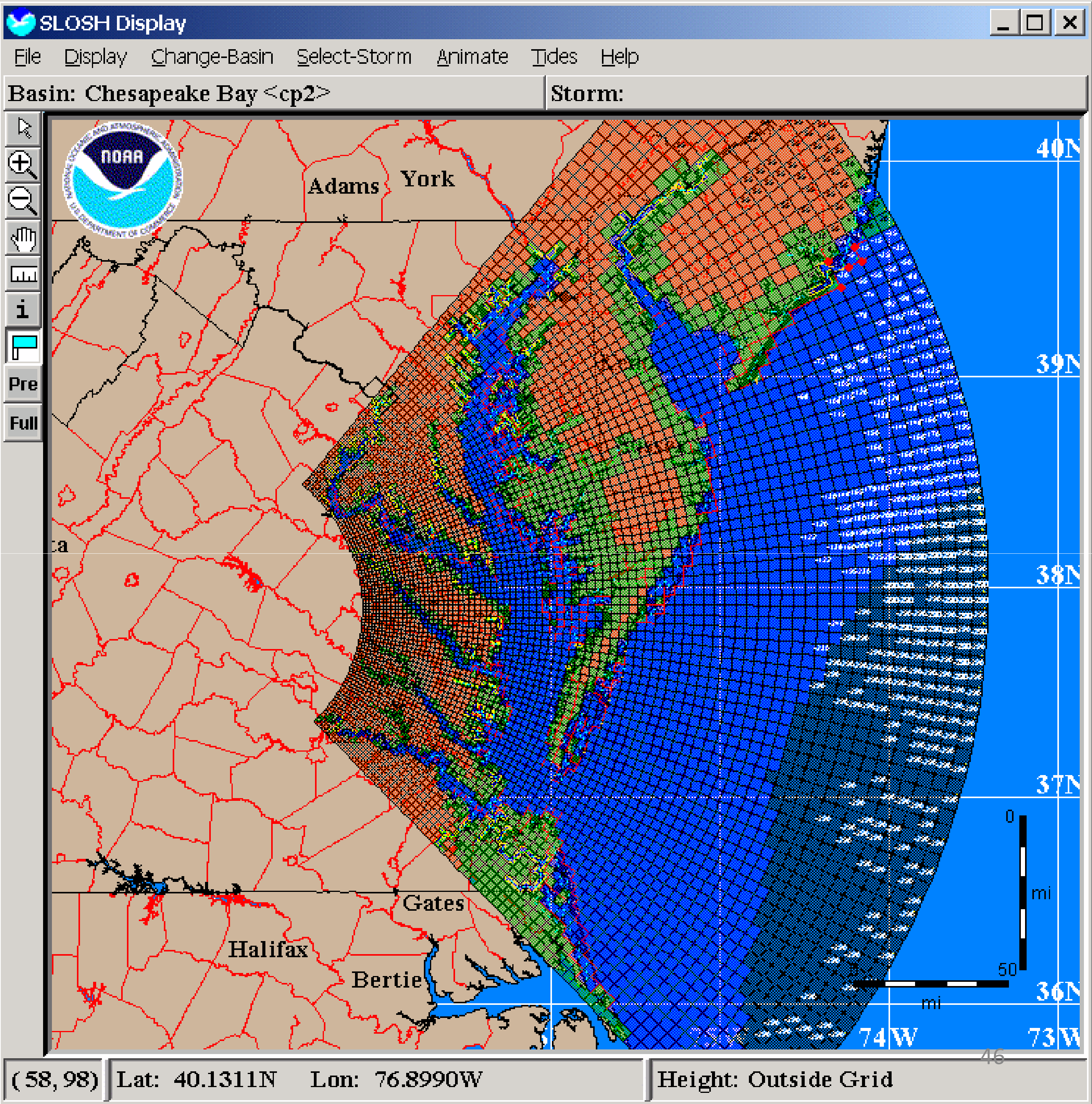
Sub-grid elements:

- 1 dimensional flow for rivers and streams
- Barriers
- Cuts between barriers
- Channel flow with chokes and expansions
- Increased friction for trees and mangroves

Individual Grid

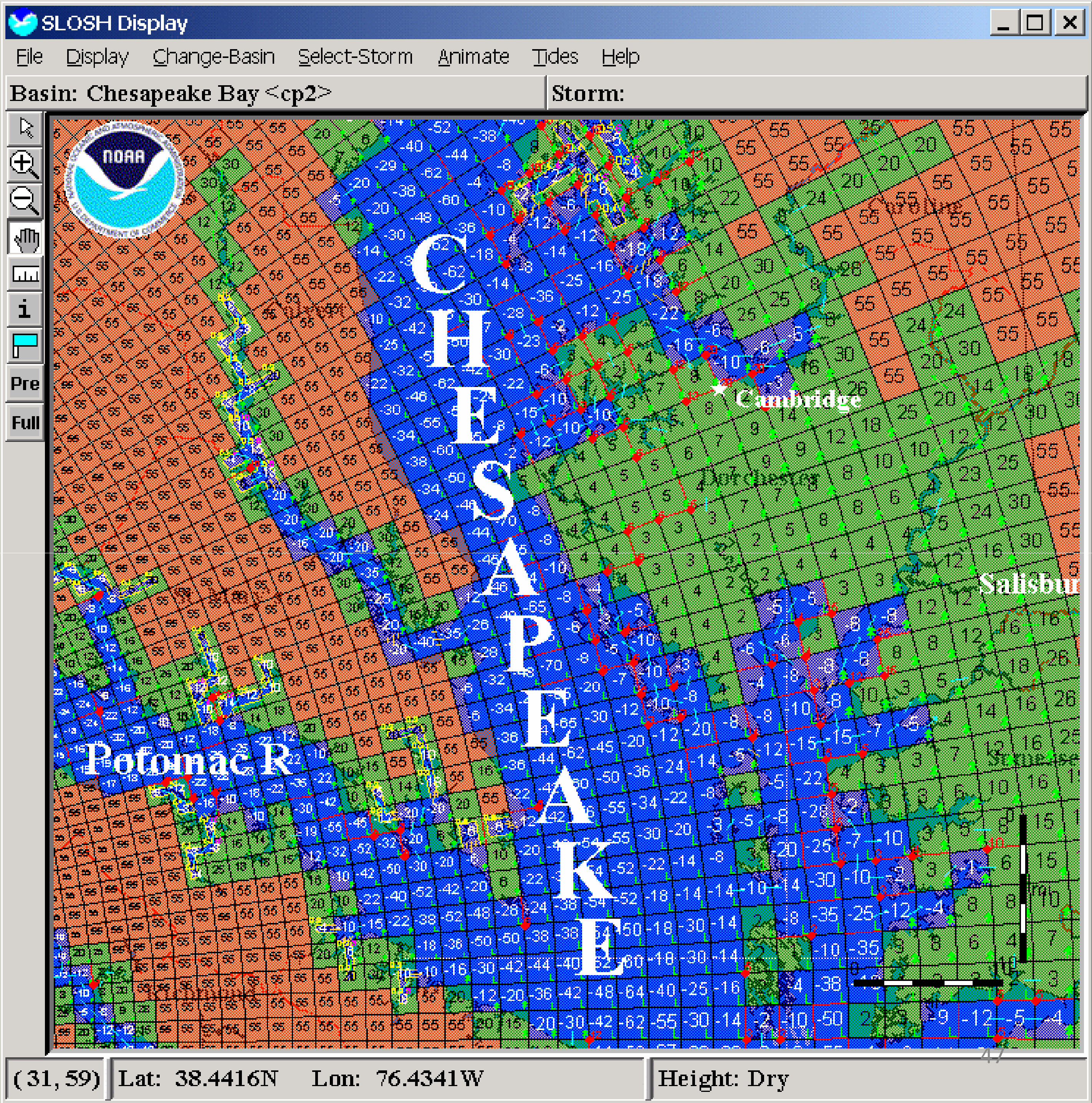


SLOSH Model grid with geographic data at full resolution

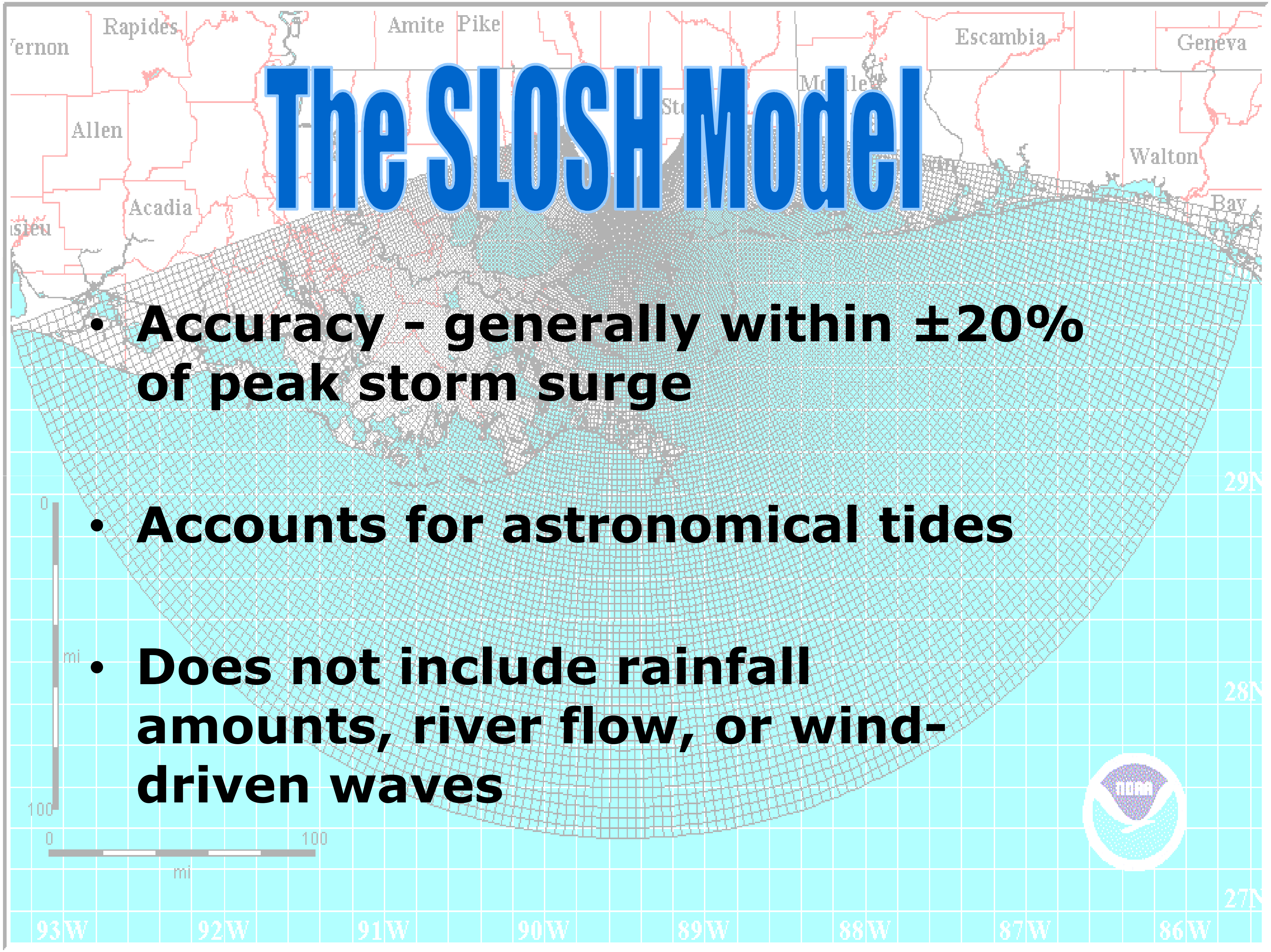


SLOSH Model grid with geographic data at finer resolution

Used by Basin Developer for quality control



The SLOSH Model



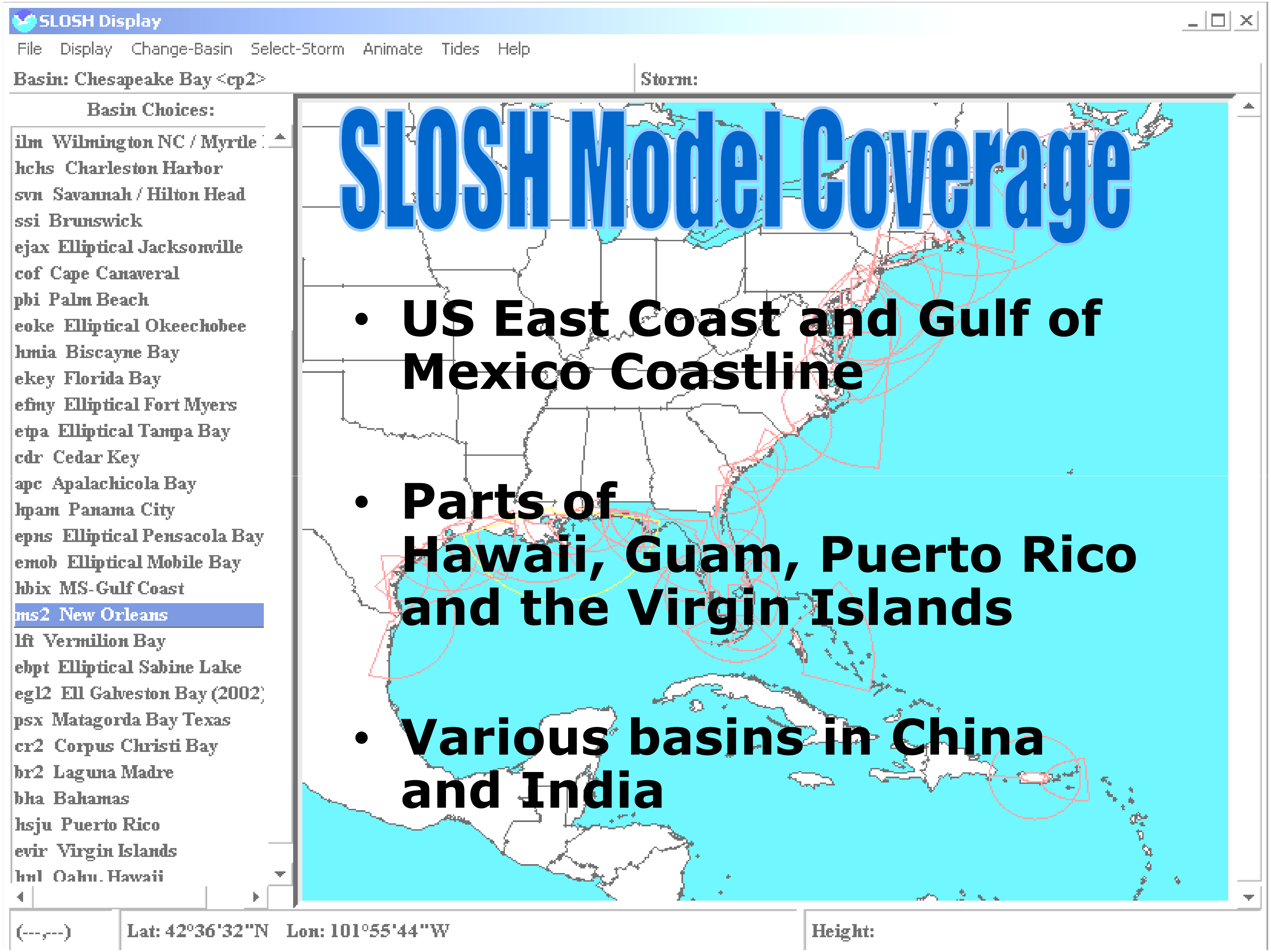
- Accuracy - generally within ±20% of peak storm surge

- Accounts for astronomical tides

- Does not include rainfall amounts, river flow, or wind-driven waves

SLOSH Model Coverage

- **US East Coast and Gulf of Mexico Coastline**
- **Parts of Hawaii, Guam, Puerto Rico and the Virgin Islands**
- **Various basins in China and India**



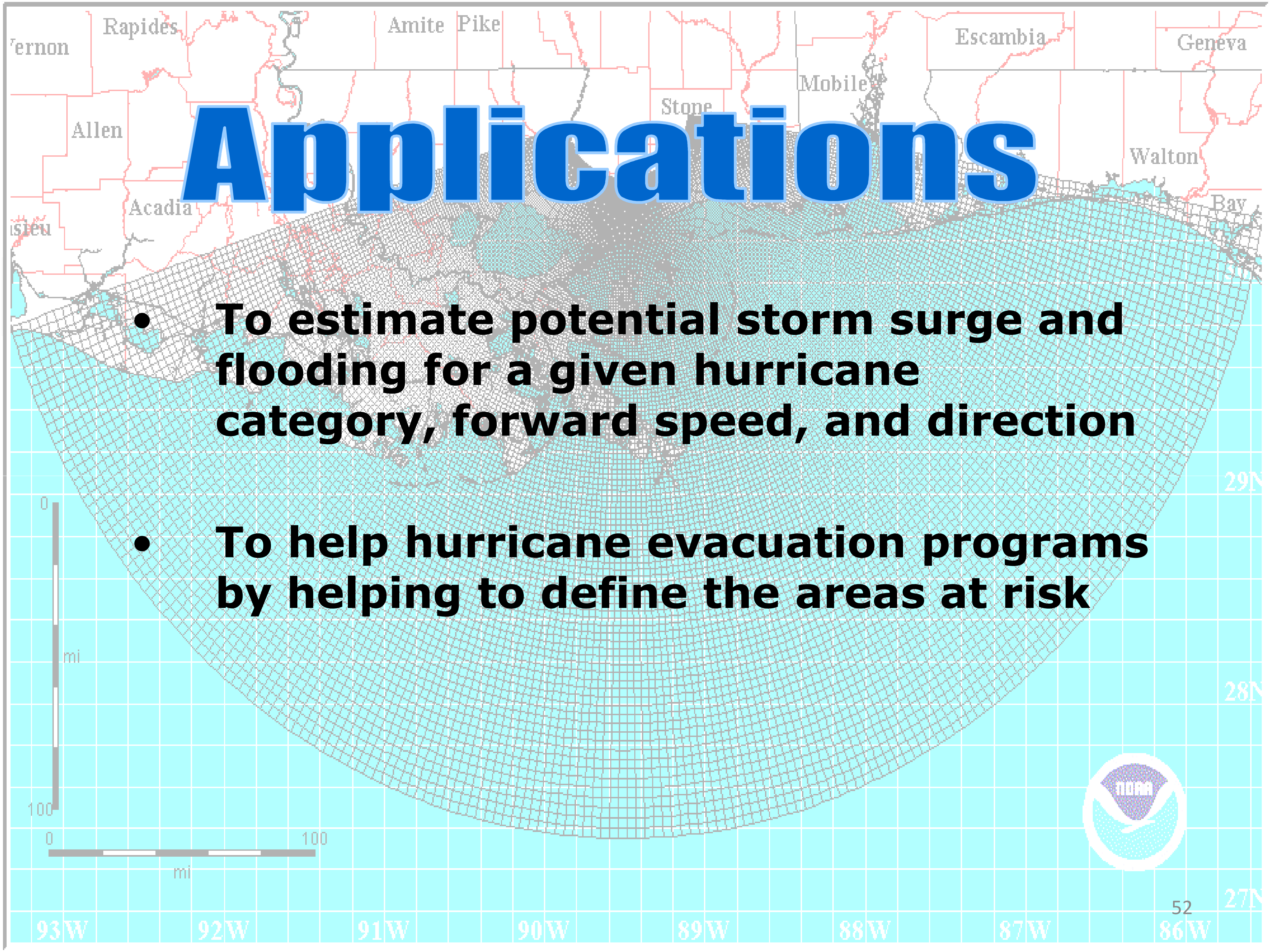
Generalizations from SLOSH

- More intense storms cause higher surges
- Highest surges usually occur to the right of the storm track
- Fast moving storms = high surges along the open coast
- Slow moving storms = greater flooding inside bays and estuaries

Generalizations from SLOSH

- Larger storms affect longer stretches of coastline
- Direction of storm approach often impacts the extent of flooding
- Shallow slopes in the continental shelf allow greater storm surge with small waves
- Storm surge is less in areas with steeper coastal slopes, but large breaking waves can occur

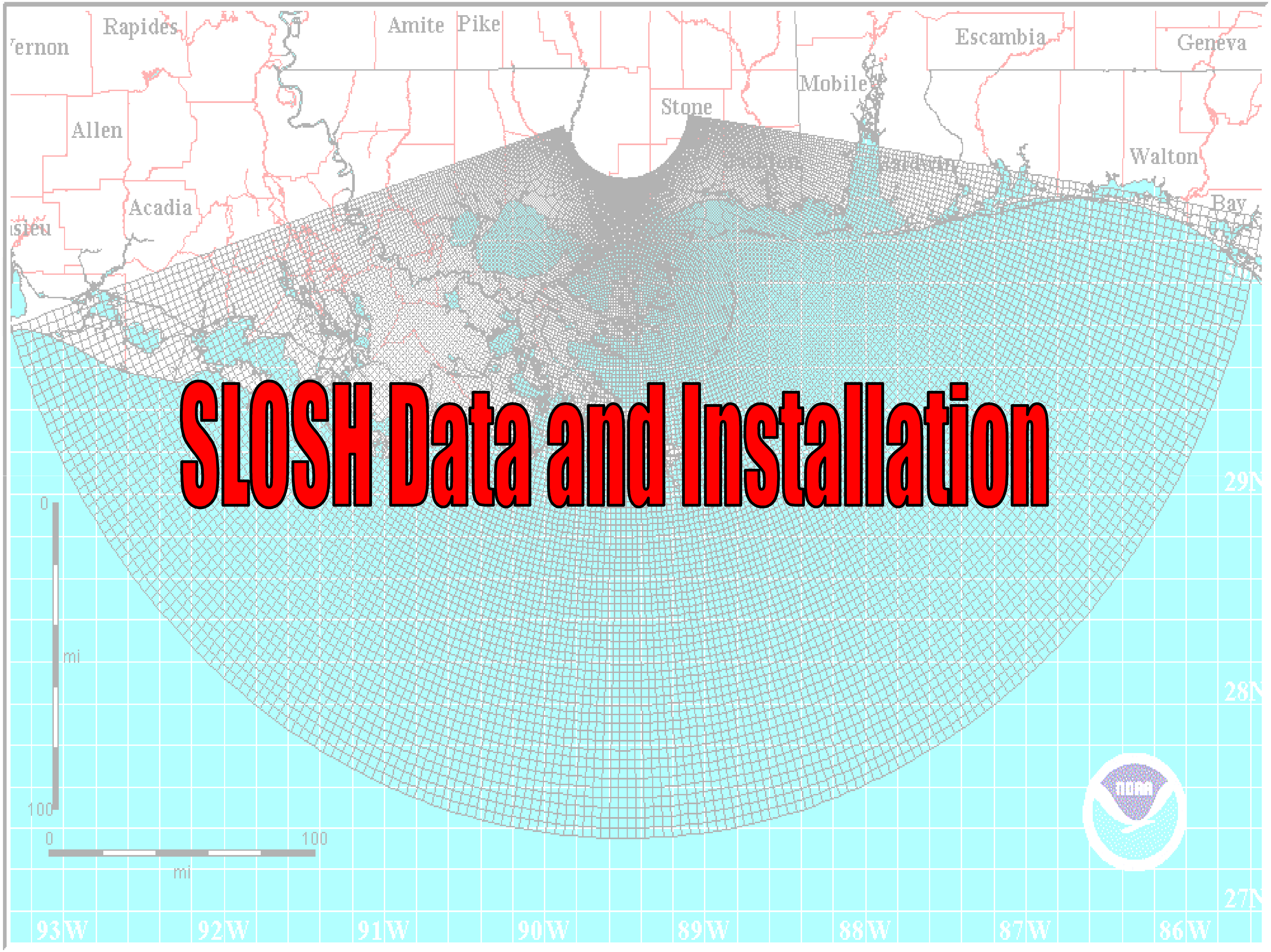
Applications



- To estimate potential storm surge and flooding for a given hurricane category, forward speed, and direction

- To help hurricane evacuation programs by helping to define the areas at risk

SLOSH Data and Installation



SLOSH Package

- SLOSH CD is available from NWS to any government employee with training working in the Emergency Management area

- The CD contains:
  - SLOSH Display for Windows
  - Tide Display for Windows
  - Hurricane Tracking Program
  - SLOSH Data

SLOSH Data

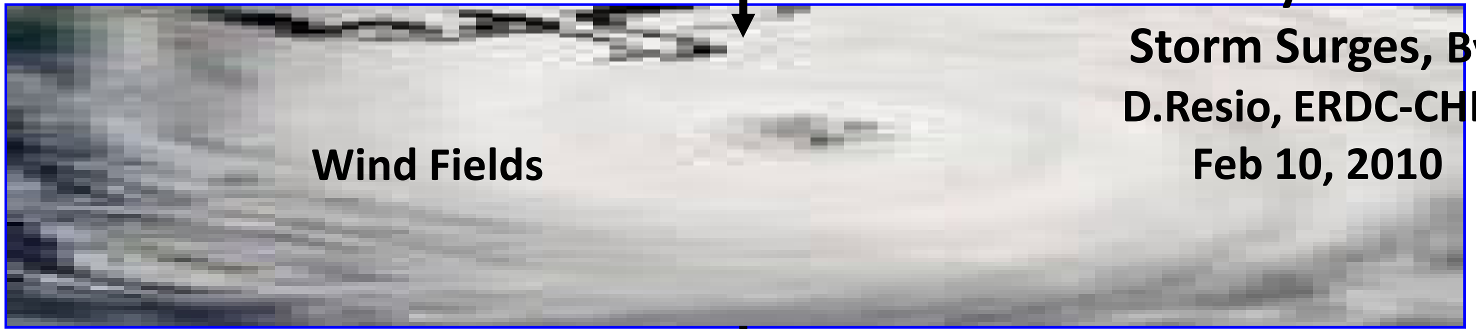
- The National Weather Service has run several thousand hypothetical hurricanes for each basin with the SLOSH model

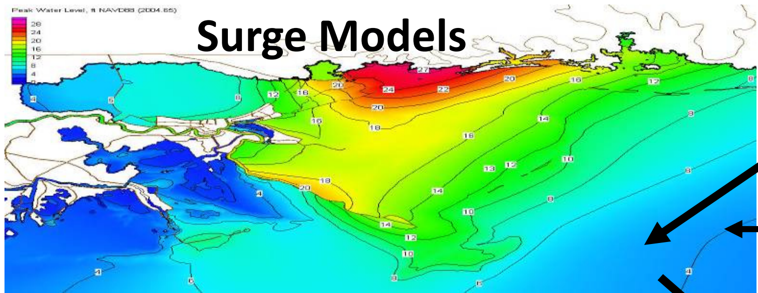
- Resulting flooding data from each run is saved

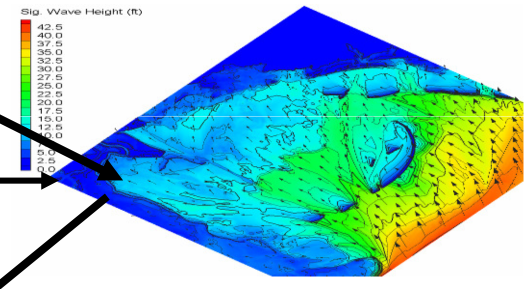
- SLOSH MEOW data is available for 39 basins

Hurricane Surge Prediction

Reproduced from: The Joint Probability Method for Storm Surges, By D.Resio, ERDC-CHL, Feb 10, 2010







coupled

Local-scale waves

Overtopping + Loads on Structures

Response to Loads and Operational Considerations

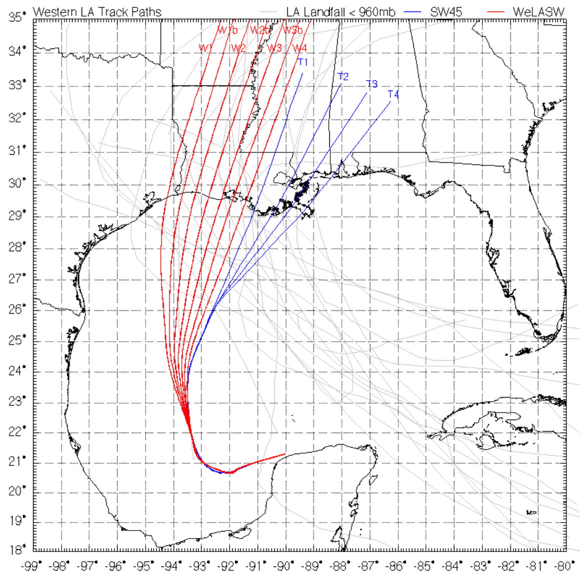
Surges outside and inside levee system

Hazard ← → Risk

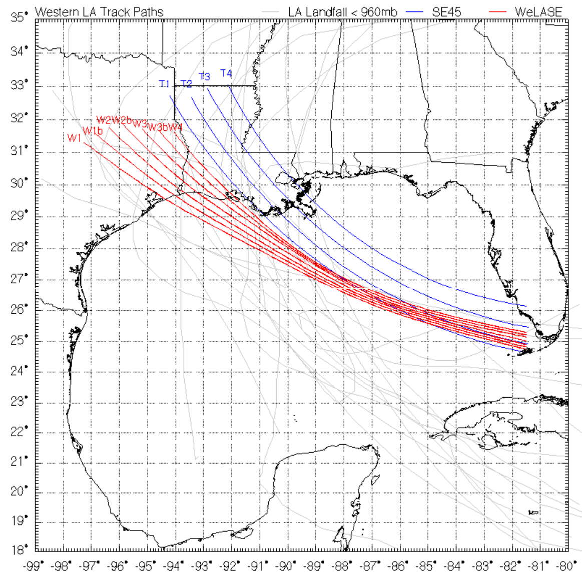
Eastern and Western LA Work

152 JPM Storms based on 3 track path classifications

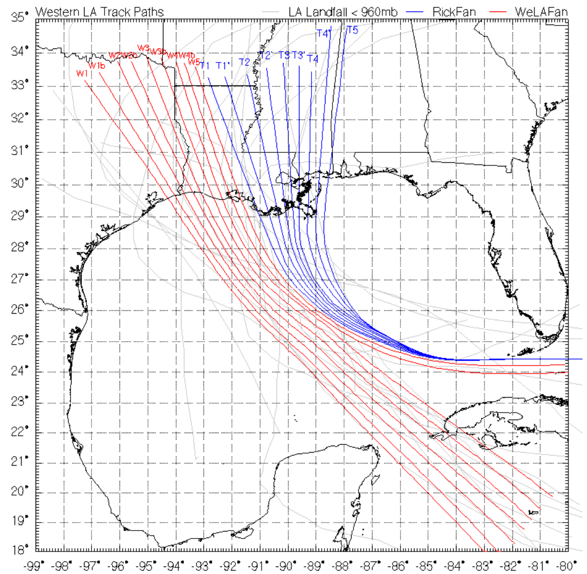
Western LA track paths shown in red, Eastern LA in blue



"SW 45"



"Mean Angle"



"SE 45"

Reproduced from: The Joint Probability Method for Storm Surges, By D.Resio, ERDC-CHL, Feb 10, 2010

Deepwater wave height estimates Tutuila Island, American Somoa

Deepwater Significant Wave Ht, Ho, based on hurricane characteristics

$$H_o = 16.5\ e\ (R\Delta p/100)\ [1+(0.208\ V_f/U_m^{0.5})]$$

R- radius of max. wind

Δp- diff pressure between normal & central pressure

V_f - forward speed of translation

U_m- max wind speed

Hurricane Wave Height Estimates
Nadi Airport Runway Extension , Fiji

Hurricane Wave Height Estimates
Nadi Airport, Fiji

Composite Hurricane Model

use hurricane wave model for 17 cyclones (1969-85) within 100 NM radius of Nadi

Composite SMB Model

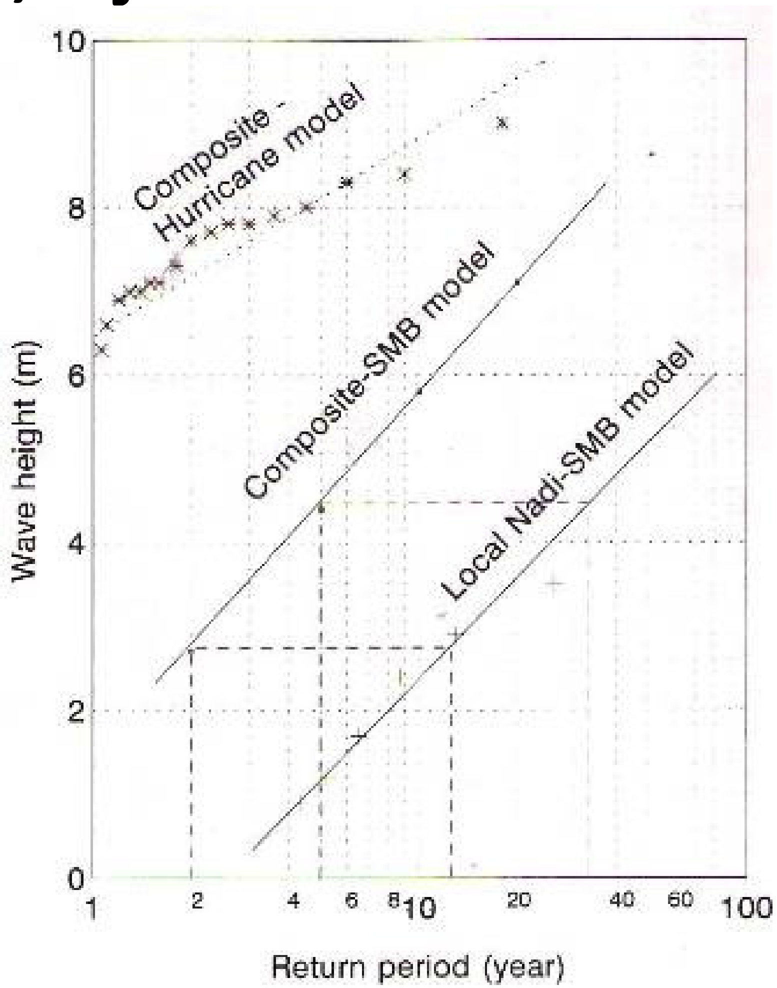
use 17 cyclones (1969-85) within 100 NMi radius of Nadi

Local Nadi SMB Model

use 6 cyclones (1969-94) passed thru Nadi

Design Conditions

Tr = 2 yr (composite) or 12 yr (Local)



End of Tutorial