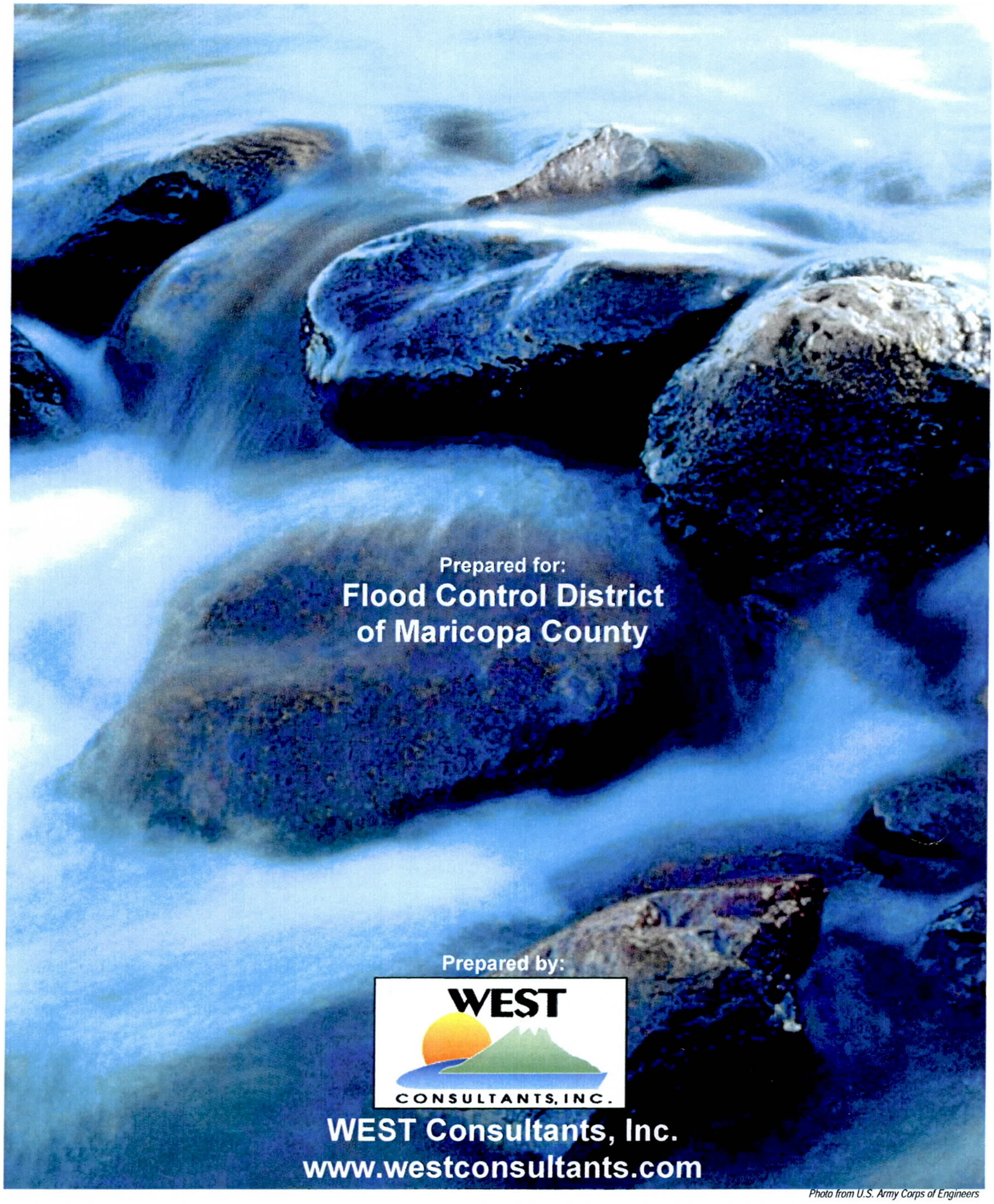
INTRODUCTION TO DAM BREAK MODELING USING HEC-RAS



Prepared for:
Flood Control District of Maricopa County

Prepared by:

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WEST Consultants, Inc.
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Flood Control District of Maricopa County (FCDMC) Free Workshop Introduction to Dam Break Modeling Using HEC-RAS (Plus a Discussion on Some of the New GIS Features in HEC-RAS 4.0.1)

About Workshop:

FCDMC will host an introductory workshop on dam break modeling using HEC-RAS. Participants will learn the basics of how to approach a dam breach problem, estimate breaching parameters, construct an HEC-RAS unsteady flow model of the dam breach, and eliminate errors and instabilities in the model run. In addition, some of the new features in the soon-to-be-released HEC-RAS 4.0.1 will be discussed. Note that dam break modeling is a complex topic and this workshop is designed only to introduce the attendees to the concepts involved in developing an unsteady dam break model.

When: Monday, August 24th, 2009

Where: FCDMC Adobe Conference Room (2801 W. Durango St. Phoenix, AZ 85009)

Outline:

Introduction	1:00 – 1:30
Overview of Unsteady HEC-RAS	1:30 – 2:00
Selection of Breach Parameters	2:00 – 2:30
BREAK	2:30 – 2:45
Setting Up a Dam Break Model in HEC-RAS	2:45 – 3:30
Advanced Unsteady Modeling Techniques	3:30 – 3:45
New Features in HEC-RAS 4.0.1	3:45 – 4:00

Instructor:

The workshop will be conducted by Brian Wahlin, Ph.D., P.E., D.WRE of WEST Consultants, Inc. Dr. Wahlin is a senior hydraulic engineer and office manager for WEST's Tempe location. Dr. Wahlin has been with WEST since 2002 and has over 16 years of experience in hydraulics, hydraulic modeling, and flow measurement. Prior to WEST, Dr. Wahlin worked at the former US Water Conservation Laboratory (now the Arid Lands Agricultural Research Center) where he developed numerous unsteady flow models of open-channel irrigation canals. Dr. Wahlin serves as an instructor for the basic, unsteady, and dam break courses that WEST teaches for the American Society of Civil Engineers. He recently taught a series of three basic HEC-RAS classes for the Arizona Floodplain Managers Association and one course for the New Mexico Floodplain Managers Association.

Introduction to Dam Breach Modeling

- **Objective**: This lecture will clearly state the purpose of this training course, provide an overview of the need for dam breach modeling, describe available modeling tools and their limitations.

1

Why is Dam Breach Modeling Important?

- No. 1 Priority: Public Safety

  Posted on: Tuesday, March 14, 2006 11:45 AM HST

  Up to 7 lost in flooding on Kauai

  A dam burst above the island's northeast coast and between 3 and 7 people are missing

- Regulatory Requirement
- Essential Information for Emergency Action Plans

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Ka Loko Dam, Kauai, Hawaii

Breach occurred March 14, 2006

View of Kaloko Reservoir.

3

Ka Loko Dam, Kauai, Hawaii

View of dam breach.

4

Ka Loko Dam, Kauai, Hawaii

View of Morita Reservoir downstream.

5

Ka Loko Dam, Kauai, Hawaii

View upstream towards Morita Reservoir.

6

Ka Loko Dam, Kauai, Hawaii

View downstream to ocean.

7

Taum Sauk Pumped Storage Project, Missouri

Breach occurred on December 14, 2005 at approximately 5:20 AM CST.

Looking downstream from reservoir through breach.

8

Taum Sauk Pumped Storage Project, Missouri

Looking downstream along flood path.

9

Taum Sauk Pumped Storage Project, Missouri

Aerial view of dam breach flood path.

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Taum Sauk Pumped Storage Project, Missouri

Downstream of the breach.

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What information can dam breach modeling provide?

- Magnitude of flow
- Timing of flow
- Volume of flow
- Information required for preparation of inundation maps
- Essential information for preparation of useful Emergency Action Plans

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Available Modeling Tools

- Empirical Models
  - Dimensionless graphs
  - Regression equations
  - Envelope curves

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Example Regression Equations [from Costa (1985)]

Summary of regression equations to predict peak discharge from constructed dams.

Type of dam	Independent Variable Qmax in m³/s; H in m; V in 10⁶ m³		
	Dam height (H)	Reservoir Volume (V)	Dam factor (H x V)
Constructed dam	$Q_{max} = 10.5\,H^{1.87}$; $r^2 = 0.80$	$Q_{max} = 961\,V^{0.48}$; $r^2 = 0.65$	$Q_{max} = 325\,(HV)^{0.42}$; $r^2 = 0.75$
	Standard Error = 82 percent	Standard Error = 124 percent	Standard Error = 95 percent

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Example Envelope Curve

Peak flow related to hydraulic depth in reservoir.

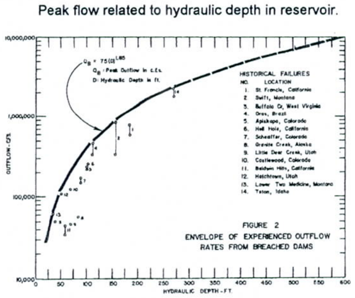

FIGURE 2
ENVELOPE OF EXPERIENCED OUTFLOW RATES FROM BREACHED DAMS

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Available Modeling Tools (continued)

- Commonly Used Tools for Determining Breach Outflow Hydrograph <u>Only</u>
  - NWS BREACH, Danny Fread, NWS
  - Dam Breach Model (DBM), Delft Hydraulics
- Numerous Other Mathematical Models Exist

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Available Modeling Tools (continued)

- Commonly Used Mathematical Models for Dam Breach Flood Routing
  - USCOE HEC-HMS
  - NWS DAMBRK, FLDWAV
  - SOBEK 1D2D (WL Delft Hydraulics)
  - DHI MIKE 11-21 (MIKE FLOOD)
  - USCOE HEC-RAS
- Numerous Other Mathematical Models Exist

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Comparison of Commonly Used Mathematical Models

Model	Developer	Cost	Hydraulic Roughness	Channel Routing Technique	Breach Outflow Computation
HEC-HMS	USCOE Hydrologic Engineering Center	0	Manning's n	Level Pool Reservoir Routing, Hydrologic River Routing	Piping or Overtopping. Time-Based.
DAMBRK	National Weather Service	$	Manning's n	Finite Difference Approximation of the full St. Venant Equations for Unsteady Flow	Piping or Overtopping (using BREACH). Time-Based.
FLDWAV	National Weather Service	$	Manning's n	Finite Difference Approximation of the full St. Venant Equations for Unsteady Flow	Piping or Overtopping (using BREACH). Time-Based.
Sobek 1D2D	WL Delft Hydraulics	$$	Chezy's C	Finite Difference Approximation of the full St. Venant Equations for Unsteady Flow coupled with 2d model for floodplain modeling	Soon. Currently use DBM.
MIKE 11-21	DHI Water & Environment	$$	Chezy's C	Finite Difference Approximation of the full St. Venant Equations for Unsteady Flow-coupled with 2d model for floodplain modeling	Piping or Overtopping. Time-Based or Erosion-Based.
HEC-RAS	USCOE Hydrologic Engineering Center	0	Manning's n	Finite Difference Approximation of the full St. Venant Equations for Unsteady Flow	Piping or Overtopping. Time-Based.

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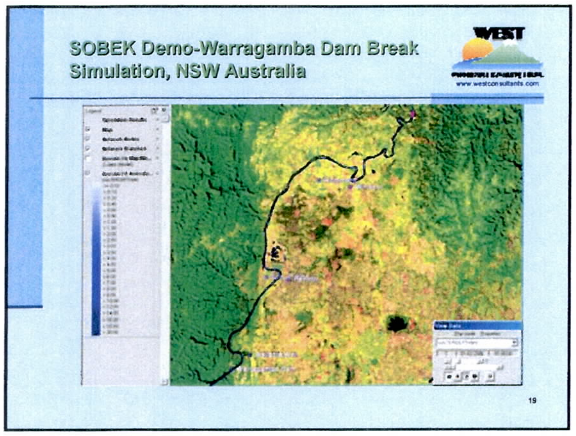
SOBEK Demo-Warragamba Dam Break Simulation, NSW Australia
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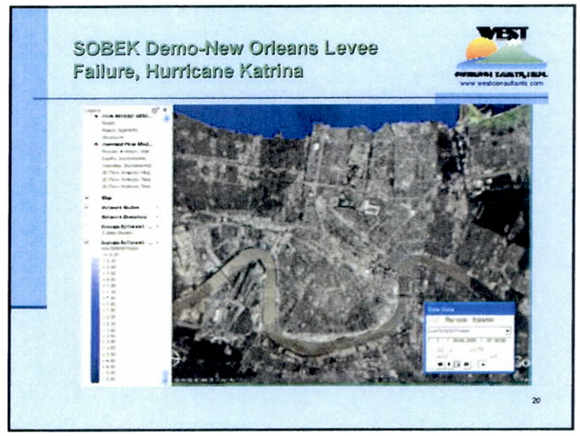
SOBEK Demo-New Orleans Levee Failure, Hurricane Katrina
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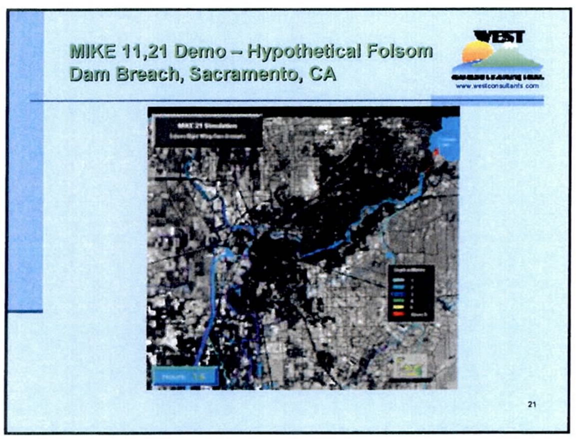
MIKE 11,21 Demo – Hypothetical Folsom Dam Breach, Sacramento, CA
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MIKE 21 Simulation
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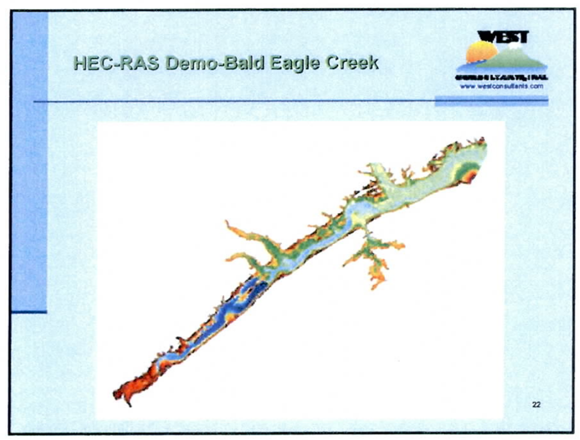
HEC-RAS Demo-Bald Eagle Creek
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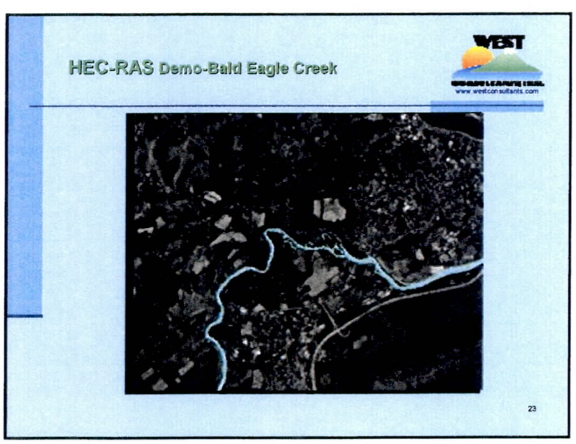
HEC-RAS Demo-Bald Eagle Creek
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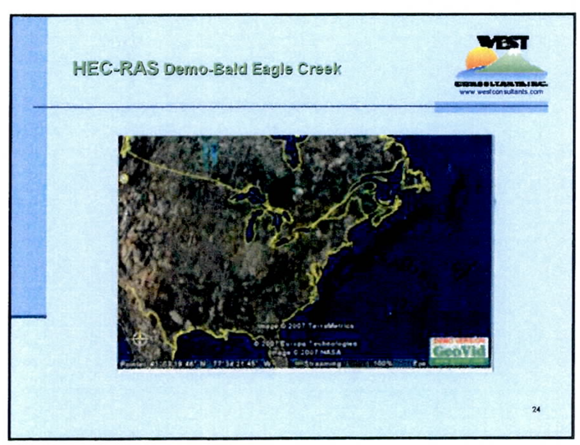
HEC-RAS Demo-Bald Eagle Creek
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GeoVid
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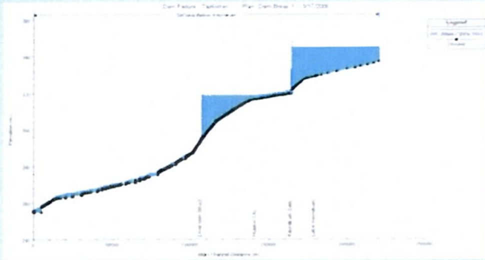
HEC-RAS Demo-Tajikistan, Kayrakum Dam Failure



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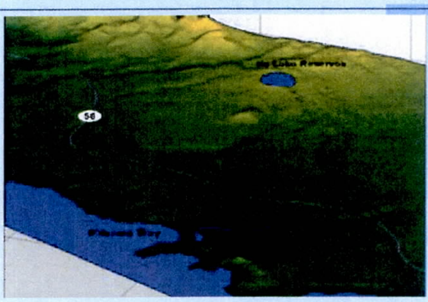
Example Presentation of Dam Breach Model Simulation



Model indicates that the flood wave would reach Kuhio Highway in 16 min

Proprietary Model Developed by Brett Sanders – UC Irvine

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Uncertainties that affect the accuracy of dam breach models

- When and how will a dam fail?
- When and by how much will a dam be overtopped?
- What is the breach size and time of formation?
- What is the storage volume and flow resistance of the downstream channel and valley?
- How will debris and sediment affect flood wave propagation?
- Can the flood wave be modeled adequately by one-dimensional equations?

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What conditions can HEC-RAS model?

- Breaches caused by overtopping
  - Reservoir storage exceedence
  - Overtopping due to a wave
- Breaches caused by piping
  - Stage
  - Duration
- Nearly instantaneous failures

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Limitations of HEC-RAS for dam breach modeling

- 1-dimensional
- Finite difference approximation of St Venant Eqs.
- Application to maximum 10 percent slope
- Simplified approximation of breach shape (trapezoid)
- Accuracy of required assumptions
  - Failure mode
  - Failure characteristics

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Introduction to Unsteady Flow Modeling with HEC-RAS

- **Objective**: This lecture will show you the basics of creating and running a RAS unsteady flow model.

This lecture was originally developed by the staff and engineers at the US Army Corps of Engineers Hydrologic Engineering Center (HEC).

Topics to Discuss

- Overview
- Geometric data
- Unsteady flow data
  - Boundary and initial conditions
- Hydraulic property tables
- Unsteady flow simulation manager
  - Creating an unsteady simulation
- Post-processor
- Additional graphics/tables to view results

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Overview

- Same geometry for steady and unsteady flow
- Simple dendritic streams to complex networks can be modeled
- Same hydraulic structures for steady and unsteady flow
- Capable of modeling a wide variety of hydraulic structures (e.g., bridges, culverts, levees, etc.)
- Uses the UNET equation solver (Dr. Robert Barkau)
  - Relatively fast matrix solver

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Why Unsteady Flow Modeling?

- An unsteady flow model is appropriate when volume or timing of flow or stage are important
- RAS unsteady (vs. steady) models can simulate:
  - Attenuation
  - Storage
  - Temporal changes in boundary conditions
    - Inflow hydrograph, tides, gate changes, etc.
  - Dam break

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How are the Unsteady Flow Computations Different?

- Governing equations
- Numerical solution
- Accounting for losses
  - Friction slope
  - Expansion/contraction
- Accounting for storage
- Boundary conditions
- Computation steps

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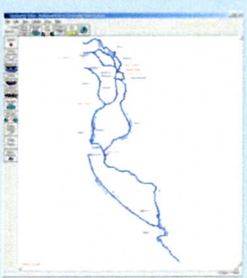
Geometric Data Editor

- Geometry is entered in the same way for steady or unsteady flow models
- Additional data may be required



Snohomish River, Washington

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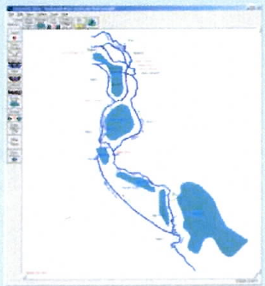
Optional Geometric Features

- Storage areas
- Storage area connections
- Inline and lateral structures
- Time or elevation controlled gates
- Bridges and culverts
- Pumps



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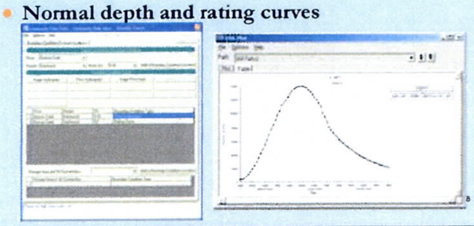
Unsteady Flow Editor – Boundary Conditions

- Flow and stage hydrographs
  - Data can be entered manually or specified from a DSS file
- Normal depth and rating curves



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Internal Boundary Conditions

- Lateral inflow to a node
- Uniform lateral inflow along a reach
- Groundwater interflow
  - Head specified over time and independent of river stage
- Time series of gate openings
- Elevation controlled gate
- Navigation dams
- Internal observed internal stage and/or flow hydrograph

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Initial Conditions

- Initial conditions must be established for the entire system by either:
  - Specifying flows for each branch; RAS then calculates the stages through a steady state simulation
  - Read in flow and stage at every node from a previous run (i.e., a "restart" file)

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Unsteady Flow Simulation Procedure

- Geometric pre-processor
  - Processes geometric data into a series of hydraulic property tables
- Unsteady flow simulation
  - Performed using a modified version of UNET
- Post-processor
  - Computes detailed hydraulic information

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Geometric Pre-processor

- For unsteady flow, geometry is pre-processed into tables ("HTab Param." button) and rating curves
  - Cross sections are processed into tables of area, conveyance, and storage
  - Bridges and culverts are processed into a family of rating curves for each structure
  - Structure and gated structure data are not determined prior to the simulation
  - Geometric pre-processor results can be viewed in graphs and tables

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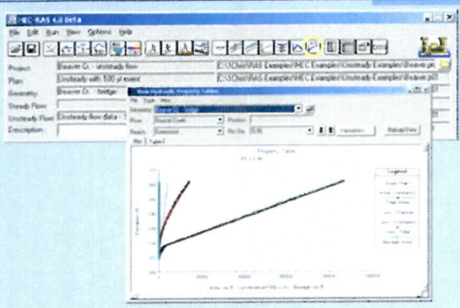
Plot of the Hydraulic Property Tables



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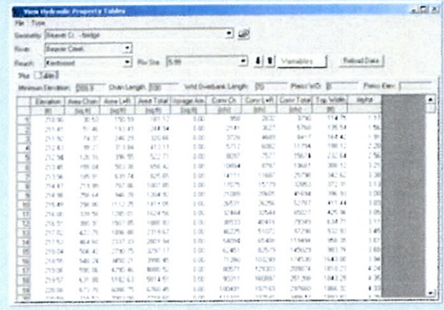
Hydraulic Property Tables



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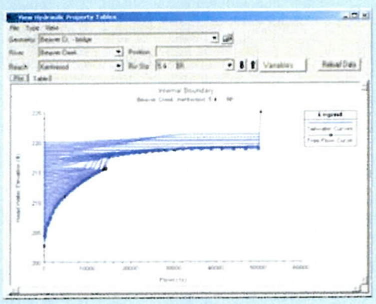
Bridge Hydraulic Properties Plot



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Creating an Unsteady Simulation

- Geometric Data Editor
  - Create geometry and add structures
- Unsteady Flow Editor
  - Specify boundary and initial conditions
- Unsteady Flow Analysis Editor
  - Create a plan

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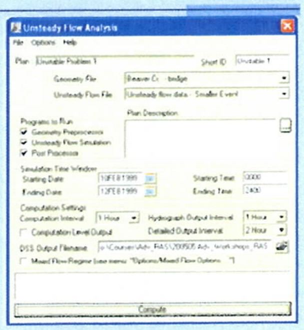
Unsteady Flow Analysis Editor

1. Define a Plan
2. Select which programs to run
3. Enter a starting and ending date and time
4. Set the computation settings
5. Press the Compute button



Simulation Options

- Stage and flow output locations
- Flow distribution locations
- Flow roughness change factors
- Seasonal roughness change factors
- Additional output options
  - Write restart file
  - Debugging level output file
- Calculation options and tolerances

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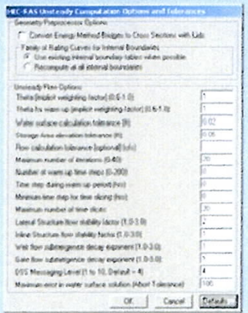
Calculation Options and Tolerances



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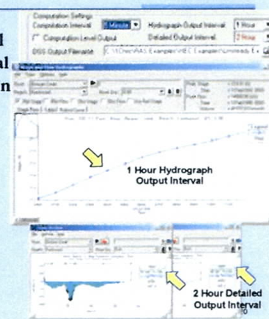
Computational Settings

- The computation interval must be less than or equal to any boundary condition intervals
- Hydrograph output interval defines the spacing of points on the hydrograph
- Detailed output interval defines the time steps when animating



Post-Processor (Detailed Output)

- Used to compute detailed hydraulic information for a set of user-specified time lines and an overall maximum water surface profile
- Computed stages and flows are passed to the steady flow program for the computation of detailed hydraulic results

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Viewing Unsteady Flow Results

- All of the output viewing options that were available for steady flow computations are available for unsteady flow (e.g., cross section, profile, and 3-D plots and tables).
- Additional ways to view unsteady results:
  - Stage and flow hydrographs
  - Time series tables
  - Animation of cross section, profile, and 3-D graphics

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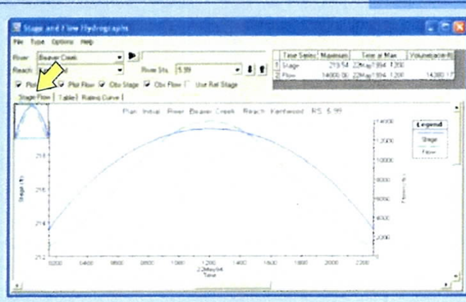
Stage and Flow Hydrographs



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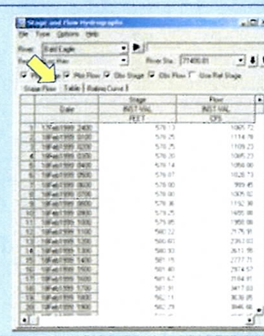
Time Series Table



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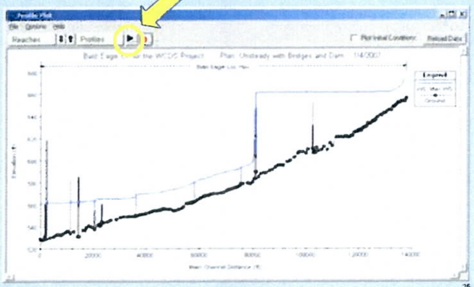
Animation



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How are the Unsteady Flow Computations Different?

- Governing equations
- Numerical solution
- Accounting for losses
  - Friction slope
  - Expansion/contraction
- Accounting for storage
- Boundary conditions
- Computation steps

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Governing Equations

- Steady
  - Energy equation

$$Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e$$

- Unsteady
  - St. Venant equations
    - Conservation of mass

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q_L = 0$$

    - Conservation of momentum (dynamic wave model)

$$\frac{\partial Q}{\partial t} + \frac{\partial (VQ)}{\partial x} + gA\left(\frac{\partial h}{\partial x} - S_0 + S_f\right) = 0$$

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Governing Equations

- Continuity equation
  - Preserves the water volume in the channel
- Momentum equation
  - Physical relationship describing the actual physics of the movement of water

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Numerical Solution

- Steady flow
  - Iterative convergence sequentially section-by-section for each flow (Standard Step method)
- Unsteady flow
  - An implicit finite difference approximation is used to solve the St. Venant equations
  - A matrix solution then determines flow and stage simultaneously at all sections for each time step

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Accounting for Losses: Expansion/Contraction

- Steady flow
  - Contraction/expansion coefficients
- Unsteady flow
  - Momentum equation includes forces acting over the surface and ends of the control volume
- Include contraction/expansion coefficients in cross section data
  - Steady and unsteady runs use the same geometry

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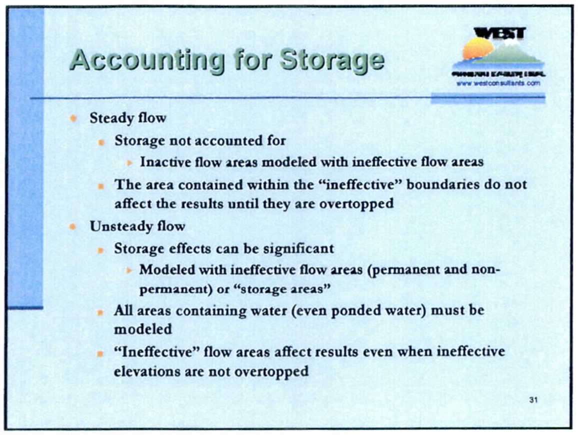
Accounting for Storage
WEST
www.westconsultants.com
Steady flow
Storage not accounted for
Inactive flow areas modeled with ineffective flow areas
The area contained within the "ineffective" boundaries do not affect the results until they are overtopped
Unsteady flow
Storage effects can be significant
Modeled with ineffective flow areas (permanent and non-permanent) or "storage areas"
All areas containing water (even ponded water) must be modeled
"Ineffective" flow areas affect results even when ineffective elevations are not overtopped
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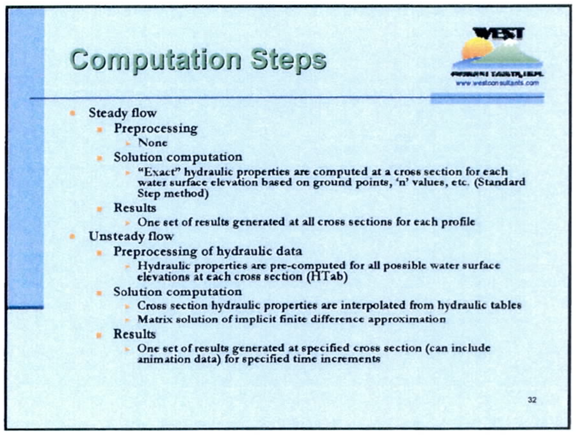
Computation Steps
WEST
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Steady flow
Preprocessing
None
Solution computation
"Exact" hydraulic properties are computed at a cross section for each water surface elevation based on ground points, 'n' values, etc. (Standard Step method)
Results
One set of results generated at all cross sections for each profile
Unsteady flow
Preprocessing of hydraulic data
Hydraulic properties are pre-computed for all possible water surface elevations at each cross section (HTab)
Solution computation
Cross section hydraulic properties are interpolated from hydraulic tables
Matrix solution of implicit finite difference approximation
Results
One set of results generated at specified cross section (can include animation data) for specified time increments
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Selecting Dam Breach Parameters

- **Objective**: This lecture will provide guidance on selecting breach parameters needed to generate the outflow hydrograph.

1

Topics to Discuss

- Probable Failure Mechanism(s)
- Breach Parameter Guidance
- Sensitivity

2

Overview

- Why do we need breach parameters?
- Which parameters do we need to estimate?
  - Initial breach conditions / failure scenario
  - Timing/rate of growth/breach mechanism
  - Ultimate Size and Shape of Breach
- How do we estimate these parameters?

3

Probable Failure Mechanisms

- Overtopping
  - Most often for embankment dams
  - Trapezoidal breach growing with time often assumed
- Piping (seepage erosion)
  - Most often for embankment and glacial blocking dams
  - Square or circular orifice grows with time
- Monolith/Section Failure
  - Most often for Concrete/RCC and glacial crevasse dams
  - A monolith or section is assumed to move – rectangular section grows with time

4

Breach Initial Conditions

- Conditions at initiation of breach include
  - Water surface elevation
    - Head applied to breach
    - Volume of water in reservoir
  - Outflow from dam
    - More important for stability of routing calculations, discussed elsewhere
  - For piping failure, initial elevation

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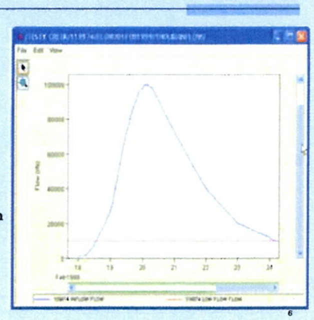
Common Failure Scenarios

- "Sunny Day"
  - Piping
  - Slides
  - Earthquakes
  - Planned Removal
  - Acts of War
- Flood Events
  - Probable Maximum Flood (PMF)
  - Usually Overtopping



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Breach Parameter Guidance

- "Rule of Thumb"
- Regression (based on observed data)
- Theoretical

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Breach Parameter Guidance

- Rules of Thumb (overtopping failures)

	Earth Dam	Concrete Gravity Dam	Concrete Arch Dam
Breach Width	1/2 to 4 dam heights	A multiple of monolith width	Total dam width
Breach Side Slope	0 to 1	0	Valley wall slope
Failure Time (hours)	0.5 to 4	0.1 to 0.5	Near instantaneous
Pool Failure Elevation	1 to 5 ft above dam crest	10 to 50 ft above dam crest	10 to 50 ft above dam crest

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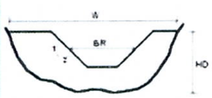
Breach Parameter Guidance

- Rules of Thumb (overtopping failures)

Parameter	Value	Type of Dam
Average width of Breach (BR)	BR ≈ Crest Length	Arch
	BR = Width of 1 or more Monoliths, usually BR ≤ 0.5 W	Masonry, Gravity
	HD ≤ BR ≤ 5HD (usually between 2HD & 4HD)	Earthen, Rockfill, Timber Crib
	BR ≥ 0.8 x Crest Length	Slag, Refuse



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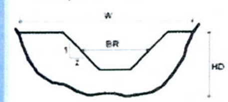
Breach Parameter Guidance

- Rules of Thumb (overtopping failures)

Parameter	Value	Type of Dam
Horizontal Component of Side Slope of Breach (z)	0 ≤ z ≤ slope of valley walls	Arch
	z = 0	Masonry, Gravity, Timber Crib
	1/4 ≤ z ≤ 1	Earthen (Engineered, Compacted)
	1 ≤ z ≤ 2	Slag, Refuse (Non-Engineered)

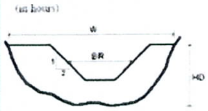


10

Breach Parameter Guidance

- Rules of Thumb (overtopping failures)

Parameter	Value	Type of Dam
Time to Failure (TFH) (in hours)	TFH ≤ 0.1	Arch
	0.1 ≤ TFH ≤ 0.3	Masonry, Gravity
	0.1 ≤ TFH ≤ 1.0	Earthen (Engineered, Compacted), Timber Crib
	0.1 ≤ TFH ≤ 0.5	Earthen (Non Engineered, Poor Construction)
	0.1 ≤ TFH ≤ 0.3	Slag, Refuse



11

Breach Parameter Guidance

- Regression
  - Envelope or best-fit lines from observed data
  - Separate predictive equations for
    - Breach width
    - Failure Time
    - Peak Flow
  - Peak flow usually a rough check on computed peak flow from breach algorithms (HEC-RAS, DAMBRK, etc.)

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Breach Width Equations

- Bureau of Reclamation (1988): $B=3h_w$
- MacDonald & Langridge-Monopolis (1984): $V_{er}=0.0261(V_w h_w)^{0.769}$ earthfill $V_{er}=0.00348(V_w h_w)^{0.852}$ nonearthfill (e.g. rockfill)
- Von Thun & Gillette (1990): $B=2.5h_w+C_b$
- Froehlich (1995): $B=0.1803KV_w^{0.32}h_b^{0.19}$

Note: All equations are in metric form

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Failure Time Equations

- Bureau of Reclamation (1988): $t=0.011B$
- MacDonald & Langridge-Monopolis (1984): $t=0.0179V_{er}^{0.364}$
- Von Thun & Gillette (1990):

  $t=0.015h_w$ easily erodible
  $t=0.020h_w+0.25$ erosion resistant
  $t=B/(4h_w+61)$ highly erodible
  $t=B/4h_w$ erosion resistant

Froehlich (1995): $t=0.00254V_w^{0.53}h_b^{-0.9}$

Note: All equations are in metric form

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Peak Flow Equations

- Bureau of Reclamation (1982): $Q=19.1(h_w)^{1.85}$ (envelope equation)
- MacDonald & Langridge-Monopolis (1984): $Q=1.154(V_w h_w)^{0.412}$
  $Q=3.85(V_w h_w)^{0.411}$ (envelope equation)
- Froehlich (1995): $Q=0.607V_w^{0.295}h_w^{1.24}$
- Kirkpatrick (1977): $Q=1.268(h_w+0.3)^{1.24}$
- SCS (1981): $Q=16.6h_w^{1.85}$
- Hagen (1982): $Q=0.54(S \cdot h_d)^{0.5}$

Note: All equations are in metric form

15

Peak Flow Equations (cont'd)

- Singh & Snorrason (1984): $Q=13.4(h_d)^{1.89}$
- Singh & Snorrason (1984): $Q=1.776(S)^{0.47}$
- Costa (1985): $Q= 10.5(h_d)^{1.87}$
- Costa (1985): $Q= 961(S')^{0.48}$
- Costa (1985): $Q= 325(h_d S')^{0.42}$
- Evans (1986): $Q=0.72V_w^{0.53}$
- Walder & O'Connor (1997): Q estimated by computational and graphical method using relative erodibility of dam and volume of reservoir (see next slide).

Note: All equations are in metric form

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Breach Parameter Guidance

- Theoretical
  - Not many available
  - Walder & O'Connor (1997) based on numerical simulations of idealized dam failure cases
    - Range of dam and reservoir configurations
    - Range of assumed erodibility
    - Dimensionless parameter separates "large reservoir /fast erosion" cases from "small reservoir / slow erosion" cases

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Breach Parameter Guidance

- Sensitivity
- Wahl (2004) compared results from many equations to observed data to test uncertainty
  - Breach width equations had mean prediction errors less than 0.1 order of magnitude, most uncertainty bands ±0.3-0.4 log cycles.
  - Failure time equations all under predict by 0.2-0.67 orders of magnitude (designed to be conservative), very large error bands ±0.6-1 log cycles.
  - Peak flow equations tend to over predict, envelope curves by 0.67-0.75 orders of magnitude, uncertainty bands ±0.5-1 log cycles.

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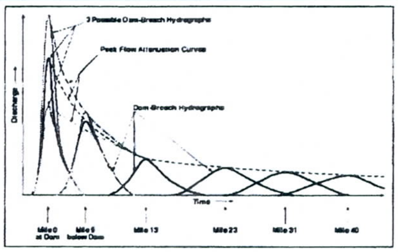
Breach Parameter Guidance

- Dam breach hydrographs often coalesce relatively rapidly and differences diminish as the waves move downstream



19

BREACH

- BREACH: An erosion model for earthen dam failures (Fread, 1984).
- NWS model for breach formation
- Requires data related to
  - Reservoir bathymetry
  - Dam geometry
  - Tailwater channel
  - Embankment materials
  - Initial conditions

20

BREACH (cont'd)

- Physically based model simulates hydraulic and erosion processes
- This and other models do not adequately model headcut-type erosion that dominates with cohesive soil embankments.

21

DAMBRK/FLDWAV

- DAMBRK and DWOPR models replaced by FLDWAV.
- FLDWAV uses same breach algorithms as DAMBRK and performs routing.
  - Can also input breach hydrograph from another source (e.g., BREACH) and then route.
- The breach is always assumed to develop over a finite interval of time (τ) and will have a final size determined by a terminal bottom width parameter (b) and various shapes depending on side slope (1 vertical : z horizontal). τ, b, and z are specified by the user.
- Parametric representation of the breach is utilized in FLDWAV for reasons of simplicity, generality, wide applicability, and the uncertainty in the actual failure mechanism.

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DAMBRK/FLDWAV

- Another way of checking the reasonableness of the breach parameters (b and τ) is to use the following equations:

$$Q_p^* = 370(V_r h_d)^{0.5} \quad \text{Eqn 6.12} \qquad Q_p = 3.1b\left(\frac{C}{\tau + C/\sqrt{h_d}}\right)^3 \quad \text{Eqn 6.13}$$

- Q^*_p and Q_p are the expected peak discharge (cfs) through the breach, V_r and h_d are the reservoir volume (acre-ft) and height (ft) of dam, respectively, and C = 23.4 (As/b) in which As is the surface area (acres) of the reservoir at the top of the dam.

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HEC-RAS

- Can model overtopping or piping failures
- Routes flood wave downstream using unsteady flow equations
- Need to specify dam breach parameters on inline structure editor

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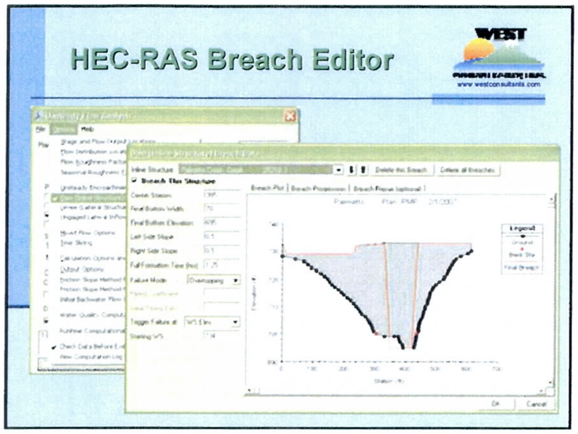
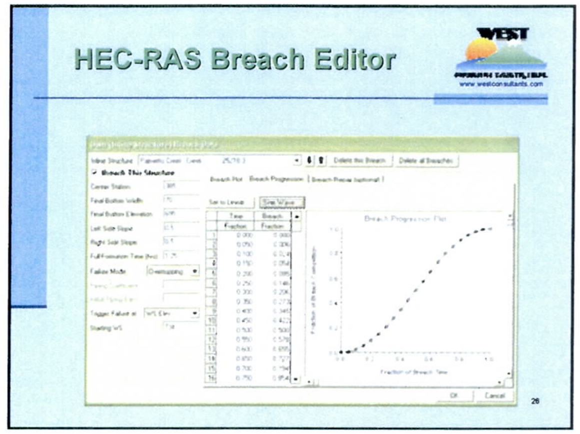

HEC-RAS Breach Editor
WEST
www.westconsultants.com


HEC-RAS Breach Editor
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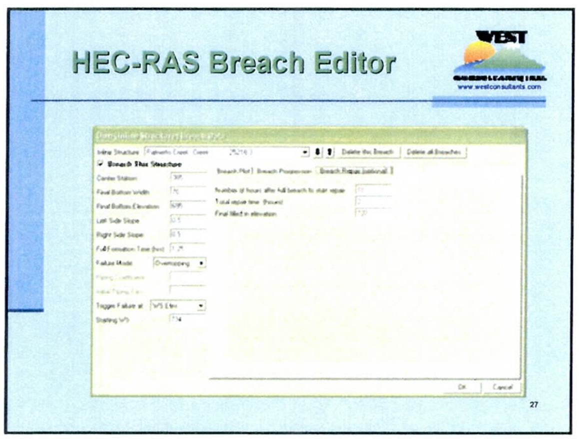
HEC-RAS Breach Editor
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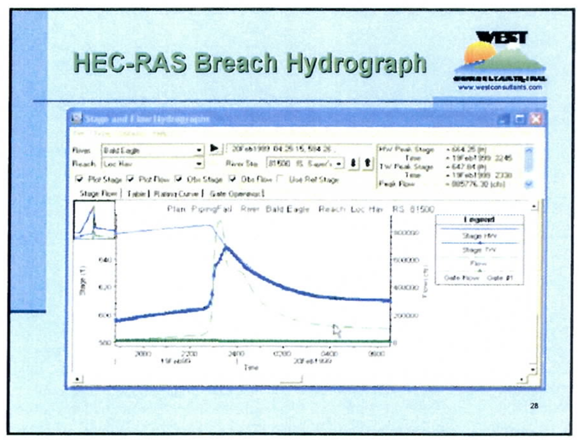
27


HEC-RAS Breach Hydrograph
WEST
www.westconsultants.com
28

Setting up an HEC-RAS Dam Breach Model

- **Objective**: This lecture will show you the basics of setting up an HEC-RAS dam breach unsteady flow model.

1

Topics to Discuss

- Geometric data
- Unsteady flow data
  - Boundary and initial conditions
- Unsteady flow simulation manager
  - Creating an unsteady simulation
- Suggestions for setting up dam breach models

2

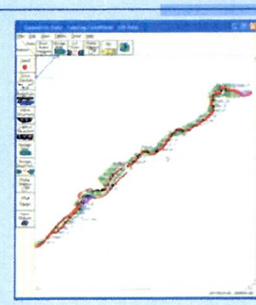
Overview

- Unsteady Flow Model
- Simple dendritic streams to complex networks can be modeled.
- Capable of modeling all of the available hydraulic structures upstream and/or downstream of the breach
- More Complex = More Difficult
- Keep it Simple

3

Geometric Data

- Geometry is entered in the same way for steady or unsteady flow models
- Additional data may be required



Bald Eagle Creek, Pennsylvania
Courtesy Hydrologic Engineering Center, Davis, CA

4

Geometric Data

- Cross Section Spacing
- Graphical XS Editor
- XS Interpolation
- Pilot Channels
- Outlet Works
- n-Values
- Breach Editor

5

Cross Section Spacing

- Cross sections should first be placed at representative locations to describe the changes in geometry
- Additional cross sections should be added at locations where changes occur in discharge, slope, velocity, and roughness
- Cross sections must also be added at levees, bridges, culverts, and other structures
- Finally, there must be adequate cross sections to satisfy the numerical solution
  - Samuels (1989) and Fread (2003) have equations for maximum spacing
  - Other references (USGS, USACE)

6

Samuels' Equation for Cross Section Spacing

Samuels' Equation for Cross Section Spacing

$$\Delta x \le \frac{0.15D}{S_0}$$

Where: Δx is the cross section spacing distance; D is the bankfull depth; and S_0 is the bed slope

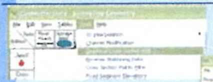
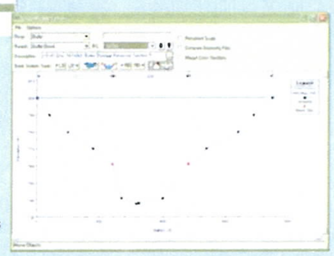
Fread's Equation for Cross Section Spacing

$$\Delta x \le \frac{cT_r}{20}$$

Where: Δx is the cross section spacing distance; c is the wave celerity; and T_r is minimum rise time of the hydrograph

7

Graphical XS Editor

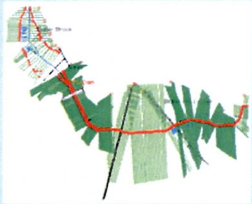



- Bank Stations
- Add Sta/Elev Points
- Add Ineffective Triggers
- Add Levees
- Add Obstructions
- Move Objects
- Move n-Value Break Pts
- Hint (use "A" and "Z" keys)

8

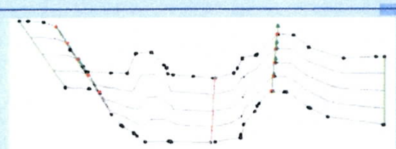
XS Interpolation

- Frequently necessary for model stability
- Easy to do, but be careful! We're after model stability while *still maintaining accuracy*.
- Avoid "Blind" Interpolation for final run.
- Multiple Block Ineffective Triggers are NOT automatically interpolated
- Extrapolation?



9

XS Interpolation



Blind Interpolation

Which Interpolation is correct???

User-Defined Major Chords

10

Manning's n Values

- Manning's n values can have a big influence on the stability of dam break models.
  - Common to underestimate n values particularly in steep reaches.
    - Can cause water surface elevations to dip too low.
    - Can cause supercritical flow.
    - Can cause velocities to be too high.
  - Jarrett's equation is a good check for steep streams.

$$n = 0.39S^{0.38}R^{-0.16}$$

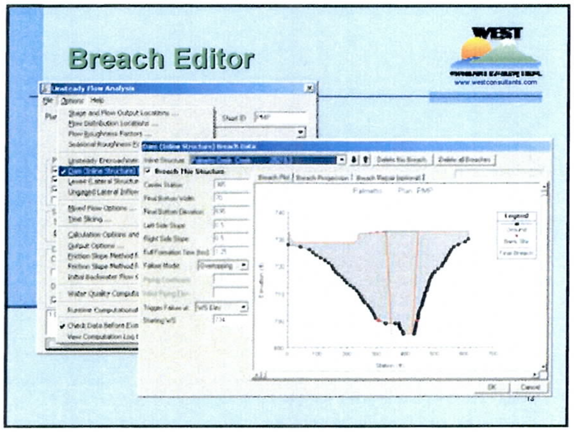
where S = energy slope
R = Hydraulic Radius

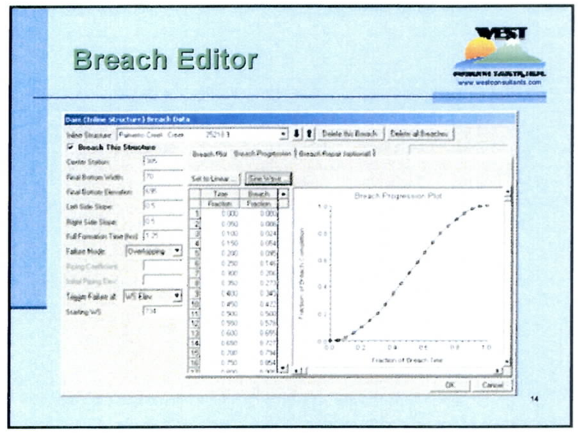
11

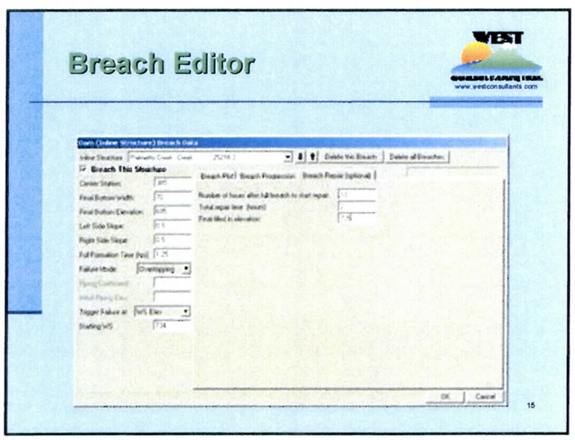
Manning's n Values

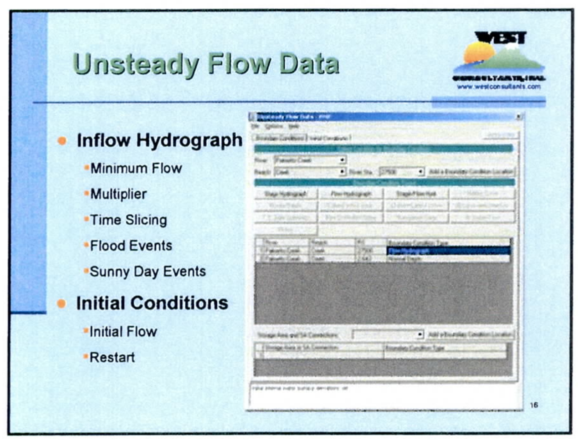
- May need to increase n values just downstream of the dam (particularly for replication studies).
  - Highly turbulent during the breach
  - Lots of sediment/debris mixed in with the water

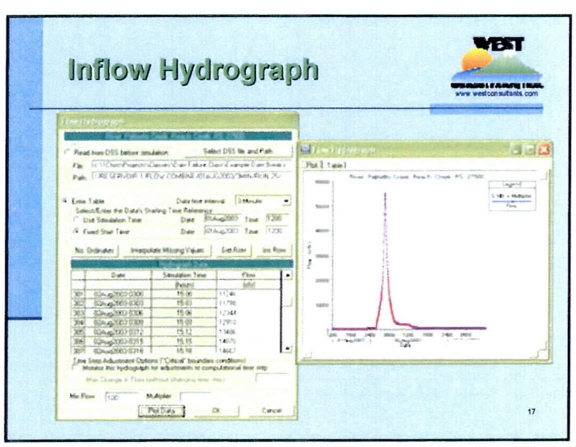
12

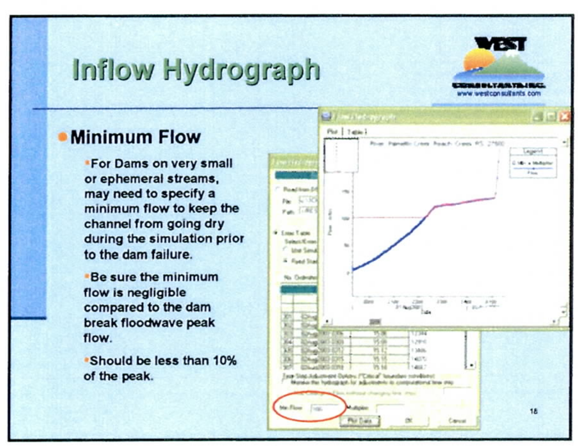

Breach Editor
WEST
13

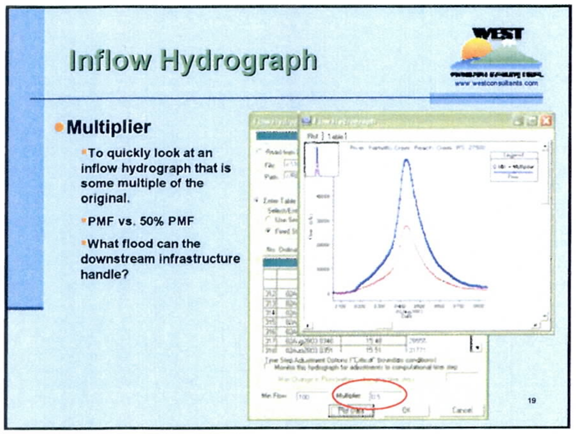

Breach Editor
WEST
14

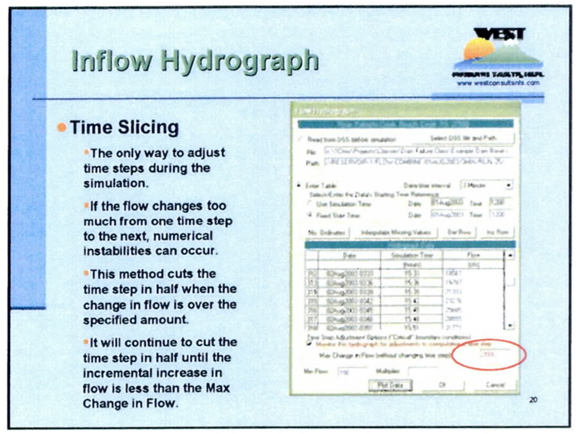

Breach Editor
WEST
15

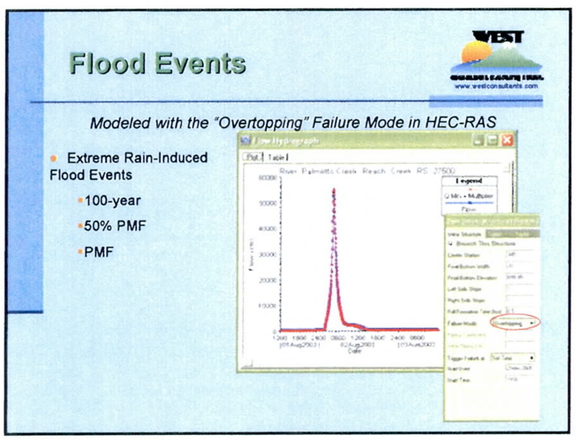

Unsteady Flow Data
WEST
Inflow Hydrograph
Minimum Flow
Multiplier
Time Slicing
Flood Events
Sunny Day Events
Initial Conditions
Initial Flow
Restart
16

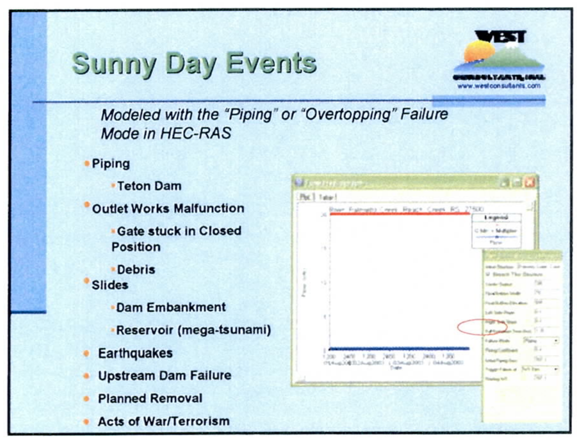

Inflow Hydrograph
WEST
17

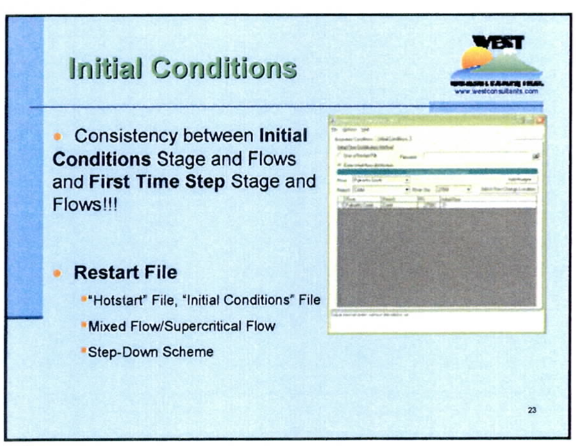

Inflow Hydrograph
WEST
Minimum Flow
For Dams on very small or ephemeral streams, may need to specify a minimum flow to keep the channel from going dry during the simulation prior to the dam failure.
Be sure the minimum flow is negligible compared to the dam break floodwave peak flow.
Should be less than 10% of the peak.
18

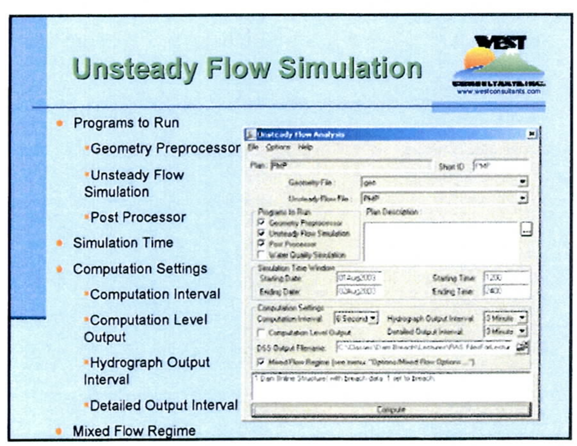

Inflow Hydrograph
Multiplier
To quickly look at an inflow hydrograph that is some multiple of the original.
PMF vs. 50% PMF
What flood can the downstream infrastructure handle?
19


Inflow Hydrograph
Time Slicing
The only way to adjust time steps during the simulation.
If the flow changes too much from one time step to the next, numerical instabilities can occur.
This method cuts the time step in half when the change in flow is over the specified amount.
It will continue to cut the time step in half until the incremental increase in flow is less than the Max Change in Flow.
20


Flood Events
Modeled with the "Overtopping" Failure Mode in HEC-RAS
Extreme Rain-Induced Flood Events
100-year
50% PMF
PMF

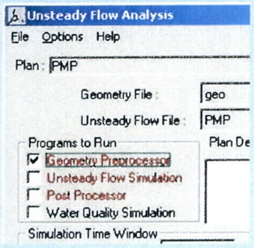

Sunny Day Events
Modeled with the "Piping" or "Overtopping" Failure Mode in HEC-RAS
Piping
Teton Dam
Outlet Works Malfunction
Gate stuck in Closed Position
Debris
Slides
Dam Embankment
Reservoir (mega-tsunami)
Earthquakes
Upstream Dam Failure
Planned Removal
Acts of War/Terrorism


Initial Conditions
Consistency between Initial Conditions Stage and Flows and First Time Step Stage and Flows!!!
Restart File
"Hotstart" File, "Initial Conditions" File
Mixed Flow/Supercritical Flow
Step-Down Scheme
23


Unsteady Flow Simulation
Programs to Run
Geometry Preprocessor
Unsteady Flow Simulation
Post Processor
Simulation Time
Computation Settings
Computation Interval
Computation Level Output
Hydrograph Output Interval
Detailed Output Interval
Mixed Flow Regime

Programs to Run

- **Geometry Preprocessor**
  - Processes geometric data into a series of hydraulic tables and rating curves at cross sections and bridges/culverts.
  - Computations made prior to, and independent of, unsteady flow calculations.
  - As long as geometry remains the same, this only needs to be run once.



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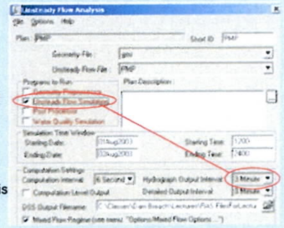
Programs to Run

- **Unsteady Flow Simulation**
  - Runs the computations
  - Produces Hydrographs of flow and depth at selected cross sections and internal/external boundaries.
  - Hydrograph Output Interval determines how often this data is provided.



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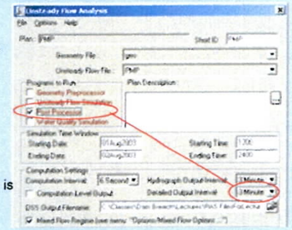
Programs to Run

- **Post Processor**
  - Processes the flow and stage results into all of the available variables.
  - Produces profile plots, cross section plots, xyz plots for animation.
  - Detailed Output Interval determines how often this data is provided.



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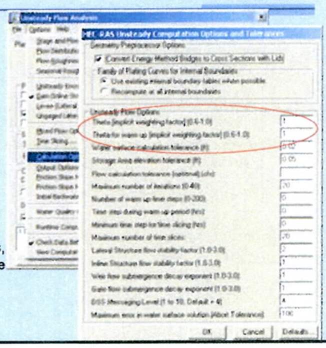
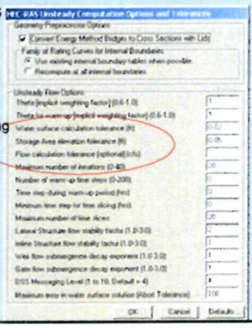
Unsteady Flow Analysis Options

- **Theta**
  - Weighting applied to finite difference approximations
  - Can range from 0.6 to1.0
  - 0.6 considered most accurate
  - 1.0 considered most stable
  - For practical purposes, keep Theta = 1.0. Once model is stable, try to reduce towards 0.6.



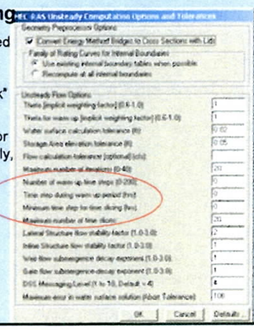
Unsteady Flow Analysis Options

- **Tolerances and Iterations**
  - The defaults are generally fine-even for dam breach modeling
  - Don't change to try to improve stability.
  - Increasing tolerances or decreasing iterations may help to improve computation time.



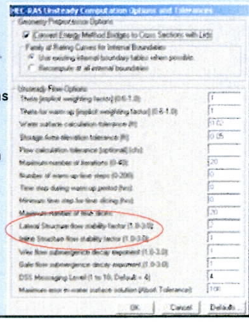
Unsteady Flow Analysis Options

- **Warm up and Time Slicing**
  - A warm-up period can be specified by the user to give the model a chance to settle into an unsteady solution before a "hydrologic shock" is introduced.
  - Time slicing provides a method for reducing the time step automatically, during the computations, when boundary condition flows increase too quickly.



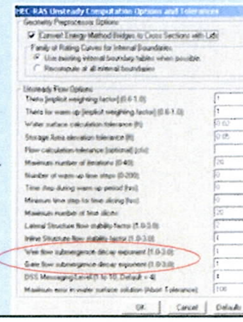
Unsteady Flow Analysis Options

- **Stability Factors**
  - May help to stabilize solutions around lateral and inline structures.
  - Lateral Structure Flow Stability Factor: To help dampen oscillations at lateral structures.
  - Inline Structure Flow Stability Factor: To help dampen oscillation at inline structures.
  - Default is 1. 3 is the most stable.



Unsteady Flow Analysis Options

- **Submergence Decay Exponents**
  - May help to stabilize solutions around weirs and inline structures that become highly submerged.
  - Particularly useful when reverse flow is possible.
  - Default is 1. 3 is the most stable.



Suggestions for Dam Breach Model

- Construct the model in stages. Start simple and add components one at a time, running the model after each added component.
- Run the Geometric Preprocessor first. Scan the Hydraulic Property Plots for obvious problems.
- Run the Unsteady Flow Simulation *without* postprocessing. Use finely spaced hydrograph output intervals to help pinpoint problem areas.
- If the model is still unstable, run the postprocessor and view the profile plots for clues to problems.
- Keep simulation time as short as possible.
- Keep relatively short hydrograph output intervals. Simulation time is more a function of computation interval than hydrograph output interval.
- Keep relatively long detailed output intervals. Only shorten the detailed output interval if you need to use the animation to diagnose problems, or for presentations.

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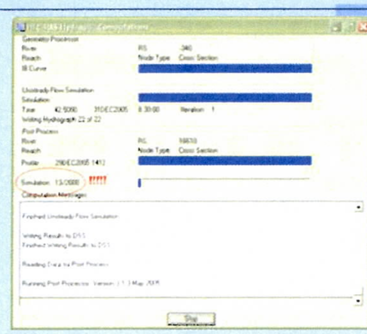
Suggestions for Dam Breach Model



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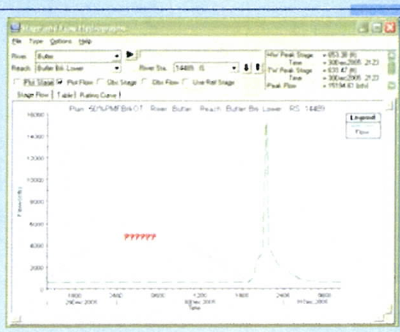
Suggestions for Dam Breach Model



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Advanced Unsteady Modeling Techniques

- **Objective: This lecture will show you how to fix errors and instabilities in HEC-RAS Dam Breach Models.**

1

Topics to Discuss

- Overview
- XS Spacing
- Time Steps
- Mixed Flow
- Base Flow
- Time Slicing
- Pilot Channels
- Hot Start Files

2

Overview

- Once a Model's Sources of Errors are Diagnosed
  - How to fix them
- Target Sources of Errors, not Symptoms of Errors

3

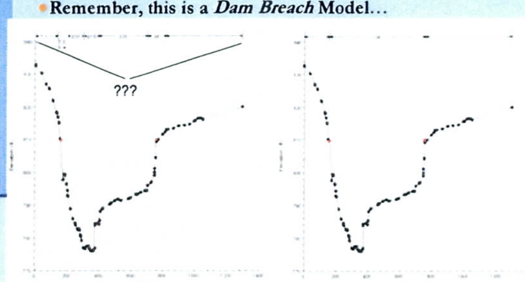
Overview

- Approach the Model Simplistically
  - Construct a basic model
  - Start with artificially high n values, then lower to real values
    - Steep Stream will have higher n-values
  - Then add bridges/structures one at a time
  - Finally add the dam breach

4

Overview

- Remember, this is a *Dam Breach* Model…



Cross Section Spacing

- Perform an Initial Reach-wide Interpolation to meet Fread's or Samuel's Equation.

$$\Delta x \le \frac{cT_r}{20} \qquad \Delta x \le \frac{0.15D}{S_0}$$

- Further Interpolate locally if needed.
  - Transition zones
  - Grade breaks
  - Steep reaches

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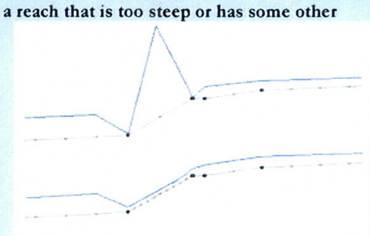
Cross Section Spacing

- At problem areas try "halving" the spacing and continue until the profile looks more reasonable.
- ***Stay Reasonable.*** i.e. Spacing less than 10 ft probably suggests a reach that is too steep or has some other problem.



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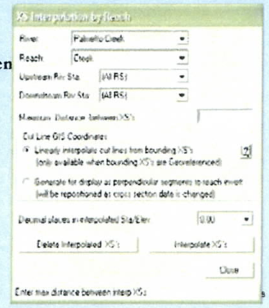
Cross Section Spacing

- Reach-wide Interpolation
- Can interpolate between two or more cross sections
- Avoid "Blind" Interpolation



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Time Steps

- After the reach-wide interpolation, use the Courant Condition to determine a good starting point for the computational time interval.

$$\Delta t \leq \frac{\Delta x}{V + c}$$

Wave Speed

- What is V? What is c?
- For medium to large rivers the Courant condition may yield time steps that are too restrictive

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Time Steps

- Once the time step is determined, it is generally left alone.
- May need to decrease the time step after the breach is included in the model.
- Dam Breach HEC-RAS models normally have time steps on the order of 1 minute or less.
- Remember, a model with a 15 second time step will take twice as long to compute than a model with a 30 second time step.
- *Suggestion: Use the Courant Condition to come up with an initial time step but don't use less than 5 seconds unless it is necessary.*

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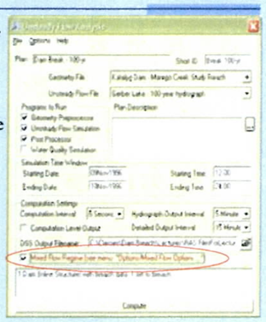
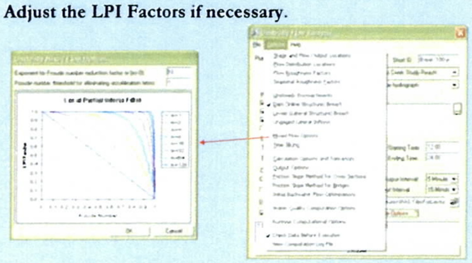
Mixed Flow

- When the Froude Number approaches 1 during a simulation, the inertial terms of the St. Venant equation tend to propagate errors towards instability.
- Turn on "Mixed Flow" in the Unsteady Flow Simulation Window.



Mixed Flow

- As a matter of practice, should always have "Mixed Flow" turned on for a dam breach model.
- Adjust the LPI Factors if necessary.



Base Flow

- For ephemeral streams, or small streams in steep watersheds.
- Low depths = decreased numerical stability
- To keep depths high enough, add in a base flow.
- The base flow should be small enough that it's contribution to the flood wave peak is negligible.
- Rule of thumb: Start with 1% of peak, don't exceed 10% of peak.

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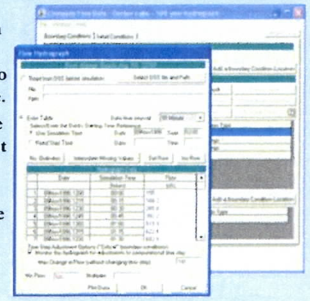
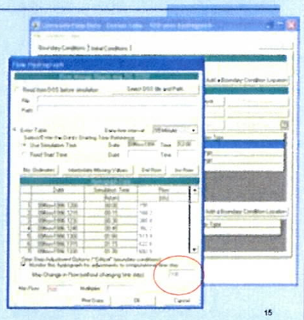
Base Flow

- Anytime a flow value of "zero" is present in a boundary hydrograph, be sure to use a Min. Flow value.
- If the Min. Flow value is greater than the first time step flow, then change the Initial Conditions Flow value accordingly.



Time Slicing

- At steep portions of the hydrograph, flow may change too drastically from one time step to the next.
- HEC-RAS can automatically "slice" the time step until the increase in flow is less than a user-defined maximum.
- Only works for inflow hydrographs-not dam breach-induced hydrographs.



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Pilot Channels

- As depths become too low, the St. Venant equations can become unstable.
- At low depths, any change in stage is a large *percentage* change.
- Also, at times during the iterative procedure of matrix inversion, if depths are low, some of the initial iterations may actually produce a negative depth.
- Pilot channels can trick the numerical solution into thinking there is more depth.

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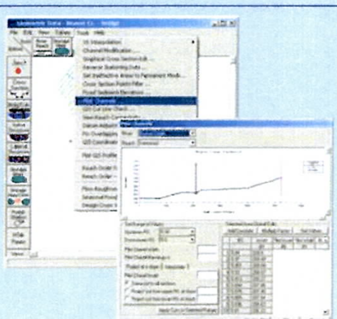
Pilot Channels



- Pilot channels should be used to:
  - Ensure that the reach remains wet
  - Improve stability for low flow/depths

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Hot Start Files

- May be necessary to begin the simulation.
- Requires some effort to set up.
- Also called "Restart" file and "Initial Conditions" file
- Drawn out the model and slowly lower the water surface into a true unsteady solution.

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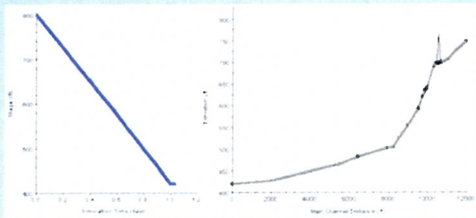
Hot Start Files

Downstream Boundary

Profile Plot



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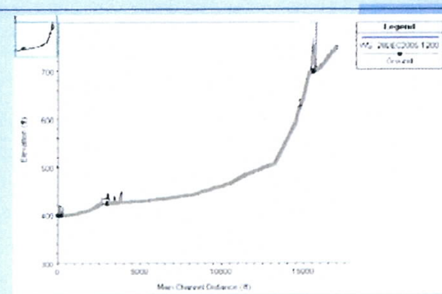
Hot Start Files



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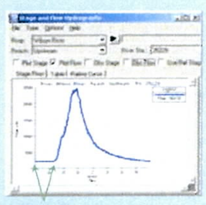
Suggested Steps for Creating a Stable Unsteady Flow Model

1. Start simple
   - Create the main stem reach
   - Leave out structures (e.g., bridges, lateral structures, etc.)
   - Run in unsteady mode with a constant inflow hydrograph
   - Not running?
     - Check your initial flow distribution
     - Are HTab values exceeded?



Add steady flow to boundary hydrograph if necessary

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Suggested Steps for Creating a Stable Unsteady Flow Model *(Continued)*

2. Add in any additional reaches
   - Side channels, tributaries, etc.
3. Include the unsteady flow data
   - Fix HTab, ineffective flow, or geometry problems
   - Are there instabilities in your boundary condition data?
   - May need to run the model with a range of "steady" unsteady flow files, or a gradual linearly increasing hydrograph, to identify problem locations
4. Systematically include structures
   - Fix HTab, ineffective flow area, or structure geometry problems
   - Ensure the model runs successfully after each structure is added

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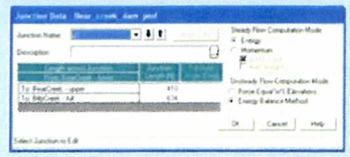
New Features in HEC-RAS 4.0.1 (beta)

- **Objective**: This lecture will give a quick overview of some of the new features in HEC-RAS

1

Junctions

- Previously junctions caused problems with unsteady flow in areas of steep slope and shallow flow.
- Junction editor allows the user to change the computation mode to perform an energy balance around the junction.



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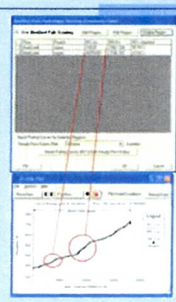
Modified Puls Hydrologic Routing

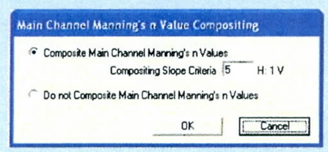
- Steep, shallow reaches often cause problems in dynamic unsteady flow models
- A portion of any reach can be solved using the Modified Puls Hydrologic routing technique



3

Manning's n Value Compositing

- Can change the Compositing Slope Criteria
- Can turn off automatic n-value composition



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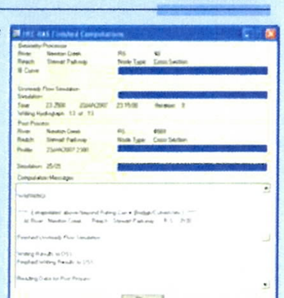
View Runtime Messages File

- Gone are the days where you have to rerun your 10 minute-long simulation just to find out where it crashed because you inadvertently closed the computation message window.
- RAS now stores this info in a log file.



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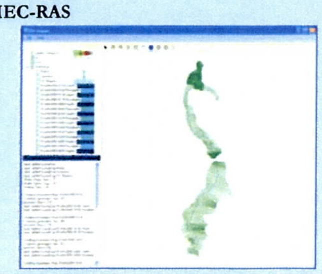
RAS Mapper

- RAS Mapper allows the user to map the floodplains directly in the HEC-RAS environment
  - Steady
  - Unsteady



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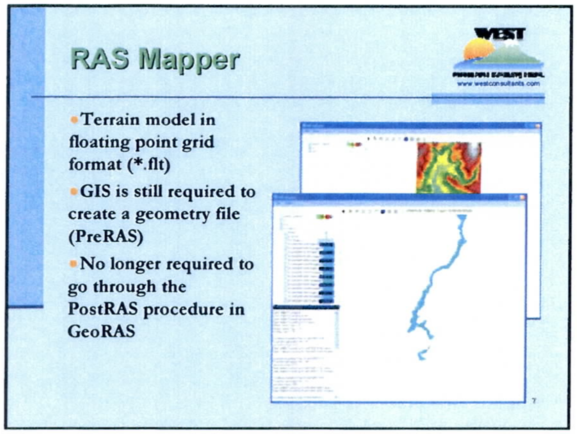
RAS Mapper
Terrain model in floating point grid format (*.flt)
GIS is still required to create a geometry file (PreRAS)
No longer required to go through the PostRAS procedure in GeoRAS