USG Pakistan Water Resources Program: Water Resources Model Development

PEER Kabul River Basin Forum

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US Embassy Islamabad Pakistan
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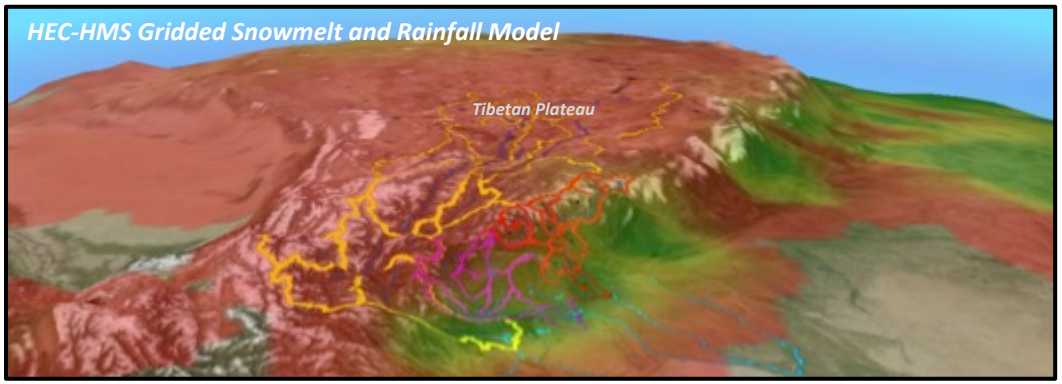
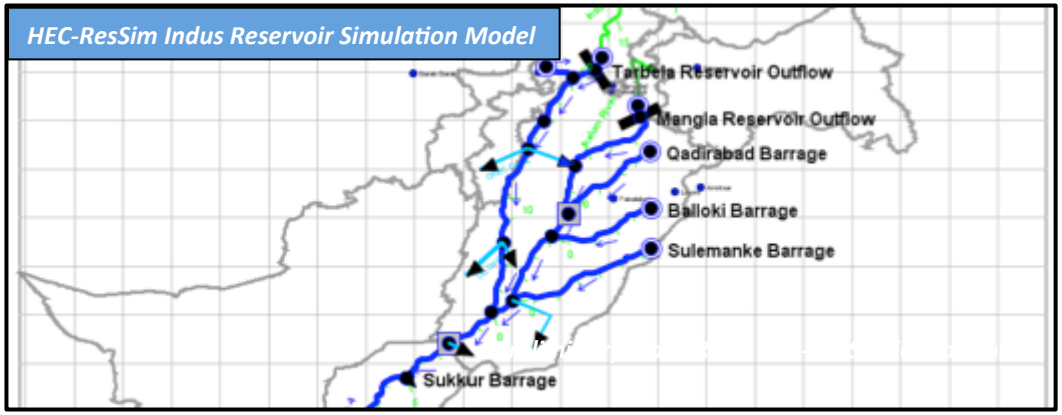
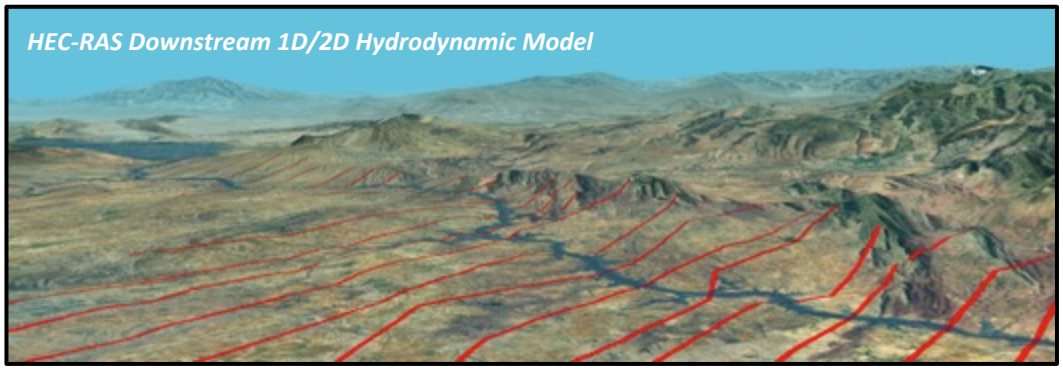
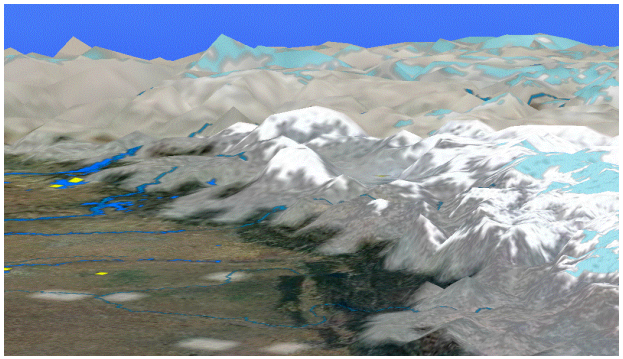






USG Pakistan Water Resources Program-
Presentation Summary



Objectives
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Project Description
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Project Status
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Preliminary Water Resources Models
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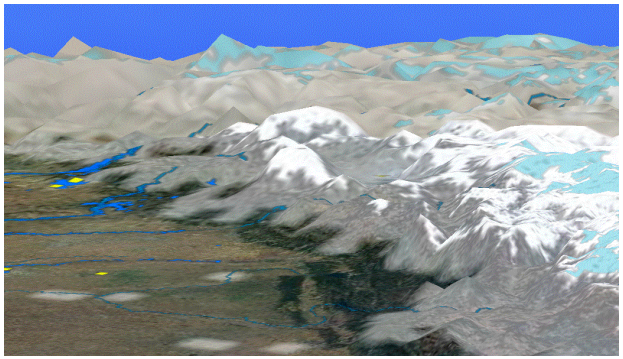
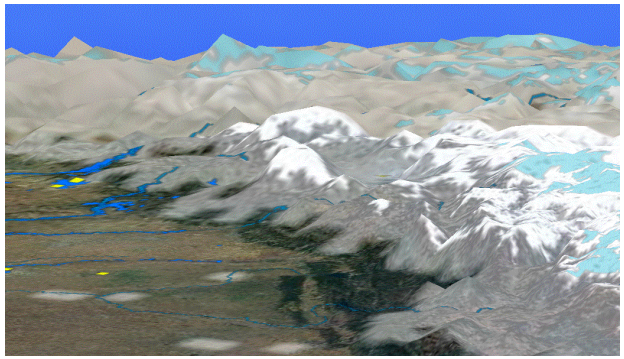
USG Pakistan Water Resources Program-
Objectives



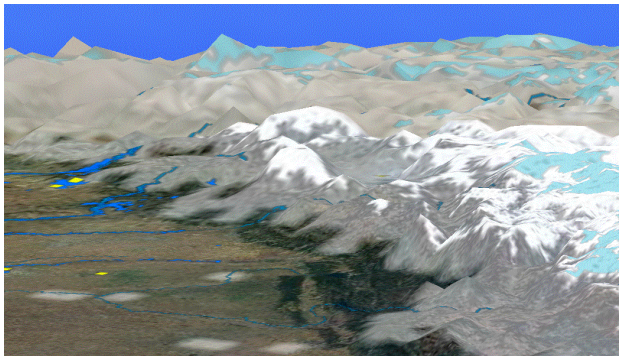
- Water Resources Technology Transfer Between U.S. and Pakistan
- Provide for National and Regional Stability
- Improving Water, Food, and Energy Security
- Improving U.S. and Pakistan Relations

USG Pakistan Water Resources Program-
Project Description



- Joint US-Pakistan Climate and Water Resources Model Development
- U.S. – DoS, USAID, USACE, NCAR, NSIDC
- Pakistan – MoWP, WAPDA, IRSA, FFC, PID, SID
- Model Development for Long-Term Climate Change Adaptation Analysis and Real-Time Reservoir Operations
- Climate and Water Resources Models:
  - -South Asia NCAR Weather Research and Forecasting (WRF) Regional Climate Model
  - -Indus River Basin HEC-HMS Rainfall/Snowmelt/Runoff Model
  - -Indus Reservoir HEC-RAS Reservoir Sedimentation Model
  - -Indus Basin HEC-ResSim Reservoir Simulation Model
  - -Downstream HEC-RAS 1D/2D Hydrodynamic Routing Model
- Initial Training at Model Developer Facilities in U.S.:
  - -National Center for Atmospheric Research in Boulder Colorado
  - -Hydrologic Engineering Center in Davis California
  - -USACE Cold Regions Research and Engineering Laboratory (CRREL) in Hanover New Hampshire
- Joint US/Pak Model Development
  - -Goal: Directly team up U.S. model developers who wrote and know the numerical models with GOP Engineers and Scientists who really know and understand the climate and hydrology of Pakistan
- All Final Models Become Property of GOP

USG Pakistan Water Resources Program-
Project Status



- Climate and Water Resources Models:

-South Asia NCAR Weather Research and Forecasting (WRF) Regional Climate Model

* **2 Ministry of Climate Change Nominated Climate Scientists**
* **Economic Affairs Division Approved Training and Candidates**
* **Weather Research and Forecasting Training January 2018**

-Indus River Basin HEC-HMS Rainfall/Snowmelt/Runoff Model

* **MoCC Nominated Two Hydrologists**
* **Awaiting EAD Approval**
* **Training in U.S. Anticipated in November in Hanover New Hampshire at CCREL**

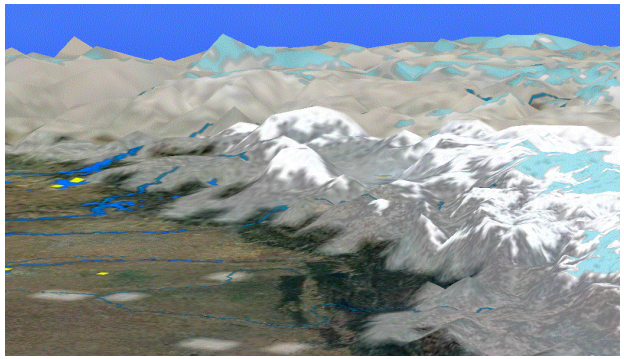
-Indus Reservoir HEC-RAS Reservoir Sedimentation Model and Indus Basin HEC-ResSim Model

* **MoWP Nominated Fifteen Engineers and Scientists**
* **Awaiting EAD Approval**
* **Training in U.S. Anticipated in October in Davis California at HEC**

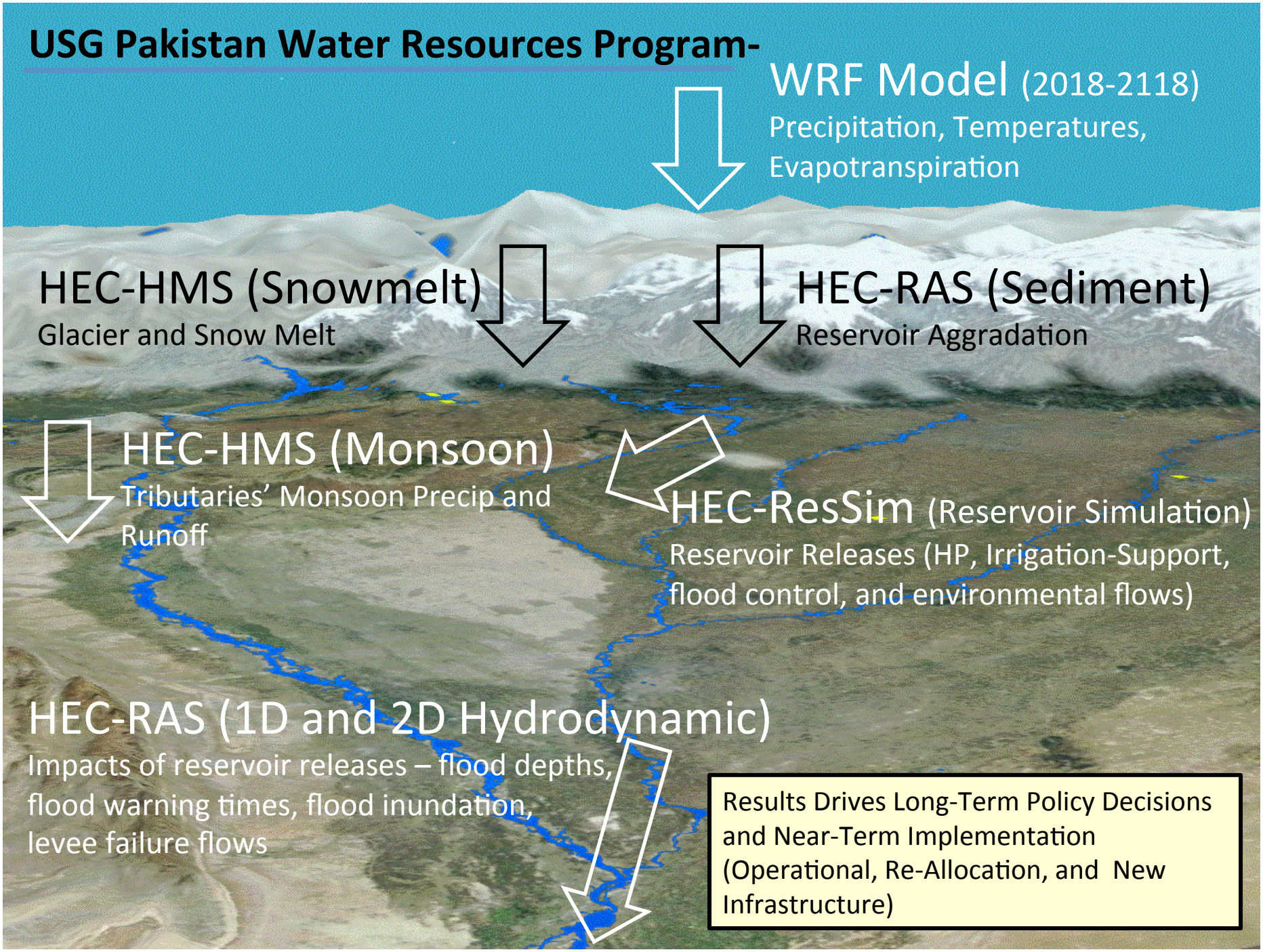
-Downstream HEC-RAS 1D/2D Hydrodynamic Routing Model

* **Still Working on Scope**
* **Still Working with GoP on Candidates**
* **Training in U.S. Anticipated in Jan-Feb 2018 in Davis California at HEC**

USG Pakistan Water Resources Program-
Preliminary Water Resources Models



- Provide a “Blue-Print” for Eventual Joint USG/GOP Model Dev
- Test new Features of Numeric Models on Indus River Basin
- Provide Quick Answers to Immediate Water Resources Issues
- For the Most Part – Minimally Calibrated
- Climate and Water Resources Models:
  - -South Asia NCAR Weather Research and Forecasting (WRF) Regional Climate Model
  - -**Indus River Basin HEC-HMS Rainfall/Snowmelt/Runoff Model**
  - -Indus Reservoir HEC-RAS Reservoir Sedimentation Model
  - -**Indus Basin HEC-ResSim Reservoir Simulation Model**
  - -**Downstream HEC-RAS 1D/2D Hydrodynamic Routing Model**


USG Pakistan Water Resources Program-
WRF Model (2018-2118)
Precipitation, Temperatures, Evapotranspiration
HEC-HMS (Snowmelt)
Glacier and Snow Melt
HEC-RAS (Sediment)
Reservoir Aggradation
HEC-HMS (Monsoon)
Tributaries' Monsoon Precip and Runoff
HEC-ResSim (Reservoir Simulation)
Reservoir Releases (HP, Irrigation-Support, flood control, and environmental flows)
HEC-RAS (1D and 2D Hydrodynamic)
Impacts of reservoir releases – flood depths, flood warning times, flood inundation, levee failure flows
Results Drives Long-Term Policy Decisions and Near-Term Implementation (Operational, Re-Allocation, and New Infrastructure)

USG Pakistan Water Resources Program-
Indus River Basin HEC-HMS Model

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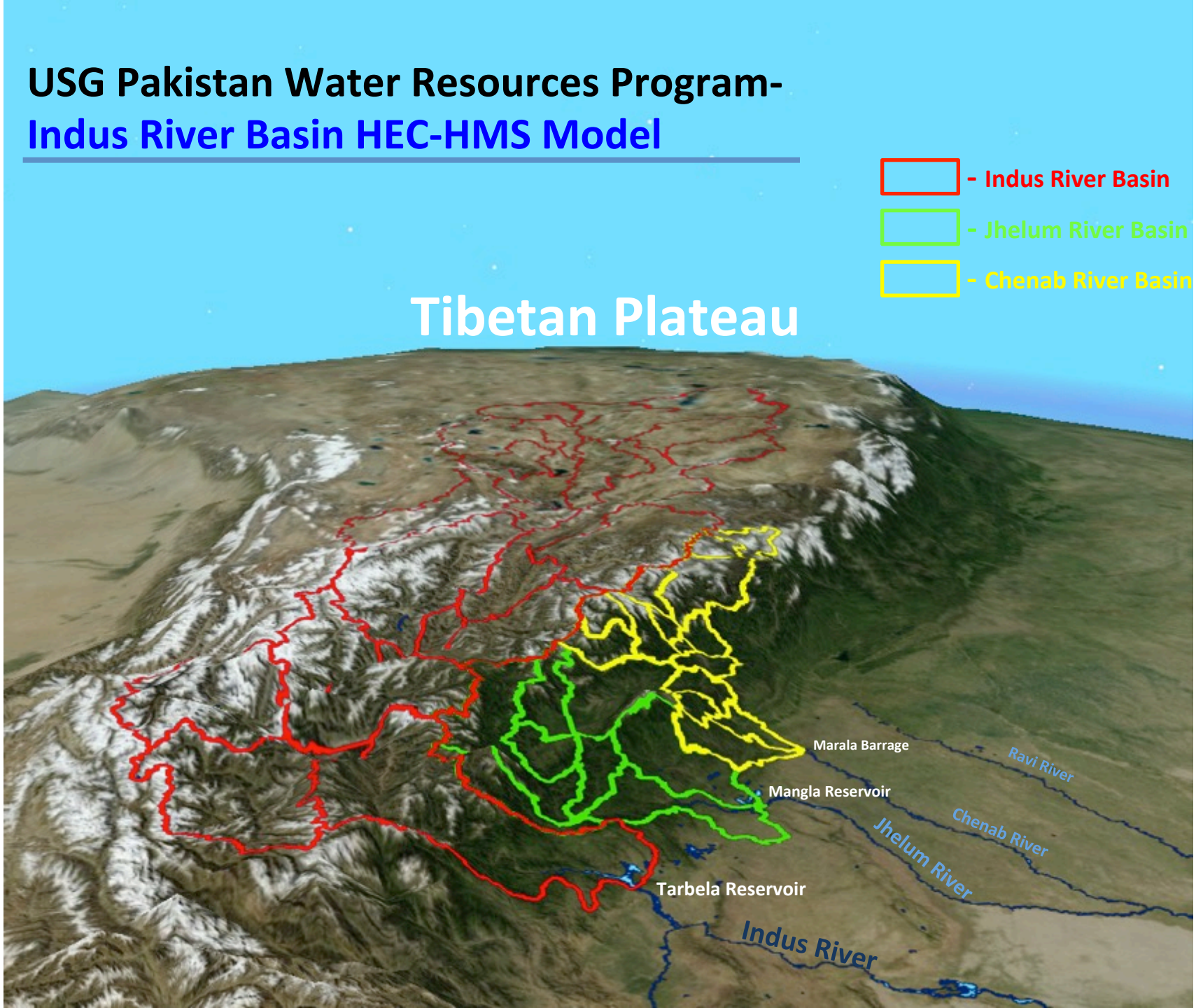
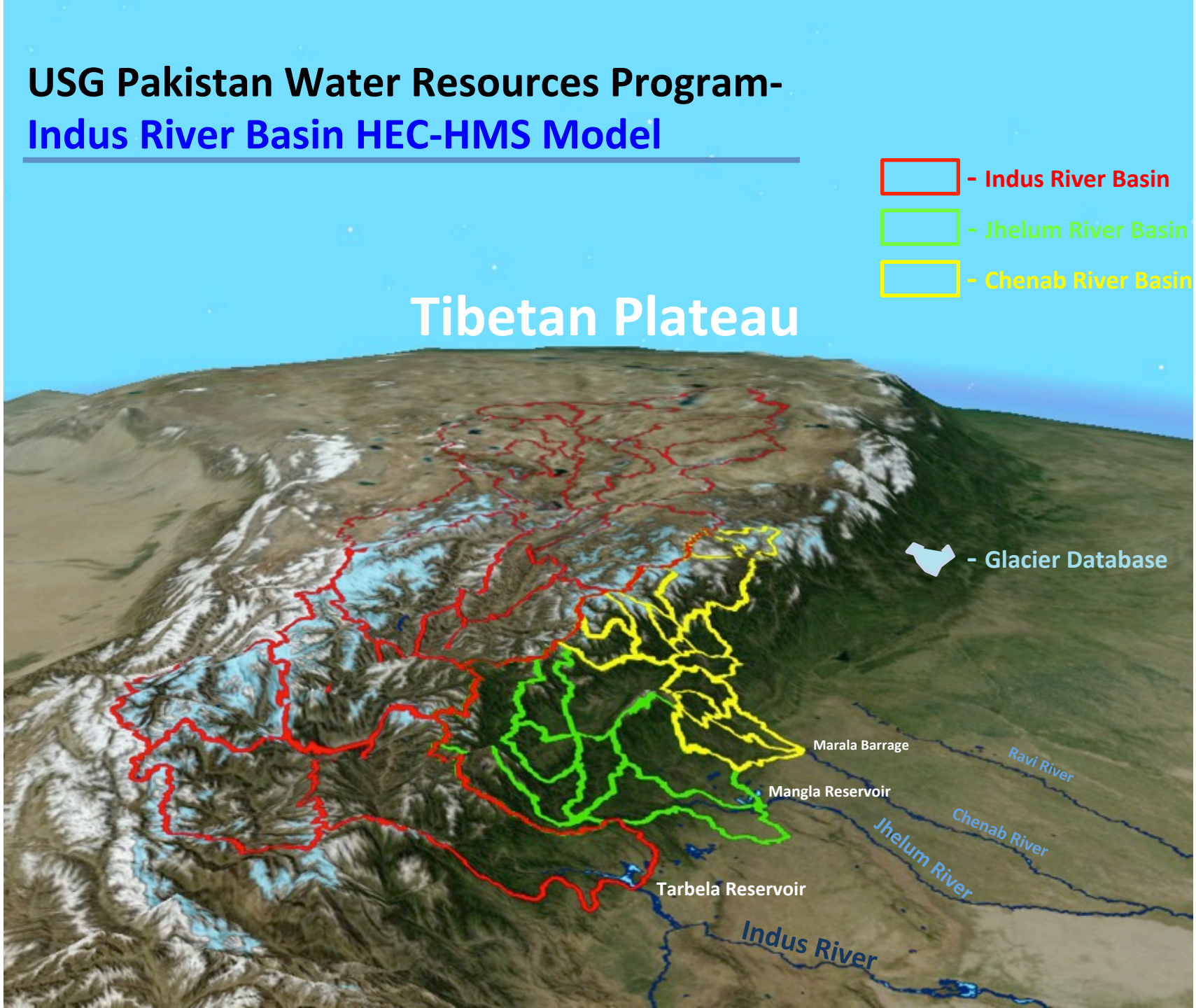


USG Pakistan Water Resources Program-
Indus River Basin HEC-HMS Model



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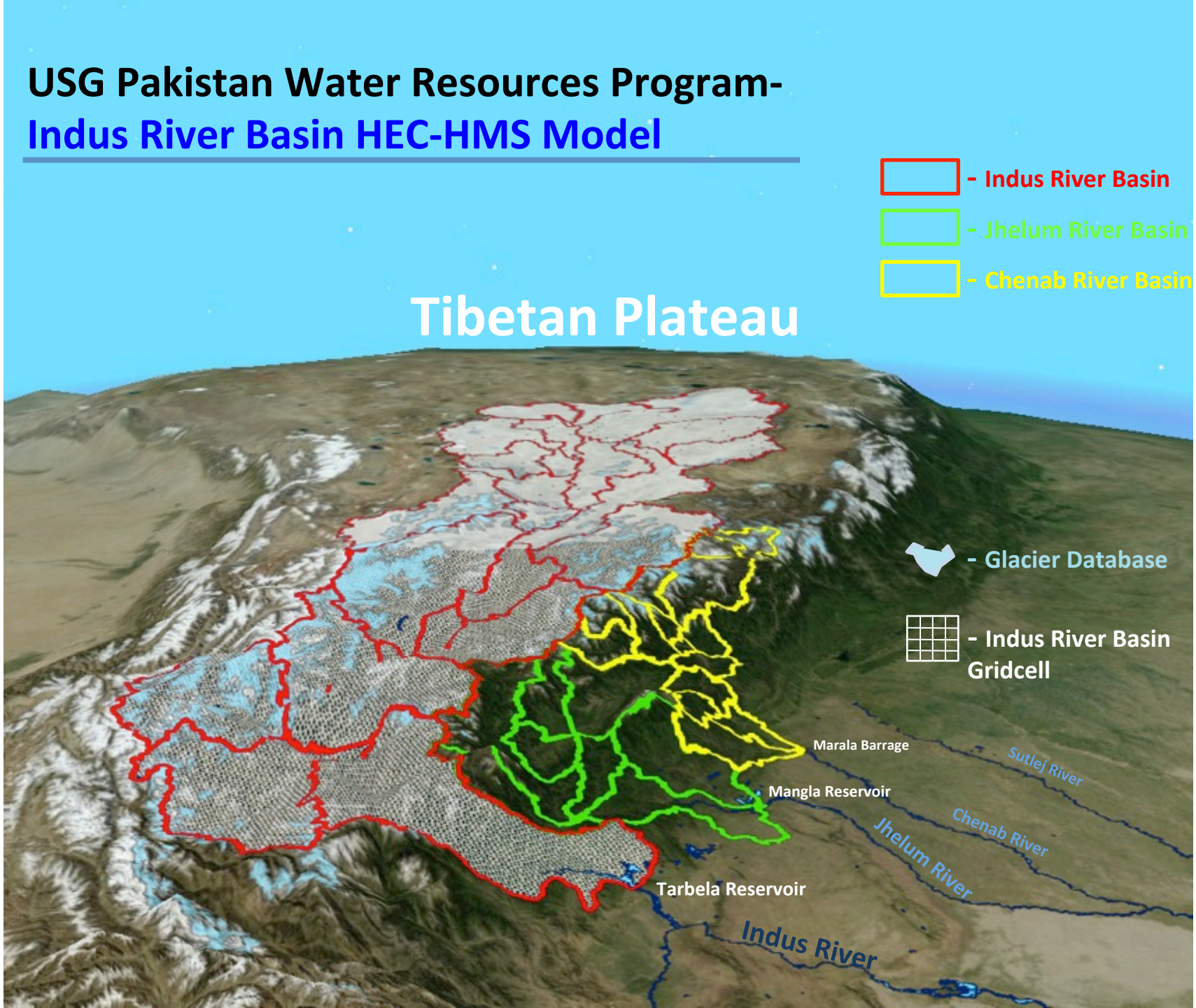

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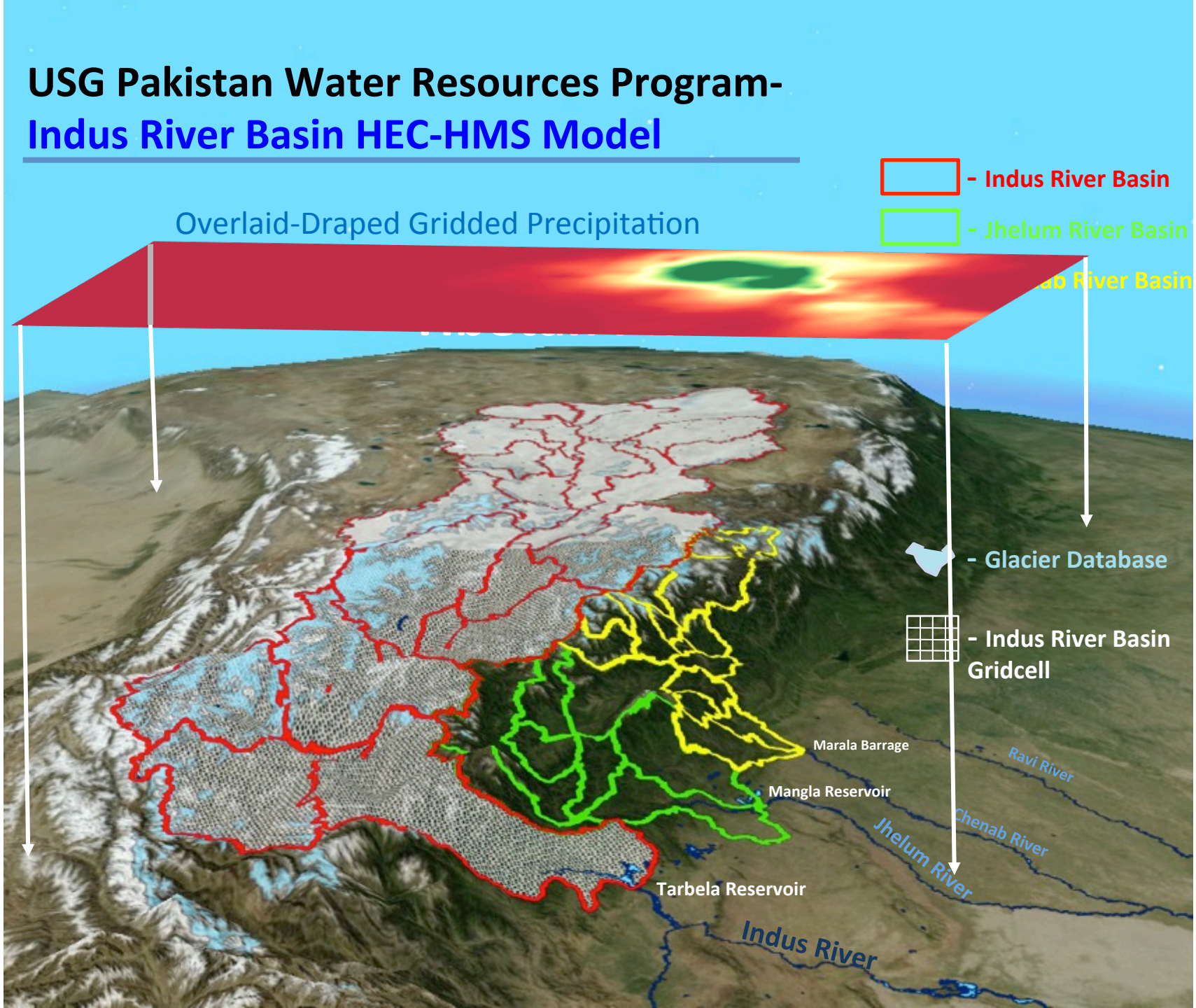

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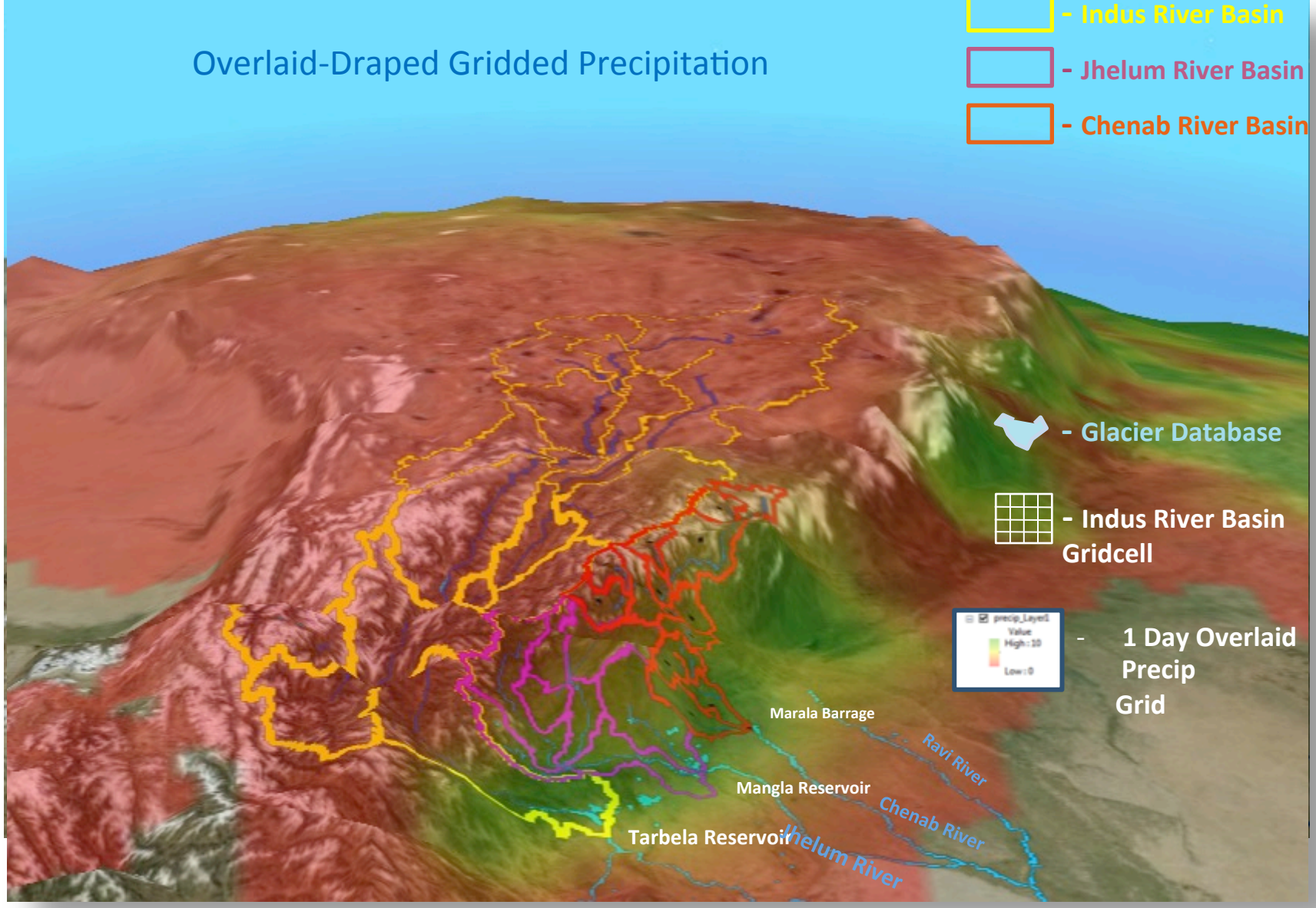
Indus River Basin HEC-HMS Model

Overlaid-Draped Gridded Precipitation



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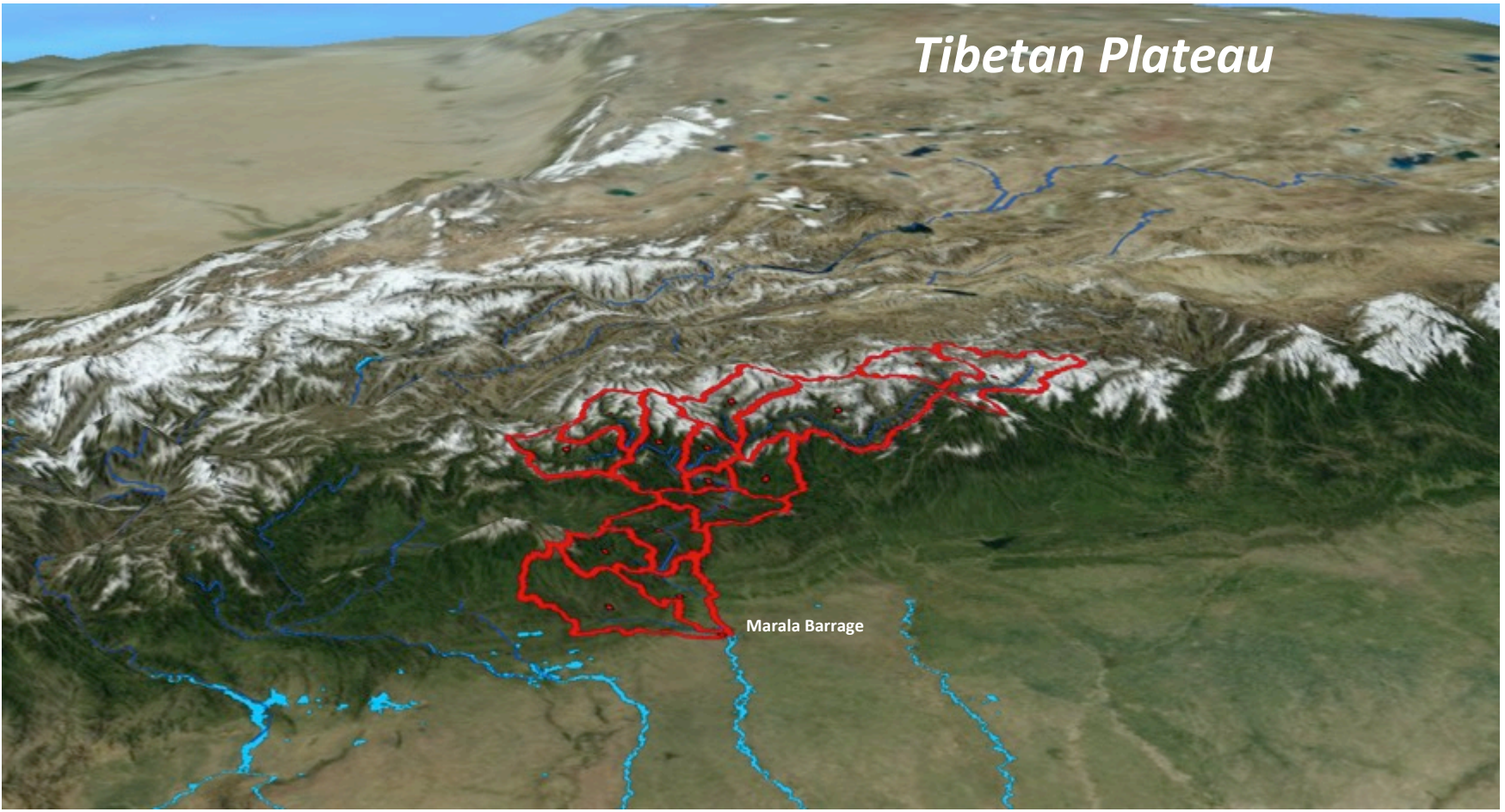

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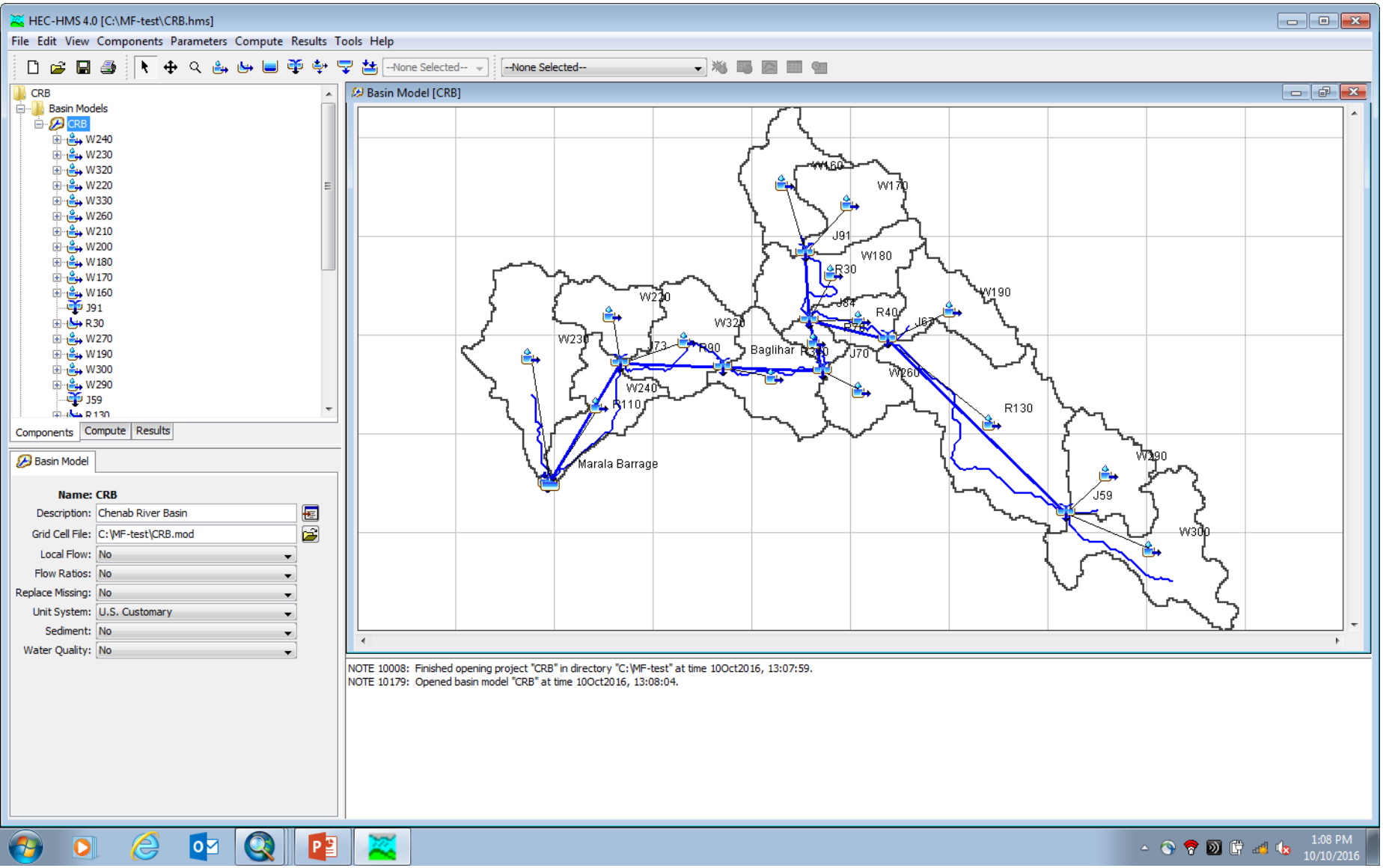

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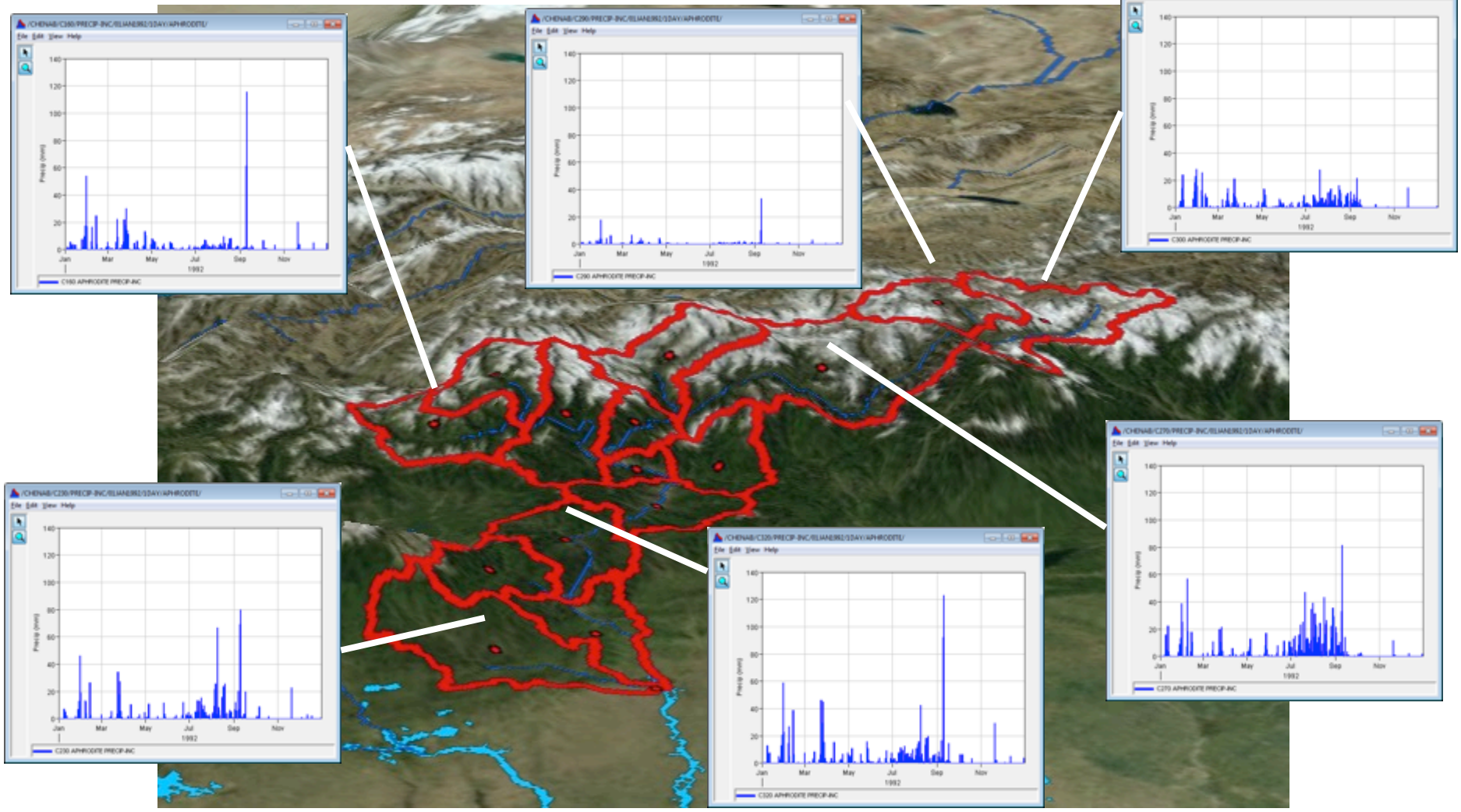

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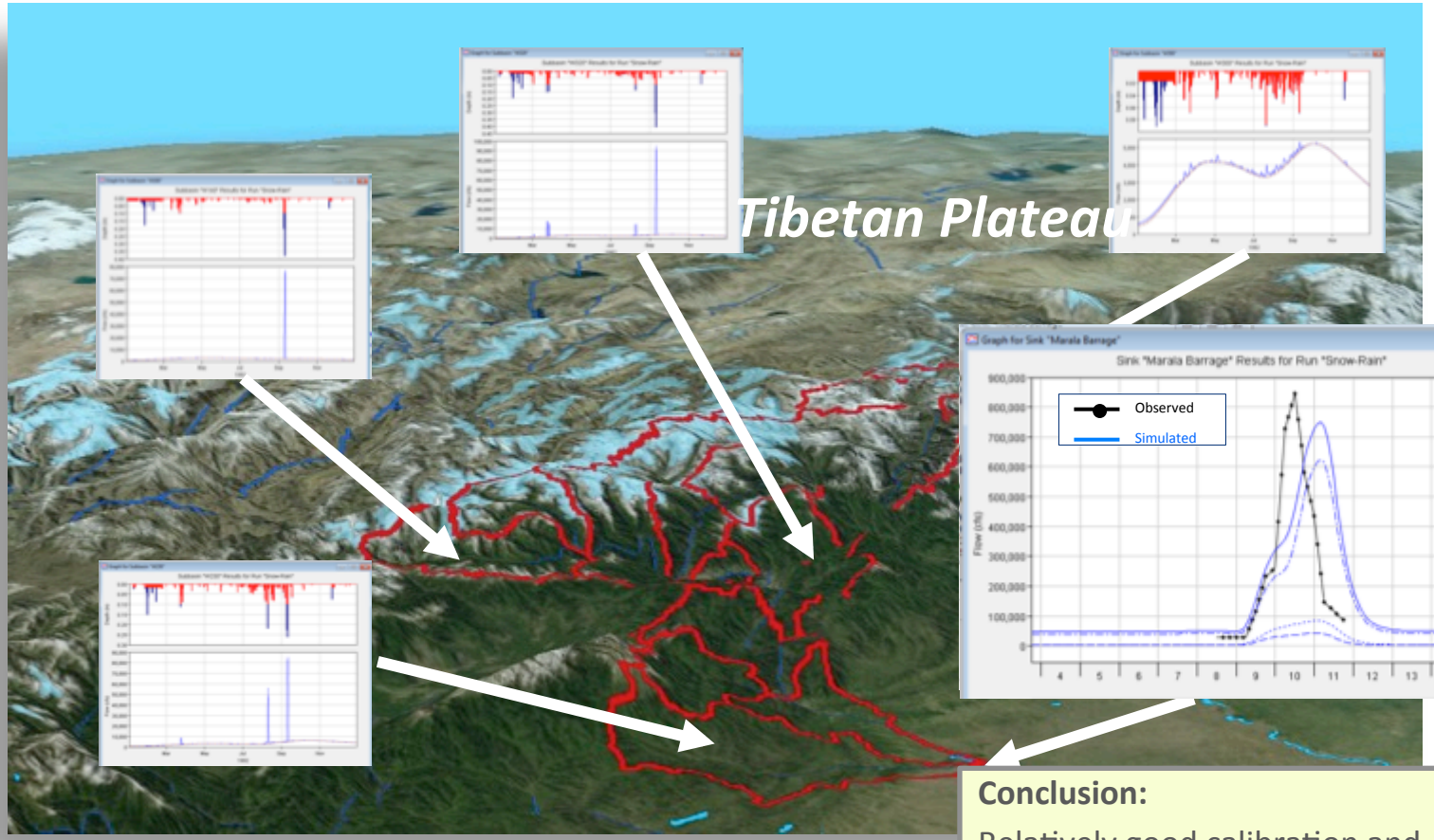

Conclusion:

Relatively good calibration and model can duplicate existing monsoon rainfall to runoff processes

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Indus River Basin HEC-ResSim Model

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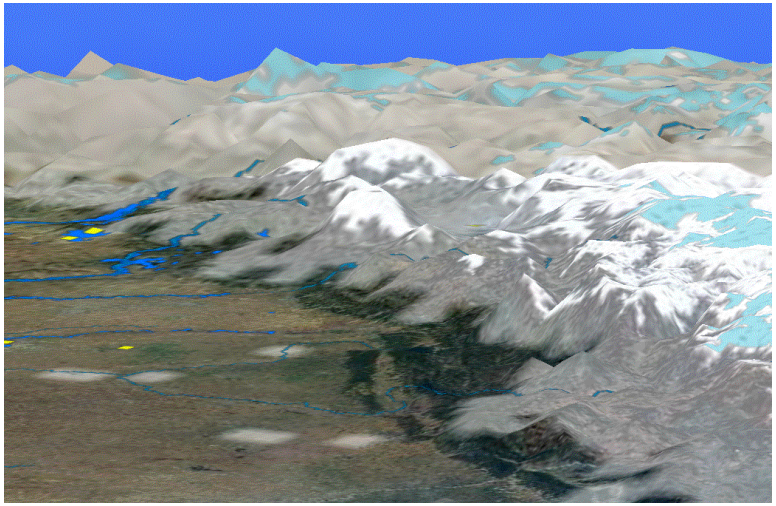
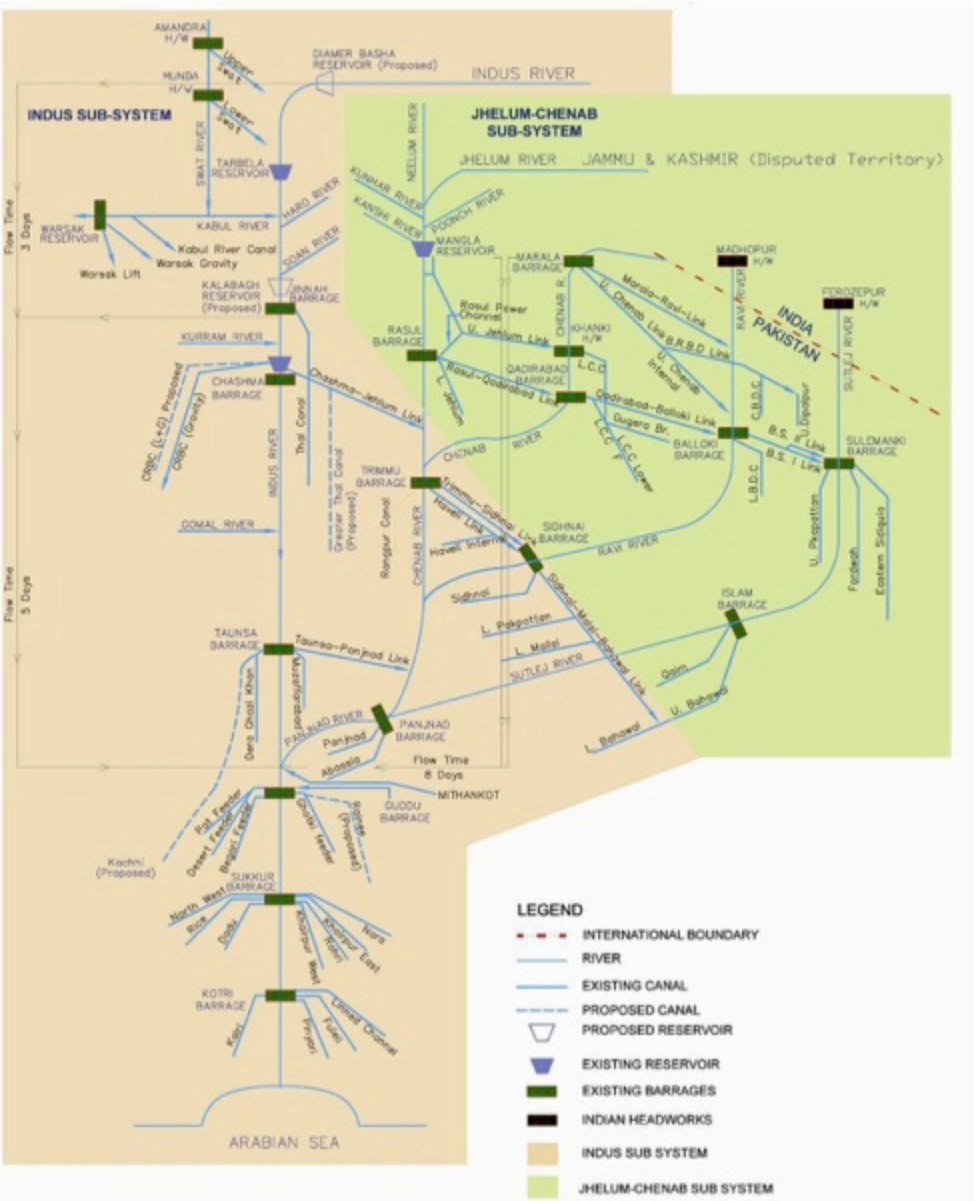
USG Pakistan Water Resources Program-
Indus River Basin HEC-ResSim Model

- 2 major multi-purpose reservoirs
  – Tarbela and Mangla
- 19 barrages (low head dams)
- 12 Inter-river link canals
- 45 major irrigation canal commands covering 60,000 square miles
- 120,000 canals delivering water to farms



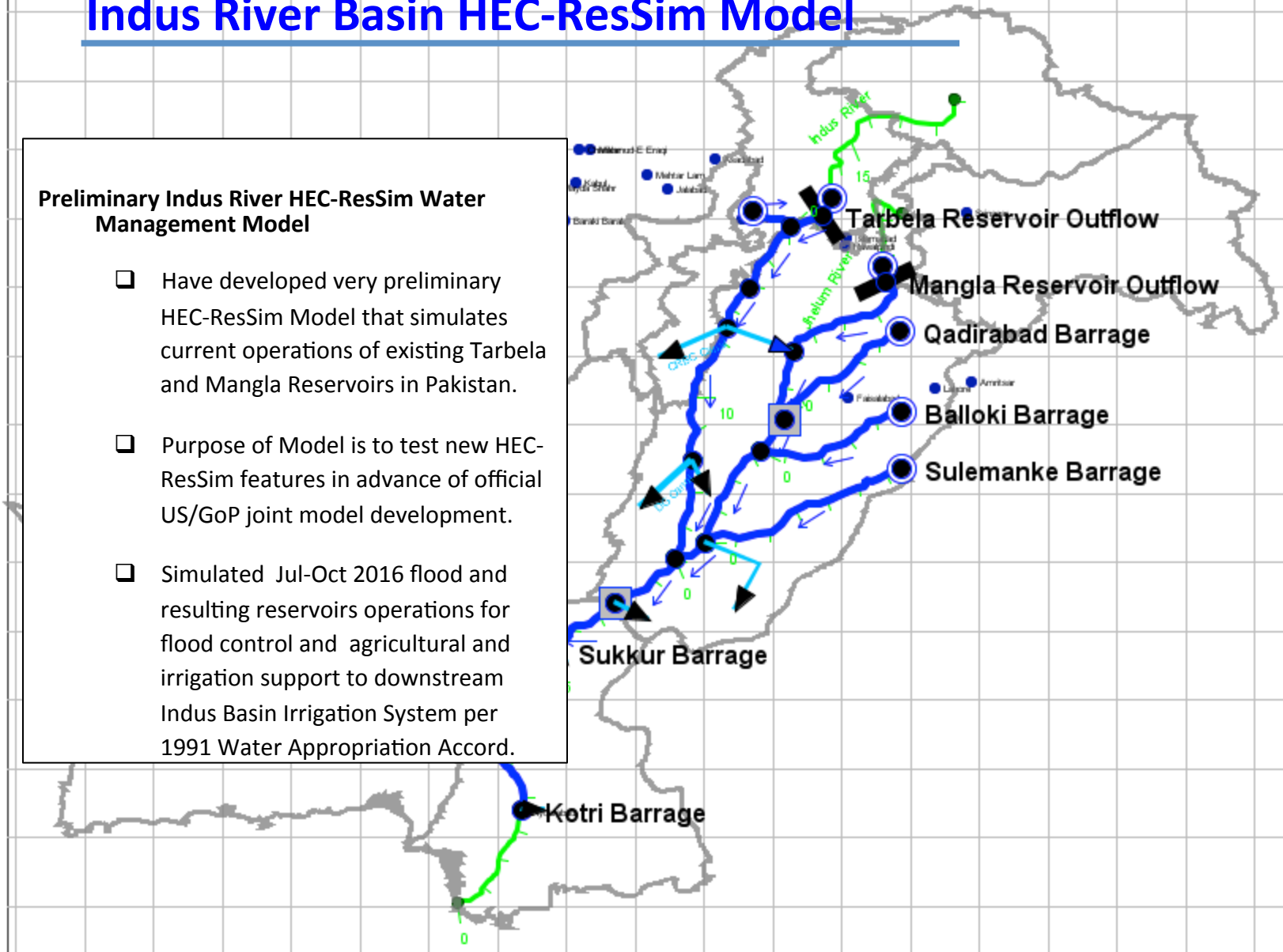


USG Pakistan Water Resources Program-

Indus River Basin HEC-ResSim Model

Preliminary Indus River HEC-ResSim Water Management Model

- Have developed very preliminary HEC-ResSim Model that simulates current operations of existing Tarbela and Mangla Reservoirs in Pakistan.
- Purpose of Model is to test new HEC-ResSim features in advance of official US/GoP joint model development.
- Simulated Jul-Oct 2016 flood and resulting reservoirs operations for flood control and agricultural and irrigation support to downstream Indus Basin Irrigation System per 1991 Water Appropriation Accord.



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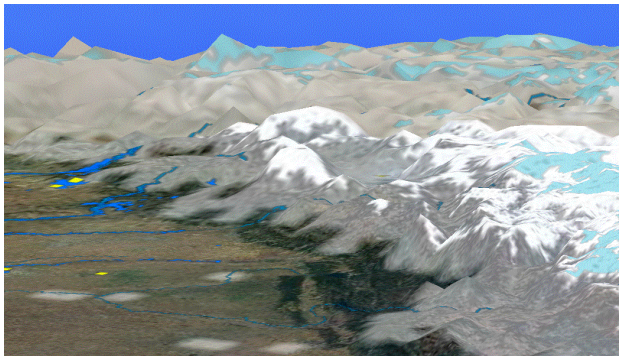

Physical Components of Tarbela and Mangla Dams

- Most current reservoir elevation-area-capacity relationships from bathymetric surveys
- Critical dam elevations:
- Top of dam, outlet works inverts, principle spillway inverts, emergency spillway inverts, power tunnel inverts
- Tailwater rating curves
- Elevation-discharge rating curves:
- Outlet works, power tunnels, principal spillway, emergency spillway
- Energy Generation rating curves:
- Reservoir storage vs capacity (MW), Reservoir release vs Capacity (MW), Reservoir head vs capacity (MW)

Period of Record Historic Daily Flows

- Inflows to Mangla and Tarbela
- Releases from Mangla and Tarbela
- Mangla and Tarbela Pool Levels
- Downstream Tributary "Rim" Flows (Kabul River, Qadirabad, Balloki, Sulemanki)
- Downstream Barrage Flows (Guddu, Sukkur, Kotri)
- Inter-River Links (All 12)

Historical Energy Generation (MW-hr)

- Mangla and Tarbela

Current Reservoir Operating Rule Curves and Constraints

- Minimum and maximum rule curve, reservoir pool rates of raise and fall constraints

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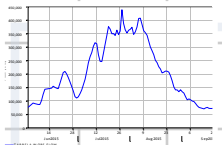
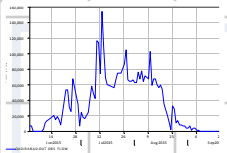
Indus River Basin HEC-ResSim Model

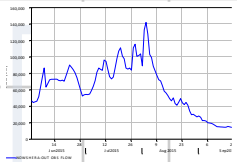
Tarbela Inflows



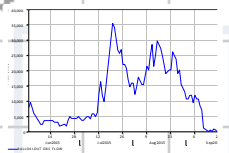
Mangla Inflows



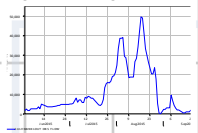
Qadirabad Outflow



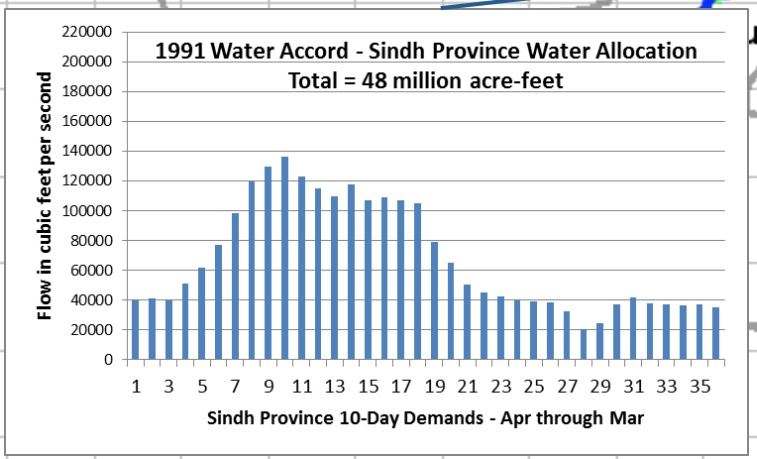
Kabul River Flows

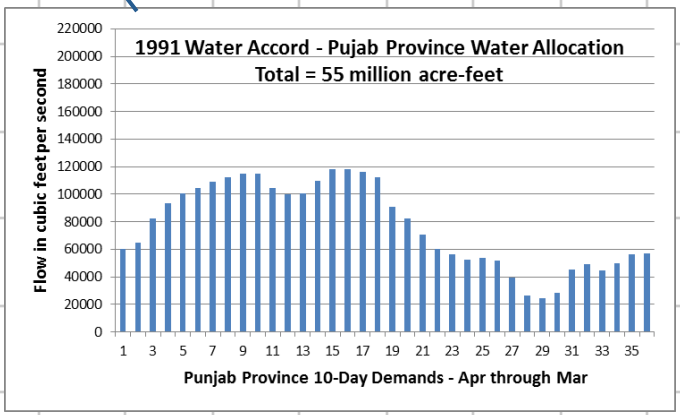


Balloki Outflow

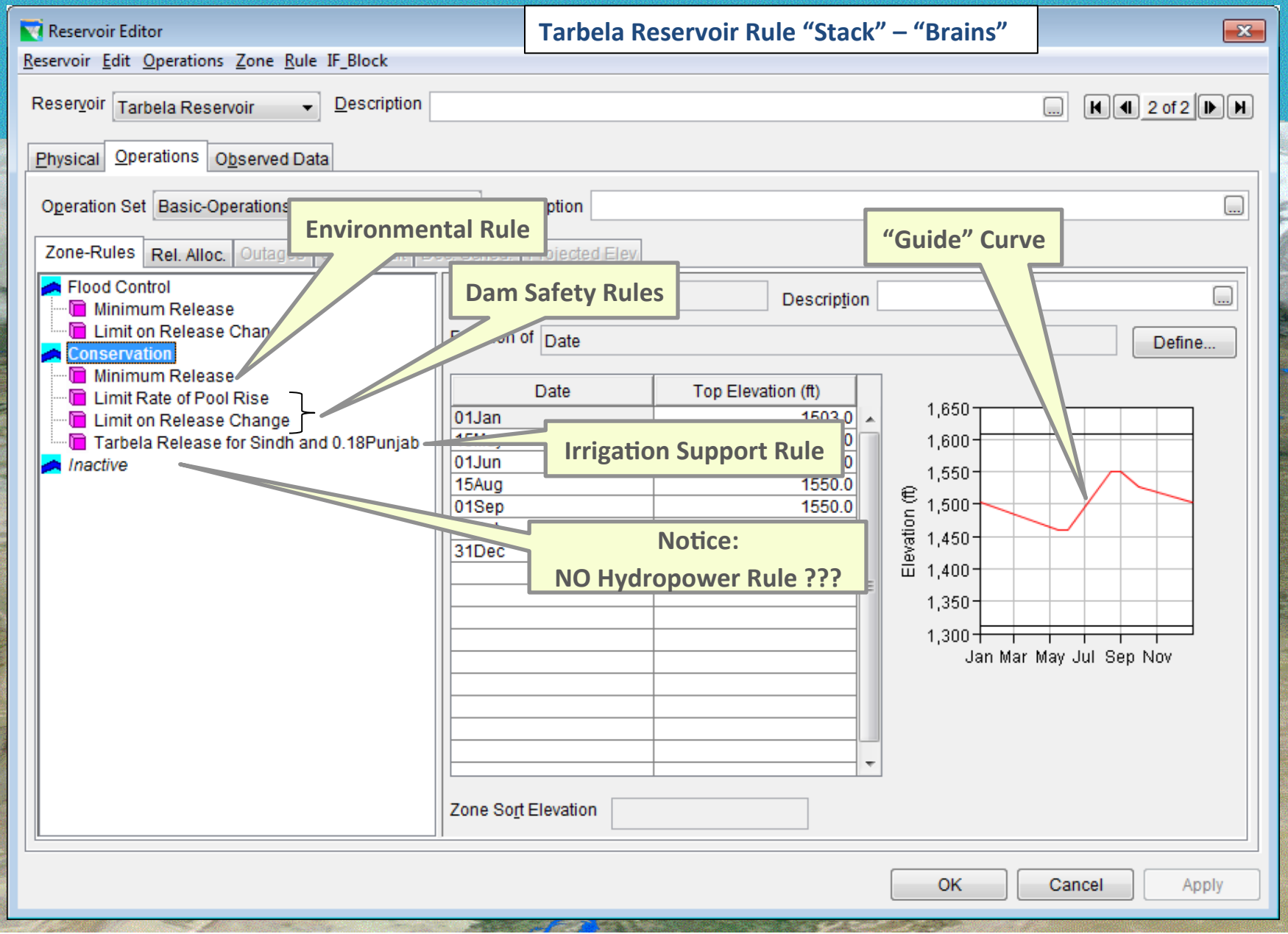


Sulemanki Outflow





HEC-ResSim Reservoir Modelling Concept
Simulation of Actual 2016 Tarbela and Mangla Dams Operations



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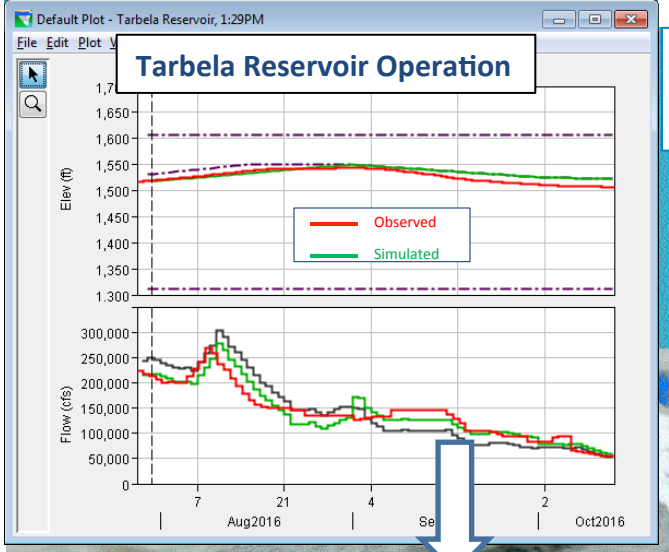

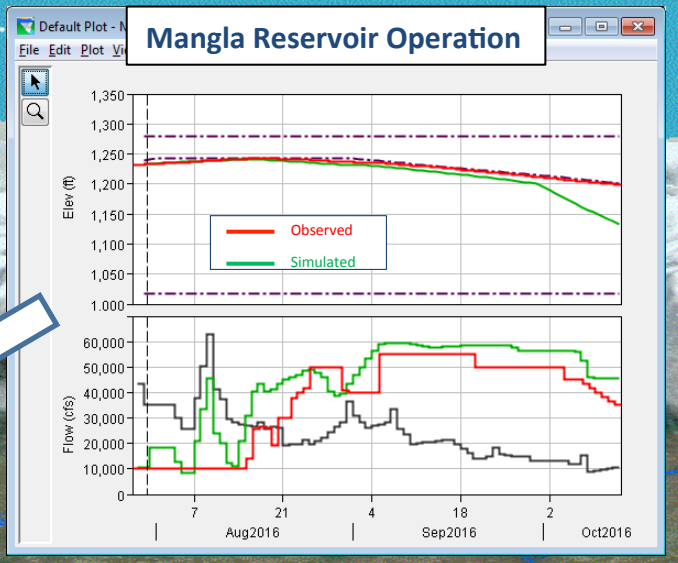

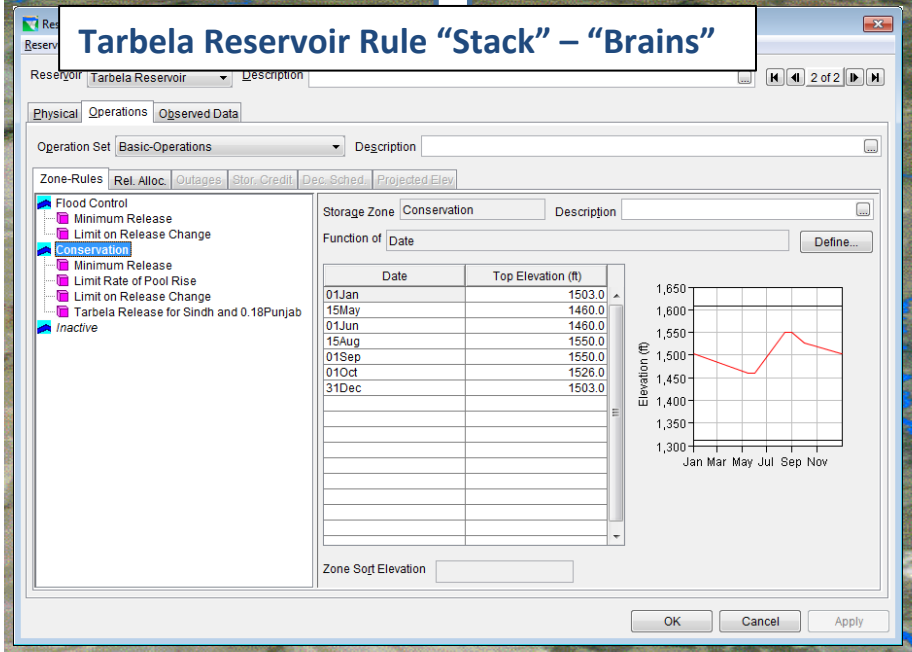

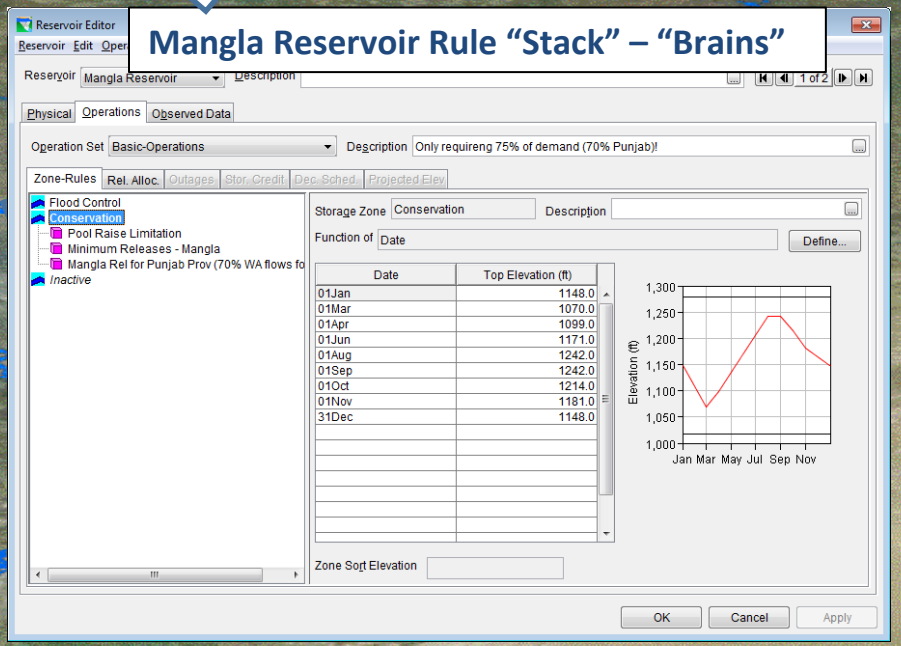

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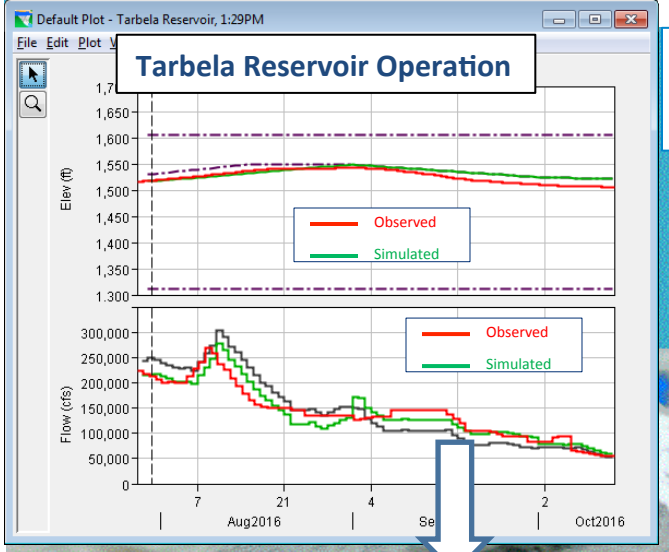

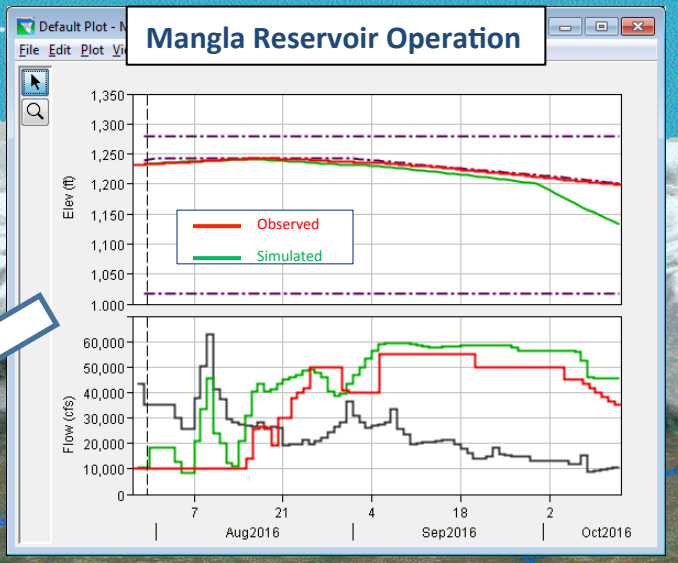

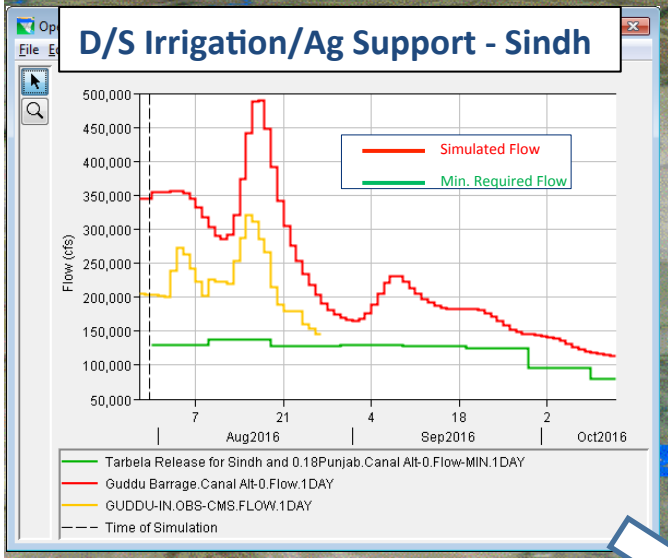

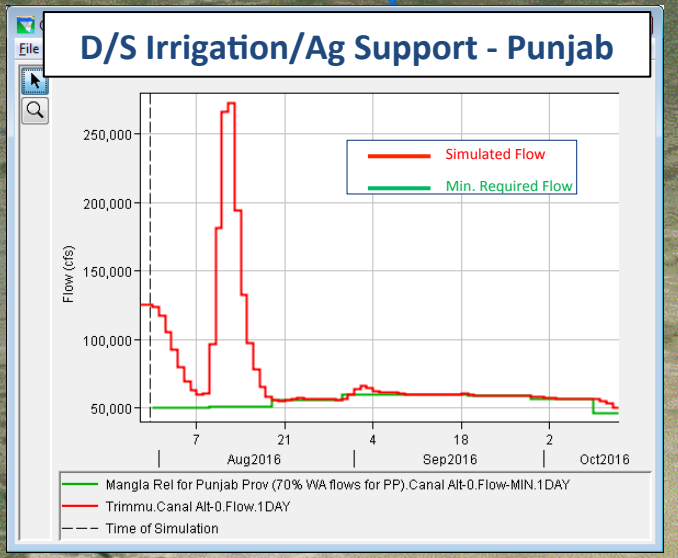

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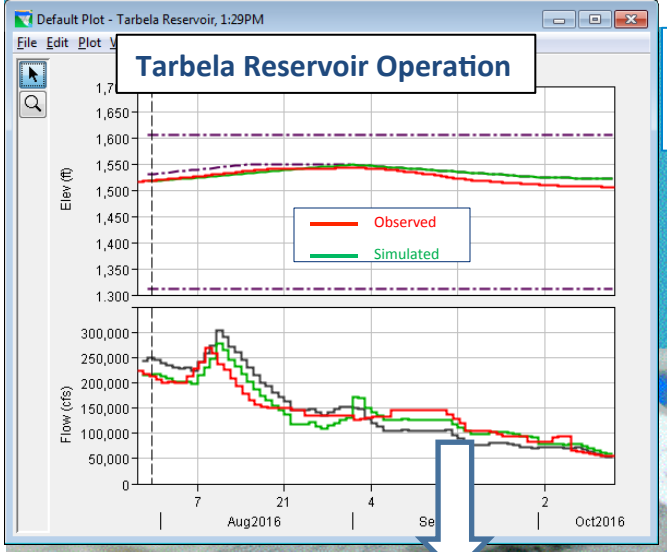
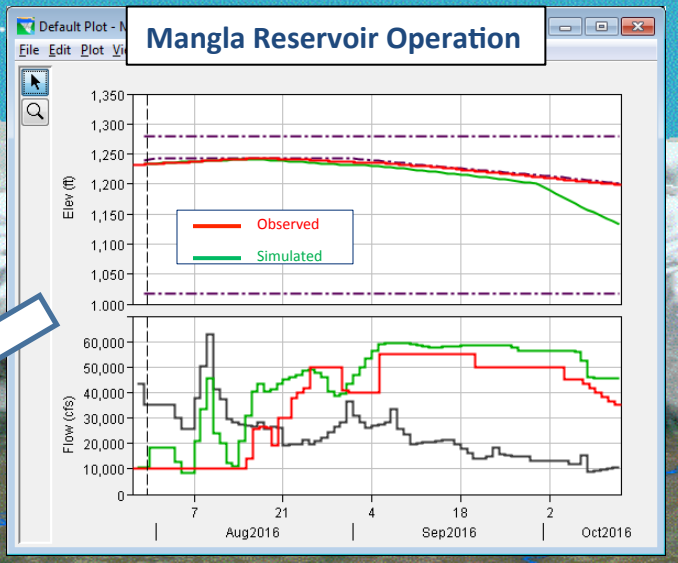
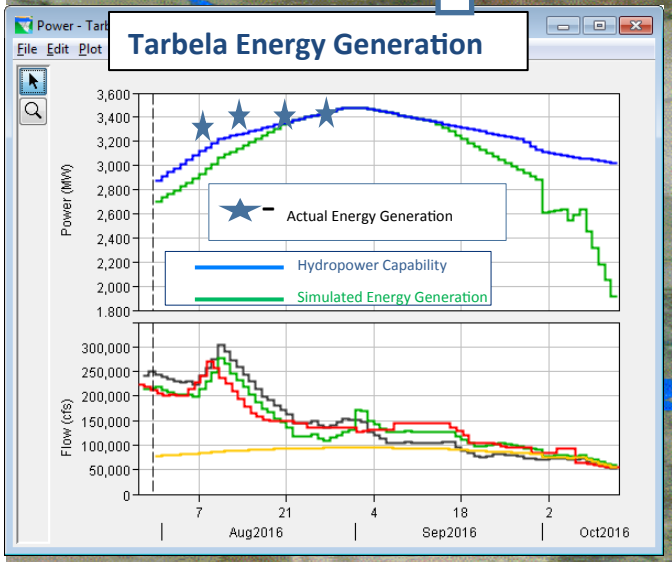
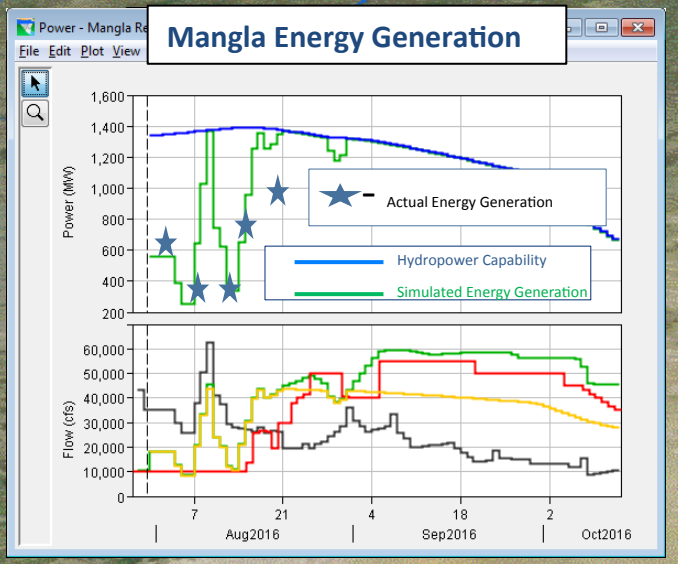


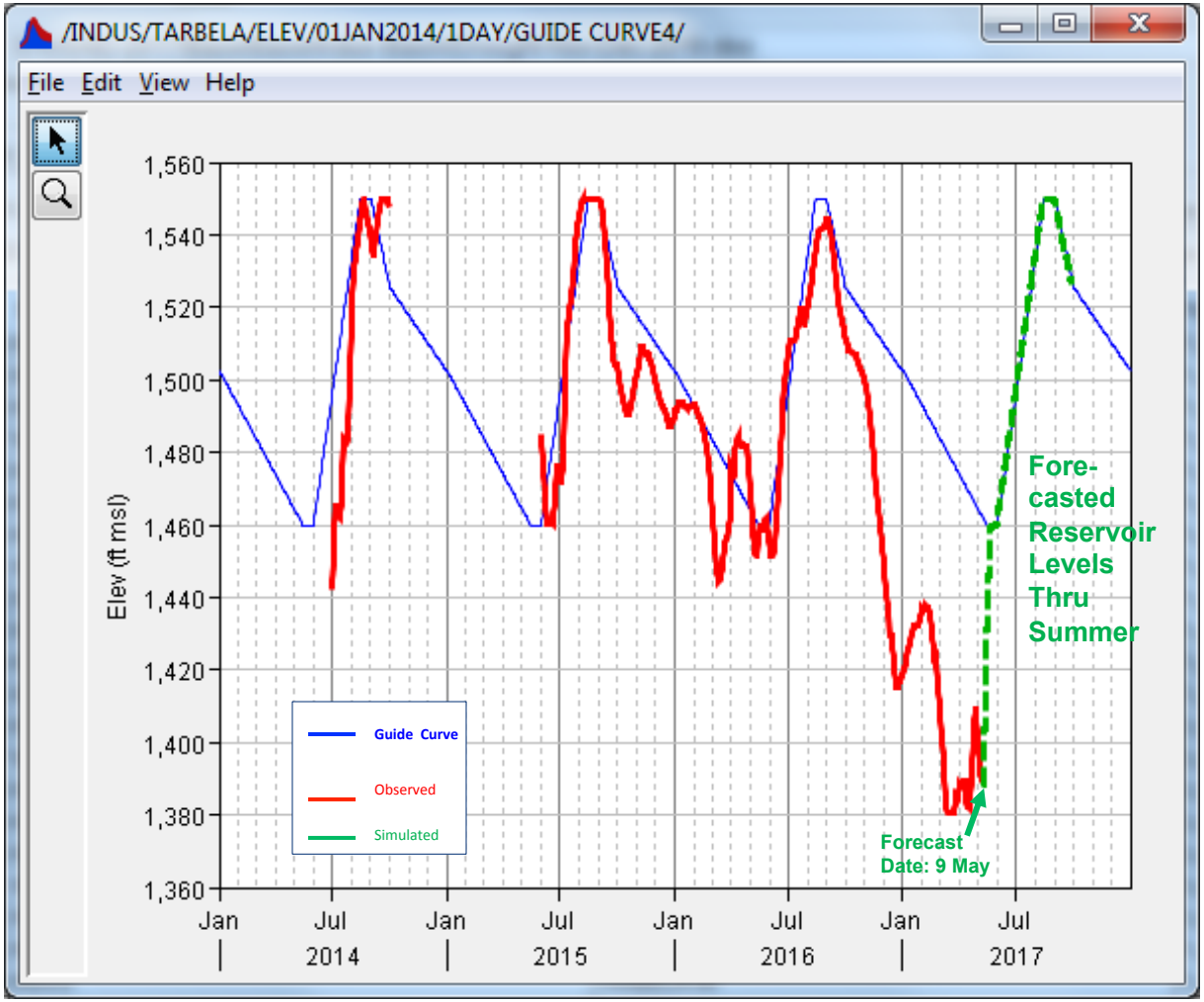






USG Pakistan Water Resources Program-

Indus River Basin HEC-ResSim Model



Results from existing HEC-ResSim model:

1. Initial forecast made 9 May, showed that with normal inflows and reducing reservoir releases, Tarbela Pool Level would approach normal levels by the first week in June.

USG Pakistan Water Resources Program-

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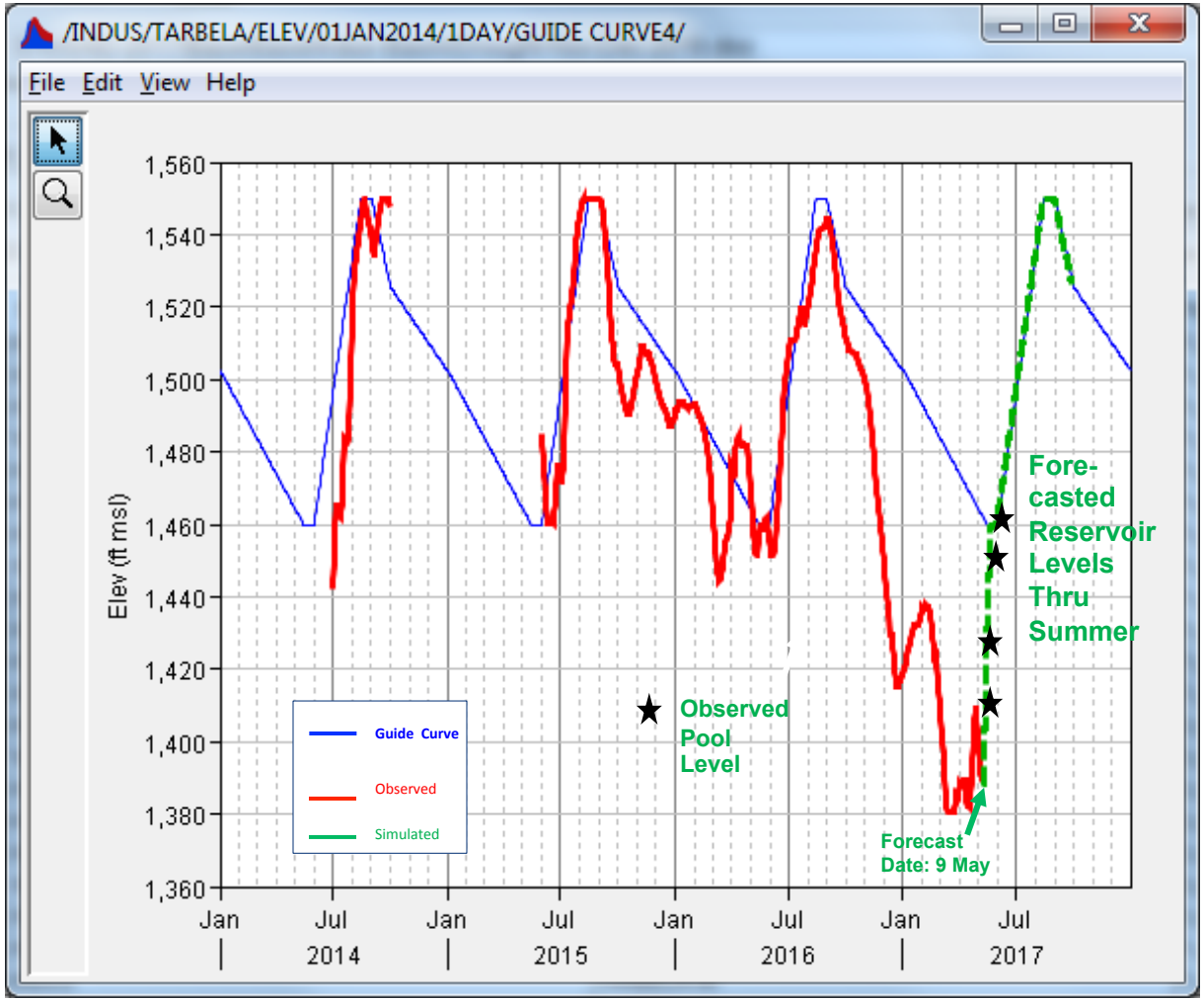
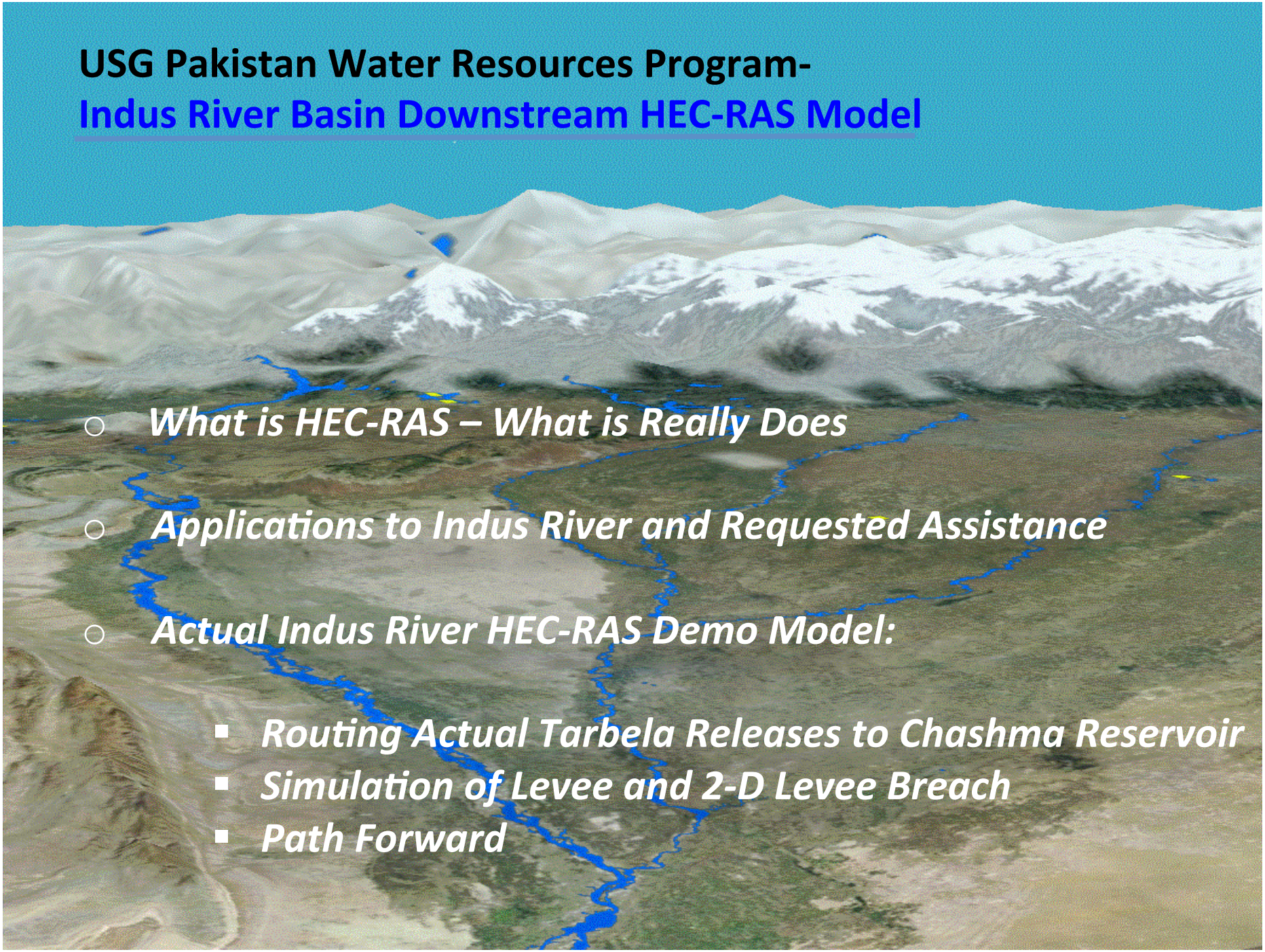


Results from existing HEC-ResSim model:

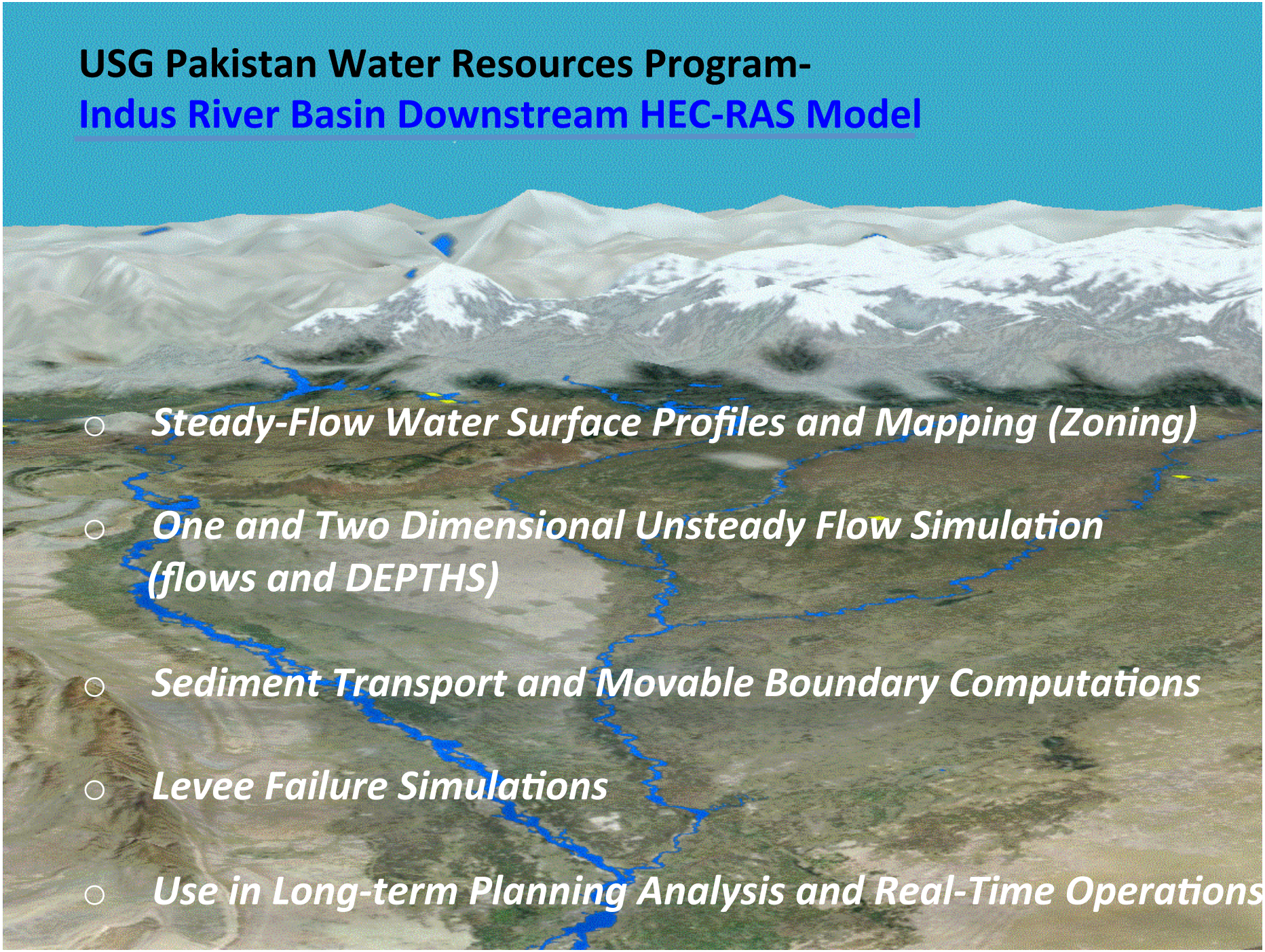
1. Since the initial forecast made 9 May, the observed pool levels have followed forecasted pool levels relatively well.

USG Pakistan Water Resources Program-
Indus River Basin Downstream HEC-RAS Model



- *What is HEC-RAS – What is Really Does*
- *Applications to Indus River and Requested Assistance*
- *Actual Indus River HEC-RAS Demo Model:*
  - *Routing Actual Tarbela Releases to Chashma Reservoir*
  - *Simulation of Levee and 2-D Levee Breach*
  - *Path Forward*

USG Pakistan Water Resources Program-
Indus River Basin Downstream HEC-RAS Model



- *Steady-Flow Water Surface Profiles and Mapping (Zoning)*
- *One and Two Dimensional Unsteady Flow Simulation (flows and DEPTHS)*
- *Sediment Transport and Movable Boundary Computations*
- *Levee Failure Simulations*
- *Use in Long-term Planning Analysis and Real-Time Operations*

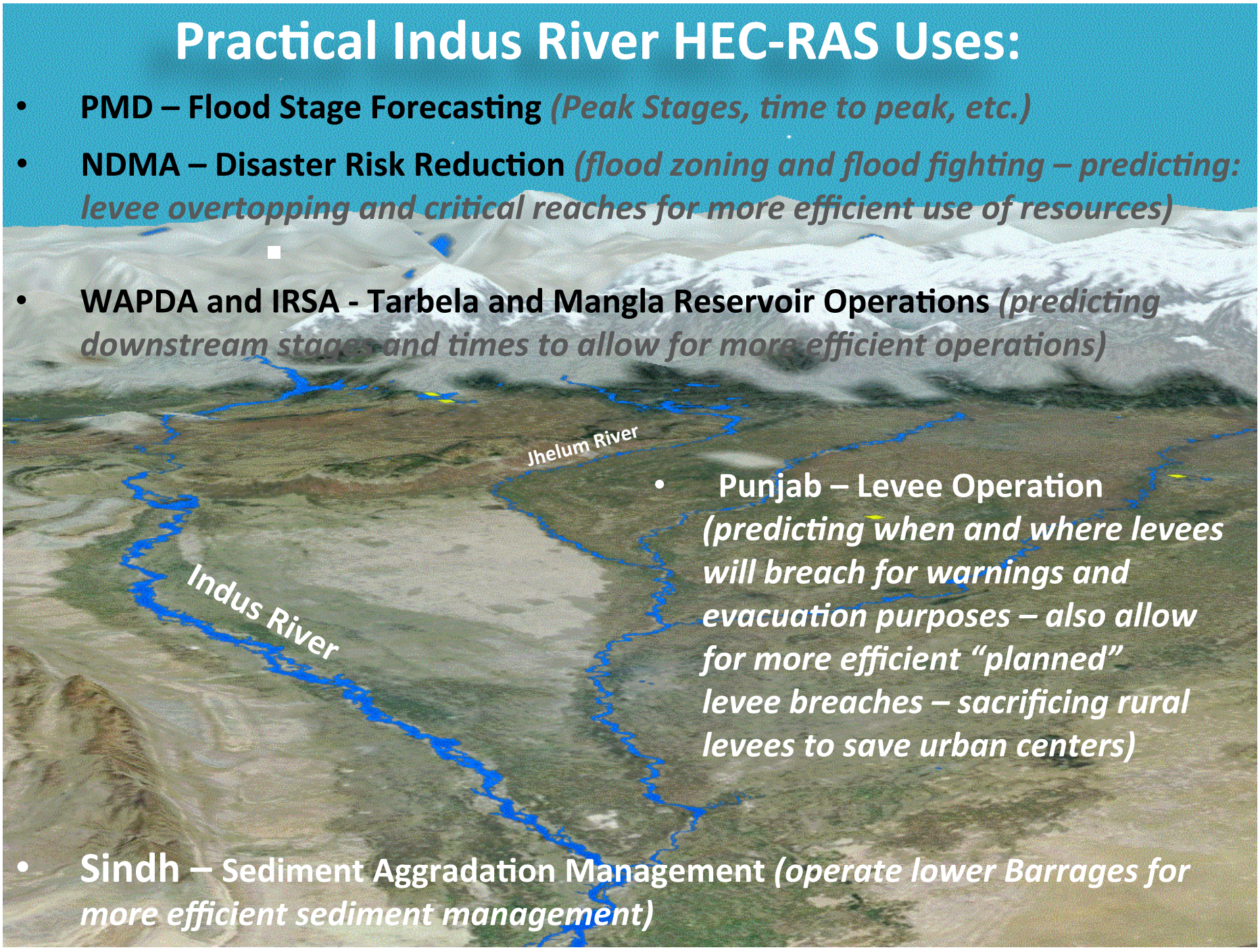
Water Sector Task Force – Friends of Democratic Pakistan:

"Hydrodynamic models will optimize the river system's day-to-day operations by utilizing forecasts of river inflows and real-time water orders coupled with the ability to reproduce the river's behavior."

"Improved service delivery in some parts of the system; more reliable delivery to all water users; greater technology options for irrigators; improved equity for water delivery between users; efficient flood operations to mitigate impacts downstream of the dams; and more confidence in the operation and measurement of the Indus system. River operators will have access to all the information required to make informed and optimal decisions for river operations and for operational planning"

Practical Indus River HEC-RAS Uses:

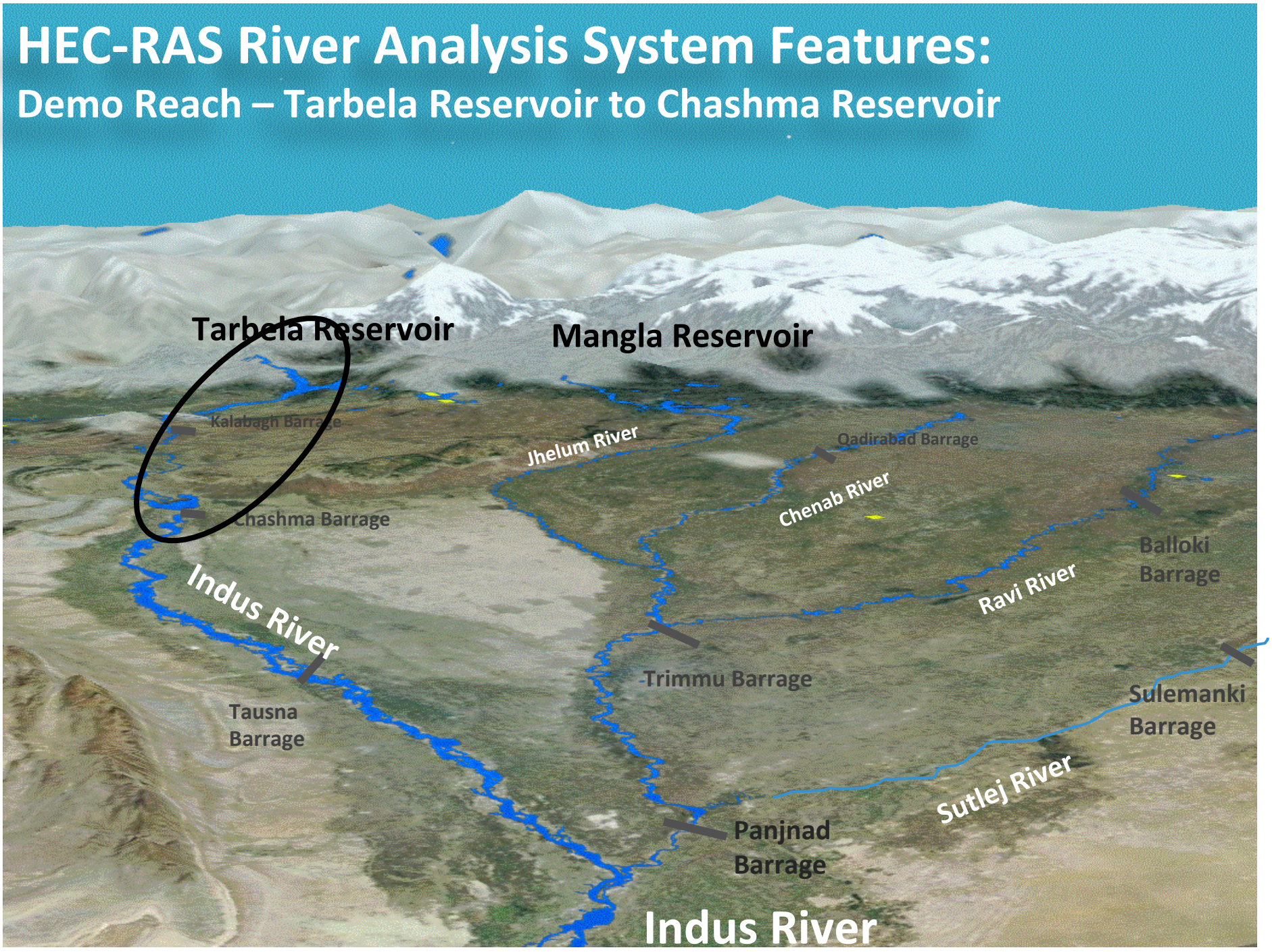
- **PMD – Flood Stage Forecasting** *(Peak Stages, time to peak, etc.)*
- **NDMA – Disaster Risk Reduction** *(flood zoning and flood fighting – predicting: levee overtopping and critical reaches for more efficient use of resources)*
- **WAPDA and IRSA - Tarbela and Mangla Reservoir Operations** *(predicting downstream stages and times to allow for more efficient operations)*



- **Punjab – Levee Operation** *(predicting when and where levees will breach for warnings and evacuation purposes – also allow for more efficient "planned" levee breaches – sacrificing rural levees to save urban centers)*
- **Sindh – Sediment Aggradation Management** *(operate lower Barrages for more efficient sediment management)*

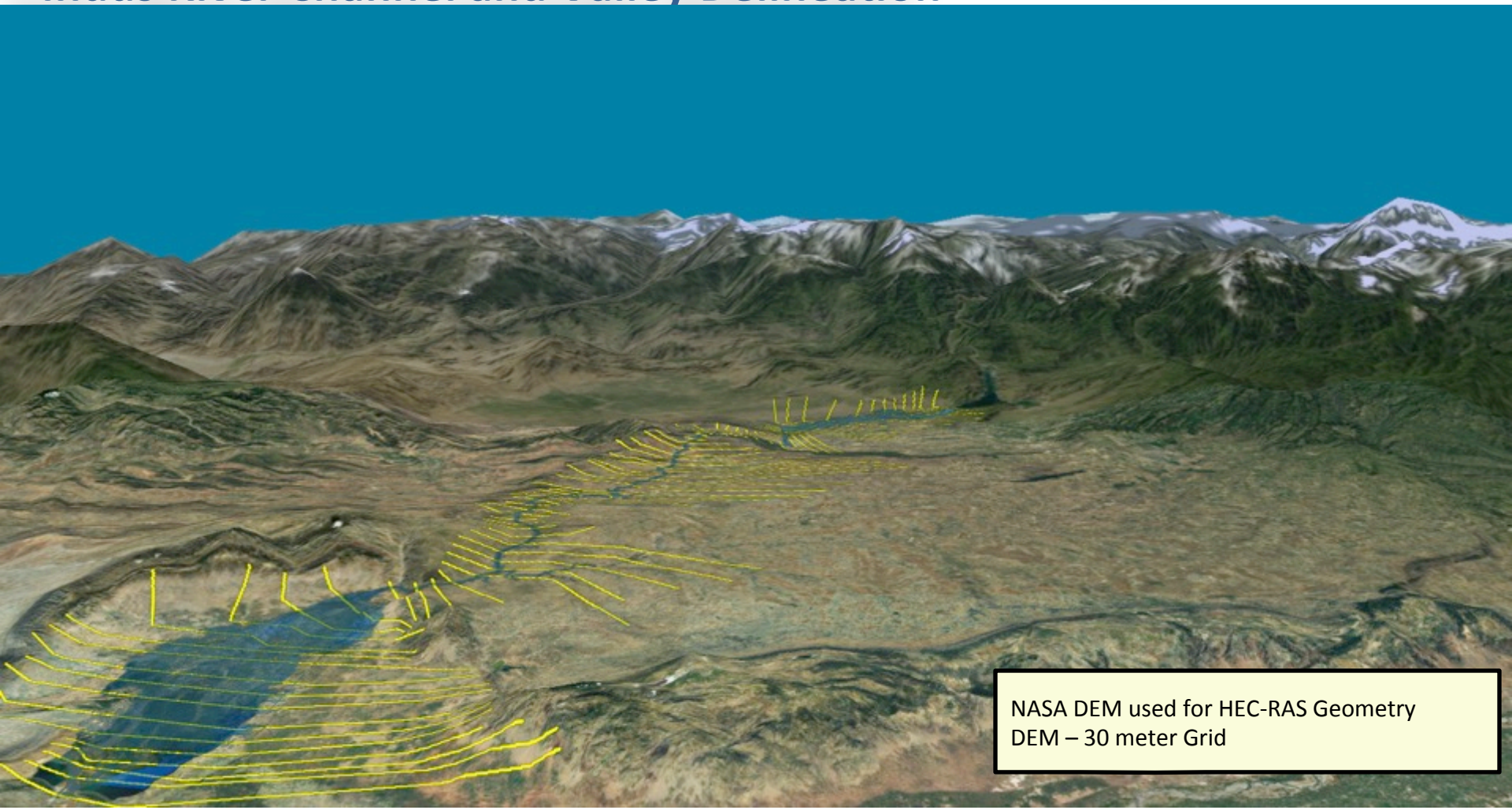
HEC-RAS River Analysis System Features:

Demo Reach – Tarbela Reservoir to Chashma Reservoir



HEC-RAS River Analysis System Data Requirements:

Indus River Channel and Valley Delineation

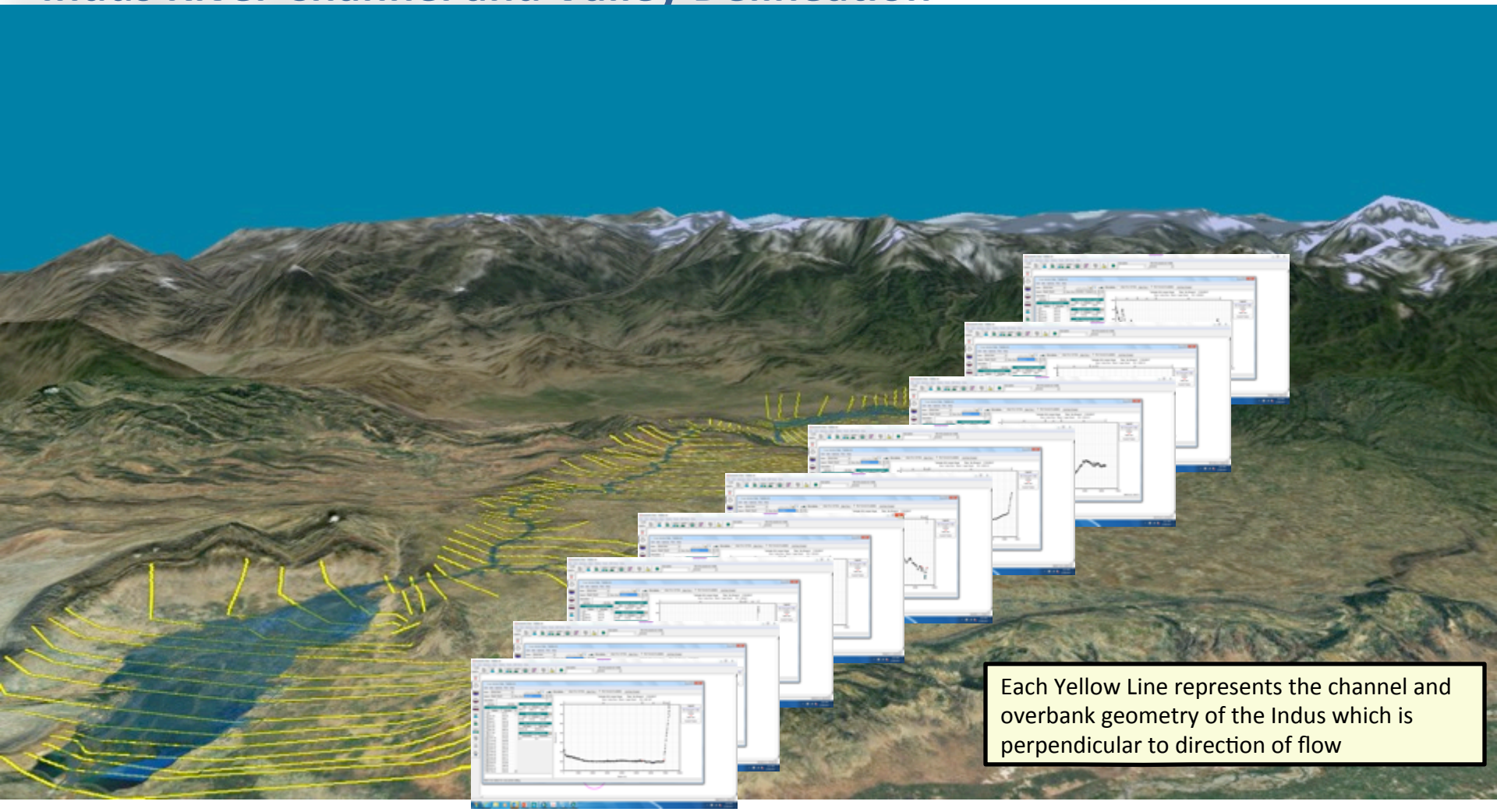


Data Sources: NASA ASTER Global Digital Elevation Model Version 2 – 30 m

350 km reach-length represented by 79 1-D cross-sections

HEC-RAS River Analysis System Data Requirements:

Indus River Channel and Valley Delineation



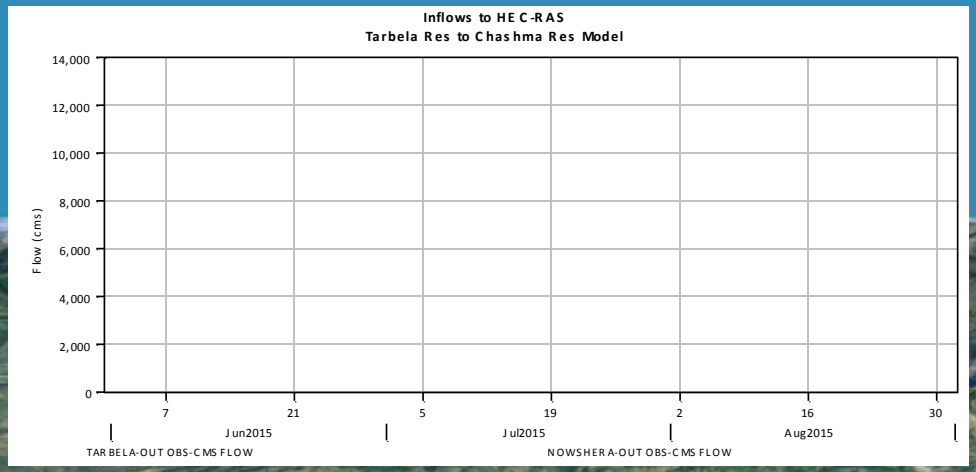
Data Sources: NASA ASTER Global Digital Elevation Model Version 2 – 30 m

350 km reach-length represented by 79 1-D cross-sections

Cross-sections automatically generated with HEC-GeoRAS and imported into HEC-RAS Model

HEC-RAS River Analysis System Unsteady Flow:

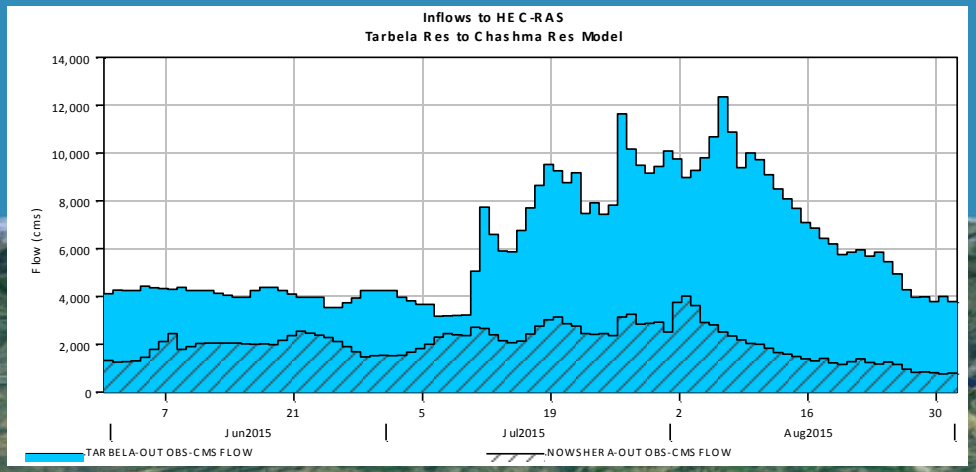
Historic Mean Daily Flows – Tarbela Reservoir and Kabul River 01Jun2015-31Aug2015



Upstream Boundary for model was 3 months of Tarbela Reservoir mean daily releases, supplemented with Kabul River Tributary Flows

HEC-RAS River Analysis System Unsteady Flow:

Historic Mean Daily Flows – Tarbela Reservoir and Kabul River 01Jun2015-31Aug2015



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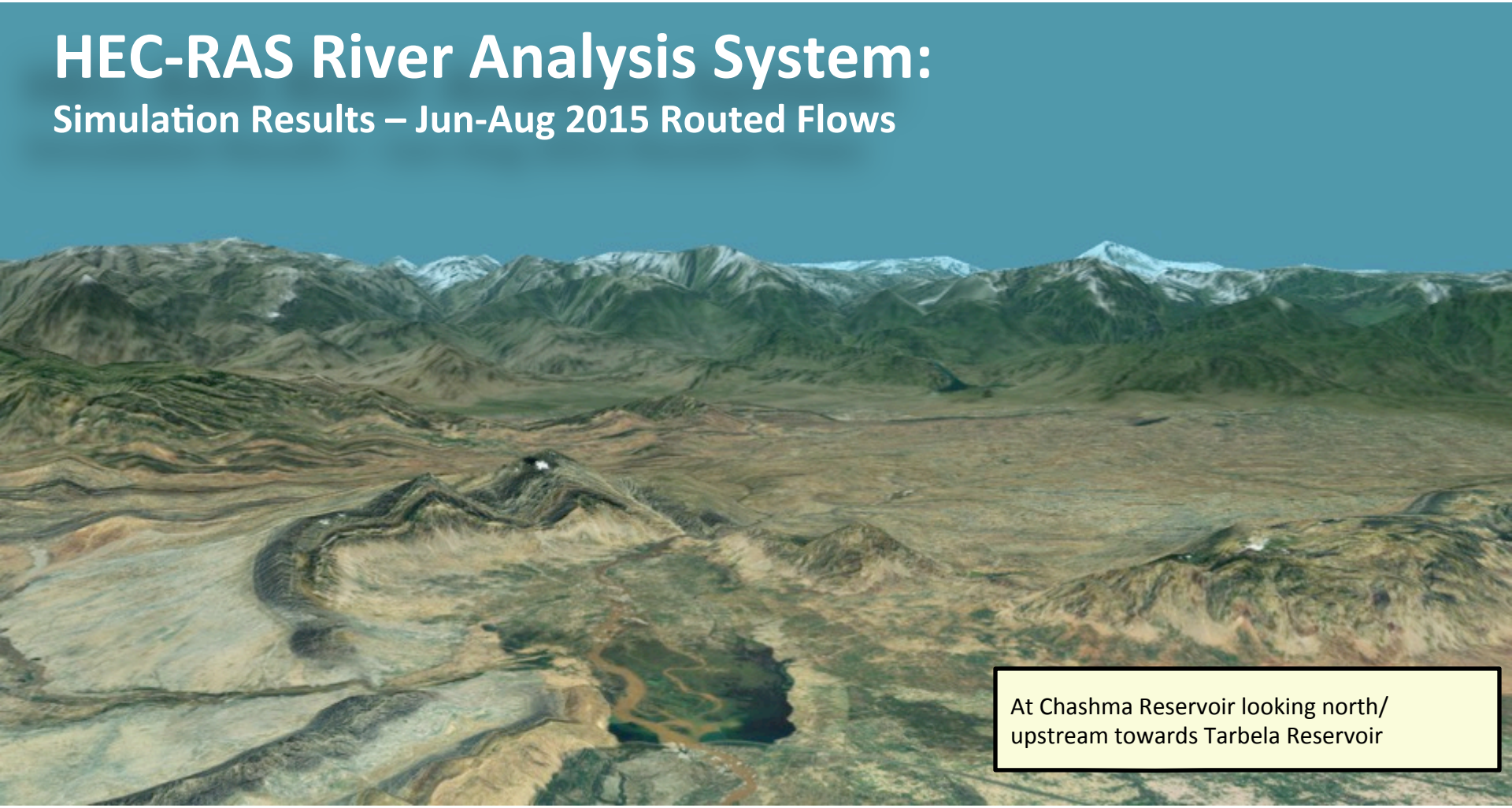
HEC-RAS River Analysis System:

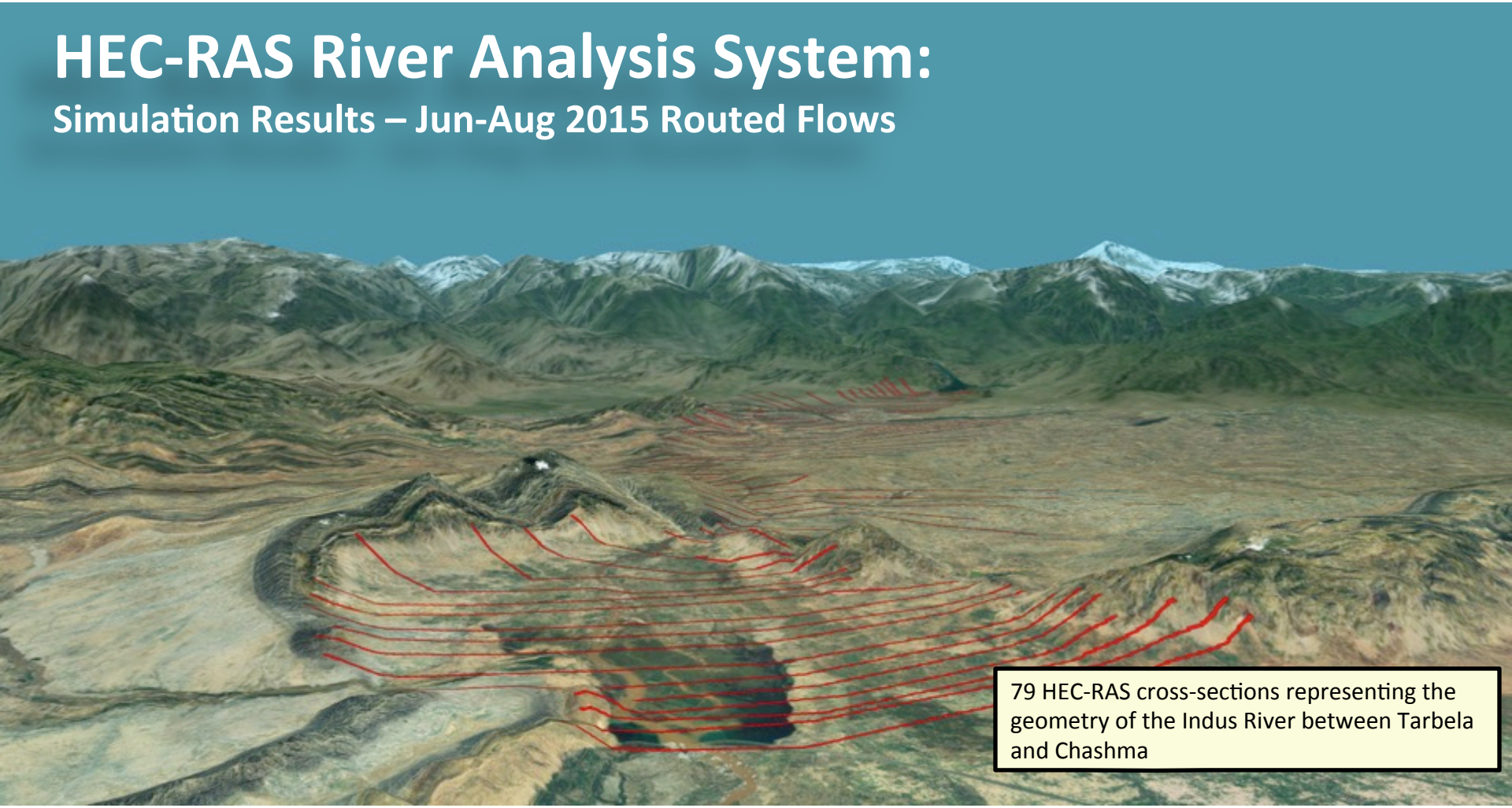
Simulation Results – Jun-Aug 2015 Routed Flows



At Chashma Reservoir looking north/
upstream towards Tarbela Reservoir

HEC-RAS River Analysis System:

Simulation Results – Jun-Aug 2015 Routed Flows



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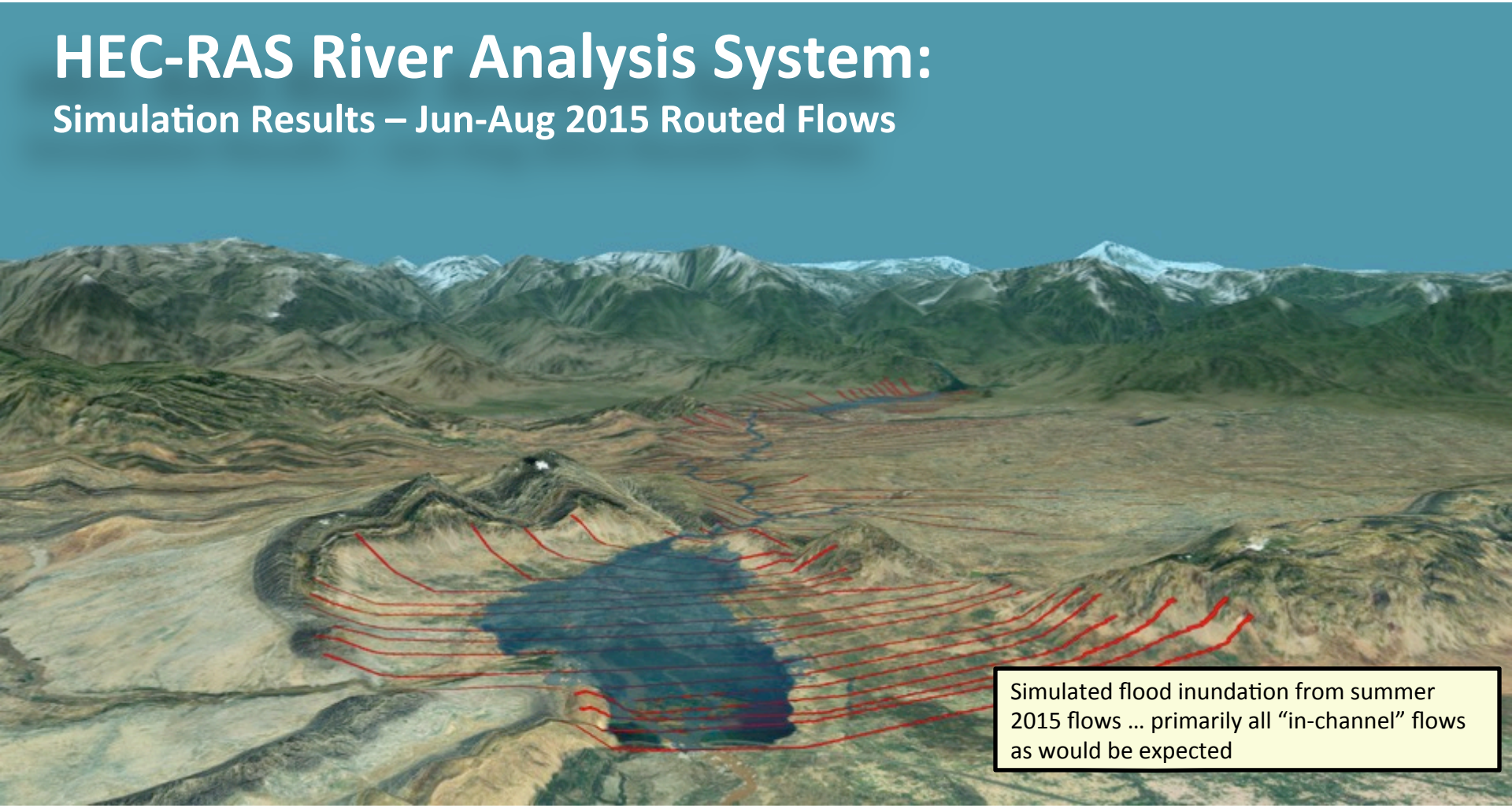
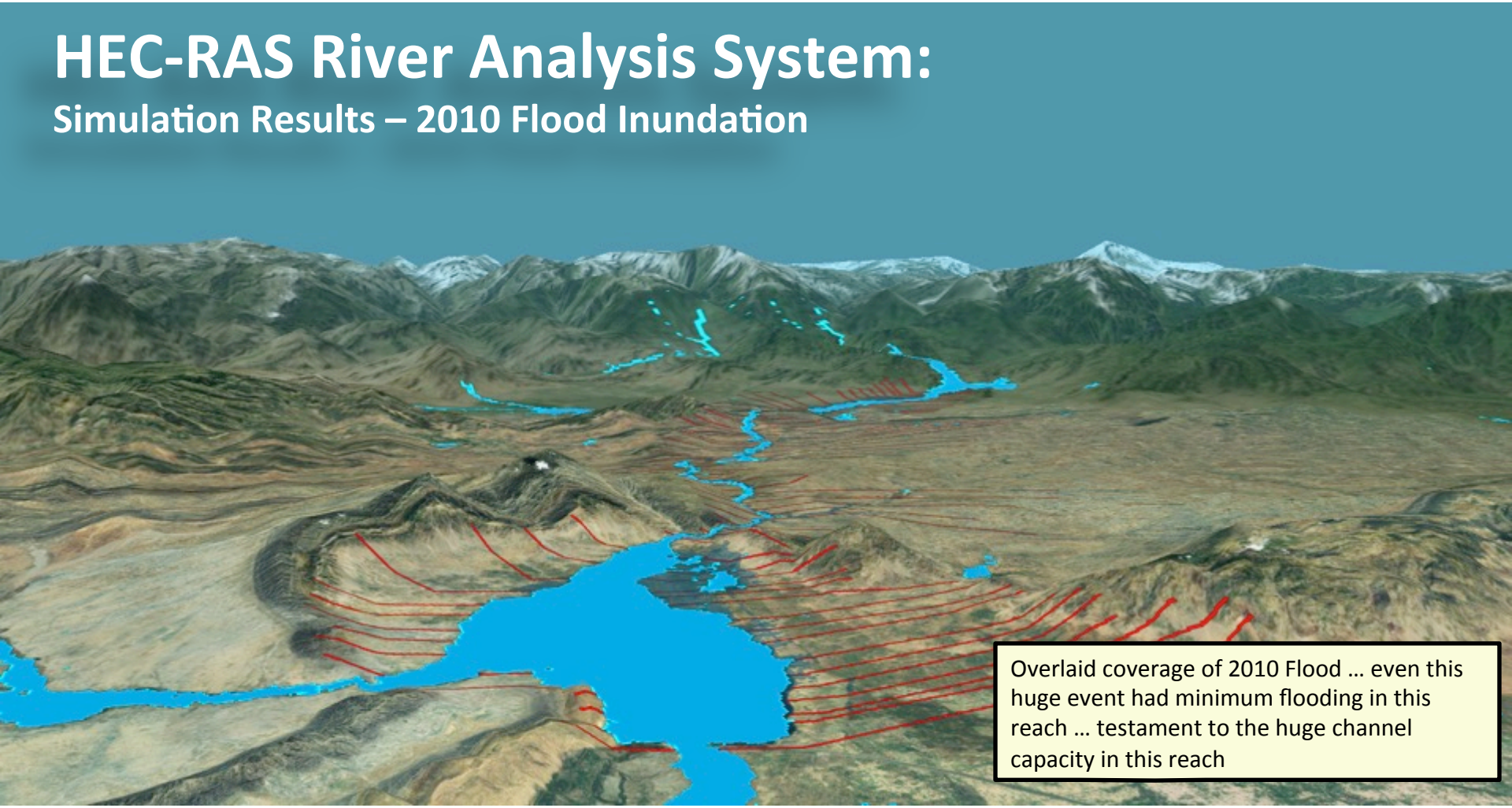
Simulation Results – Jun-Aug 2015 Routed Flows



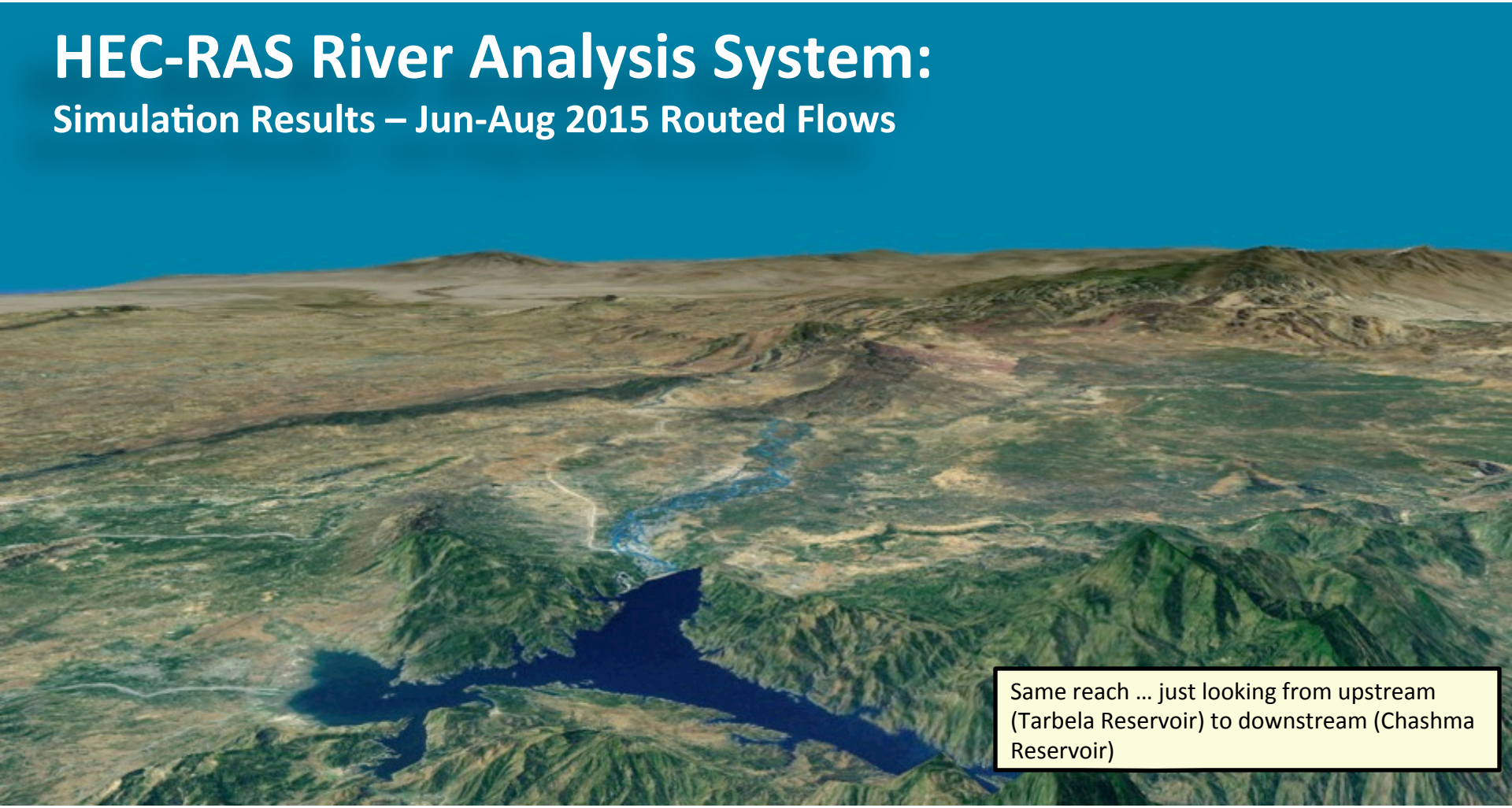
HEC-RAS River Analysis System:

Simulation Results – 2010 Flood Inundation



HEC-RAS River Analysis System:

Simulation Results – Jun-Aug 2015 Routed Flows



HEC-RAS River Analysis System:

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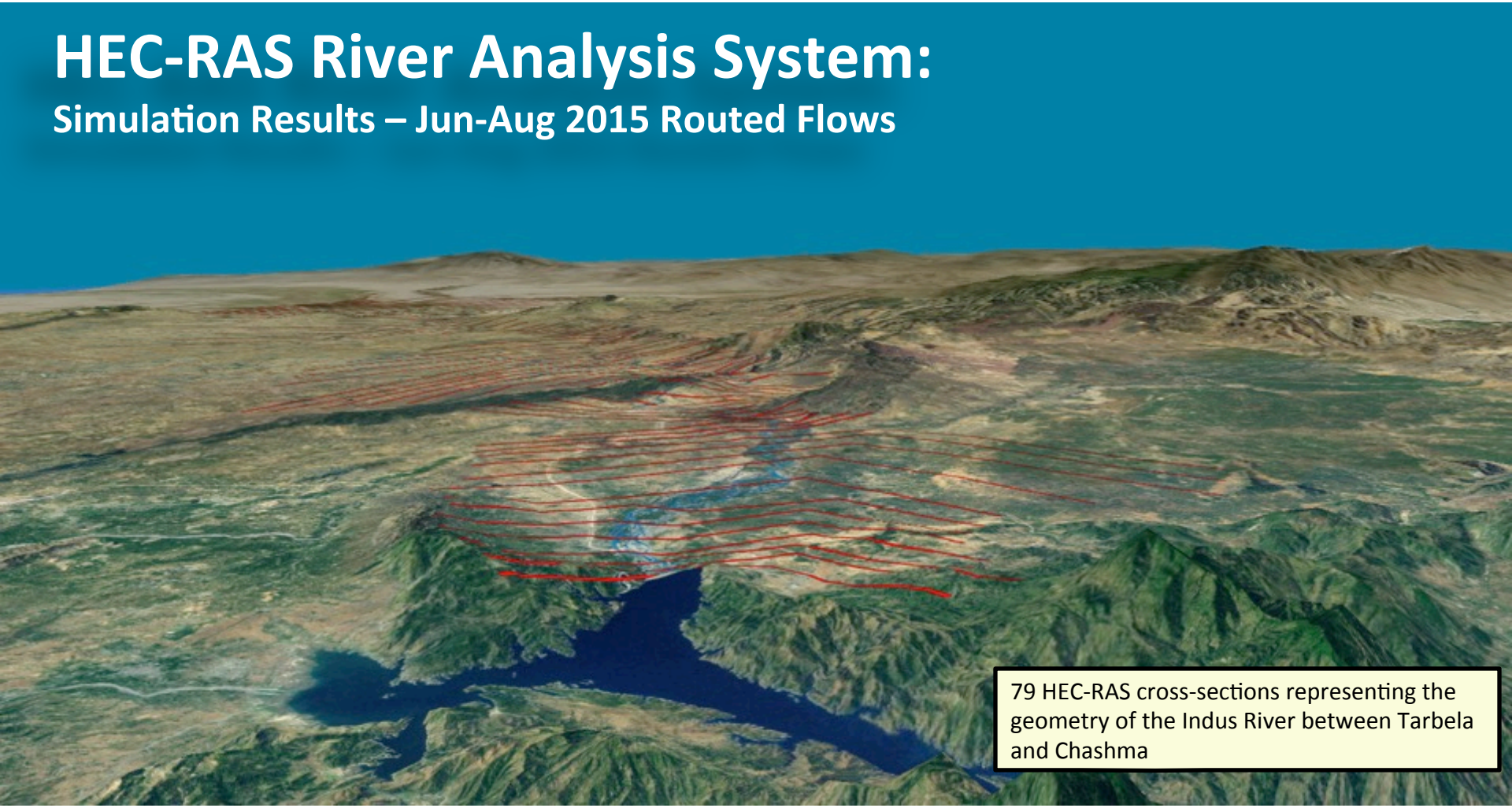
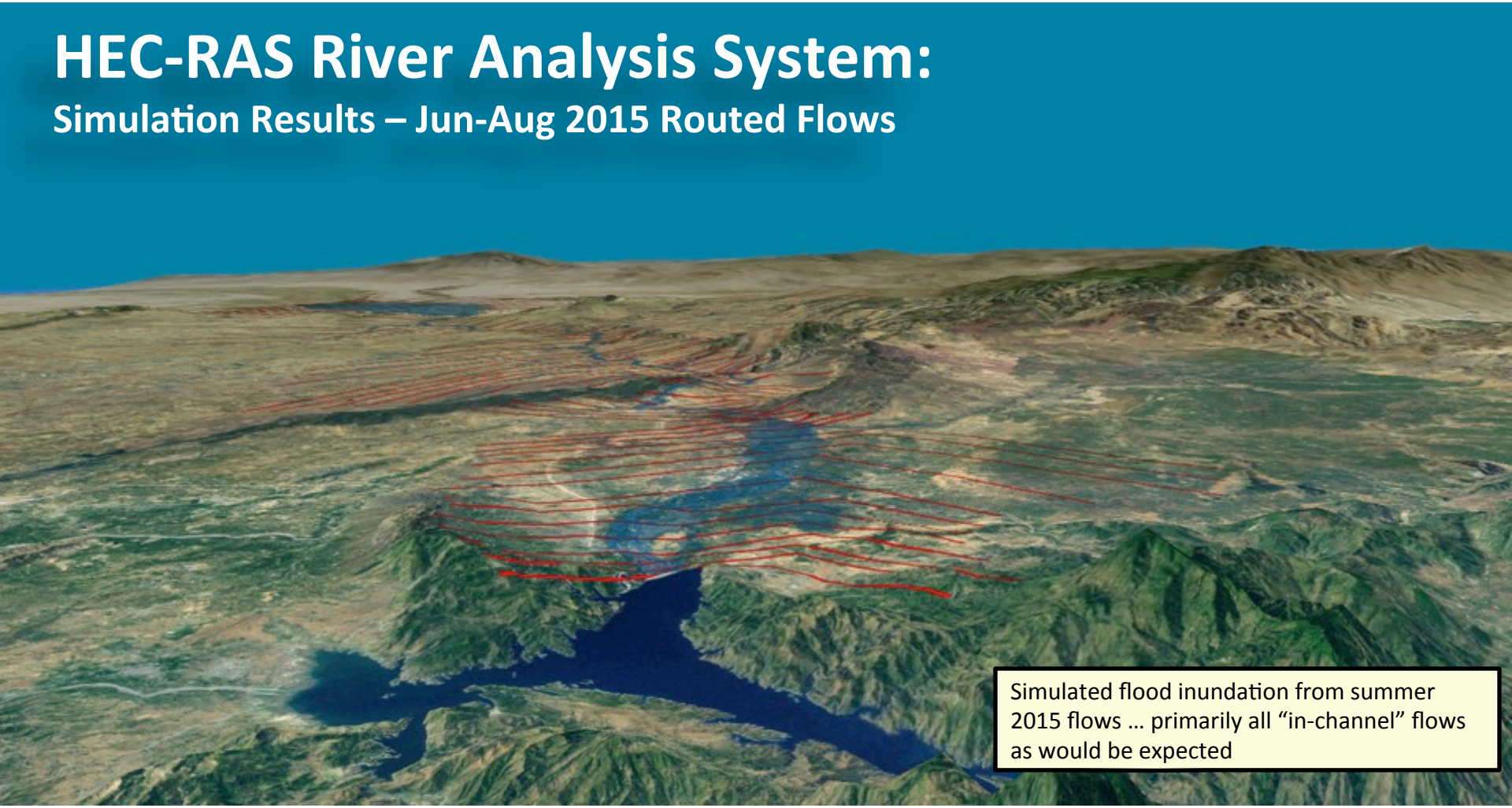


HEC-RAS River Analysis System:

Simulation Results – Jun-Aug 2015 Routed Flows



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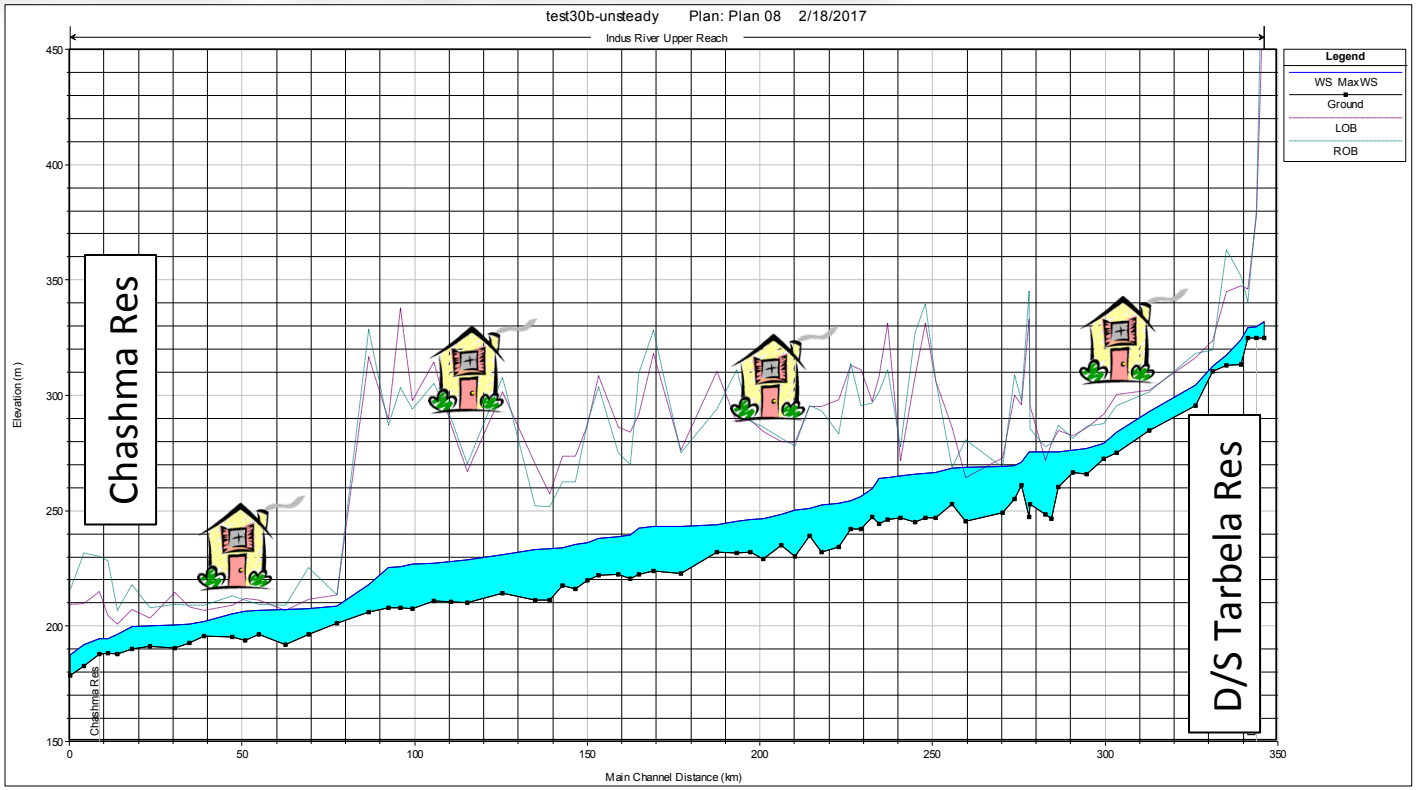


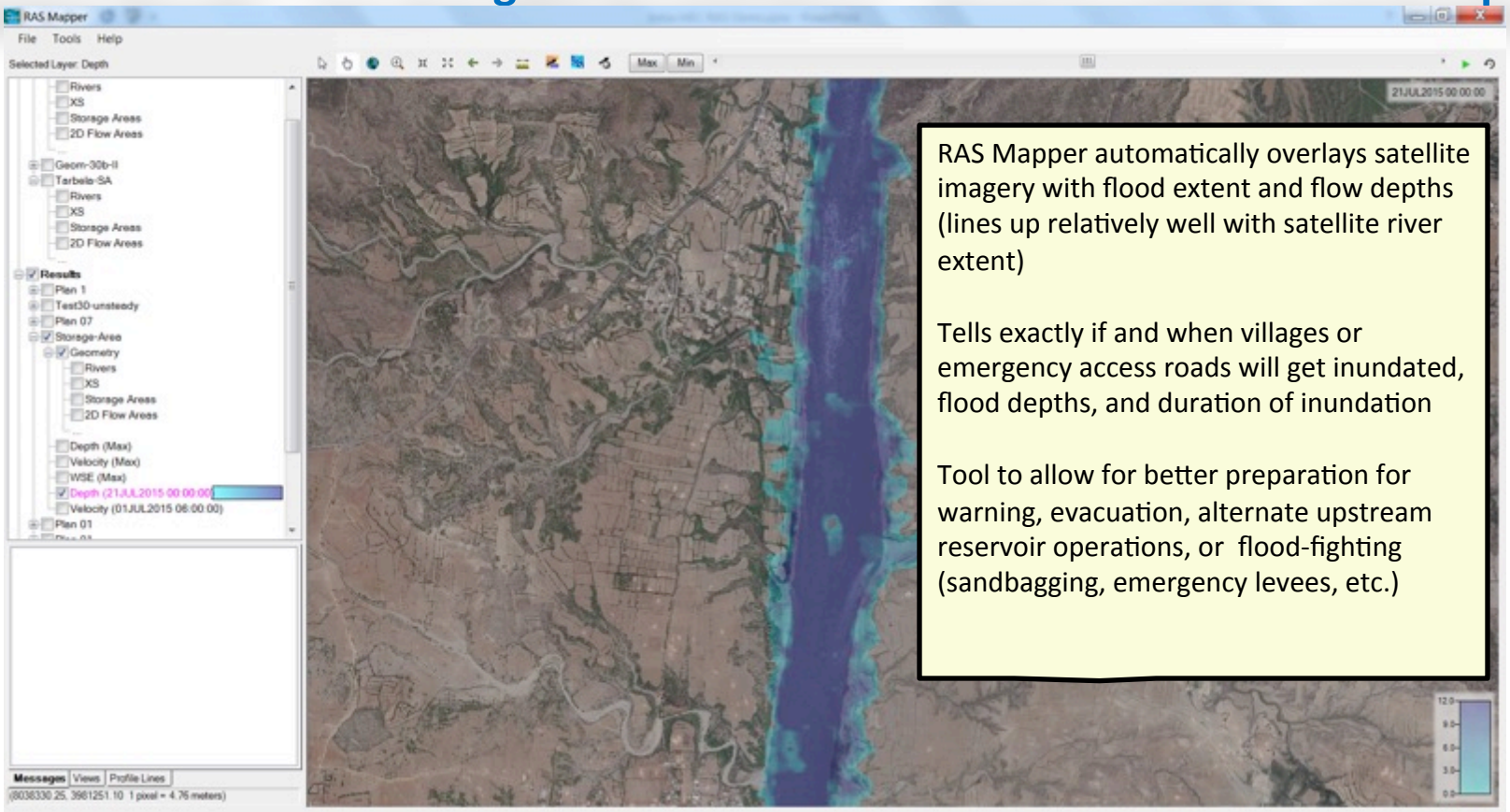
Simulated flow profile … reflective of "normal high flows" … all within channel banks and no appreciable damaging flows above overbanks

HEC-RAS River Analysis System:

Simulation Results – Jun-Aug 2015 Routed Flows – Flood Inundation and Depths

HEC-RAS River Analysis System:

Simulation Results – Jun-Aug 2015 Routed Flows – Flood Inundation and Depths



RAS Mapper automatically overlays satellite imagery with flood extent and flow depths (lines up relatively well with satellite river extent)

Tells exactly if and when villages or emergency access roads will get inundated, flood depths, and duration of inundation

Tool to allow for better preparation for warning, evacuation, alternate upstream reservoir operations, or flood-fighting (sandbagging, emergency levees, etc.)

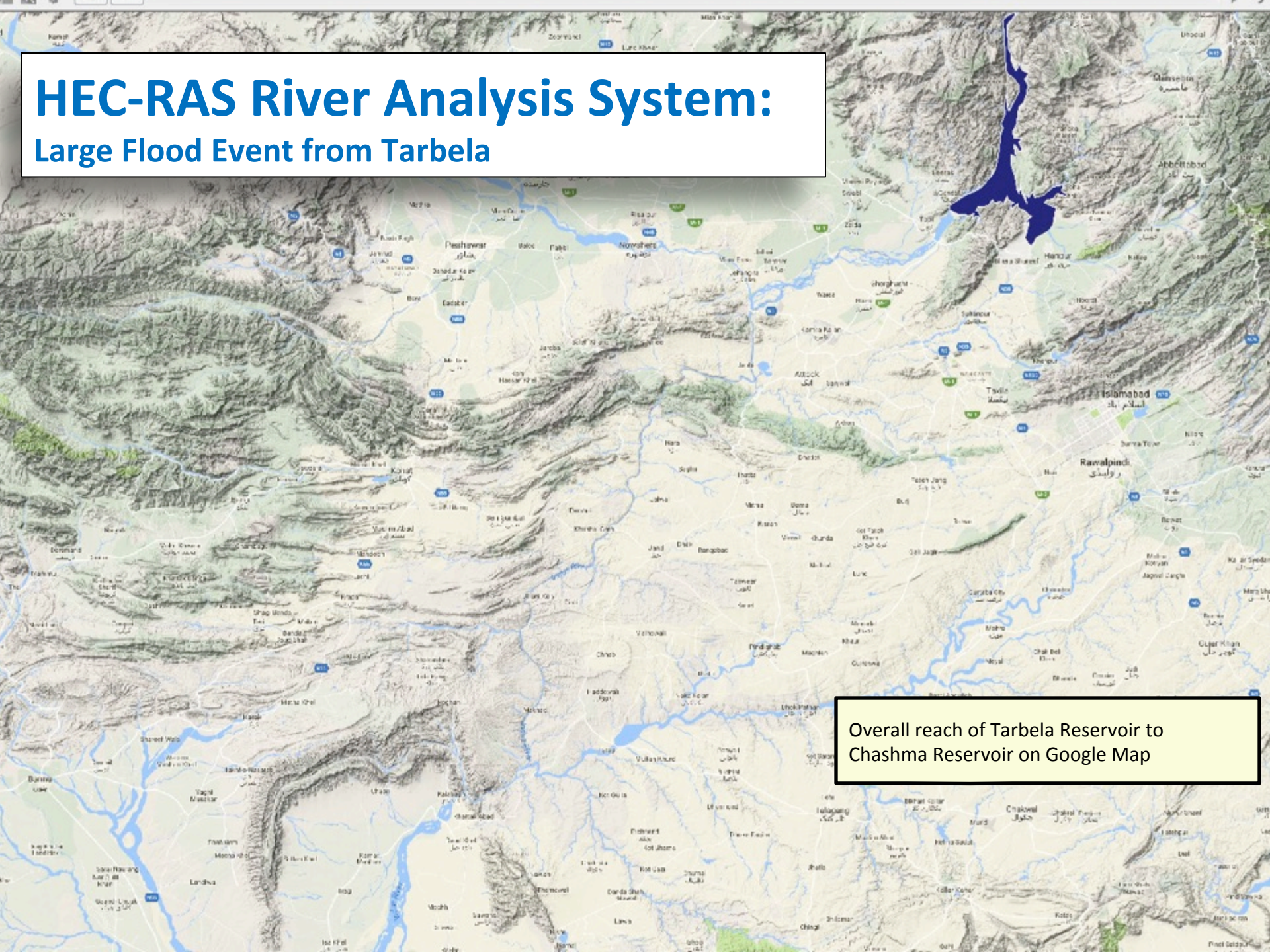
HEC-RAS River Analysis System:

Simulation Results – Jun-Aug 2015 Routed Flows – Flood Inundation and Depths

As an example, this closeup shows this village and road would be safe and dry (as would expect for relatively normal Tarbela summer release) – though there may be shallow overbank flooding right next to river

HEC-RAS River Analysis System:

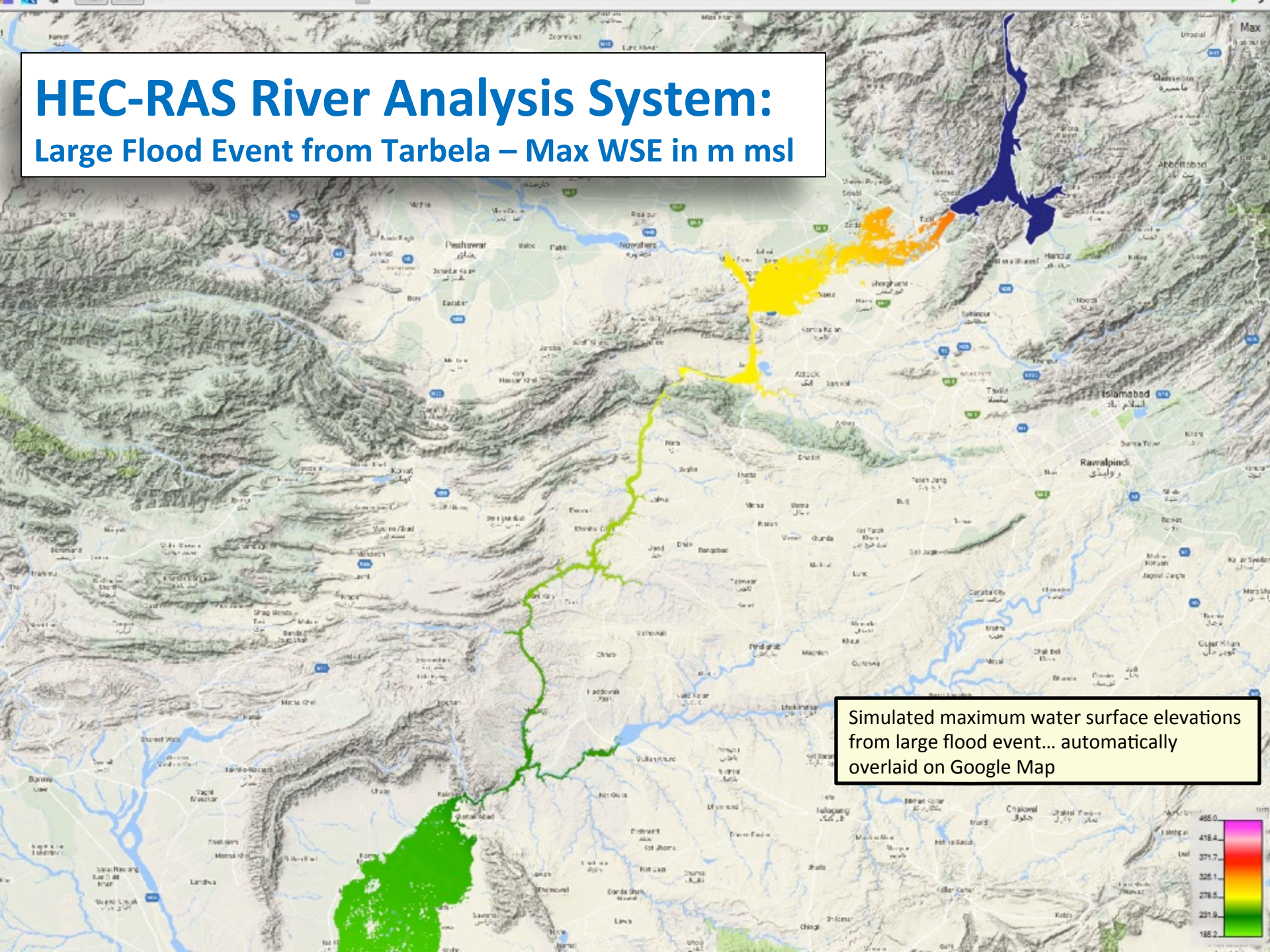
Large Flood Event from Tarbela



Overall reach of Tarbela Reservoir to Chashma Reservoir on Google Map

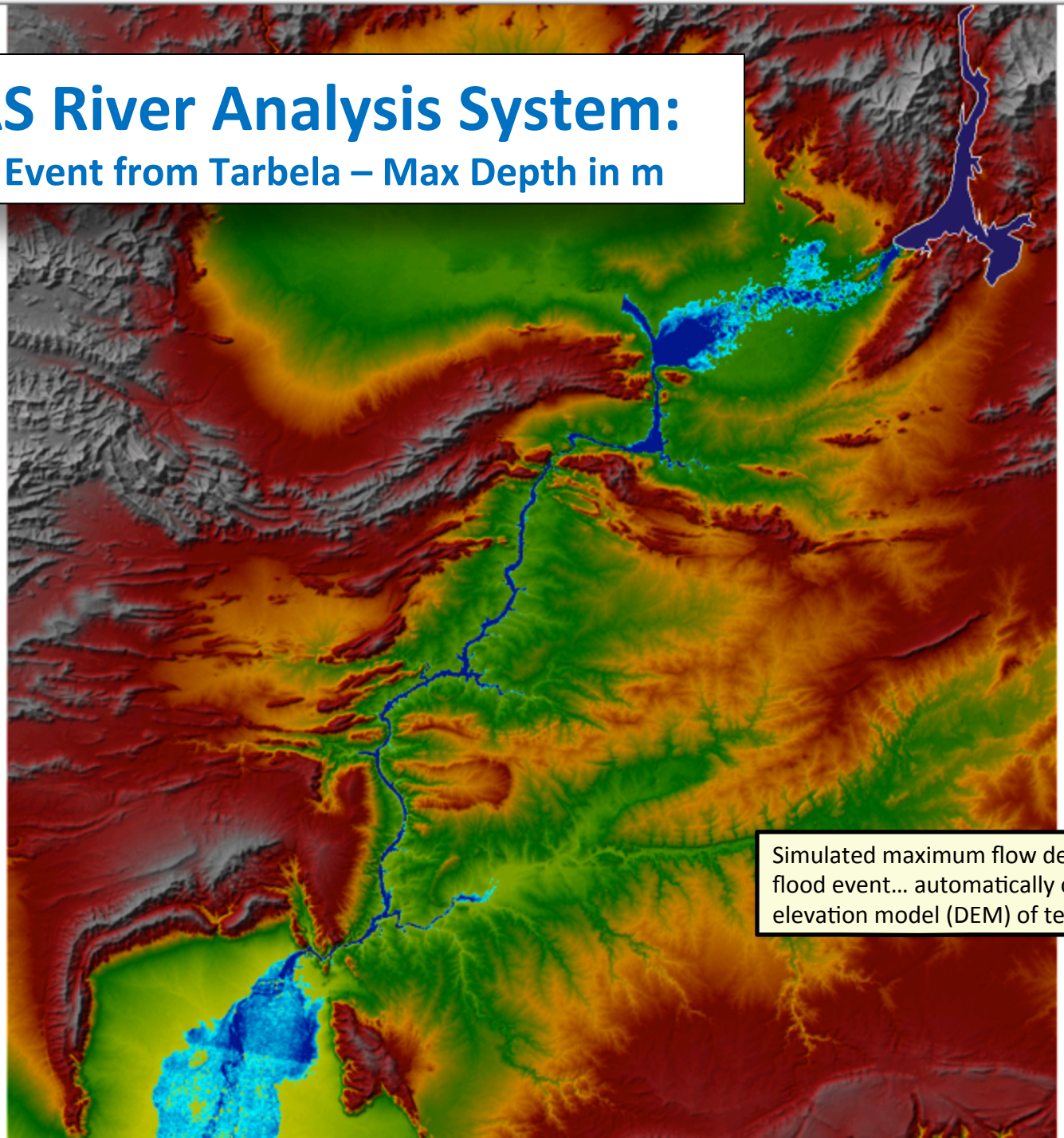
HEC-RAS River Analysis System:

Large Flood Event from Tarbela – Max WSE in m msl



HEC-RAS River Analysis System:

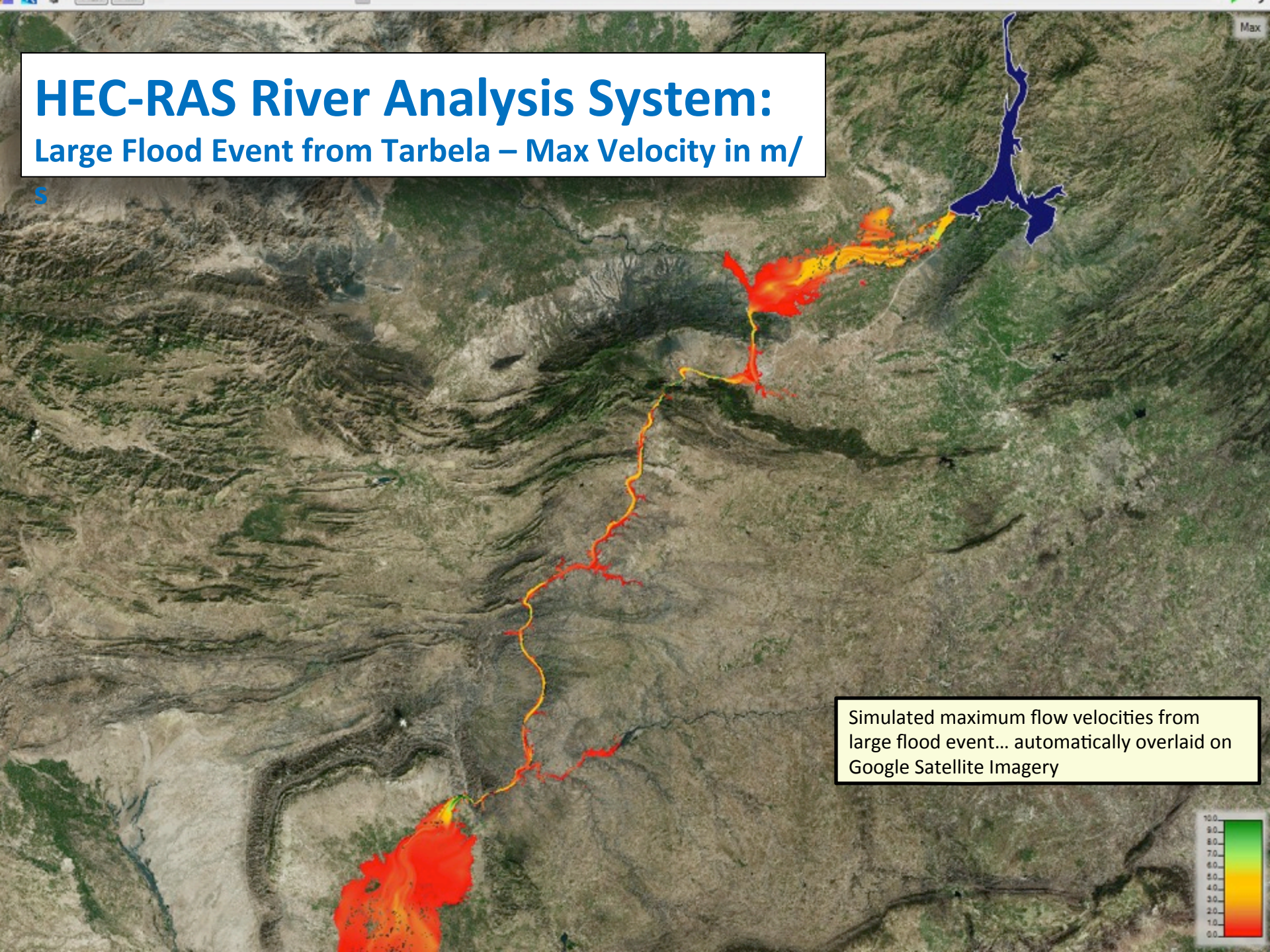
Large Flood Event from Tarbela – Max Depth in m



Simulated maximum flow depths from large flood event… automatically overlaid on digital elevation model (DEM) of terrain

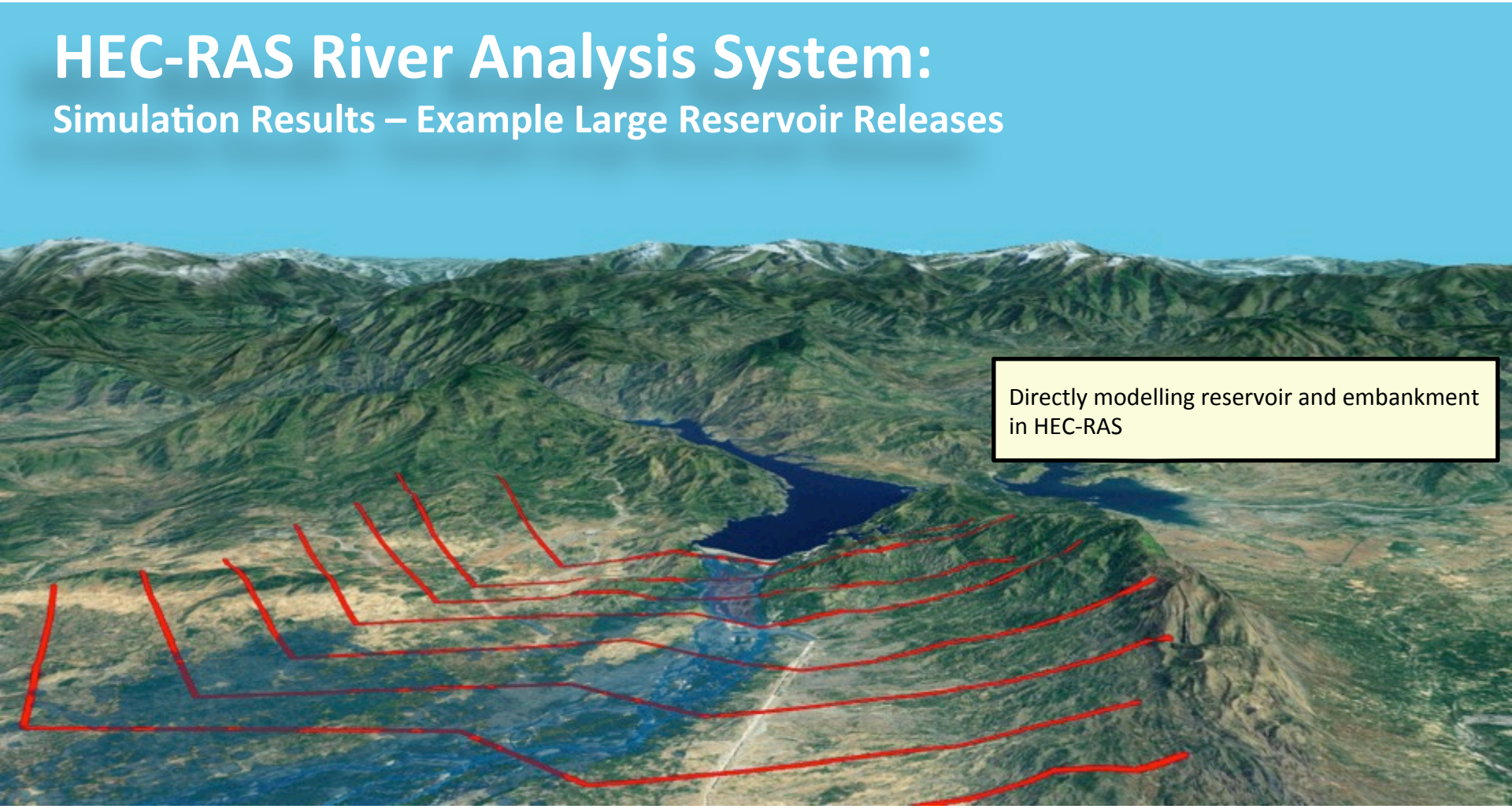
HEC-RAS River Analysis System:

Large Flood Event from Tarbela – Max Velocity in m/s



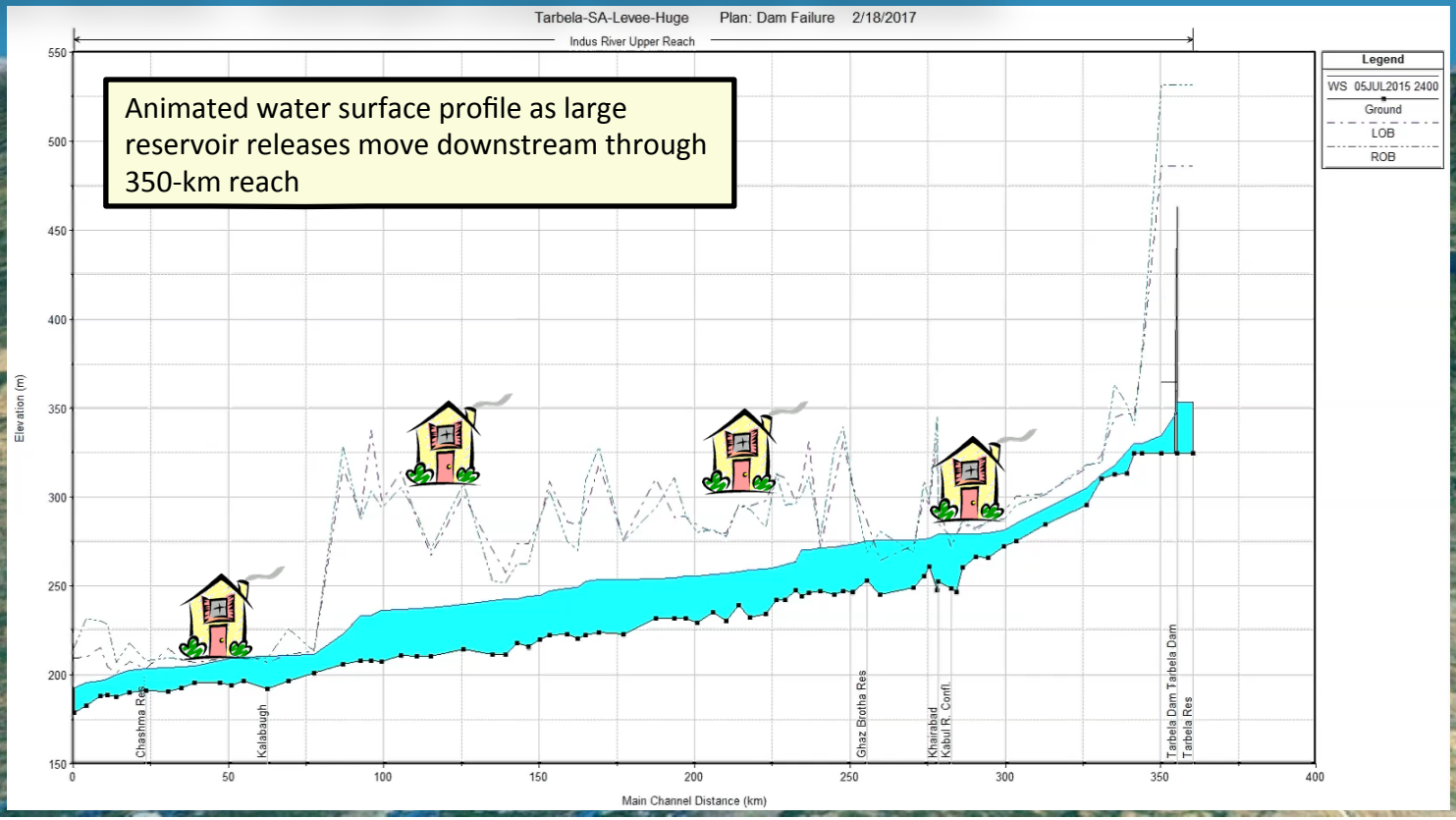
HEC-RAS River Analysis System:

Simulation Results – Example Large Reservoir Releases



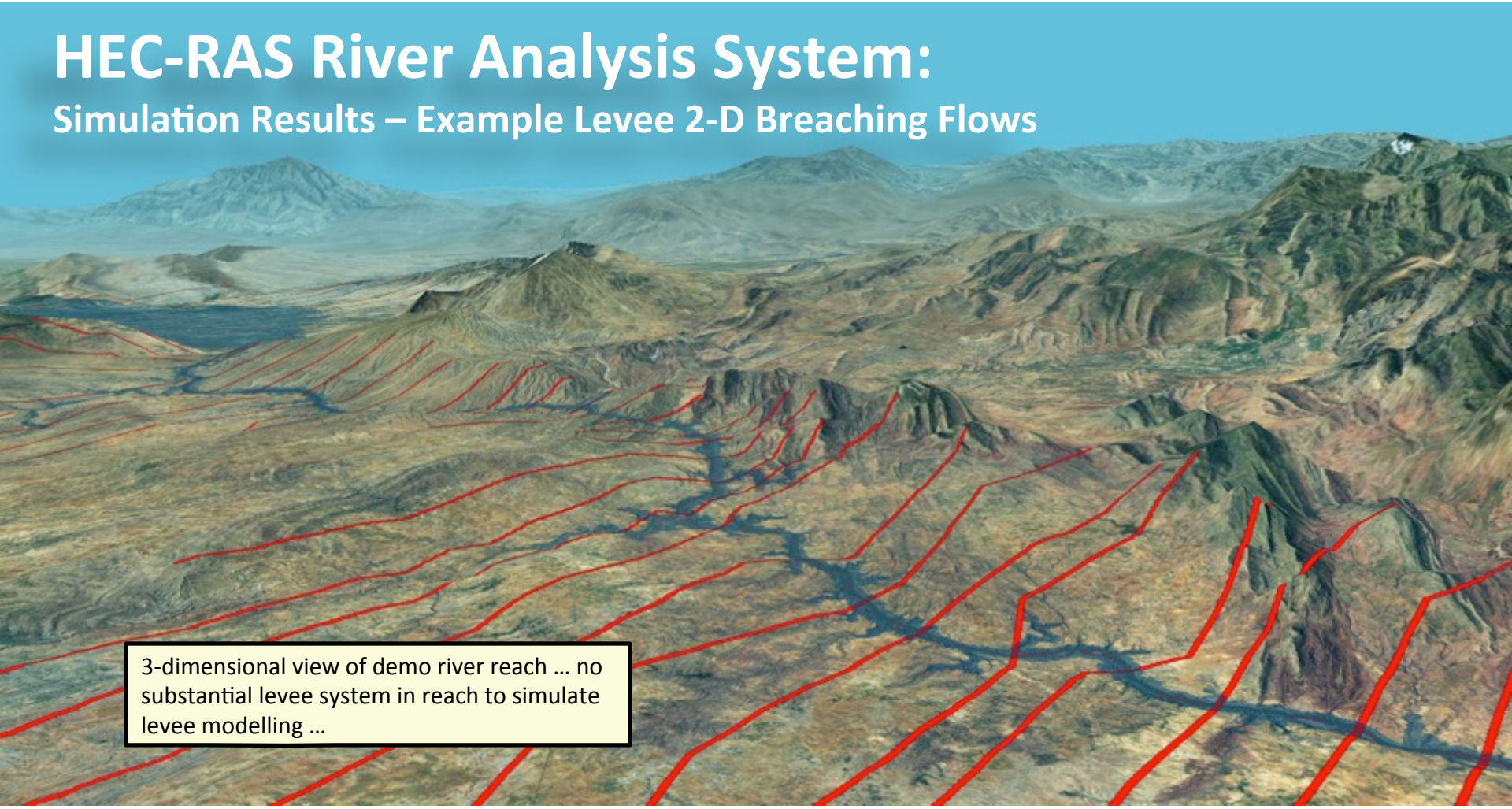
HEC-RAS River Analysis System:

Simulation Results – Example Large Reservoir Releases



HEC-RAS River Analysis System:

Simulation Results – Example Levee 2-D Breaching Flows



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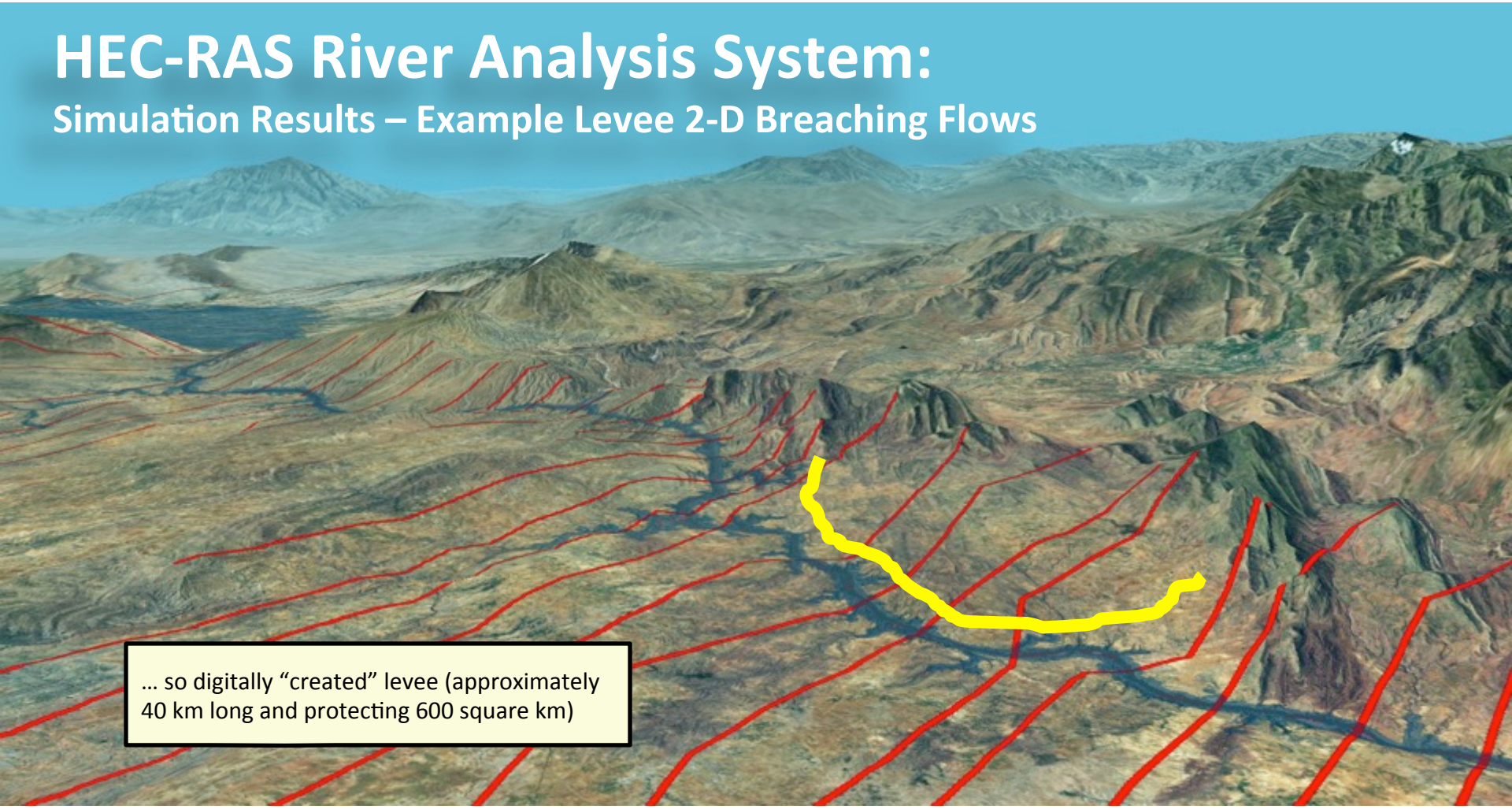

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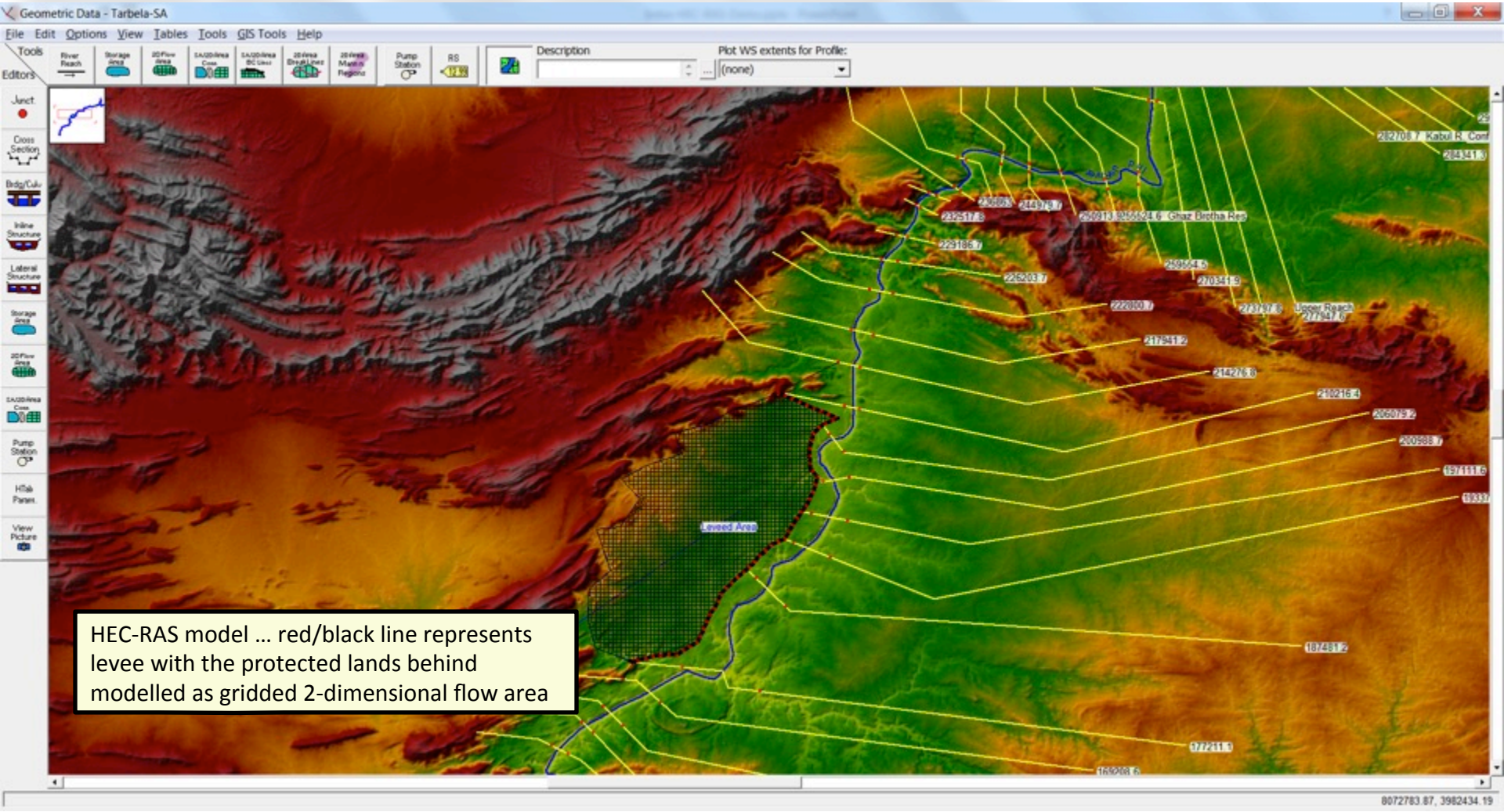
Simulation Results – Example Levee 2-D Breaching Flows



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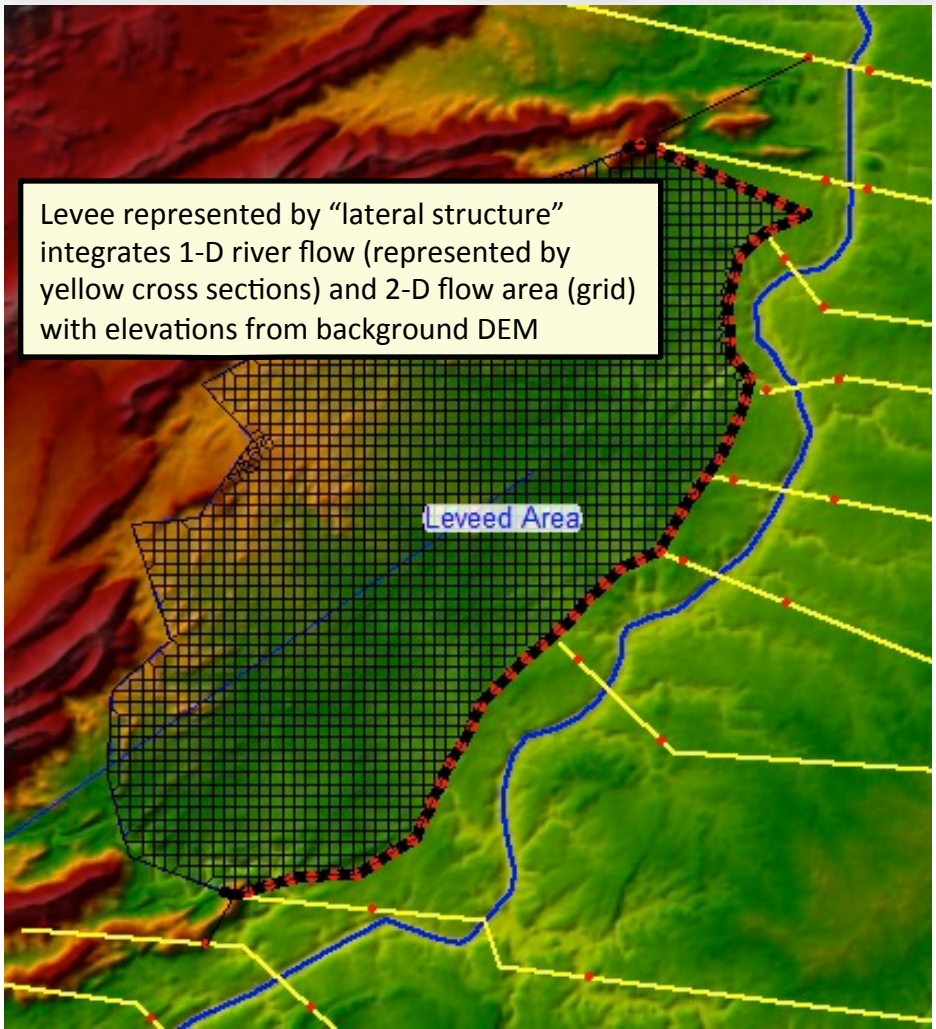

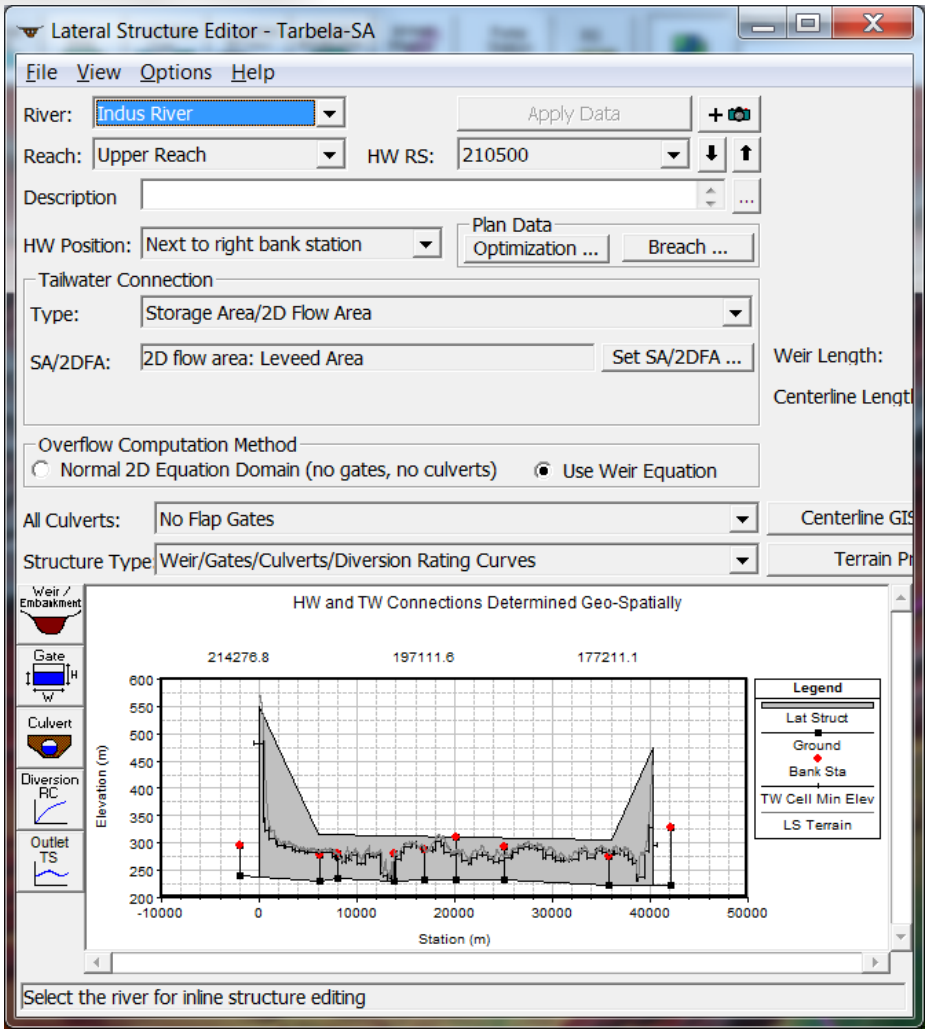

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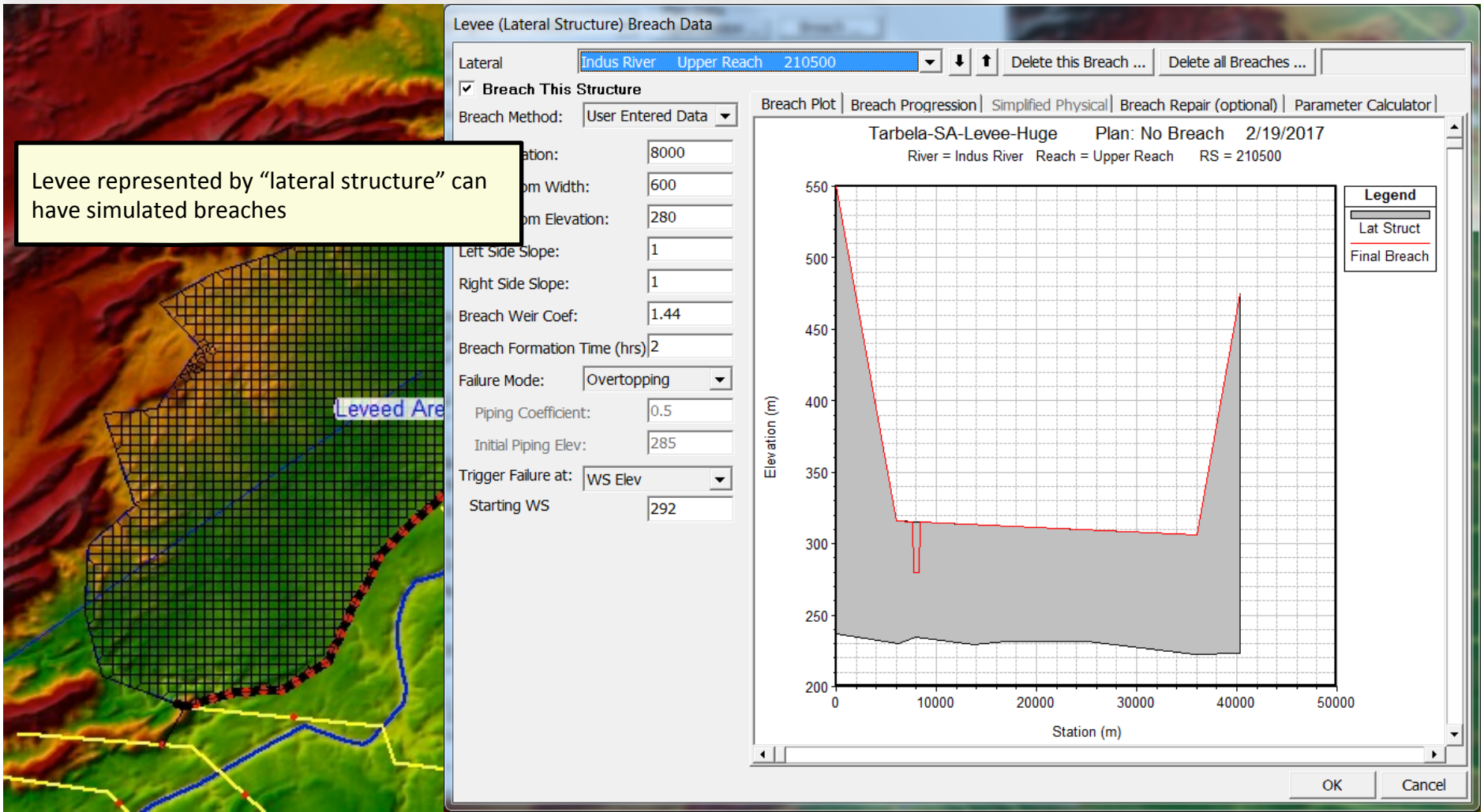
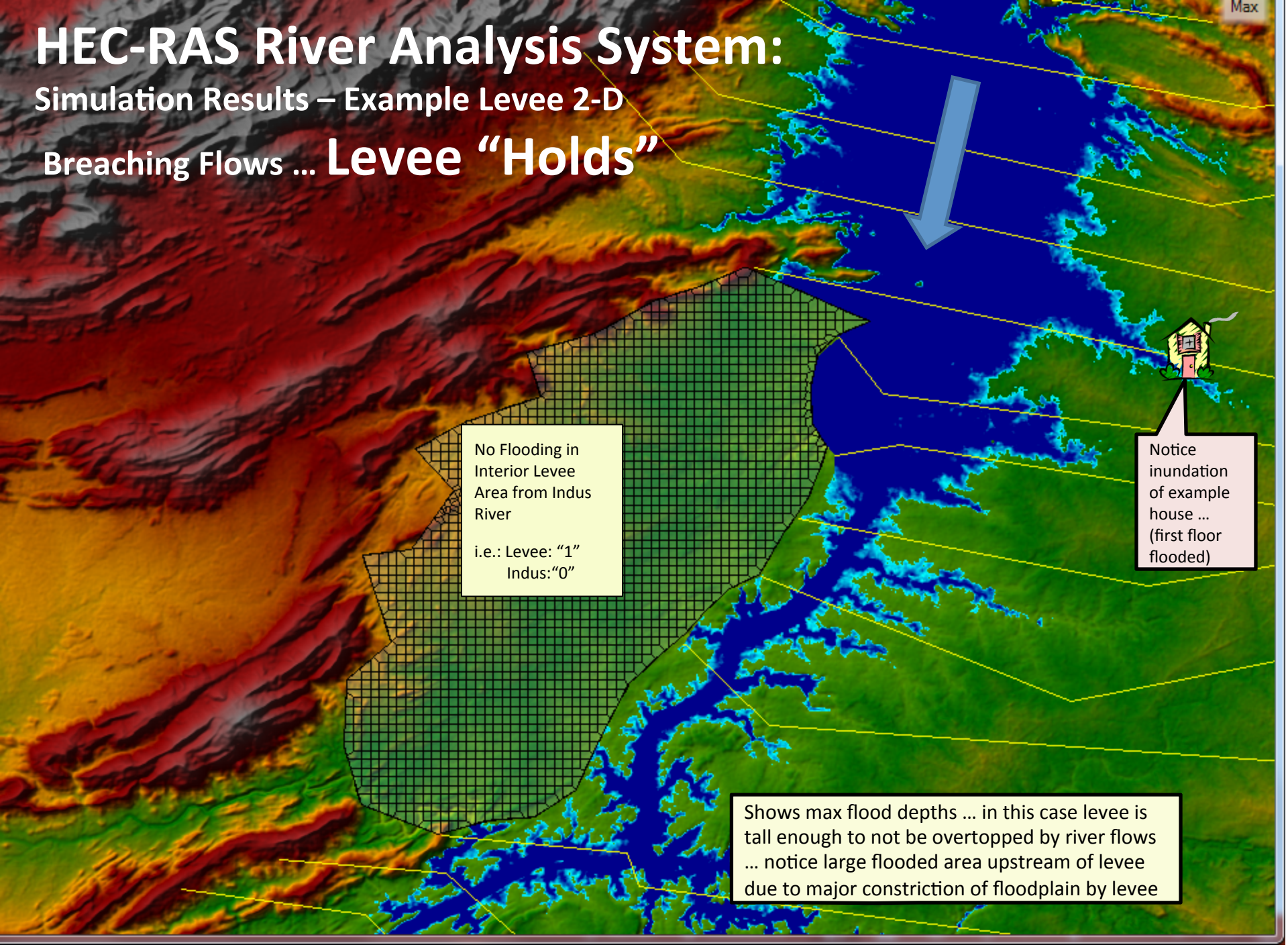
Simulation Results – Example Levee 2-D Breaching Flows



HEC-RAS River Analysis System:

Simulation Results – Example Levee 2-D

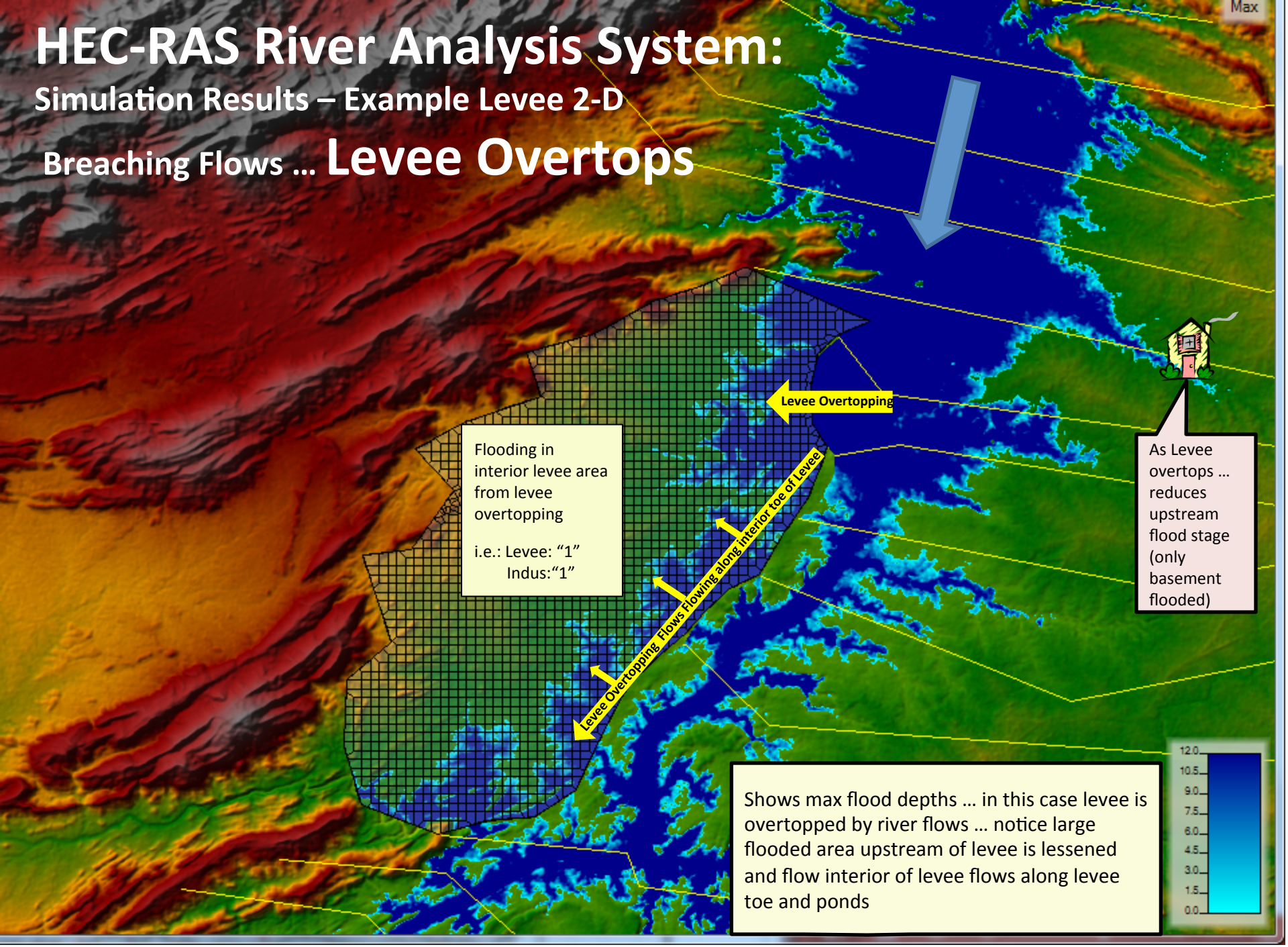
Breaching Flows … Levee "Holds"



HEC-RAS River Analysis System:

Simulation Results – Example Levee 2-D

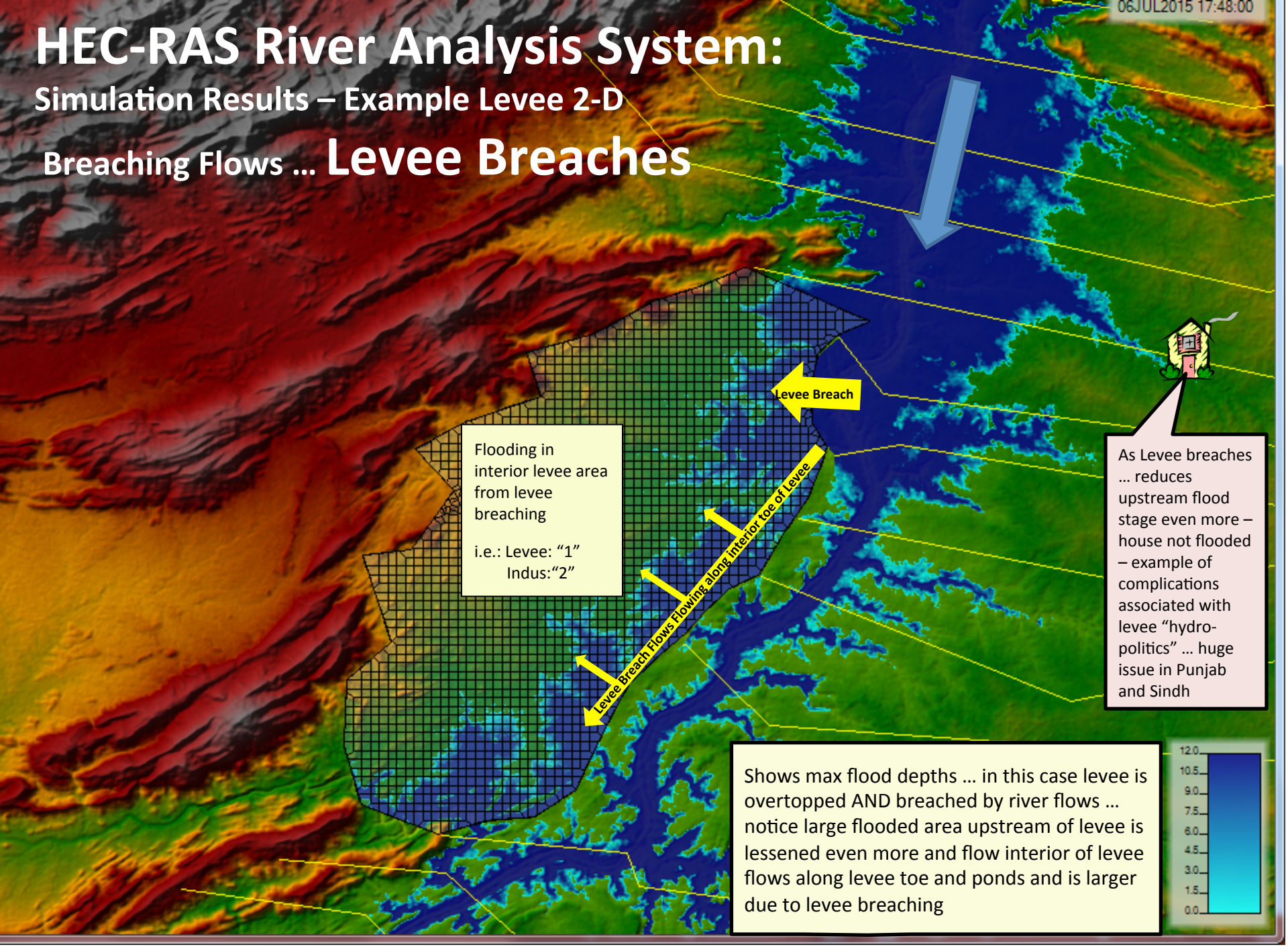
Breaching Flows … Levee Overtops



HEC-RAS River Analysis System:

Simulation Results – Example Levee 2-D

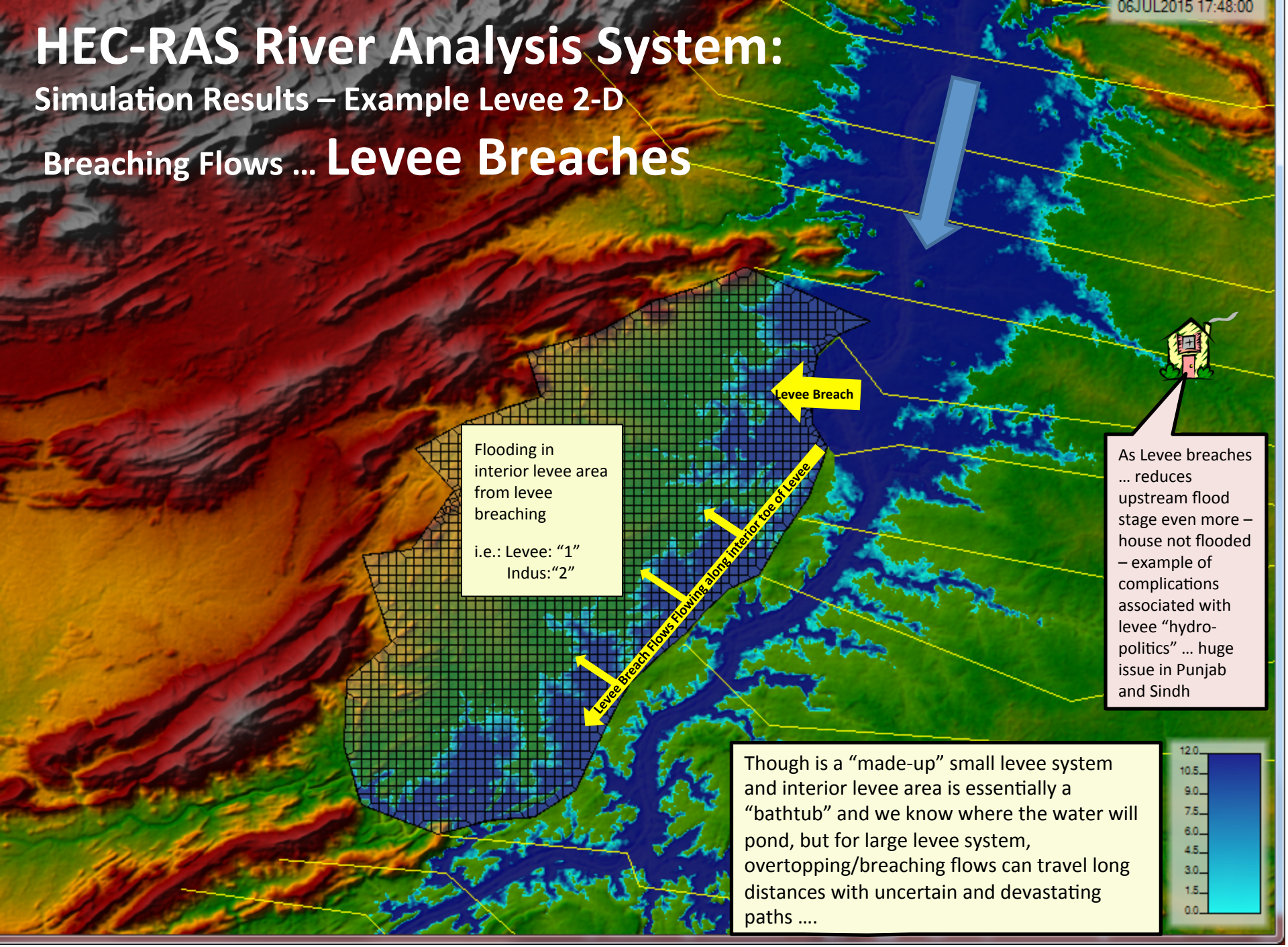
Breaching Flows … Levee Breaches



HEC-RAS River Analysis System:

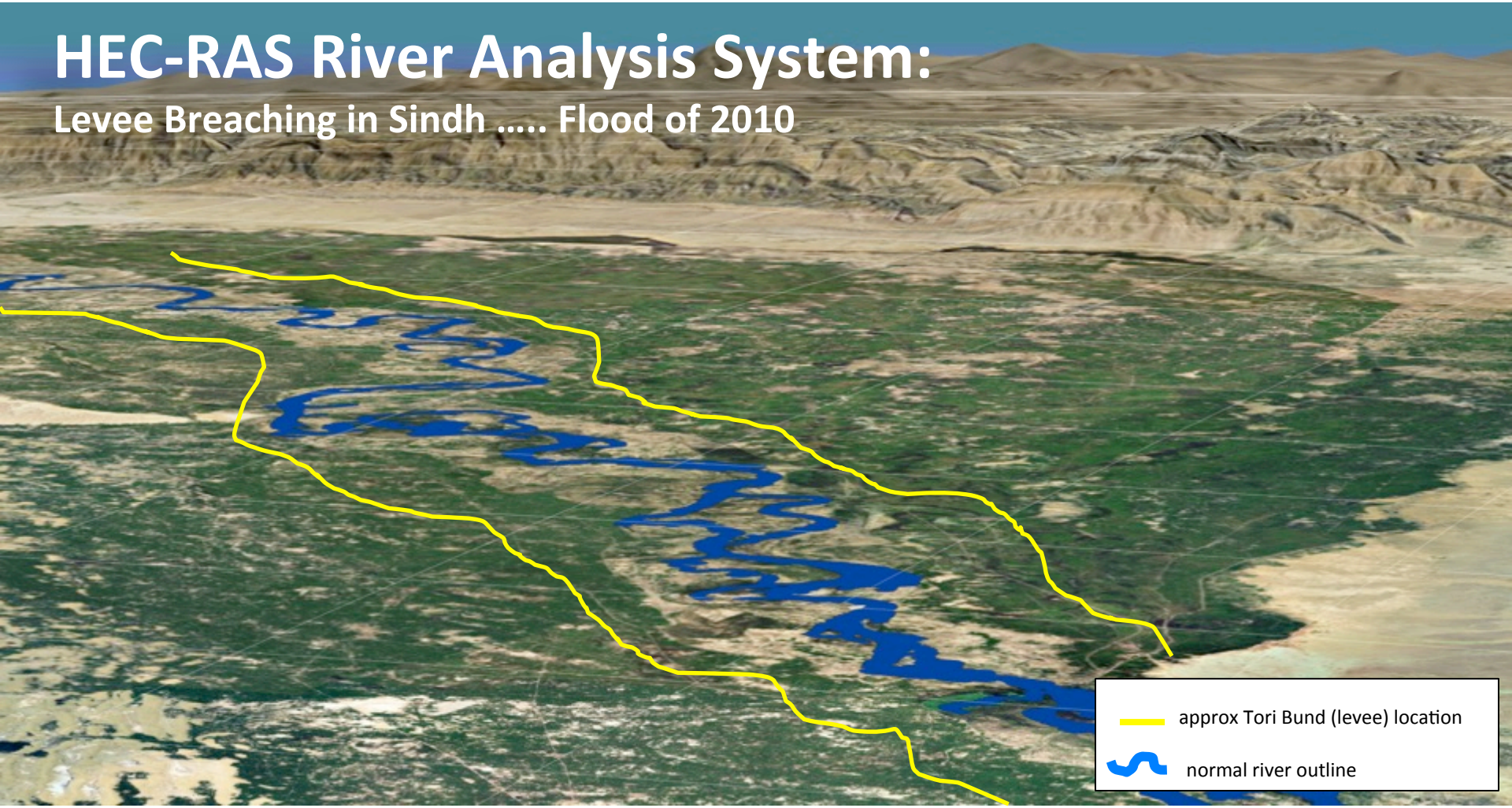
Simulation Results – Example Levee 2-D

Breaching Flows … Levee Breaches



HEC-RAS River Analysis System:

Levee Breaching in Sindh ….. Flood of 2010



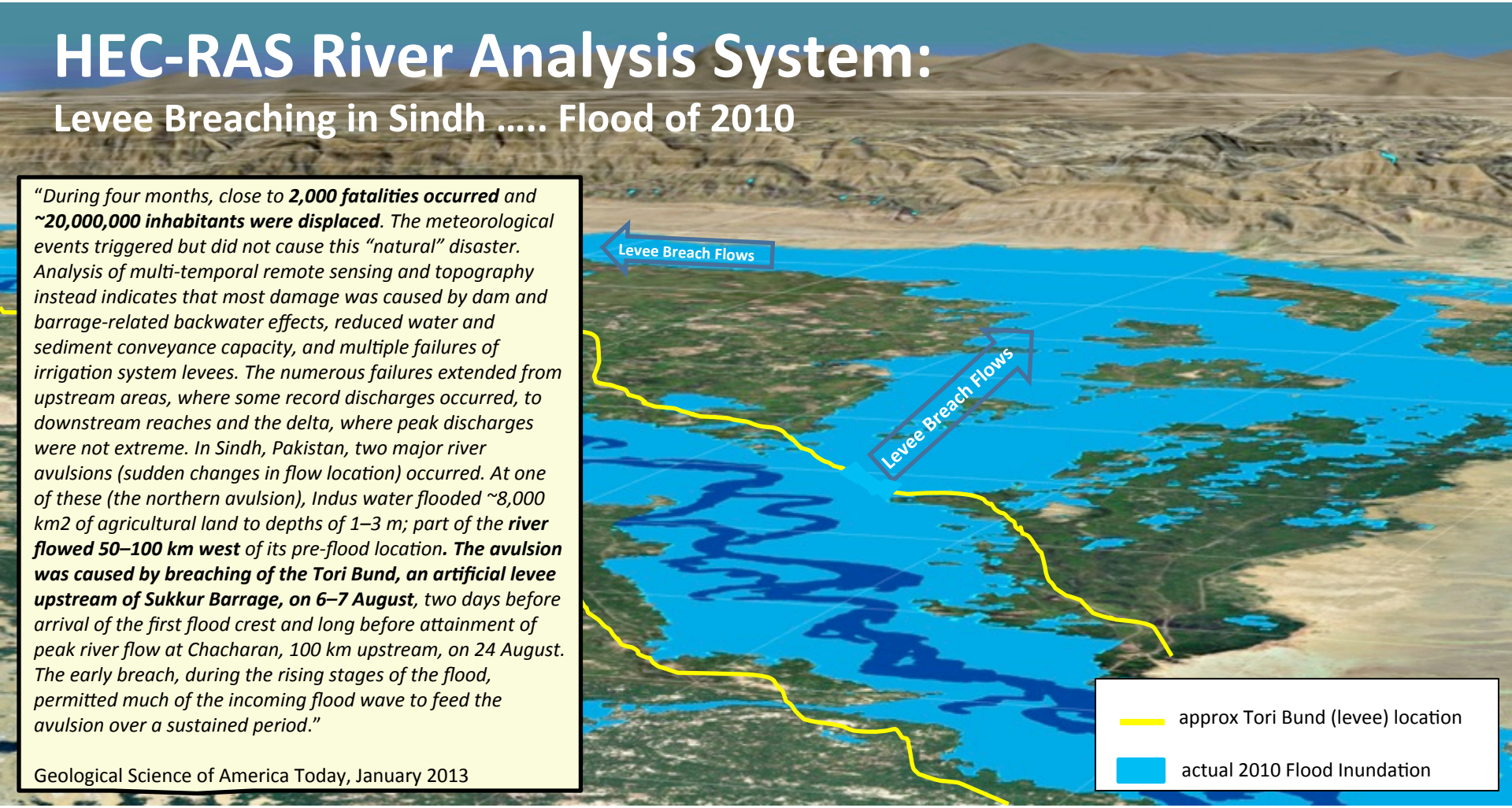
…. such as the extensive levee system in Southern Punjab and Northern Sindh which sustained a major levee breach in the flood of 2010 …

HEC-RAS River Analysis System:

Levee Breaching in Sindh ….. Flood of 2010

*"During four months, close to **2,000 fatalities occurred** and **~20,000,000 inhabitants were displaced**. The meteorological events triggered but did not cause this "natural" disaster. Analysis of multi-temporal remote sensing and topography instead indicates that most damage was caused by dam and barrage-related backwater effects, reduced water and sediment conveyance capacity, and multiple failures of irrigation system levees. The numerous failures extended from upstream areas, where some record discharges occurred, to downstream reaches and the delta, where peak discharges were not extreme. In Sindh, Pakistan, two major river avulsions (sudden changes in flow location) occurred. At one of these (the northern avulsion), Indus water flooded ~8,000 km2 of agricultural land to depths of 1–3 m; part of the **river flowed 50–100 km west** of its pre-flood location**. The avulsion was caused by breaching of the Tori Bund, an artificial levee upstream of Sukkur Barrage, on 6–7 August**, two days before arrival of the first flood crest and long before attainment of peak river flow at Chacharan, 100 km upstream, on 24 August. The early breach, during the rising stages of the flood, permitted much of the incoming flood wave to feed the avulsion over a sustained period."*

Geological Science of America Today, January 2013

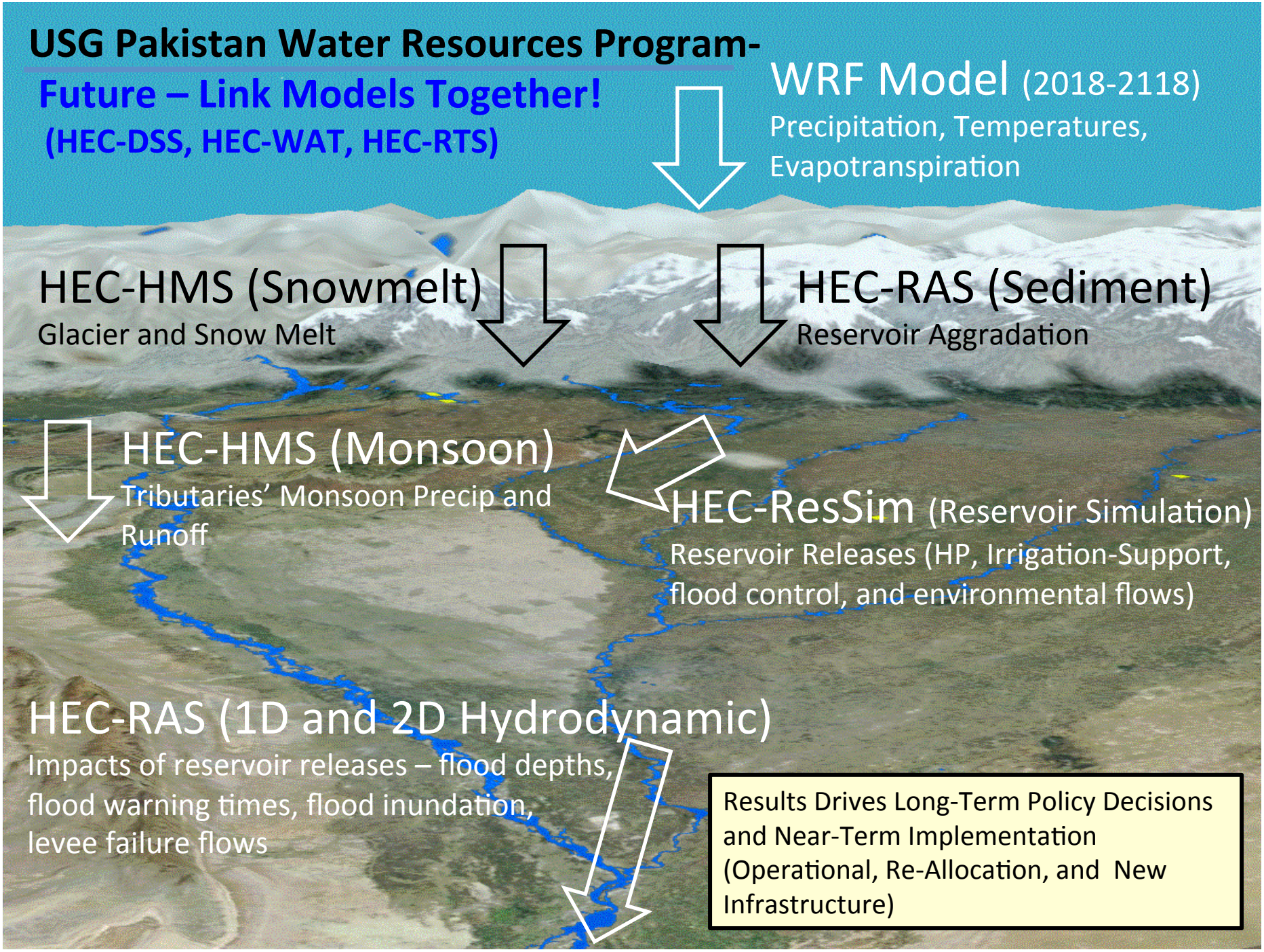


HEC-RAS would provide advance warning that due to forecasted water stages, the levee was susceptible to potential failure, allowing possible flood-fighting techniques (24/7 monitoring, sandbagging, or emergency repair) to be employed. HEC-RAS would also forecast if the levee could not be saved – what would the consequence be (when and where the water would go) for warning and evacuation purposes.

Indus River HEC-RAS Model

Looking Forward (actually downstream):

- Coordination *(Status – currently doing)*
  - Pak Ministries – MoWP, FFC, NDMA, PID, SID, PMD
  - Donor Community – Any Interest in Collaboration?
- Collaborative USG/GoP Model Development *(Status – Start Fall '17)*
  - Belief people responsible for using model should be involved in model DEVELOPMENT!
  - Initial Training at Hydrologic Engineering Center at Davis, CA
  - Develop Work Plan for collaborative model development team
- Unsteady FLOW HEC-RAS Model *(Status - Start Fall '17)*
  - Tarbela to Arabian Sea, including Jhelum, Chenab, Ravi, Sutlej Rivers
  - Calibration, Calibration, Calibration … Historic Floods
  - Add Major Levees and Corresponding 2-D Flow Areas
- Unsteady SEDIMENT HEC-RAS Model *(Status - Start Spring '18)*
  - Historic cross-section bathometry or cross-sections, sediment data
  - Again … Calibration, Calibration, Calibration … Historic Floods
  - Barrage Operational Scenarios to minimize sediment impacts in Lower Reaches


USG Pakistan Water Resources Program-
Future – Link Models Together!
(HEC-DSS, HEC-WAT, HEC-RTS)
WRF Model (2018-2118)
Precipitation, Temperatures, Evapotranspiration
HEC-HMS (Snowmelt)
Glacier and Snow Melt
HEC-RAS (Sediment)
Reservoir Aggradation
HEC-HMS (Monsoon)
Tributaries' Monsoon Precip and Runoff
HEC-ResSim (Reservoir Simulation)
Reservoir Releases (HP, Irrigation-Support, flood control, and environmental flows)
HEC-RAS (1D and 2D Hydrodynamic)
Impacts of reservoir releases – flood depths, flood warning times, flood inundation, levee failure flows
Results Drives Long-Term Policy Decisions and Near-Term Implementation (Operational, Re-Allocation, and New Infrastructure)

THE END