Criteria for Selecting Numeric Hydraulic Modeling Software (NCHRP 24-24)

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Purpose

Develop a Decision Analysis Tool and Guidelines for Selecting the Most Appropriate Numerical Model for Analyzing Bridge Openings

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Approach

- Phase I
  - Literature Review and Survey of the State of the Practice
    - Commonly Employed Software
    - Site Conditions and Design Requirements that Affect Model Selection
    - Locate Appropriate Data Sets for the Verification Stage of This Work
  - Synthesize Results
  - Sensitivity Testing
    - Applicability of Models for Various Site Conditions
    - Determined from Survey/Literature Review
  - Develop Preliminary Decision Tool
  - Interim Report
- Phase II
  - Additional Tool Development
  - Perform Example Application
  - Final Report

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Literature Review

- Purpose – Compare/Contrast Applications of One-dimensional and Two-dimensional Models at Bridge Crossings
- Very Little Literature Exists
- Literature Review Revised:
  - Commonly Applied One- and Two-dimensional Models
  - Case Studies
  - Comparison Articles

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Email Survey

- Short and Focused
- Identify
  - Models Employed
  - Common Problems
  - Data Sets
- Sent to State DOTs and FHWA Personnel (80 people)
- Received 47 Responses (42/50 DOTs)

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Survey Results – Models

Model	Riverine				Tidal			
	1st	2nd	3rd	4th +	1st	2nd	3rd	4th +
HEC-RAS	36	3			9			
WSPRO	3	13	8		1			
SWMM			1	1	1			
HEC-2		15	6			7		
UNET				1				
E-431				2				
Bri-Stars	1		1	1				
HEC-6			2					

Model	River				Tidal			
	1st	2nd	3rd	4th +	1st	2nd	3rd	4th +
FESWMS	18				6	2		
RMA2		4			2	2		

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Survey Results - Other

- 26% Have Model Selection Guidelines
- 47% of Agencies Prohibits or Discourages Use of Specific Programs
  - Only Accept Specific Models
    - HEC-RAS
    - HEC-2
    - FESWMS

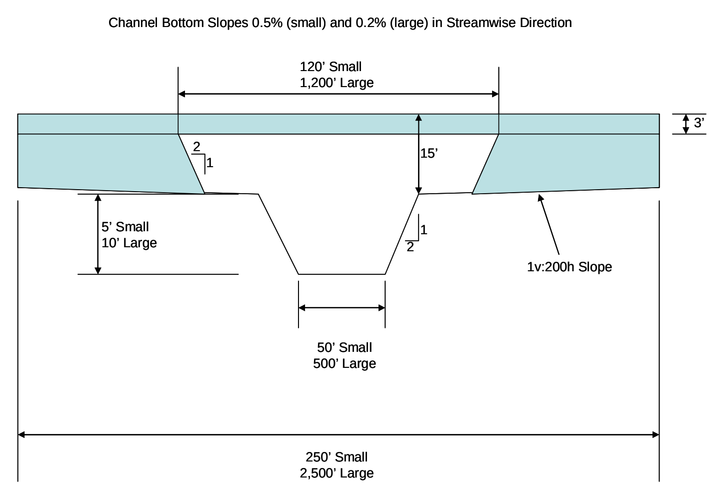
Synthesis of Review

- Several Common Themes
- Ability to Test Factors
- Combinations of More Quantifiable Factors
- Measure of Modeling Accuracy
- Factors:
  - Multiple Openings
  - Bridges Located on River Bends
  - Bridges near Confluences
  - Bridges with Significant Constrictions
  - Overtopping Flow
  - Embankment Skew
  - Bridges over Meandering Rivers
  - Bridges with Asymmetric Floodplains
  - Bridges with Large Piers/High Blockage
  - Tidal Hydraulics

Sensitivity Testing Plan

- One-dimensional Model: HEC-RAS
- Two-dimensional Model:
  - FESWMS – Steady State Flows
  - RMA2 – Time Dependent Flows
- Baseline Geometry
  - Small Channel
  - Large Channel

Baseline Geometry



Sensitivity Testing Plan

- 10 Factors Tested
- Boundary Conditions:
  - Flow :
    - 95,000 cfs (Large)
    - 5,000 cfs (Small)
  - Elevation: Adjusted Such That
    - ~10 ft Normal Depth at Bridge (Small)
    - ~15 ft Normal Depth at Bridge (Large)
- 88 Individual Conditions, 176 Individual Simulations

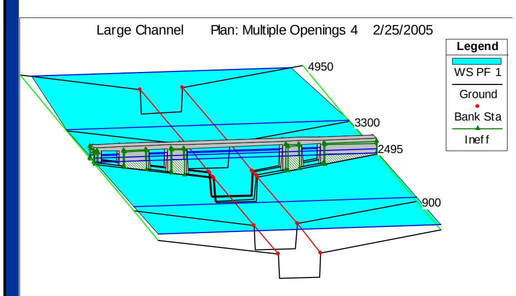
Modeling Approach

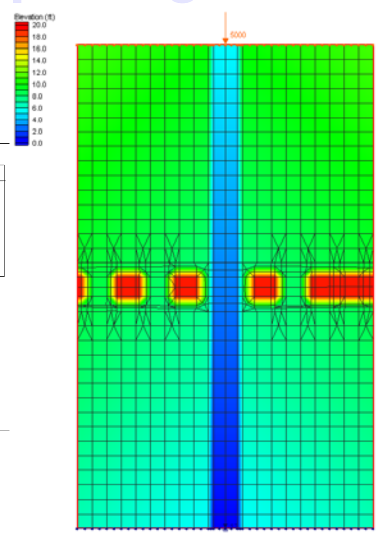
- Two dimensional models developed first
  - Average Water Density = 1.937 slugs/ft^3
  - Unit Flow Convergence = 0.01 to 0.001
  - Unit Water Depth Convergence = 0.01 to 0.001
  - Depth Tolerance for Drying = 0.25 to 0.5 ft
  - Manning's n (Constant with Depth)
    - 0.025 for the Channel
    - 0.045 for the Roadway Embankments
    - 0.75 for the Overbank Areas
  - Constant Eddy Viscosities of 5 to 10 ft^2/sec in the Channel and 10 to 50 ft^2/sec on the Embankments.
  - Small Relaxation Factor and a High Number of Iterations to Ensure Convergence

Modeling Approach

- Next, 2-D Mesh Provided to 1-D Modeler
  - Energy (Standard Step) Bridge Method
  - Cross Sections near Bridge Located According to the HEC-RAS Users Manual and the Applications Guide
  - Expansion and Contraction Coefficients = 0.1 and 0.3, Respectively
  - Roughness Values = 2-D model Values, Except Higher Roughness for Abutments
  - Boundary Conditions (Flow and Starting Water Surface Elevation) Matched 2-D Model

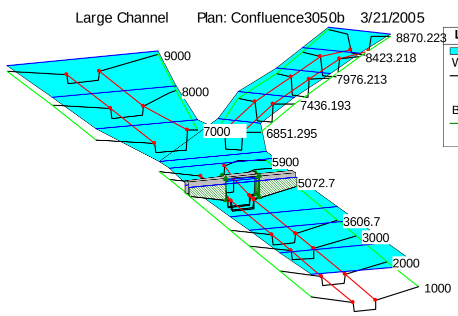
Multiple Openings



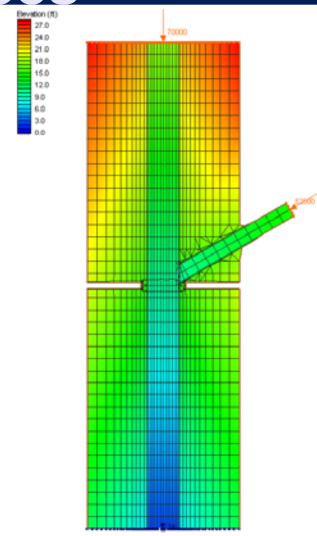


Small Channel

Confluences

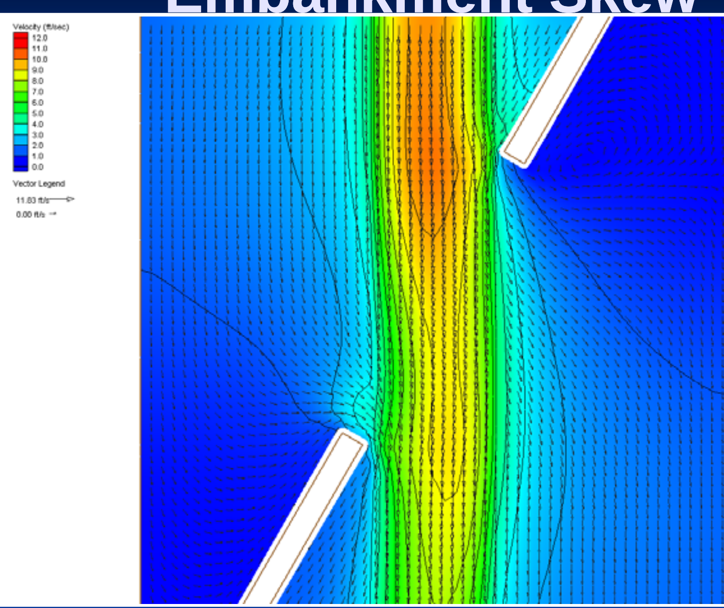


30° Confluence at Bridge with 50% Flow

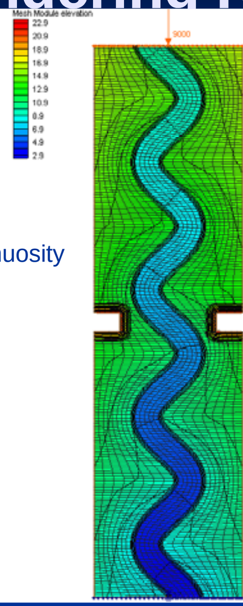


Large Channel 60° Confluence at Bridge with 75% Flow

Embankment Skew

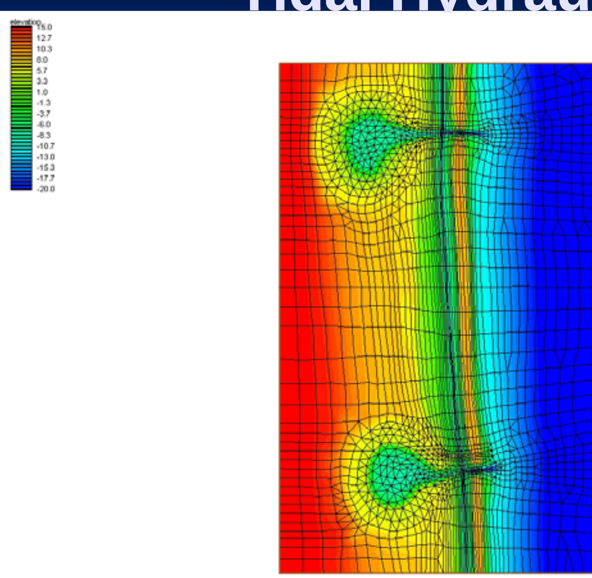


Meandering Rivers



Small Channel with 1.25 Sinuosity

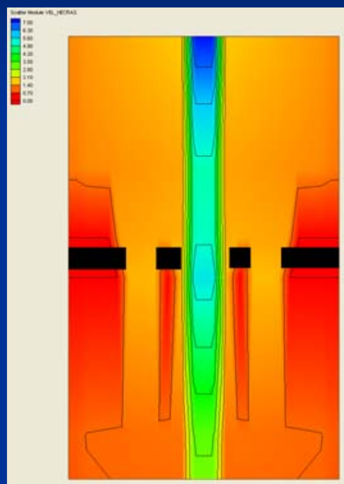
Tidal Hydraulics



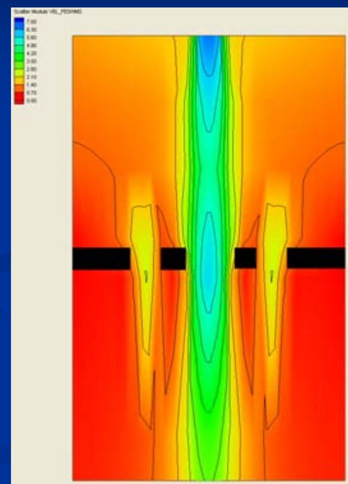
Simple Case

Velocity Magnitude Contours

1-D



2-D



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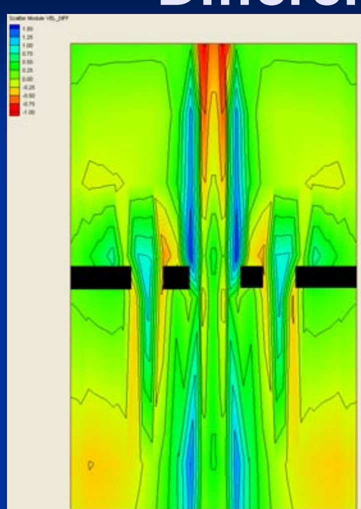
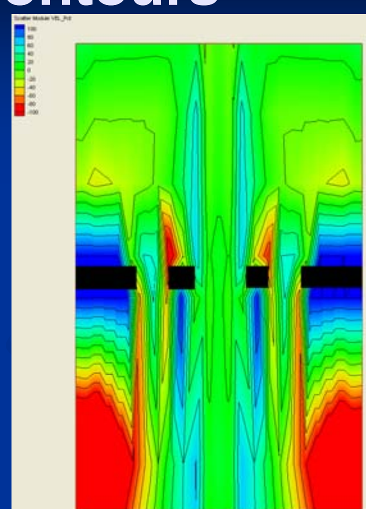
Difference Contours



Absolute Difference



Percentage Difference

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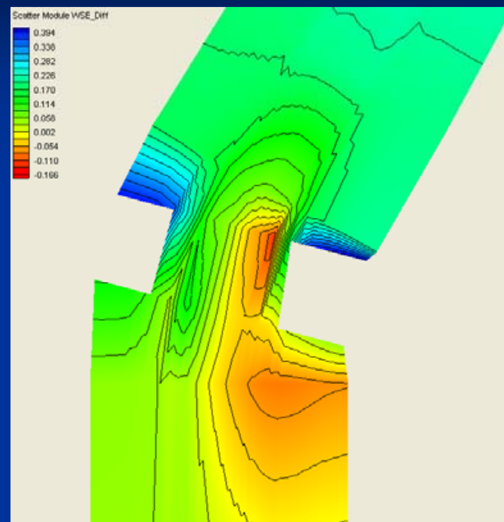
Difference Contours

- Small Channel
- Half Radius
- 30° Bend
- WSE Absolute Difference Contours



Results – General Comments

- Large Differences in Flow Direction Results
- Better Agreement the More "One-dimensional" the Flow
  - Multiple Openings
  - Overtopping
- Labor Averages
  - One-Dimensional Models — 3.1hrs/model
  - Two-Dimensional Models — 2.4 hrs/model
  - Averages Skewed by Tidal Cases and Modeler Experience

Decision Tool Development

- Model Selection Based on:
  - Specific Site Conditions
  - Design Applications
  - Data Availability
  - Modeler's Experience and Resources
- Complex Process
- Requires Multi-pronged Approach

Approach

- Increase Engineer's Awareness with Report
  - Discussion of Model Theories
  - Comparison of Relative Performance
- Provide Design Examples/Sensitivity
  - Study Types (e.g. Flooding, Scour Eval.)
  - Structure Design (e.g. Slope Protection)
- Decision Tool & Guidelines

Design Criteria Considerations

- Riprap Sizing for Scour, Abutment, or Slope Protection
- Armor Units for Scour, Abutment, or Slope Protection
- Concrete Block for Scour, Abutment, or Slope Protection
- Abutment Scour Calculation
- Pier Scour Calculation
- FEMA “No-Rise” Studies
- Bendway Weirs/Stone Spurs

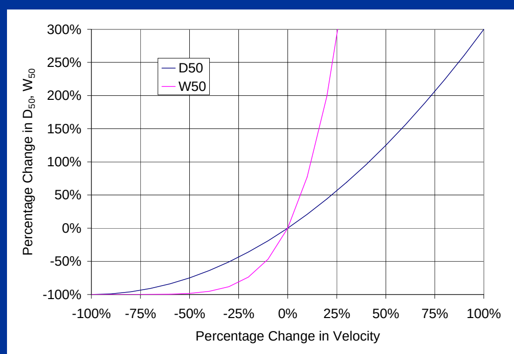
Other Project Considerations

- Available Resources
  - Available Software
  - Software Features
  - User Experience
- Outside Constraints
  - Schedule
  - Data Availability

Design Issues Example

- Riprap Sizing for Bank Slope Protection
- HEC-23: Ishbash Equation

$$\frac{D_{50}}{y} = \frac{K}{(S_s - 1)}\left[\frac{V^2}{gy}\right]$$



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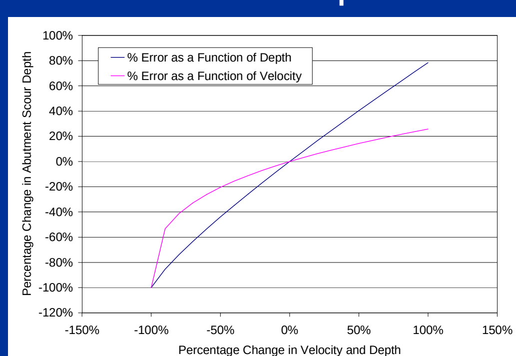
Design Issues Example (continued)

- Abutment Scour Calculation
- HEC-18: HIRE Equation

$$\frac{y_s}{y_1} = 4Fr_1^{0.33}\frac{K_1}{0.55}K_2$$



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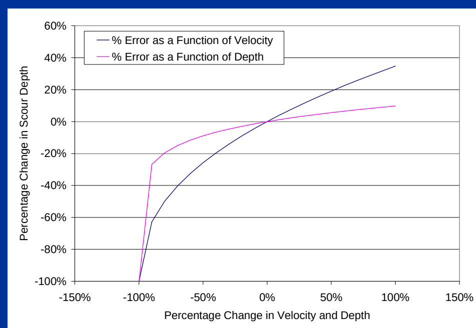
Design Issues Example (continued)

- Local Scour Calculation
- HEC-18: CSU Equation

$$\frac{y_s}{y_1} = 2.0K_1K_2K_3K_4\left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43}$$



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Decision Tool

- Decision Matrix – 4 Step Development
- 1) Identification of Alternatives
  - 1-D vs. 2-D
- 2) Identification of Decision Criteria
  - Site Conditions
  - Design Considerations
  - Project Considerations

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Decision Tool

- 3) Weighting the Criteria
  - Critical Evaluation by Engineer
  - Relative Importance
  - Assignation of Weights
- 4) Scoring System/Tool Application
  - Model Performance
  - Design Sensitivity
  - Project Specifics/Engineer Qualifications

Design Criteria	Weight	One Dimensional Model		Two Dimensional Model	
		Score 1=low 3=medium 5=high	Weight x Score	Score 1=low 3=medium 5=high	Weight x Score
Site Conditions	(1-10)				
Multiple Openings					
Bridges Located on River Bends					
Bridges near Confluences					
Bridges with Significant Constrictions					
Overtopping Flow					
Embankment Skew					
Bridges over Meandering Rivers					
Bridges with Asymmetric Floodplains					
Bridges with Large Piers/High Blockage					
Tidal Hydraulics					
Design Requirements	(1-10)				
Riprap					
Armor Units					
Concrete Block					
Abutment Scour Calculation					
Pier Scour Calculation					
FEMA "No-Rise"					
Bendway Weirs					
Other Considerations	(1-10)				
Modeler Experience					
Scheduling					
Data Availability					
Totals (Sum of Weight x Score)					

Design Criteria	Weight	One Dimensional Model		Two Dimensional Model	
		Score 1=low 3=mediu 5=high	Weight x Score	Score 1=low 3=mediu 5=high	Weight x Score
Site Conditions	(1-10)				
Multiple Openings	4	3	12	3	12
Bridges Located on River Bends	10	3	30	5	50
Bridges near Confluences					
Bridges with Significant Constrictions					
Overtopping Flow					
Embankment Skew					
Bridges over Meandering Rivers					
Bridges with Asymmetric Floodplains	5	3	15	5	25
Bridges with Large Piers/High Blockage					
Tidal Hydraulics					
Design Requirements	(1-10)				
Riprap	10	3	30	5	50
Armor Units					
Concrete Block					
Abutment Scour Calculation					
Pier Scour Calculation	10	3	30	5	50
FEMA "No-Rise"					
Bendway Weirs					
Other Considerations	(1-10)				
Modeler Experience	8	5	40	1	8
Scheduling	10	5	50	1	10
Data Availability	2	3	6	3	6
Totals (Sum of Weight x Score)			213		211

Example

Highway 130 Bridge over Buckhorn Creek

Example

- Step 1 – Identify Alternatives
  - Choosing between FESWMS and HEC-RAS
- Step 2 – Identify Decision Criteria
  - Asymmetric Floodplains
  - Bridges over Meandering Rivers
  - Riprap
  - Pier Scour Calculation
  - Modeler Experience
  - Scheduling
  - Data Availability

Example

- Step 3 – Weight the Criteria

Design Criteria	Weight	One Dimensional Model		Two Dimensional Model	
		Score 1=low 3=medium 5=high	Weight x Score	Score 1=low 3=medium 5=high	Weight x Score
Site Conditions	**(1-10)**				
Bridges over Meandering Rivers	2				
Bridges with Asymmetric Floodplains	7				
Design Requirements	**(1-10)**				
Riprap	9				
Pier Scour Calculation	3				
Other Considerations	**(1-10)**				
Modeler Experience	3				
Scheduling	10				
Data Availability	3				
Totals (Sum of Weight x Score)					

Example

- Step 4 - Scoring

Design Criteria	Weight	One Dimensional Model		Two Dimensional Model	
		Score 1=low 3=medium 5=high	Weight x Score	Score 1=low 3=medium 5=high	Weight x Score
Site Conditions	**(1-10)**				
Bridges over Meandering Rivers	2	3	***6***	5	***10***
Bridges with Asymmetric Floodplains	7	3	***21***	5	***35***
Design Requirements	**(1-10)**				
Riprap	9	3	***27***	3	***27***
Pier Scour Calculation	3	3	***9***	3	***9***
Other Considerations	**(1-10)**				
Modeler Experience	3	5	***15***	5	***15***
Scheduling	10	5	***50***	3	***30***
Data Availability	3	5	***15***	5	***15***
Totals (Sum of Weight x Score)			***143***		***141***

Summary

- Resources for Engineers
  - Comparison of Models
    - Examination of Theory
    - Sensitivity Test
  - Consequences of Selection
    - Study Type
    - Design Issues
  - Framework for Selection – Decision Tool

Questions, Comments?