HydroGeoSphere Modelling of a Representative Reach of the South River

May 13, 2015

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Project Objectives

- Use a computer simulation of surface and subsurface water flow and transport to improve conceptual understanding of how bank soils along the South River respond during a flood event. Specifically looking at:
  - surface water/groundwater interaction
  - bank drainage
  - groundwater fluxes following storm events along the South River

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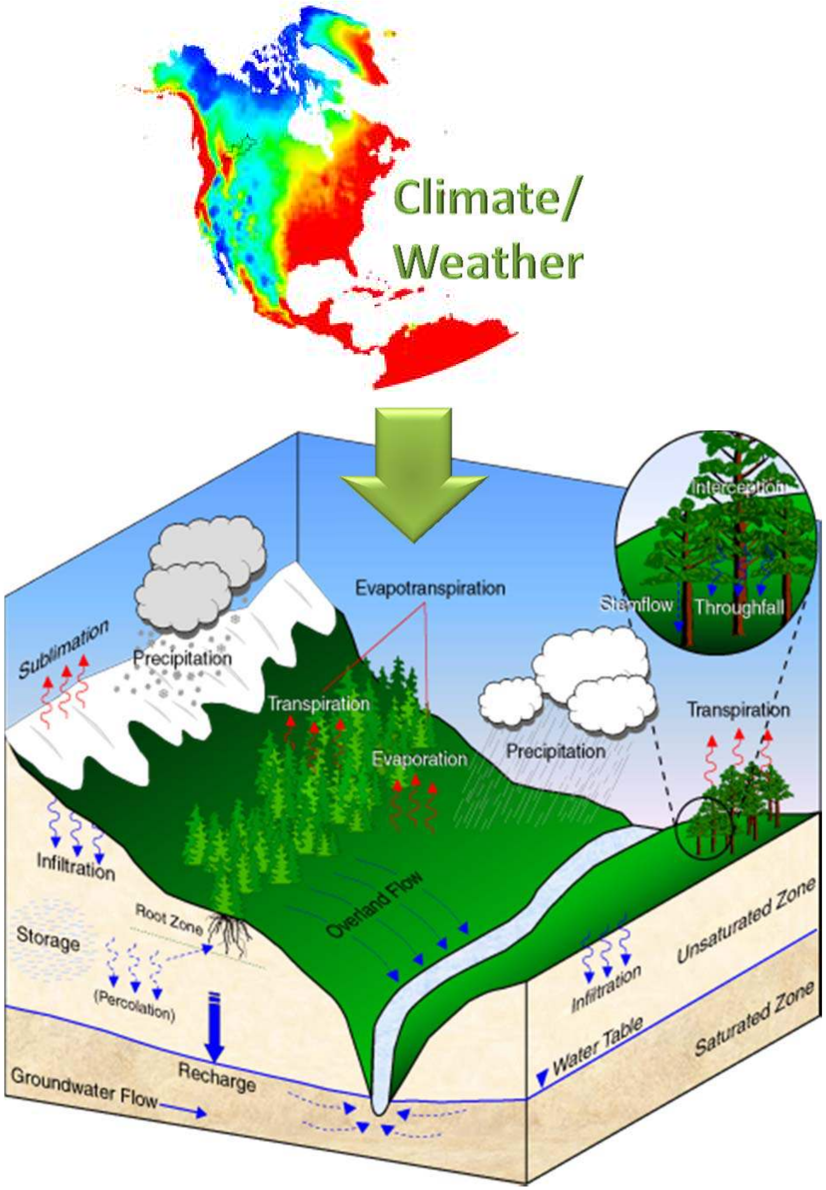
Simulation Platform - HydroGeoSphere



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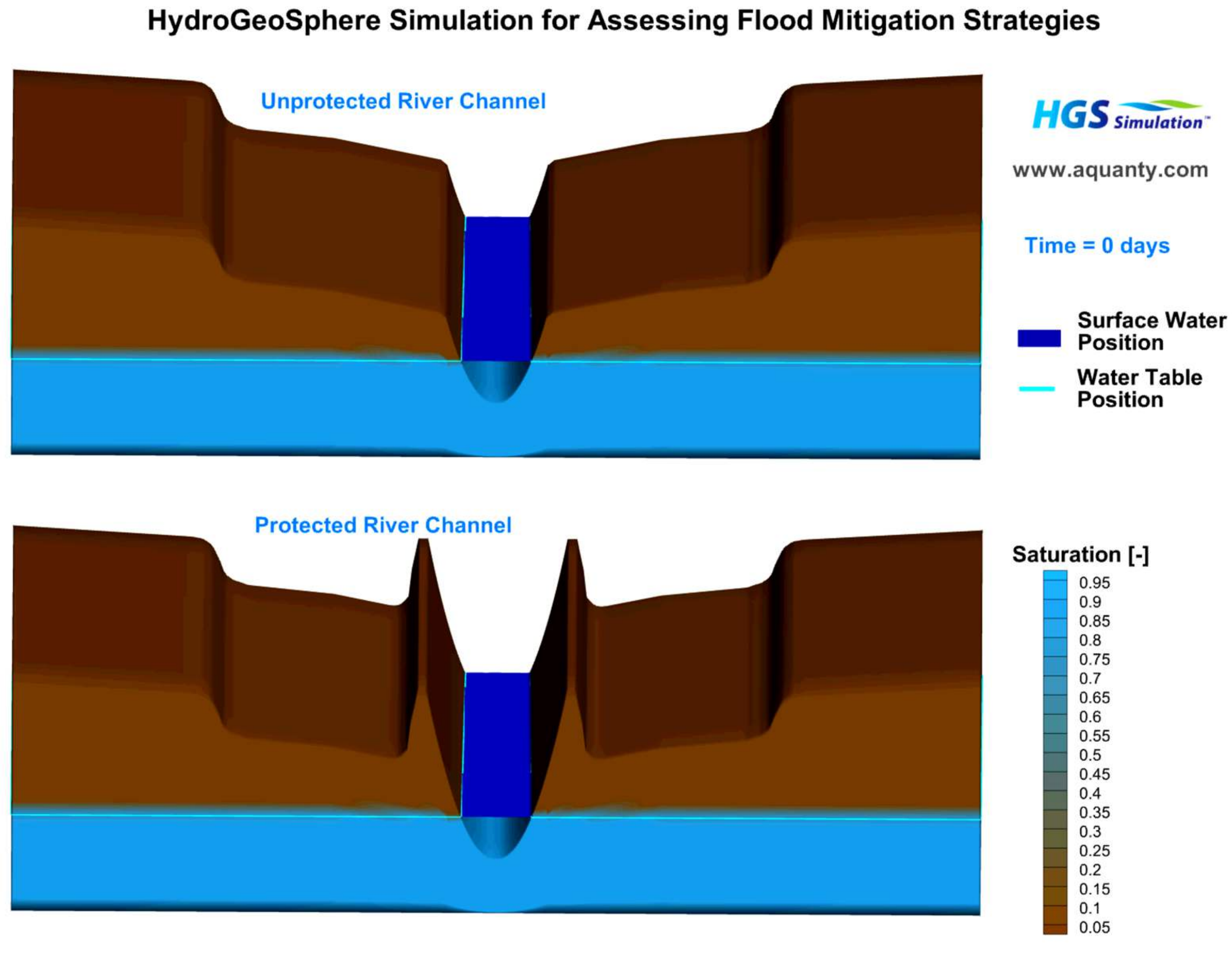
HydroGeoSphere – Sample Animation



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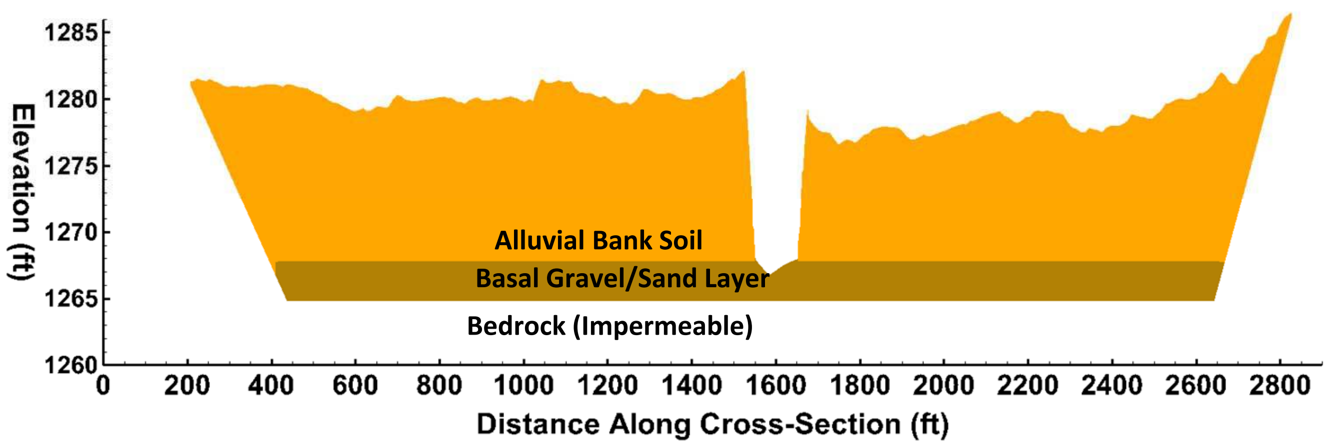
Conceptual Model - Geometry

- The model is 'representative' and does not portray any specific location along the South River
- Topography is based on a cross-section near Constitution Park, and includes the 100 year floodplain
- Subsurface geology is based on a general understanding of material distributions along the river (e.g., soil cores)



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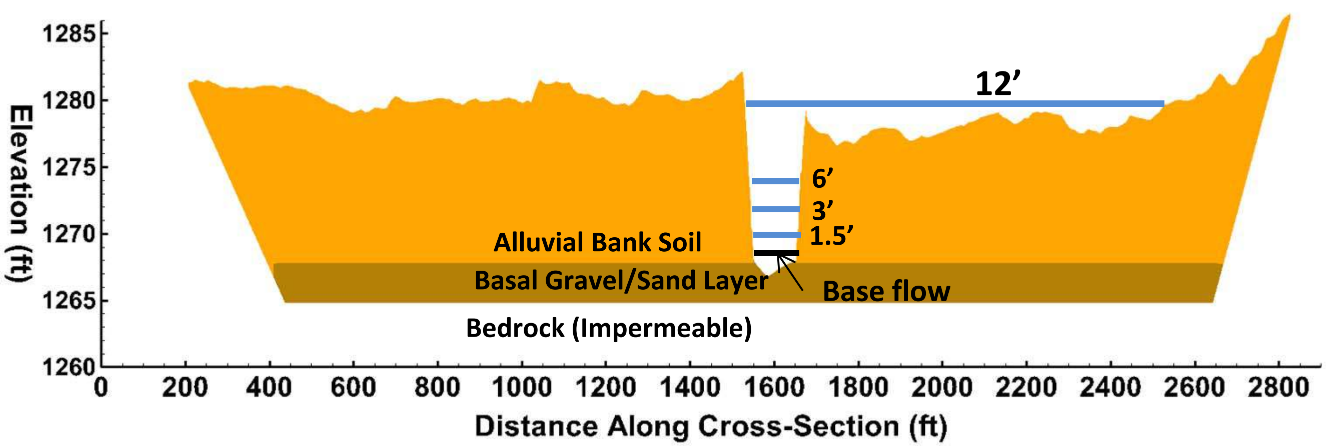
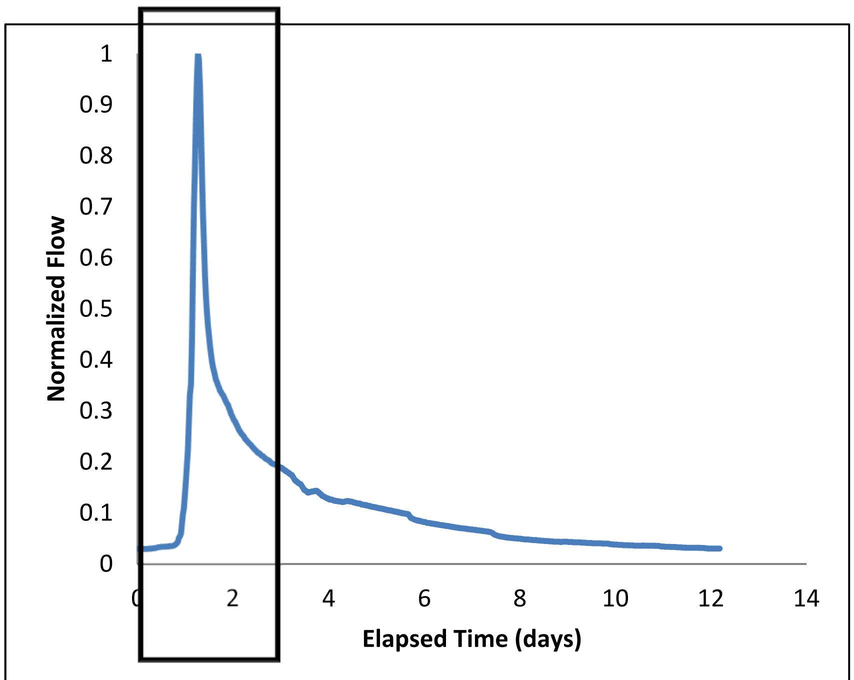
Conceptual Model – Flood Events

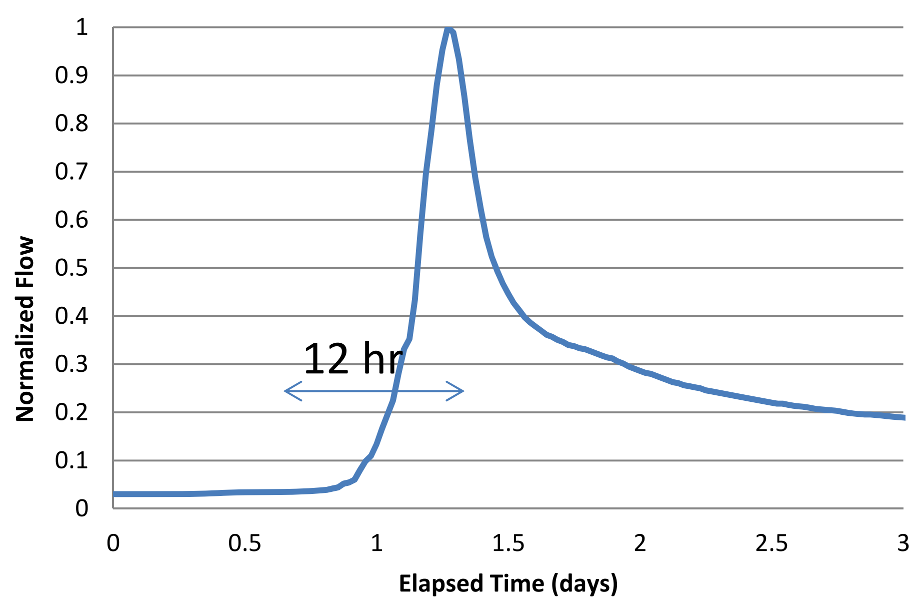
- Idealized flood hydrograph from historic data was scaled to represent different flood stages
- 4 flood events with different stage heights were simulated:
  - 3 in-channel events
    - 1.5', 3' and 6' stage rises
  - 1 floodplain event
    - 12' stage rise



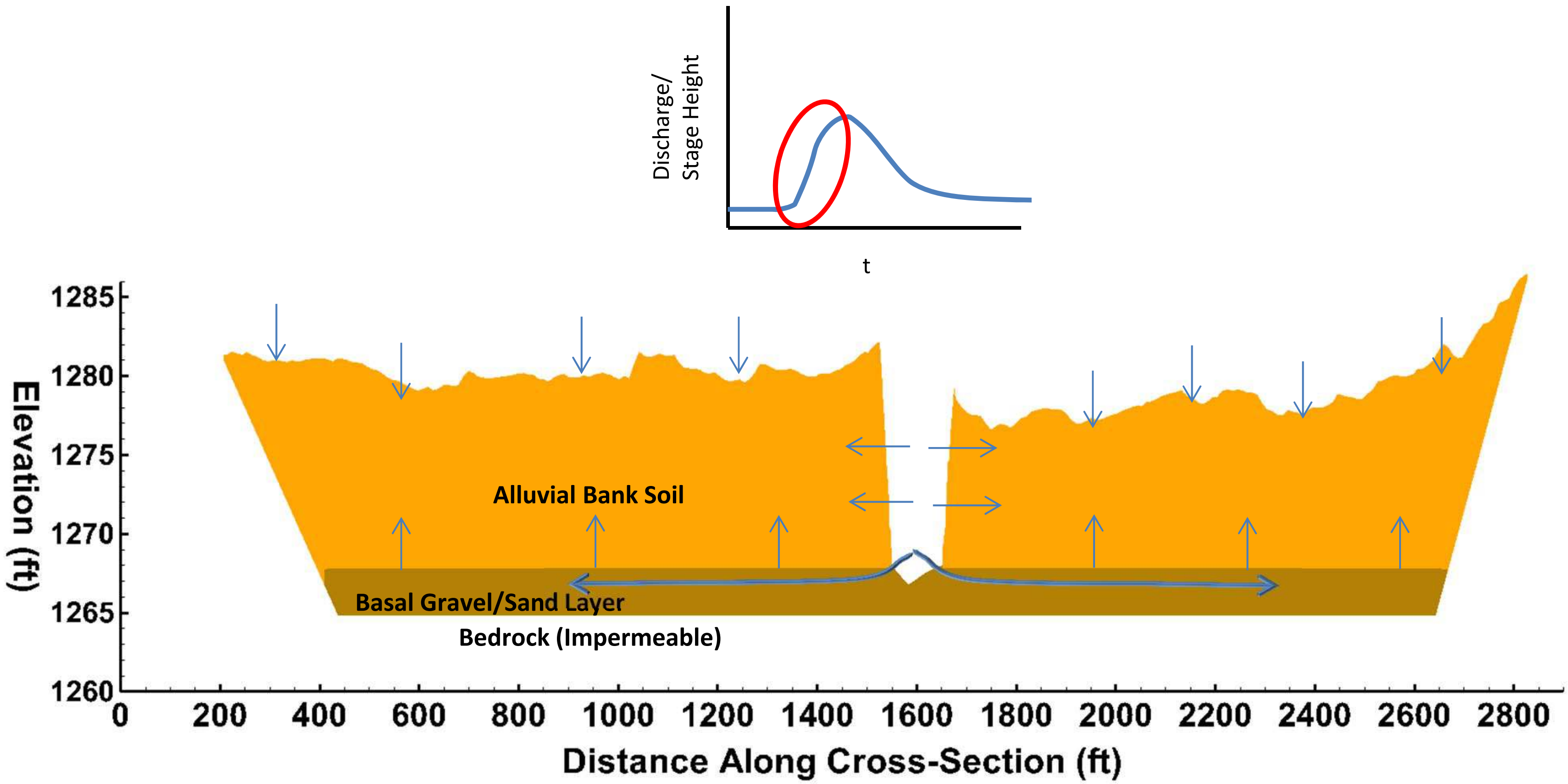
Conceptual Model – Flood Hydrograph

- Isolated flood event identified in historic data at Waynesboro Gauging Station
- Scaled for different stage heights (e.g., 1.5', 3', 6' and 12')
- Precipitation applied from 0.75 days to 1.25 days (12 hrs)
- Precipitation rate associated with approximate return period of the flood event

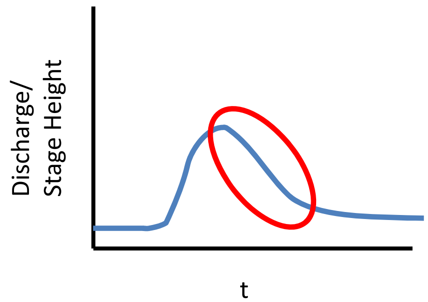


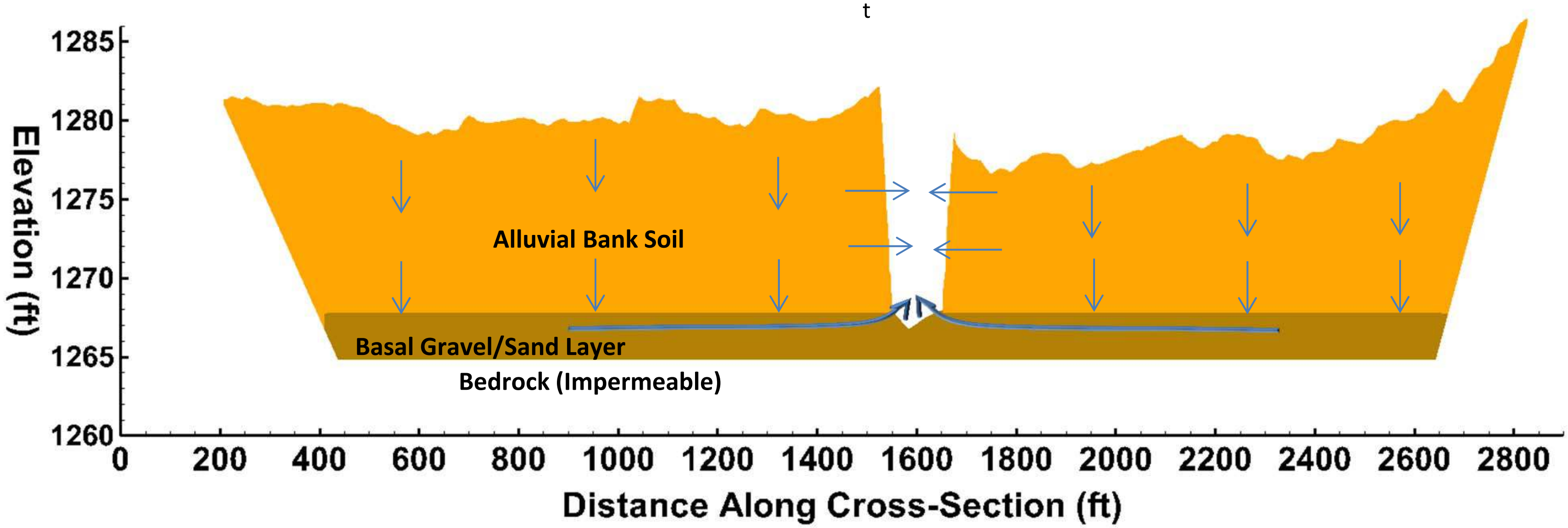


Conceptual Model – Expected Early Time Behavior

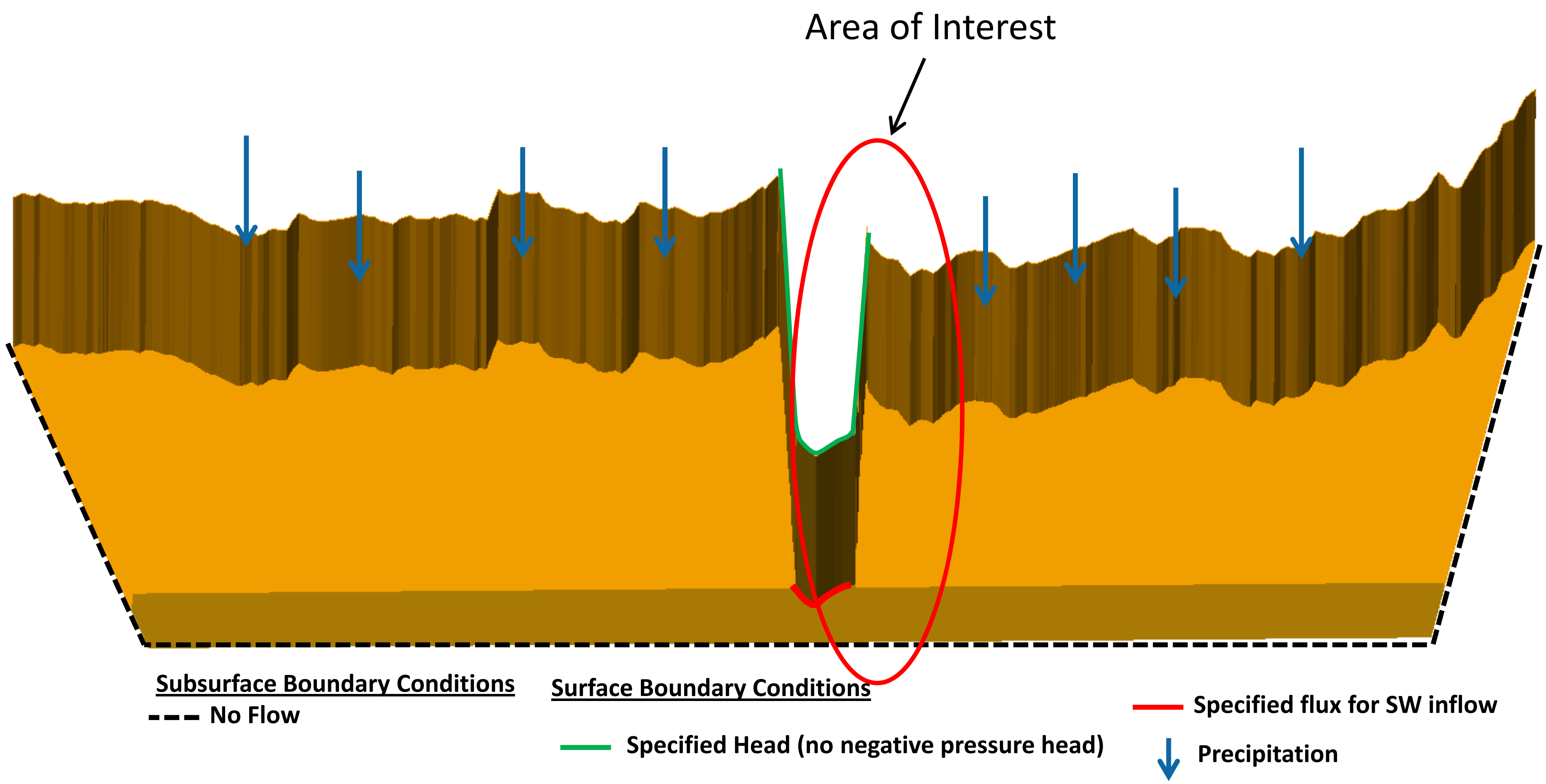


Conceptual Model – Expected Late Time Behavior





Model Setup – Boundary Condition Assignment



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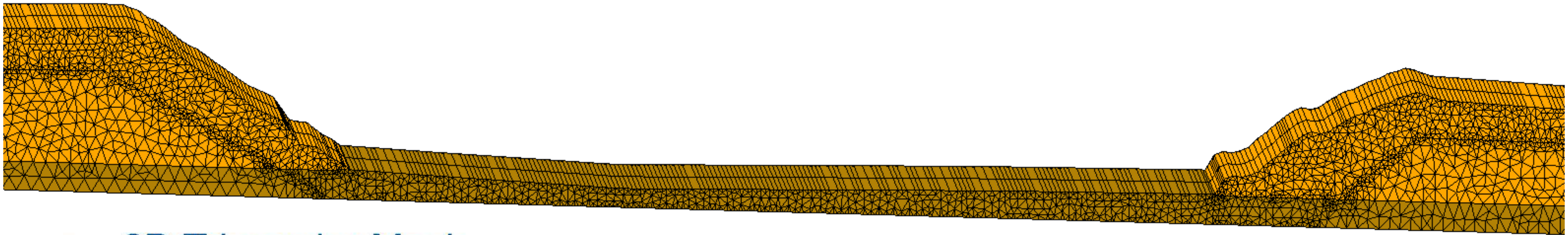
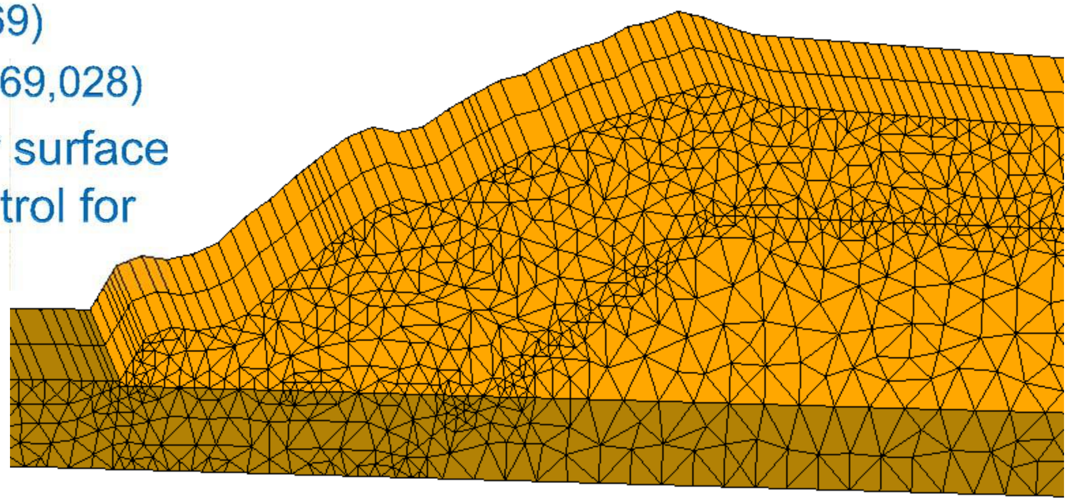
Numerical Model – Mesh Construction (Channel close up)



- 2D Triangular Mesh
  - Nodes = 45,723
  - Elements = 84,514
- 3D Triangular Prism Mesh
  - 3 node sheets (Nodes = 137,169)
  - 2 element layers (Elements = 169,028)
- Selective mesh refinement near surface and near the channel, node control for basal sand/gravel layer



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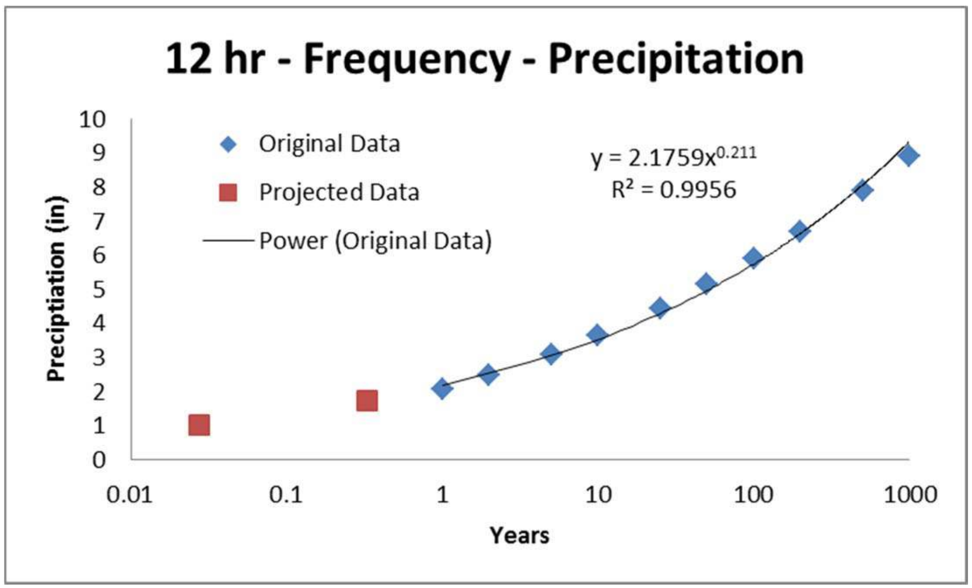
Stage Heights and Precipitation Data

	Stage (ft)	Stage (ft asl)	Flow (cfs)	Approximate Return Period	12 hr Precipitation (in)
Base Flow	2.4	1,269.2	30		0
1.5 ft Rise	3.9	1,270.7	447	10-30 day	1.02
3 ft Rise	5.4	1,272.2	1,170	90 – 120 day	1.72
6 ft Rise	8.4	1,275.2	3,630	2 – 5 yr	2.47
12 ft Rise	14.4	1,281.2	10,000	10 yr	3.65



Sensitivity Analysis – Permeability Cases

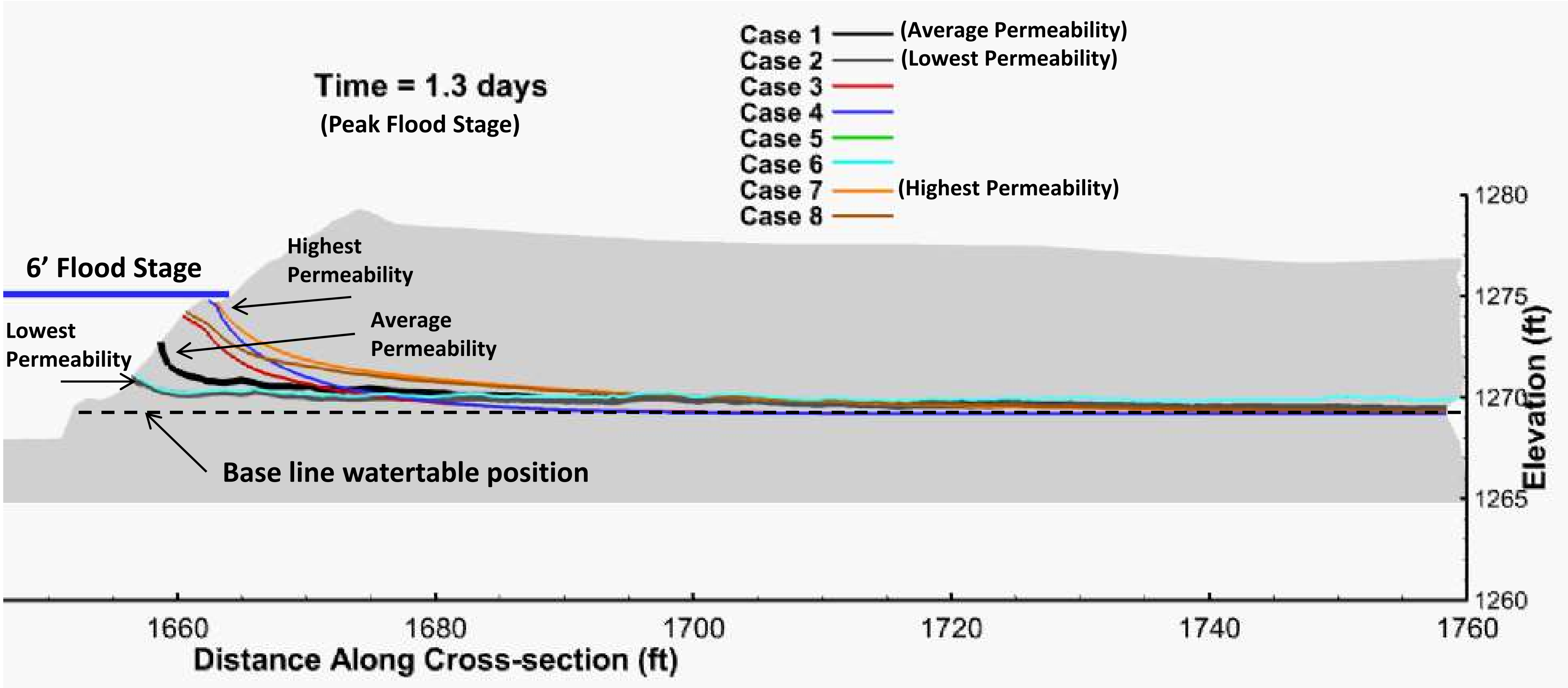
- The impact of soil permeability (e.g., hydraulic conductivity) on the response of bank soil was investigated through a sensitivity analysis

Table 1. Parameter Configurations for Sensitivity Analysis

Case#	Alluvial Bank Soil (ABS)		Basal Gravel/Sand Layer (BG/SL)		Comment
	K_h (ft/day)	K_h/K_v (ft/day)	K_h (ft/day)	K_h/K_v (ft/day)	
1	1	6	50	6	**Base Case – average of range for all units**
2	**0.1**	**10**	**10**	**10**	**Lowest K for all units**
3	**10**	10	10	10	Increase ABS K_h
4	10	**3**	10	10	Increase ABS K_v
5	0.1	10	**100**	10	Low K ABS, High K_h BG/SL
6	0.1	10	100	**3**	Increase BG/SL K_v
7	**10**	3	100	3	**Highest K for all units**
8	10	**10**	100	**10**	Increase K_h/K_v for both units

10 Values are **bold and underlined** to indicated changes from the preceding case.

Water Table Position During a 6' Flood Event with Different Soil Permeability (Sensitivity Analysis)



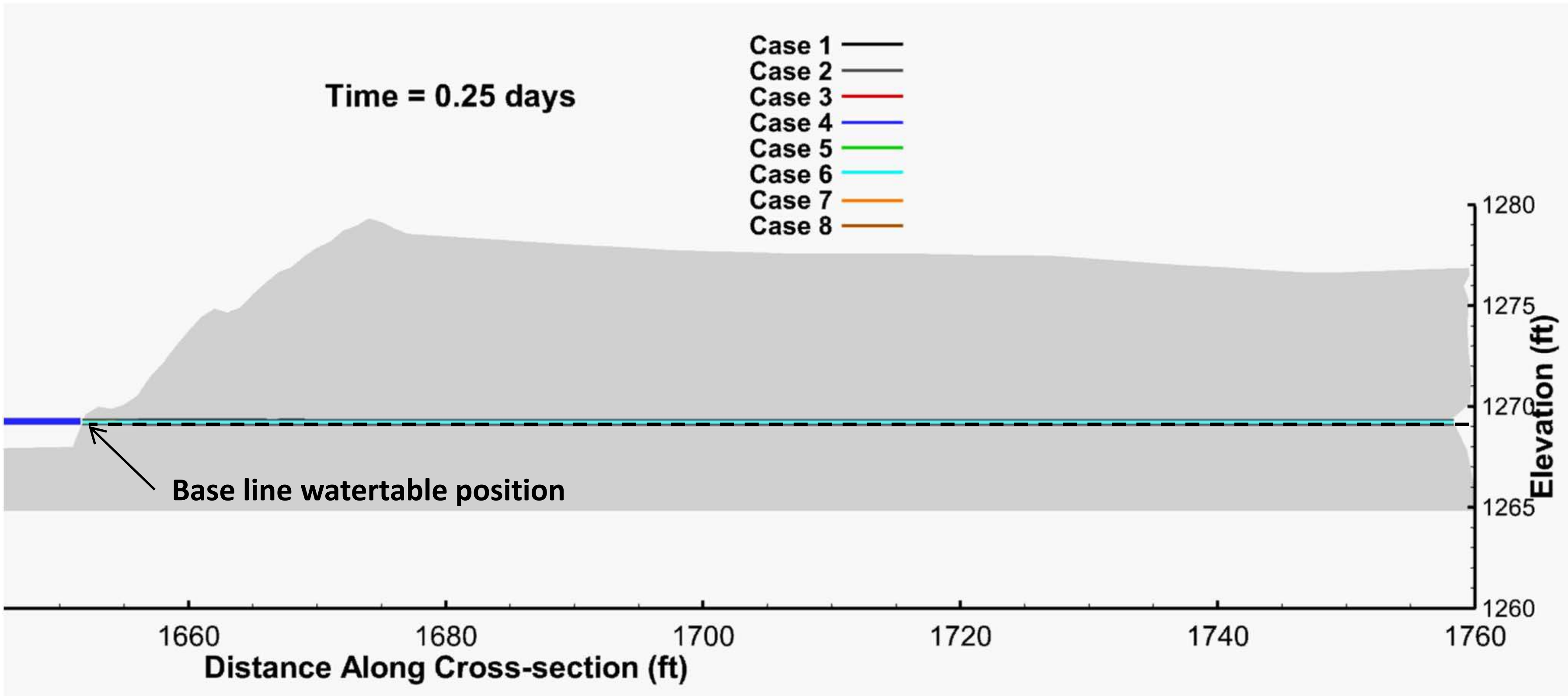
<u>Infiltration/Inundation</u>

Minimum = Case 2 (Lowest Permeability)

Median = Case 1 (Average Permeability)

Maximum = Case 7 (Highest Permeability)

Water Table Position During a 6' Flood Event with Different Soil Permeability (Sensitivity Analysis)



<u>Infiltration/Inundation</u>

Minimum = Case 2 (Lowest Permeability)

Median = Case 1 (Average Permeability)

Maximum = Case 7 (Highest Permeability)

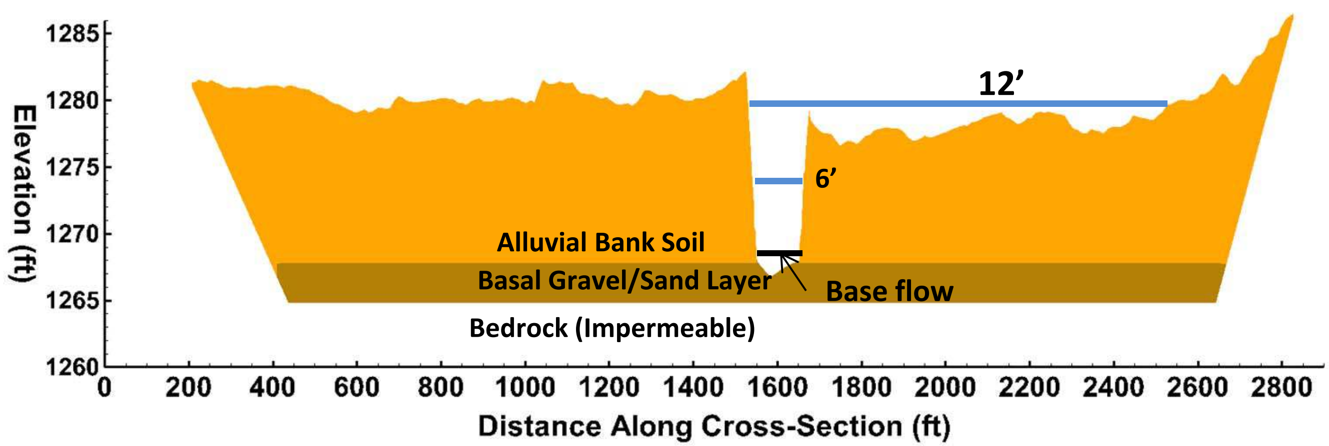
Sensitivity Analysis - Observations

- Response of the system is highly dependent on the permeability of the bank soils
- The greater the permeability (hydraulic conductivity) of the bank soils, the greater the watertable response (e.g., Case 7 shows the greatest change, the furthest into the bank)
- The lower the permeability of the bank soils, the less the water table response (e.g., Case 2 shows the least response to the flood wave)
- Accurately characterizing the permeability of the bank soils is necessary to accurately simulate a flood event along the South River

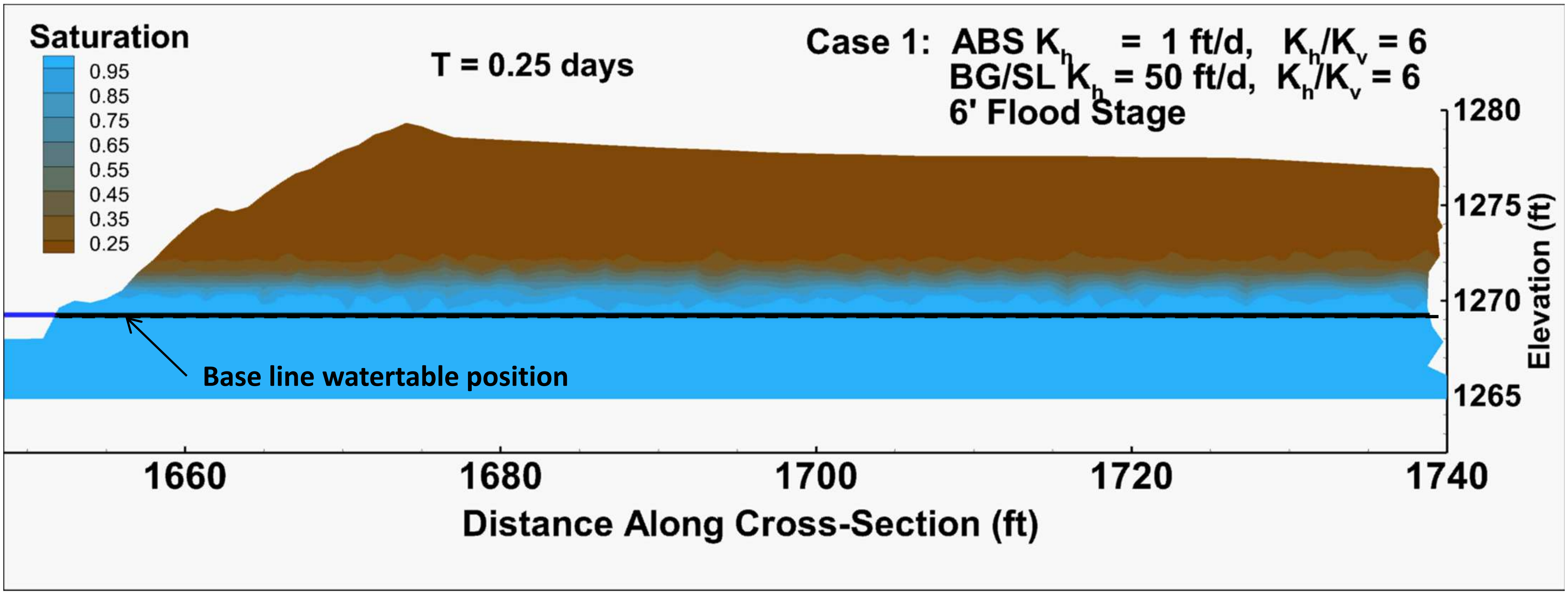
In-channel vs. Floodplain Events

- Surface water from in-channel events only interacts with bank soils along the bank face of the South River
- Infiltration and inundation largely controlled by stage height and soil properties

- Surface water from floodplain events can infiltrate through the bank face, as well as through the floodplain
- Standing water on the floodplain may contribute to additional infiltration



Saturation and Water Table Response
Average Permeability – 6' Flood Stage (in-channel)



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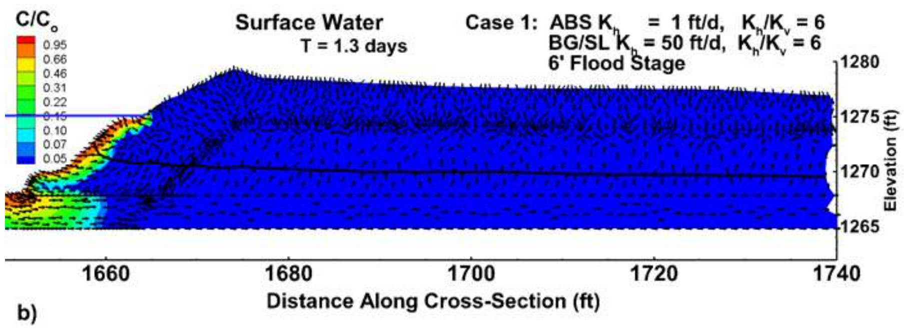
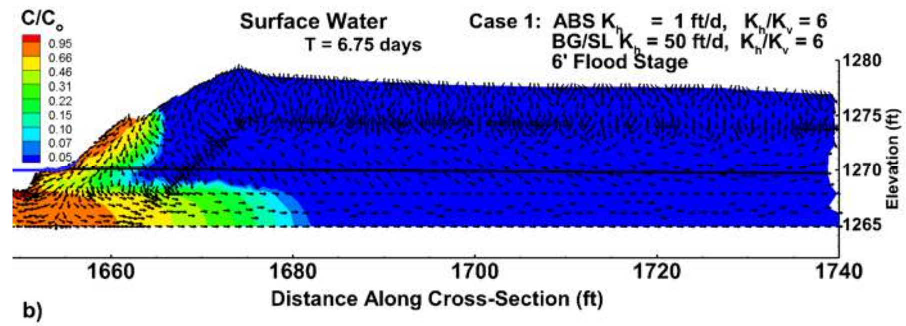
Movement of Surface Water into the Bank Soils
Average Permeability - 6’ Flood Stage (in-channel)

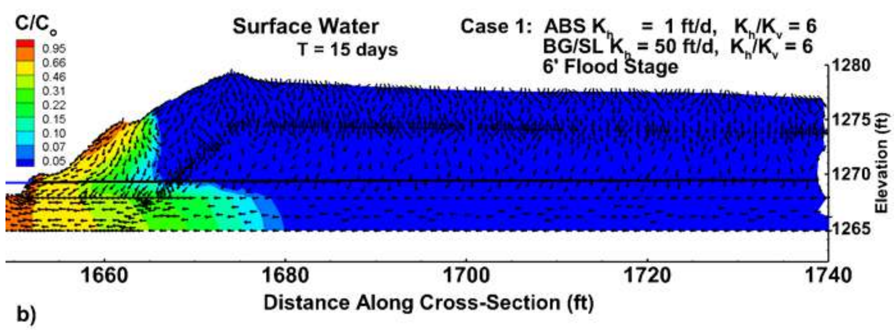
Peak Stage Height



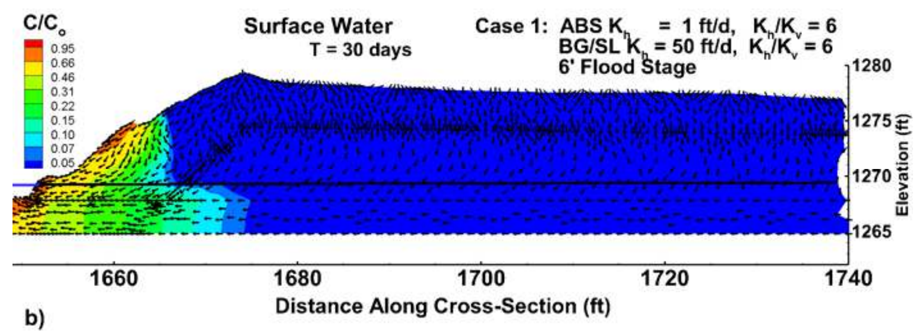
Discharge to Channel Begins



~ 2 weeks after peak



~ 1 month after peak



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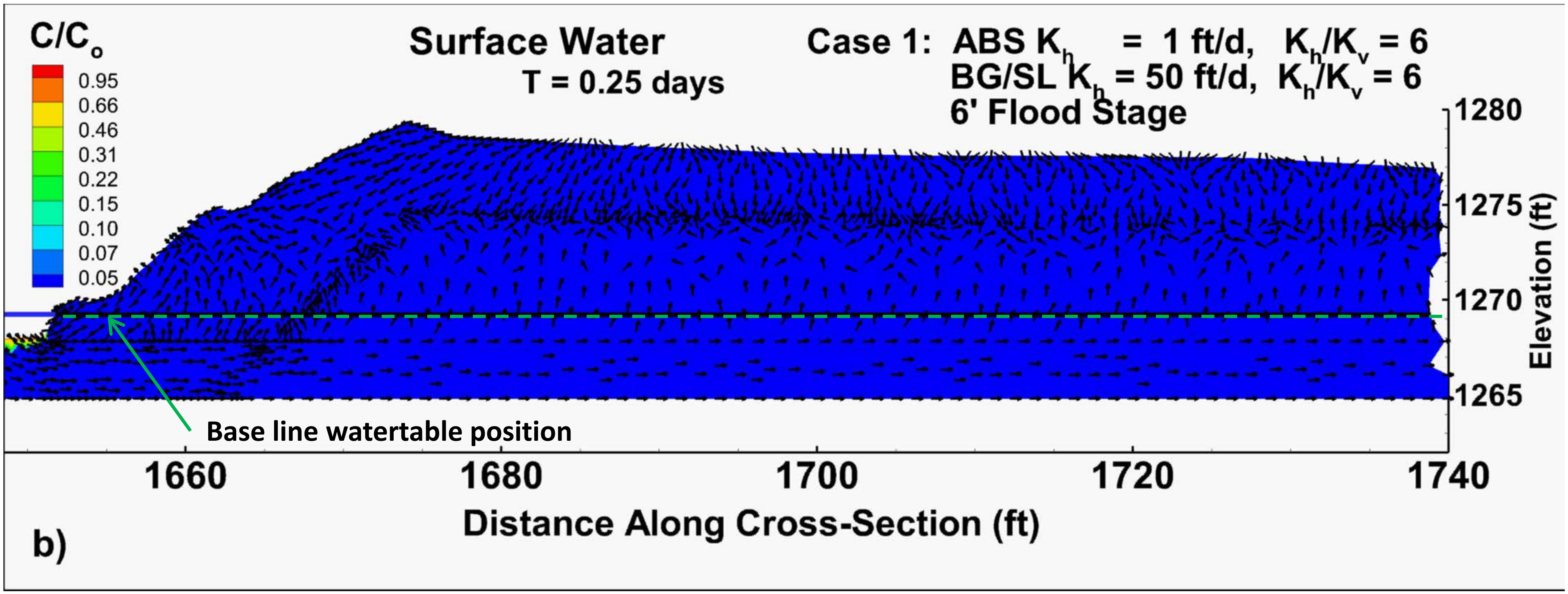
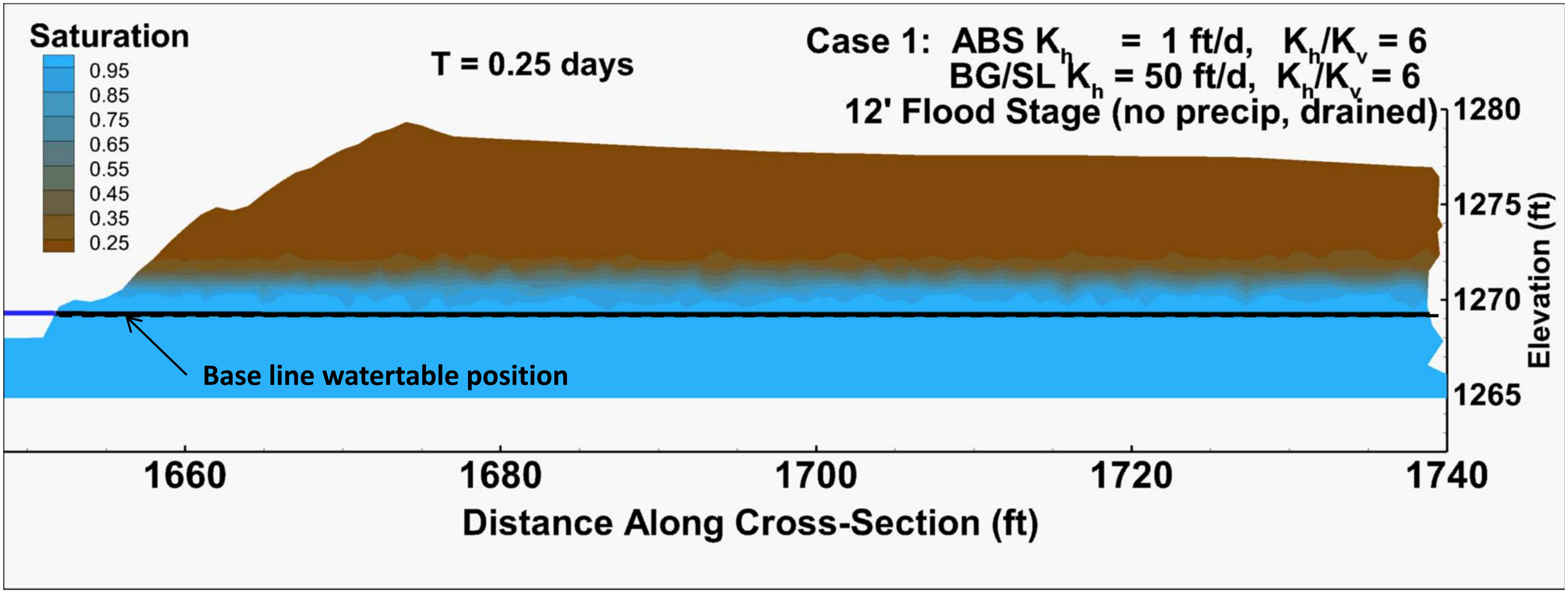
Inundation of Surface Water - 6' Flood Stage

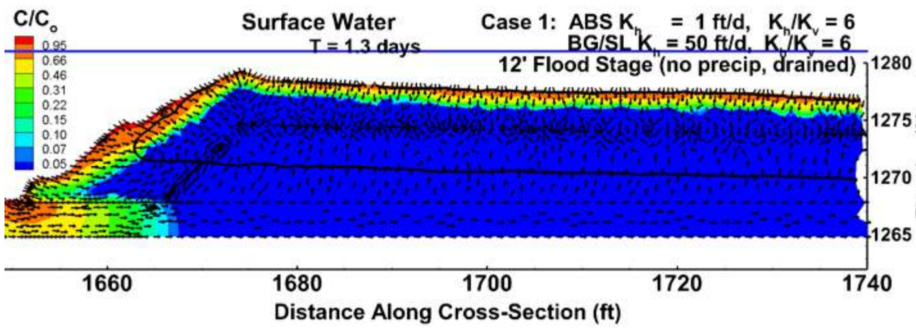


Saturation and Water Table Response
Average Permeability – 12' Flood Stage (floodplain)

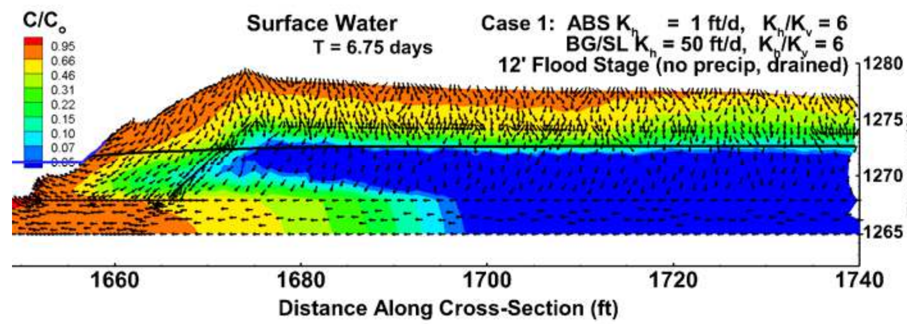


Movement of Surface Water into the Bank Soils
Average Permeability - 12' Flood Stage (floodplain)

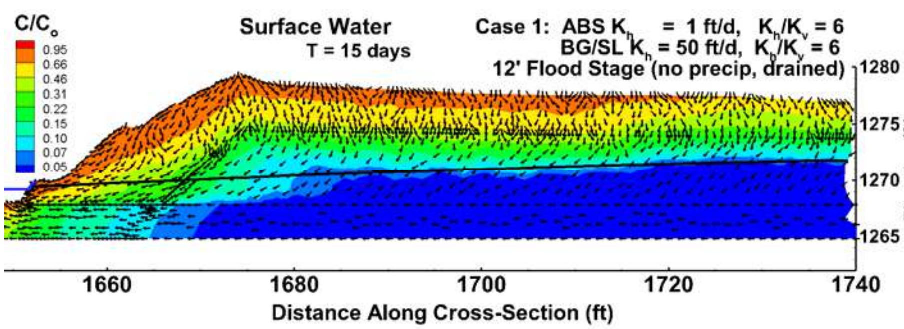
Peak Stage Height



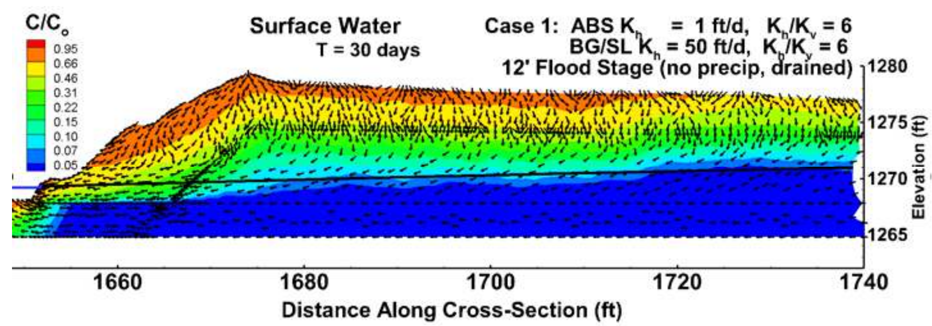
~ 5 days after peak



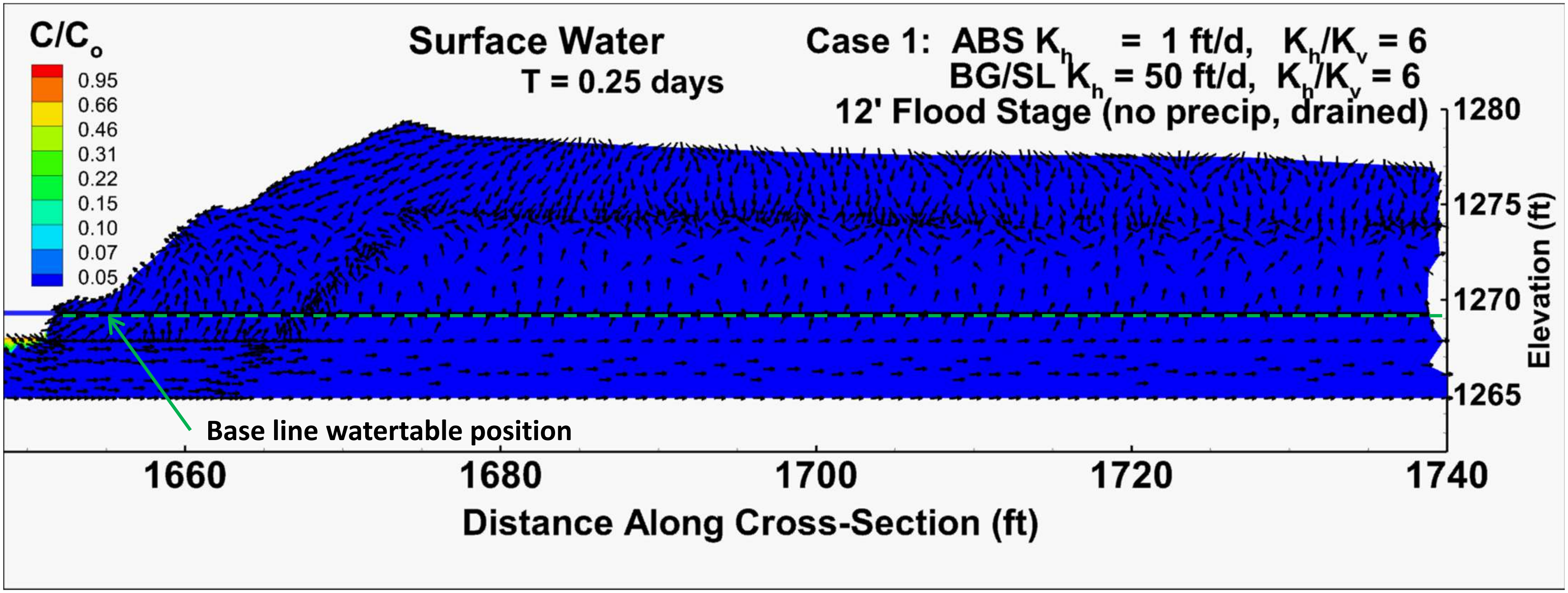
~ 2 weeks after peak



~ 1 month after peak



Inundation of Surface Water - 12’ Flood Stage



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Impact of Stage Height on Surface Water Inundation

- Within a given Case, 1.5', 3' and 6' stage heights behave similarly, though magnitude of response varies
- 12' stage height is unique as it activates the flood plain and the amount of water infiltrating in the flood plain is significantly greater than the precipitation in the other cases

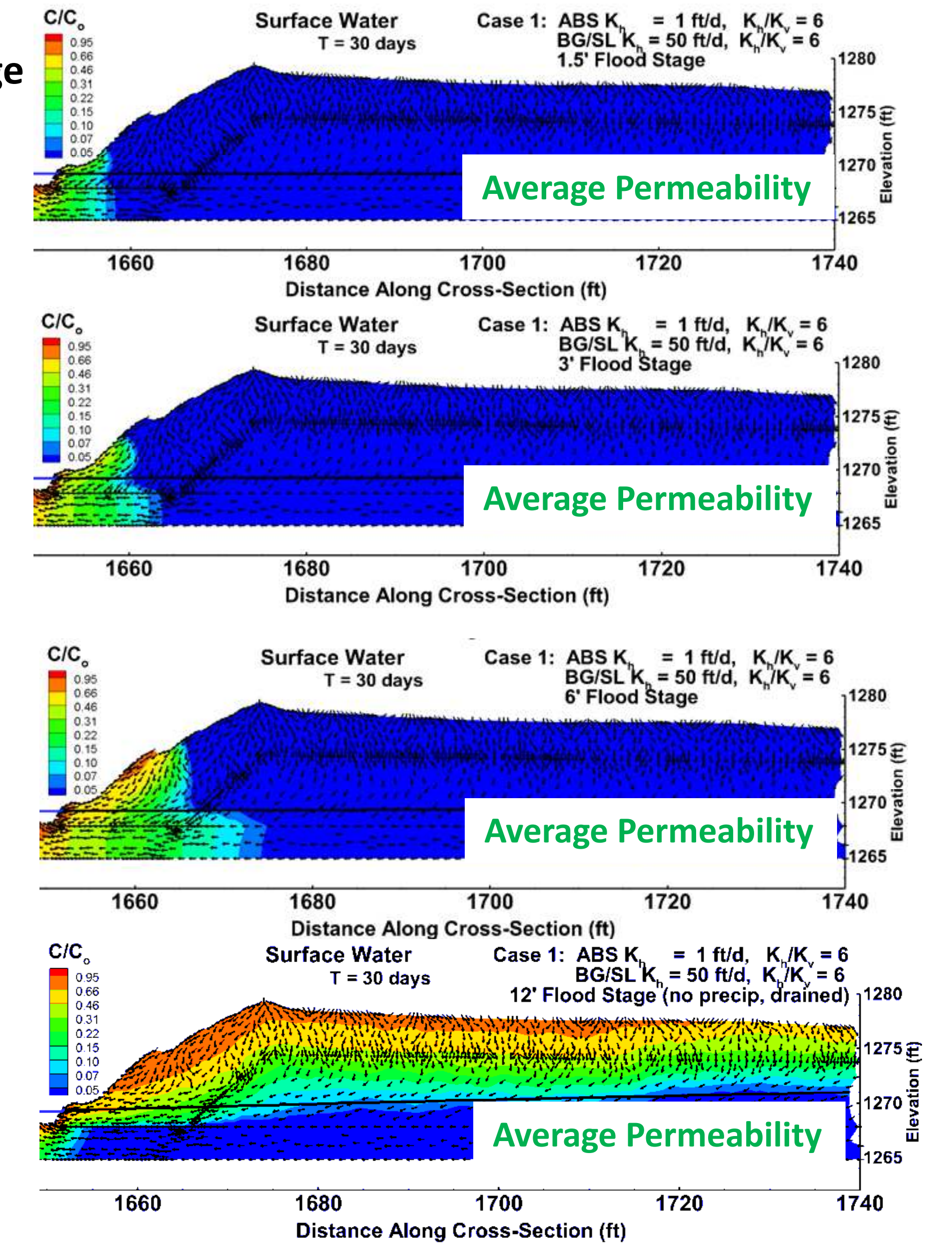
Flood Stage

1.5'

3'

6'

12'



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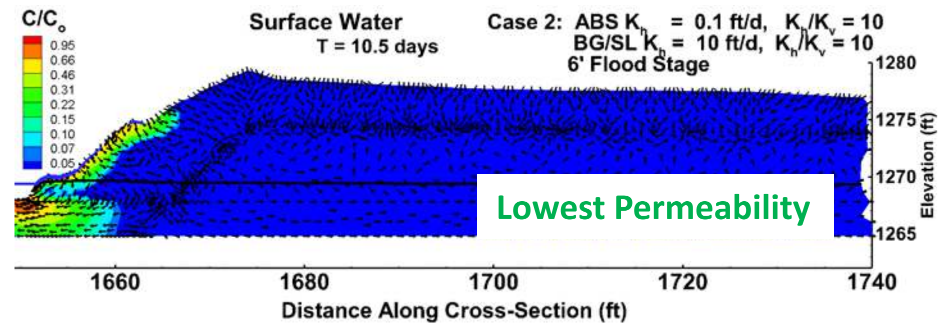
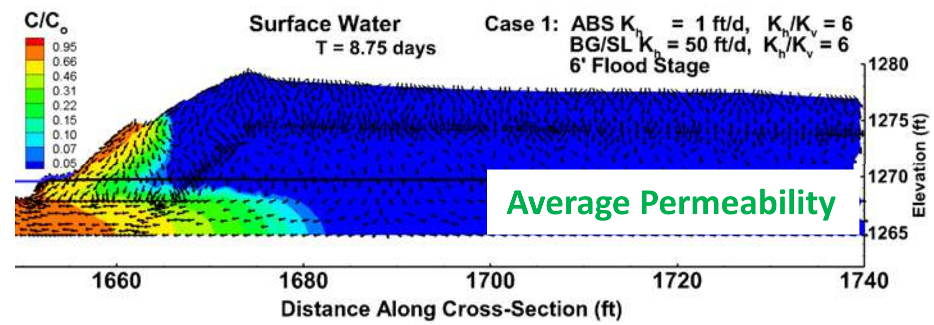
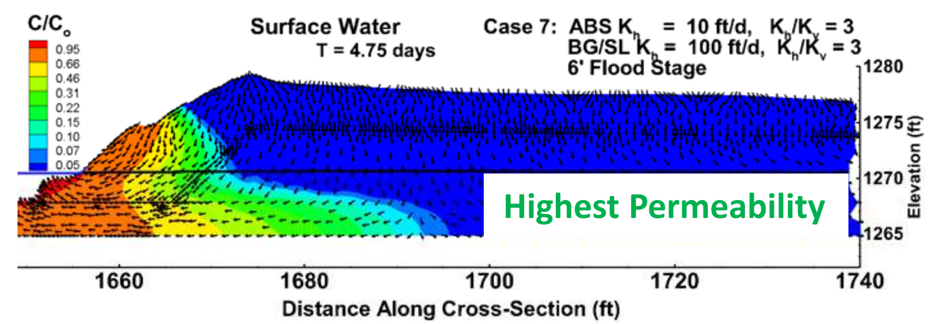
Impact of Permeability on Surface Water Inundation

- Maximum inundation of surface water generally occurs in the BG/SL
- As *K* increases inundation distance increases
- Maximum inundation distance occurs earlier with higher K







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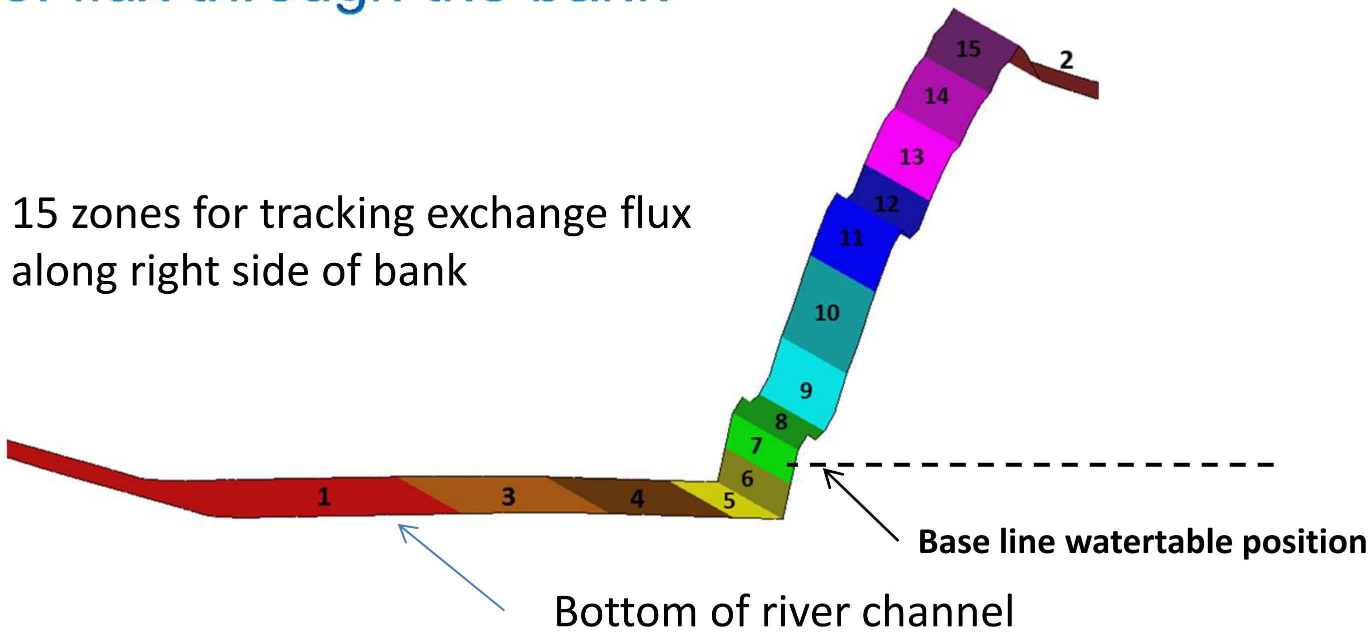
Assessment of flux through the bank



- Bank face subdivided into zones to track the movement of water in and out of the bank
- Volumetric flux of water across each zone tracked with time for the average permeability case

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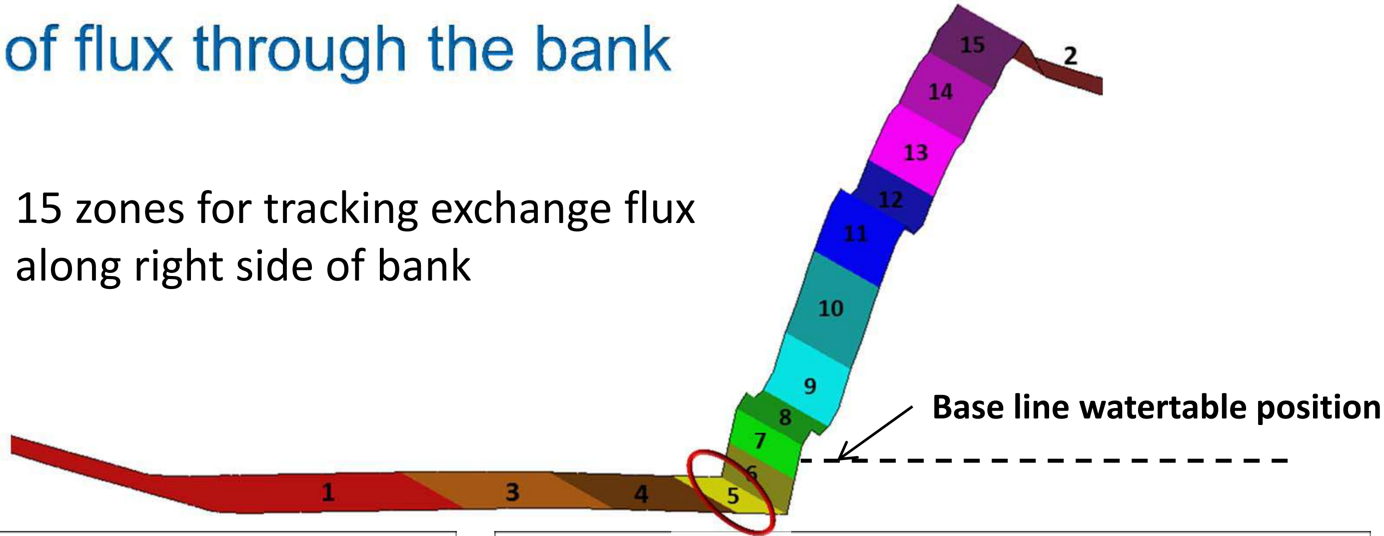
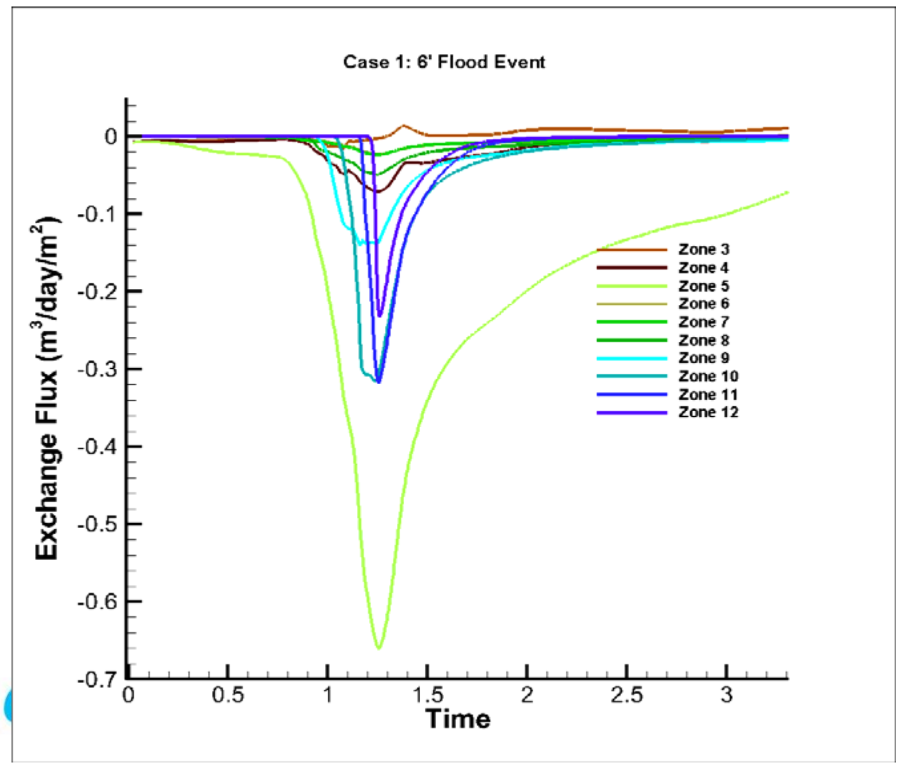
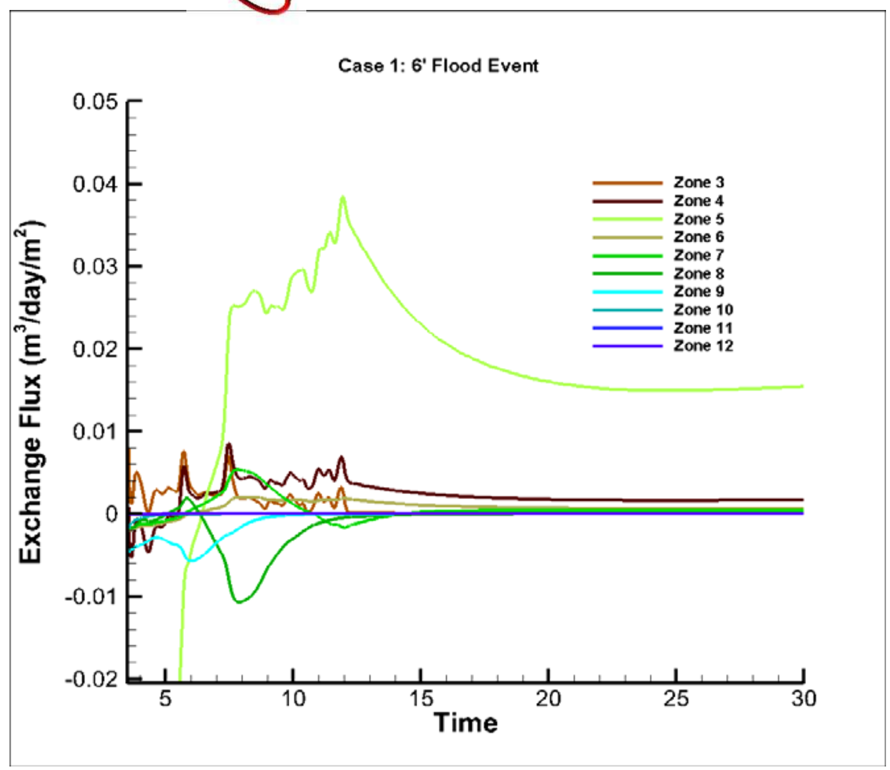
Assessment of flux through the bank

15 zones for tracking exchange flux along right side of bank

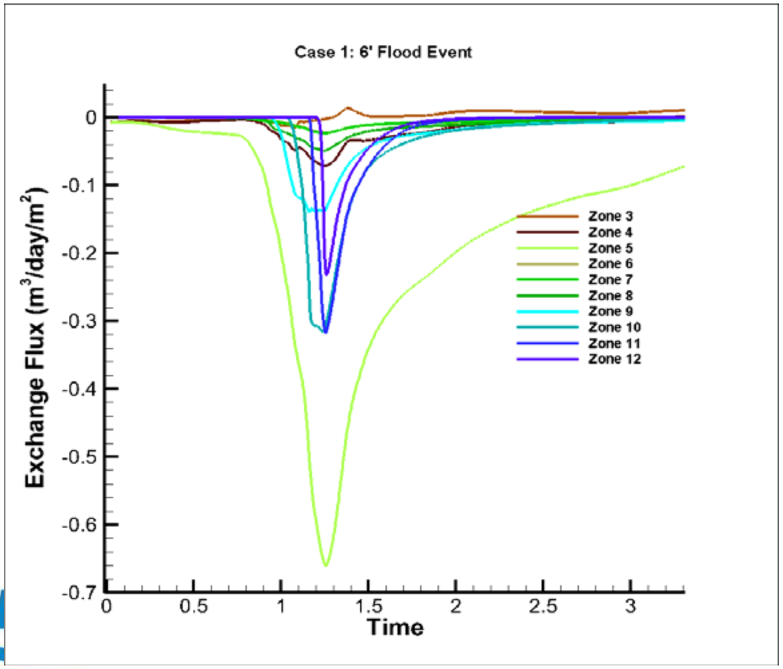


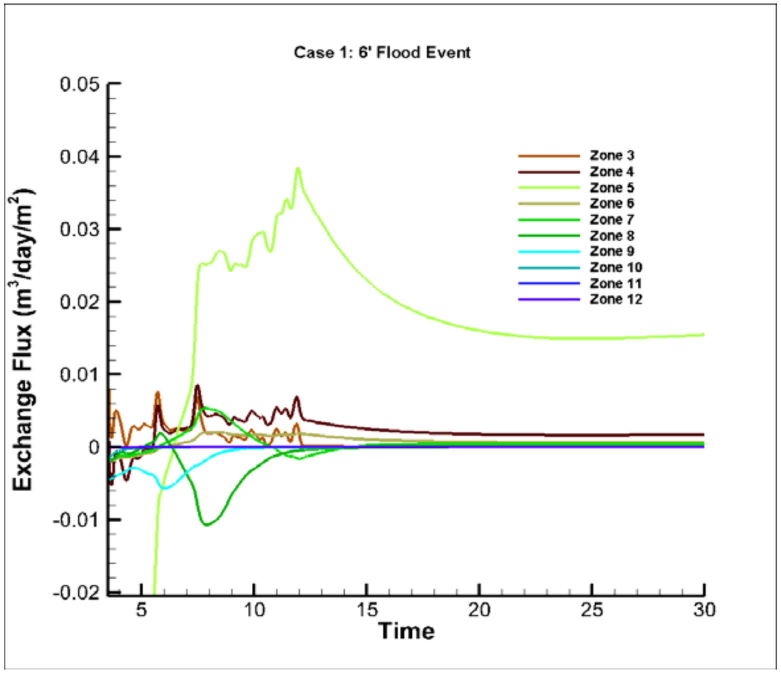




Bank flux – General Observations

- Zone 5 is the most active zone
- Infiltration rate during the flood wave is an order of magnitude greater than discharge rate due to difference gradients
- In addition to Zone 5, some infiltration occurs higher up on the bank face, however, return flow to the channel is predominantly through Zone 5





Conclusions and General Observations

- The degree of bank infiltration is highly dependent on the material properties of the bank, as well as the magnitude of the flood event
- In-channel and floodplain events behave very differently and may activate different portions of the bank
- During an in-channel event most of the water enters the system through the high-permeability layer at the base of the river (Zone 5)
- The rate of infiltration during a flood event is approximately an order of magnitude greater then the exfiltration rates during the receding limb
- Infiltration into the bank may persist for several days following the peak of the flood event, and the timing of the reversal is related to the soil properties of the system

Questions