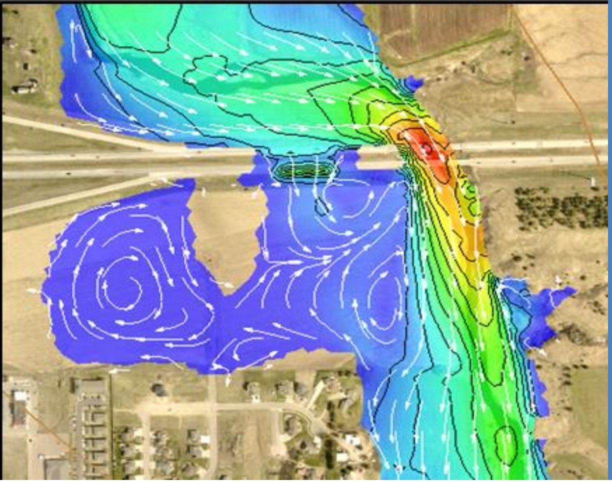


HOW TO REVIEW 2D MODELS AND WHAT TO SUBMIT IN CLIENT SUBMITTALS

Cameron Jenkins PE CFM

Bowen Collins & Associates

Senior Engineer

POLL QUESTION

DO YOU KNOW WHAT A 2D MODEL IS? (YES OR NO)

HAVE YOU EVER CREATED OR REVIEWED A 2D MODEL? (YES OR NO)

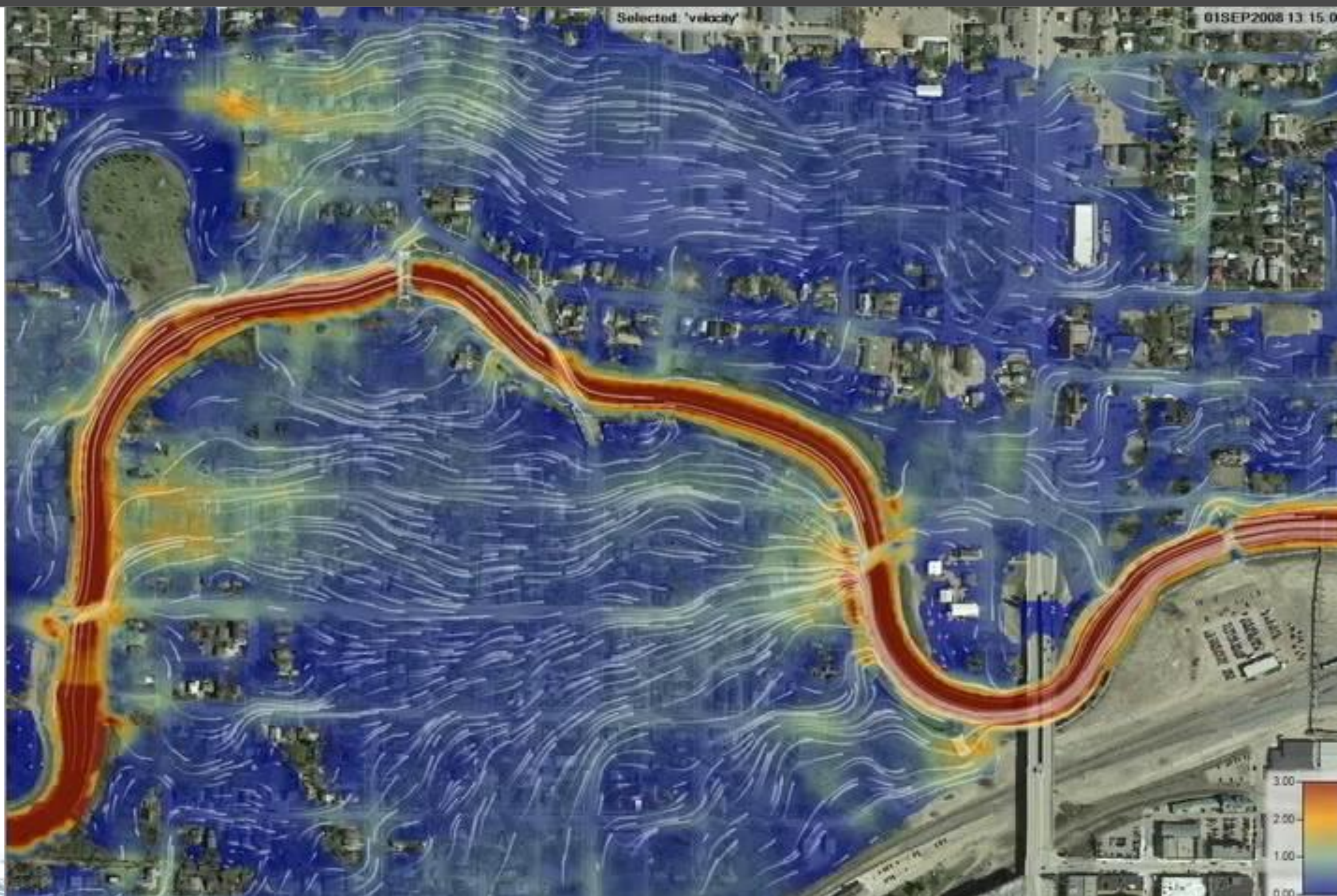
The good news about computers is that they do what you tell them to do. The bad news is that they do what you tell them to do.

-Ted Nelson

Presentation Overview

- Crash Course in 2D Modeling
- 2D Guidelines
- How to Review 2D Models
- What to Submit to Clients
- Questions

Crash Course in 2D Modeling



Modeling History Timeline

Experimentation and understanding of more complex fluid processes (turbulence, advection-diffusion, etc.)

Due to computational limitations, 1D models are applied broadly with the advent of PC.

GPU's

Cloud Computing

1900

1940

1960

1990

2017

Free-surface flow governing equations

Development of numerical models with the advent of computing

Advances in computing allow for broad use of more complex codes which better reflect governing equations (i.e., 1D/2D, 2D, 3D)

Future of Modeling
"Video Games for Adults"

Retail Price

Video Card $1,500

Game Rig $30,000

RTX 3090 GAMING X TRIO 24G PCI Express 4.0 Video Card

Condition: New | Ticker: NVDA-MSGR3DB | 100% Authentic

Last Sale -- 0 (0%)
View All Sales

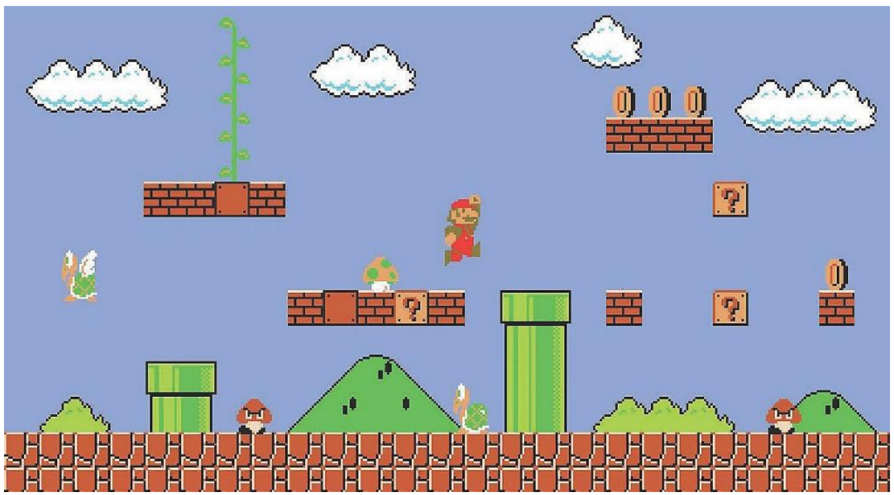
$9,999 Lowest Ask | Buy or Bid
View All Asks

$2,100 Highest Bid | Sell or Ask
View All Bids

What do you do for work? I play video games

Video Games for Adults

1D Modeling



2D Modeling

Video Games for Adults

3D Modeling

Is that Hunter our “Cruise Director” taking a swim!!

Different Types of Equations

- Physical Modeling
- 3-D Navier Stokes Equations
- 2-D Saint Venant Equations
  - Approximation of NSE using depth-averaging
- 1-D Saint Venant Equation
  - Approximation of 2-D SVE using width-averaging
- Backwater curves (i.e., steady flow)
  - Approximation of 1-D SVE by ignoring time terms
- Uniform flow (i.e., Manning's equation)
- All models are simplifications of complex processes!! No model can represent all processes accurately.

Conservation of Mass

$$\frac{\partial H}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = \text{Sources - Sinks}$$

- $\frac{\partial H}{\partial t}$ is the rate of increase (or decrease) in water level, which for a fixed cell size is representative of the rate of change of volume of water contained in the cell

- $\frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y}$ is the spatial variation in inflow (or outflow) across the cell in the x and y directions

- **Sources** = Rainfall, Stormwater Outlets, or Pump Outlets
- **Sinks** = Pump Intakes, Infiltration, or Evaporation

Conservation of Momentum

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial H}{\partial x} + \mu_t\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - c_f u + f_v$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial H}{\partial y} + \mu_t\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - c_f v - f_u$$

Where:

$$\underbrace{\frac{\partial u}{\partial t}}_{\text{Local Acceleration}} + \underbrace{u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}}_{\text{Advective Acceleration}} = flow\ acceleration$$

$$g\frac{\partial H}{\partial x} = hydrostatic\ pressure\ gradient$$

$$\mu_t\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) = turbulent\ (eddy)\ viscosity$$

$c_f u$ = *bed friction*

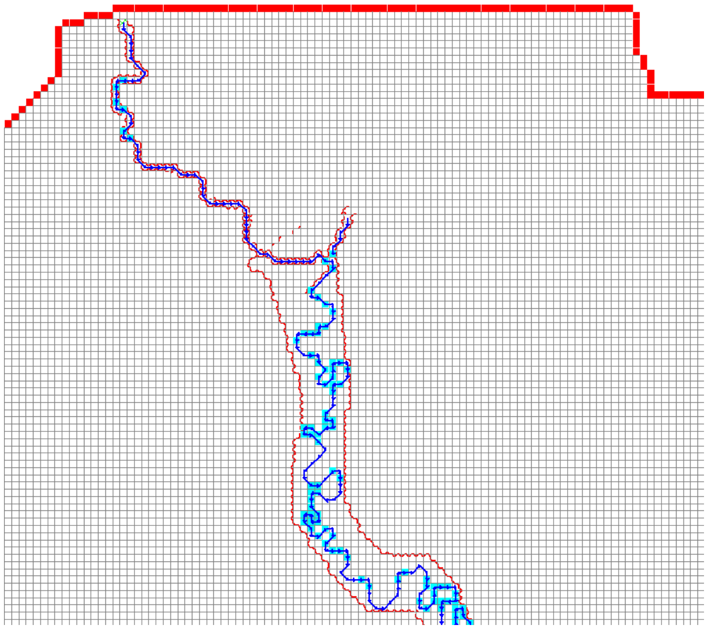
f_v = *Coriolis acceleration*

Different Types of Modeling

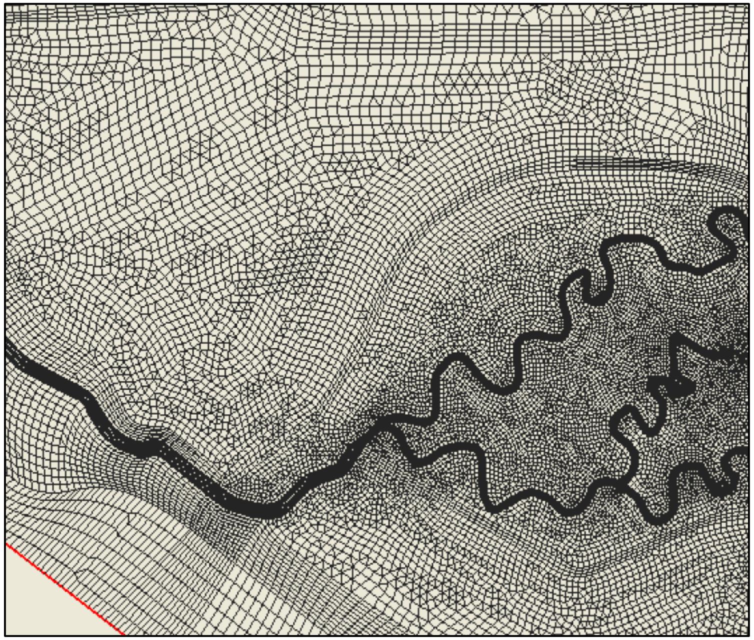
Steady flow 1-D	Seconds
Unsteady flow 1-D	Minutes
Sediment transport 1-D (event)	Minutes
Sediment transport 1-D (long-term)	Hours
Steady flow 2-D	Minutes/hours
Unsteady flow 2-D	Hours/days
Sediment transport 2-D	Hours/days
Unsteady flow 3-D	Days/weeks

* 2D model costs can be similar to 1D depending on complexity

Types or Meshes



Finite Difference (Grid)



Finite Element/Volume (Triangles/ Other Shapes)

Model	Discrectization (FD, FE, FV)	Numerical Solution Scheme	Notes	Proprietary
AdH	**FV**	**Various**	**Adaptive Mesh**	**No**
FLO-2D	**FD**	**Explicit**	**Hydrology**	**Yes**
HEC-RAS	**FV**	**Semi-Implicit**	**Captures cell-face topography**	**No**
Mike Flood	**FV and FD**	**Implicit**	**GPU Solver**	**Yes**
RiverFlow2D	**FE and FV**	**Explicit**	**GPU Solver**	**Yes**
SRH-2D	**FV**	**Implicit**	**Sediment Transport**	**No**
XPSWMM/ TUFLOW	**FV and FD**	**Implicit**	**Hydrology for the FD GPU Solver**	**Yes**

Advantages/Disadvantages

2D Better Results

- Behind levee systems
- Bays and estuaries
- Braided streams
- Alluvial fans
- Abrupt bends
- Wide floodplains
- Applications where velocities are important (bridges)

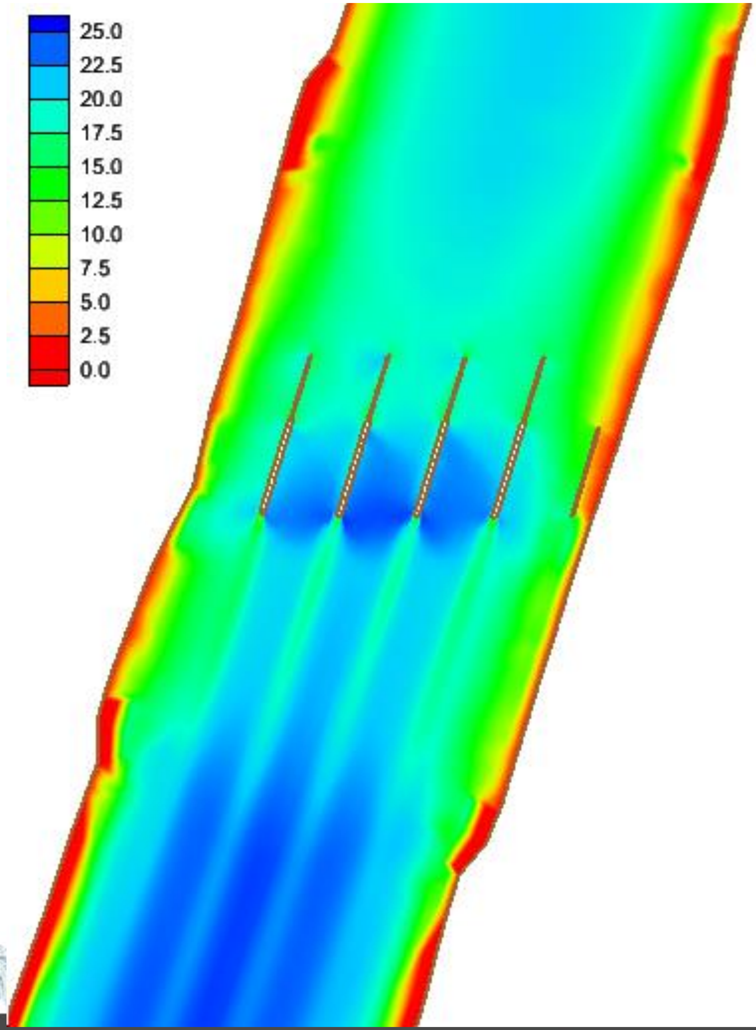
1D Better Results

- Rivers which dominant flow in one direction
- Steep stream highly gravity driven
- Large models (over 100 miles)
- No detailed data

Accuracy

1-D = Less Accurate
2-D = More Accurate

- Accuracy is a product of sound engineering judgment and proper application of any model
- Complexity does not equal the best answer for your project



Examples

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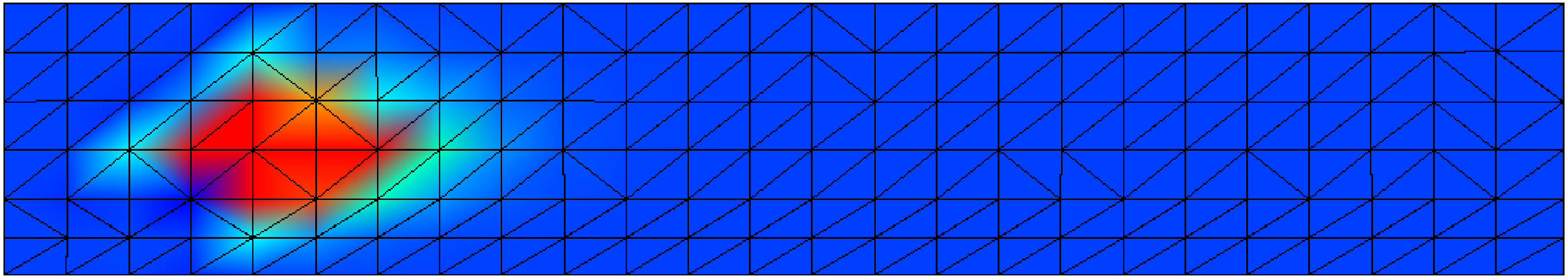
Scatter Module FLOW DEPTH
3.7
3.3
2.9
2.5
2.1
1.7
1.3
0.9
0.5
0.1



POLL QUESTION

WHAT REPRESENTS BED FRICTION

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial H}{\partial x} + \mu_t\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - c_f u + f_v$$

A

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}$$

B

$$g\frac{\partial H}{\partial x}$$

C

$$\mu_t\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right)$$

D

$$c_f u$$

2D GUIDELINES

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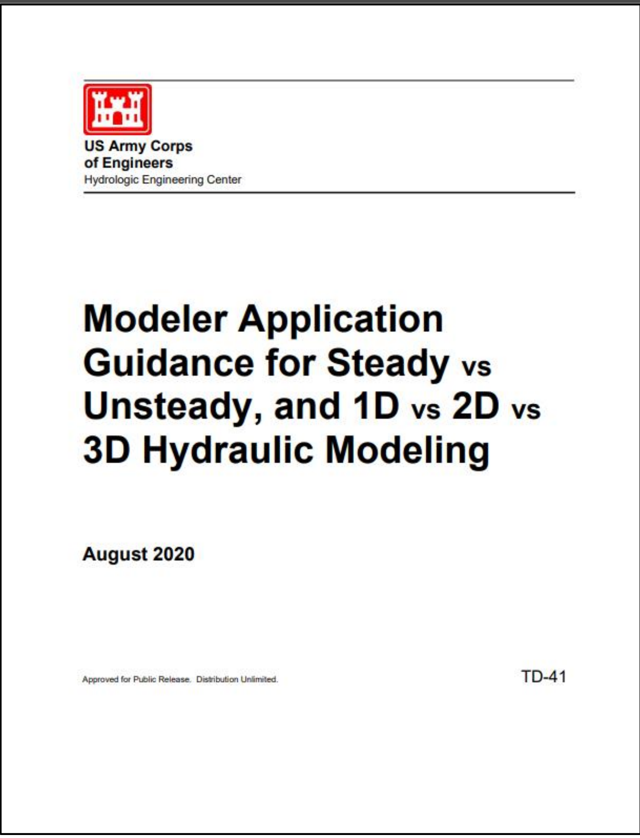
2D Guidelines Document

- Discussion of 2D Models
- Data Requirements
- 2D Modeling References
- Modeling and Mapping
- Model Review
- What to Submit for Review
- What to Submit to FEMA

Email me if you want a copy

Appendix includes references and checklists

Popular Guidance Documents



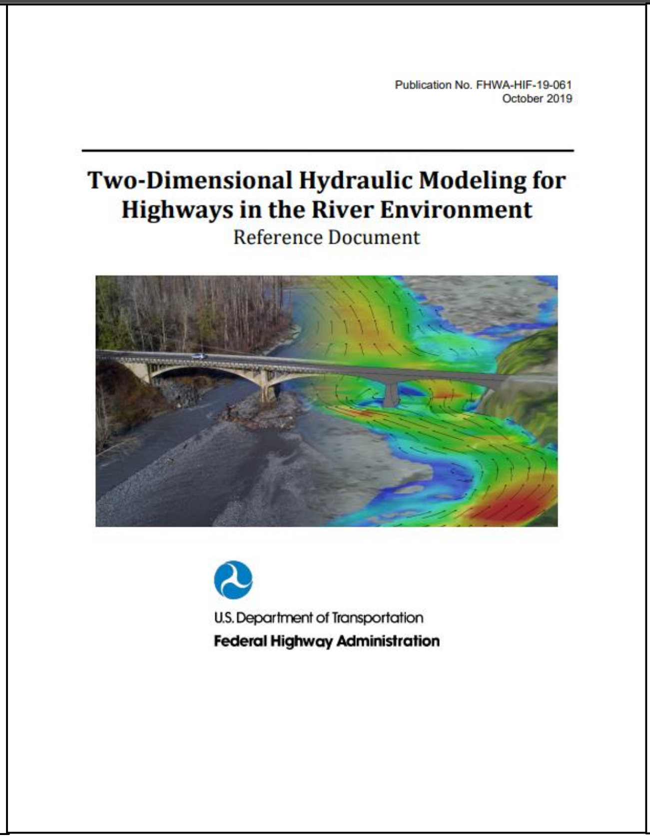
US Army Corps of Engineers
Hydrologic Engineering Center

Modeler Application Guidance for Steady vs Unsteady, and 1D vs 2D vs 3D Hydraulic Modeling

August 2020

Approved for Public Release. Distribution Unlimited.

TD-41



Publication No. FHWA-HIF-19-061
October 2019

Two-Dimensional Hydraulic Modeling for Highways in the River Environment

Reference Document

U.S. Department of Transportation
Federal Highway Administration

Australian Rainfall & Runoff

Revision Projects

PROJECT 15

Two Dimensional Modelling in Urban and Rural floodplains

STAGE 1&2 REPORT

P15/S1/009

NOVEMBER 2012

ENGINEERS AUSTRALIA
Water Engineering

2D MODELING 5-STEP REVIEW PROCESS

1 PREPARE FOR REVIEW

- Arrange meeting with project manager and lead modeler
- Define overall purpose
- Who is the project for
- What should be reviewed
- Review schedule
- QA/QC documentation requirements
- Obtain software (if needed)

2 OBTAIN DATA

- Report or summary
- Model files
- Hydrology
- Terrain data
- Imagery
- Landuse
- Structure data
- Calibration
- Other

3 INPUT REVIEW

- Boundary conditions
- Terrain
- Geometry
- Roughness
- Model control inputs
- Structures and storm drains
- 1D channels
- Infiltration
- Levees and walls

4 OUTPUT

- Numerical health
- Structures and storm drains
- Infiltration
- Levees and walls
- 1D Channels
- Depths and velocities
- Calibration
- Plots/maps

5 QA/QC DOCUMENTATION

- Ready for review
- Independent review
- Address comments
- Make changes
- Verification/backcheck

1. PREPARE FOR REVIEW

The "Getting up to Speed Phase" you need to gain an understanding of:

•Understand the Purpose of the Analysis

•Who is the Ana

•What is the lev h the purpose and Audience?

•Do you have th

•Am I a Disintere viewer?

•What elements

•Is the time allo

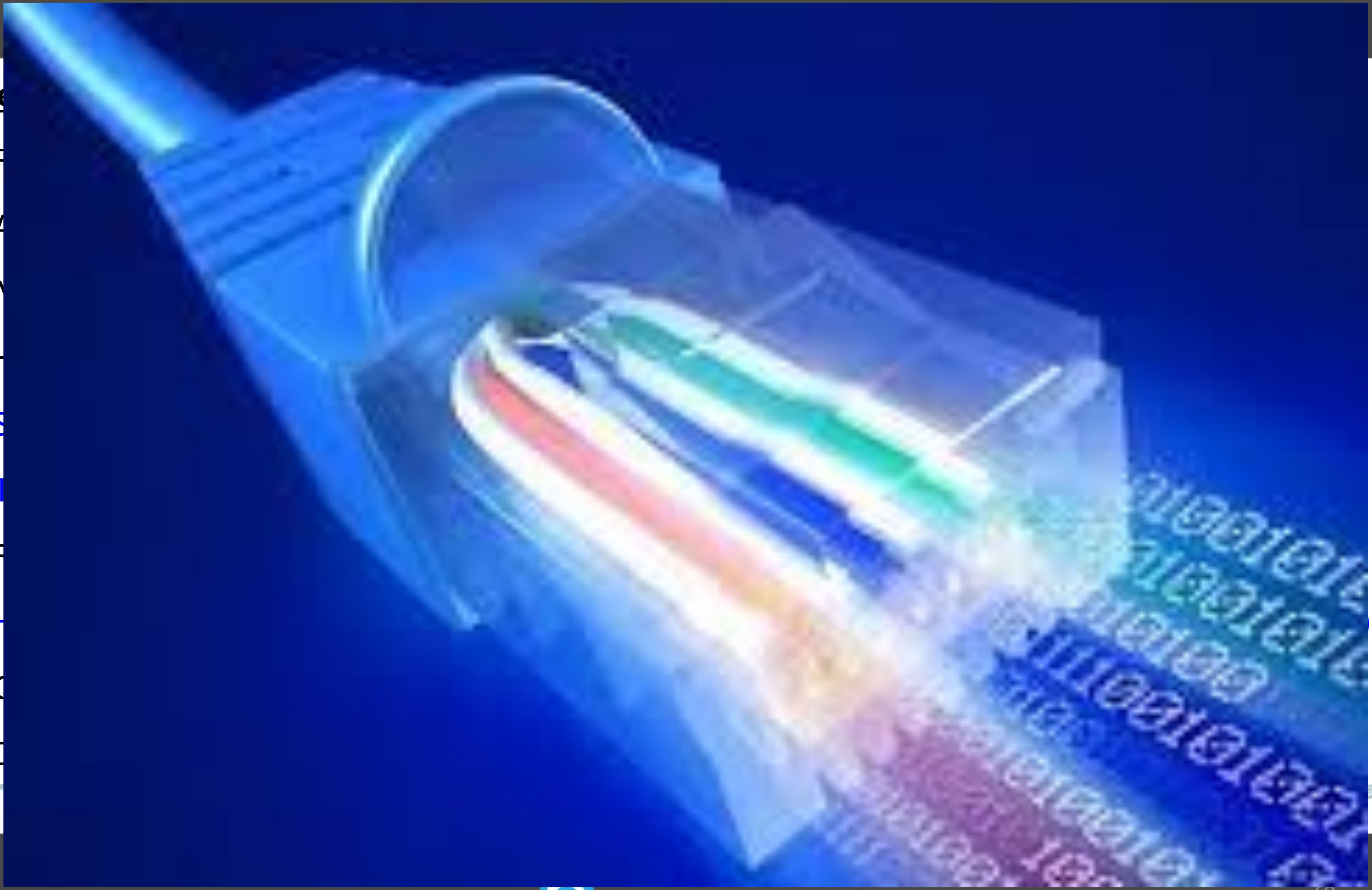
•What is the inte

•DATA: What for

•What level of C eam with this in advance)

•Do I have Adequate Software to review (version number, known bugs or issues, etc…)

2. OBTAINING DATA



Ite

- •F
- •A
- •N
- •H
- •S
- •T
- •F
- •H
- •C
- •D

2. OBTAINING DATA

Structures, Levees, and other Significant Model Elements:

- Engineering Drawings, or As-Builts (Hardcopy or Digital)
- Survey Data
- GIS or Database of Elements (Inlets, Outlets, Sizes and Inverts, etc…)
- Maintenance Records (Debris?)

Digital Image and Photo Files:

- Images: Geo-Referenced?
- Photos: Geo Located – Is there a drawing that shows where all photos were taken and what direction they were taken

2. OBTAINING DATA

Terrains: Information About the Data:

- Vertical Datum and Horizontal Projection for each data provided
- Accuracy of the data for each
- When/how was the data obtained
- Conditions at the time the data was obtained (water in channel)
- Metadata

Terrain Data – Basis of the Surface:

- RAW Data (direct survey data, LiDAR data point files)
- Final Terrain Basis
    - Description of the process used to develop this
        - Combination of sources,
        - What data was excluded and why?
    - Locations where adjustments were made

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2. OBTAINING DATA

Sources of Runoff Data:

- Previously reviewed and Approved/Accepted Study and/or Model
- Locally accepted method or model
- Stream gage data?
- Stated Values? (assumed)

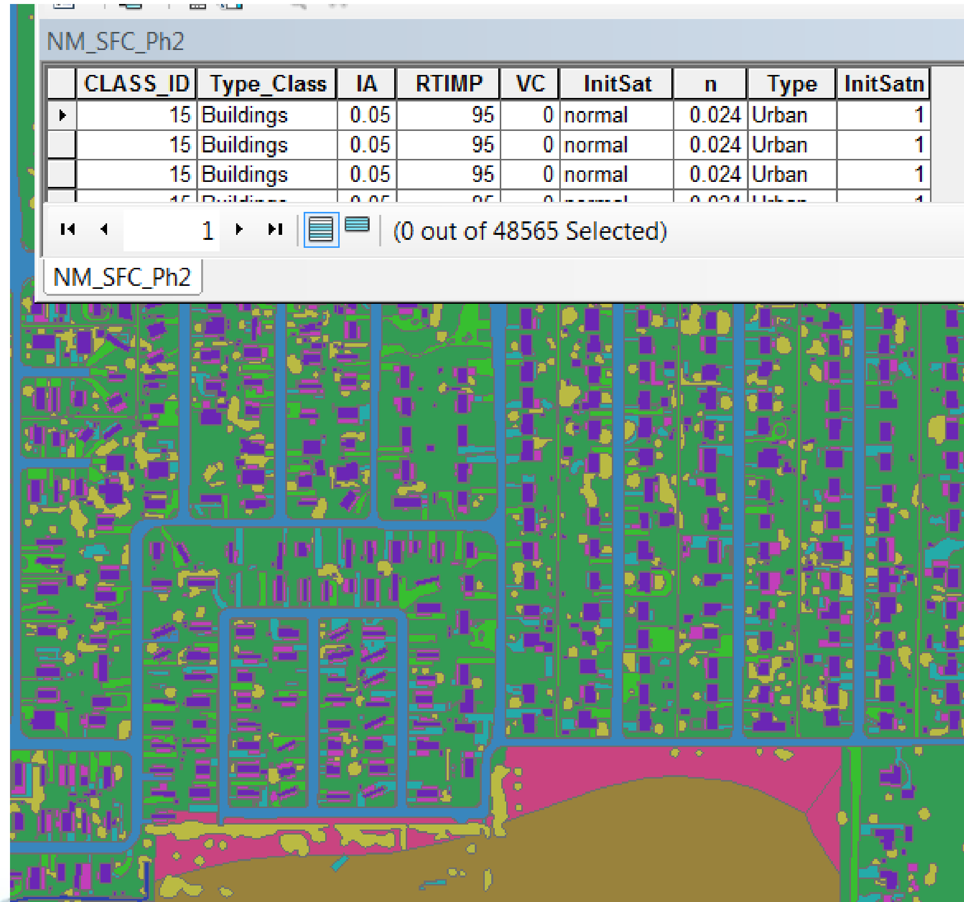
Hydrology – Reality Check other Resources:

- Compare to FEMA FIS published rates?
- Compare to USGS regression equations
- Compare to NOAA Atlas
- Compare to historical known events or locally recorded information

2. OBTAINING DATA

Hydrology Data Sets:

- Soils Data
- Land cover, land use, vegetation type
- Infiltration potential
- Rainfall: Elevation varied, spatially varied



CLASS_ID	Type_Class	IA	RTIMP	VC	InitSat	n	Type	InitSatn
15	Buildings	0.05	95	0	normal	0.024	Urban	1
15	Buildings	0.05	95	0	normal	0.024	Urban	1
15	Buildings	0.05	95	0	normal	0.024	Urban	1

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3. INPUT REVIEW

Boundary Conditions Verification:

- Bo
- Infl
- Is t
- Init
- Are

3. INPUT REVIEW

Terrain Review:

•Verify Horizontal Projection of all data sets

•Verify Vertical Datum of all data sets

•Verify accuracy of terrain

•Verify High/Low ground grade breaks were included

•Verify inverts of channels are ground not water or obstructed/interpolated

•Verify Seams of combined data do not include vertical changes

•Check final Terrain, vs. Raw data.

•Verify intended Terrain Modifications were incorporated into final model.

3. INPUT REVIEW

Model Geometry Decision Review:

- Does the model Geometry represent the Terrain well?
  - Are **elements** of appropriate size, shape & alignment to adequately describe the **terrain** and **water slope surface**? Is timing appropriate, and combined appropriately
  - Does the Geometry account for features like levees and embankments?
  - Does the Geometry account for flow restrictions such as walls or structures (if not accounted for by other means such as roughness)?
  - If variable element sizes are used, does the transition from small to large cells occur gradually?
- Was a sensitivity analysis for Element size performed?
  - Does making the element sizes smaller produce significantly different results?

3. INPUT REVIEW

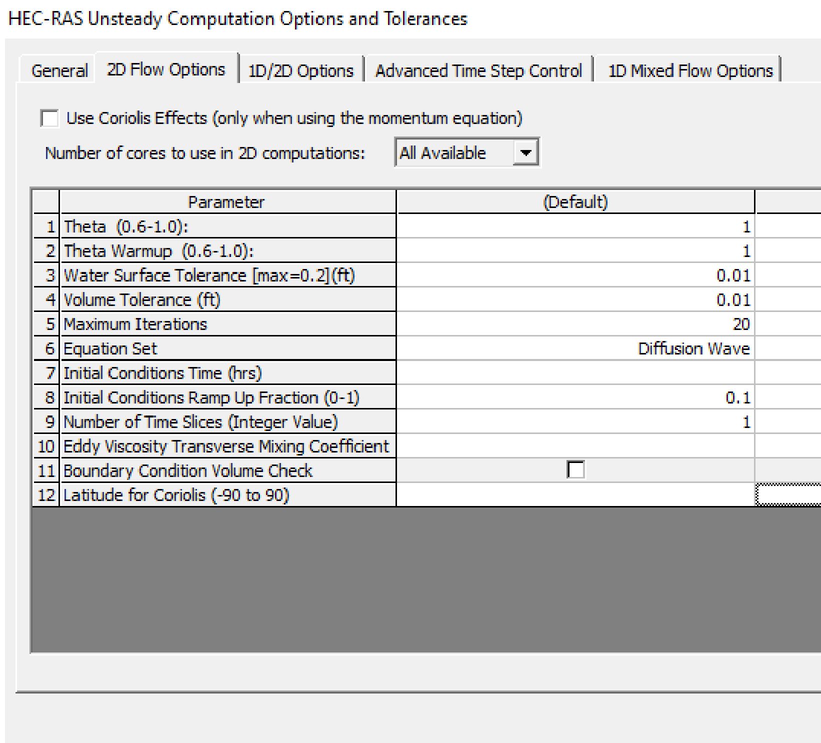
Roughness Review:

- Details of how roughness is accounted for in the model
- References available: agency guidelines, other standard references
- Are values reasonable for the “purpose”, and within the range of published values
- If roughness is variable, check to see how model is adjusting those values during the run.
- Does roughness account for impediments (not accounted for in terrain)?

3. INPUT REVIEW

Model Control Variable Inputs Review:

- Different for each model environment, verify if appropriate values were used
  - Time Steps (if applicable)
  - Simulation duration cover the entire event
  - Output Interval
  - Depth for water movement (if rain on grid, should be smaller)
  - Vertical Tolerances, Flow rate Tolerances
  - Courant, etc (per software recommendations)
- Was sensitivity analysis performed for the Control Variables, and are inputs consistent with those findings?



	Parameter	(Default)
1	Theta (0.6-1.0):	1
2	Theta Warmup (0.6-1.0):	1
3	Water Surface Tolerance [max=0.2](ft)	0.01
4	Volume Tolerance (ft)	0.01
5	Maximum Iterations	20
6	Equation Set	Diffusion Wave
7	Initial Conditions Time (hrs)	
8	Initial Conditions Ramp Up Fraction (0-1)	0.1
9	Number of Time Slices (Integer Value)	1
10	Eddy Viscosity Transverse Mixing Coefficient	
11	Boundary Condition Volume Check	☐
12	Latitude for Coriolis (-90 to 90)	

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3. INPUT REVIEW

<u>Structures, Special Facilities and other embedded 1D Elements Input Review:</u>

- Compare input values to data source (as-builts, GIS)
  - Inverts, Slope, Rims, Size
  - Location is correct spatially
  - Modification data was included
- 1D Channels
  - Cross Section Spacing is appropriate
  - Roughness, reach lengths
  - Trimmed and linked to 2D correctly

- Check that all structures were included, and no undocumented structures were added.

3. INPUT REVIEW

Infiltration:

- Verified if allowed for project "purpose" and per Agency requirements
- Review if method used, is being applied appropriately
- Verify inputs match the source data

Levees and Walls:

- Review Agency guidelines and requirements
- Verify locations are appropriate
  - Verify continuity, ending and starting points
  - Verify top elevations against source data

4. OUTPUT REVIEW

“M
d
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e

4. OUTPUT REVIEW

WHAT CAN BE/NEEDS TO BE REVIEWED IS VERY DEPENDANT ON WHICH SOFTWARE IS BEING USED:

It is important in ALL CASES to review:

- Primary Variable Results
  - Water Surface
  - Velocity (x and y)
- Secondary Variable Results
  - Depth
  - Flow
  - Depth-Velocity Relationships
  - Fr – Froude Number

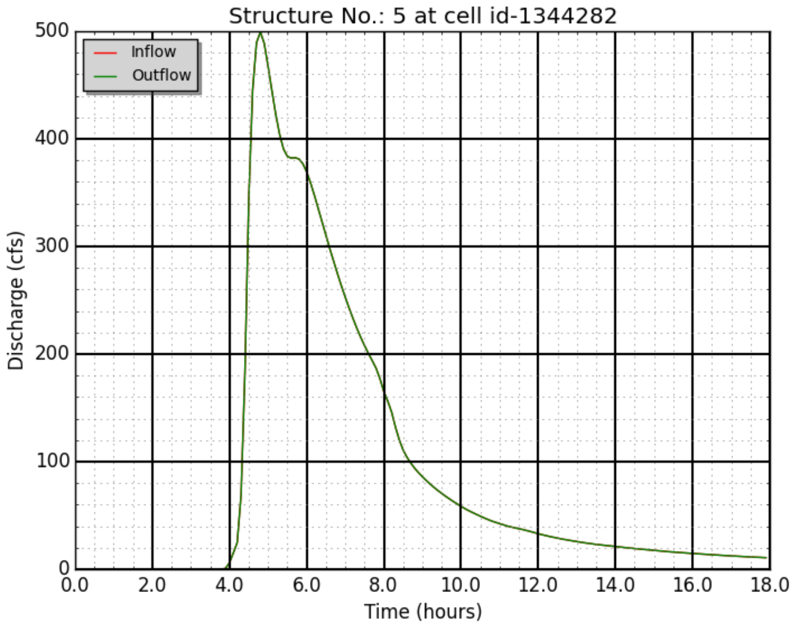
Tertiary Variable Results:

- Output relating to the numerical health of the model (Cumulative and Incremental)
  - Mass/Volume Conservation
  - Time step variation or incrementing
  - Warnings/Errors noted

4. OUTPUT REVIEW

NUMERICAL HEALTH:

- **Mass/Volume Balance Errors:**
    - (< 1% industry standard**)**
- High velocities
- Perched water surface elevations
- Oscillations
- Time Step Variations
    - May be a particular area of the model is causing this
- Fr – Froude Number
- Control variables approaching or exceeding range limits



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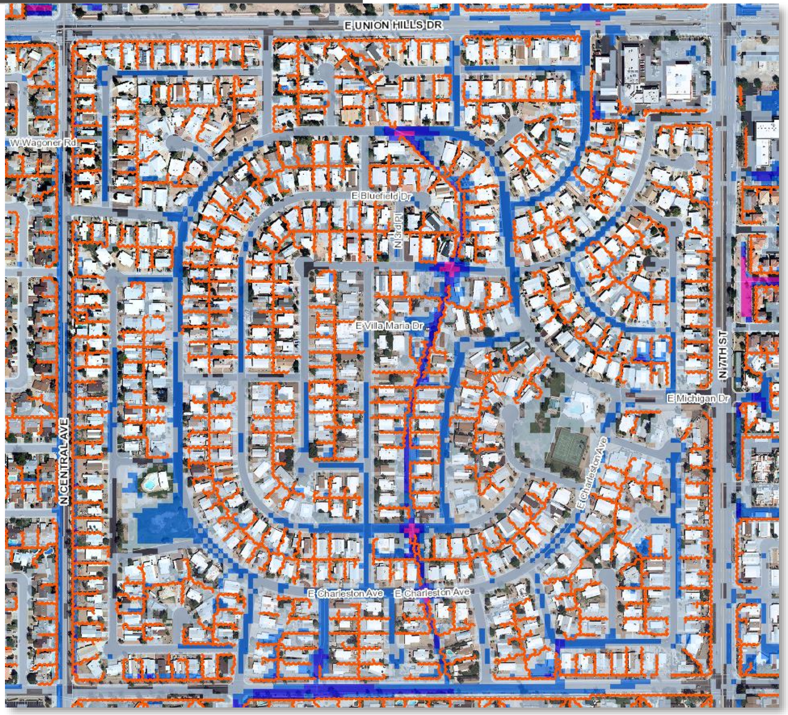
4. OUTPUT REVIEW

SPECIAL FEATURES:

- 1D Elements Pipes, Ditches, etc…:
    - Do they carry any water? – Review hydrograph
    - Are there oscillations?
    - Depths and Velocities realistic?
    - Do results make sense (hand calc)
- Levees and Walls
    - Do they leak?
    - Does water surface near them rise or fall suddenly?
    - If overtopped, does overflow make sense for the available head and overtopping length?
    - Are they safe for the head differential being modeled?




Impacts of walls

4. OUTPUT REVIEW

2D Areas:

- Flooding Extents:
  - Does it make sense? High areas wet? Low areas dry?
  - Unexplained sudden rise or lowering of water surface?
- Depths and Velocities:
  - Are Velocities Reasonable?
    - Anything >12fps should be examined
  - Are Velocity directions reasonable?

TOTAL MODEL:

- DOCUMENTATION, PLOTS and EXHBIITS:
  - Do they match the final model results

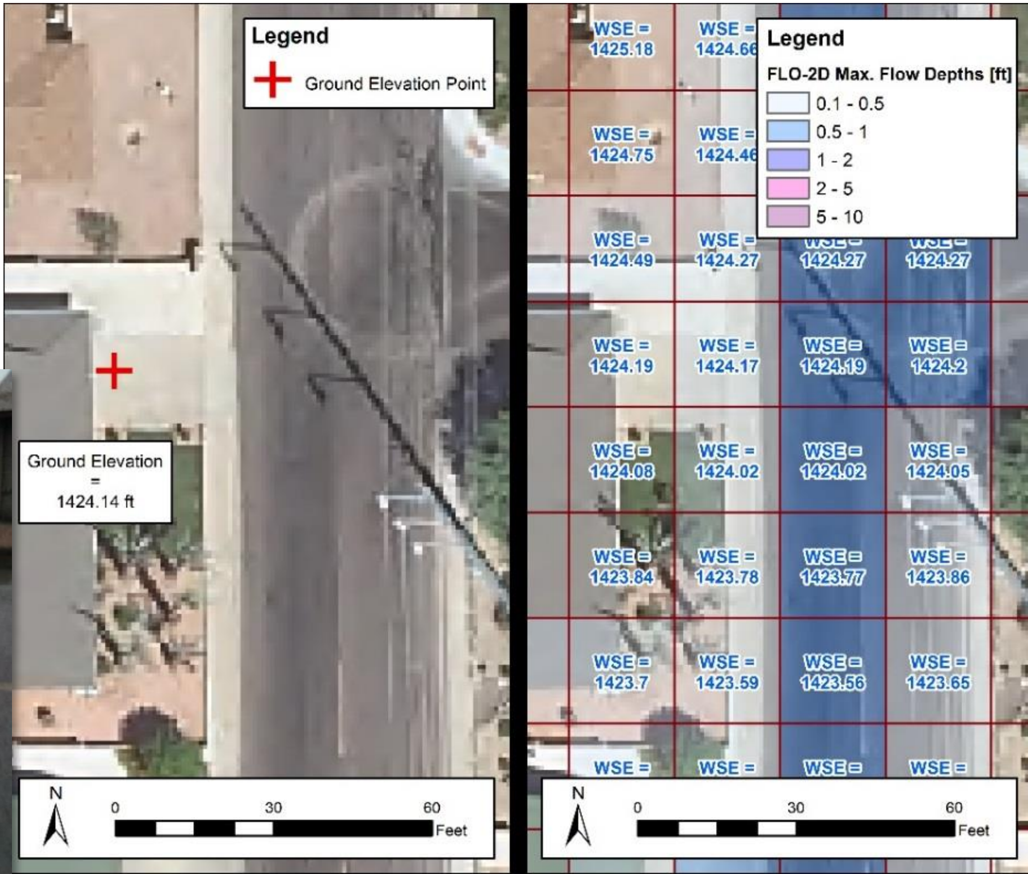
RE-EXECUTE THE MODEL:

- Do your results match the results provided?

4. OUTPUT REVIEW

- Calibration:
  - Verify results against the data
  - Do you agree that the results verify the model for the calibration event?

- August 2014 Storm




Before


After

5. QA/QC DOCUMENTATION OF THE REVIEW

WHO?

- Document who p

Use a SYSTEM of :

- As each step of t ed so that each subsequent reviewer does not element:
    - Reviewers c n red things they found in error
    - Comments irned
    - Provide a m s in an orderly way:
        - How al in future" and provide them sc
    - Provide a m sponses

5. QA/QC DOCUMENTATION OF THE REVIEW

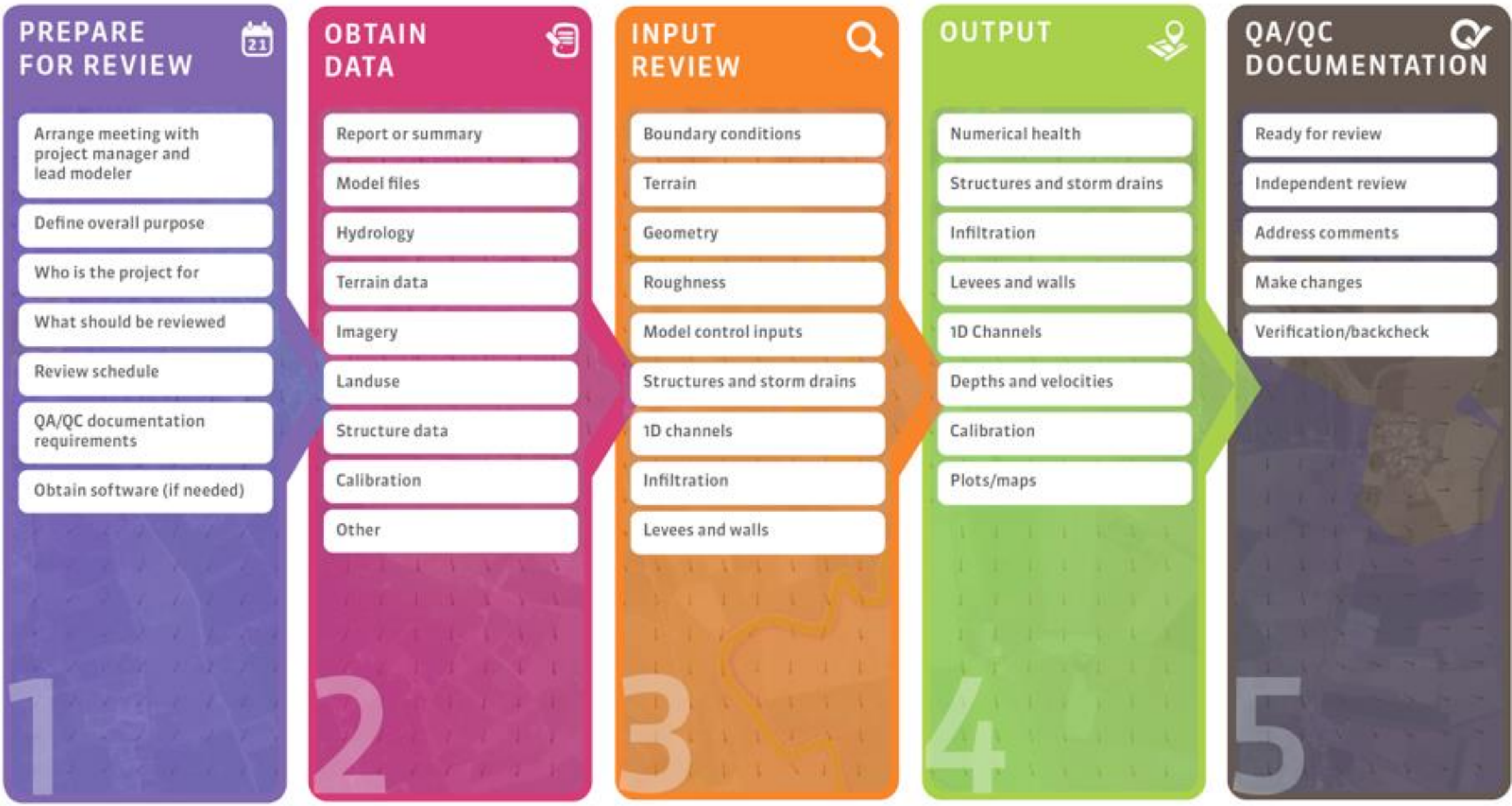
QA/QC - FLO-2D Review Checklist

Project Title:							
Project No.:		**Project Task:**		**Date Submitted for Review:**		**Date of Review:**	
Preparer Name:				**Reviewer Name:**			
Preparer Company:				**Reviewer Company:**			

Item No.	Hydraulic Model Review Item	Comments	Status	Response to Comments
	1. Data Requirements			
1.1	FLO-2D model version documented?			
1.2	Vertical and horizontal datum of project provided?			
1.3	Topographic information provided (vertical and horizontal datum, what kind)? If multiple data sets are used, are the extents for each one known?			
1.4	Soil data information used documented and provided?			
1.5	Land use information documented and provided?			
1.6	Documentation on techniques and procedures provided?			
	2. SUMMARY.OUT			
2.1	Check total rainfall volume.			
2.2	Check total inflow volume.			
2.3	Check percent infiltration. In general, should be 20-40% for heavily urbanized, 25-50% for urbanized, and 40-70% for natural of total rainfall.			
2.4	Verify that volume conservation errors are minimal.			
2.5	Verify that the file was written to completion.			
	3. CONT.DAT			
3.1	Check the limiting Froude number setting (typically 0.9-0.95 unless in steep areas).			
3.2	Check that the Shallow n value is reasonable (typically 0.1-0.2, but it may be turned off for some project			
3.3	Verify that model run time is adequate (i.e., all TIMETOPEAK.OUT values < run time).			
3.4	Check to see if IBACKUP switch is turned off to increase model speed.			
3.5	Check that all required component switches are turned on.			
	4. TOLER.DAT			
4.1	Check TOL value to make sure it is reasonable; if this is a hydrology model, it should be lowered to 0.03			
4.2	If rainfall model, check TOL and see if it correlates to IA. TOL should be subtracted from IA to avoid dout			

Ask me if you want some of these

What are the Data needs to make this Happen?



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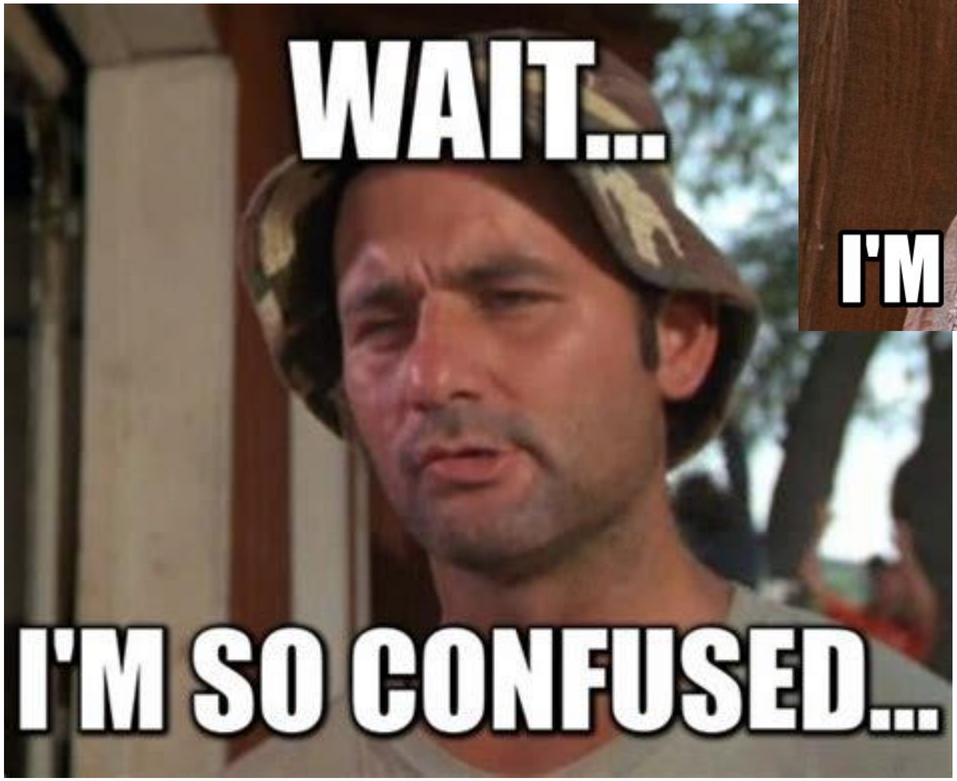
Word of Caution

POLL QUESTION

WHEN SHOULD THE REVIEW PROCESS START?

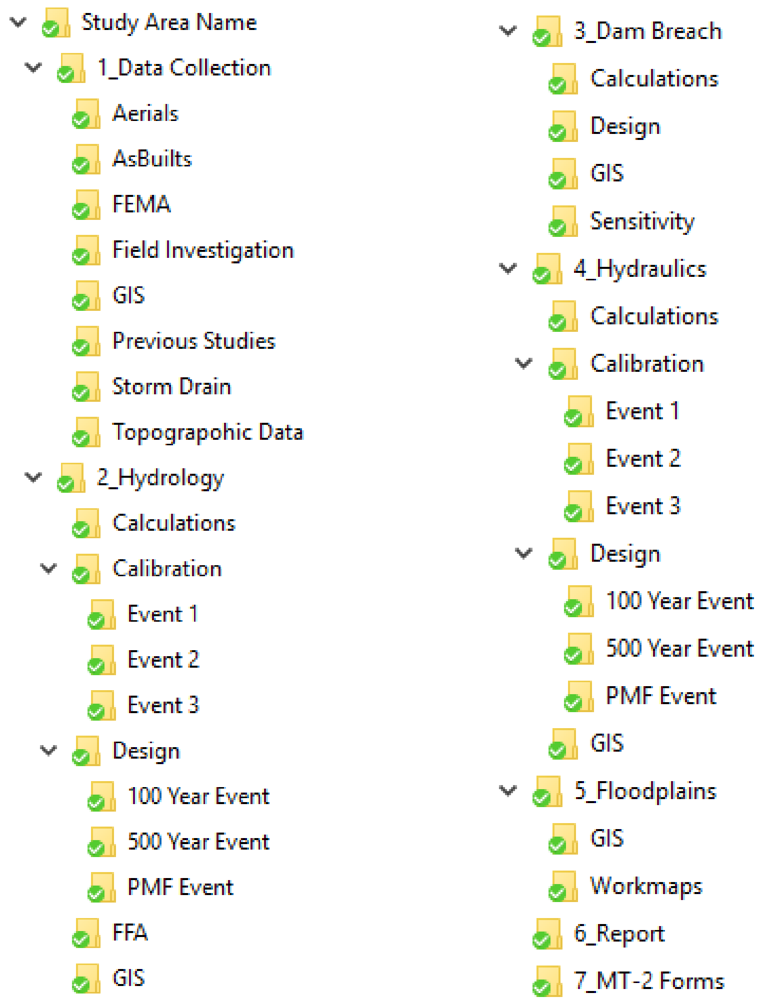
A – BEFORE PROJECT STARTS
B – BEGINNING OF PROJECT
C – MIDDLE OF PROJECT
D – END OF PROJECT



WHAT SHOULD YOU SUBMIT?

Folder Structure

- Organized
- Readme File
- List of data being provided
- Don’t make FEMA search through thousands of documents



Report

- Title Page
- Table of Contents
- Section 1 Introduction
- Section 2 FEMA Forms
- Section 3 Survey and Mapping
- Section 4 Hydrology
- Section 5 Hydraulics
- Section 6 Erosion, Sediment Transport, and Geomorphic Analysis
- Section 7 Draft FIS Data
- Appendix A References
- Appendix B General Documentation and Correspondence
- Appendix C Survey Field Notes
- Appendix D Hydrologic Documentation
- Appendix E Hydraulic Documentation
- Appendix F Erosion, Sediment Transport, and Geomorphic Documentation
- Exhibit Maps

Data Collection and Correspondence

- As-builts
- Imagery
- Field notes
- Meeting notes
- Previous studies
- Effective FEMA Data

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Model Files

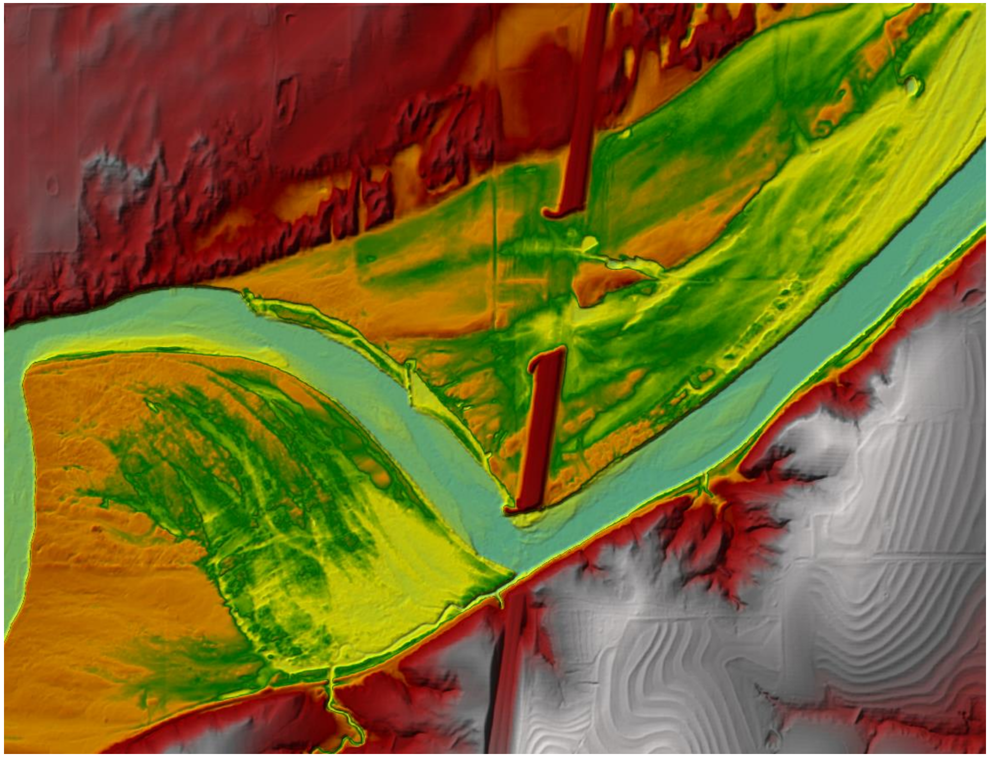
- Correct model files
- Inputs
- Outputs
- Existing Conditions
- Proposed Conditions
- Calibration

GIS Layers

- Floodplains
- Cross-sections
- BFE’s
- Channel Streamline
- Levees
- Other useful data

Terrain

- Raw data
- Final terrain
- Datums
- Certification of data



From Aquaveo

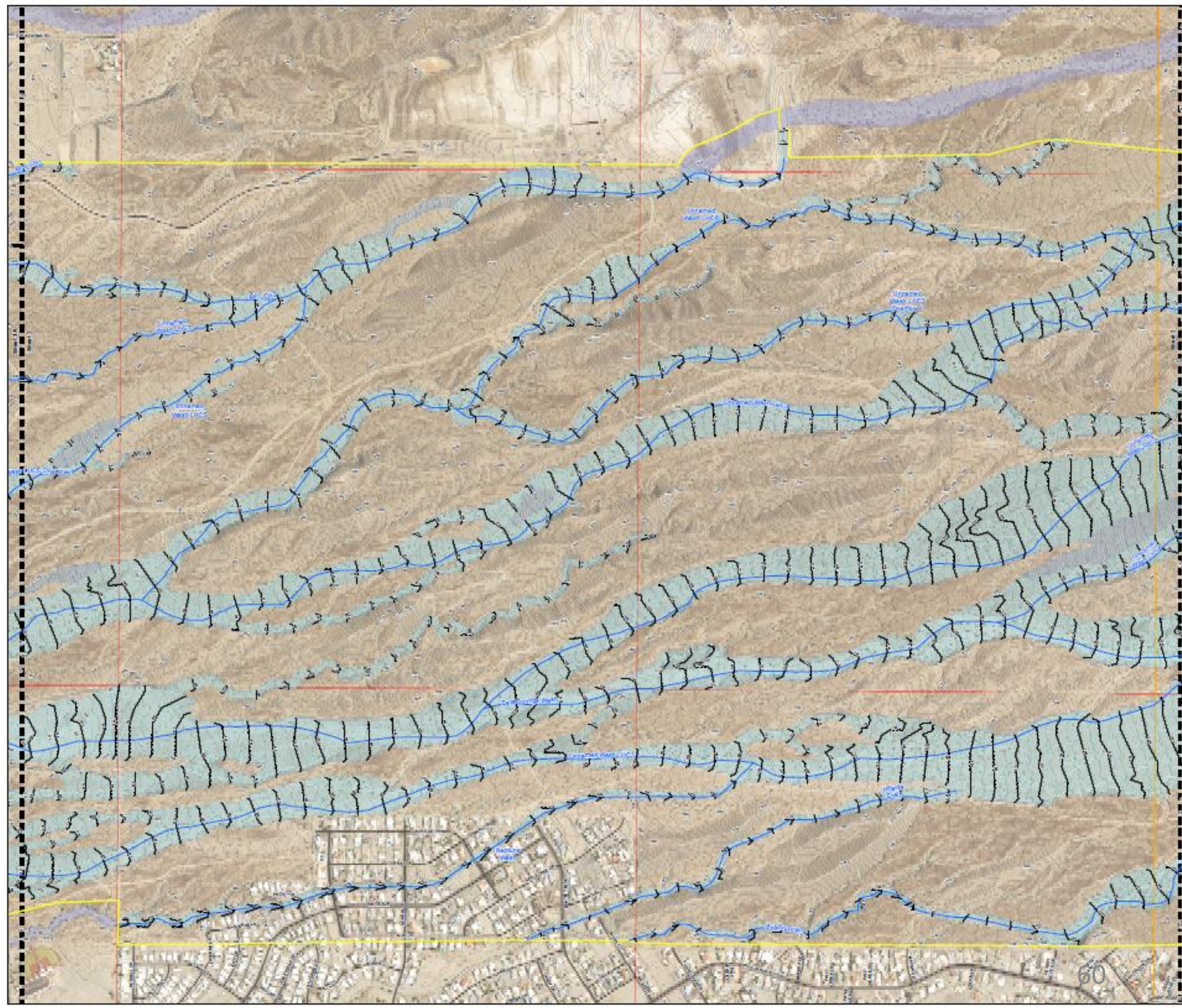
Workmap

Legend

- Base Flood Elevation
- Sheet Matchline
- Stream Centerline
- Limit of Study
- Township-Range
- Section Lines
- Index Contours
- Intermediate Contours
- Streets
- Effective FEMA SFHA

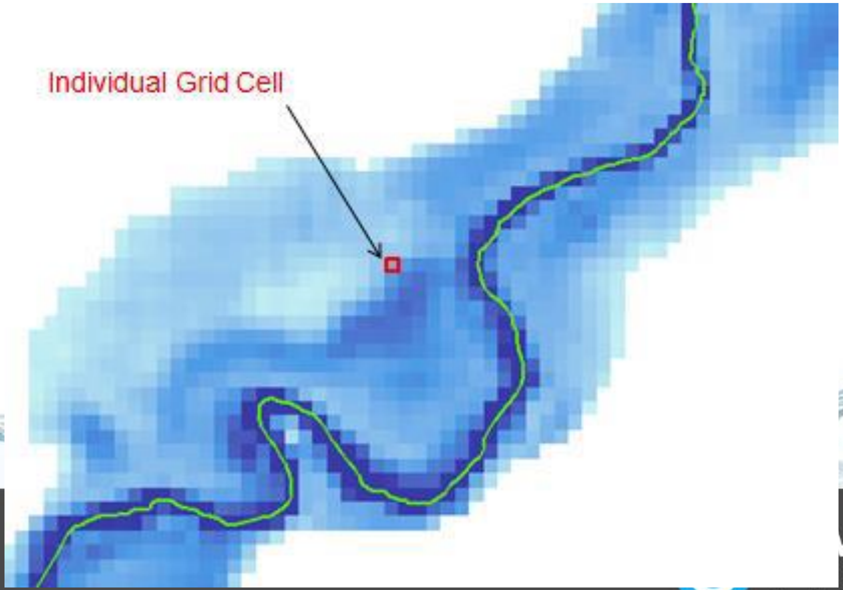
Revised Floodplains

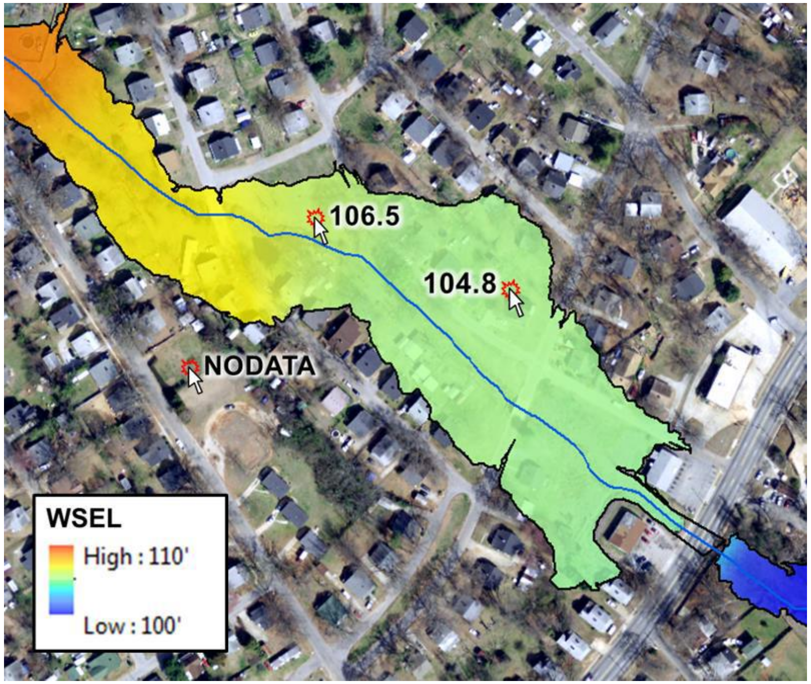
- AE
- AO, Depth 2
- AO, Depth 1 & Vel 3
- AO, Depth 2 & Vel 6
- AO, Depth 1 & Vel 4
- AO, Depth 2 & Vel 10
- AO, Depth 1 & Vel 6
- AO, Depth 3 & Vel 10
- A
- Shaded Zone X (500-year)



Analysis Grids

- Depth Grids
- Water Surface Grids
- Velocity Grids
- See FEMA Guidance





Questions

Congratulations. You made it through my presentation and 2020

Property or Factor	1D Modeling	2D Modeling
Flow Direction	**Precsribed (streamwise)**	**Computed**
Tranverse Velocity and Momentum	**Neglected**	**Computed**
Vertical Velocity and Momentum	**Neglected**	**Neglected**
Velocity Averaged	**XS Area**	**Depth at a Point**
Transverse Velocity Distribution	**Porportioanal to Conveyance**	**Computed**
Tranvese Variations in Water Surface	**Neglected**	**Computed**
Vertical Variations	**Neglected**	**Neglected**

2D Guidelines Categories

- Pre-Modeling Guidelines
  - Planning
- Modeling Guidelines
  - User Manuals
  - Best Management Practices
- Post-Modeling Guidelines
  - Deliverables

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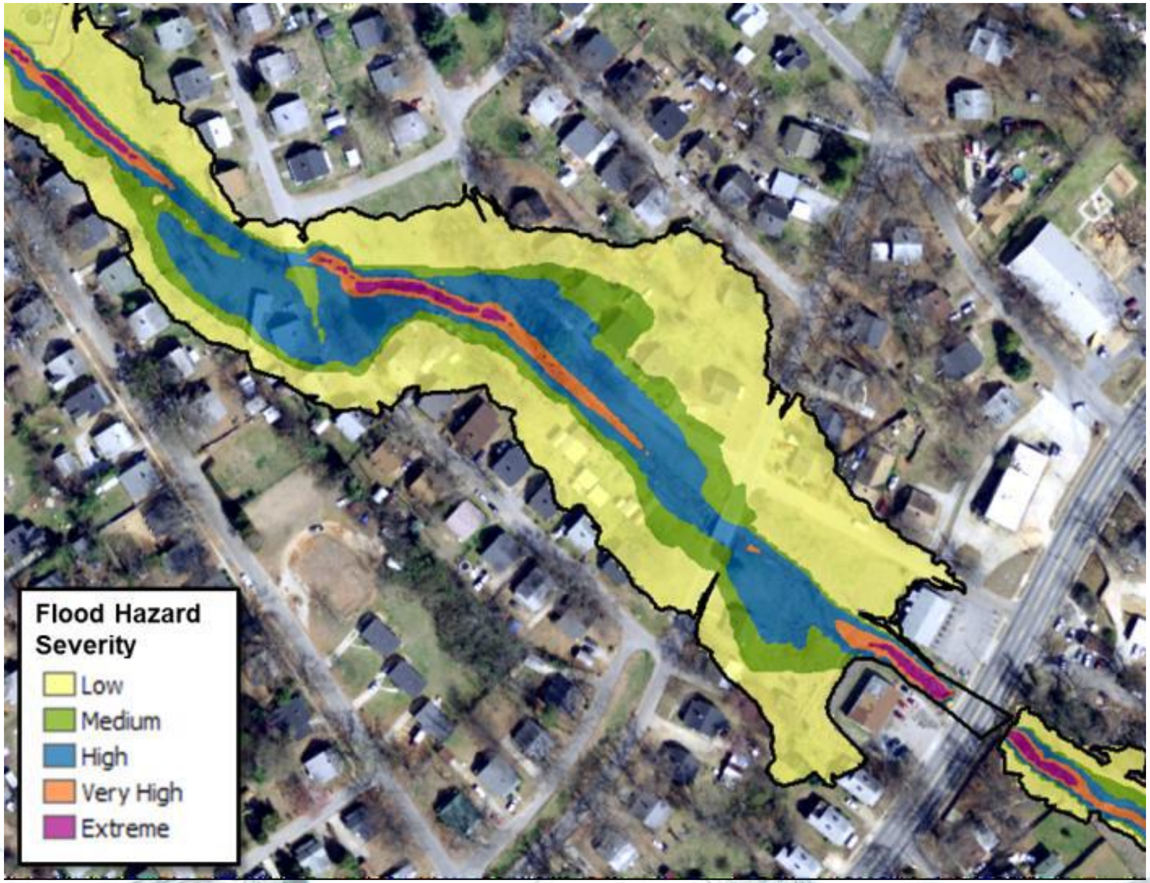
Flood Severity/Hazard Grid (Optional)

- Depth * Velocity
- Different methods
  - USBR
  - Australia
  - FLO-2D
- See FEMA Guidance



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