1D vs 2D Unsteady Flow Modeling

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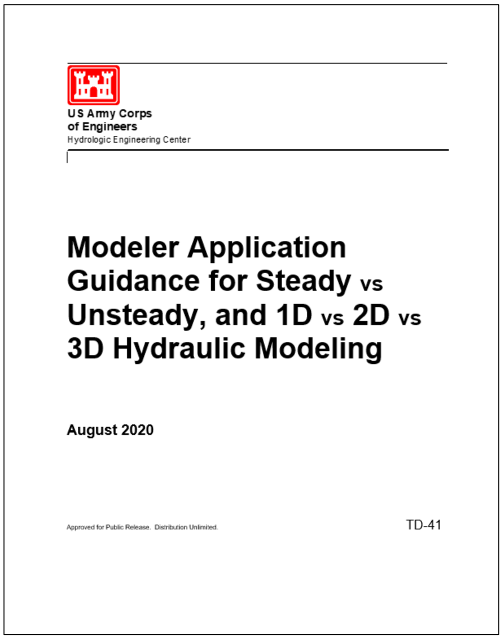

US Army Corps
of Engineers
Hydrologic Engineering Center

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

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TD-41

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Overview

- Knowledge of the Physical System
- Purpose of Hydraulic Modeling
- Data Requirements for 1D and 2D models
- Output/Results from 1D and 2D models
- 1D vs 2D Modeling
  - Computational Differences
  - Model Calibration
  - Time and Cost Issues
  - Summary of 1D and 2D Modeling Advantages and Disadvantages
  - Application Examples

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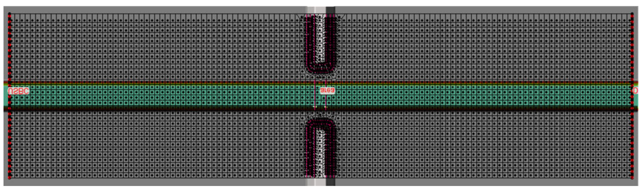
The purpose of this presentation is to provide entry to mid-level hydraulic engineer's with guidance on when to use Unsteady Flow modeling instead of Steady flow modeling; and when to use one-dimensional (1D), two-dimensional (2D), or three-dimensional (3D) modeling.

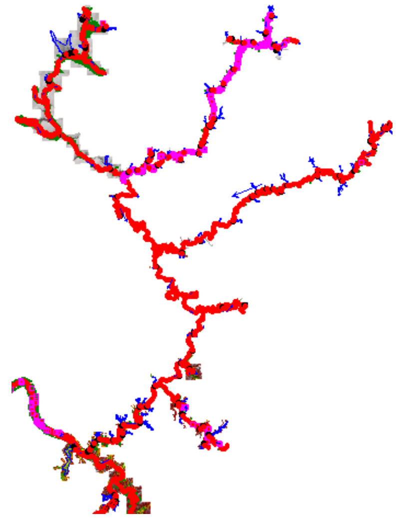
Knowledge of the Hydraulic System

- What is the size/ length of the systems to be modelled?
  - 1 mile, 10, 50, 100, 500, or 1000 miles?
  - Detailed 2D models may not work well for very large systems due to excessive run times.
  - For very larger systems may need to use 1D or combined 1D/2D modeling



Bridge Flume

Allegheny River System



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- Allegheny River System is thousands of miles long and there is no way that could be modeled in 2D in practice.
- However, the idealized flume experiment of a bridge can easily be modeled in detail with a 2D model.

Knowledge of the Hydraulic System

- What is the complexity of the system to be modelled?
  - Is the system hydraulically steep, or have steep areas?
    - Steep systems can be more difficult to model that flat river systems
    - In a hydraulically steep system there are higher velocities, and more rapid changes in depth, area, and velocity.
  - How many/what type of hydraulic structures are in the system?
    - Bridges and Culverts
    - Dams, weirs, gated structures (special operating rules)

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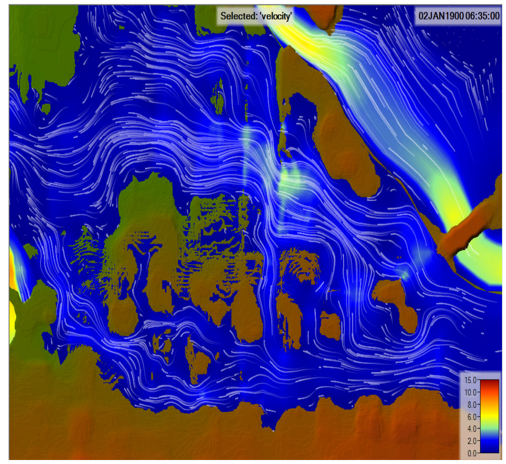
Knowledge of the River System

- Is the flow path of the water generally known for the full range of events?
  - 1D modeling requires knowledge of the flow path before laying out the model cross sections.
  - If the flow path of the water is not fully known for all events, then 2D modeling will be more accurate and easier to use.
  - If the flow path changes during an event, 2D models can handle this and 1D cannot.



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Knowledge of the Hydraulic System

- Are there unique aspects of the system that will significantly affect the computed results?
  - Tidally influenced?
  - Does wind speed affect the water surface elevations?
  - Floating ice or ice jams?
  - Debris issues during flood - does the debris tends to pile up at hydraulic structures
  - Levee systems that may be overtopped or breached?
  - Unique hydraulic structures that require specialized modeling or gate operations

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Purpose of the Model

- Hydraulic models are developed for all kinds of purposes:
  - A model to produce rough answers quickly
    - Generally, 1D or 2D models can be developed that are not very detailed
    - However, a simple 2D model are faster to develop than a 1D model
  - Detailed Planning study
    - 1D, 2D, or combined 1D/2D
  - Design study - model will be directly used to design a structure
    - Not uncommon to use a 1D or a 2D model as a preliminary screening tool
    - 3D models and physical models are generally used to design hydraulic structures
  - Real-time modeling and mapping, etc.
    - Generally, need to runs fast

Sources and Accuracy of the Data

- What is the level of detail and accuracy of
  - Terrain data
  - Cross section data
  - levee information
  - Hydraulic structure data?
- Hydrology and boundary conditions
  - Peak flows only
  - Full hydrographs at gaged locations
  - Full blown hydrologic model

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Duration of Events to be Modelled

- Duration of an event depends on
  - Size of the watershed/river system
  - Study purpose
- Event durations
  - Peak flows or snapshot in time – 1D, 2D, or 3D
  - Single events: 1 day to months – 1D, 2D
  - Period of record analysis: many years – 1D

Data Requirements

- Data requirements can vary significantly for 1D and 2D modeling approaches, as well as steady versus unsteady flow modeling
- Amount and quality of available data may dictate the type of modeling that can be accomplished
- Main areas in which data requirements may be different are
  - Terrain data
  - Roughness - channel and floodplain vegetation/landuse
  - Hydraulic Structure information
  - Calibration/validation data

Terrain Data

- **1D models**
  - Only need cross sections at the necessary locations for computing an accurate water surface
- **2D modeling**
  - Must have a terrain model
- **Quality of terrain will also affect model choice**
  - Lack of underwater channel data – 1D easier
  - 2D requires channel data in the terrain model

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Spatially Variable Roughness

- 1D Modeling
  - Roughness can be defined cross section by cross section
  - or with Land Cover layer
- 2D Modeling
  - Requires a Land Cover layer
  - Channels usually not resolved in Land Cover layer and need to be over-written with user defined polygons

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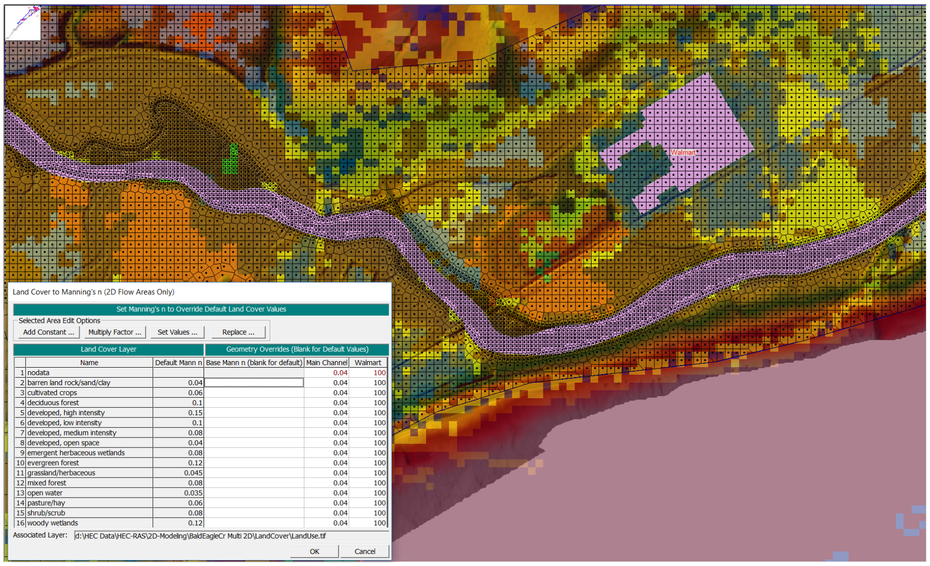
Example 2D Model Land Cover and Channel Roughness Polygons



	Name	Default Mann n	Base Mann n (blank for default)	Main Channel	Walmart
1	nodata			0.04	100
2	barren land rock/sand/clay	0.04		0.04	100
3	cultivated crops	0.06		0.04	100
4	deciduous forest	0.1		0.04	100
5	developed, high intensity	0.15		0.04	100
6	developed, low intensity	0.1		0.04	100
7	developed, medium intensity	0.08		0.04	100
8	developed, open space	0.04		0.04	100
9	emergent herbaceous wetlands	0.08		0.04	100
10	evergreen forest	0.12		0.04	100
11	grassland/herbaceous	0.045		0.04	100
12	mixed forest	0.08		0.04	100
13	open water	0.035		0.04	100
14	pasture/hay	0.06		0.04	100
15	shrub/scrub	0.08		0.04	100
16	woody wetlands	0.12		0.04	100

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Hydraulic Structures

- Data requirements will vary between 1D and 2D modeling approaches
  - 1D Modeling
    - Physics-based equations (energy, momentum): cross sections, roughness
    - Semi-empirical equations: user-defined coefficients
    - Rating curves: computed outside of the model
  - 2D Modeling
    - Same as 1D approaches above (1D Hydraulics)
    - True 2D modeling through and over the structure – Much more detail need to describe the terrain data

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Calibration/Validation

- Required regardless of the model type
  - 1D Modeling
    - Observed flow and stage hydrographs at gages
    - High water marks
    - Historical inundation maps
  - 2D Modeling
    - Same as 1D plus
    - Observed velocities
      (necessary for calibrating turbulence coefficients
      or modeling sediment transport)

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Model Output/Results

- Requirements for hydraulic model outputs, as well as level of detail, will influence the type of model used for a study
- Questions that modelers should ask at the beginning of a study are:
  - What are the required hydraulic results needed for this study?
  - What level of detail is needed?
  - What level of accuracy is expected/desired?

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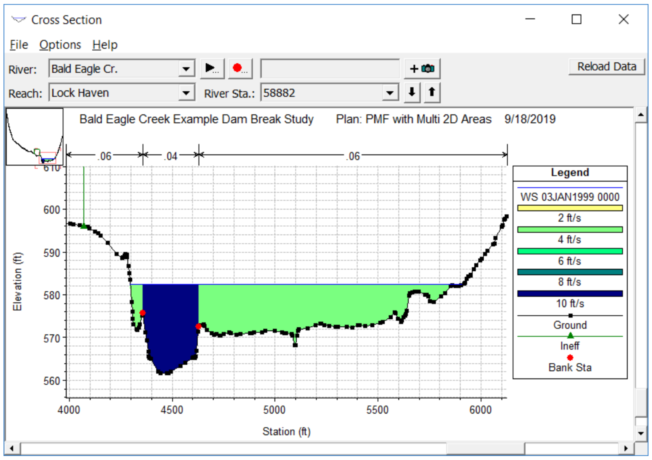
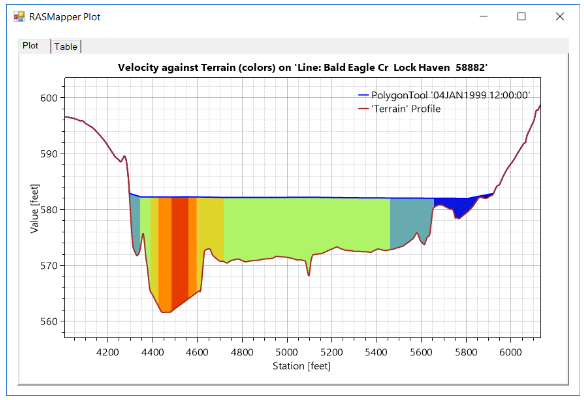
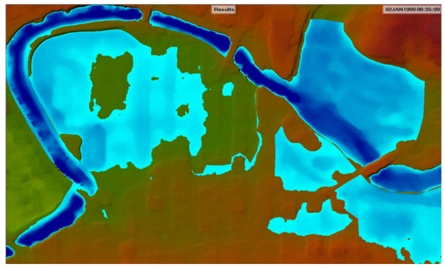
Example 1D and 2D XS WS and Velocities

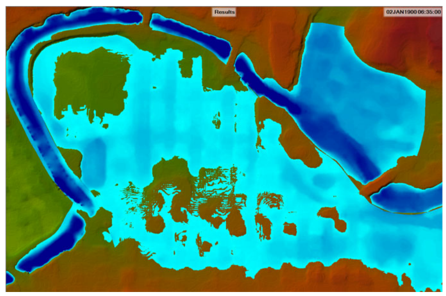




Example 1D vs 2D Inundation Map



1D Model with Storage Areas used for interior floodplain area



2D Model of Interior Floodplain area

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Contractions and Expansions

- Contractions and expansions are inherently a 3D process
- 1D Modeling
  - Empirical coefficients times a change in velocity head
- 2D Modeling
  - Contractions and expansions directly simulated in 2D flow
  - However, the full 3D effects of contractions and expansion may not be captured
  - In addition, 2D turbulence modeling requires 1 to 3 empirical coefficients which may need to be calibrated

Storage/Ineffective Flow Areas

- 1D Modeling
  - Ineffective flow areas are required in order to get the correct amount of active (effective) flow area
  - **1D storage areas** can also be used to model off channel storage

- 2D Modeling
  - Ineffective flow areas are not required, as ineffective flow areas are automatically computed

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Hydraulic Structures

- 1D Modeling
  - Physics-based equations (energy, momentum)
  - Semi-empirical equations (Yarnell, pressure flow, weir flow)
  - Rating curves
- 2D Modeling
  - Same as 1D approaches above, and
  - 2D modeling through and over the structure

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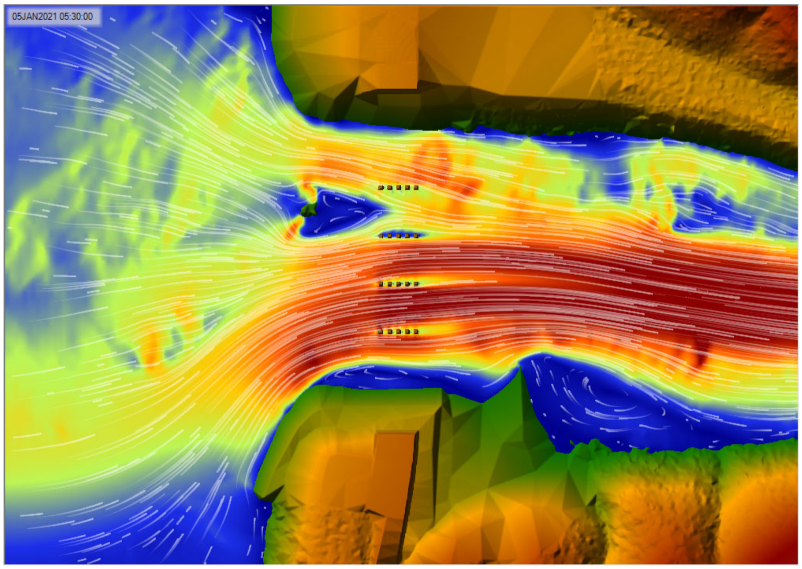
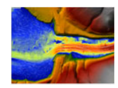
Example Velocity Field for a Detailed 2D Model of a Bridge





1D Model Calibration

- Accomplished by changing/adjusting
  - Roughness parameters
  - Contraction and expansion coefficients
  - Ineffective flow area extents and height trigger elevations
  - Hydraulic structure coefficients
  - Bend loss coefficients (rare to use these)
  - Boundary condition information, such as energy slopes, or even potentially rating curve values
  - Debris blockage information at structures
  - Levee breach dimensions and timing values

2D Model Calibration

- Calibrating a 2D model is very similar to 1D approaches, but with some of the following differences
  - Modifying roughness can be more difficult and time consuming
  - No contraction/expansion coefficients
  - No ineffective flow areas
  - Refinement of 2D models may require changes in order to match observed velocity measurements
  - Calibration to velocity information will generally require changes in roughness, possible eddy viscosity coefficients, and maybe even terrain adjustments, if appropriate and justified
  - Models runs take longer, so may have less runs available to change parameters and find optimal calibration parameter values

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Time and Cost Issues

- Time to develop a model with the 1D or 2D approach can vary, depending on the type and purpose of the model
  - "Quick and Dirty" model during a flood emergency
    - Much faster to lay out a 2D model – draw flow area polygon, set a basic cell/element size, attach some boundary conditions, and go.
  - Detailed model is being developed,
    - both approaches will ultimately take about the same amount of time to develop the initial model
    - 1D models require XS layout, ineffective flows, etc…
    - 2D models require changes in mesh resolution; breaklines; refinement regions.
- Computational Time and Resource Requirements
  - 1D is much faster and single threaded
  - 2D much slower and generally uses multiple threads

1D Modeling Advantages

- In general, 1D models require less terrain data, in that the channel portion of the model can be from separate detailed cross-sectional surveys, or it can be approximated with a trapezoid
- 1D models are often (not always) easier to calibrate, due to the sim of changing parameters such as roughness coefficients, and other variables
- Modeling of hydraulic structures is often easier, requiring less data a computational requirements
- 1D models require significantly less computational time and compu resources

The question of 1D versus 2D hydraulic modeling is a much tougher question than steady versus unsteady flow. There are definitely some areas where 2D modeling can produce better results than 1D modeling, and there are also situations in which 1D modeling can produce as good as or better results than 2D models… with less effort and computational requirements. Unfortunately, there is a very large range of situations that fall into a gray area, and one could list the positive and negative aspects of both methodologies for specific applications. Here are some areas where I think 2D modeling can give better results than 1D modeling:

When modeling an area behind a leveed system, and the levee will be overtopped and/or breached, the water can go in many directions. If that interior area has a slope to it, water will travel overland in potentially many directions before it finds its way to the lowest point of the protected area, and then it will begin to pond and potentially overtop and/or breach the levee on the lower end of the system. However, if a protected area is small, and ultimately the whole area will fill to a level pool, then 1D model is fine for predicting the final water surface and extent of the inundation.

Very wide and flat flood plains, such that when the flows goes out into the overbank area, the water will take multiple flow paths and have varying water surface elevations and velocities in multiple directions.

Alluvial fans – however, this is very debatable that any numerical model can capture a flood event accurately on an alluvial fan, due to the episodic nature of flow evolutions that can change the whole direction of the channels during the event.

Bays and estuaries in which the flow will continuously go in multiple directions due to tidal fluctuations and river flows coming into the bay/estuary at multiple locations and times.

Highly braided streams

Flow around abrupt bends in which a significant amount of super elevation will occur during the event.

Applications where it is very important to obtain detailed velocities for the hydraulics of flow around an object, such as a bridge abutment or bridge piers, etc…

1D Modeling Disadvantages

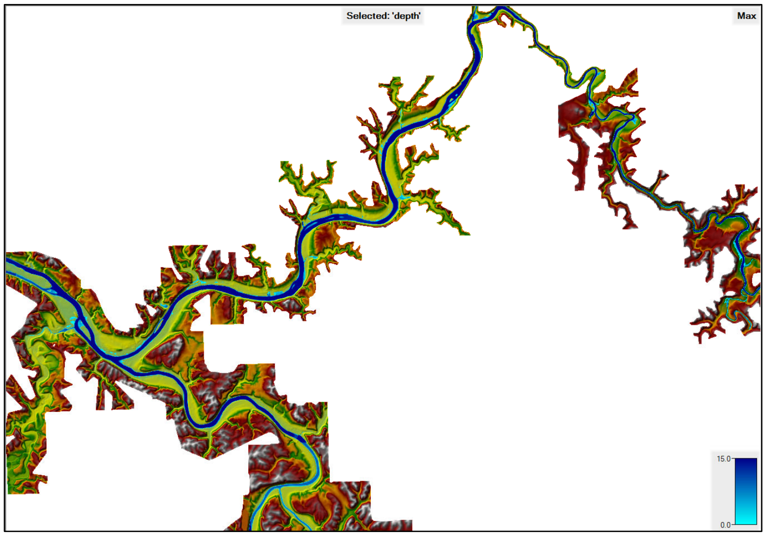
- Water flow path must be known ahead of time
  - Not always possible to know, especially in flat areas
  - 1D cross sections must be laid out perpendicular to the flow
  - in order to get an accurate representation of the true flow area.
  - Not always possible to do this for the full range of events or for flat areas
  - May require more than one geometric representation of the system
- Single-averaged water surface elevation per cross-section
- Velocity output is limited and based on conveyance
- Friction losses are averaged between cross sections
- Energy and/or force losses due to contractions and expansion require the modeler to define empirical coefficients (Cc and Ce) and ineffective flow areas.
- Flow distribution is based on the individual cross-section conveyance, and does not conside advection or diffusion of momentum
- Mapping of the inundated area based on the assumption that the water surface changes lin between any two cross sections, and that the water surface is flat inside of storage areas

Areas Where 1D Modeling Can Produce Similar Results to 2D Modeling (with less effort)

- Steep streams that are highly gravity driven and have small overbank
- Rivers and floodplains in which the dominant flow directions and forc follow the general river flow path.
- Medium to large river systems, where we are modeling a large portio the system (100 or more miles), and it is necessary to run longer time period simulations (i.e. 2 week to 6-month events, or period of recor simulations).
- River systems that contain a lot of bridges/culverts, weirs, dams, gate structures, levees, pump stations, etc….
- Areas in which the basic data does not support the potential gain of using a 2D model

The following are areas in which I think 1D modeling can produce similar results to 2D modeling, with less effort (both from a model development, calibration, and application viewpoint, as well as a computational time viewpoint):
Steep streams that are highly gravity driven and have small overbank areas, such that the flow is confined to the channel and a small floodplain area.
Rivers and floodplains in which the dominant flow directions and forces follow the general river flow path. Flow paths of the water in overbank/floodplain areas are known. This covers a lot of river systems, but it is debatable as to the significance that lateral and vertical velocities and forces impact the computed water surface elevations and flood inundation boundary.
Medium to large river systems, where we are modeling a large portion of the system (100 or more miles), and it is necessary to run longer time period simulations (i.e. 2 week to 6 month events, or period of record simulations). Even with the tremendous advancements in multi-processor computing, and GPU (Graphics Processor Units) computing, there are still significant spatial and simulation time limitations on what we can effectively use 2D models for in the real time forecasting domain, or even in a planning study. This will obviously be changing over time as computers and software improve.
River systems that contain a lot of bridges/culvert crossings, weirs, dams, gated structures, levees, pump stations, etc…. and these structures impact the computed stages and flows within the river system. This is an area that the current state of the art in 1D models is far ahead of the 2D models. This statement does not mean that these capabilities cannot be incorporated into a 2D model, It just means that I have not seen a widely used 2D model that has such a comprehensive set of capabilities.
Areas in which the basic data does not support the potential gain of using a 2D model. If you do not have detailed overbank and channel bathymetry, or you only have detailed cross sections at representative distances apart, many of the benefits of the 2D model will not be realized due to the poor accuracy of the terrain data.

Example of a highly one-dimensional flowing river system (Allegheny - Monongahela Rivers, confluence at Pittsburgh, PA)



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2D Modeling Advantages

- Water flow path does **not** have to be known ahead of time
  - Direction of the flow can change during the event
  - Water can move in any direction, based on energy and momentum of the flow
- However, the extent of the flooding does need to be correctly defined
- Velocity, momentum, and the direction of the flow are more accurately accounted for. This especially true for flow going over roads, levees, barriers, structures, around bends, and at junctions/splits. Additionally, 2D models can be used to analyze eddy zones within the flov Around bends, 2D models produce accurate water surface elevations, but velocity distribut might be erroneous due to the existence of helical flow.
- Energy and force losses due to contractions and expansions, etc. are directly accounted for not require empirical coefficients, increased roughness, or user defined ineffective flow are
- Mapping of the inundated areas, as well as velocities, and flood hazards (depth x velocity) i accurate
- Detailed modeling of hydraulic structures, in a 2D modeling approach, can provide more in the flow distribution approaching, going through, and coming out of a structure

The question of 1D versus 2D hydraulic modeling is a much tougher question than steady versus unsteady flow. There are definitely some areas where 2D modeling can produce better results than 1D modeling, and there are also situations in which 1D modeling can produce as good as or better results than 2D models… with less effort and computational requirements. Unfortunately, there is a very large range of situations that fall into a gray area, and one could list the positive and negative aspects of both methodologies for specific applications. Here are some areas where I think 2D modeling can give better results than 1D modeling:

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Bays and estuaries in which the flow will continuously go in multiple directions due to tidal fluctuations and river flows coming into the bay/estuary at multiple locations and times.

Highly braided streams

Flow around abrupt bends in which a significant amount of super elevation will occur during the event.

Applications where it is very important to obtain detailed velocities for the hydraulics of flow around an object, such as a bridge abutment or bridge piers, etc…

2D Modeling Disadvantages

- More detailed terrain models are required in order to run a 2D model. The terrain include the details of the channels at all locations within the model.
- Defining and modifying roughness values requires more spatial definition and can difficult and time consuming during the calibration process
- Turbulence Modeling coefficients must be calibrated
- Requires significantly more computational time and/or computational resources. require the purchase of a very high-level computer (many cores, fast CPU's, lots of and fast hard disk), or utilizing HPC and cloud computing solutions.
- May require using larger grid sizes than desirable for the problem, in order to redu run times to a manageable amount of time.
- May not really produce better results, if the data used to perform the modeling (te channel data, and roughness) do not support the level required for accurate 2D mo

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Areas Where 2D Modeling Can Give Better Results than 1D Modeling

- When modeling an area behind a levee system in which the flow will go in multiple d
- Areas and/or events in which the flow path of the water is not completely known, or change during the event.
- Very wide and flat flood plains, where water will go in multiple directions when it en floodplain
- Bays and estuaries in which the flow will continuously go in multiple directions
- Highly braided streams
- Alluvial fans
- Flow around abrupt bends in which a significant amount of super elevation will occu
- At Hydraulic Structures where it is very important to obtain detailed water surface el and velocities in two dimensions

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Example of a leveed system breach with water going in many directions

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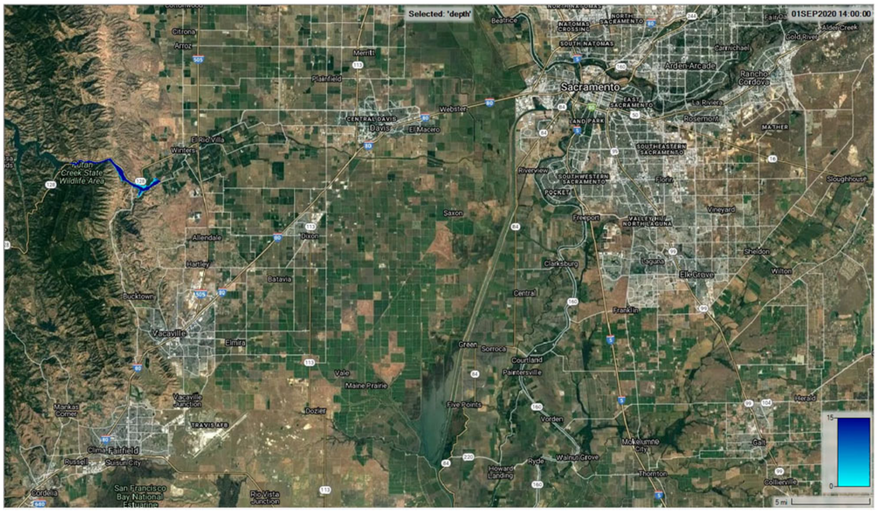
Example Dambreak that goes out into an extremely flat area and spreads out



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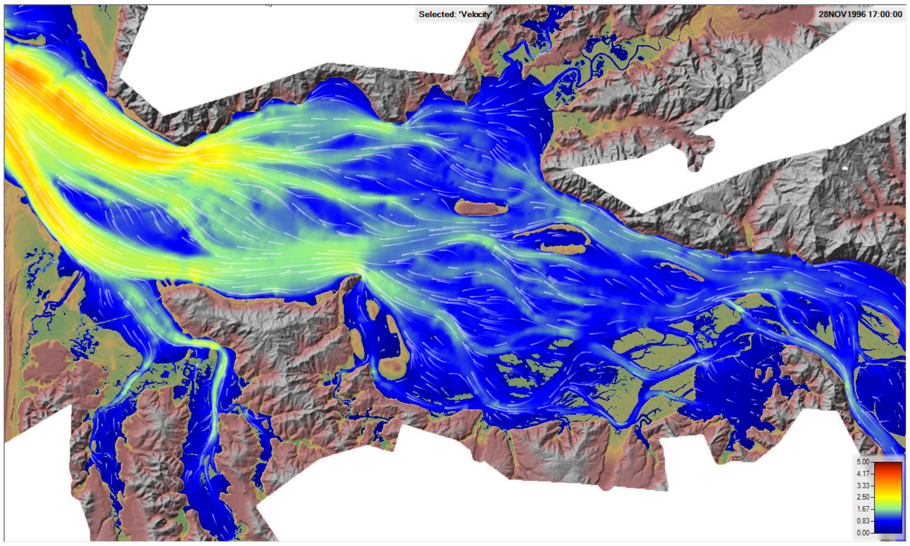
Lower Columbia River Bay



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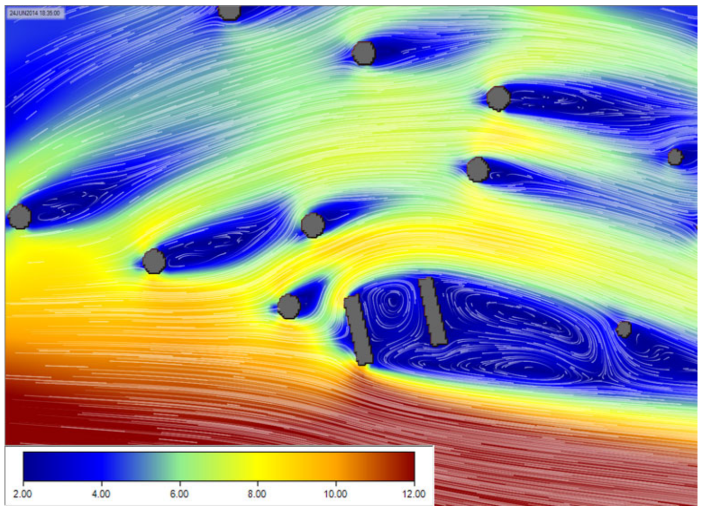
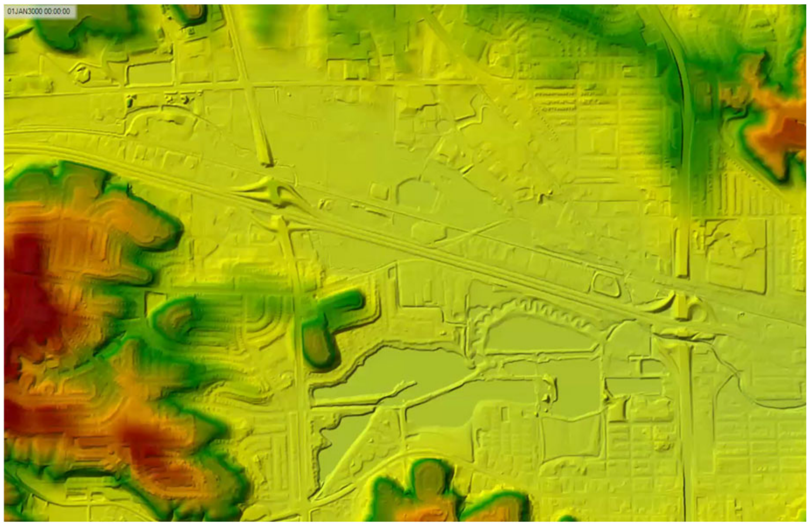
Detailed 2D Model of Flow Going around Piers from a Railroad Station Platform



Overbank Flow in an Urban Area



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Thank You!

HEC-RAS Website:
https://www.hec.usace.army.mil/software/hec-ras/

Online Documentation:
https://www.hec.usace.army.mil/confluence/rasdocs

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- And with that, thank you for watching.
- For HEC-RAS downloads, documentation, and other things please visit the HEC-RAS website shown here.
- The latest online documentation can be found on our Confluence website shown here.