Modelling Tools for River Engineering: “Applications on River Morphology for the Nile Basin”

Introduction to Application of GIS and RS in River Morphology

By: Dr. Bashar, K.E.

UNESCO Chair in Water Resources, Sudan.

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- Conventional versus Remotely Sensed Methods of River Morphology
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Introduction

- River is a natural stream of water flowing regularly or intermittently over a bed in a definite channel following the slope of the land.
- W.M.Davis (1899) first presented a general theory of landform development called "Normal Cycle of Erosion" which describes a genetic classification and systematic description of landforms developed by the fluvial process.
- Three successive stages in the evolution of fluvial landforms were identified like, 'Youthful Stage', 'Mature Stage' and 'Old Stage'.
- River changes its own course and shapes the surrounding landscapes in different stages by continuous changing its hydrodynamic and morpho-dynamic processes following the slope, terrain characteristics, rock and soil characteristics, vegetation cover in the region.

Introduction

- The old stage of a river is characterized by the low elevation with very gentle slope of land.
- The entire landscapes is dominated by graded valley-sides and divide crests, broad, open and gently sloping valleys having extensive floodplains, well developed meanders, cut-off meanders, abandoned channels, oxbow lakes etc (Singh, 2003).

River Morphology Overview

River Morphology

- The term river morphology is used to describe the shapes of river channel and how they change over time.
- In geomorphologicaly active area, shape of river channel is not preserved for long time.
- Erosions and depositions change the shape of
  - depositional features within the channel,
  - shape and dimension of the channel and
  - the path of active flowing water.

River Morphology Issues

- River bank erosion/accretion occurs simultaneously mainly due to change in river course.
- At the bend of the river, the flowing water dashes straight into the outer bank and erodes it into a steep river cliff.
- The water piles up on the outside of the bend because of the centrifugal force.
- A bottom current is set up in a corkscrew motion and is hurled back into mid-stream and inner bank.
- Thus deposition occurs in the inner bank forming the very gentle slip-off slope.
- Such simultaneous erosion and accretion processes results in change in areal extent. (Morisawa, 1985)

River Morphology
Conventional versus Remotely Sensed Methods

River Morphological Studies

- RM is concerned with the structure and form of rivers including channel configuration, channel geometry, bed form and profile characteristics.
- Various flood control structural measures such as construction of embankments, channel improvements, raising of villages, selective dredging etc. have been implemented in the past to reduce the impact of the flood disaster on human life and property.
- It is essential to monitor the embankments regularly to identify the vulnerable reaches.
- Conventional methods of river surveys are time consuming and expensive.
- Most of the flood prone rivers worldwide change their course after every flood wave eroding river banks.

Remote Sensing Based Morphological Studies

- Satellite remote sensing based morphological studies are quite useful in following areas:
  - To identify the changes in river course over a time period.
  - To identify the erosion prone areas along the river course
  - To study the efficacy of flood management structures
  - To identify flood prone areas (inundation and flood plain mapping)
  - Flood management
  - etc
- The river configuration and flood control works maps can be effectively used to identify the vulnerable river reaches and status of the flood control embankments/spurs so that necessary measures can be taken accordingly to avoid breaches.
- The bank erosion maps can be used for planning bank protection works.
- The study of river configuration will be useful to understand the behavior of the river and can be used for laying physical models.

Role of Space Technology in Flood Management

Space Technology

- The unique capabilities of satellites to provide comprehensive, synoptic and multi-temporal coverage of very large areas at regular interval and with quick turn around time have been very valuable in monitoring and managing river dynamics.
- In fact, it is only space technology, which has for the first time provided the basic information needed in the space, time and frequency domain.
- In order that appropriate flood control and anti-erosion works are scientifically planned, executed, monitored and maintained as per the best standards, it is necessary to acquire timely and reliable information about the flooded areas, watershed areas, river behaviour and configurations, etc. prior to floods, during floods, and after floods.
- Such information is difficult to acquire in time for decision making from conventional ground survey methods in vogue, which are arduous, time consuming and beset with various limitations, especially while studying floods of large river basins.

Space Technology

- Several satellites are available
  - Earth Observation Satellites
  - Geostationary Satellites
  - Communication Satellites

Earth Observation Satellites

- The earth Observation satellites provide comprehensive, synoptic and multi-temporal coverage of large areas in real time and at frequent intervals
- It is valuable for continuous monitoring of atmospheric as well as surface parameters related to flood and other hydrological parameters.

Earth Observation Satellites

- Satellites, by virtue of their remote sensing and data transmission capabilities provide comprehensive multi-date and multi-spectral information on dynamic phenomena covering very large as well as small river basins
- Therefore, they are admirably suitable for mapping/monitoring and studying:
  - (i) flood inundated and drainage congested areas,
  - (ii) extent of damages to crops, structures etc.
  - (iii) river configuration, silt deposits, shoals etc. and vulnerable areas of bank erosion
  - (iv) watershed characteristics and land cover/land use in command areas and
  - (v) hydrological and meteorological data transmission from data collection platforms.

Earth Observation Satellites

- The flooded areas, which extend to several thousands of square kilometers, could be mapped very effectively using the satellite data.
- They are also useful in delineating the boundaries of flood prone zones.
- Digital analysis of satellite data can detect changes on the sections of the inundated flood plains as well as in water quality.
- The multi temporal data from satellites are proved to be very valuable in the identification of the site ideal for taking up structural measures to control floods.

Geostationary Satellites

- Geostationary satellites provide continuous and synoptic observations over large areas on weather including cyclone monitoring.
- The use of meteorological satellites for forecasting heavy rainfall events, snowmelt runoff and monitoring of convective/frontal systems has improved the observational system greatly.
- The use of high resolution data from Remote Sensing satellites has greatly contributed to our understanding of various parameters relevant to rainfall run-off analysis, flood forecasting and flood mapping including flood damage assessment

Communication Satellites

- The vast capabilities of communication satellites are available for timely dissemination of early warning and real-time coordination of relief operations.
- Satellite communication capabilities, fixed and mobile, are vital for effective communication, especially in data collection, distress alerting, position location and coordinating relief operations in the field.

Space Technology in Conclusion

- Play an important role in providing valuable information particularly useful in the flood assessment, mitigation and preparedness phases of floods besides weather monitoring and effective communication for early warning and management of the floods.
- Some of the applications of Space Technology are development of early warning systems, monitoring & assessment, preparation of developmental plans for relief, rehabilitation and post-flood assessment, apart from tele-medicinal services.
- Advancement in the sensor technologies and hydrological and hydraulic models has paved the tremendous scope for remote sensing to play a greater role in the field of flood management.

Remote Sensing and GIS Applications in Flood Management

RS and GIS

- Advancements in the remote sensing technology and the Geographic Information Systems (GIS) help in real time monitoring, early warning, quick damage assessment of flood disasters and other morphological studies.
- A Geographic Information System is a tool that can assist floodplain managers in identifying flood prone areas in their community.
- With a GIS, geographical information is stored in a database that can be queried and graphically displayed for analysis.
- By overlaying or intersecting different geographical layers, flood prone areas can be identified and targeted for mitigation or stricter floodplain management practices and morphological changes can be detected.

RS and GIS

- Remote Sensing can be very effective for flood management in the following way:
  - Detailed mapping that is required for the production of hazard assessment maps and for input to various types of hydrological models.
  - Developing a larger scale view of the general flood situation within a river basin with the aim of identifying areas at greatest risk and in the need of immediate assistance.
- Remote sensing and GIS technique has successfully established its application in the following areas of flood management such as flood inundation mapping, flood plain zoning and river morphological studies.

Flood Inundation Mapping

- Flood mapping during the flooding and flood plain mapping after the flood recedes is essential.
- One of the important information required is the nature and extent of the damage caused by floods in the flood prone areas.
- Satellite remote sensing provides synoptic view of the flood-affected areas at frequent intervals for assessing the progression and recession of the flood inundation in short span of time which can be used for planning and organizing the relief operations effectively.
- Remote sensing can effectively be used for mapping the flood-damaged areas.

Flood Inundation Mapping

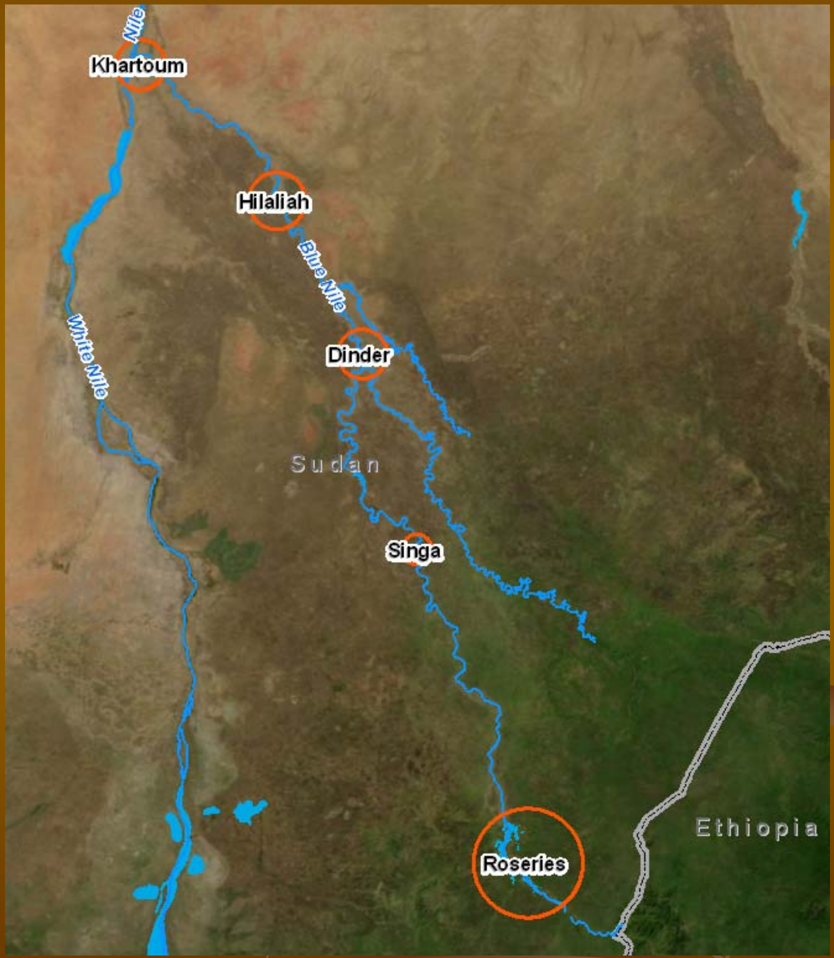
- For mapping purposes, a pre-flood scene and a peak flood image would be compared to delineate the inundated area.
- Flood inundation maps can be used:
  - To define spatial extent of flood inundation.
  - To identify the worst flood affected areas.
  - To evaluate impact of flooding on environmental concerns, such as, coastlines, forests, open space etc.
  - To plan relief operation.
  - To assess damage.

Flood Plain Zoning

- Flood hazard zone mapping can be used as a means of non-structural flood control planning of the flood plain and for making policy decisions to regulate the flood plain development activities.
- Using historic satellite data combined with hydrological and close contour data, a flood hazard zone map can be prepared for flood prone basins.

Case Study

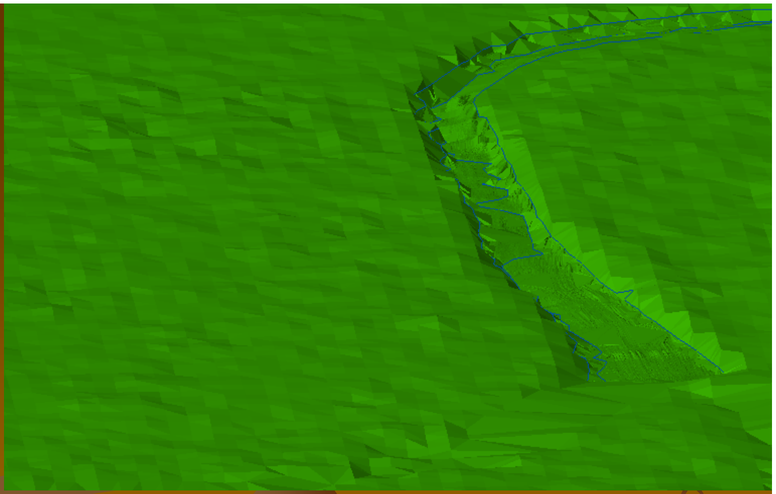
Blue Nile-Sudan



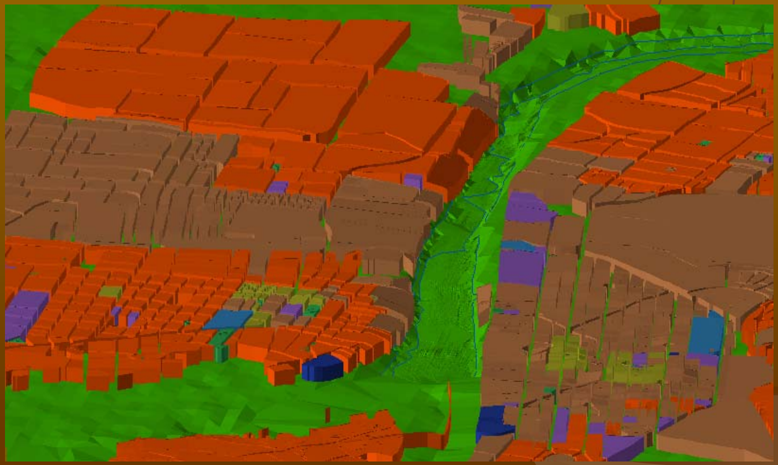
Flood History

- Severe flooding in 1878, 1946, 1988, and more recently in 2003, 2006, and 2007
- Flash flood and riverine flood impacts
  - Loss of crops, cattle, agricultural machinery
  - Loss of houses and properties
  - Displacement of large communities
  - Deterioration of health conditions
  - Disruption of social life
- 1998 heavy rain and flooding occurred in 18 or 26 Sudan states affecting over one million people
- 2006 flooding in Khartoum exceeded 1988 levels

Topographic Survey and Data Collection



- Accurate topography required for hydraulic modeling and for flood extent mapping
- Field survey captures river channel

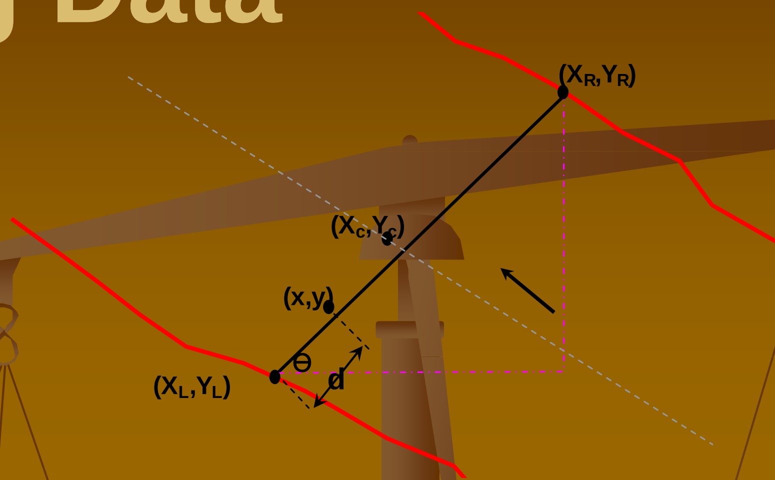


- Remotely sensed data provides extension into broad floodplain
- (it's not obvious where the extents will be until after a first hydraulic model run)

Topographic Survey Existing Data

- 1992 Field Survey Data for the Blue Nile River
- 2007 Bathymetric Survey for the 25 km Blue Nile River Reach between Khartoum and Bagair
- 2007 Bathymetric Survey for Roseires Reservoir

Topographic Survey
Existing Data



Geo-referencing Methodology

- With known cross section centerline coordinates, a Cutline is drawn perpendicular to the centerline of the reach
- Establish the left and right coordinates, (X_L, Y_L) (X_R, Y_R), so that the distance between the points equals the width given from raw, *d* surveyed data
- Intermediate points given as:

$$Sin\theta = \frac{(Y_R - Y_L)}{\sqrt{(X_R - X_L)^2 + (Y_R - Y_L)^2}}$$

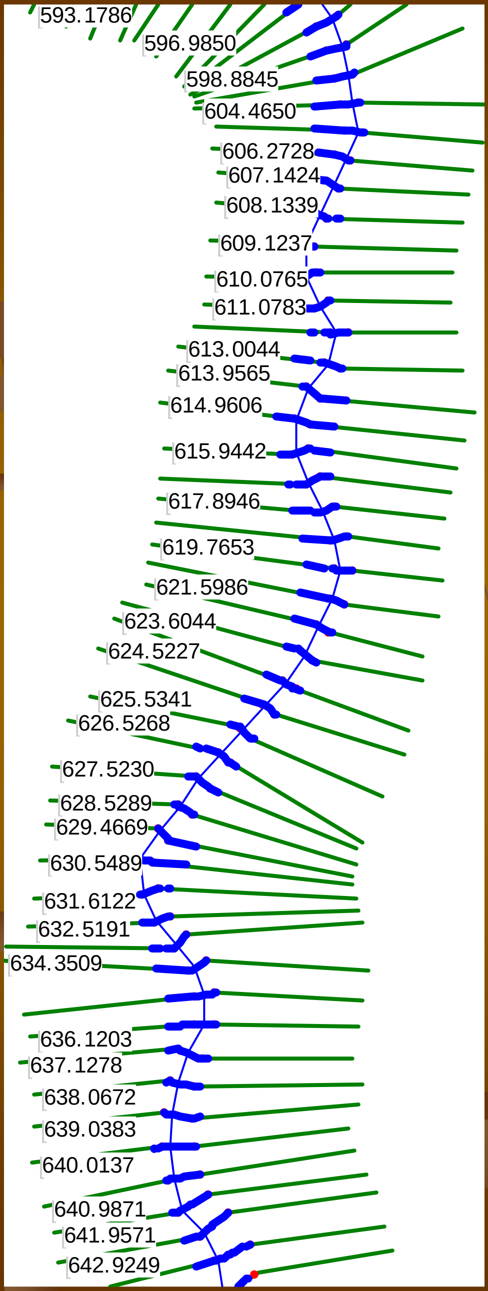
$$Cos\theta = \frac{(X_R - X_L)}{\sqrt{(X_R - X_L)^2 + (Y_R - Y_L)^2}}$$

$$x = X_L + dCos\theta$$

$$y = Y_L + dSin\theta$$

1992 Field Survey Data for the Blue Nile River

- Used in the configuration of the Flood Early Warning System (FEWS) developed in 1992
- 87 surveyed cross-sections from Roseries to Khartoum on the Blue Nile
- Only distance-elevation format
- Geo-referencing
  - Most upstream cross section set just downstream of Roseries Reservoir, all others set on centerline of the river
  - A total shift of 7 km equally distributed among the sections
  - Error of 12.9 m in the horizontal alignment, insignificant



2007 Bathymetric Survey

25 km Blue Nile River Reach between Khartoum and Bagair

- Recent bathymetric survey performed by the Dam Implementation Unit (SUDAN) in association with Ministry of Irrigation and Water Resources (MOIWR Sudan)
- Collected at an interval of 100m along reach
- Distance-water depth format

- Geo-referencing
  - Geo-referenced using the same approach as the 1992 Field Survey Data for the Blue Nile River
  - Almost no error or shift encountered

2007 Bathymetric Survey for Roseires Reservoir

- Recent bathymetric survey
  - performed by the Dam Implementation Unit (SUDAN) in association with Ministry of Irrigation and Water Resources (MOIWR Sudan)
  - Covers 110 km upstream of Roseires Reservoir
- Geo-referencing
  - Already geo-referenced
  - Screened for correct projections and verified for accuracy

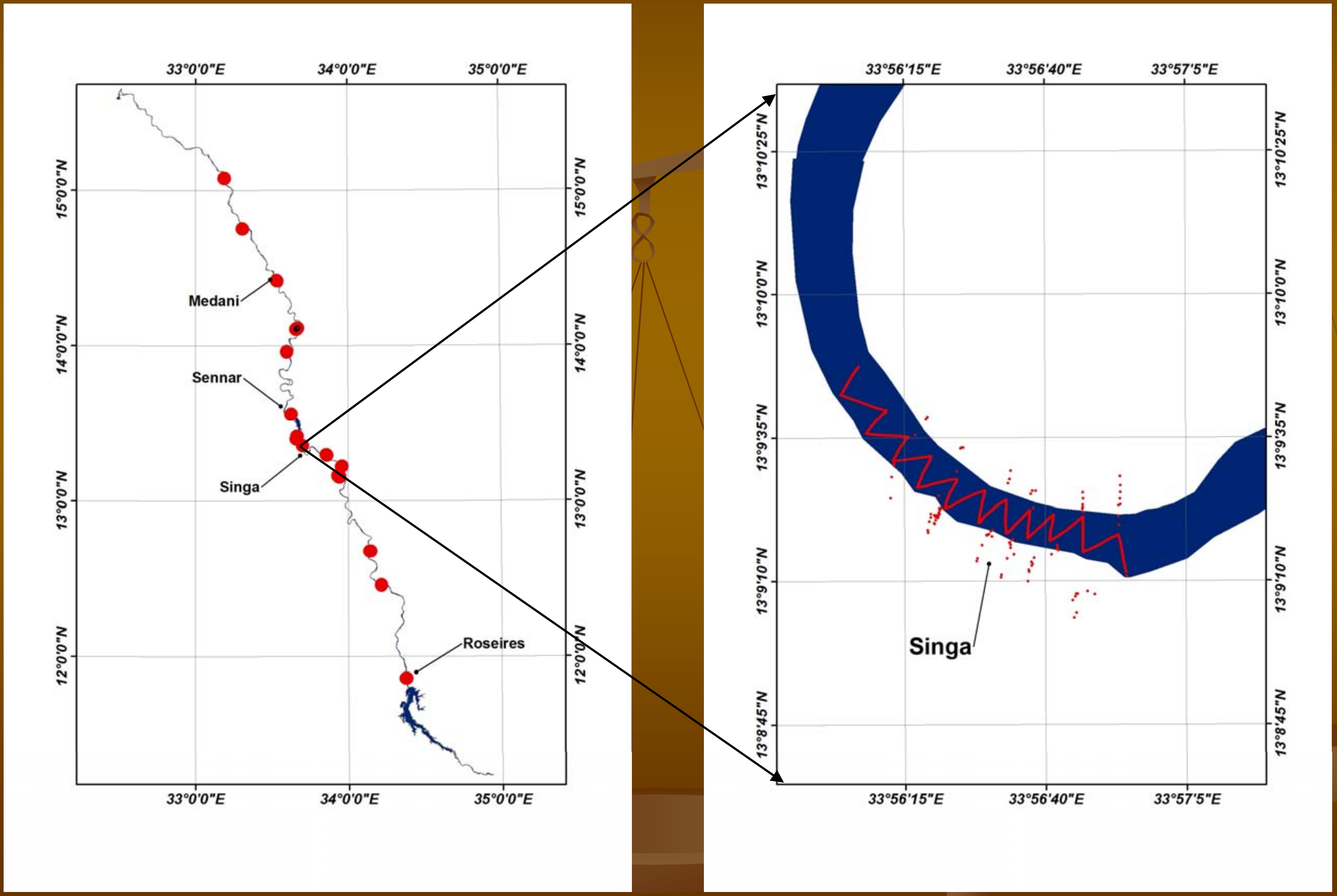
Topographic Survey
Additional Survey Locations

Supplement available data and verify accuracy
  - Survey at each cross section tied to a control elevation
  - Datum chosen as MOIWR, 3 m vertical shift
- Cross sections needed at closer spacing and extended further into the flood plain than existing data
- Benchmarks
  - National Survey Department Handbook unavailable or destroyed
  - Reliance given to known control points – gauging stations and hydraulic structures – pumping stations, irrigation features, etc.
- 42 additional cross sections surveyed along Blue Nile
  - Distributed throughout the reach for comparison with historical cross sections
  - Taken at higher densities in pilot areas

Topographic Survey
Field Survey

- Locations
  - Singa Pilot Area
  - Dinder River Pilot Area
  - Khartoum Pilot Area from U/S of the confluence with the White Nile up to Soba
  - Hilaliah/Hashyisa Pilot Area in the reach between Medani and Kamlin
  - 13 select locations that corresponded with known control points
- Based on proximity to control points of known elevation
- Topography and Soils - Geomorphic units of the Blue Nile
  - Recent Terrace
  - Upper Terrace
  - Sand Bar
  - Abandoned Channel
  - Ox-bow Lake
  - Central Clay Plain

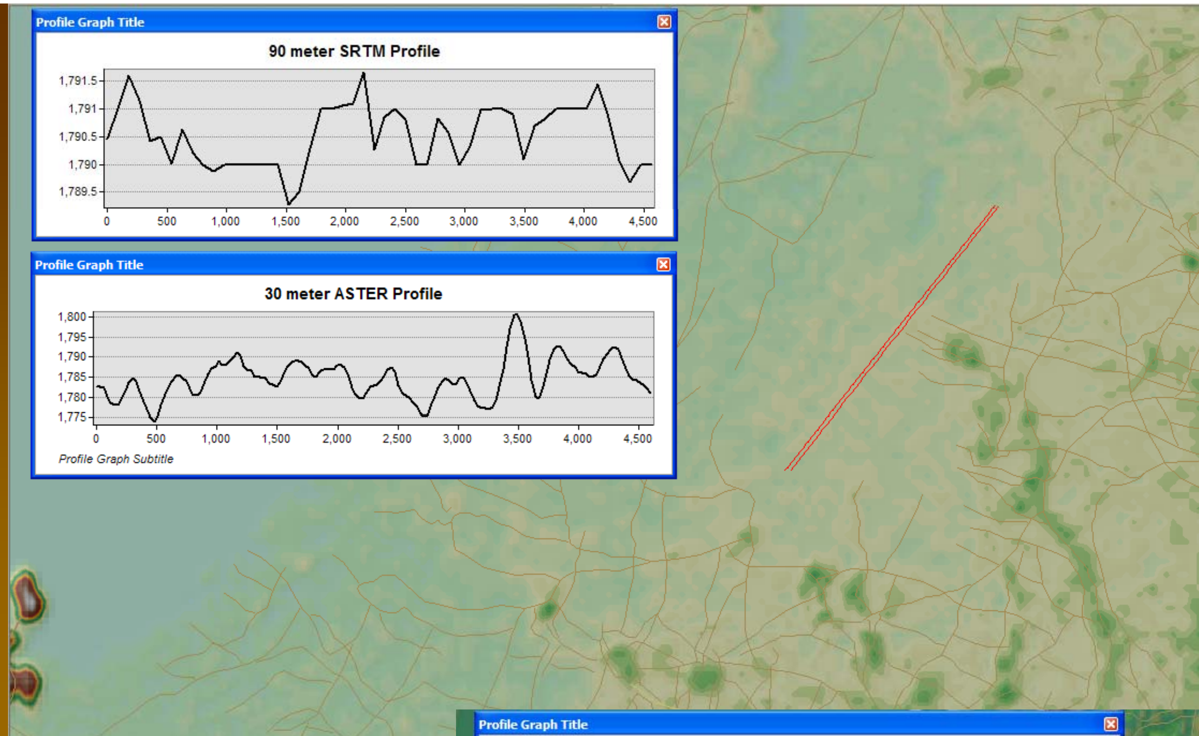
Topographic Survey
Field Survey



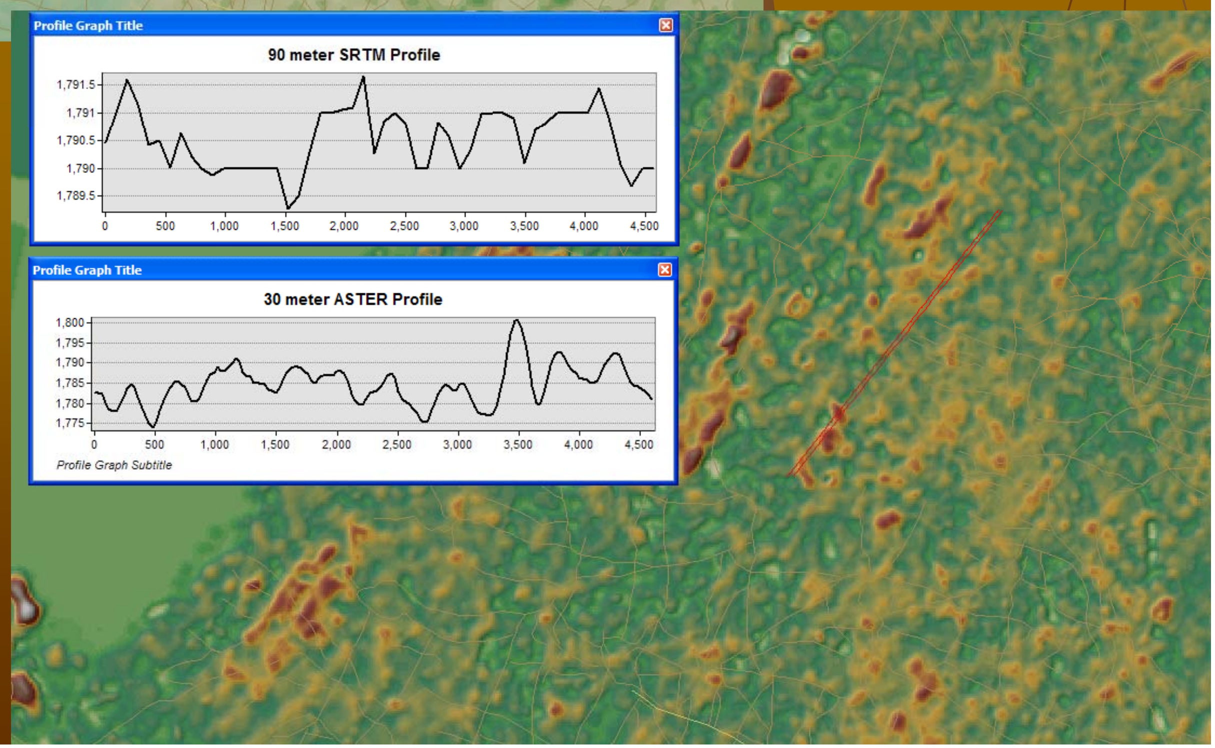
Terrain Model Development
Source DEM

- Accurate Digital Elevation Model (DEM) needed for hydraulic modeling and flood mapping
- Survey data
  - Cost prohibitive to attain large enough extent for flood modeling
- 90 m DEM
  - Lacks spatial detail needed for river channel modeling
- 30 m Global Digital Elevation Model (GDEM) (ASTER)
  - Large error when compared with elevation of the 90 SRTM DEM

90 m DEM showed greatest consistency, quality control, and agreement with survey data collected for the project



90m DEM



30m DEM

Terrain Model Development
TIN Creation

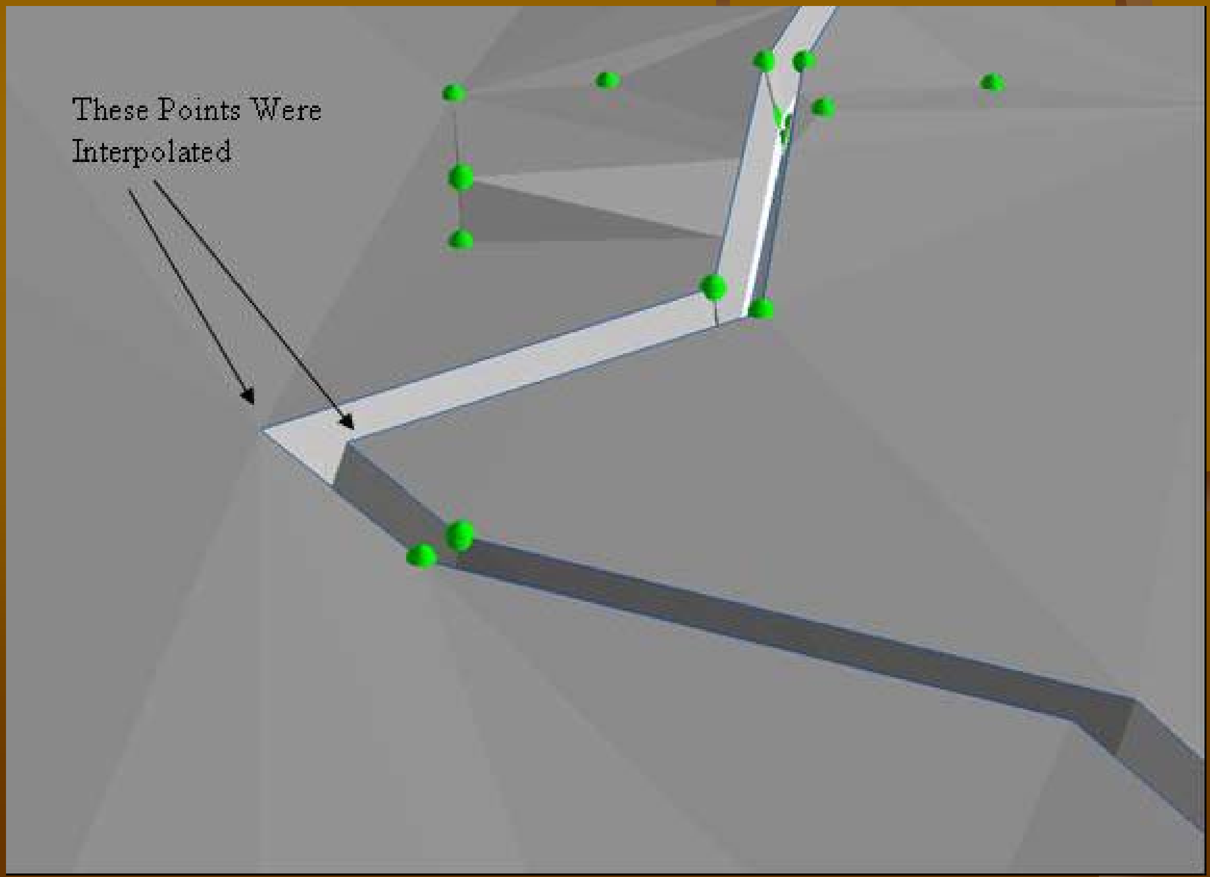
- Combined Terrain Model
  - Field survey captured river channel
  - 90 m DEM captured flood plain
  - Employ "breaklines" to prevent DEM encroachment on survey area

Terrain Model Development
TIN Creation

Bankline analysis creates a continuous channel

Terrain Model Development Channel Topography Definition

- Creating a combined channel and floodplain TIN

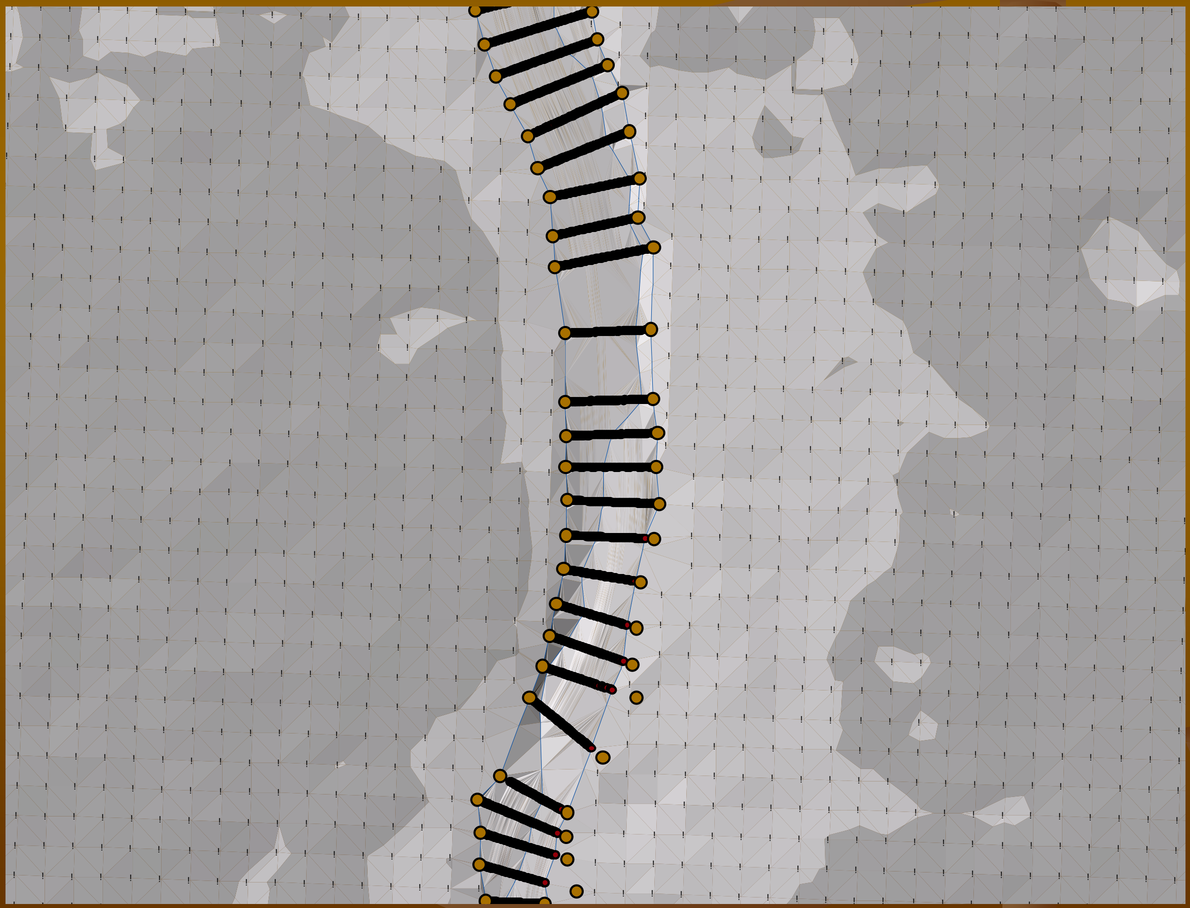


Terrain Model Development Integration with DEM

- General Procedure
  - Define channel from Survey
  - Use survey to identify DEM bias
  - Create a deviation surface from differences between Survey and DEM; blend into terrain beyond survey extents
  - Modify DEM using deviation surface
  - Create combined surface from adjusted DEM, Channel survey data
- Channel is defined by survey
- Floodplain texture is defined by DEM
- Survey points beyond channel are used to adjust DEM.

Terrain Model Development Channel Topography Definition

Extracting floodplain elevation data



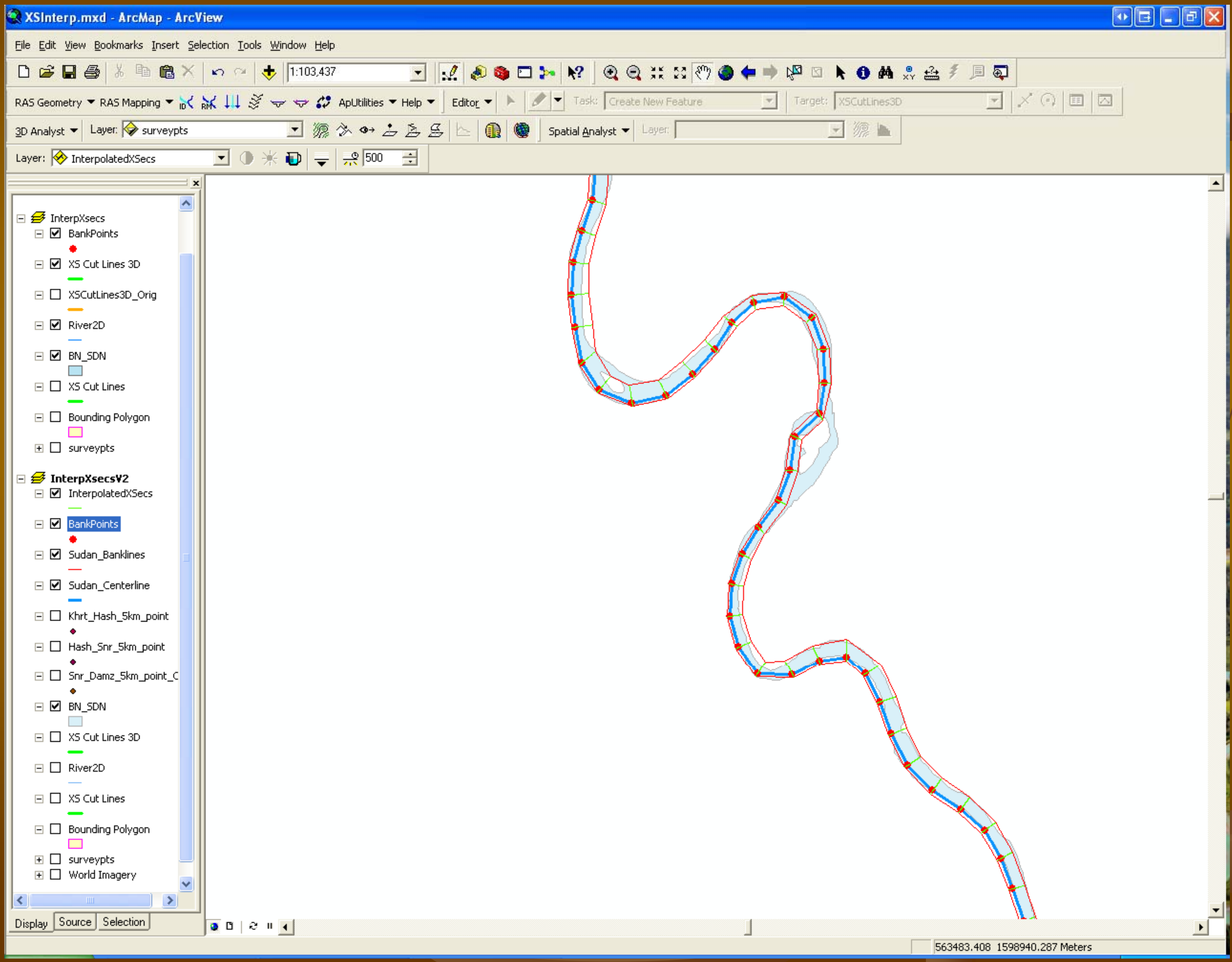
Blue Nile Supplemental Technique

- Retain information content of old and new cross sections plus horizontal alignment of river from satellite images
- Use rational process to fill in between surveyed cross sections
- Apply to hydraulic model and hazard mapping.

Supplemental Methodology

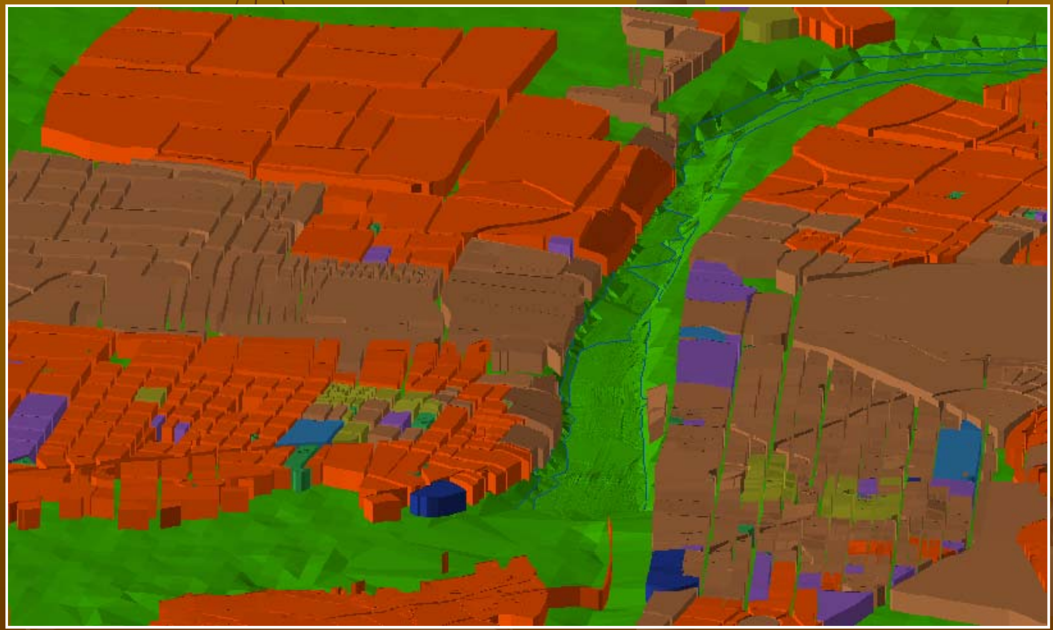
- Delineate cross sections in GeoRAS limited to river channel (with breaklines)
- Import into HEC-RAS
- Use HEC-RAS to interpolate additional cross sections along the river center line (digitized previously)
- Export the new cross sections
- Create combined surface
- Extend GeoRAS cross sections and extract to RAS

Interpolation – with decisions



Final Terrain With Infrastructure

- Final multi- resolution terrain
- Structures: residential, commercial, government



Hydrologic Analysis

- Purpose
  - To develop discharges that are representative of peak flows for floods for specific probability levels
  - Estimate peak flows corresponding with 2, 5, 10, 50, and 100 year return periods
  - Frequency Analysis performed for historical peak flows

Flood Frequency Analysis

- General Methodology
  - Peak flow data extracted from daily streamflow
  - Underlying statistical distribution identified
- Six gage stations
  - Eddeim, Roseries, Sennar, and Khartoum
  - Two on tributaries of the Blue Nile
- Analysis used historical peak mean-daily flows
  - River flows at Eddeim gage exhibit peak runoff events that occur over several days

Flood Frequency Analysis

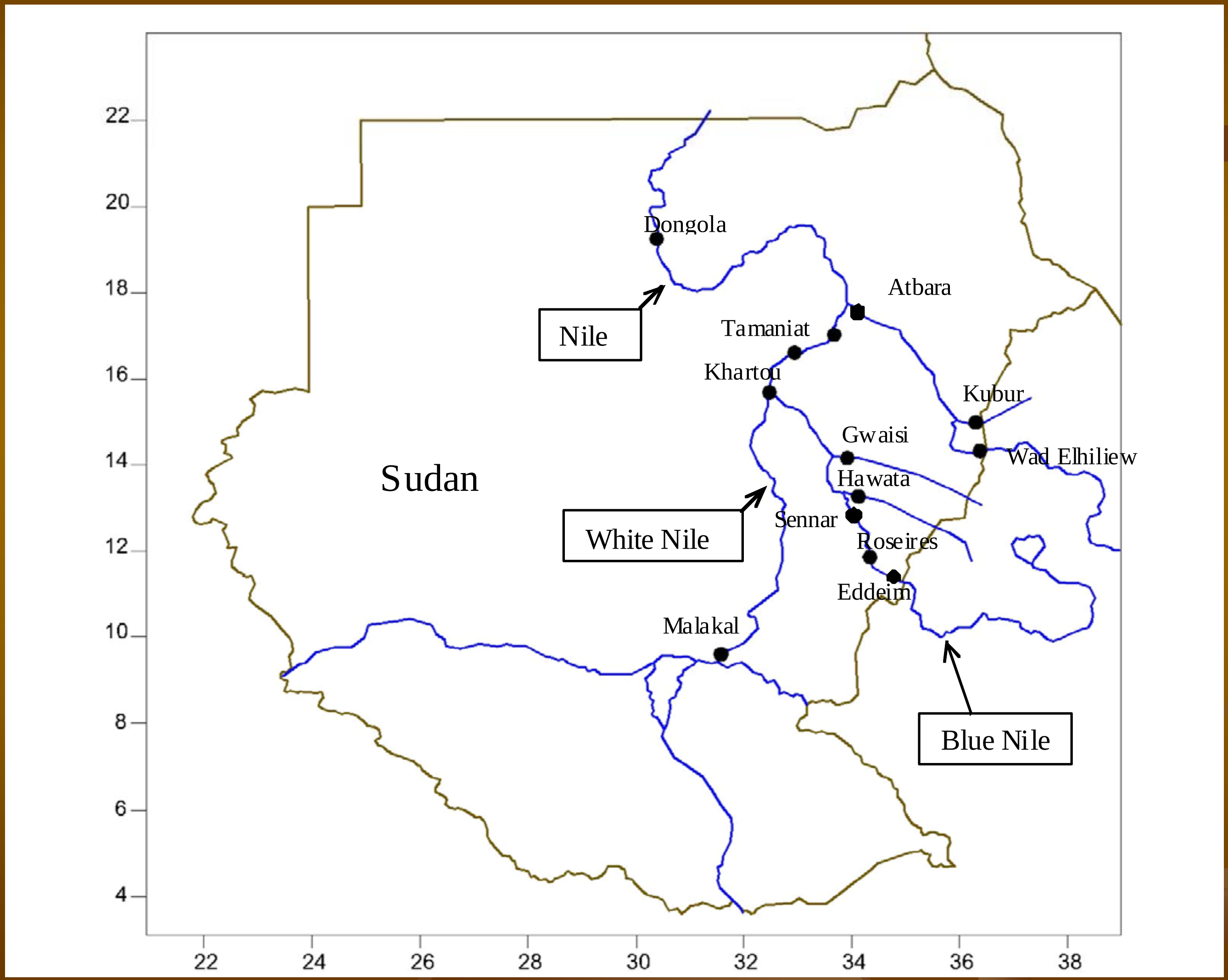
Available Data Used in the Analysis

- All data used provided by Ministry of Irrigation and Water Resources (MOIWR)
- Data available in daily format
- Annual maximum daily flow extracted from raw data

Period of record and maximum streamflow data at the six selected sites

Station Name	Period of Record	Maximum Flow (Cumecs)
Eddeim	1965-2007	11052.68 in (2006)
Roseires	1967-2007	9384.14 in (2001)
Sennar	1968-2007	9699.07 in (2006)
Khartoum	1965-2007	11057.97 in (1975)
Hawata	1972-2006	205.73 in (1981)
Gwaisi	1972-2006	1064.01 in (1975)

Flood Frequency Analysis



Locations of streamflow gages within the Nile Basin in Sudan

Flood Frequency Analysis

Daily peak streamflow data

Sample moments from the streamflow data at six gage stations

Station Name	**Sample Moments**			
	Sample Size, n	**Mean**	**Standard Deviation**	**Skewness**
Khartoum	43	7563.46	1795.90	-0.23
Sennar	40	6801.69	1431.58	-0.38
Roseires	40	6941.16	1645.08	-1.13
Eddeim	38	7658.10	1648.86	+0.36
Dinder	35	516.44	185.91	+0.42
Rahad	35	165.91	20.77	-1.43

Flood Frequency Analysis

- Results and Discussion

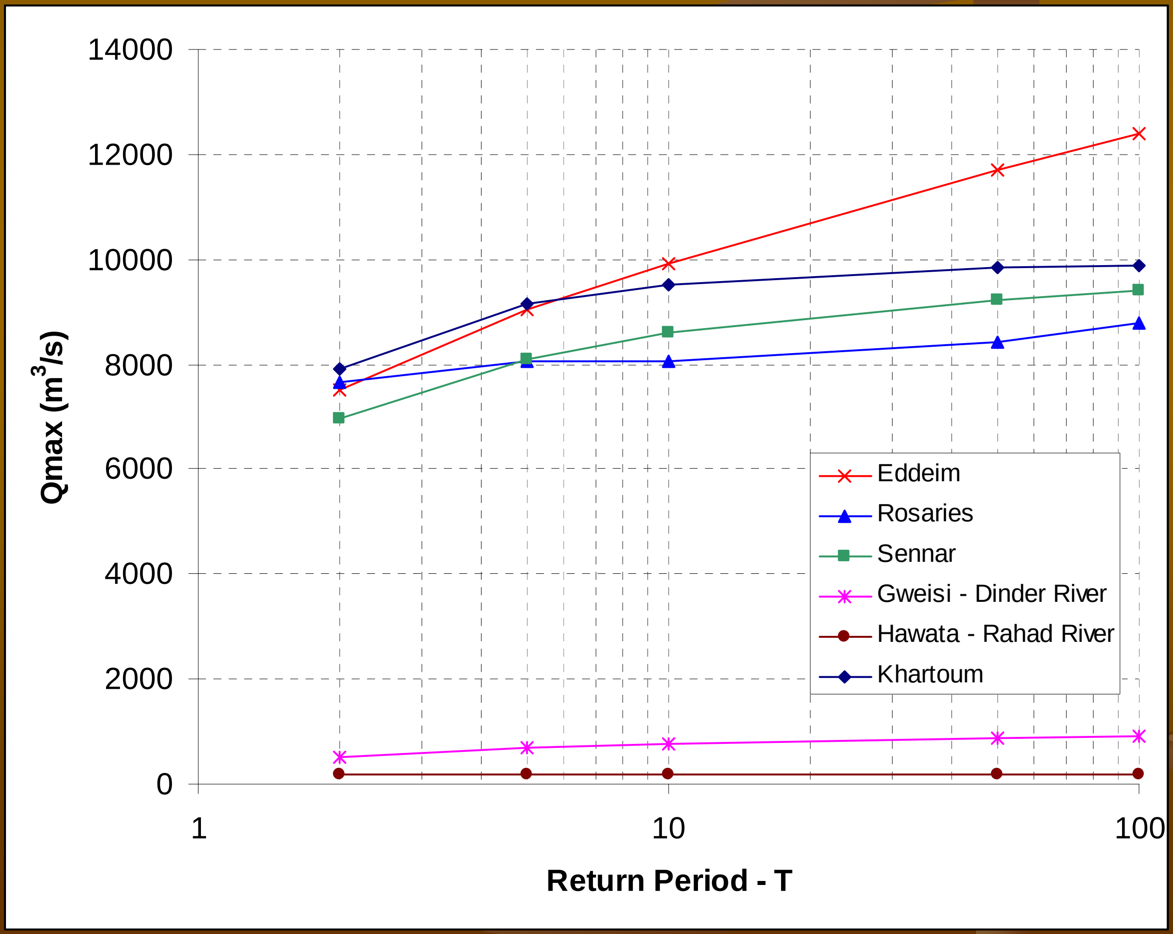
Peak discharges for different frequencies using Log-Person III and Extreme Value

STATION NAME	2-yr Peak (CMS)	5-yr Peak (CMS)	10-yr Peak (CMS)	50-yr Peak (CMS)	100-yr Peak (CMS)
Khartoum					
LP3	7930	9140	9517	9830	9865
EVI	7918	8865	9888	12139	13090
Sennar					
LP3	6950	8106	8594	9237	9400
EVI	6607	7853	8677	10493	11260
Roseires					
LP3	7674	8058	8065	8410	8796
EVI	6717	8149	9097	11182	12064
Eddeim					
LP3	7510	9033	9932	11700	12386
EVI	7434	8880	9838	11947	12838
Dinder/Gwaisi					
LP3	517	685	766	885	919
EVI	491	657	766	1007	1109
Rahad/Hawata					
LP3	174	181	182	182	183
EVI	163	182	194	221	232

Flood Frequency Analysis

- Results and Discussion

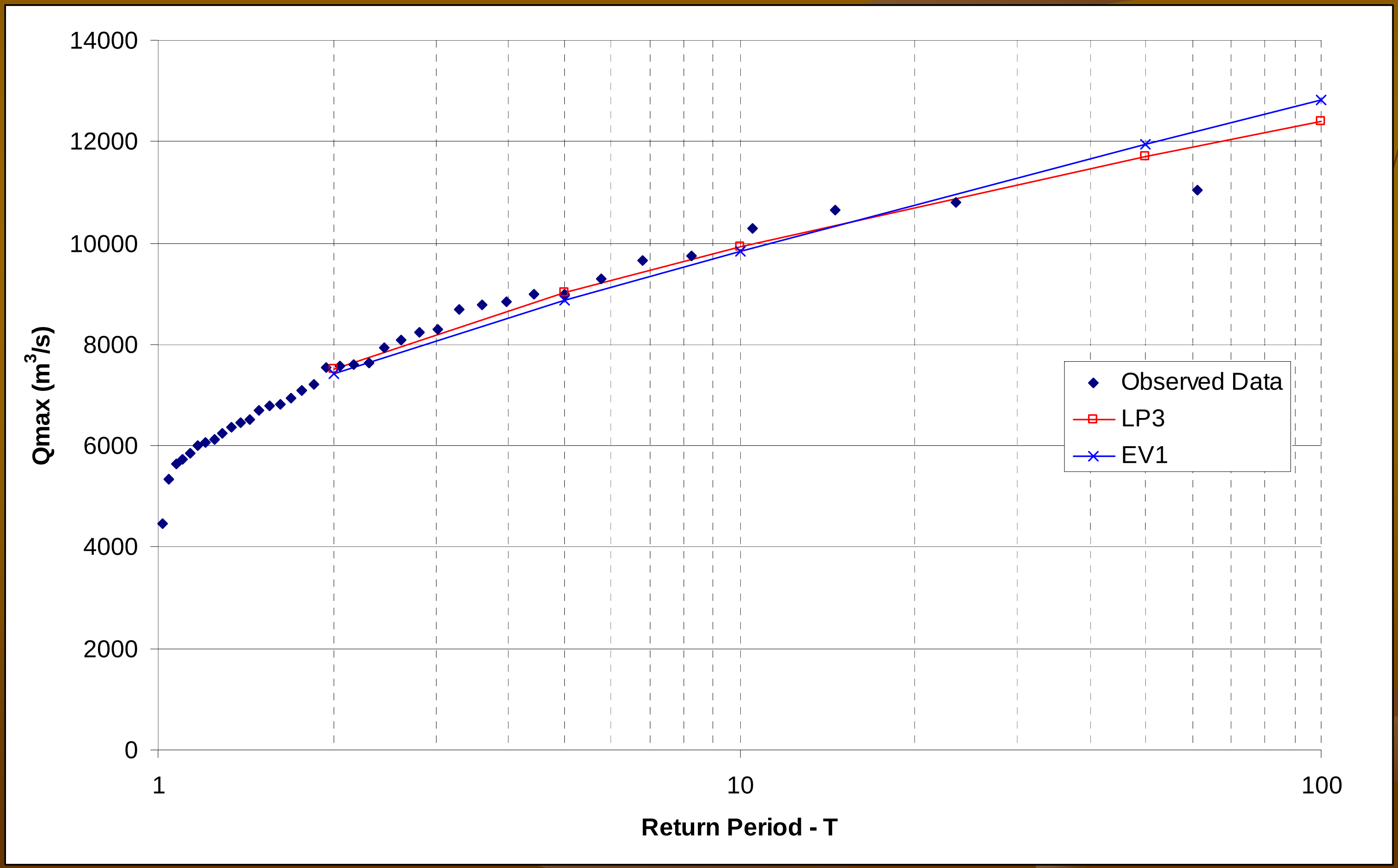
Q-T relationships based on LP3 distribution



Flood Frequency Analysis

- Results and Discussion

Comparison of observed data and LP3 and EV1 probability distributions at Eddeim station

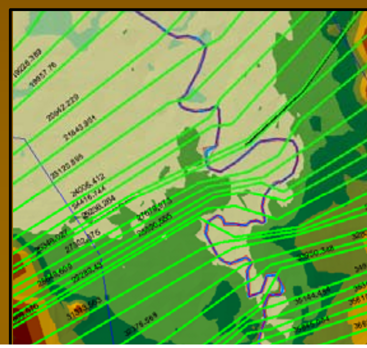


Hydraulic Modeling

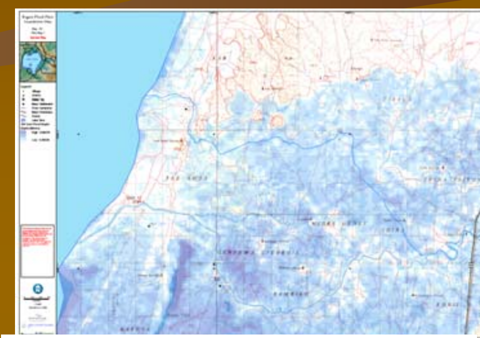
- Hydrologic Engineering Center River Analysis System (HEC-RAS)
  - 1-D Steady Flow Analysis
  - Provides channel width and flood plain elevations
  - Predicts inundation extent and water surface elevations
  - Gives depths for determining flood hazard areas for floods up to and including 100-yr return period
- HEC-GeoRAS
  - Digitizes channel geometry from terrain model and imports into HEC-RAS
  - Coupled with RAS for an iterative process during calibration using the flood inundation mapping

Hydraulic Modeling
HEC-RAS and HEC-GeoRAS Overview

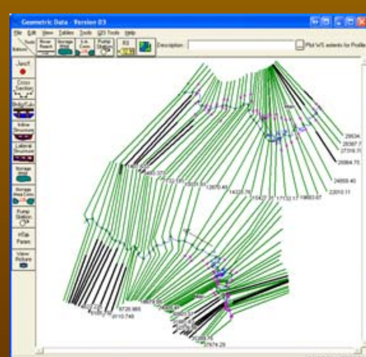
Model Development



HEC-GeoRAS Pre-processor

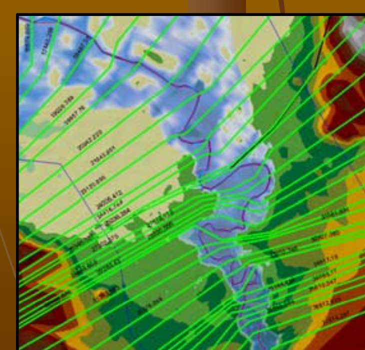


Flood Inundation Map



HEC-RAS

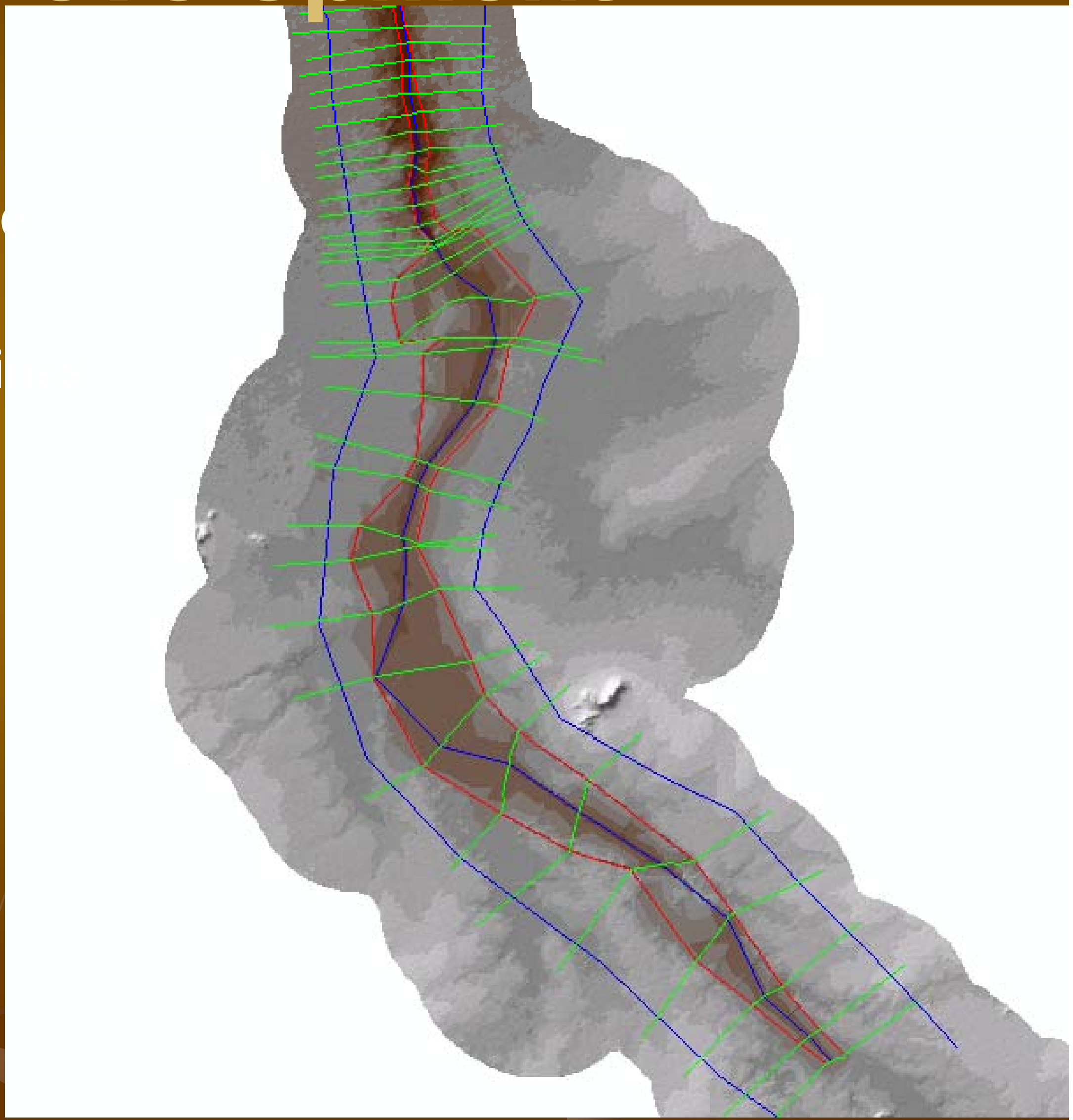
Calibration



HEC-GeoRAS Post-processor

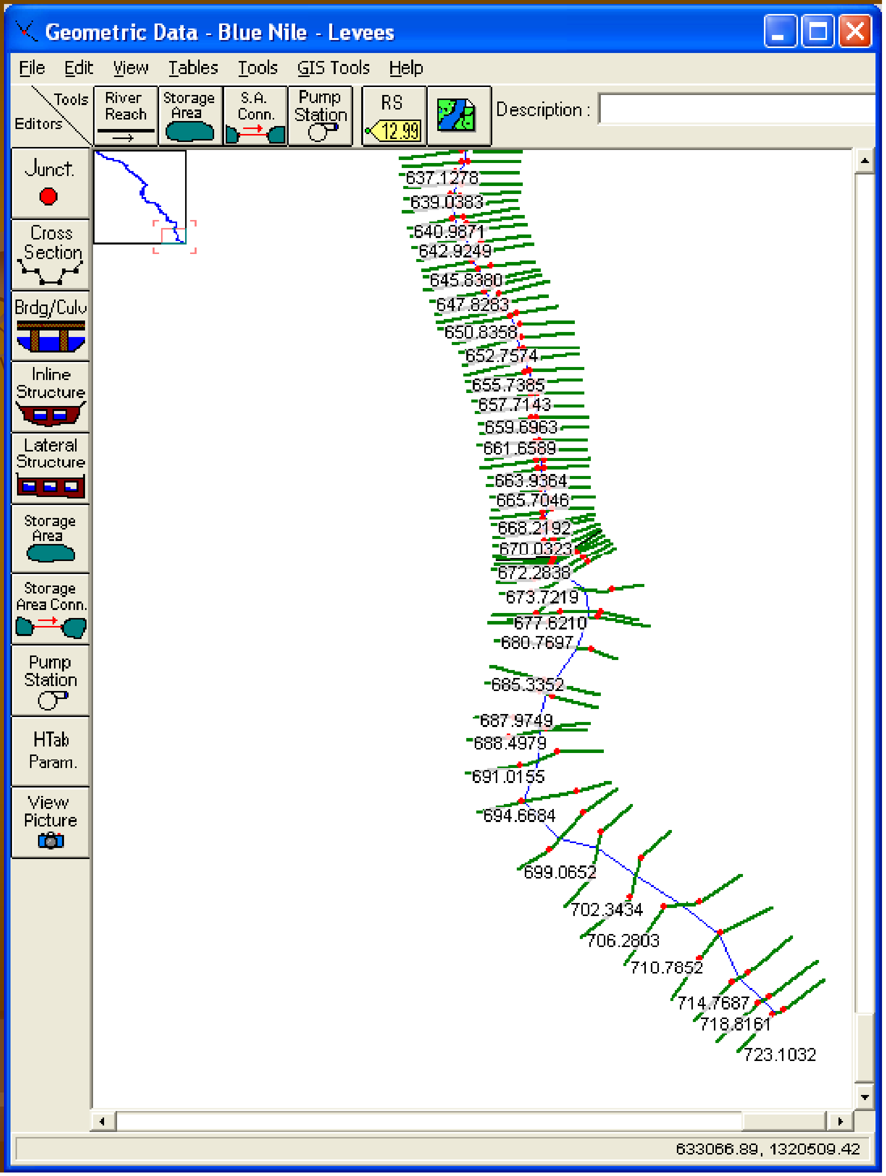
Hydraulic Modeling Model Development

- Geometric Data
  - River Center Lin
  - Bank Lines
  - Overbank flow li
  - Cross sections
  - Topography



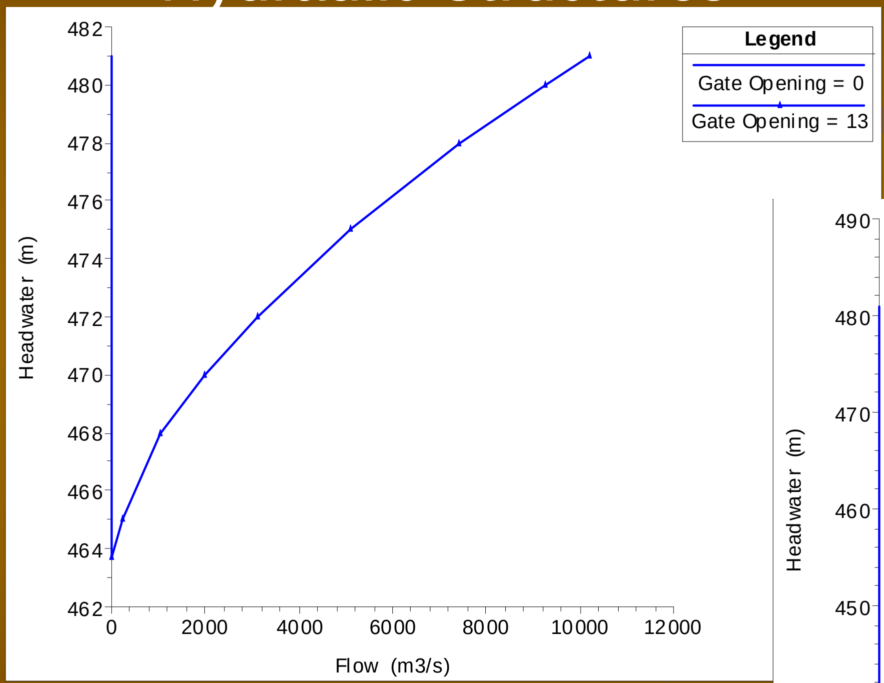
Hydraulic Modeling
Model Development

- Geometric Data
  - Extracted from GIS
  - Imported into hydraulic model environment

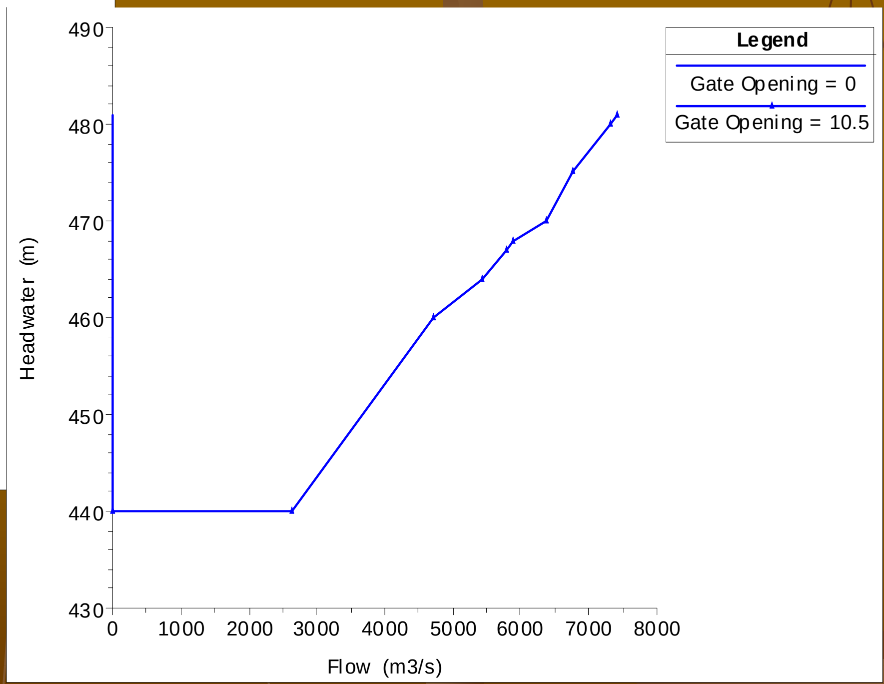


Hydraulic Modeling Model Development

- Hydraulic Structures



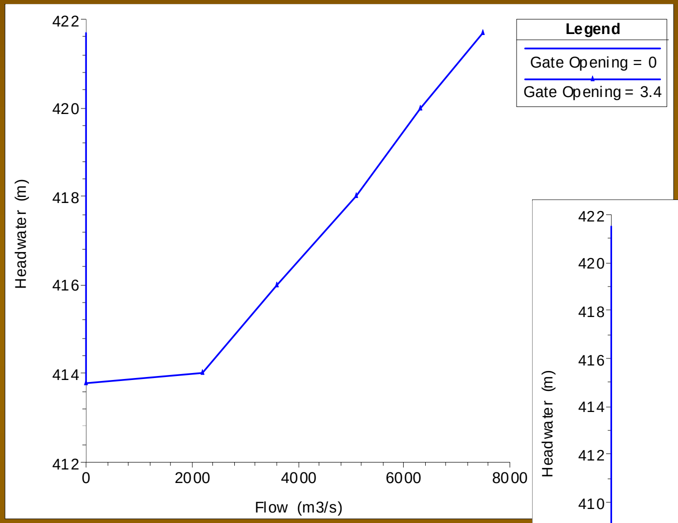
Roseires Dam Spillway Rating Curve



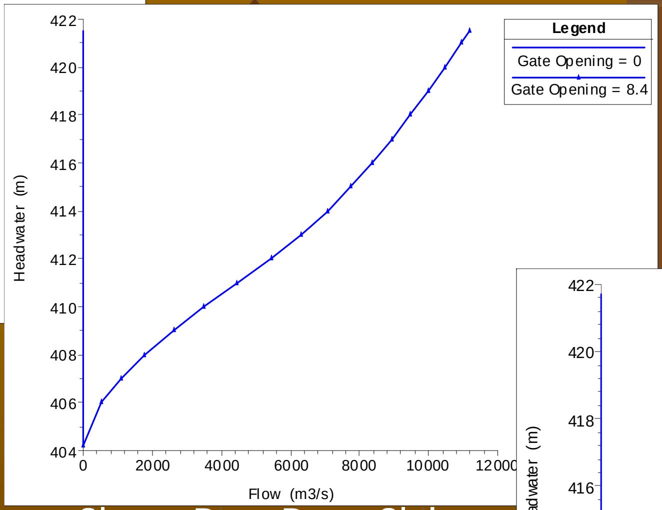
Roseires Dam Deep Sluices Rating Curve

Hydraulic Modeling
Model Development

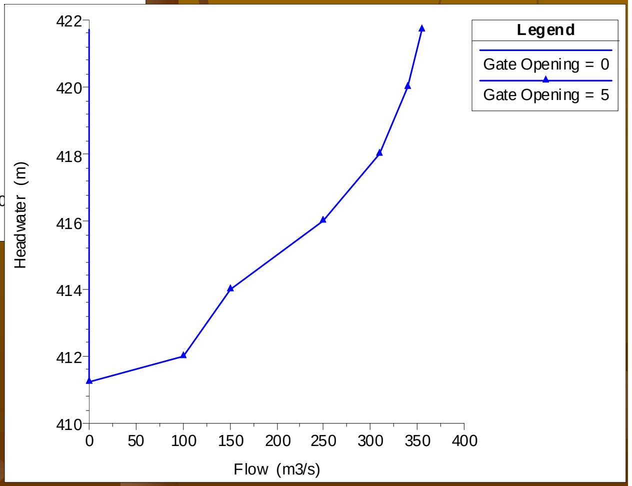
- Hydraulic Structures



Sinnar Dam Spillway Rating Curve



Sinnar Dam Deep Sluices Rating Curve



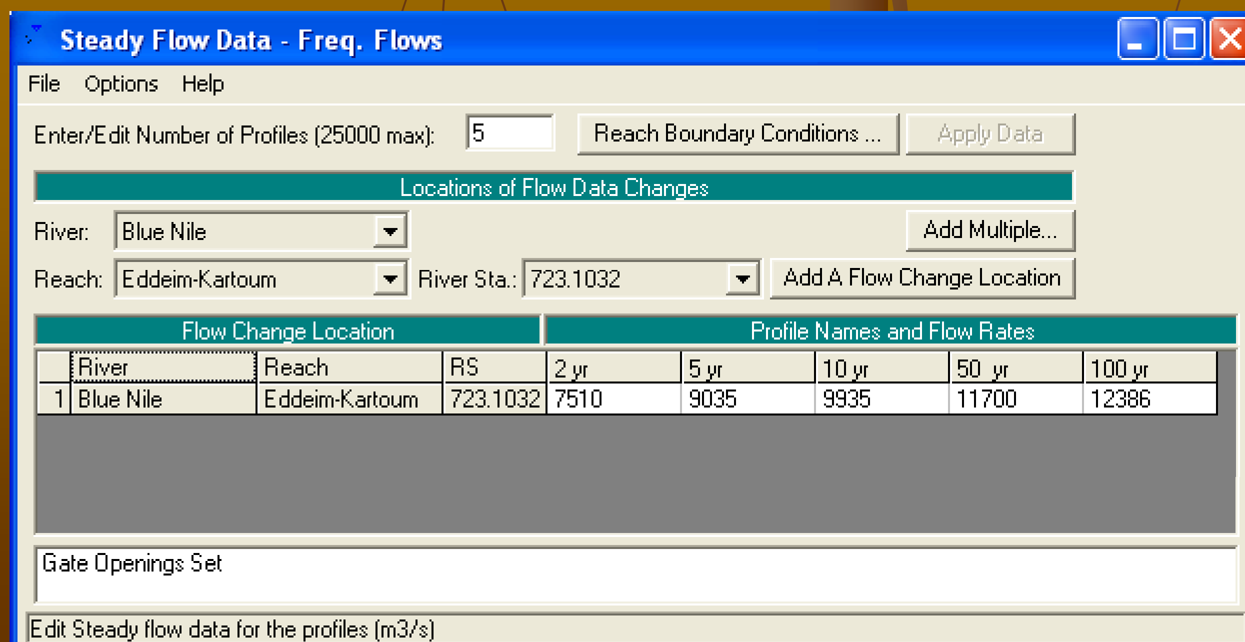
Gezira and Managil Gate Rating Curve

Hydraulic Modeling
Model Development

- Roughness Characteristics of the River
  - Represent resistance to flow
  - Impact is proportional to velocity squared
  - Higher values represent more resistance, increased water surfaces
- Selected Manning's "n" values
  - Main Channel – generally taken as 0.03
  - Roseires Dam – 0.04
  - Sinnar Dam – 0.04

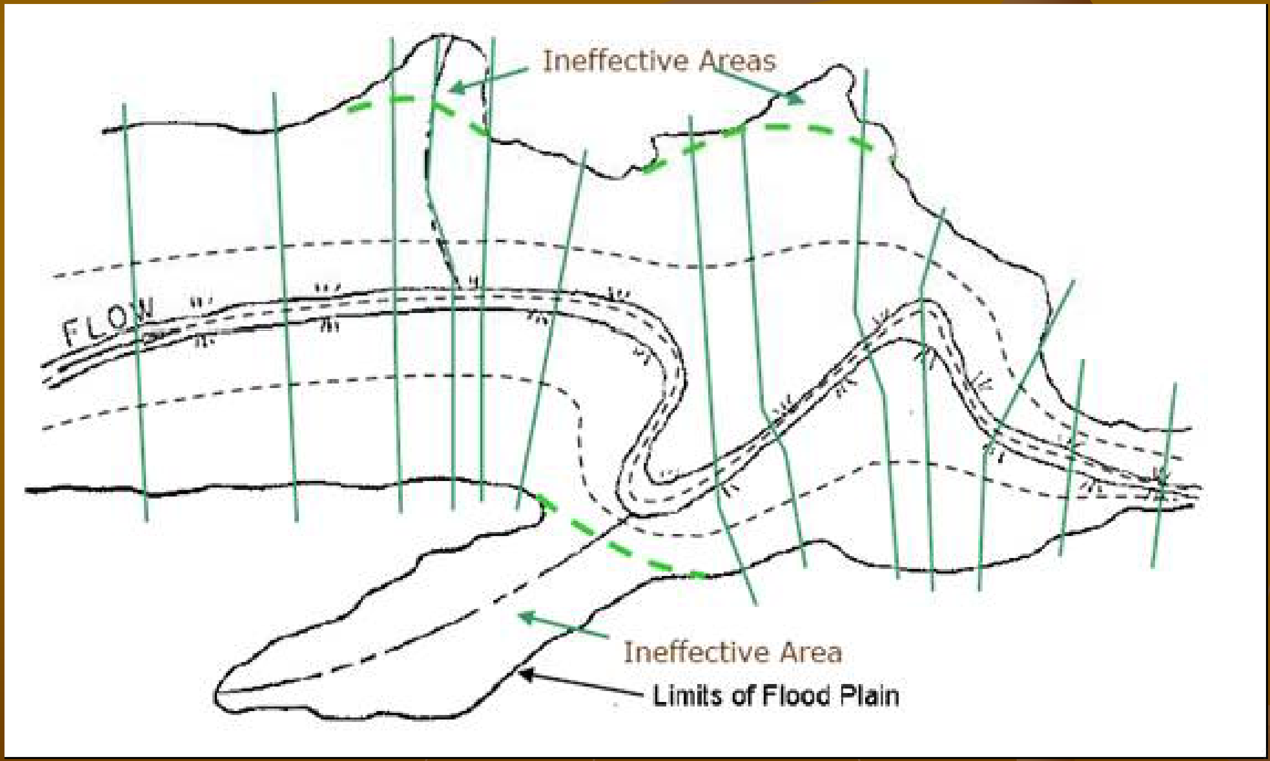
Hydraulic Modeling Model Development

- Boundary Conditions
  - Peak flow data for 2, 5, 10, 50, and 100 year discharges were used for the steady flow analysis
  - Downstream boundary condition
    - Khartoum station rating curve given as discrete values of elevation and corresponding discharge

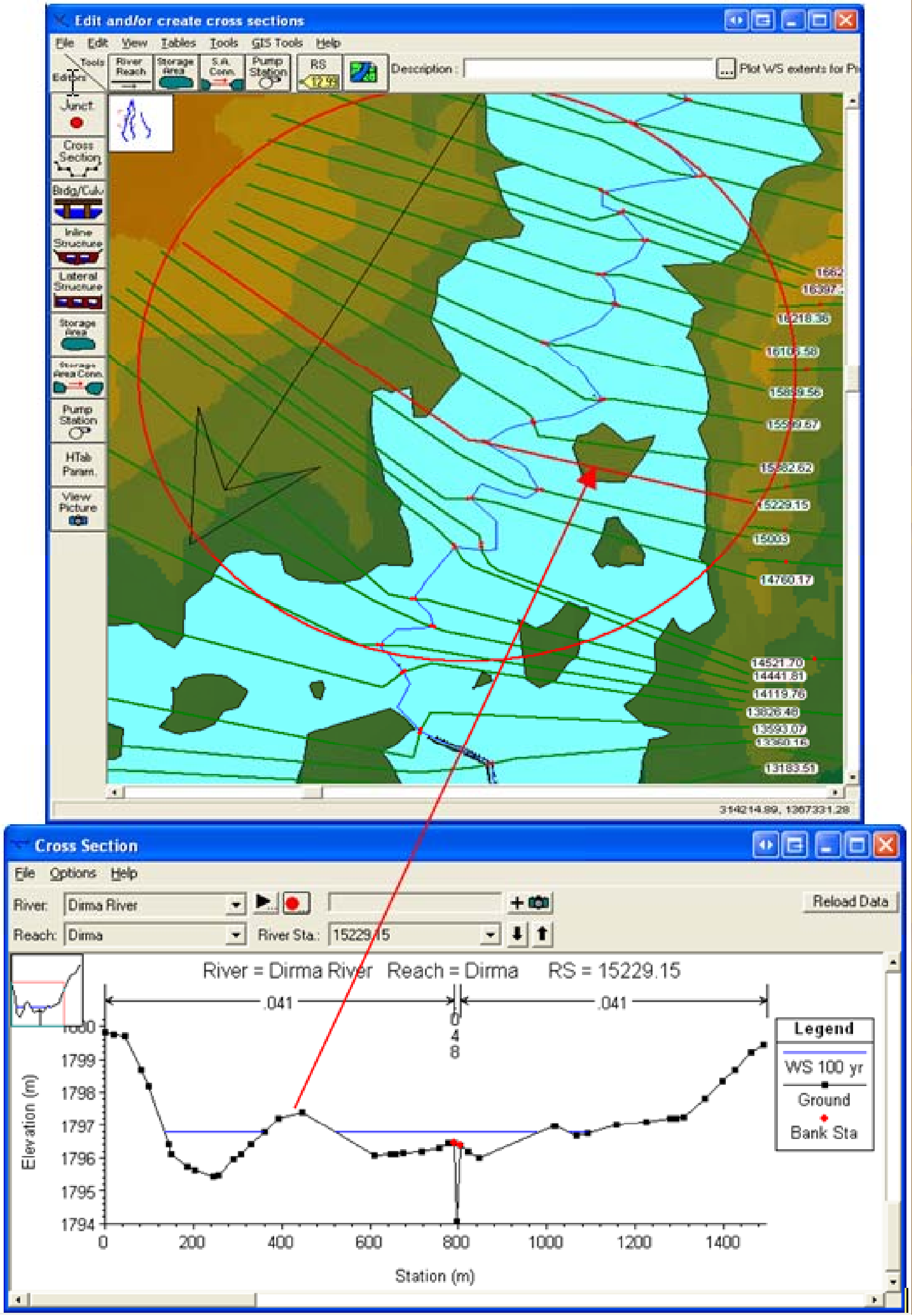


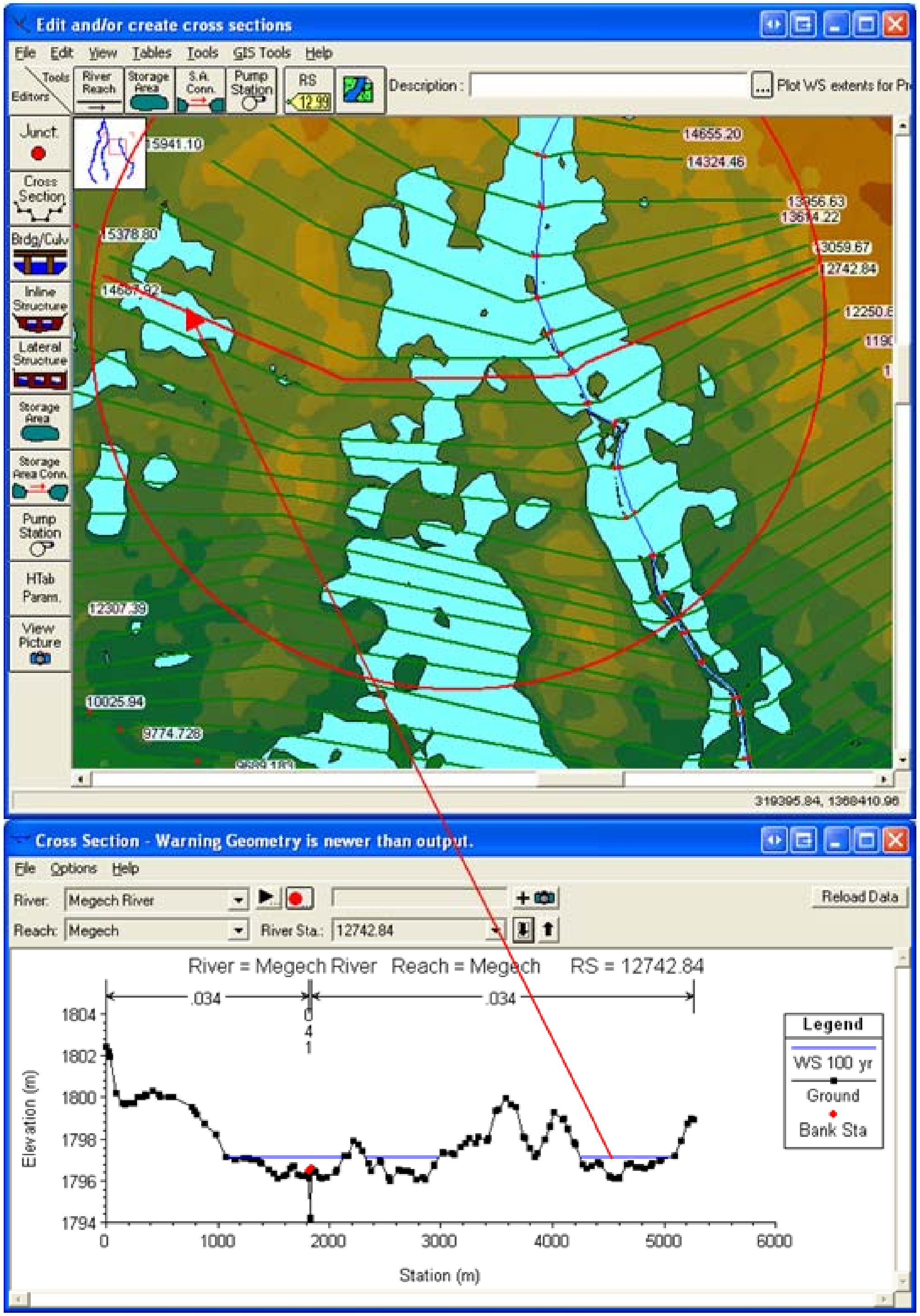
Hydraulic Modeling Model Development

- Ineffective Flow Areas



Example of ineffective flow areas in a floodplain (HEC-RAS Reference Manual)


Edit and/or create cross sections
File Edit View Tables Tools GIS Tools Help
Description :
Plot WS extents for Pr
Junct.
Cross Section
Brdg/Culv
Inline Structure
Lateral Structure
Storage Area
Storage Area Conn.
Pump Station
HTab Param.
View Picture
16218.36
15229.15
15003
14760.17
14521.70
14441.81
14119.76
13826.48
13593.07
13183.51
314214.89, 1367331.28
Cross Section
File Options Help
River: Dirma River
Reach: Dirma
River Sta.: 15229.15
Reload Data
River = Dirma River Reach = Dirma RS = 15229.15
.041
.041
Legend
WS 100 yr
Ground
Bank Sta
Elevation (m)
Station (m)


Edit and/or create cross sections
File Edit View Tables Tools GIS Tools Help
Tools
Editors
River Reach
Storage Area
S.A. Conn.
Pump Station
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Description :
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Junct.
Cross Section
Brdg/Culv
Inline Structure
Lateral Structure
Storage Area
Storage Area Conn.
Pump Station
HTab Param.
View Picture
15941.10
15378.80
14667.92
14655.20
14324.46
13956.63
13614.22
13059.67
12742.84
12307.39
10025.94
9774.728
319395.84, 1368410.96
Cross Section - Warning Geometry is newer than output.
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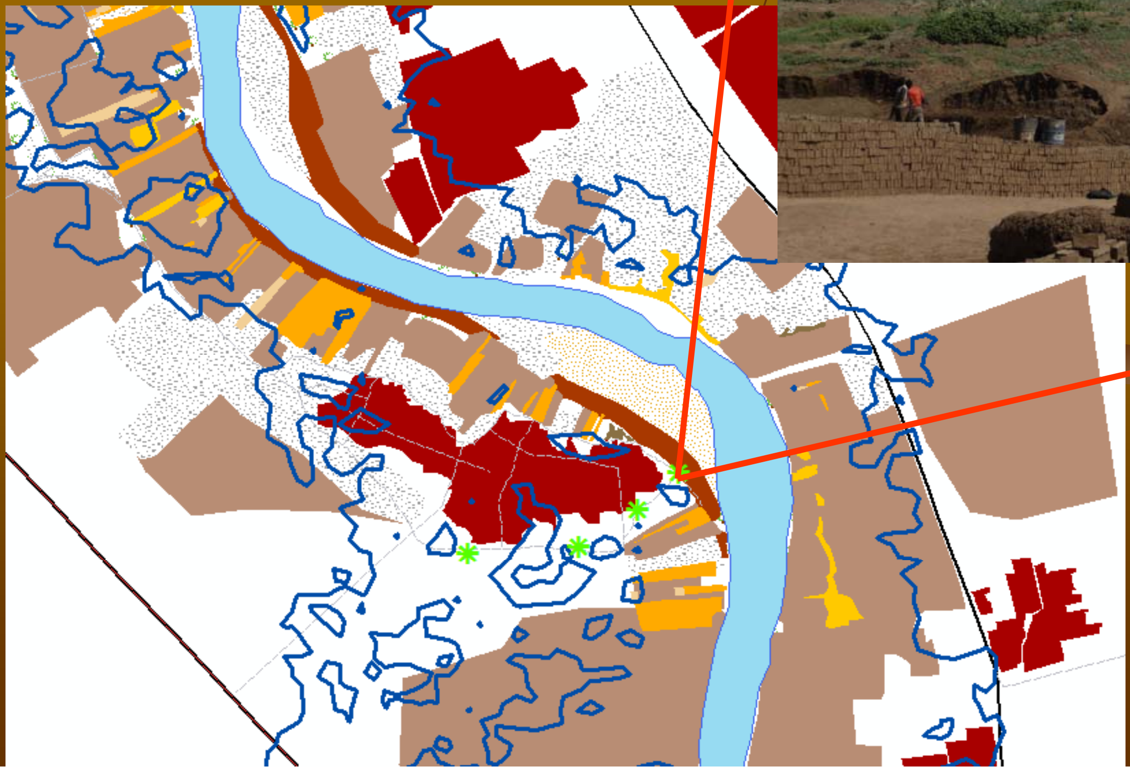
Reach: Megech
River Sta.: 12742.84
Reload Data
River = Megech River Reach = Megech RS = 12742.84
.034
.034
Elevation (m)
Station (m)
Legend
WS 100 yr
Ground
Bank Sta

Hydraulic Modeling
Model Verification

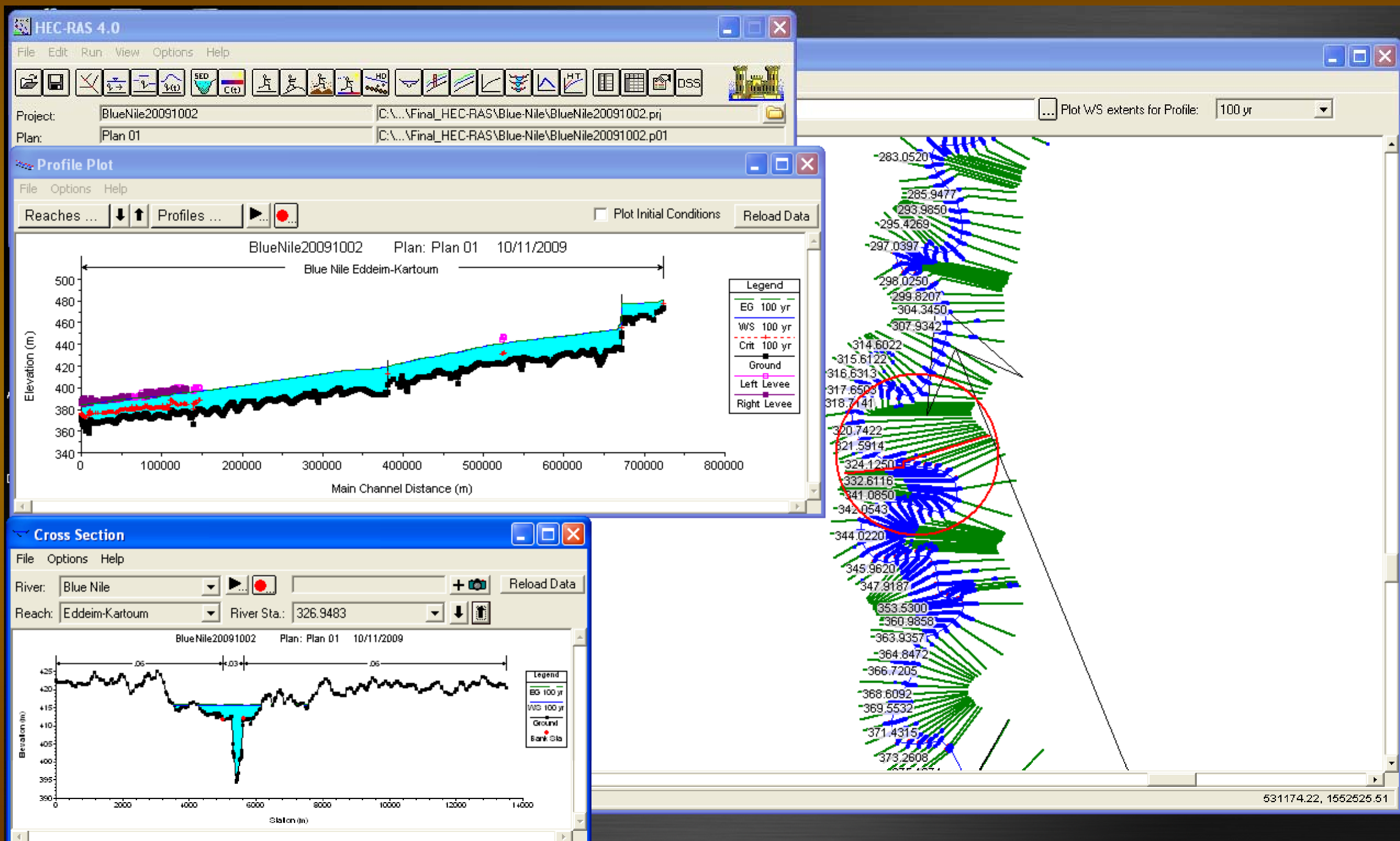
- An analysis of the impact of variation in “n” value
- Field verification based on discussion with farmers and villagers

Hydraulic Modeling Model Verification

- Field verification
- Several sites inspected, located with GPS, and discussed with locals

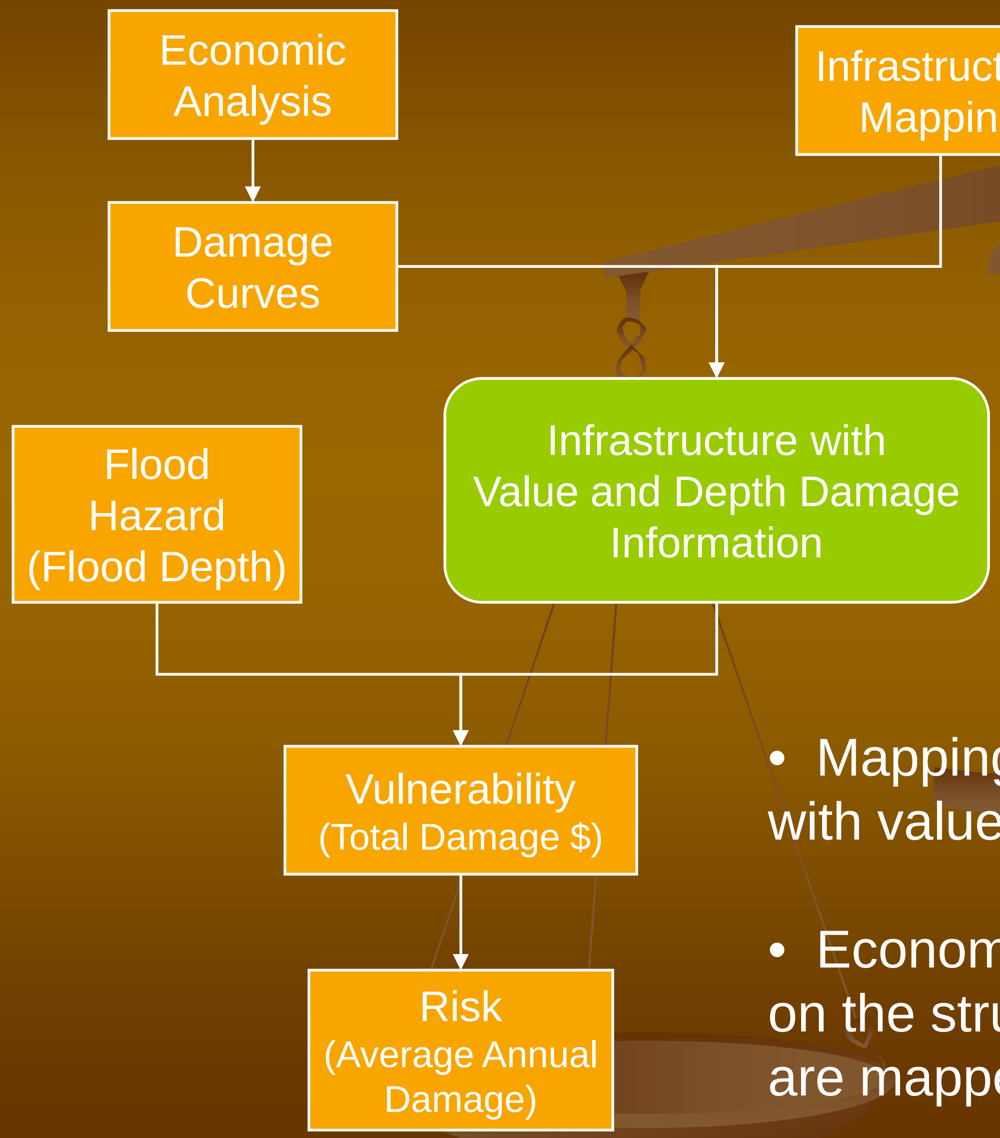


Hydraulic Model Demonstration



Flood Risk Mapping

Flood Risk Assessment



- Mapping focuses on areas with value
- Economic Analysis focuses on the structure types that are mapped

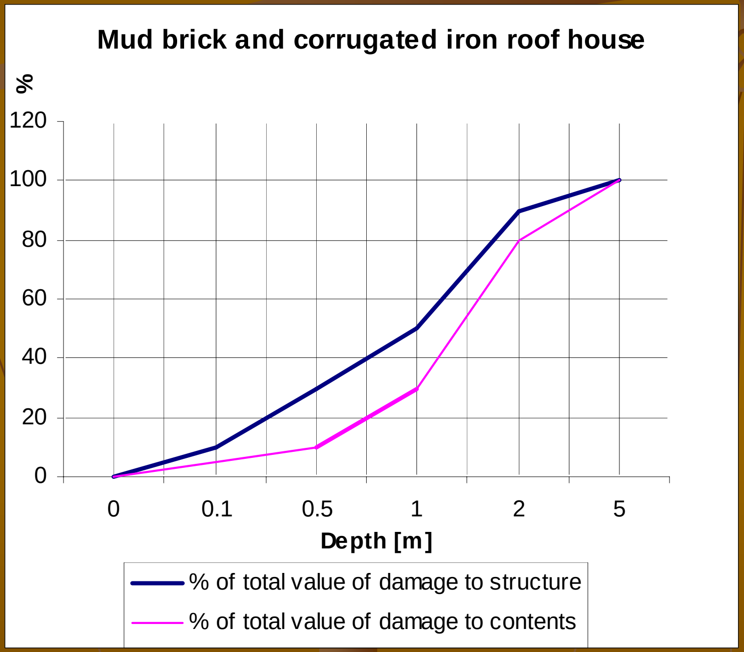
Flood Risk Assessment Economic Analysis

Value assessment categories

- **Structures** – estimate value of structure contents per structure or per unit area of neighborhood of the same class
- **Transportation infrastructure** – estimate replacement cost per unit length
- **Agriculture** – estimate value of lost production per unit area for each class
- Estimate damages due to flooding to various water depths using a depth versus percent damage function for various classes

Economic Analysis
Depth Damage Curves

Depth [m]	% of total value of damage to structure	% of total value of damage to contents
0.0	0	0
0.1	5	5
0.5	10	10
1.0	30	30
2.0	50	80
5.0	100	100



Economic Analysis
Mapping Considerations

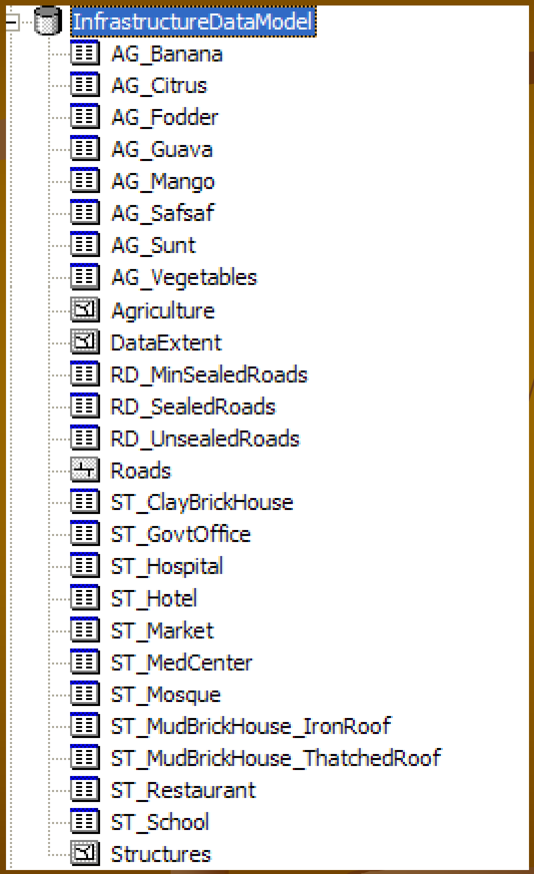
- Value assessment for entire length of reach
- Data availability
- Combine infrastructure mapping with economic analysis
- How to collect data efficiently with enough information to identify the value?
- Combination of GIS mapping, Remote Sensing, and local knowledge

Convert Mapping into Data Model

- Structure Mapping not possible to capture each building
- Mapped parcels or blocks with consistent structural properties
  - Residential
  - Commercial
  - Service
  - Industrial Area
  - Public Utility
- *Show Structure Frequency Table*

Risk Assessment Infrastructure Data Model

- ArcGIS Data Model store value information
- Value stored for each feature (Road, Parcel, Structure)
- Value calculated by type
- Depth Damage curve separate tables
- *Show Data Model in ArcCatalog*

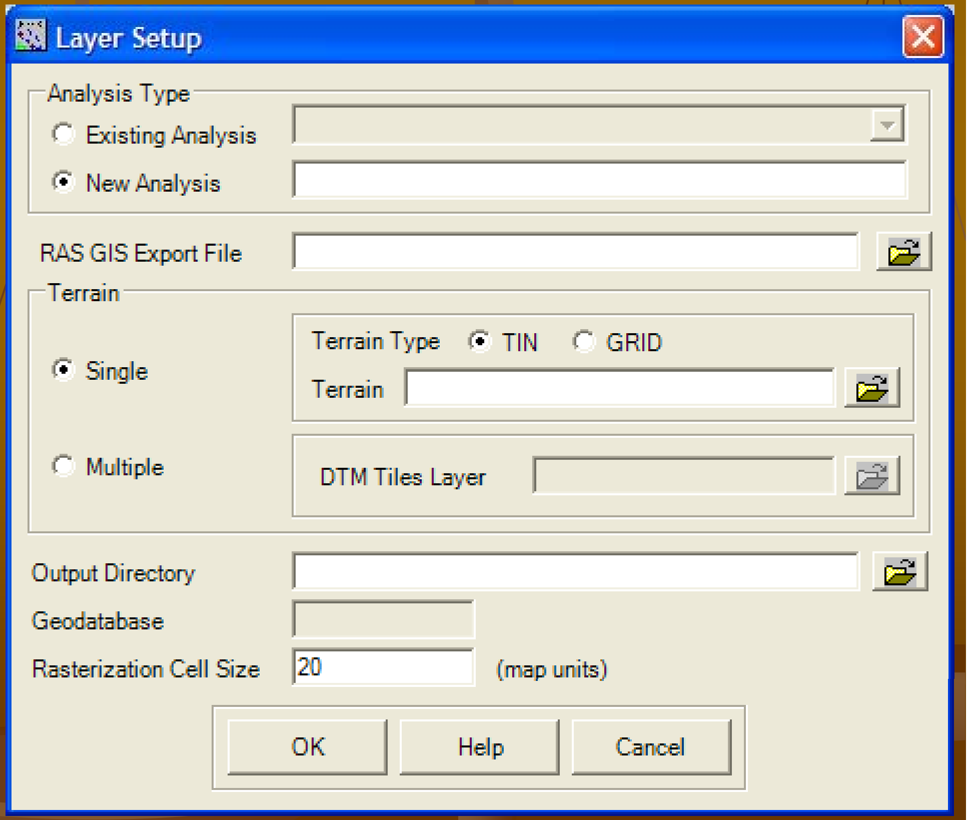


Calculating Structure Value

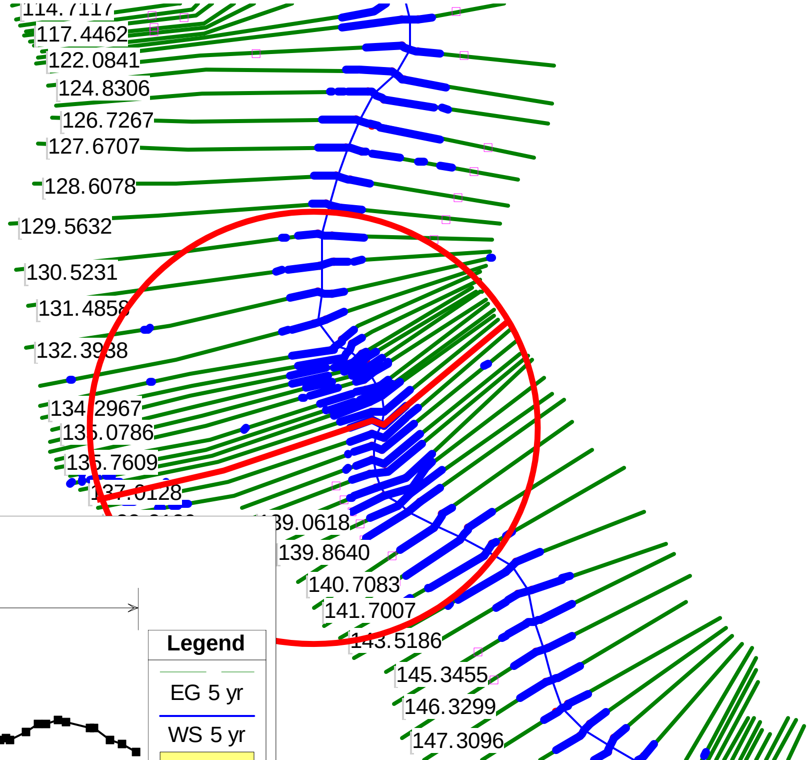
- Value and Prorated Value
  - Value1 and 2 is per unit value (16 M^2)
  - Prorated Value = Area/16M^2 * Value
- Building Density
  - Prorated Value = Area***BldgDensity***/16M^2 * Value

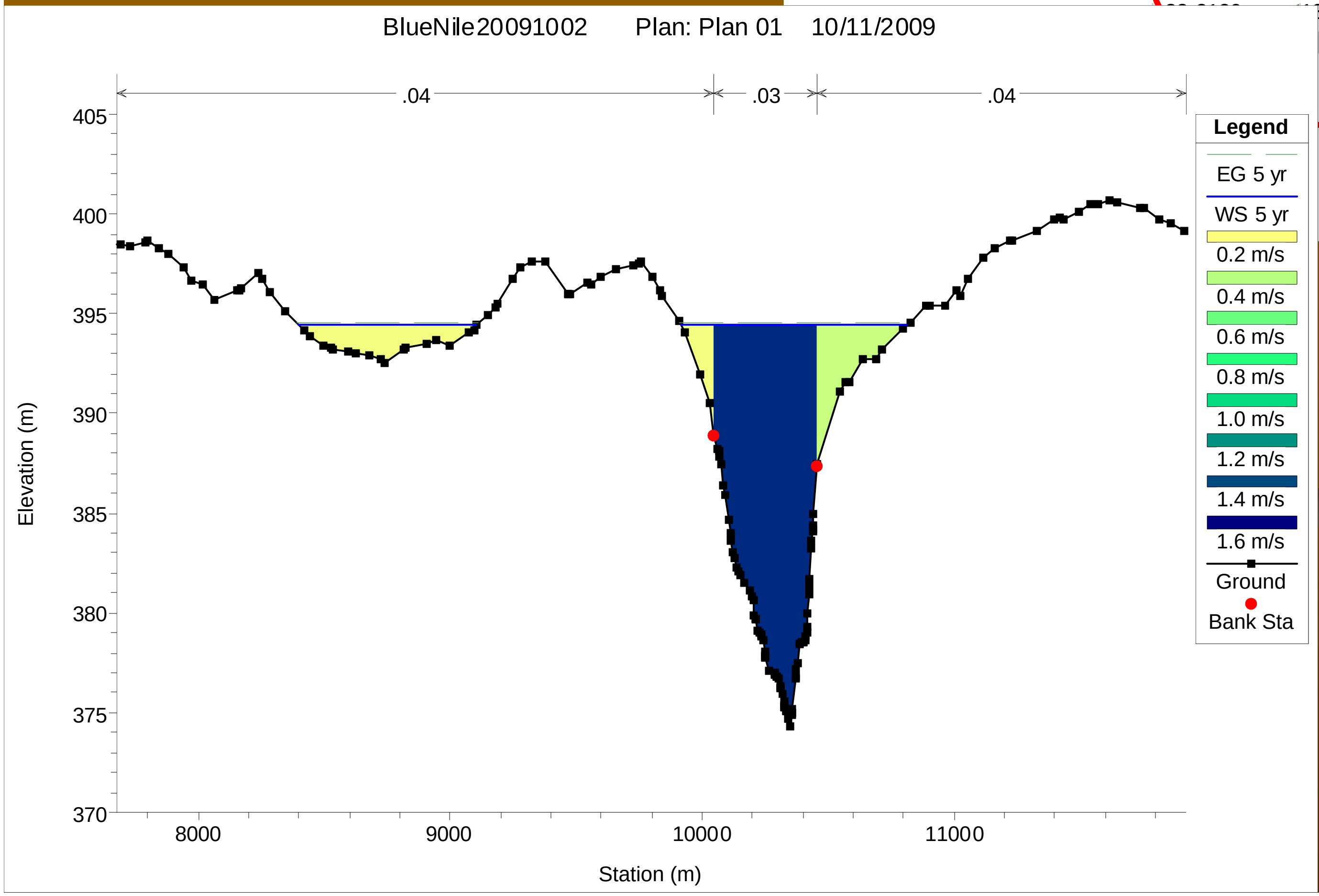
Flood Hazard Mapping (Flood Depth)

- HEC-RAS and HEC-GeoRAS produce simulated water surfaces to GIS to produce inundation maps
- HEC-GeoRAS maps inundation & Depth
- Iterative
- Flood hazard
  - Inundation area
  - **Depth** of inundation
  - Velocity



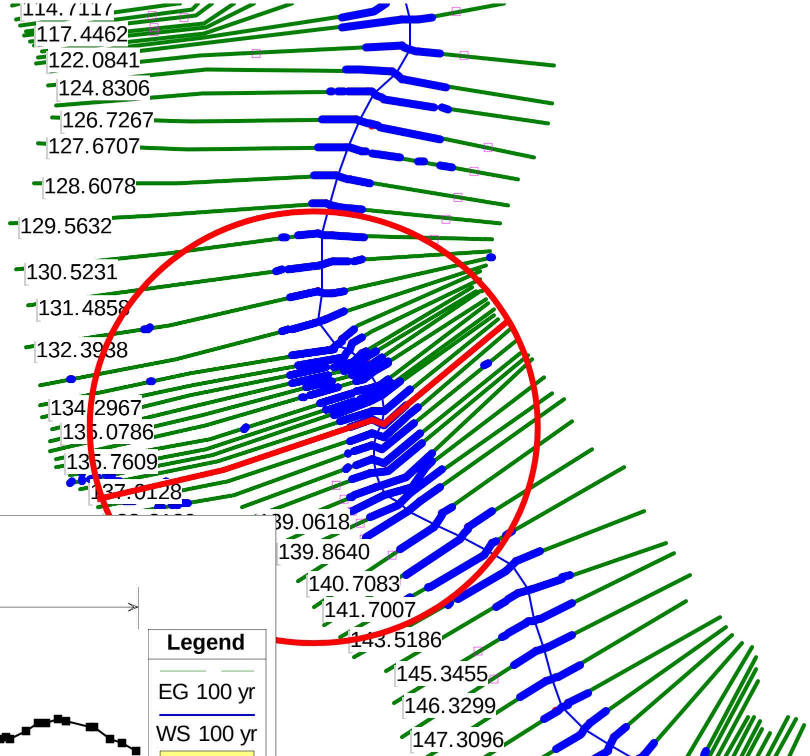
Velocity and depth mapping

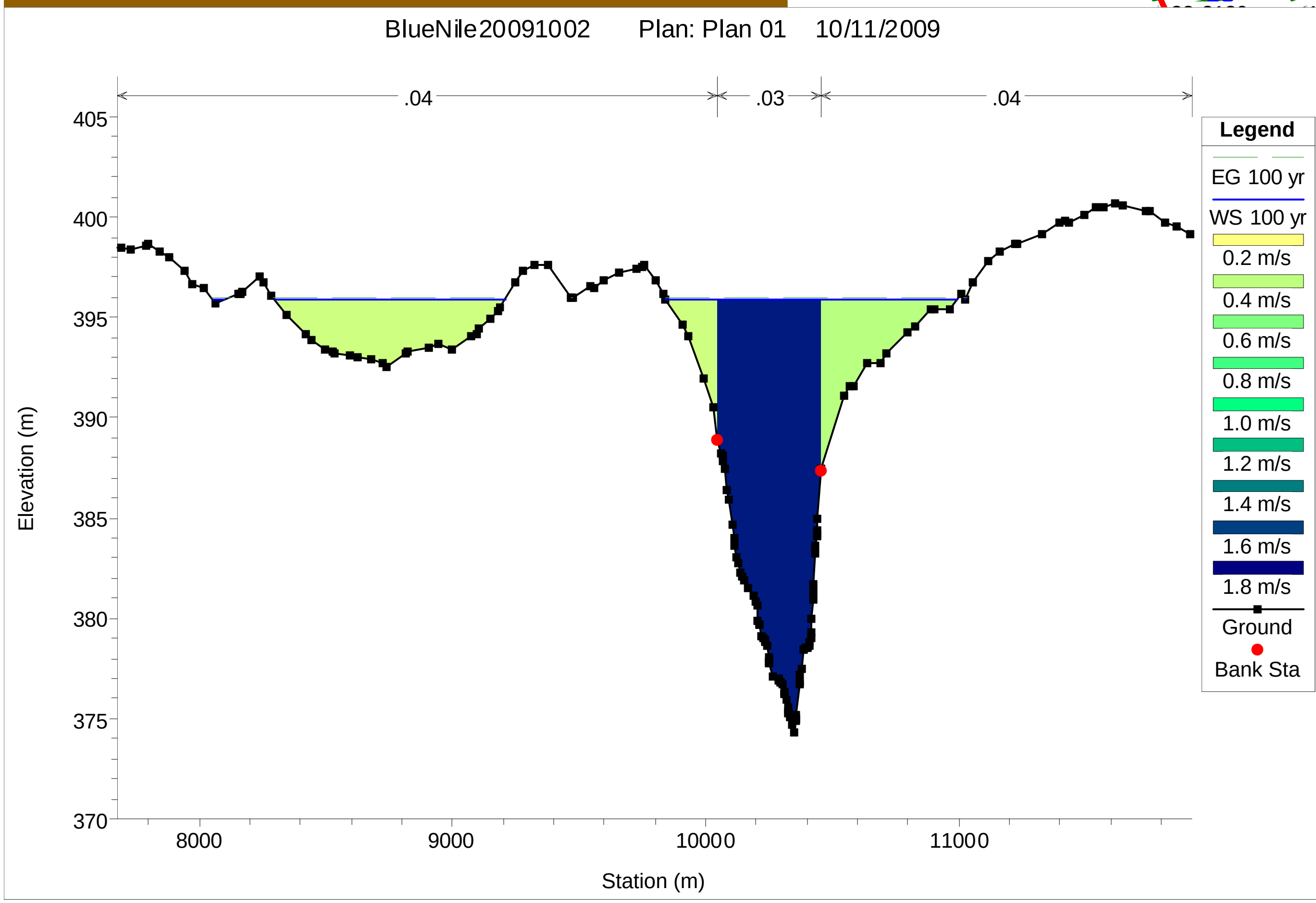


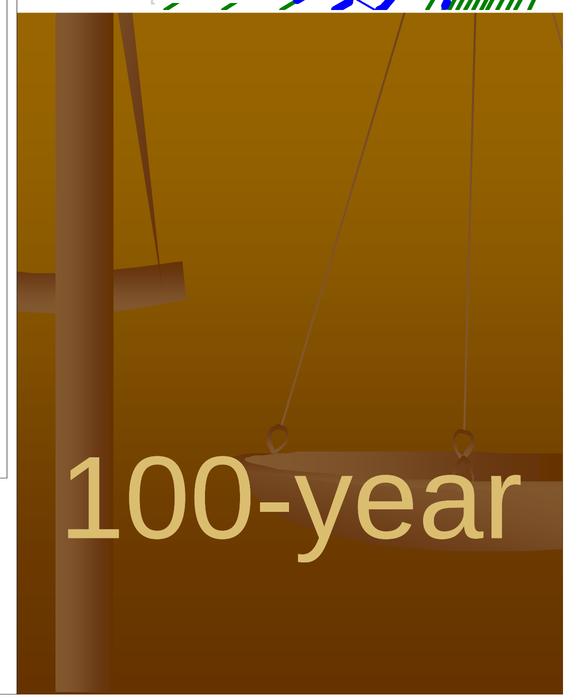


5-year

Velocity and Depth Mapping





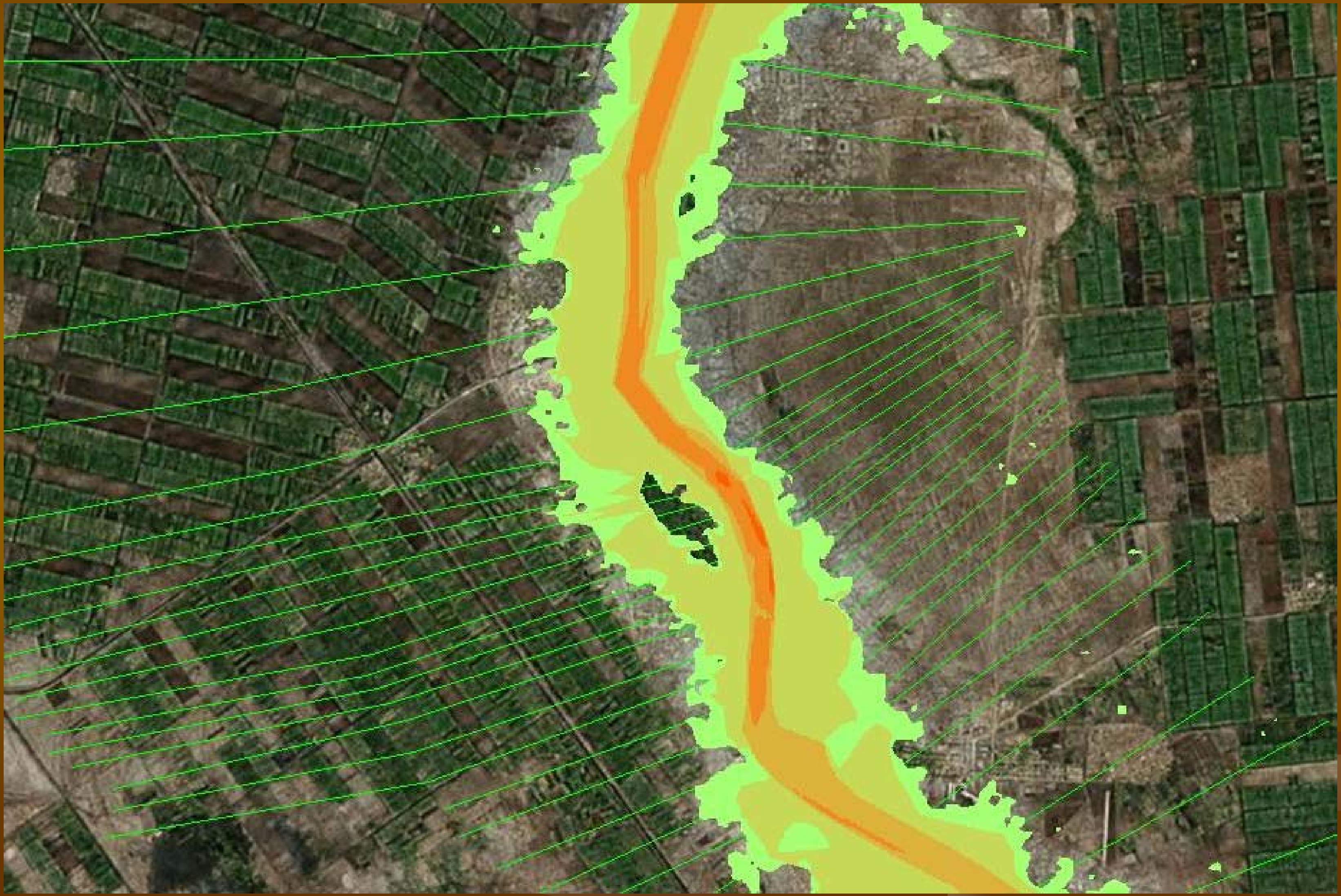


Flood Depth Mapping

- Overview

Development of inundation extent (red outline) and depth (blue gradient)

Flow Velocity Mapping



Development of velocity grid

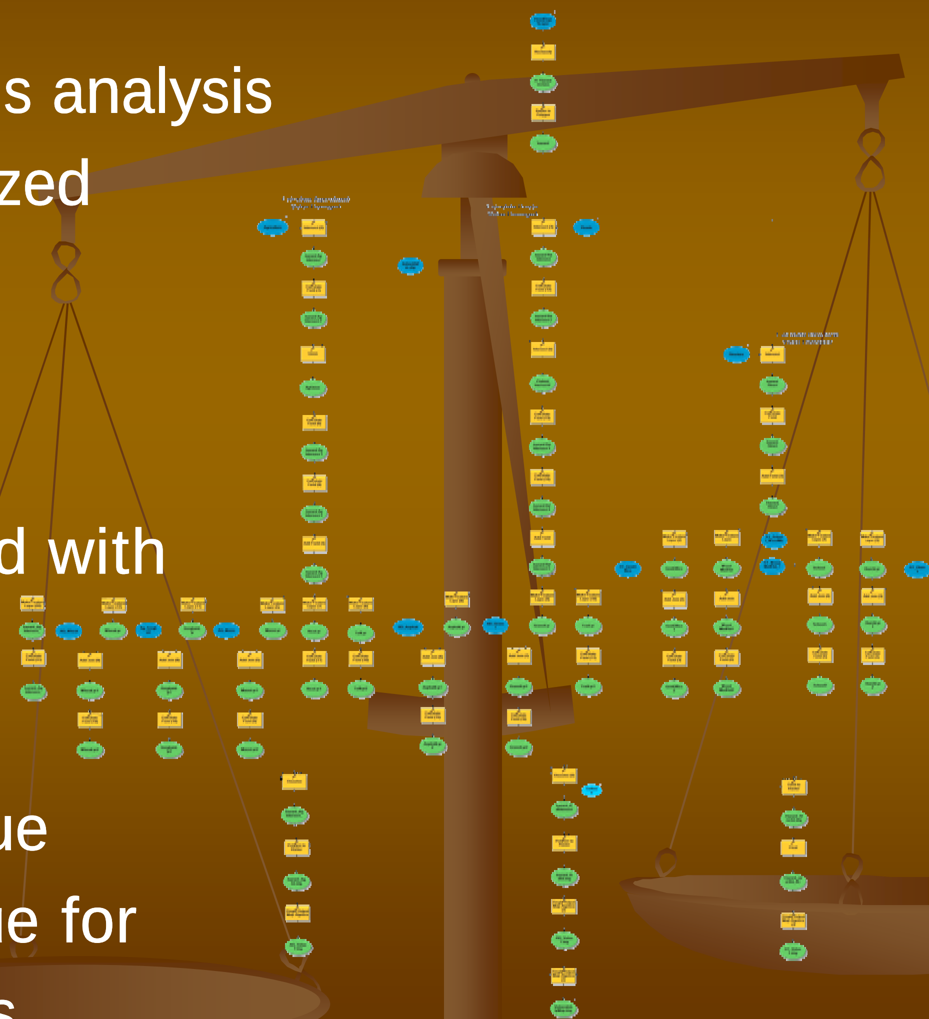
Flood Hazard (Depth)

Flood Velocity

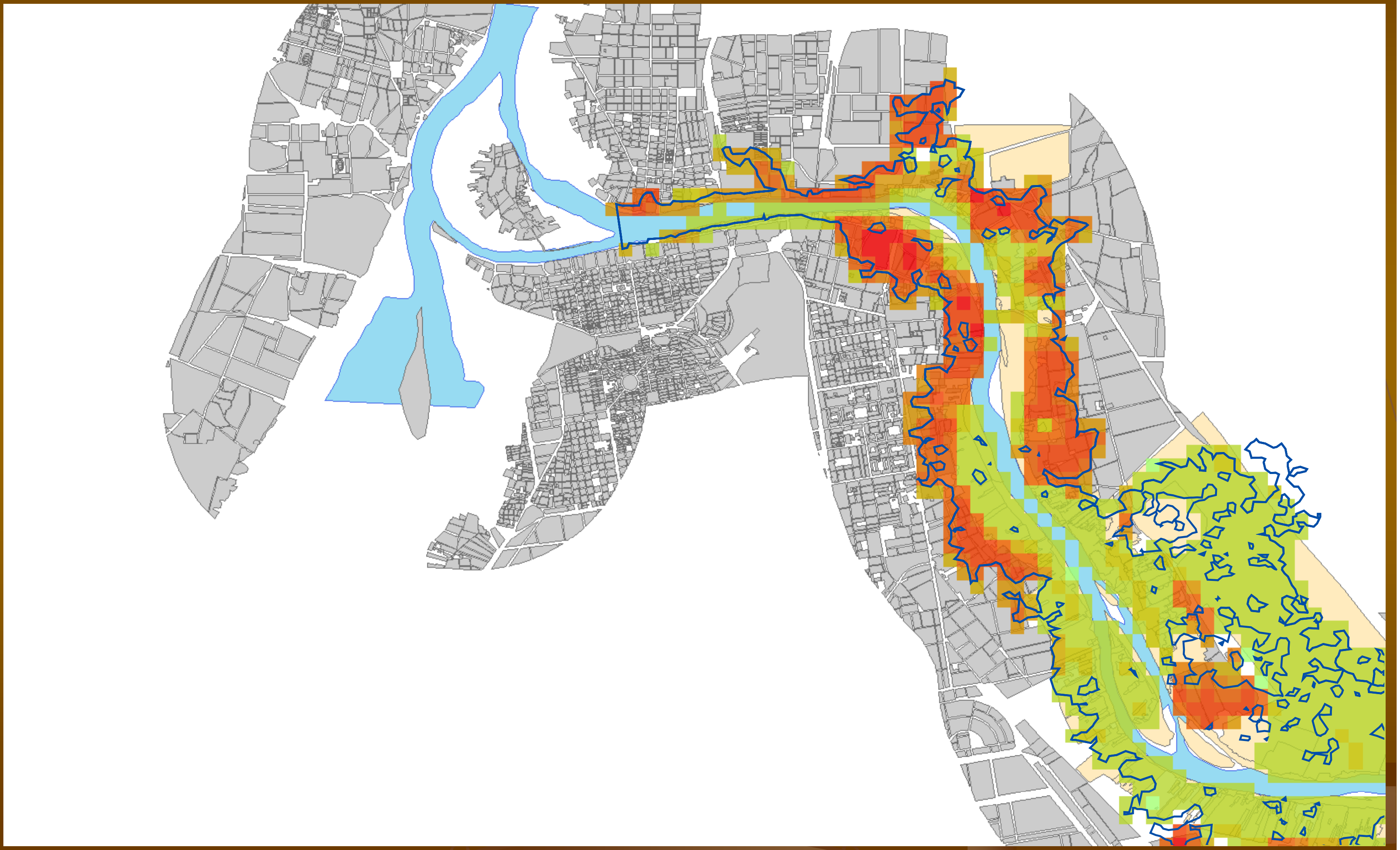
Flood Risk Assessment
Vulnerability Assessment

- ArcGIS Model performs analysis
- Repeatable, standardized

- Create grid to summarize value
- Intersects flood hazard with infrastructure data
- Calculate new area
- Calculate damage value
- Combine damage value for All infrastructure types



Flood Risk Assessment
Vulnerability Assessment

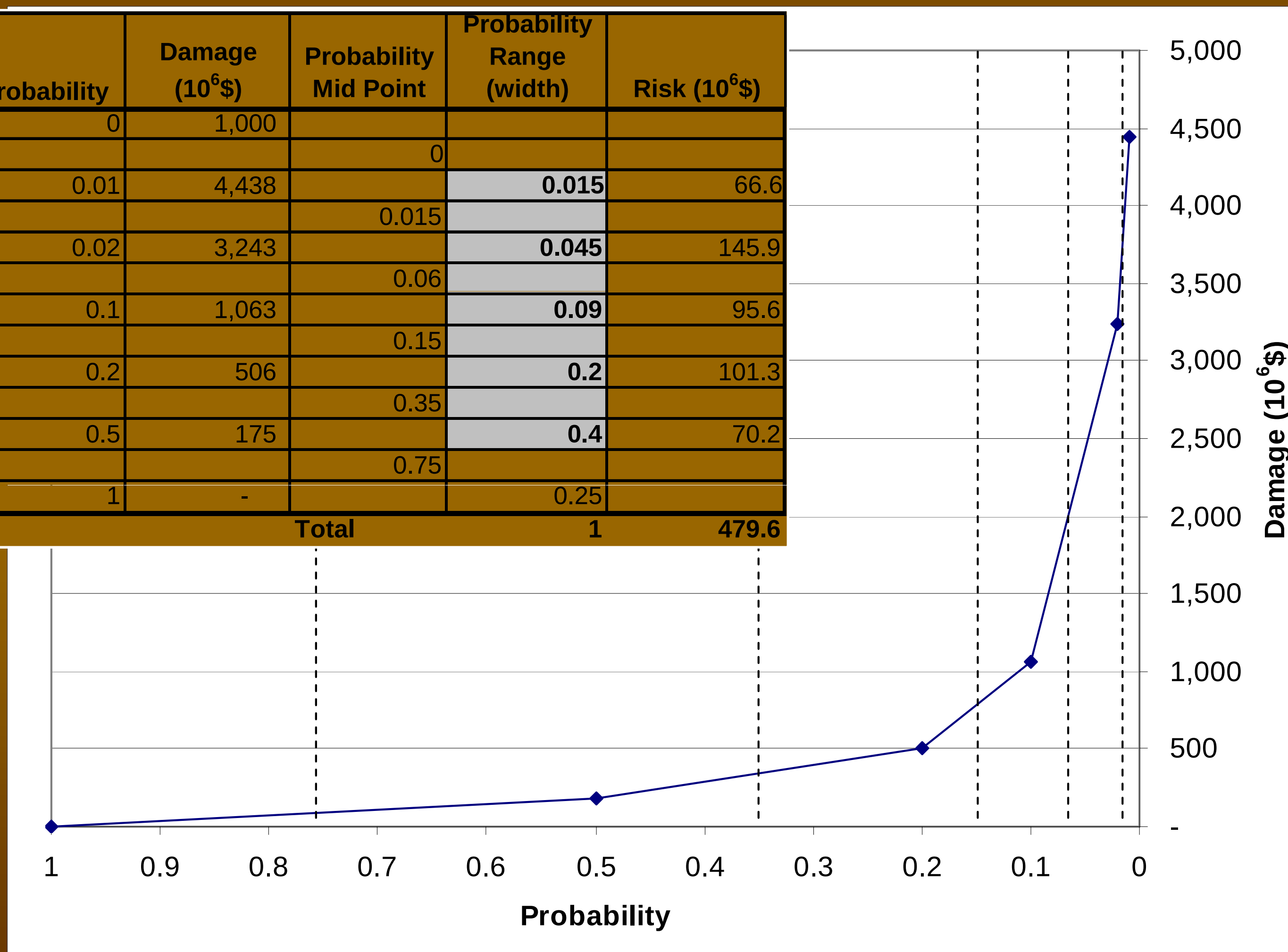


Flood Risk Assessment
Risk Mapping and Assessment

- A damage probability curve was constructed from the estimated damages caused by the events with probabilities of occurrence of 0.5, 0.2, 0.1, 0.02, and 0.01 (corresponding to the events of 2, 5, 10, 50, and 100 year return periods).
- The annualized risk was computed as the area, in slices, under this curve.
- For the 2 year probability range, it was assumed that at a probability of 100 % (corresponding to 1-year return period) the damage was zero.
- For return periods greater than 100 years, the damage associated with the 100 year event was assumed, so that the 100 year probability range represented by the 100 year event extended to the limit of zero probability.
- The sum of the products of the floodplain damages and the probability ranges provided the annualized risk.
- Total annualized damage: $470M for Subset of reach

Flood Risk Assessment
Risk Mapping and Assessment

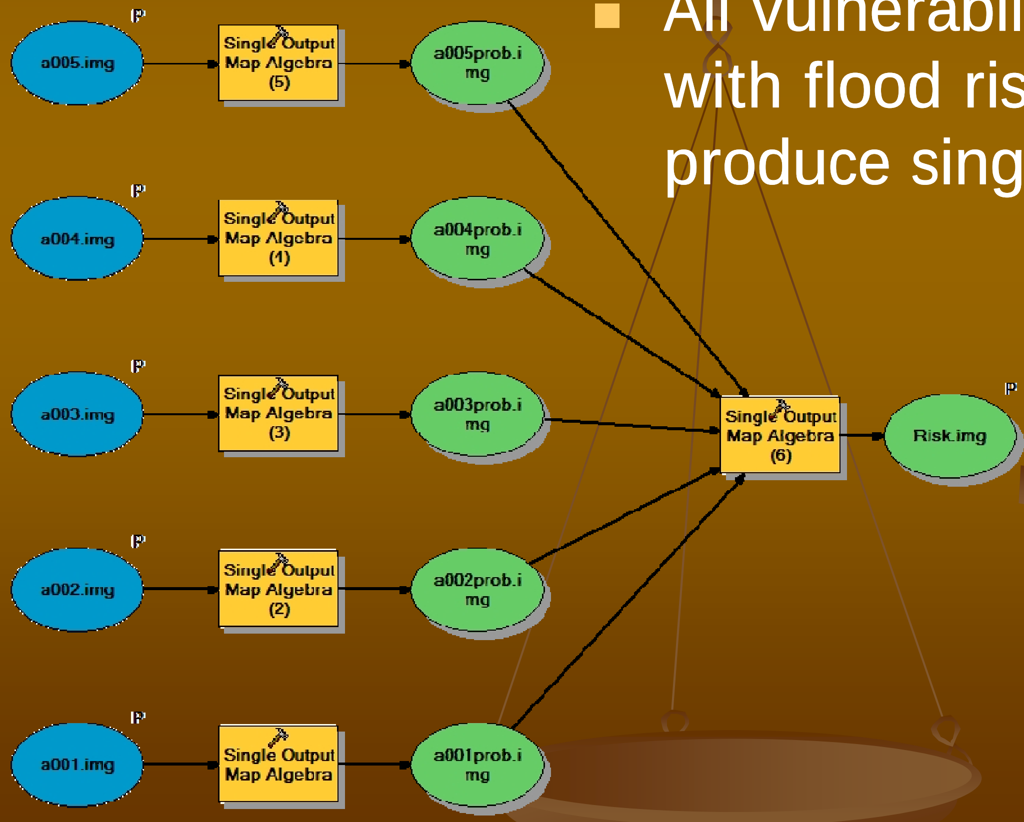
Return Period (yrs)	Probability	Damage (10^6\$)	Probability Mid Point	Probability Range (width)	Risk (10^6\$)
-> ?	0	1,000			
			0		
100	0.01	4,438		**0.015**	66.6
			0.015		
50	0.02	3,243		**0.045**	145.9
			0.06		
10	0.1	1,063		**0.09**	95.6
			0.15		
5	0.2	506		**0.2**	101.3
			0.35		
2	0.5	175		**0.4**	70.2
			0.75		
-	1	-		0.25	
			Total	**1**	**479.6**



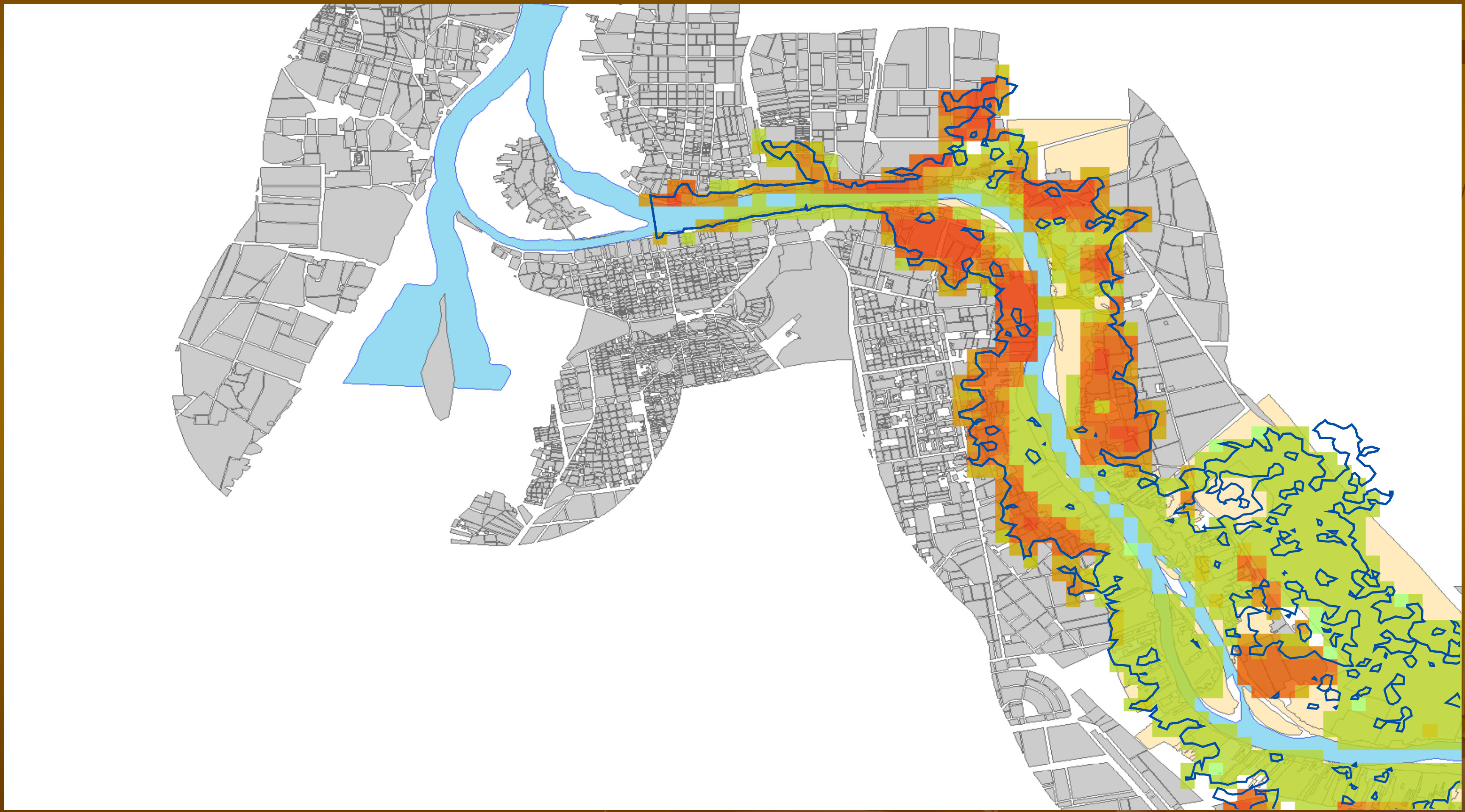
Damage-Probability Curve

Flood Risk Assessment Vulnerability Assessment

- Vulnerability calculated at each frequency
- All vulnerabilities combined with flood risk probability to produce single Risk map



Flood Risk Assessment
Risk Mapping and Assessment



Findings and Recommendations

- Survey – Terrain Model
  - Additional floodplain survey points for adjustment of DEM
  - Light Detection and Ranging (LIDAR) surveys for improvement in terrain model
- Hydraulics
  - Periodic surveying of river channel
  - Expand model with tributaries and local runoff
  - Additional verification through a planned monitoring program
- Risk
  - Investigate impact of storage and routing of larger storms
    - Requires unsteady flow modeling and characterization of hydrograph shapes
  - Take into account seasonality of cropping patterns
  - Develop national infrastructure mapping/database for this and other related future projects; improve accuracy of estimates

Findings and Recommendations

- Forecasting
  - Adjust hydraulic model for real-time reservoir operations
  - Implement a real-time operational system (Corps Water Management System - CWMS)
- Programmatic issues
  - Define multiple levels of standards for accuracy and detail of each of the components of the process

Findings and Recommendations

- Application of results
  - **Development policy** (restrict types of development within the floodplain; establish reimbursement policies to encourage responsible development)
  - Develop **flood resistant construction** materials/methods **consistent with hazard** (frequency of depth, velocity hazards
  - **Publish/disseminate results** for review by local population
  - Study maps for use in emergency response
  - Integrate hydraulic model into analysis for **design** of flood protection works (embankments)
  - Use Hydraulic model to **evaluate** increasing stages resulting from **encroachment** on the river (both steady and unsteady flow issues)
  - Find alternate uses for infrastructure mapping products that will encourage a **shared approach** for maintaining and improving the database
  - Use the flood boundary maps to identify areas of **focus** for subsequent **data collection** and refinement
  - Study vulnerability and risk maps to improve understanding of **locus of expected damages**

Thank you for Your Attention