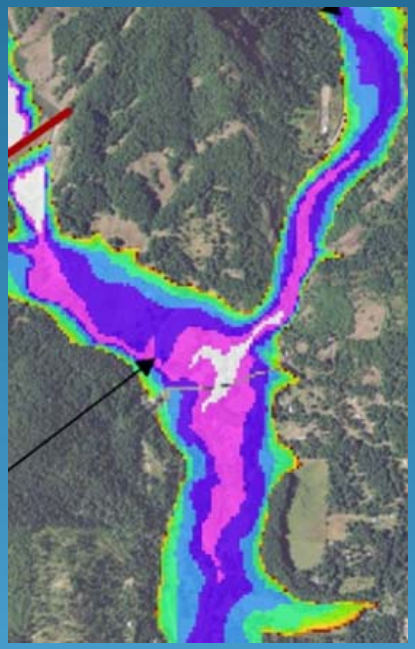
Dam Break Floods

Understanding Inundation Analysis



Christopher Goodell, P.E., D.WRE

WEST Consultants, Inc.

Portland, OR USA

What is a Dam Break Inundation Map?

- FERC Definition:

  Delineates the *"...areas that would be flooded as a result of a dam failure."*

- ASDSO Definition:

  Delineates the *"...areas that may have to be evacuated in a dam emergency."*

- Washington Dept. Ecology Definition:

  Delineates the *"...areal extent of flooding which would be produced by the dam break flood."*

- My Definition:

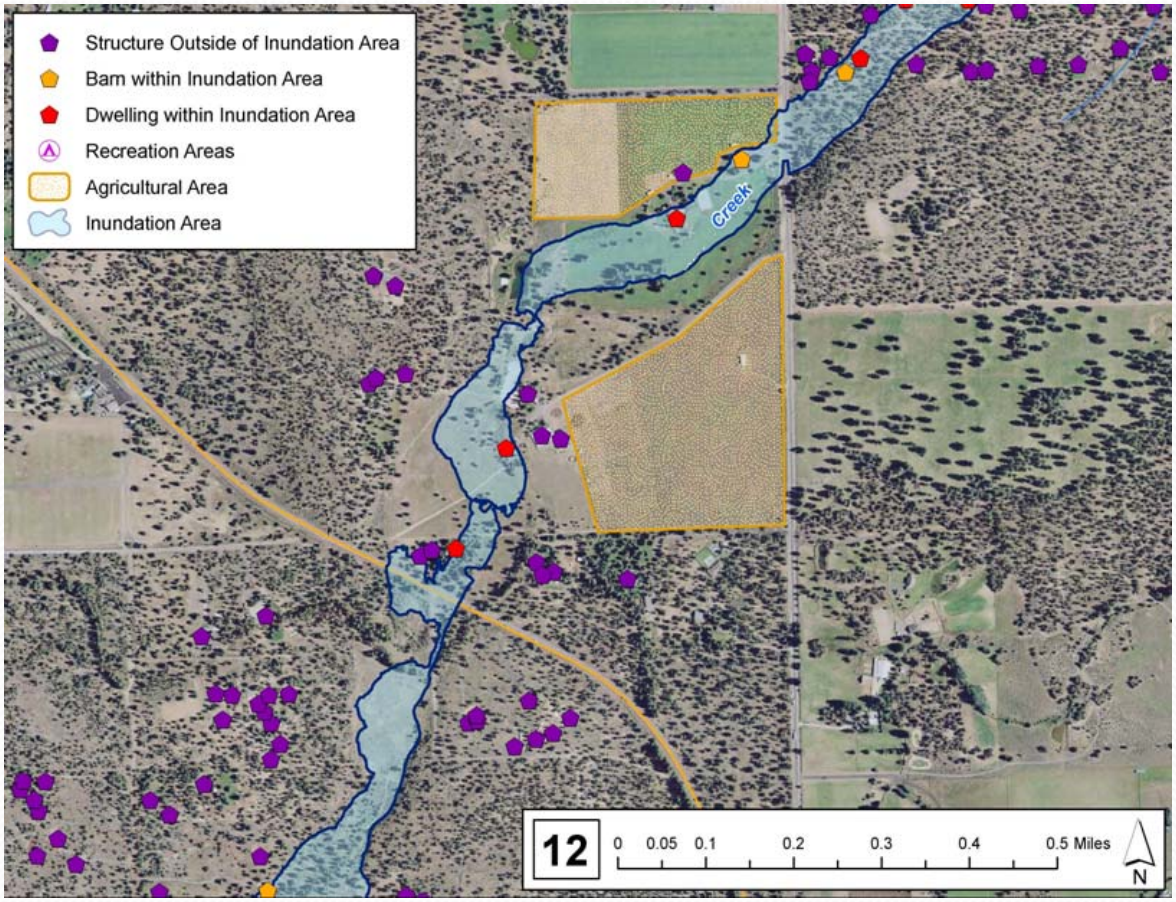
  Delineates the *"...engineer's most conservative, while still realistic estimate of areas that would be covered by water as a result of a dam failure-the accuracy of which is dependant on the quality of terrain data, the sophistication of the hydraulic model, the availability/precision of input data, and the skill of the engineer."*

Dam Break Flood Inundation Maps

- **Purpose**
- **Types**
- **Development of Inundation Maps**
- **Deterministic versus Probabilistic Approaches to Inundation Maps**

Dam Break Flood Inundation Maps
What are they used for?

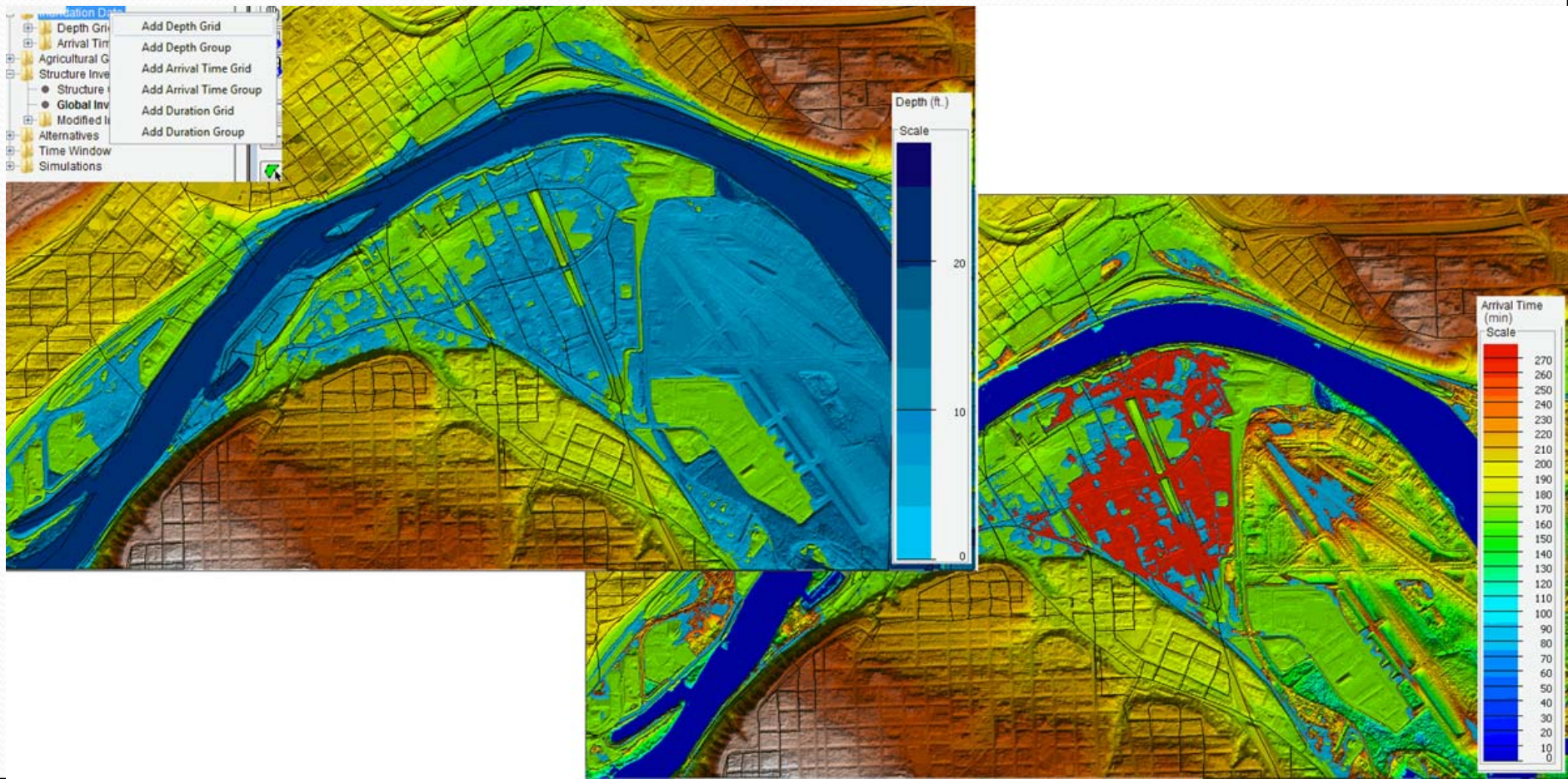
- **Hazard Classification** – Defined by evaluating potential population at risk, economic losses, and environmental damages.



Dam Break Flood Inundation Maps

What are they used for?

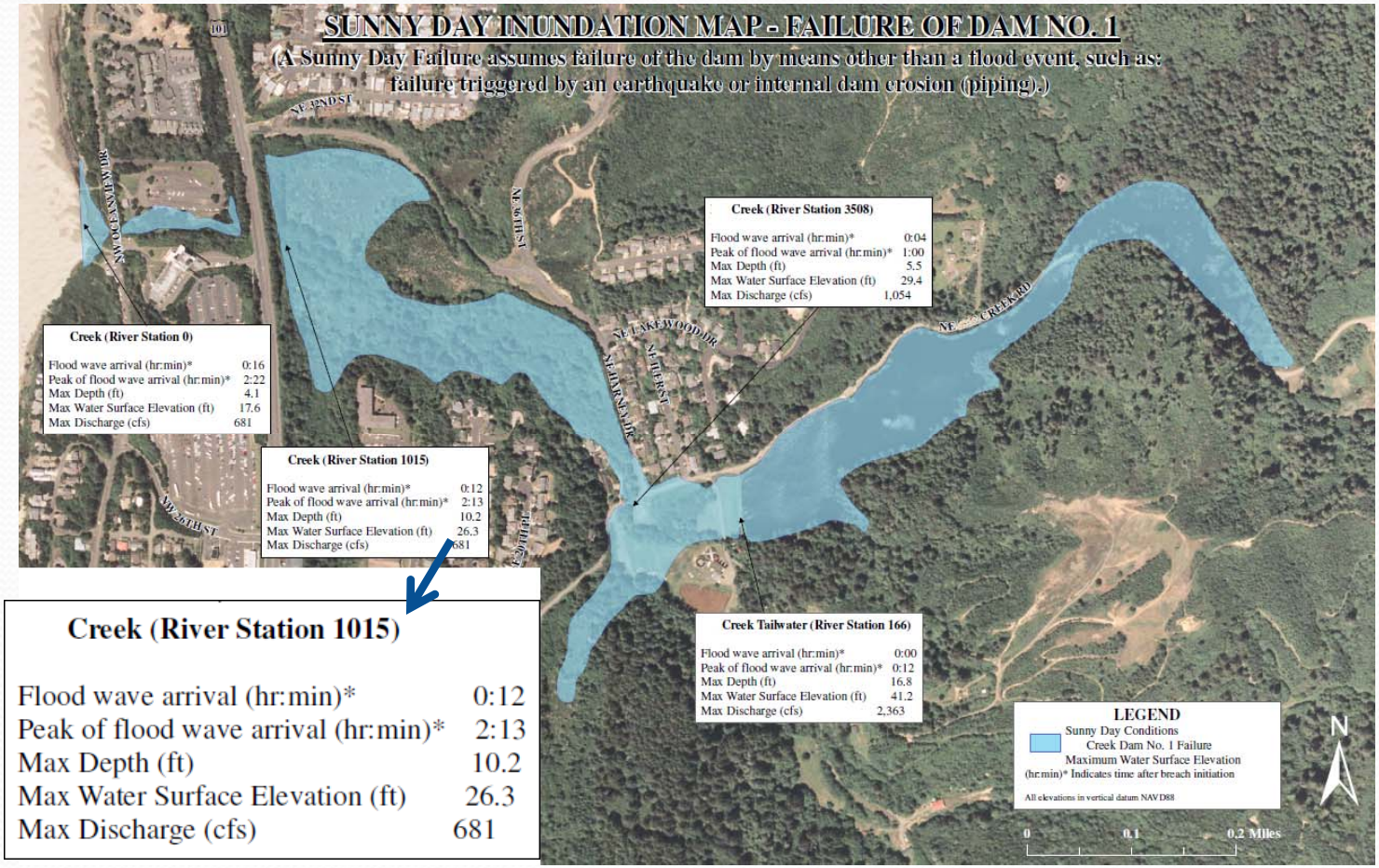
- **Consequence Analysis** – Calculates damages to structures and contents, losses to agriculture, and life loss estimates.



Dam Break Flood Inundation Maps

What are they used for?

- **Emergency Action Plans** – Identifies potential emergency conditions at a dam and preplanned actions to minimize loss of life and property damage (*Dam Safety in Oregon, 2011*).



Creek (River Station 1015)

Flood wave arrival (hr:min)*	0:12
Peak of flood wave arrival (hr:min)*	2:13
Max Depth (ft)	10.2
Max Water Surface Elevation (ft)	26.3
Max Discharge (cfs)	681

Dam Break Flood Inundation Maps
What are they used for?

- **Visualization/Perspective**

Types of Inundation Maps

- **Flood Boundary**
  - **Compute Water Surface Elevations at reference locations (i.e. cross sections, grid cells)**
  - **Flood Boundary is defined as the intersection of the water surface elevation with the terrain.**
  - **Interpolation between reference locations**

  Examples:
    - **Hazard Classification**
    - **Emergency Action Plan**

Types of Inundation Maps

- **Depth Specific/Depth Grids**
  - Compute Water Surface Elevations at reference locations (i.e. cross sections, grid cells)
  - Flood Boundary is defined as the intersection of the water surface elevation with the terrain.
  - Interpolation between reference locations
  - **Convert Water Surface and Terrain Models to Grids**
  - **Compute difference between the water surface elevation and the terrain elevation within each grid cell = Depth**

Examples:

- **Economic, Agricultural and Life Loss (i.e. Consequences) Analysis**
- **Emergency Action Plans**

Types of Inundation Maps

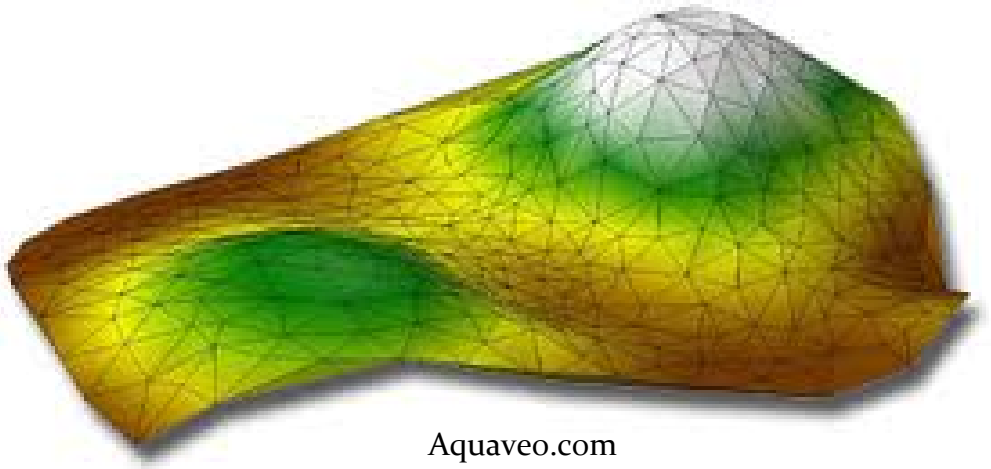
- **Damage/Threat Maps**
  - **Describes the likelihood of damage, physical injury, or death.**
  - **Typically includes other hydraulic parameters**
    - **Velocity**
    - **Shear Stress**
    - **Stream Power**
  - **“Rule of 7”: The product of Depth (ft) X Velocity (fps)**
    - **Incremental Damage Assessment**
    - **Spillway Design Floods**

Development of Dam Break Flood Maps

- **How do we model a hypothetical dam breach?**

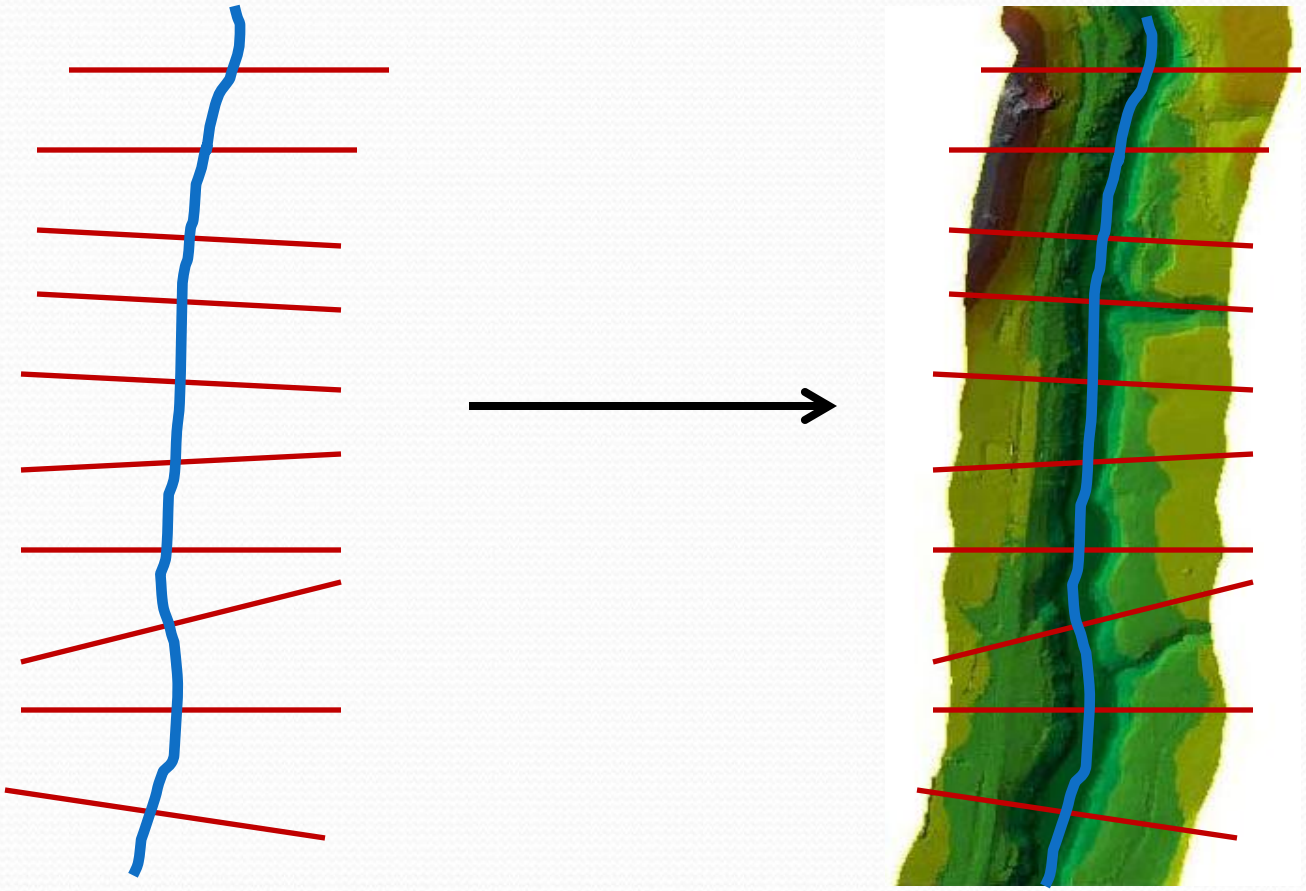
Development of Maps

- Digital Terrain Model (DTM) - TIN or Grid of channel bottom and adjacent floodplain
- DTM used to:
  - Georeference Hydraulic Model layers
  - Provide elevation data
  - Floodplain mapping
- Spatial extent of DTM extremely important

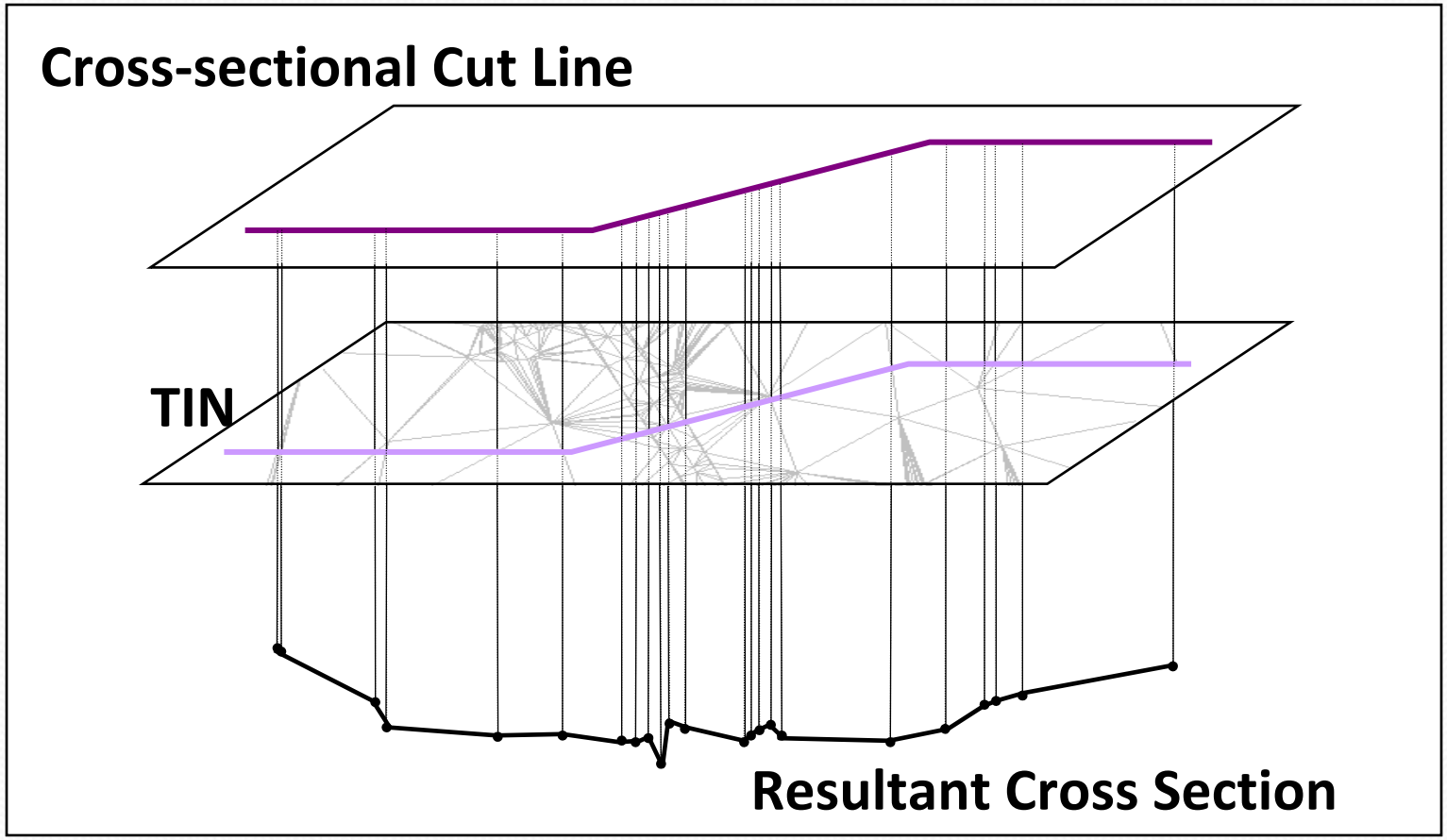


Aquaveo.com

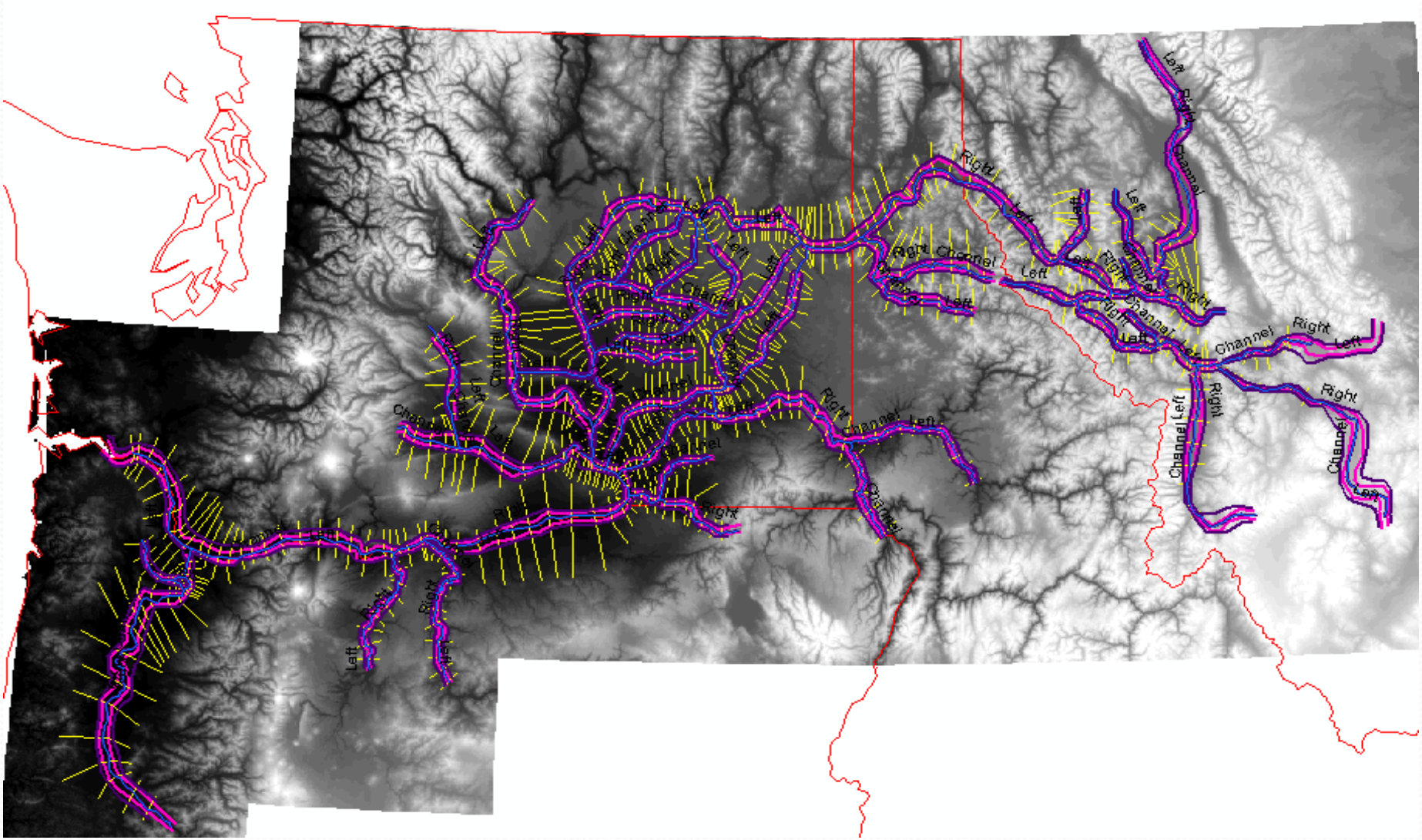
Development of Maps – 1-D Models



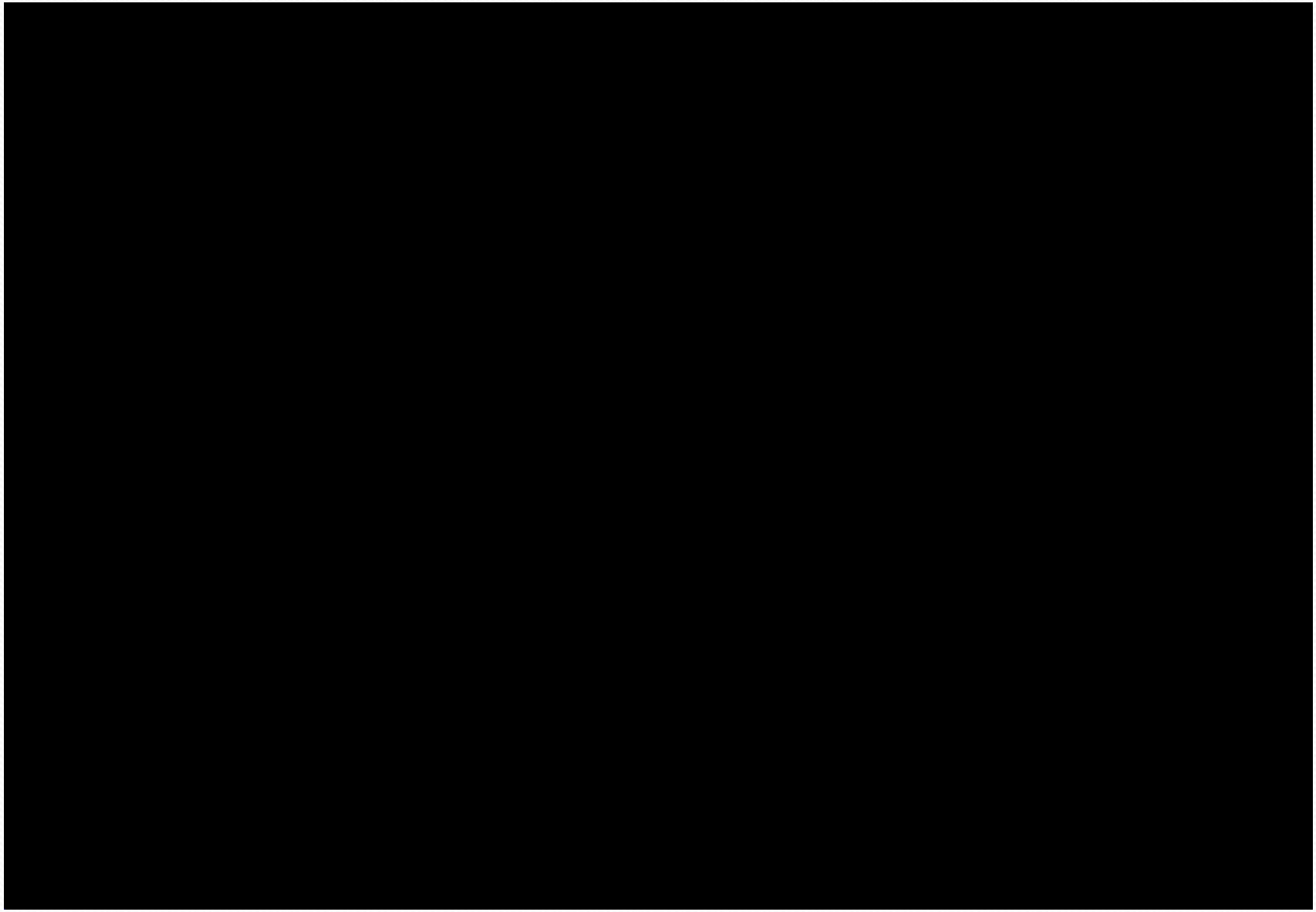
Development of Maps – 1-D Models



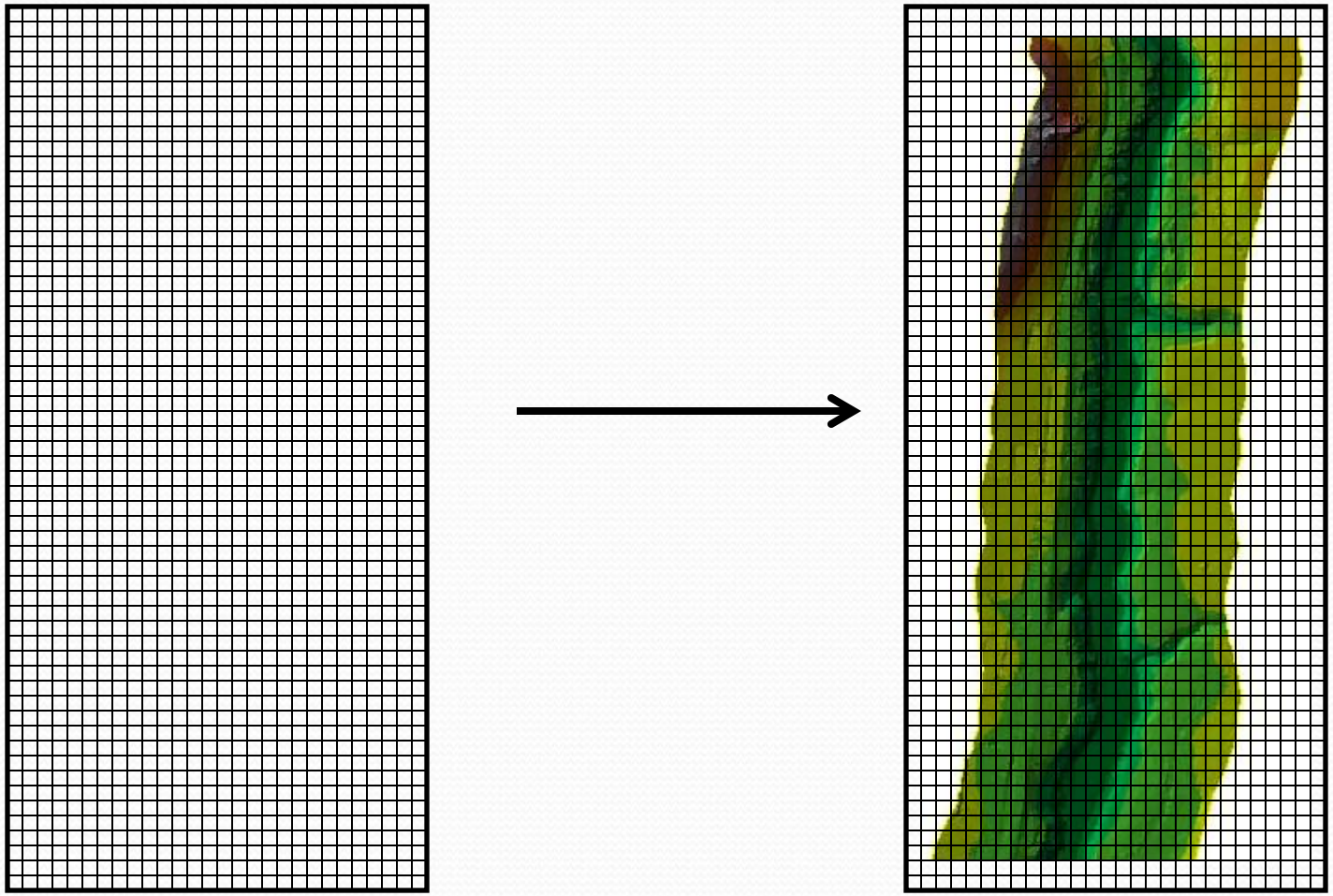
Development of Maps



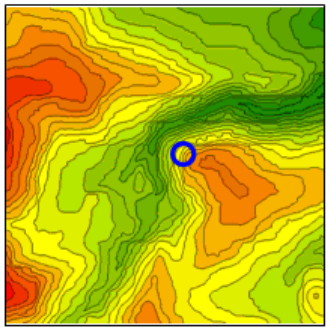
Development of Maps



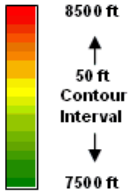
Development of Maps – 2-D Models



Development of Maps – 2-D Models



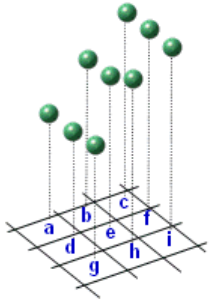
Elevation 2D Contours

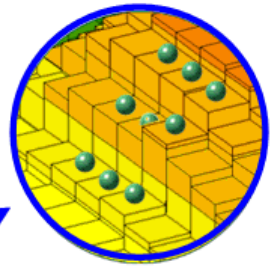


a 8071	b 8136	c 8189
d 8071	e 8136	f 8189
g 8074	h 8156	i 8186

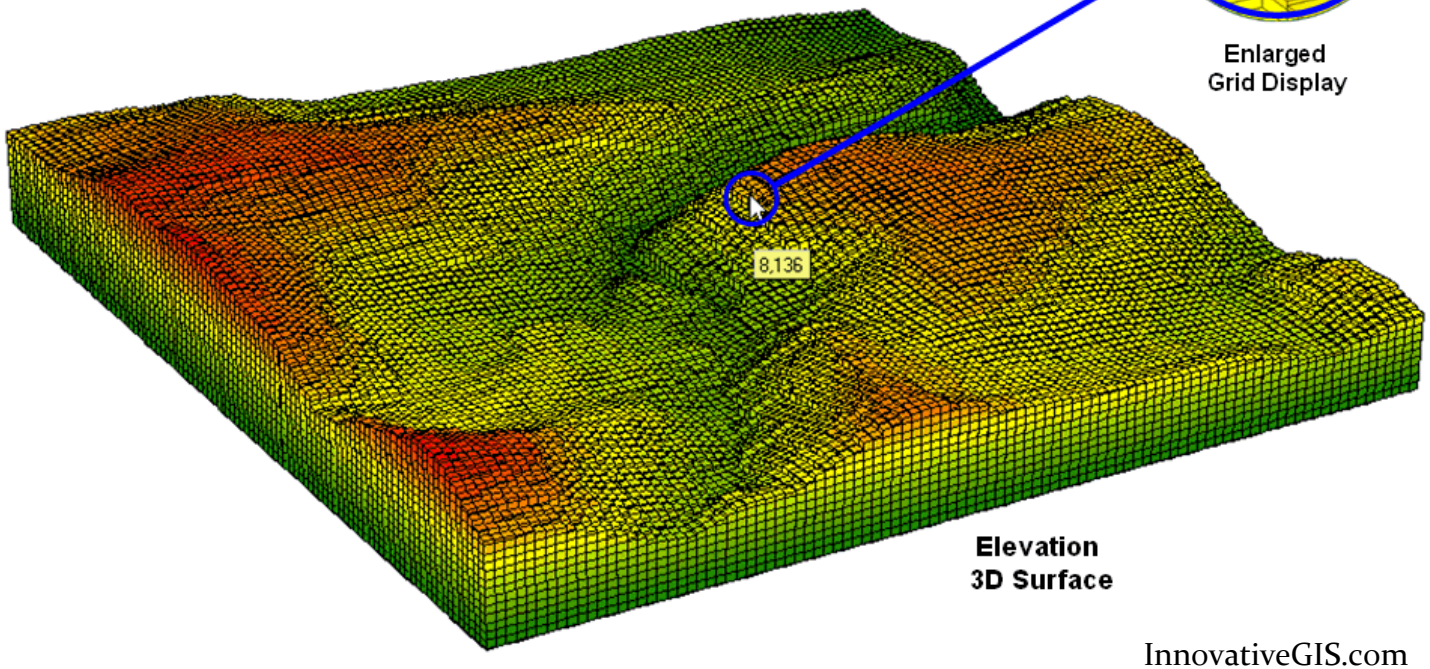
Elevation Values

Cell size = 98.43 ft





Enlarged
Grid Display



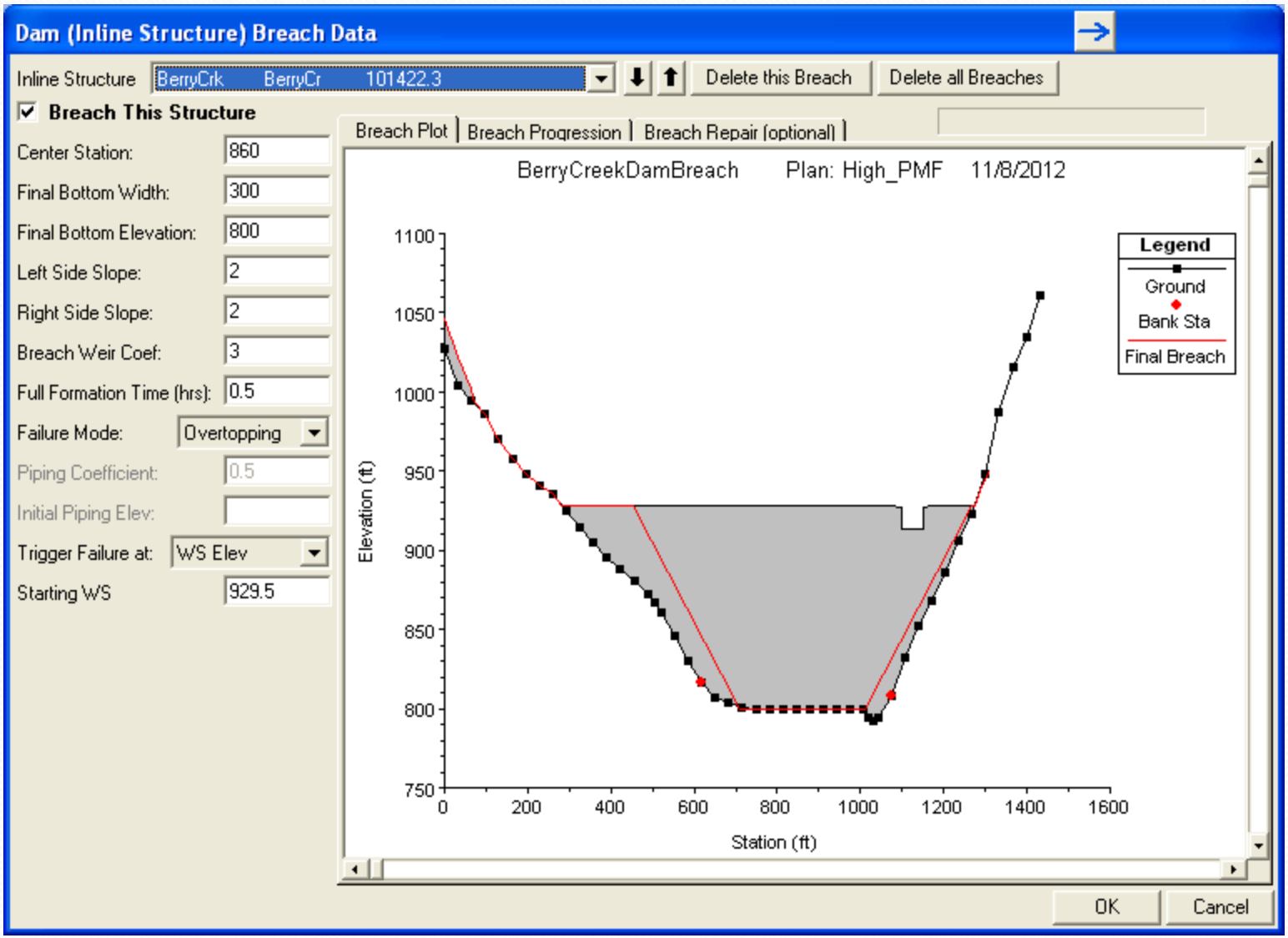
Elevation
3D Surface

InnovativeGIS.com

Development of Maps

- **Hydraulic Modeling**
  - **Requires the unsteady solution of the St. Venant Equations of**
    - **Conservation of Mass**
    - **Conservation of Momentum**
  - **Dam Breach modeling requires a definition of the size, shape, formation time, and hydraulic capacity of the Breach**
    - **Breach Parameters**
    - **Very uncertain!**

Breach Parameters

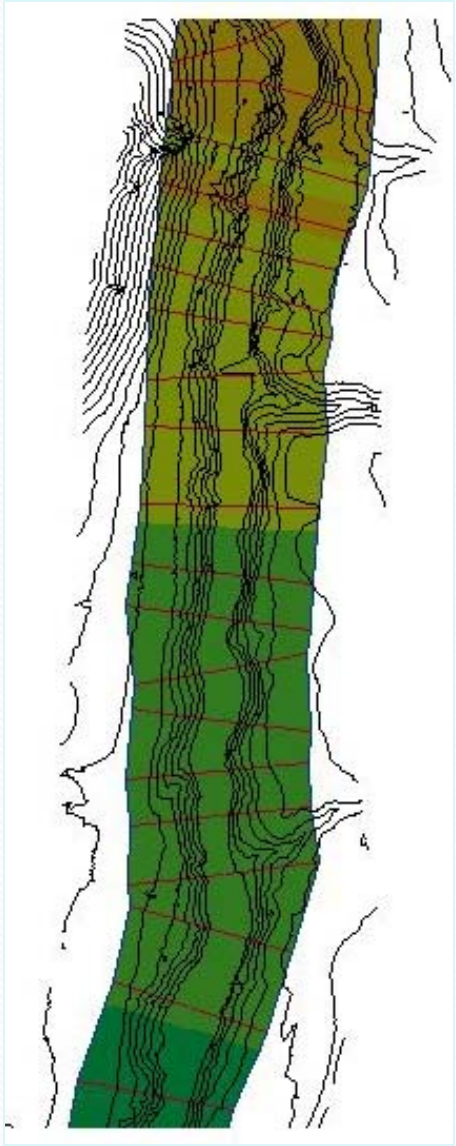


Development of Maps

- **GIS Postprocessing - 1-D Modeling**
  - **Convert Cross Section Output to Geospatial Flood Map**
  - **Extract:**
    - **Stream Centerlines**
    - **Cross Section Cut Lines**
    - **Water Surface Elevations and Velocities**

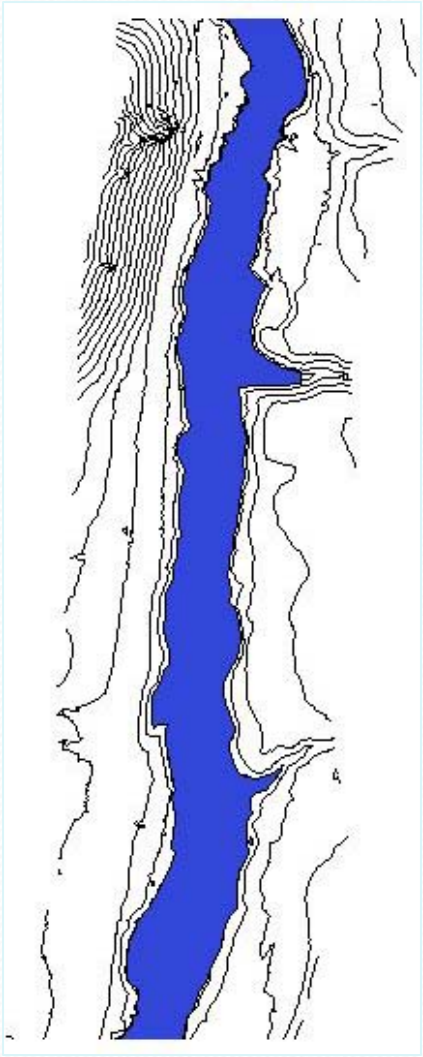
Development of Maps

- Water surface TIN is created by linear interpolation between cross section lines
  - Irrespective of land surface TIN
- Water surface TIN is then clipped with a "bounding polygon"
  - Cross-section extents
  - Levees
  - Non-overtopped bridges and culverts
  - Encroachments

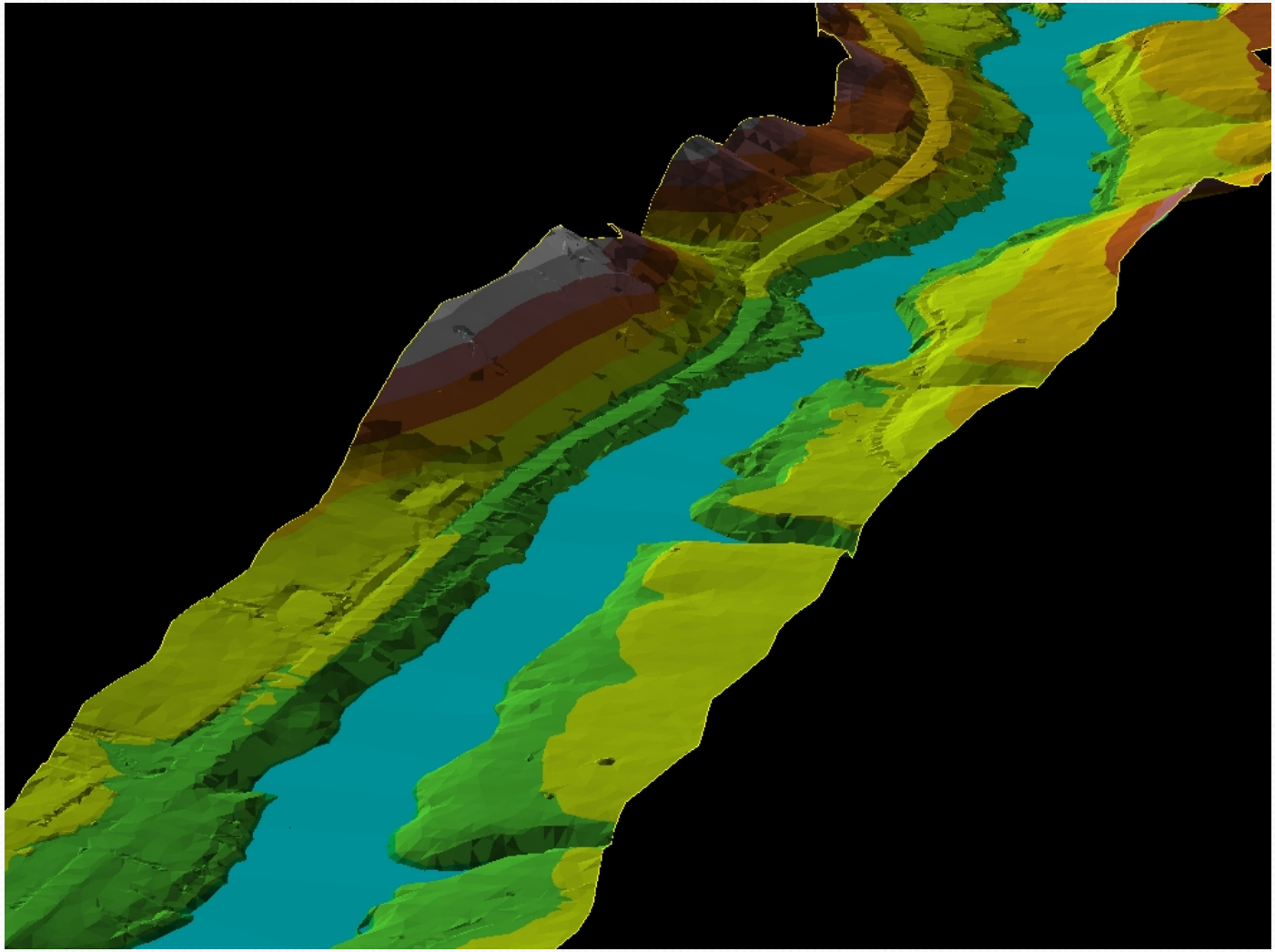


Development of Maps

- Creating the Floodplain Surface
  - Terrain model and water surface TIN are converted to grids
  - A water surface depth grid is created
  - Floodplain boundaries established by creating a polygon for depths greater than zero.
- Velocity TIN can also be created and converted to a grid.



Development of Maps



Development of Dam Break Flood Maps

- **What about Uncertainty?**

Creating a Dam Breach Inundation Map

- **Deterministic Approach**
  - **One Set of Input Parameters**
  - **One Solution**
  - **Conservativeness (i.e. worst case scenario)**

Answers the question:

Will there be flooding at a location if a dam were to fail?

- **Probabilistic Approach**
  - **Statistical Distributions of Probable Input Parameters**
  - **Statistical Distribution of Possible Inundated Areas**
  - **Accurate Presentation of Risk**

Answers the question:

What is the risk of flooding at a location if a dam were to fail?

The Deterministic Approach

- Current State of Practice
- Define a range of breach parameters from various sources.
- Run a sensitivity analysis (High Q, Medium Q, Low Q).
- Generally speaking, the "most conservative, while still realistic" set of breach parameters are chosen.
  - Sometimes by a voting process
  - Other times at the discretion of the engineer performing the analysis.
- Problem:
  - Let's say that each selected breach parameter in reality represents the **5%** exceedance probability. If we assume 4 uncertain independent parameters, the probability of all the selected values occurring for a given breach event is:
    - 0.05 * 0.05 * 0.05 * 0.05 = 0.000006 = **0.0006%!**

    or

    1/166,667

- That's on top of the overly conservative PMF, for flood-induced breach events
- No communication of risk and uncertainty. Cannot make real Risk-Informed decisions.

The Probabilistic Approach

- A Proposed Methodology
- Given the Magnitude of a Consequence
- Determine the Probability of Not Exceeding the Consequence (Conditional Non-Exceedance Probability, CNP)

The Condition = A Dam Failure

The Consequence = A Given Dam Breach Peak Outflow Rate

- Depth and Velocity at specific locations
- Structural Damage
- Indirect Loss
- Life Loss

"Given a dam failure, what discharge has a ##% probability of not being exceeded?"

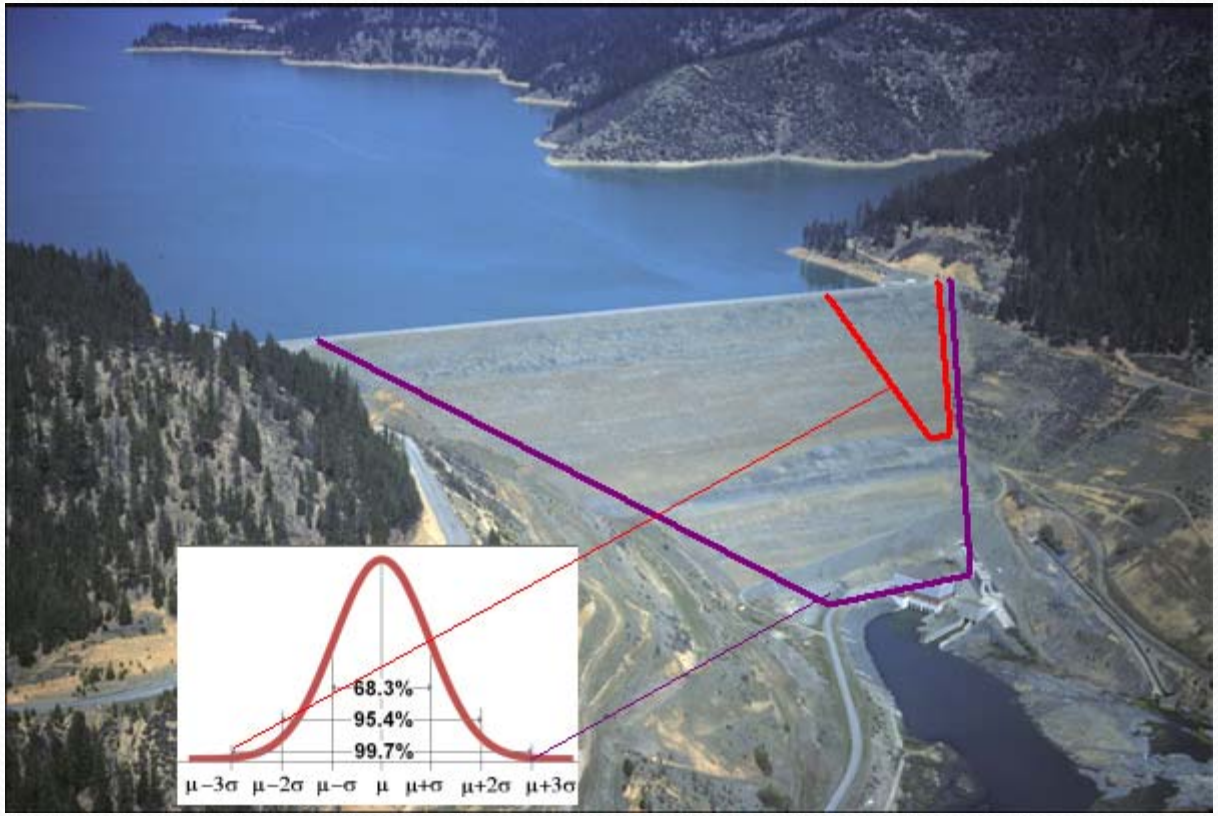
Deterministic vs. Probabilistic

- What's wrong with the Deterministic Approach? We're planning for the worst, so we'll be prepared…Right?

- Costly and Unnecessary Shutdown of Important Infrastructure.
- Costly and Unreasonable Dam Improvements.
- Unreasonable Restrictions on Downstream Zoning and Urban Planning.
- Misplaced Allocation of Resources during a Dam Breach Event.
- Public and Agency Misconception of Assumed Risk.
- Does not Support Risk Informed Decision Making.

Probabilistic Approach

Breach Width, Invert, Side Slopes

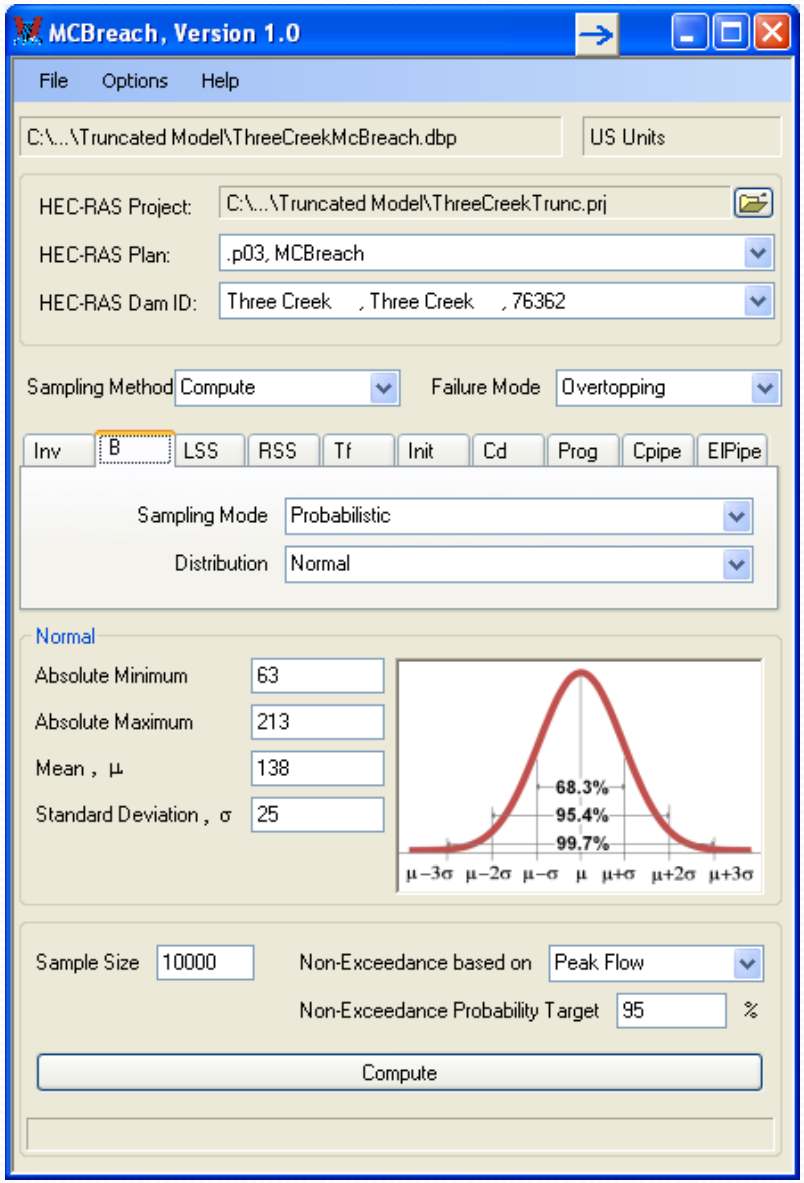


Monte Carlo Simulation

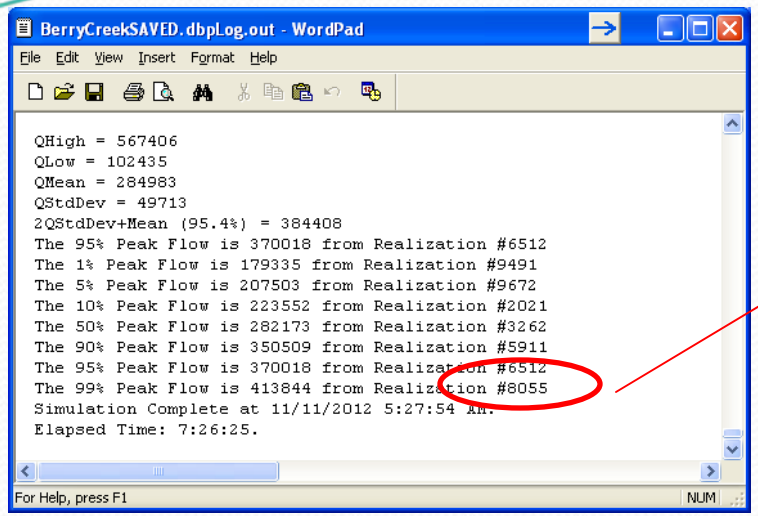
- Run 1000's of realizations of your hydraulic model using an automated process

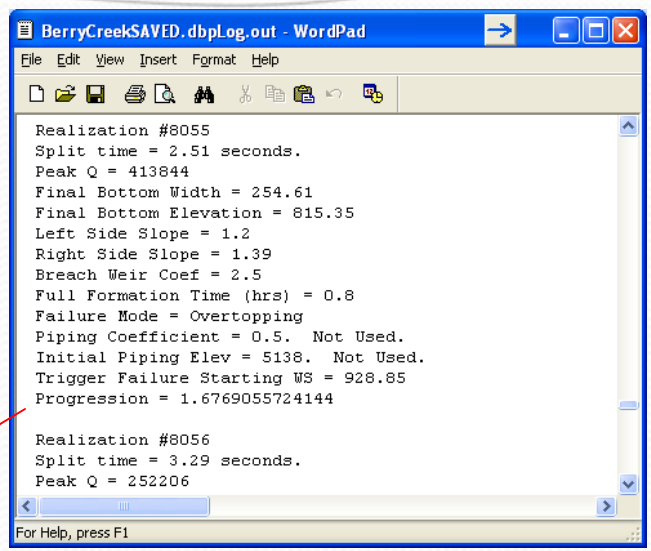
- Randomly sample input parameters about a pre-defined distribution.

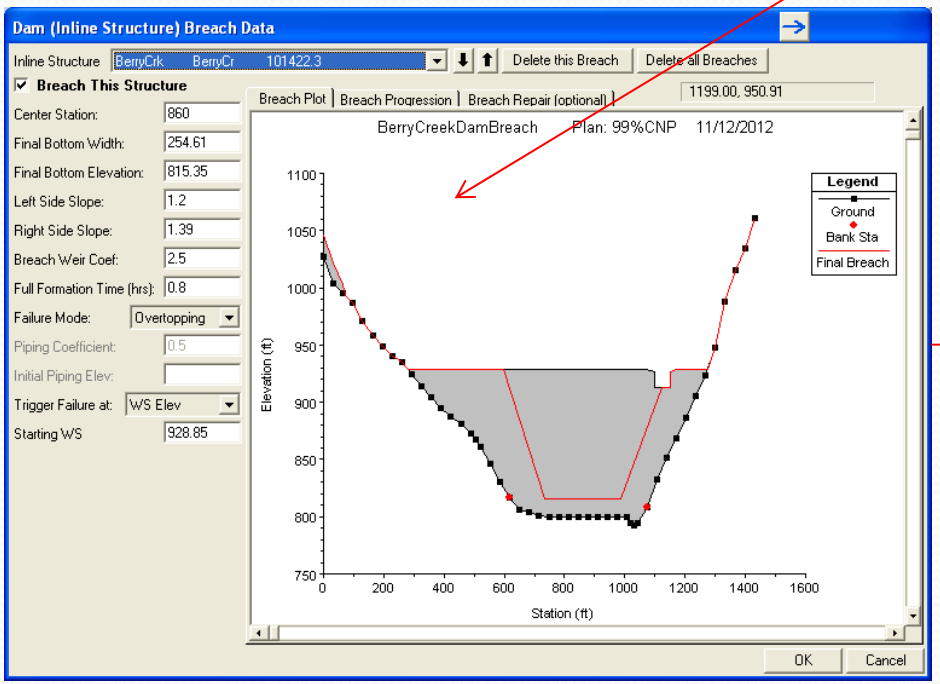
- Store and rank output results.

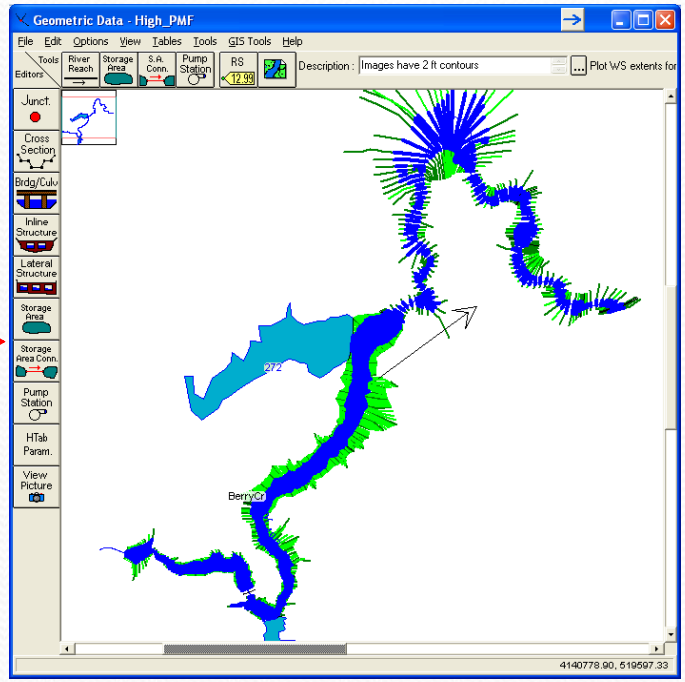


Berry Creek Dam – 99% CNP Breach

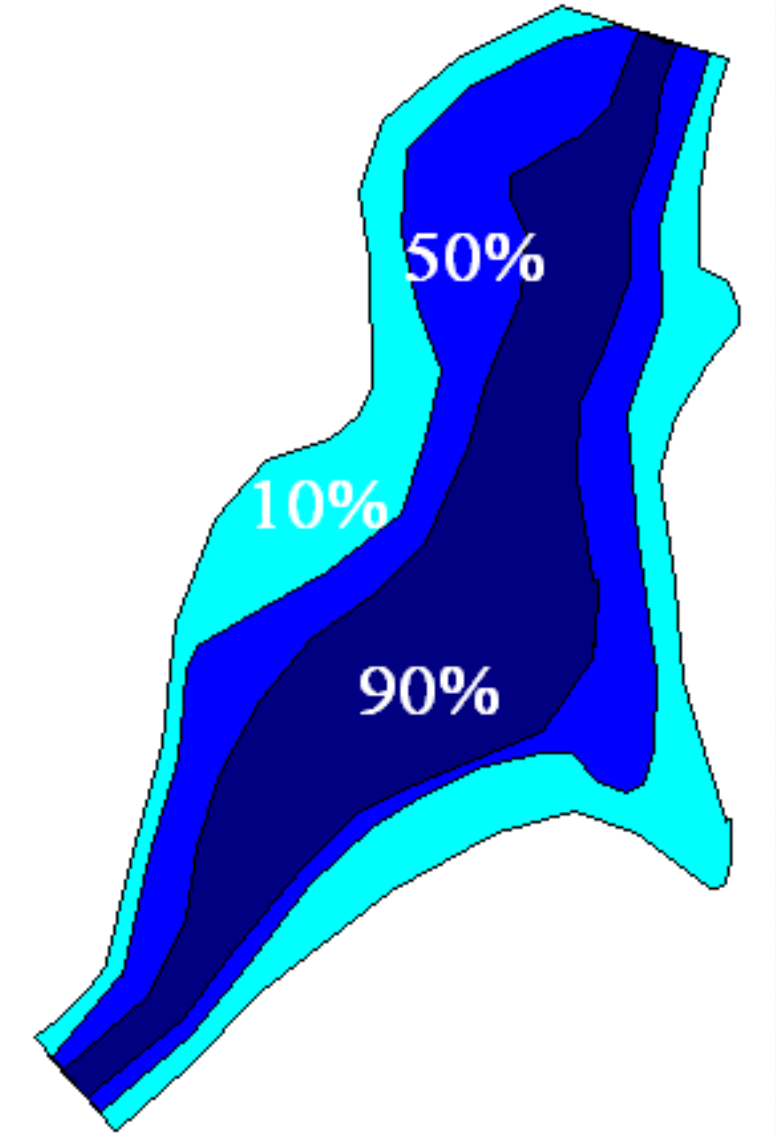




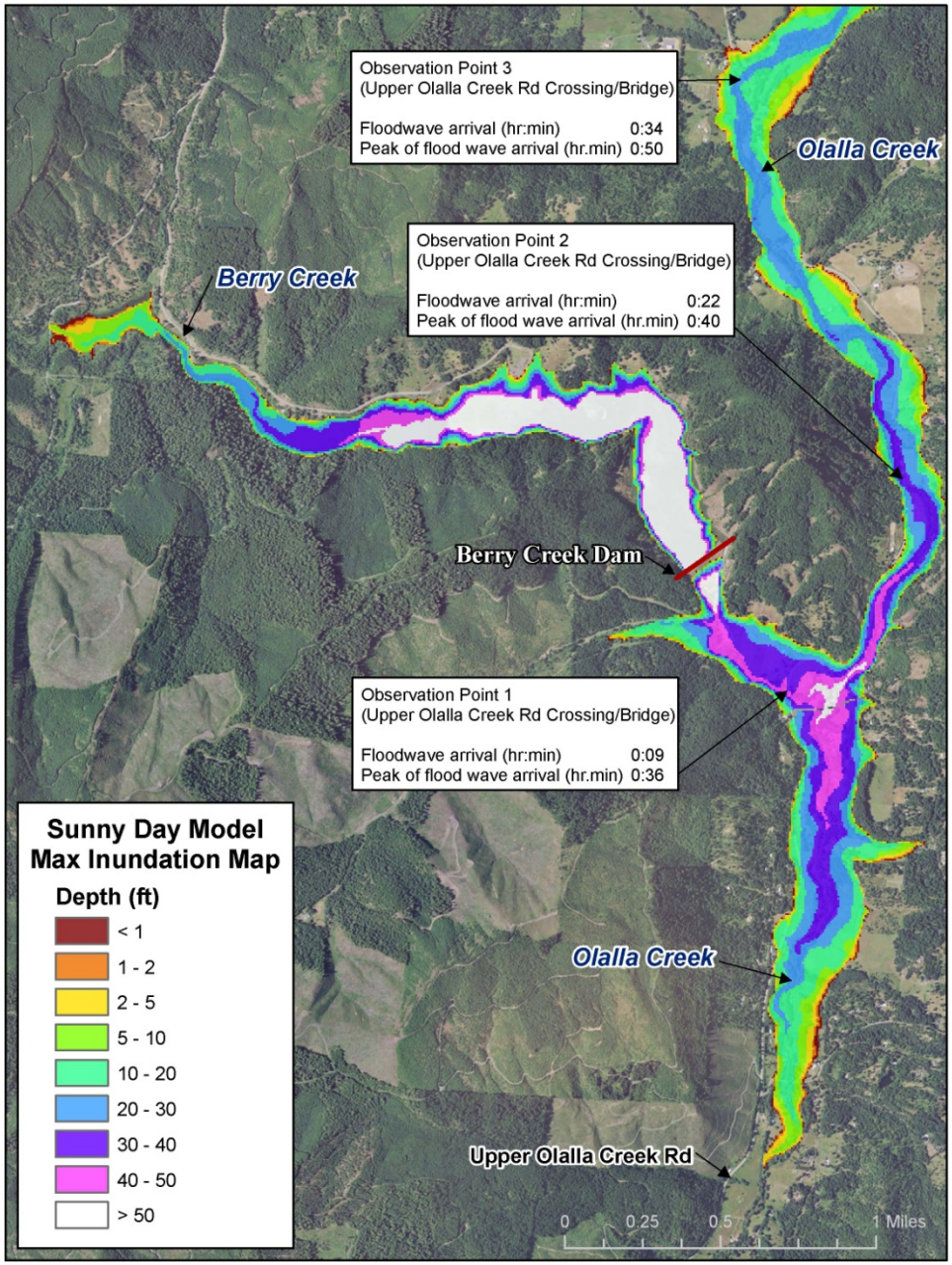


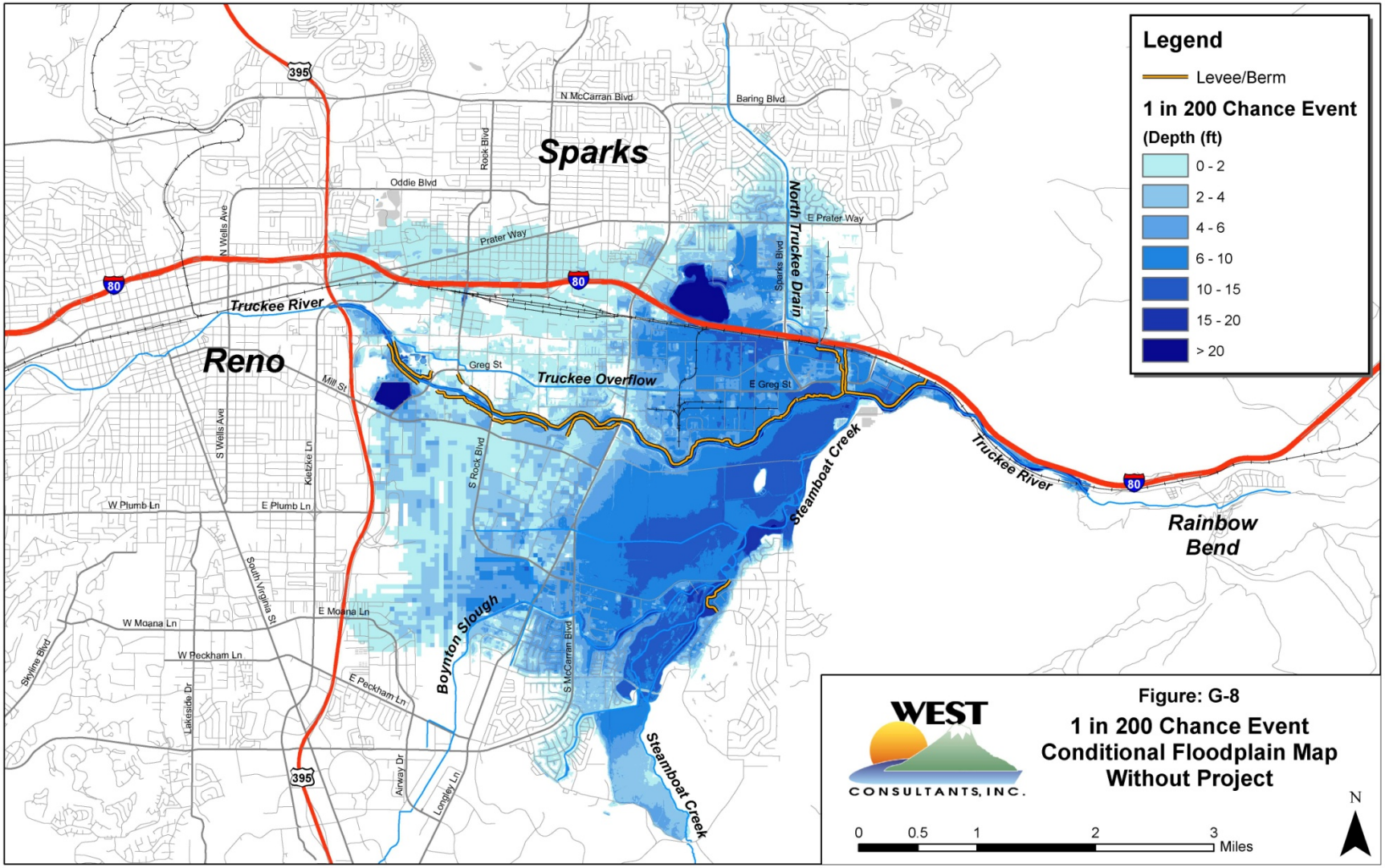


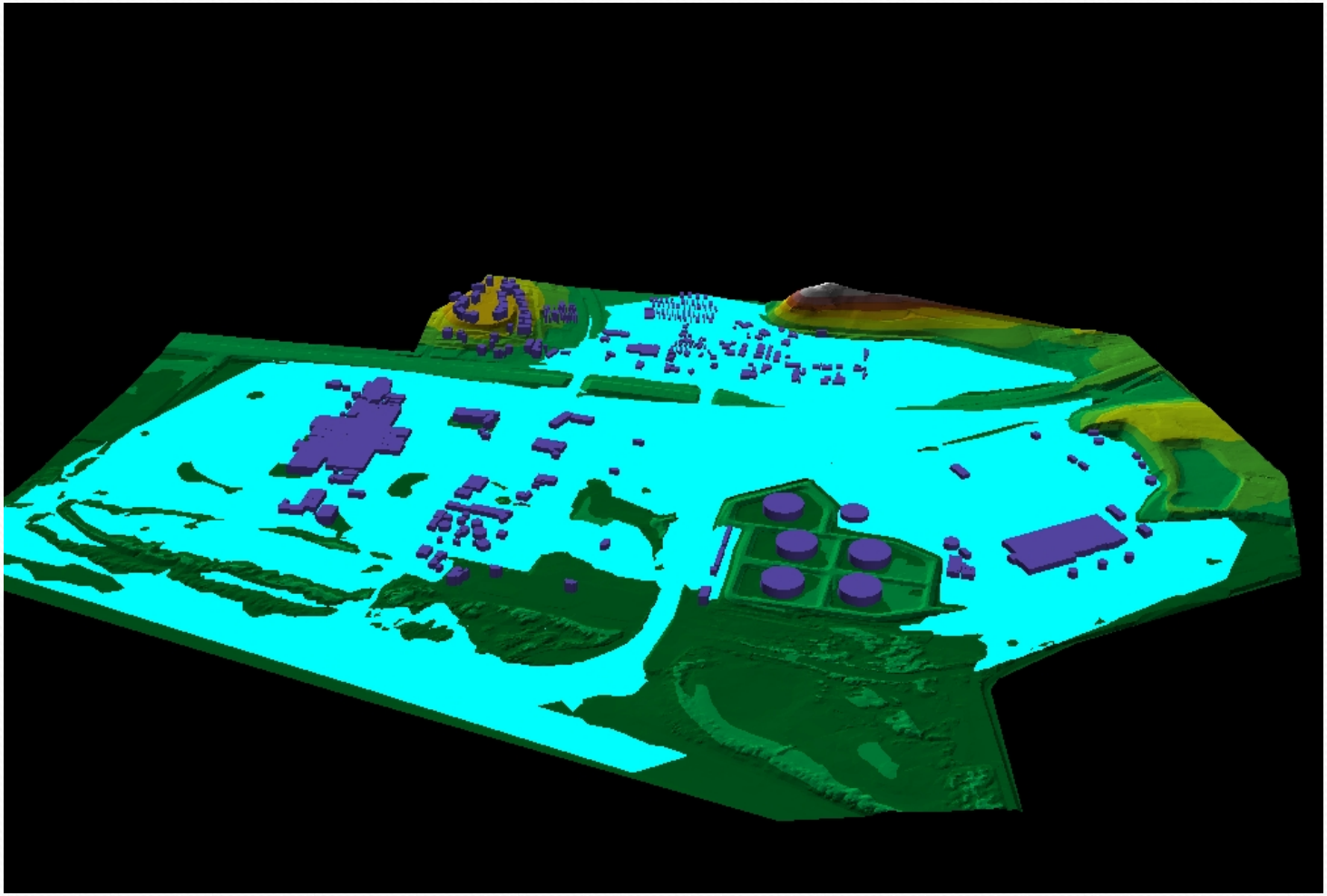
Exceedance Probability Inundation Map



And some examples…


Observation Point 3
(Upper Olalla Creek Rd Crossing/Bridge)
Floodwave arrival (hr:min) 0:34
Peak of flood wave arrival (hr.min) 0:50
Olalla Creek
Observation Point 2
(Upper Olalla Creek Rd Crossing/Bridge)
Floodwave arrival (hr:min) 0:22
Peak of flood wave arrival (hr.min) 0:40
Berry Creek
Berry Creek Dam
Observation Point 1
(Upper Olalla Creek Rd Crossing/Bridge)
Floodwave arrival (hr:min) 0:09
Peak of flood wave arrival (hr.min) 0:36
Sunny Day Model
Max Inundation Map
Depth (ft)
< 1
1 - 2
2 - 5
5 - 10
10 - 20
20 - 30
30 - 40
40 - 50
> 50
Olalla Creek
Upper Olalla Creek Rd
0
0.25
0.5
1 Miles


Legend
Levee/Berm
1 in 200 Chance Event
(Depth (ft)
0 - 2
2 - 4
4 - 6
6 - 10
10 - 15
15 - 20
> 20
Sparks
Reno
Rainbow Bend
Truckee River
Truckee Overflow
North Truckee Drain
Steamboat Creek
Boynton Slough
N McCarran Blvd
Baring Blvd
Oddie Blvd
Rock Blvd
Prater Way
E Prater Way
Sparks Blvd
N Wells Ave
Greg St
E Greg St
Mill St
S Wells Ave
Kietzke Ln
S Rock Blvd
W Plumb Ln
E Plumb Ln
South Virginia St
E Moana Ln
W Moana Ln
W Peckham Ln
E Peckham Ln
S McCarran Blvd
Skyline Blvd
Lakeside Dr
Airway Dr
Longley Ln
395
80
WEST CONSULTANTS, INC.
Figure: G-8
1 in 200 Chance Event
Conditional Floodplain Map
Without Project
0 0.5 1 2 3
Miles
N



Morro Creek, California

Courtesy of Gary Brunner, Hydrologic Engineering Center

Thank You!

Auburn Dam Cofferdam Failure of 1986, courtesy NOAA.

cgoodell@westconsultants.com