Hydraulic Modeling for the Three Rivers HC145 Structure

McClellan-Kerr Arkansas River Navigation System

Arkansas and Desha Counties, Arkansas

Client: USACE, Little Rock District

US Army Corps of Engineers

2024 IAFSM Annual Conference
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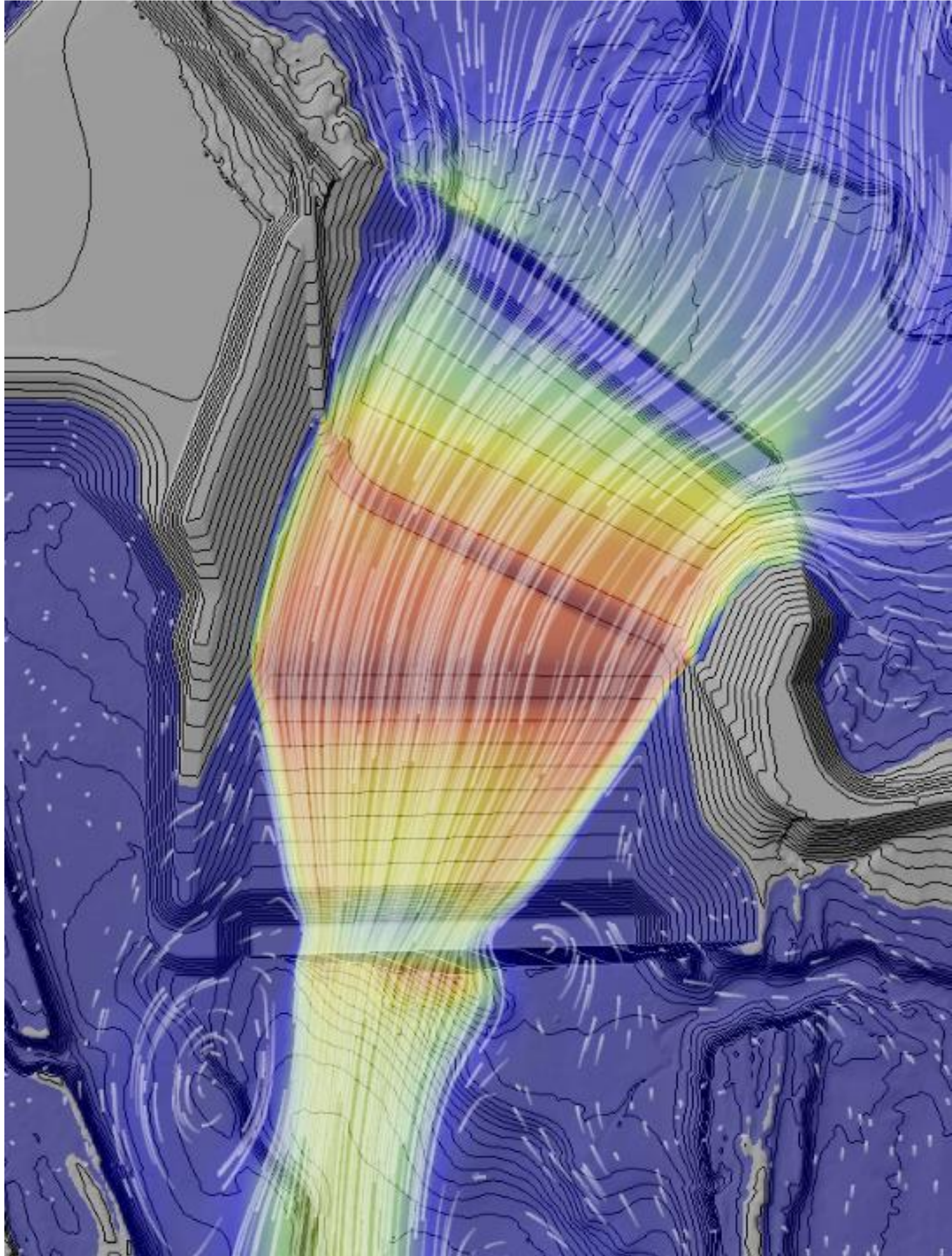


Agenda

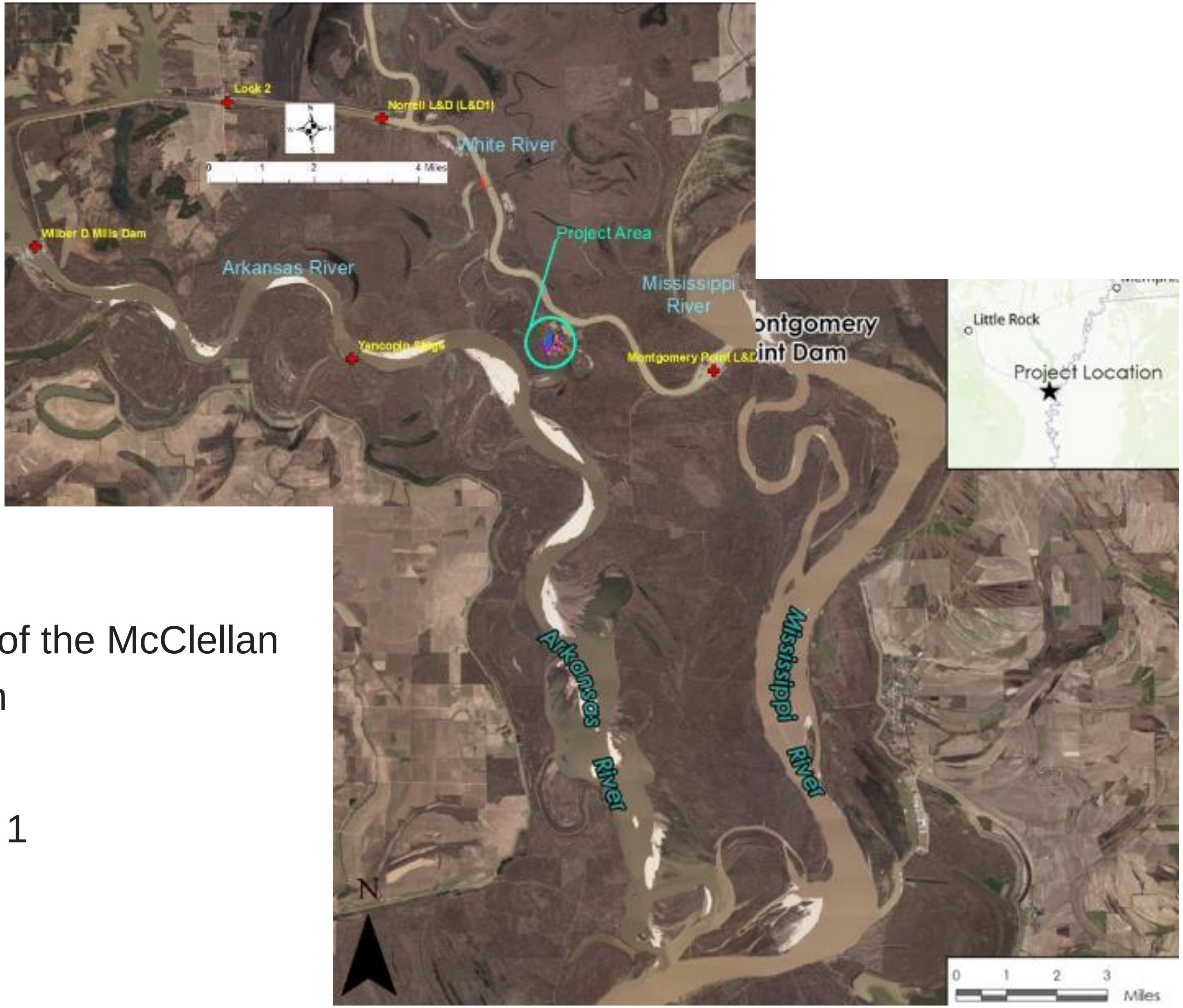
- **Project Background**
  - Project Location
  - Existing Conditions
  - Design Features
- **Hydraulic Analyses**
  - Hydraulic Modeling Framework
  - Design Criteria
  - 2D HEC-RAS Modeling
  - CFD Modeling (FLOW-3D HYDRO)
  - 1:20 Scale Physical Model Testing (Alden)
  - Sediment Transport Modeling (2D HEC-RAS)

Three Rivers, Phase 1 DB HC145

Project Background

Project Location

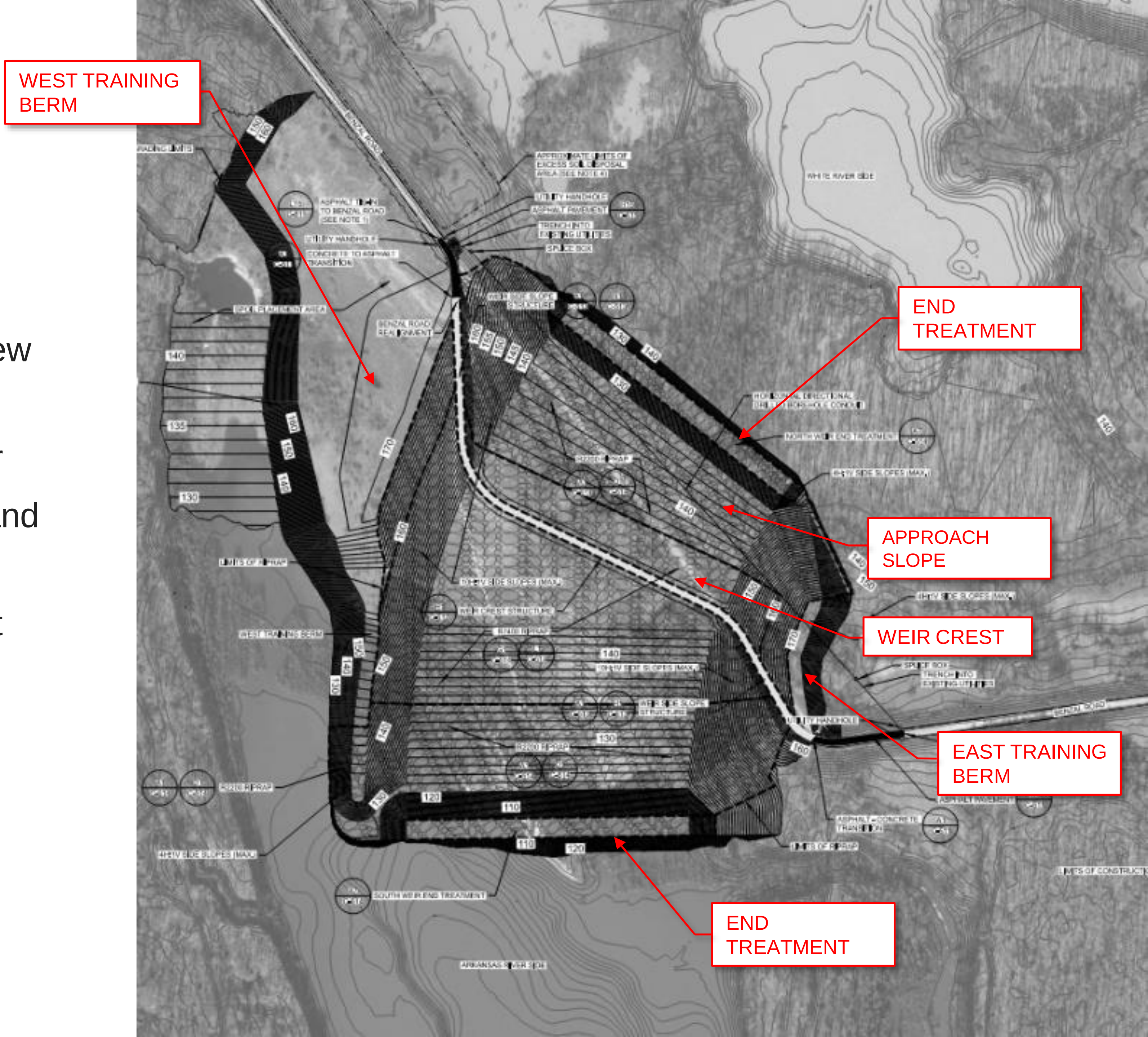
- **The proposed weir structure will regulate flow between the White River and Arkansas River during high flow events**
- Project area is located between three rivers:
  - Arkansas River
  - White River
  - Mississippi River
- Project is located at the southeast end of the McClellan Kerr Arkansas River Navigation System
- Two Phases – HC145 Project is Phase 1



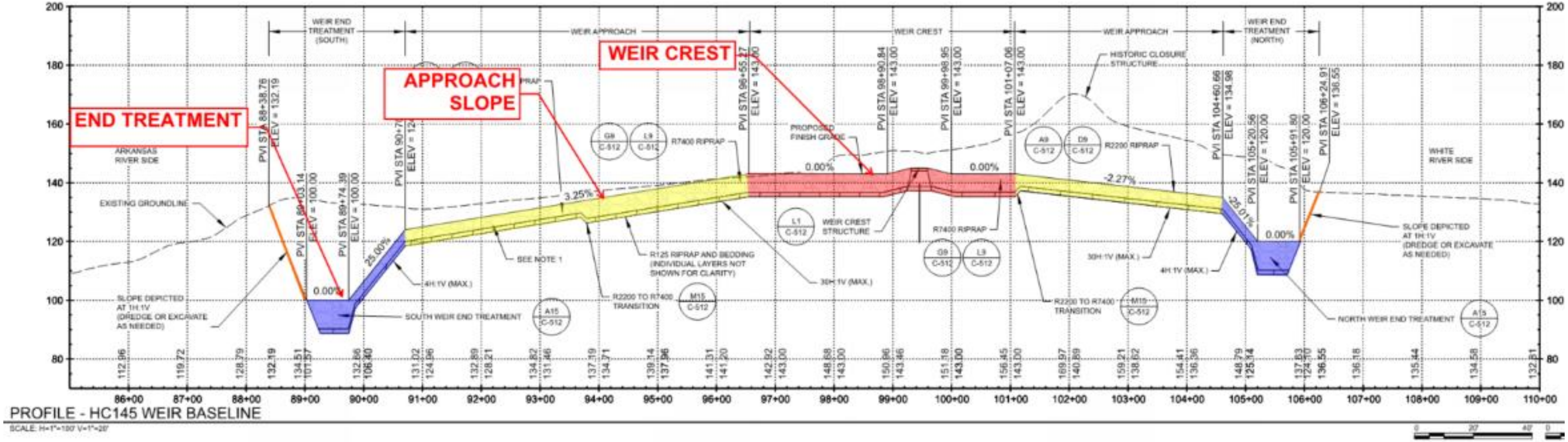
Existing Conditions – Historic Closure

Design Features

- **Key Project Features of Final Arrangement:**
  - Soil cement structure with new roadway at weir crest
  - SCB cutoff wall beneath weir
  - Rip-rap armored weir crest and approach slopes
  - Launching toe end treatment



Design Features



Three Rivers – HC-145 Project

Hydraulic Analyses

Hydraulic Modeling Framework

Utilized a multi-component modeling approach, including:

- **2D Steady and Unsteady Flow Modeling *(2D HEC-RAS)***
  - Large domain model to confirm boundary conditions at project
  - Small domain model for evaluating hydraulics through project
  - Estimate velocities and depths during design events to support riprap extents and sizing
- **CFD Modeling *(FLOW-3D HYDRO)***
  - Compare to 2D results and confirm 2D model assumptions were appropriate
- **Physical Model Testing *(Alden Laboratories)***
  - Test designed riprap stability at 65% design phase
- **Unsteady Sediment Transport Modeling *(2D HEC-RAS)***
  - Estimate scour in unarmored areas adjacent to end treatment to inform design and maintenance

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RAS

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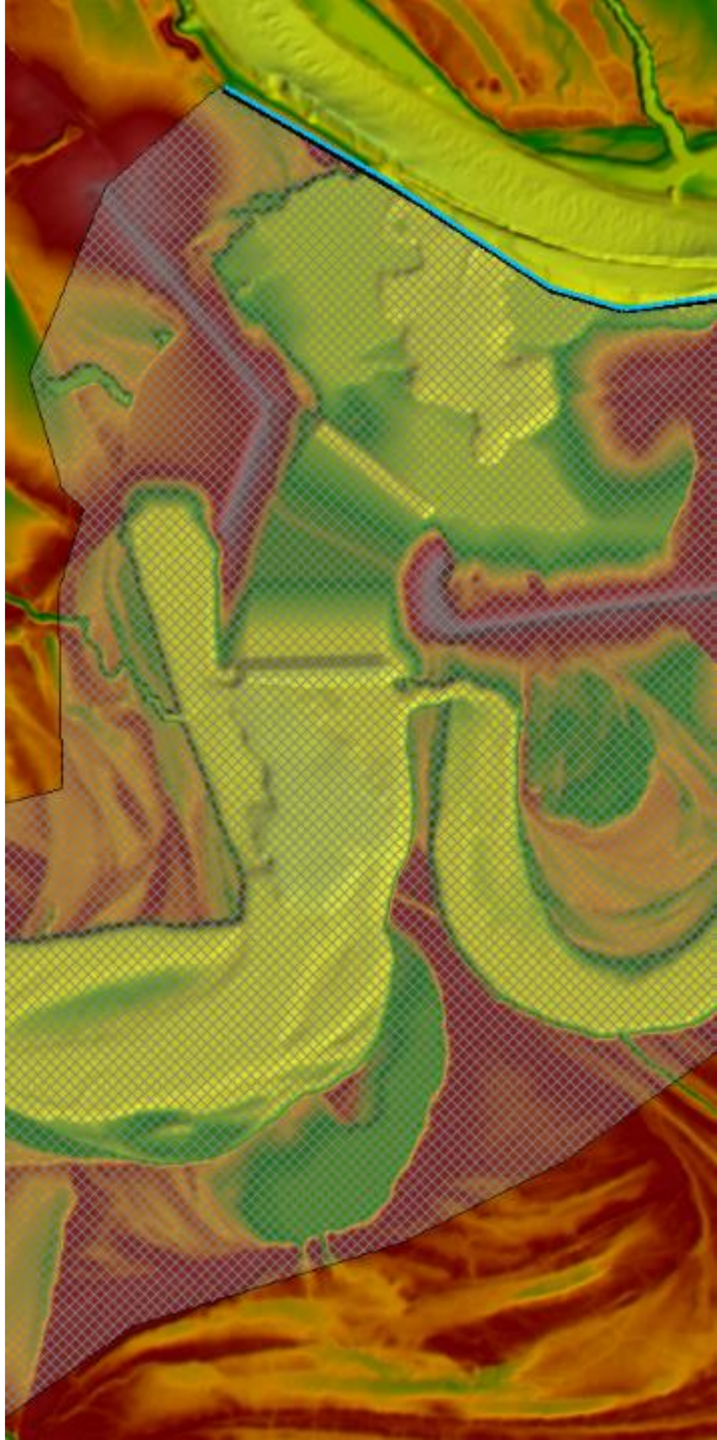
FLOW-3D HYDRO



Hydraulic Design Criteria and USACE Guidance

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- **Modeling Criteria**
  - Utilize pre-calibrated 2D HEC-RAS model and terrain supplied by USACE
  - Utilize manning's n-values of 0.039 and 0.041 for R2200/R7400
  - Utilize minimum HW/TW differentials
    - **White to Arkansas Rivers 8-ft (2011 Event)** ← **Governing Storm Event**
    - Arkansas to White Rivers 6-ft (1990 Event)

Predominant Flow Condition (Focus of Presentation)

- **Riprap Design**
  - Must be used in areas where velocities > 1.5 fps
  - Minimum gradation at any location is R2200
  - Minimum gradation where velocities > 10.0 fps is R7400
  - Minimum thickness of 2.0 * D_{50} or 1.5 * D_{100}
  - Utilize standard USACE gradations - R2200/R7400
  - Utilize Isbash equation (high turbulence assumption) with 2D model results for sizing

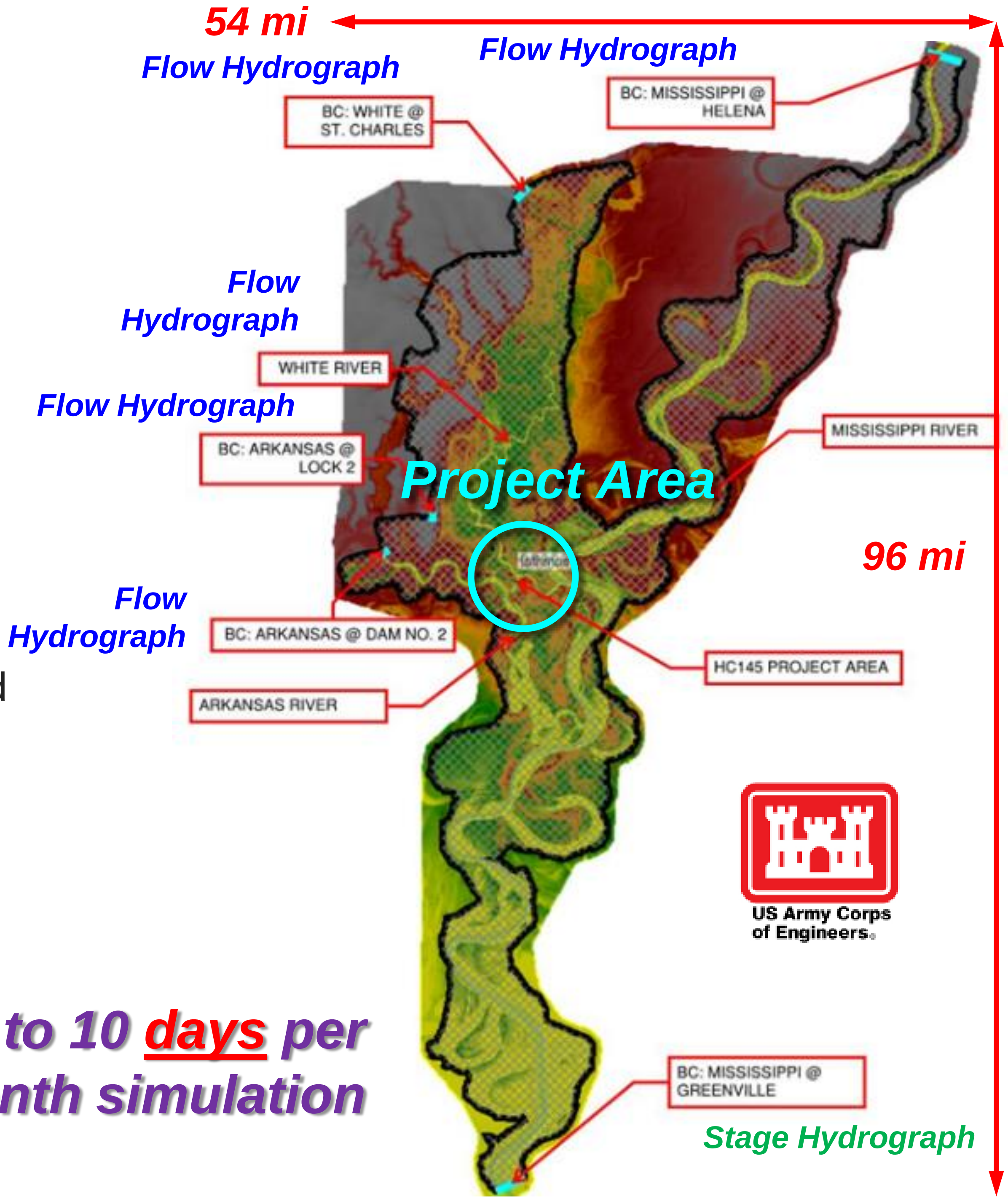
Hydraulic Analyses

2D HEC-RAS Modeling

Large Domain Model

- Base model and terrain model covers 5,200 mi^2
- **Models used to confirm HW/TW differentials from 1990 and 2011 historic events**
  - Base model
    - 1,500-ft x 1,500-ft Grid Cells (~25,000 Cells)
  - w/Project model
    - Includes 6.75-ft to 75-ft resolution around project area (~ 37,000 Cells)
- Used combination of flow and stage hydrographs on White, Arkansas and Mississippi Rivers

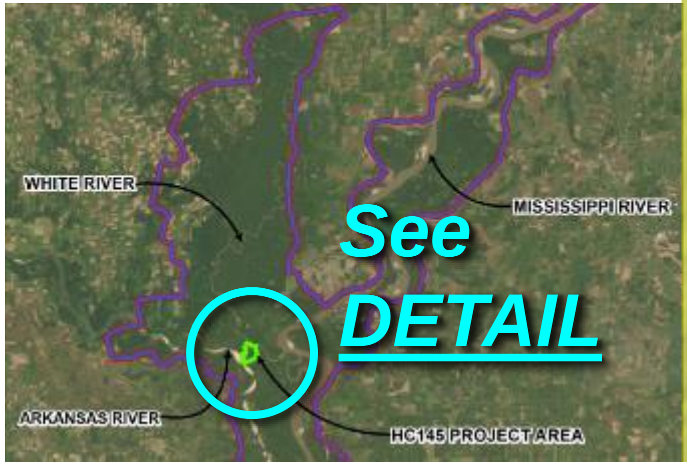
**** Run times at 8 to 10 days per multi-month simulation***

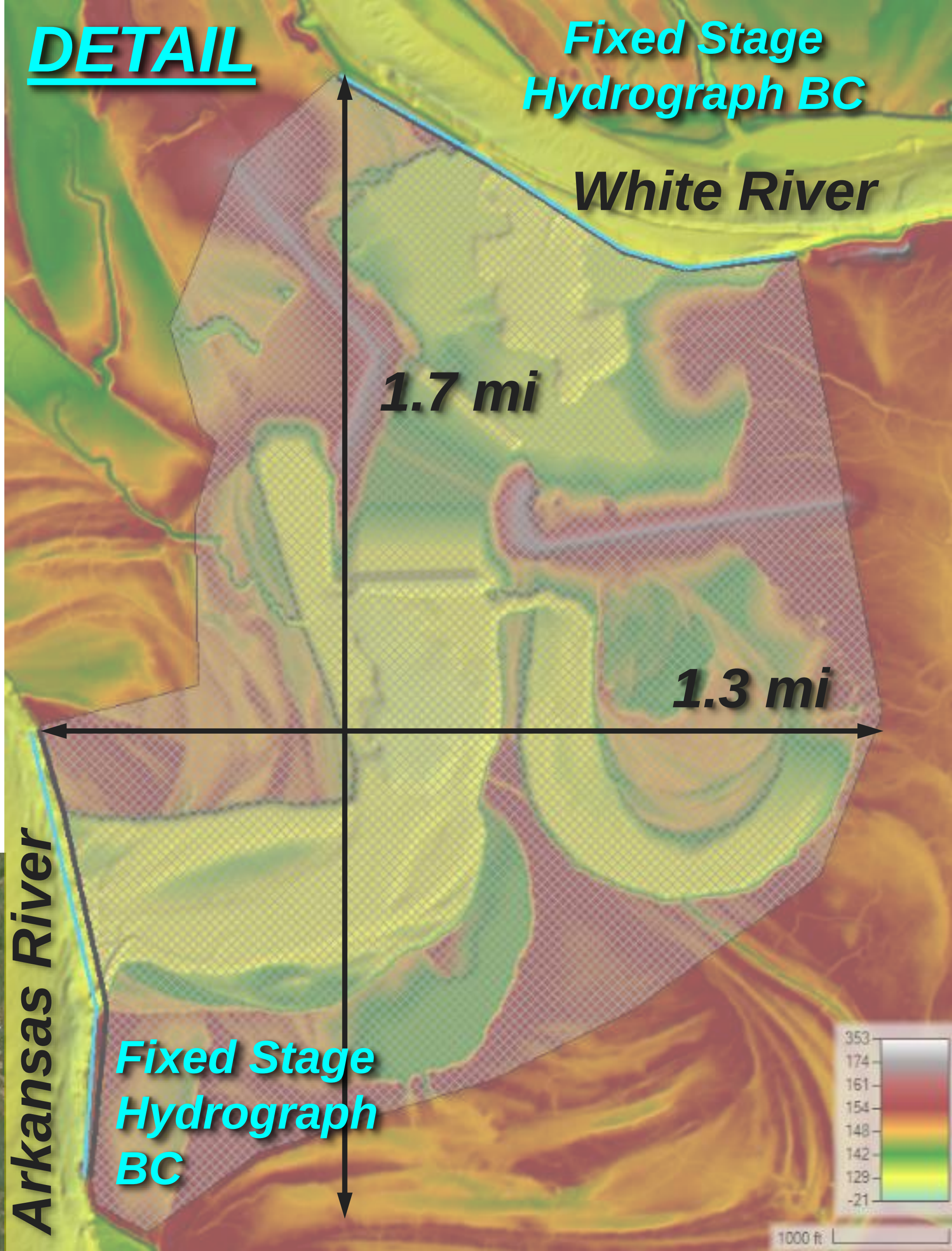


Small Domain Model

- Small subset of large domain model covering project area (~2 mi^2 down from ~5,200 mi^2)
- **Models used to rapidly test weir and grading alternatives**
- HW/TW levels set to constant stage hydrographs covering target HW/TW differentials to expedite model runtimes
- **Final w/project alternative inserted and validated within large domain model**

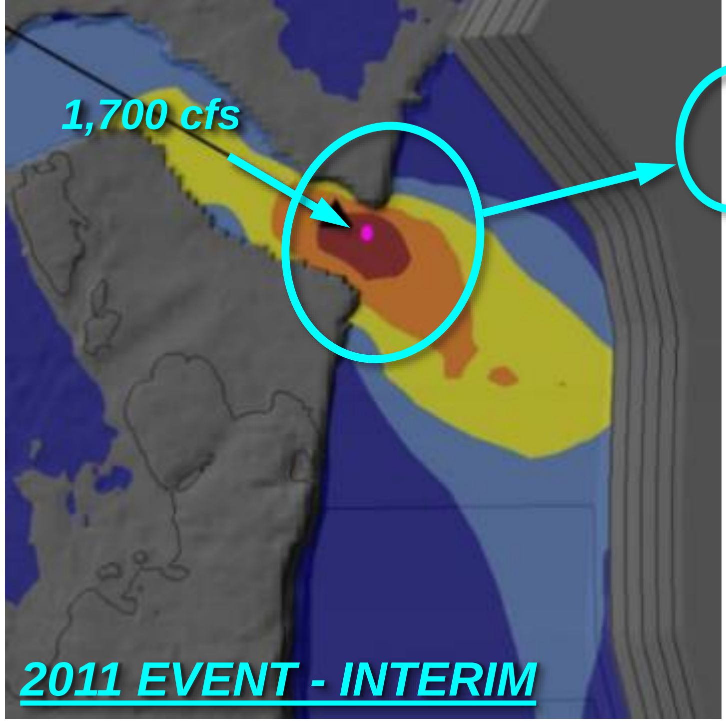
***** Run times at 2 to 4 hours per steady-state simulation***

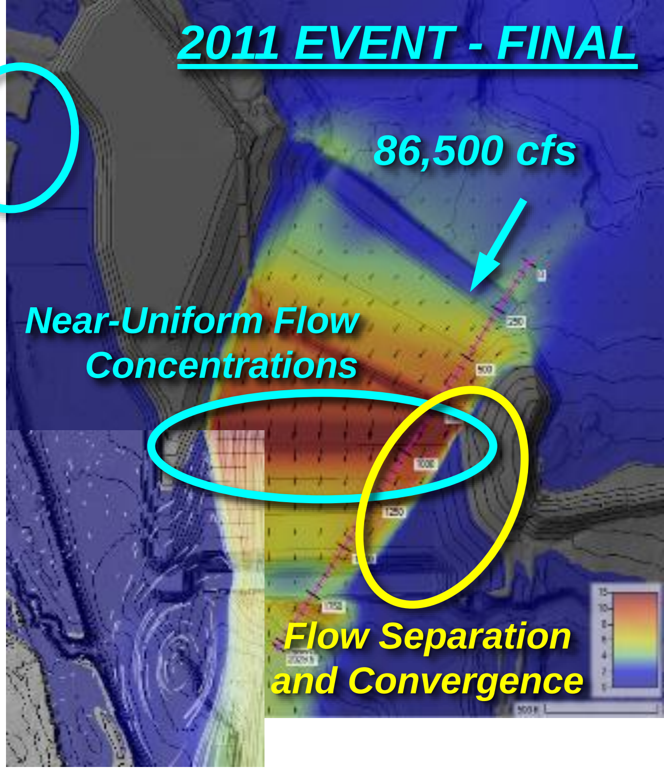


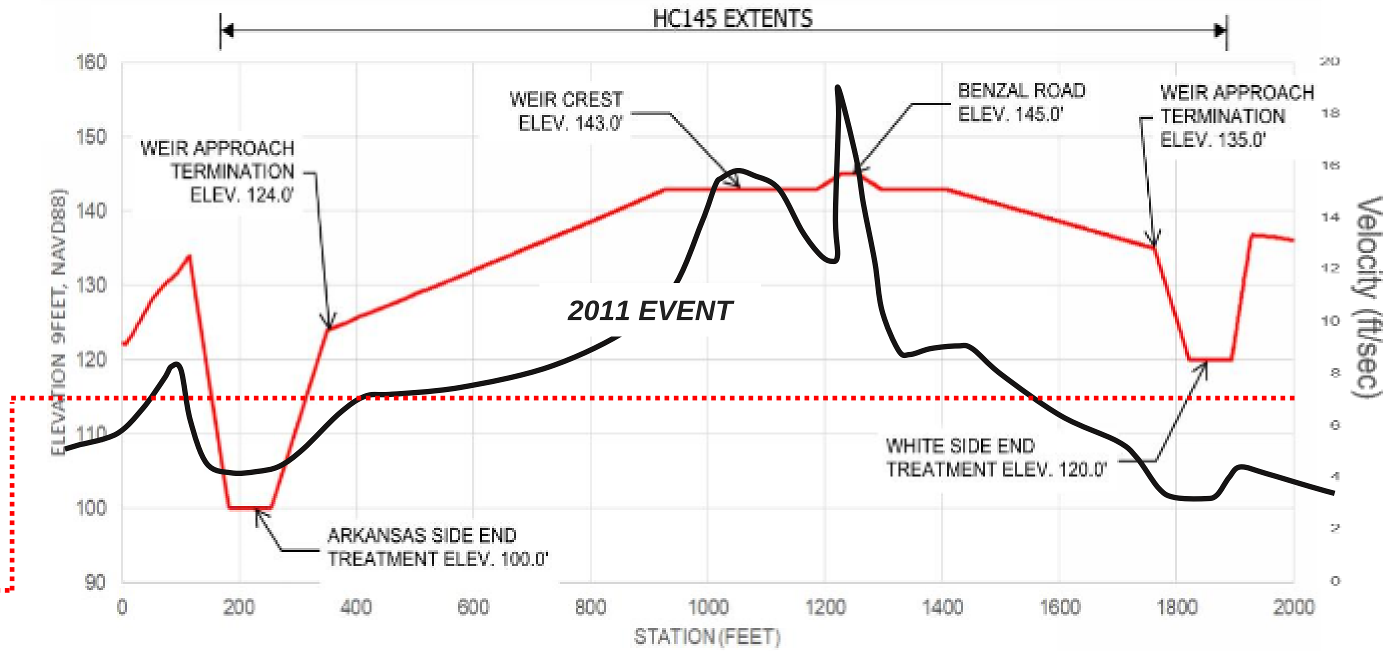


Small Domain Model Results

- **Maximum depth-averaged velocities met USACE design criteria**
  - Velocities ranged from 7 to 20 ft/s within project area
- **Near-uniform flow concentrations achieved** near weir crest
- **Flow Separation and convergence observed** along weir approach slope







Allowable Velocity Threshold at Termination of Approach Slope

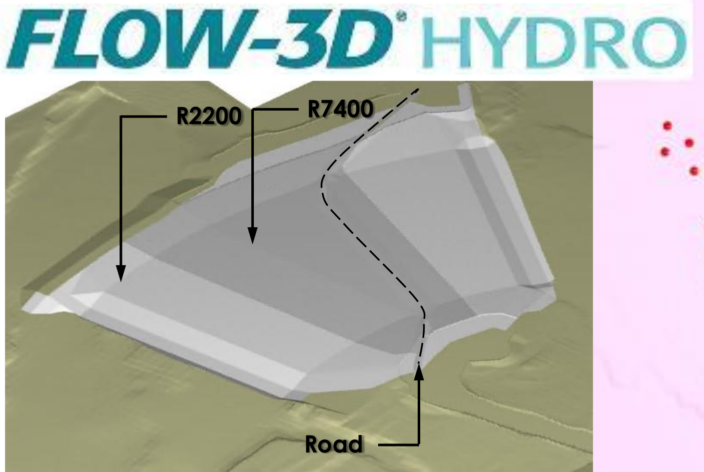
Hydraulic Analyses

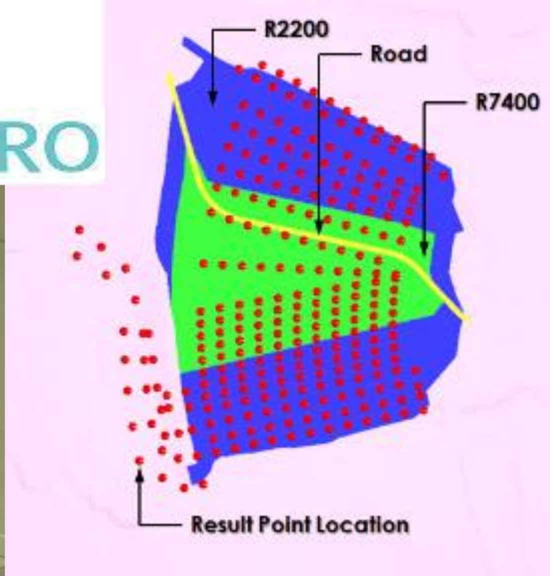
CFD Modeling

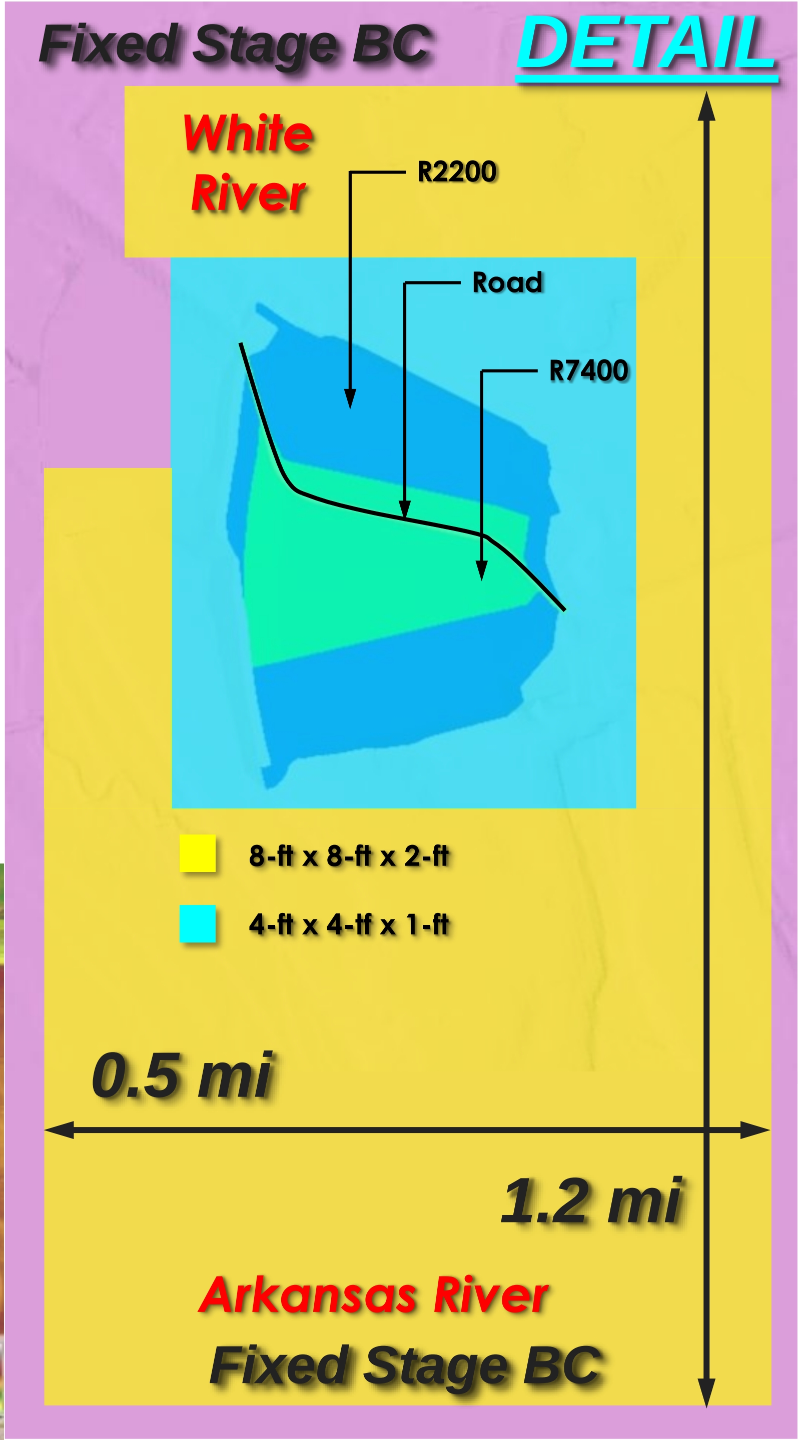
CFD Model

*** Run times at 3 to 5 days per steady-state simulation**

- Subset of small domain 2D model (~0.6 mi^2 down from ~2.0 mi^2)
- HW/TW differentials and boundary conditions matched small domain 2D HEC-RAS modeling approach
- **Models Used To:**
    - **Compare/Confirm 2D model results and assumptions were appropriate using a gridded approach**
    - Provide full 3D velocity field data for use/consideration in physical model and riprap design

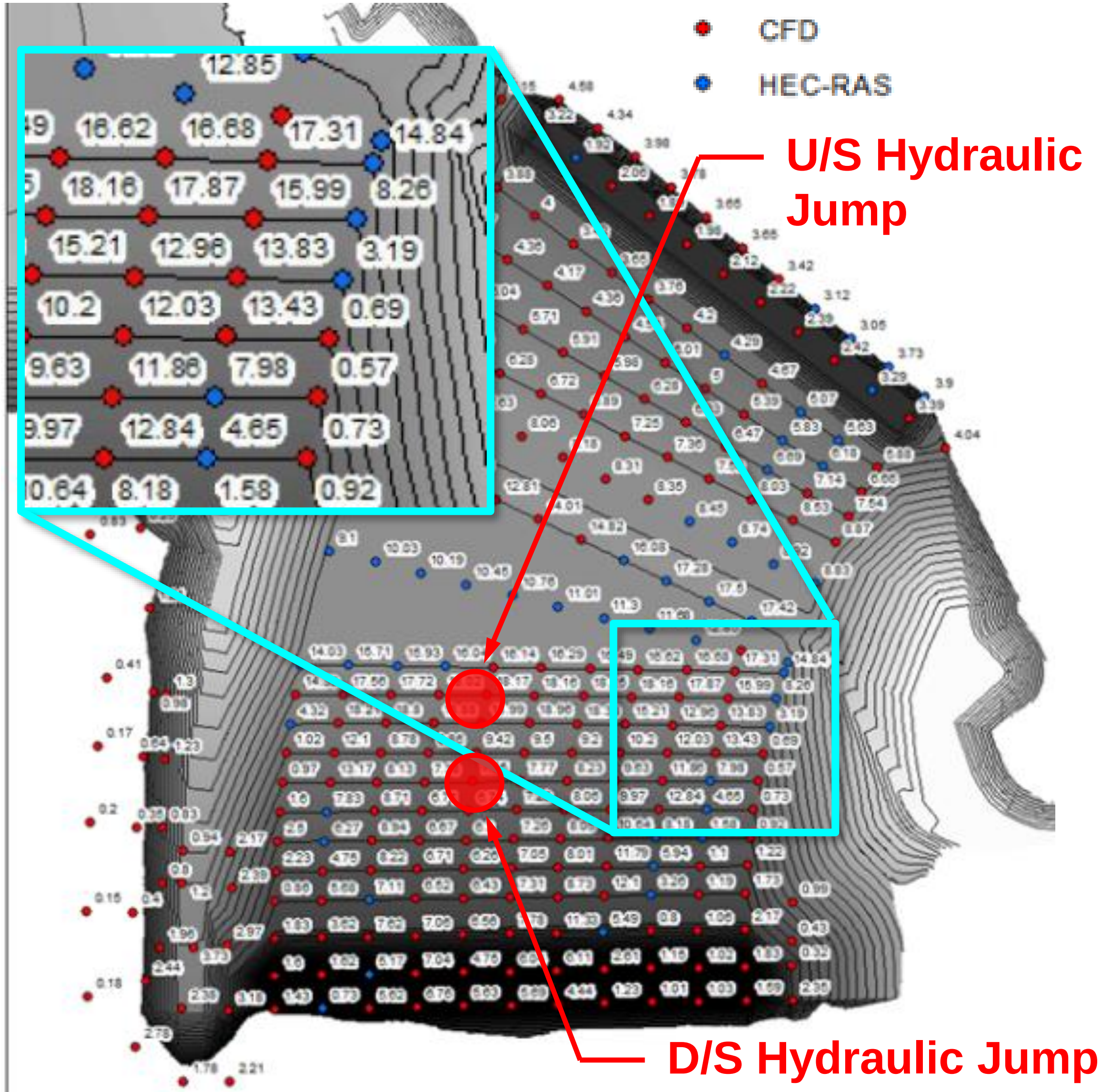


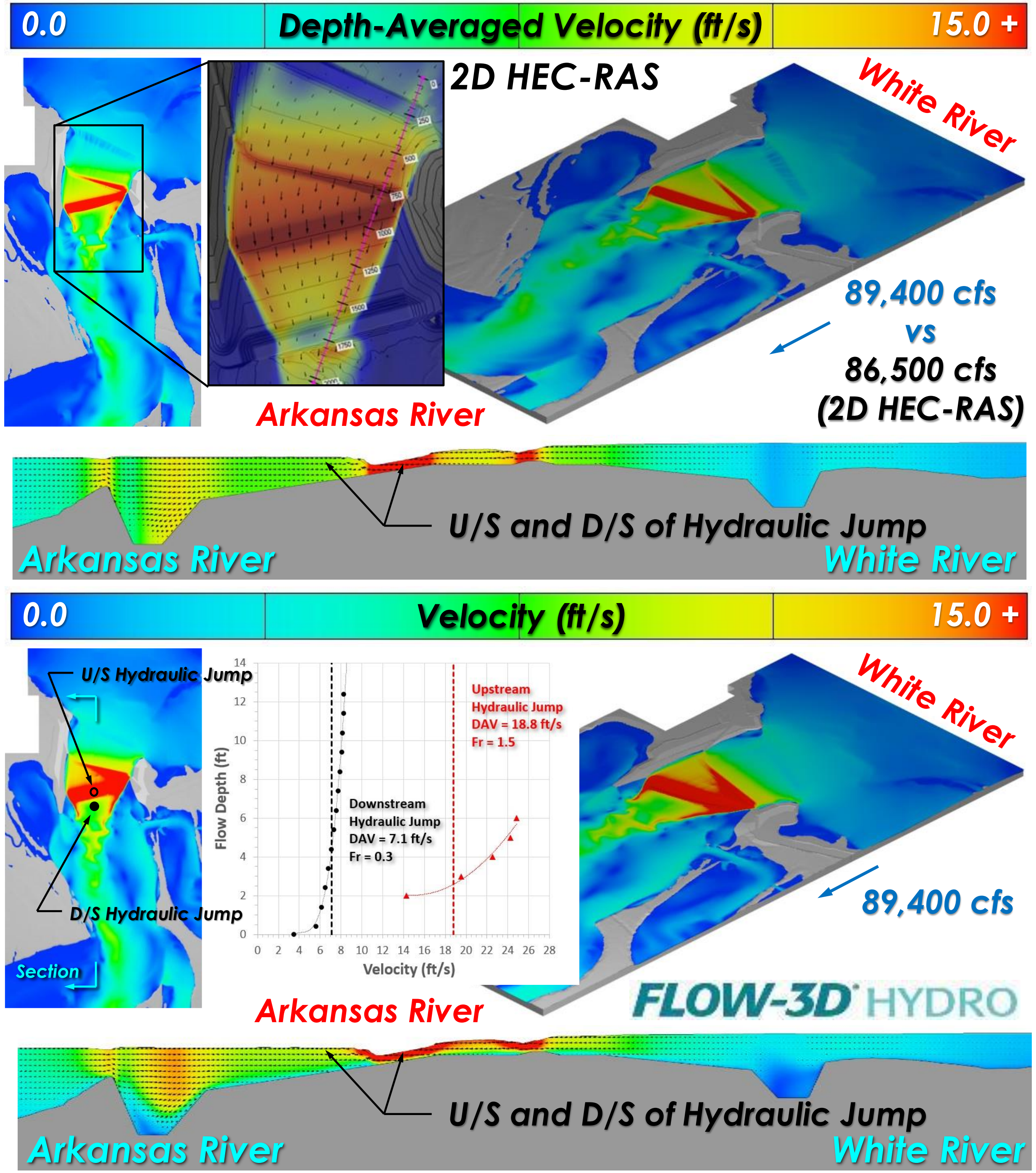




2011 EVENT - FINAL

CFD Model Results





Hydraulic Analyses

Physical Model Testing

Physical Model Testing

- 1:20 scale model
- "Unit" width model
  - 5-ft model scale represents 100-ft prototype scale
- **Used to evaluate riprap movement and stability**
- Physical model testing prepared by Alden Laboratory (Holden, MA)

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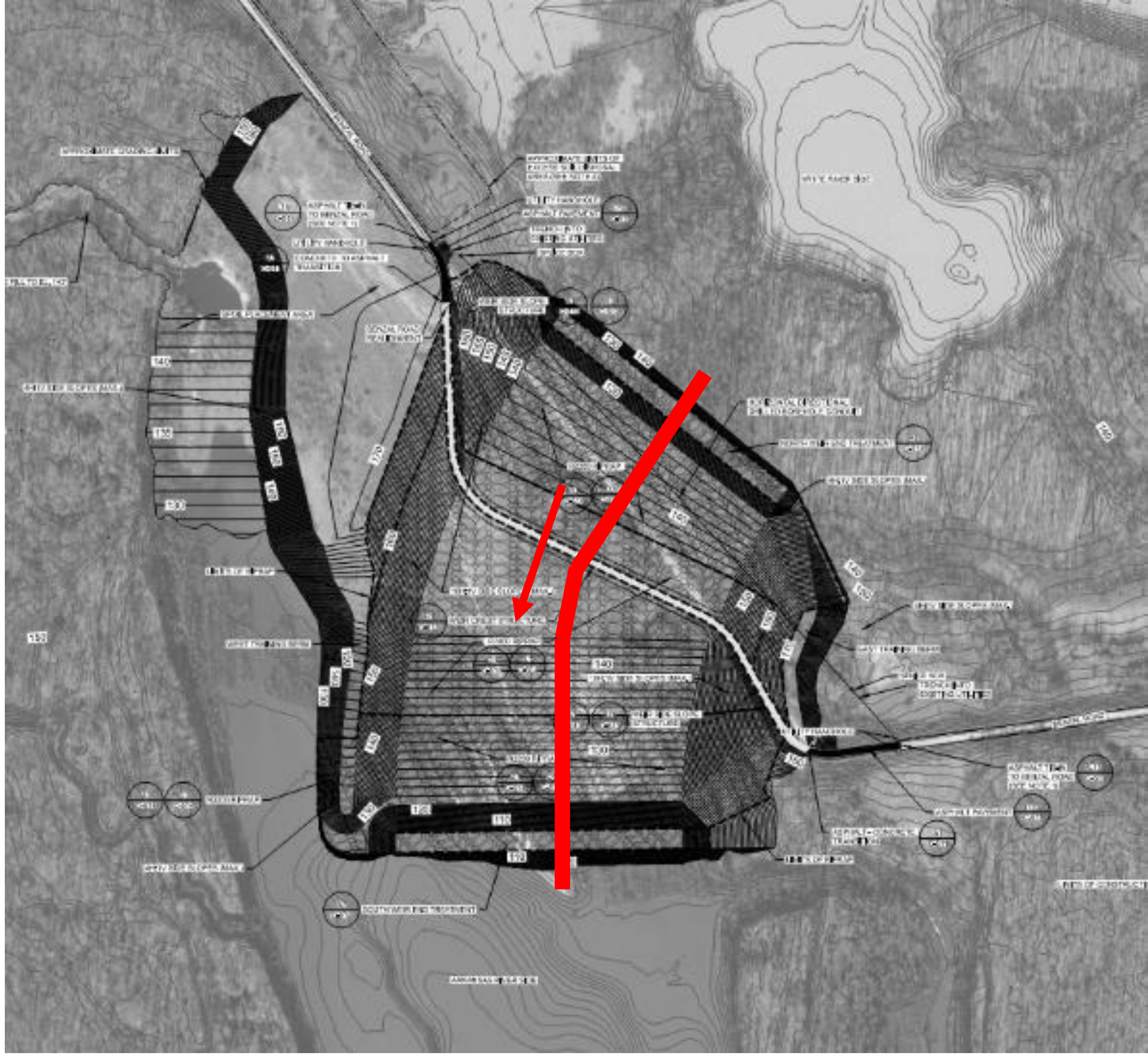

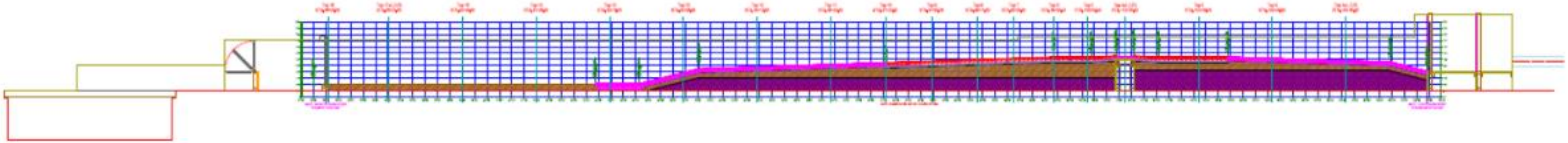

Physical Model

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- Water-tight wood frame
- Recirculating pump flow loop

Physical Model

- Stone painted to support visual observations of movement

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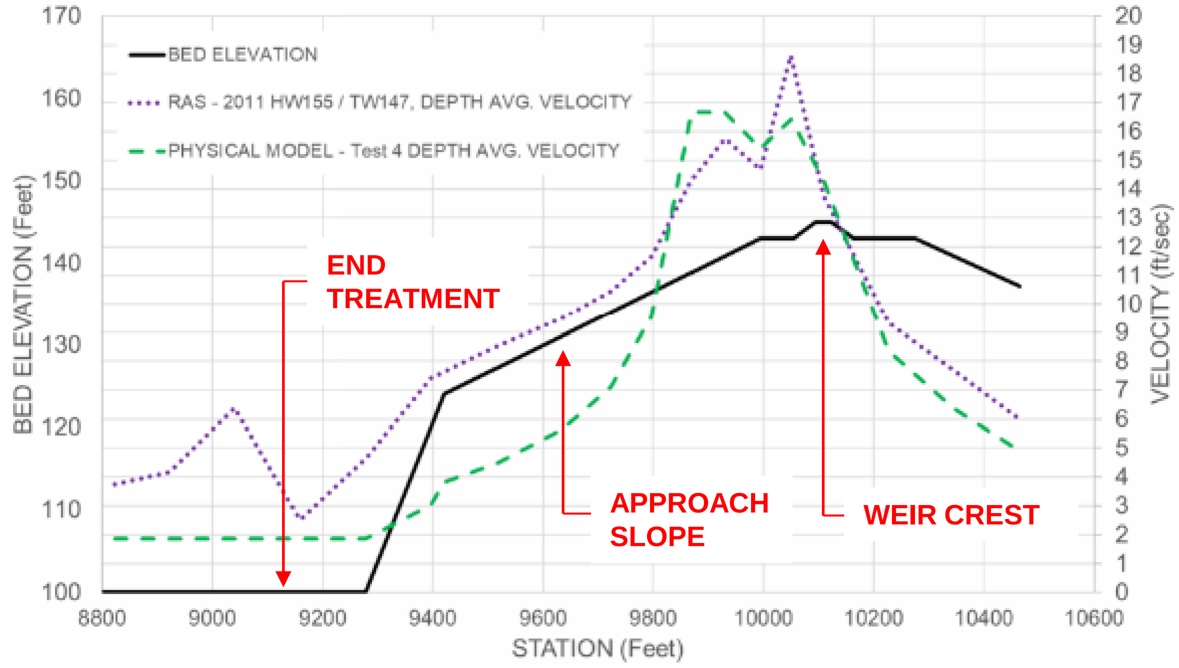
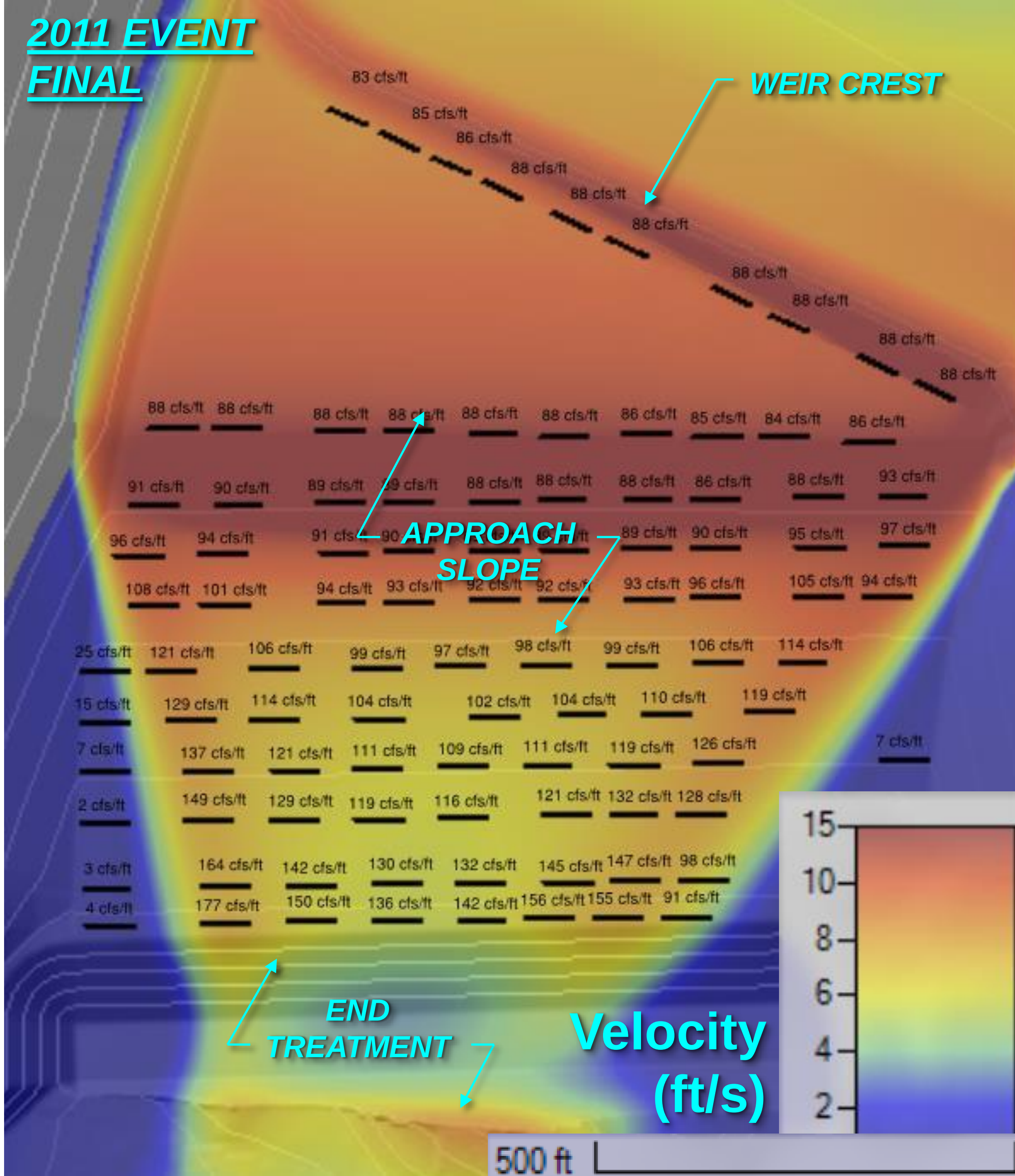
Physical Model

- **Challenge:**
  - How to replicate flow convergence seen in the 2D/3D numerical models?





Physical Model

- **Test Plan:**
  - Design Scenarios
  - Low Probability Events
  - Flow Convergence
  - Long Duration Event

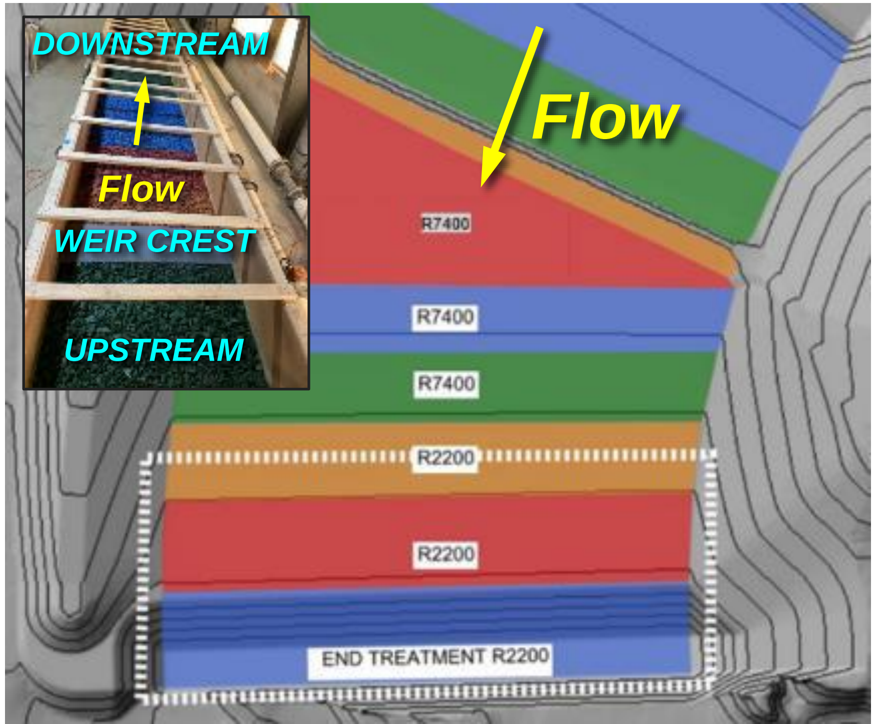


Table 1. Physical Model Test Plan

Test Number	Headwater (WSE, ft)	Tailwater (WSE, ft)	Target Unit Discharge (Q, cfs/ft)	Test Case No. and Description
1	146	138	--	2 – Event that just overtops the HC145 crest
2	147	141	--	1 – 1990 Design HW/TW Differentials used for design
3	150	142	--	2 – Event producing 8-ft differential with shallow weir flow
4	155	147	--	1 – 2011 Design HW/TW Differentials used for design
5	160	155	--	3 – Low probability event based on Copula
6	161.3[1]	160	--	3 – Low probability event
7	168.0[1]	168	--	3 – Low probability event
8	-	165	145	4 – Flow convergence (End Treatment & R2200, Stations 92+54 to 95+00)
9	-	155	135	4 – Flow convergence (End Treatment & R2200, Stations 92+54 to 96+00)
10	-	155	150	4 – Flow convergence (End Treatment & R2200, Stations 92+54 to 95+20)
11	-	165	160	4 – Flow convergence (End Treatment, Stations 92+54 to 94+24)
12	-	147	130	4 – Flow convergence (End Treatment, R2200, Stations 92+54 to 96+50)
13	-	147	155	4 – Flow convergence (End Treatment, R2200, Stations 92+54 to 95+00)
14		147	130	5 – Long Duration with three, 8-hour runs. (End Treatment, R2200, & R7400, Stations 92+54 to 96+50) Same conditions as in Test 12

1. Indicates actual headwater WSE that was achieved during testing due to constraints of pumping capacity

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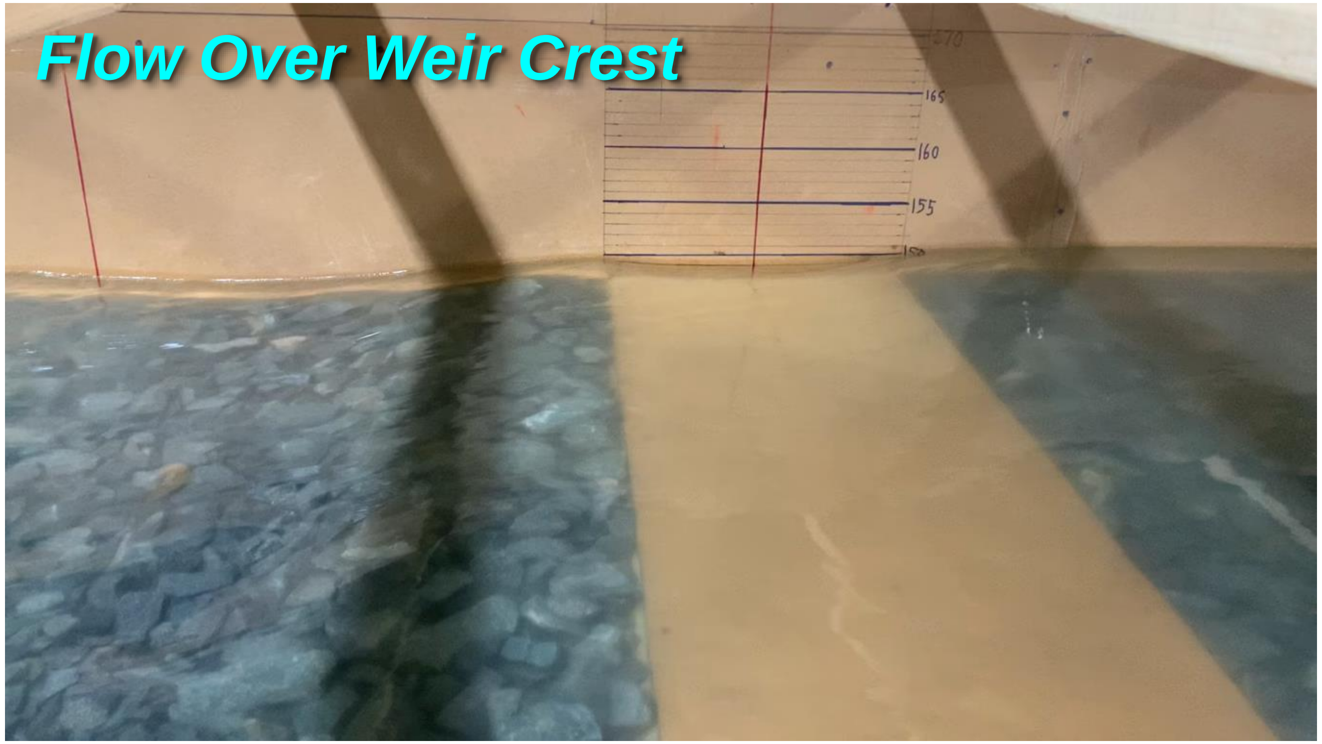
Physical Model Results



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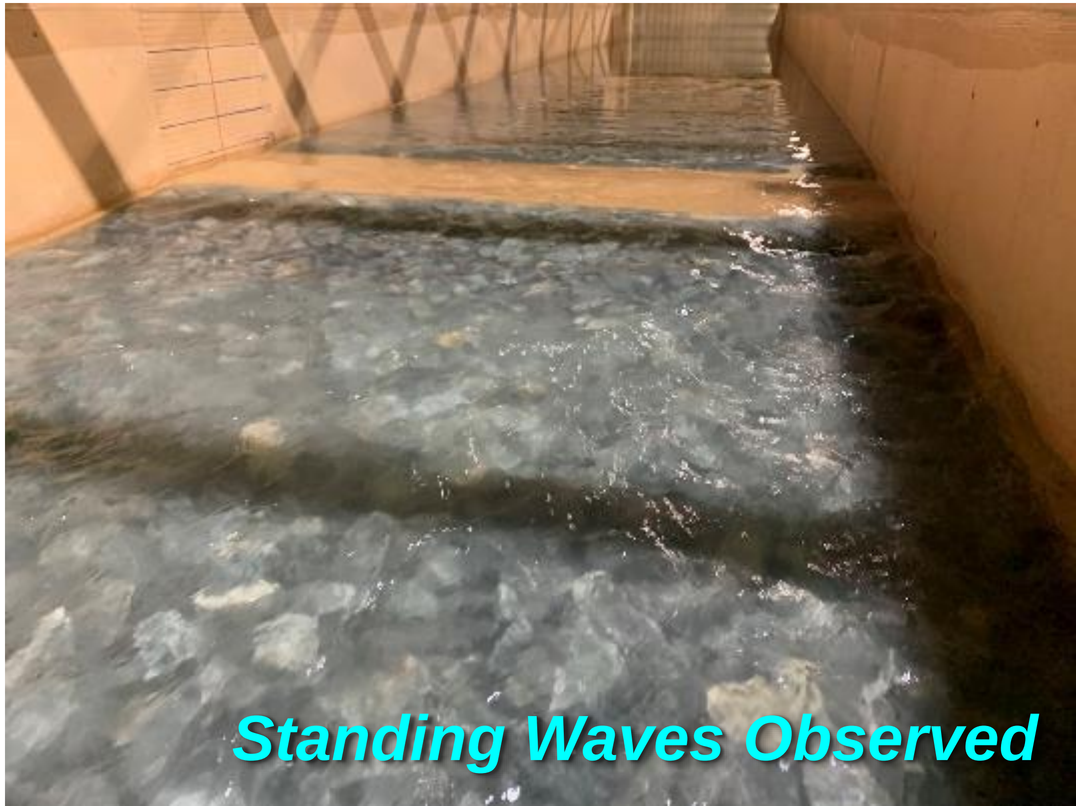
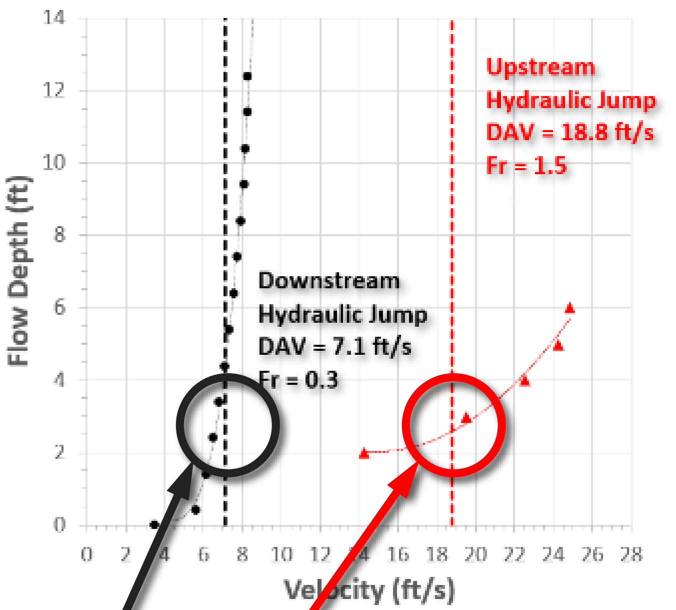


Physical Model Results

- **Hydraulic Performance**
  - Velocity, hydraulic jump location(s) showed good correlation with CFD results
- **Riprap Movement**
  - Some movement of individual stones anticipated

CFD RESULTS



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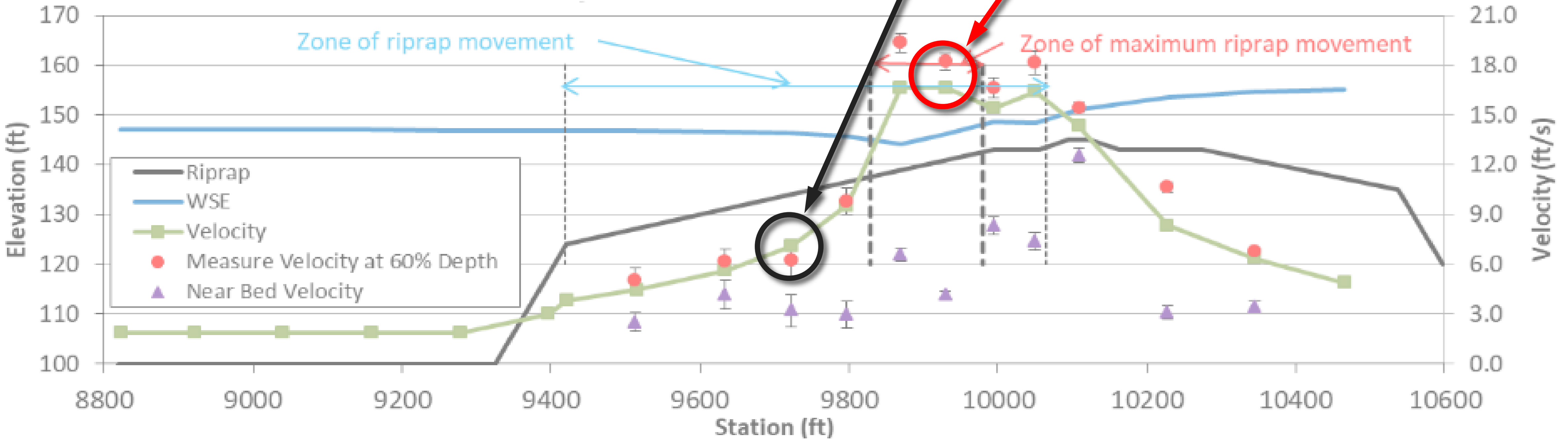
2011 EVENT FINAL



Physical Model Results

- **Challenge: Results Interpretation**
  - Some riprap will move – what is acceptable?
  - Table summarizes percent of stones moved in each region

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Riprap Class	Location	Station Range	# Stones Moved	% Area of Region	Located Within Test Focus Area?
R7400	Road to Crest Transition (Orange)	100+55 to 100+95	4	0.46%	No
R7400	Weir Crest (Red)	99+94 to 100+55	3	0.22%	No
R7400	Weir Approach Slope (Blue)	98+71 to 99+94	20	0.67%	No
R7400	Weir Approach Slope (Green)	97+26 to 98+71	57	1.92%	No
R2200	Weir Approach Slope (Orange)	95+80 to 97+23	13	0.19%	No
R2200	Weir Approach Slope (Red)	94+24 to 95+80	8	0.12%	Yes

Figure B- 56: Camera 4, Post Test 13.

Figure B- 70: Camera 5, Post Test 13.

Physical Model Results

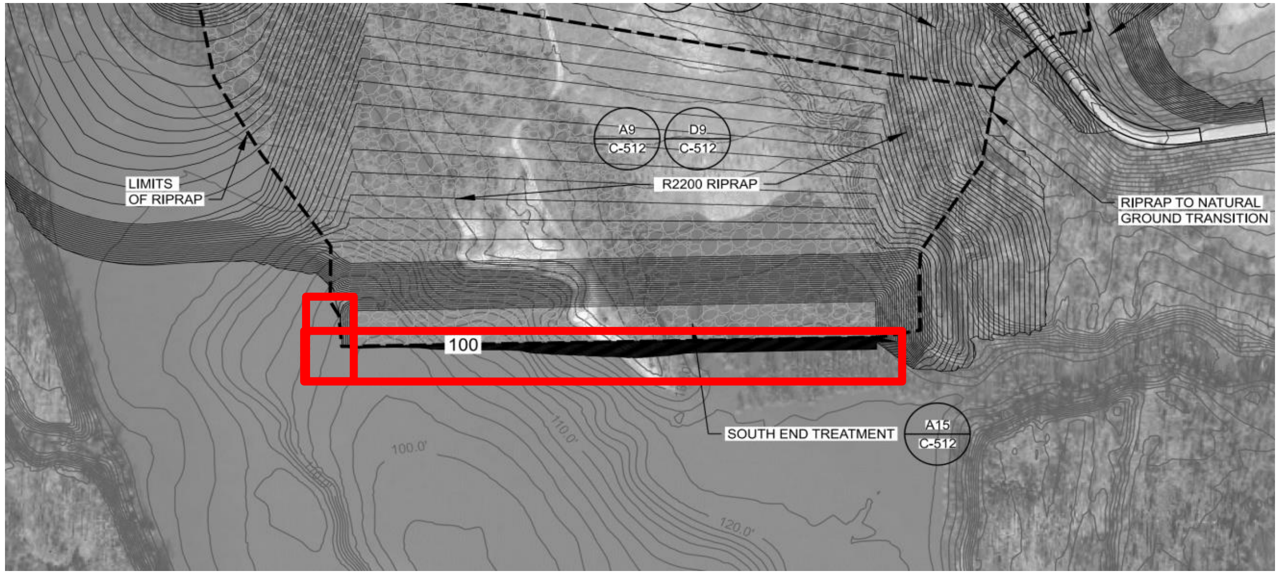
- **Conclusions:**
  - Riprap stability is a function of stone size, layer thickness and interlocking
  - Rolling/flipping of individual stones observed during testing, but stones settled back into riprap layer and did not remobilize
    - These stones were likely sticking up into flow and not locked in upon initial placement
  - No concentrated movement, no movement of more than isolated stones observed
  - Riprap configuration deemed acceptable based on model results

Hydraulic Analyses

Sediment Transport Modeling

Purpose & Approach of Sediment Modeling

- **Purpose**
- Evaluate potential scour formation
  - Southern end treatment
  - Sustained weir topping event (2011)
- Utilize scour results for design and O&M plan
  - Inform design measures
  - Estimate potential maintenance needs



- **Approach**
- Utilize available project data
  - 2D HEC-RAS and 3D CFD models
  - Geotechnical investigation
- Implement HEC-RAS 2D sediment transport modeling capabilities
- Perform sensitivity analysis of sediment transport modeling parameters
  - Inform selection of “best estimate” parameter set(s) to use in 2011 event simulations
- Utilize scour results from 2011 event simulation to inform design and O&M plan

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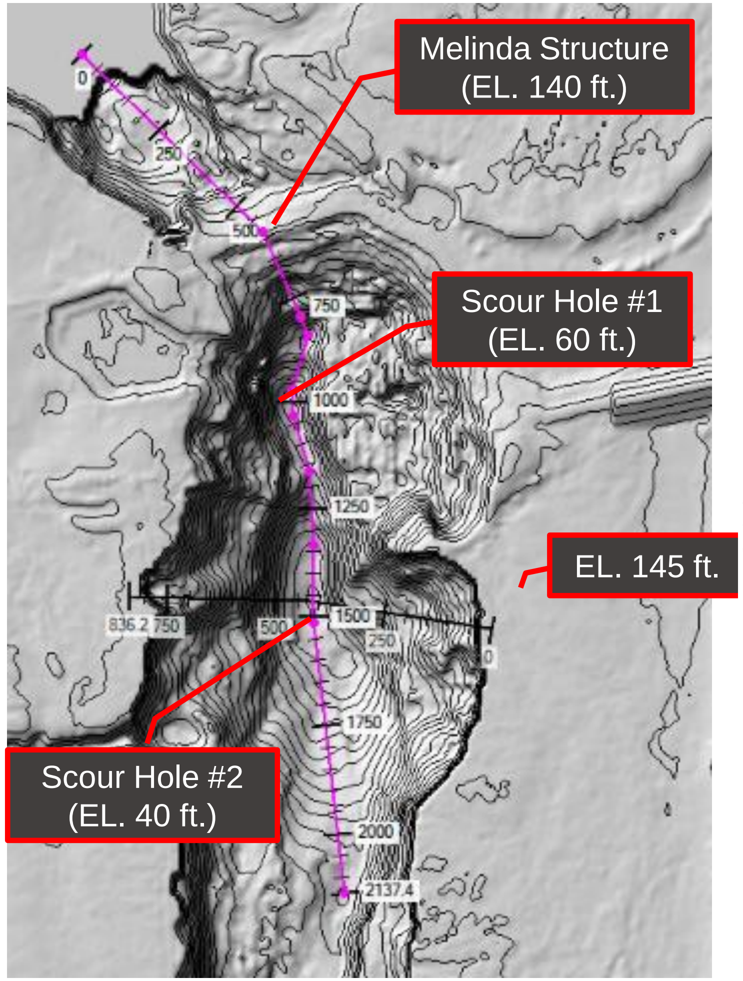
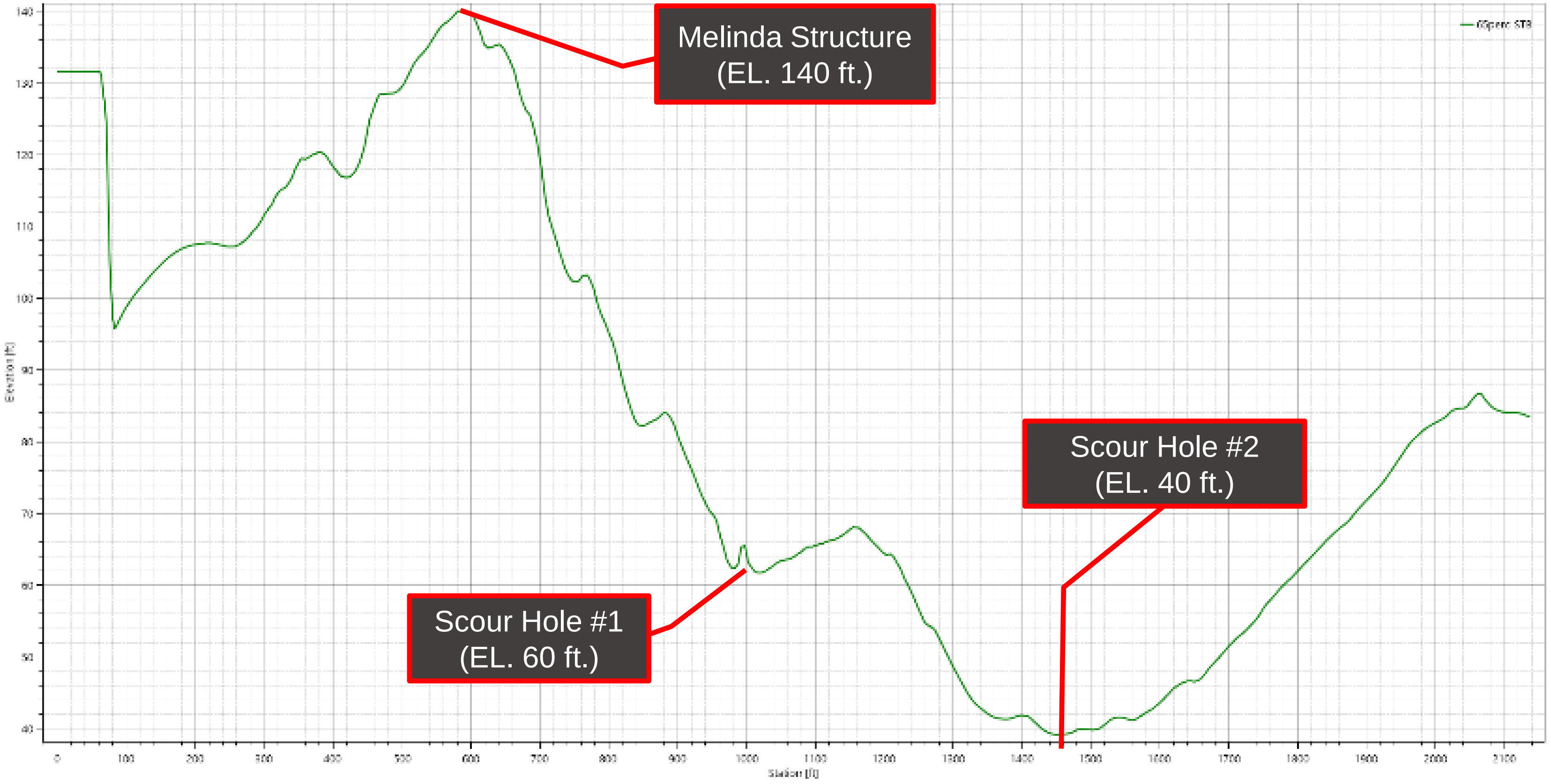
Purpose & Approach of Sediment Modeling

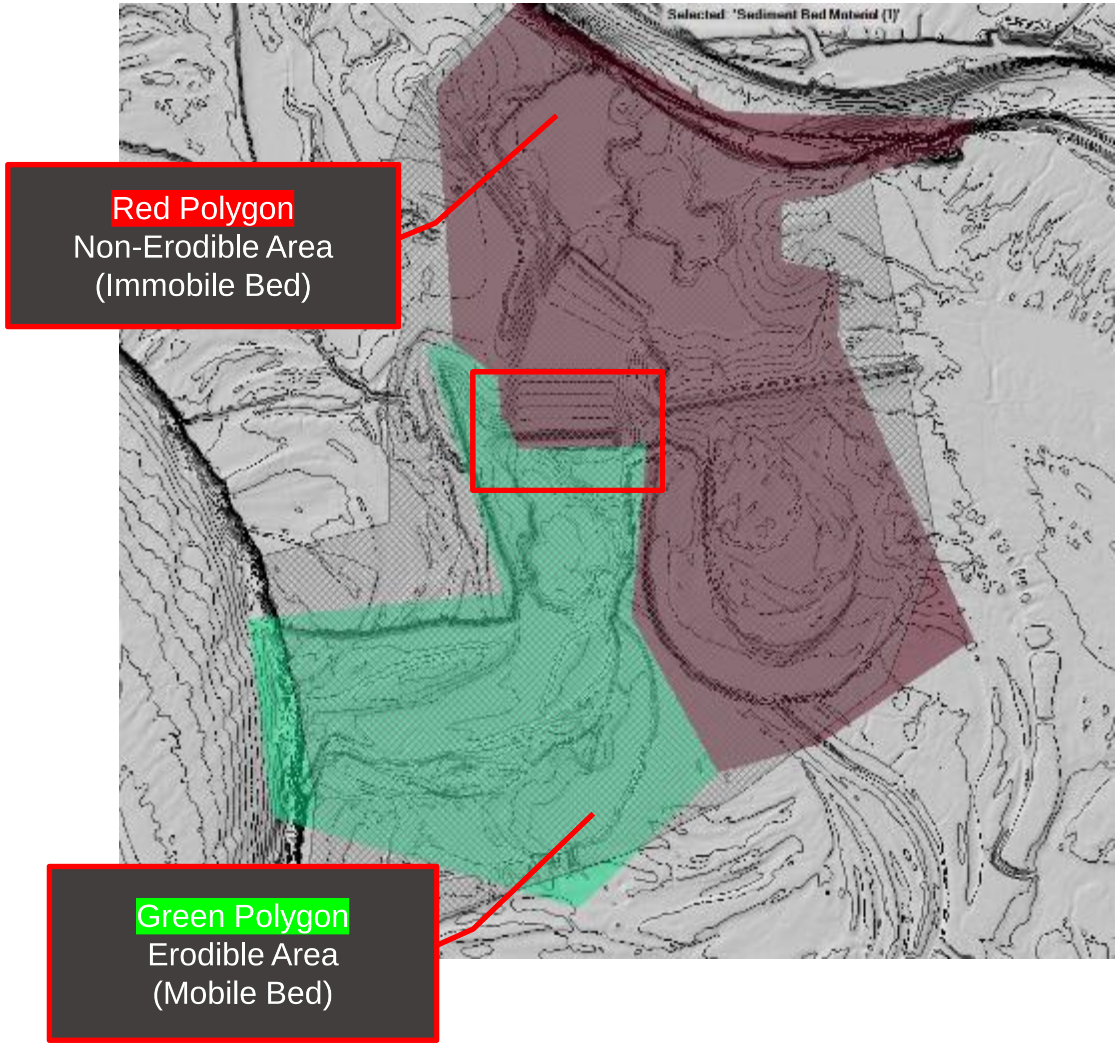
- **Why are we concerned about scour?**





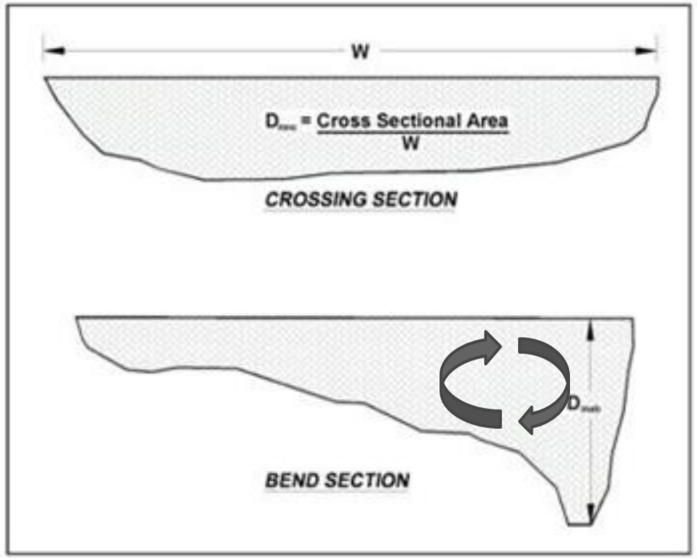
Model Setup, Data Inputs and Assumptions

- **2D Sediment Bed Material Map Layer**
  - RAS Mapper
  - Erodible area limits defined
- **Sediment Data File**
  - Sediment transport computation settings
  - Defined bed gradation(s)
  - Associated to 2D mapped layer surfaces
  - Utilized non-cohesive soil gradations & properties only
  - Predominant soil types are non-cohesive
    - Poorly graded sand (SP) & silty sand (SP-SM)
  - Cohesive soils in project area are sparse, not included
- **Single Bed Gradation Applied**
  - Assessed lab data from predominant soil samples
  - Sensitivity analysis of fine to coarse gradations
  - Conservative gradation selected for use in 2011 event run

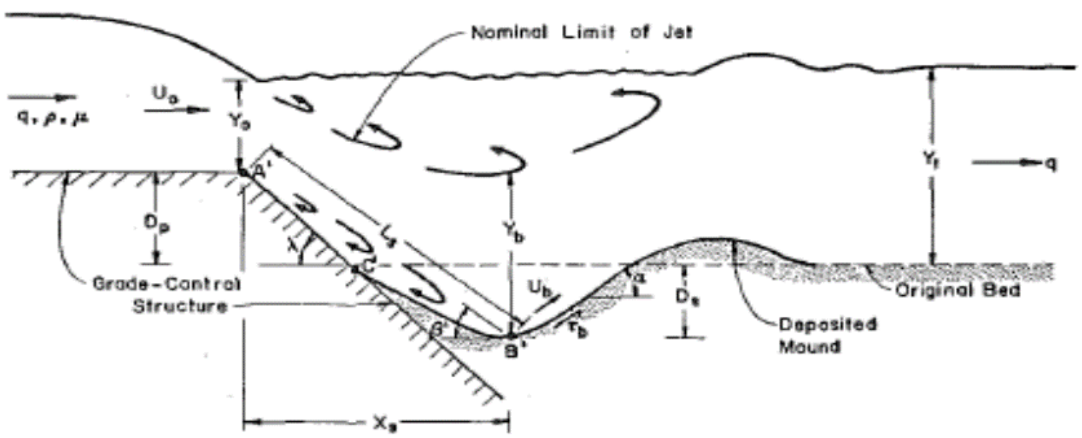


Sediment Modeling – Limitations & Uncertainties

- Vertical variation in water column is not represented
- Vertical circulations not represented
- Local scour due to complex flow patterns may not be well represented
- Pool scour in pool-riffle complexes is often under predicted
- Bank erosion prediction is still in research stage



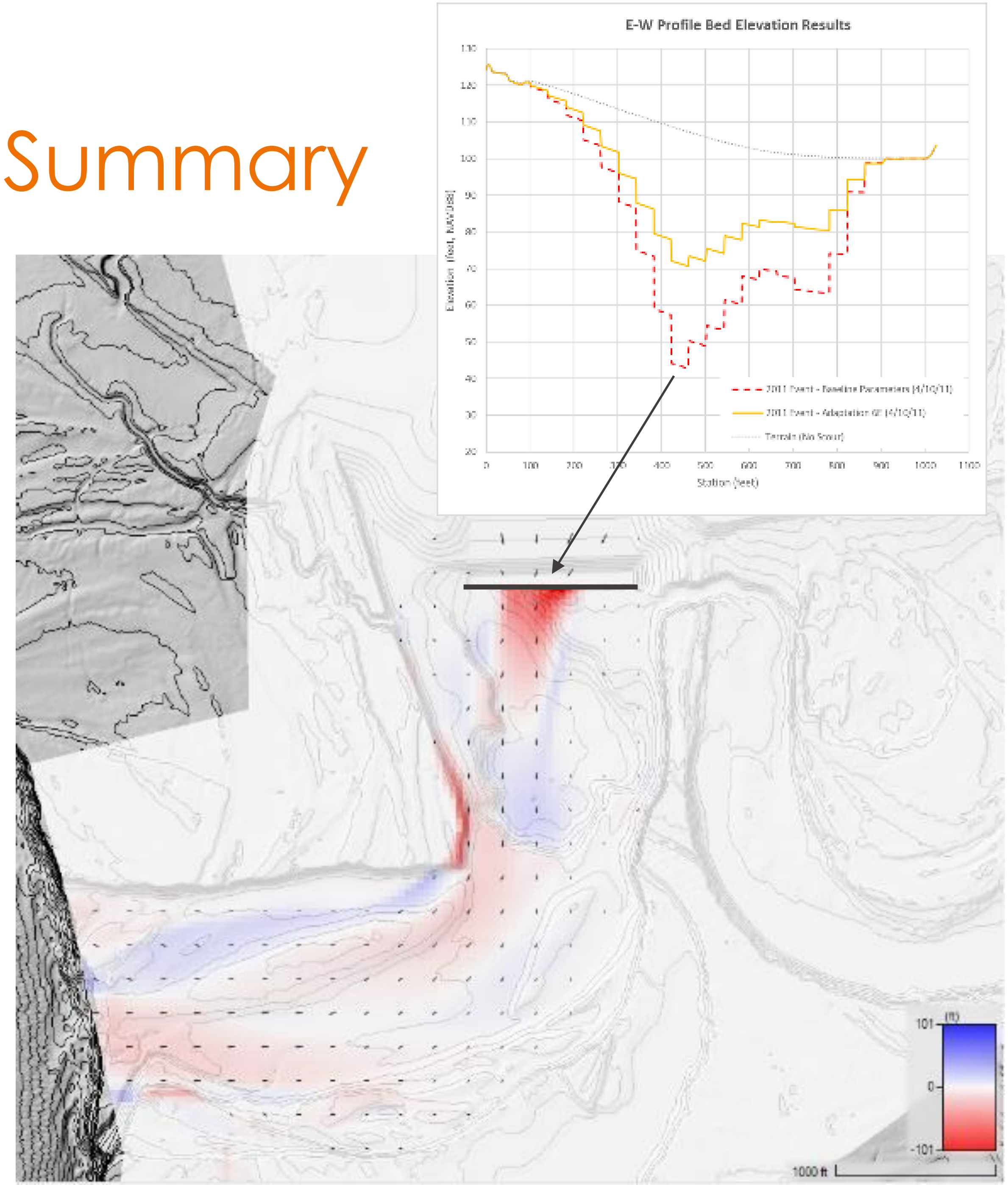
Known-Knowns • **Your experience** • **Measured input data**	**Known-Unknowns** • **Model Uncertainty** • **Future hydrologic conditions**
Unknown-Knowns • Lack of experience, knowledge, or training • Lack of data	**Unknown-Unknowns** • Unaccounted processes • Unidentified factors



modified from Borman and Julien [1991].

2011 Event Scour Results Summary

- Results have limitations, but can be used to inform potential outcomes
- Results show scour concentrating near the center of south end treatment
- Deepest scour located along face of end treatment between EL. 40 to 70 feet
- Scour elevations are comparable to historic scour at the Melinda Structure
- **<u>Conclusion:</u>**
  - **Scour in un-armored areas downstream of weir is likely to occur**

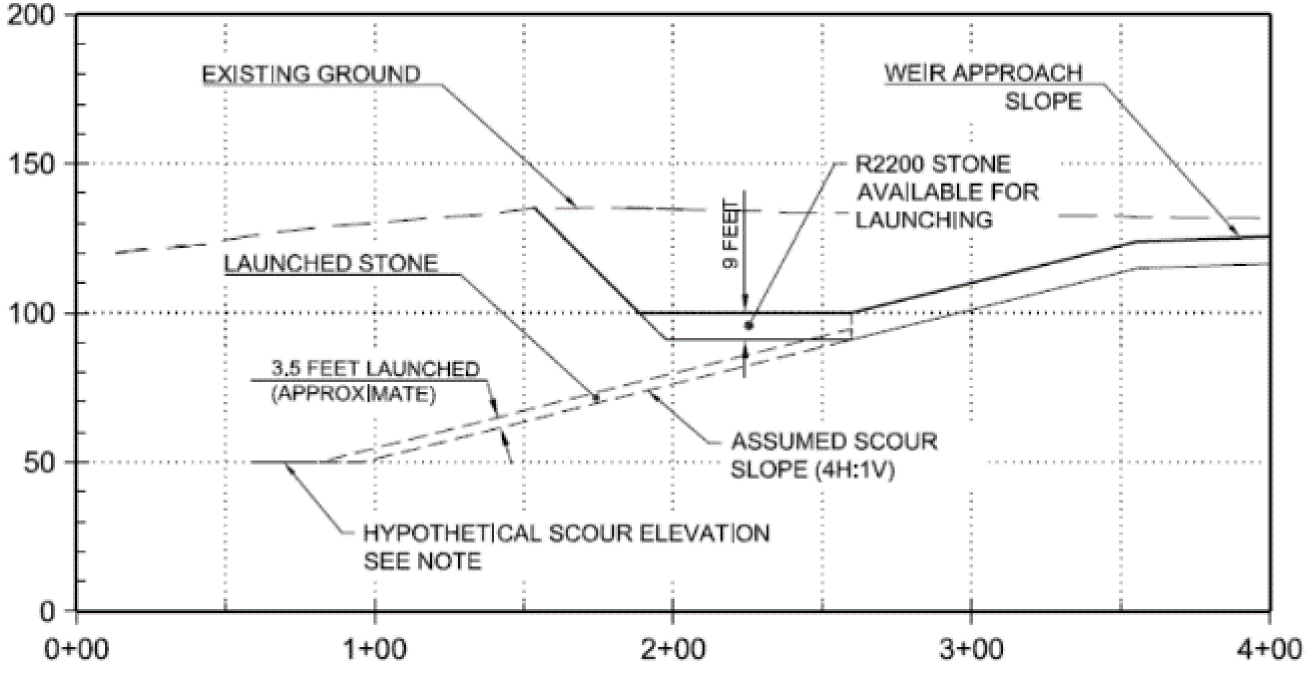


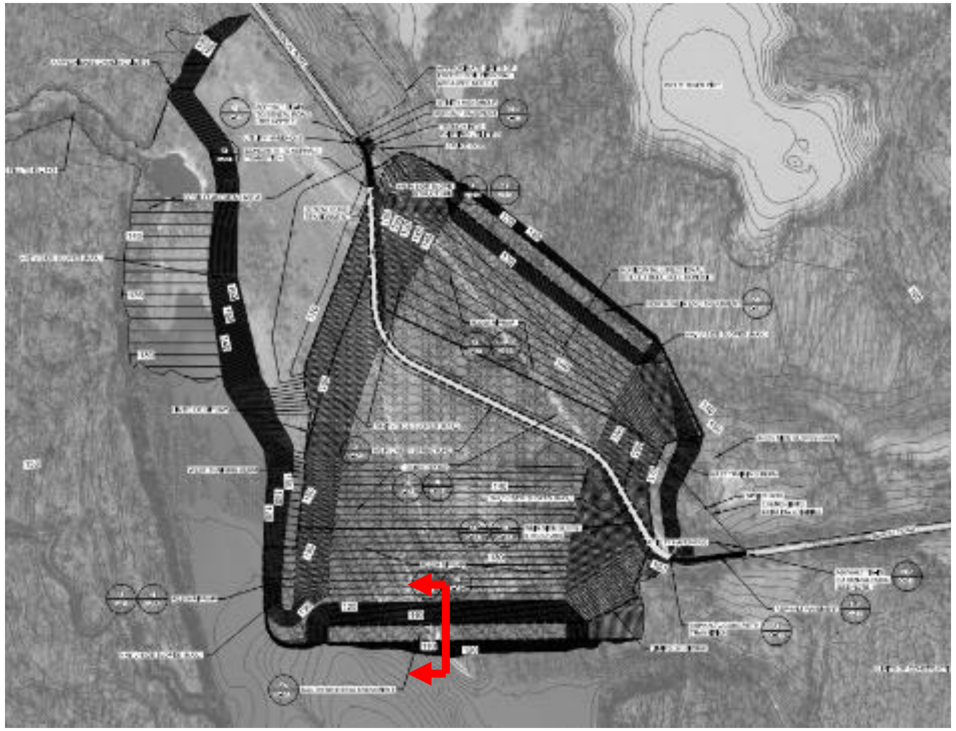
<u>2011 EVENT FINAL</u>

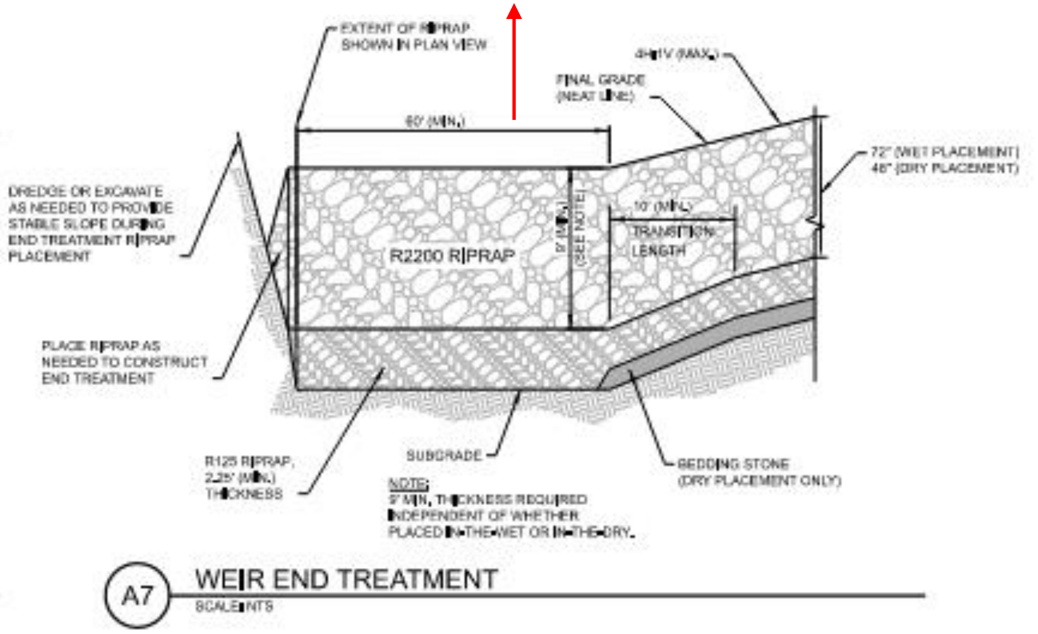
Design Application

- Launching riprap toe included in design
- O&M to include periodic surveys and addition of supplemental riprap as necessary

Potential "Launched" Configuration







Takeaways

- Establish modeling framework at beginning of project is important
- Define clear goals for and acknowledge limitations of each model being considered
- Pay close attention to limitations and uncertainties when interpreting model results

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Questions?