

# HEC-RAS 2D Sediment Workshop: Optimizing Runtimes

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## Introduction



- Sediment modeling project workflow **NOT** the same as a hydraulic modeling project
- Sediment models require higher data quality and modeling skill
- Sediment modeling is **ALWAYS** iterative
- New or inexperienced modelers often setup with a single high-resolution mesh, with too many grain classes, bad terrain, bad boundary and initial conditions and struggle to get stable results

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## Sediment Modeling Workflow



- Start Simple
  - Smallest domain possible
  - Coarsest mesh
  - Fewest number of grain classes
  - Fewest number of processes (e.g. Capacity Only)
  - Large time steps
  - Shortest simulation windows
  - “Easy” boundary conditions
- Slowly refine and add complexity
  - Modeling is an iterative process
  - Focus calibration on important parameters
  - Always conduct sensitivity analysis
- Most difficult part is...
  - Knowing how to get the “Best model for the least amount of effort”

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## Outline



- Hydraulics
  - Time Step
  - Mesh Size
  - Convergence
  - Matrix Solver
- Sediment
  - Computation Multiplier
  - Grain Classes
  - Convergence
  - Morphologic Acceleration Factor

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## Optimizing Hydraulics

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## Number of Cores



- Set for each 2D area
- Default is “All Available”
- Optimal value typically 4-8
- It is more efficient to run multiple plans at the same time

HEC-RAS Unsteady Computation Options and Tolerances

General | 2D Flow Options | 1D/2D Options | Advanced Time Step Control | 1D Mixed Flow Options

Use Coriolis Effects (not used with Diffusion Wave equation)

Parameter	(Default)	BaldEagleCr
1 Theta (0.6-1.0)	1	1
2 Theta Warmup (0.6-1.0)	1	1
3 Water Surface Tolerance (max=0.2)(ft)	0.01	0.01
4 Volume Tolerance (ft)	0.01	0.01
5 Maximum Iterations	20	20
6 Equation Set	Diffusion Wave	Diffusion Wave
7 Initial Conditions Time (hrs)		4
8 Initial Conditions Ramp Up Fraction (0-1)	0.5	0.5
9 Number of Time Slices (Integer Value)	1	1
10 Turbulence Model	Non-Conservative (original)	Non-Conservative (original)
11 Longitudinal Mixing Coefficient		
12 Transverse Mixing Coefficient		
13 Smagorinsky Coefficient	0	0
14 Boundary Condition Volume Check	<input type="checkbox"/>	<input type="checkbox"/>
15 Substitute for Coriolis (00 to 99)		
16 Solver Cores	6 Cores	6 Cores
17 Matrix Solver	PARDISO (direct)	PARDISO (direct)
18 Convergence Tolerance		
19 Minimum Iterations		
20 Maximum Iterations		
21 Restart Iteration	10	10
22 Relaxation Factor	1.3	1.3
23 SOR Preconditioner Iterations	10	10

OK Cancel Defaults ...

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## Time Step



- Most common cause of numerical instabilities
- Maximum time step usually limited by just a few cells/faces in the mesh
- Theoretical time step limits are not the same as in practice
- In practice the time step is limited by many factors including
  - Forcing such as wind
  - External and internal flows
  - Local Courant numbers
  - Shape of hydraulic property tables
  - Governing equations
  - 1D/2D and 2D/2D coupling
  - Etc.

$$\Delta t < \Delta t_{\max}$$

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## Time Step



- RAS uses a global time for each 2D area (spatially constant)  $\Delta t$
- Max time step varies in time for unsteady simulations  $\Delta t_{\max}(t)$
- Max time step is a function of the 2D flow solver
- Rules of thumb
  - SWE-ELM:  $C < 3.0$
  - SWE-EM:  $C < 1.0$
  - DWE:  $C < 5.0$
- Courant limitation for ELM and DWE is not strict but rather based on practice
- EM Courant limitation is strict

$$C = \frac{V \Delta t}{\Delta x}$$

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## Time Step Options



1. Fixed Time Step (default)
  - Can use time step slicing for 2D areas
2. Adjust Time Step Based on Courant Number
3. Adjust Time Step Based on Date/Time and a Time step divisor

HEC-RAS Unsteady Computation Options and Tolerances

General | 2D Flow Options | 1D/2D Options | **Advanced Time Step Control** | 2D M

Fixed Time Step (Basic method) 20 Second

Adjust Time Step Based on Courant

Maximum Courant: 4

Minimum Courant: 1.95

Number of steps below Minimum before doubling: 5

Maximum number of doubling base time step: 2 80.00 sec

Maximum number of halving base time step: 1 10.00 sec

Courant Methodology

Velocity/Length (face velocity \* dt / cell to cell distance)

Residence Time (cell outflow \* dt / cell volume)

Adjust Time Step Based on Time Series of Divisors [Verify Dates...](#)

Time Step	Date(ddMMMyyyy hhrmm)	Divisor
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		

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## Adaptive Time Step



- Time Step Computation  $\Delta t = \frac{\Delta t_{\max}}{2^N}$
- Maximum Courant
  - Time step is halved if  $C \geq C_{\max}$
- Minimum Courant
  - Time step is doubled if  $C \leq C_{\min}$
- Important  $C_{\min} < \frac{1}{2} C_{\min}$
- Number of steps before doubling
- Maximum number of doubling
  - Determines max times step
- Maximum number of halving
  - Determines min time step

$$C = \frac{V \Delta t}{\Delta x}$$

Fixed Time Step (Basic method) 1 Second

Adjust Time Step Based on Courant

Maximum Courant: 4.

Minimum Courant: 1.95

Number of steps below Minimum before doubling: 5

Maximum number of doubling base time step: 2 4.00 sec

Maximum number of halving base time step: 1 0.50 sec



Courant Methodology

Courant (Velocity \* dt / Length)

Residence Time (flow out \* dt / Volume)

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## Courant Number Methods

- Standard Velocity Based
 
$$C_v = \frac{V \Delta t}{\Delta x}$$
- Residence time Based
 
$$C_\Omega = \frac{Q_{out} \Delta t}{\Omega}$$

Fixed Time Step (Basic method) 1 Second

Adjust Time Step Based on Courant

Maximum Courant:

Minimum Courant:

Number of steps below Minimum before doubling:

Maximum number of doubling base time step:  4.00 sec

Maximum number of halving base time step:  0.50 sec



**Courant Methodology**

Courant (Velocity \* dt / Length)

Residence Time (flow out \* dt / Volume)

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## Mapping Output Interval

- Adaptive time step is always integer interval of Mapping Output Interval, so Unsteady may need to adjust base Computation Interval

Simulation Time Window		Maximum adaptive timestep = 10.0		Minimum adaptive timestep = 00.625	
Starting Date:	<input type="text" value="01OCT2013"/>	Initial adaptive timestep = 01.25			
Ending Date:	<input type="text" value="01OCT2013"/>	01OCT2013 00:00:06 timestep = 2.5 (sec)			
Computation Settings		01OCT2013 00:00:16 timestep = 1.25 (sec)			
Computation Interval:	<input type="text" value="2 Second"/>	01OCT2013 00:00:17 timestep = 0.625 (sec)			
Mapping Output Interval:	<input type="text" value="10 Second"/>	01OCT2013 00:01:22 timestep = 1.25 (sec)			
DSS Output Filename:	<input type="text" value="C:\Users\q0hecssp\Doc"/>	01OCT2013 00:03:25 timestep = 2.5 (sec)			
Time Step is controlled by courant condition.		01OCT2013 00:11:20 timestep = 5 (sec)			
		<b>Writing Results to DSS</b>			
		<b>Finished Unsteady Flow Simulation</b>			

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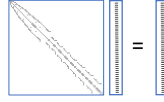


## Matrix Solvers: Introduction



- Linear System of Equations

$$Ax = b$$



- Direct Solvers

- Examples: Gaussian elimination, LU, Cholesky, and QR decompositions
- Can be “black boxes”
- Usually have few input parameters
- High-accuracy
- Can fail or be very slow for large matrices
- Can be slow for unsteady or non-linear systems

- Iterative Solvers

- Examples: GS, SOR, CG, GMRES
- Require more options and input parameters
- Usually require preconditioners, matrix balancing, ordering, etc.
- Less accurate
- Good for large problems
- Good for unsteady or non-linear systems
- Improper use can lead to instability problems or solution divergence

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## HEC-RAS Direct Solver



- PARDISO

High-performance, robust, memory efficient and easy-to-use solver for symmetric and non-symmetric linear systems.

- Version in Intel Math Kernel Library
- Parallel on PC's
- Can be used as a “black box”
  - Very little parameters
  - No need matrix balancing, ordering, etc.

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## HEC-RAS Iterative Solvers



- **SOR: Successive Over-Relaxation**
  - Relaxation factor ( $0 < \omega < 2$ )
  - Asynchronous (ASOR) parallel implementation
  - Extremely simple
  - May take many iterations to converge but each iteration is very inexpensive
- **FGMRES-SOR: Flexible Generalized Minimal RESidual**
  - “Flexible” variant of GMRES which allows preconditioner to vary from iteration to iteration
  - SOR as preconditioner

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## Iterative Solver Input Parameters



- **Convergence Tolerance**
  - Determines the overall accuracy
- **Minimum Iterations**
  - Increases accuracy, avoids solution drift, and allows the solver to stabilize
- **Maximum Iterations**
  - Avoids stalling and too many iterations caused by a small convergence tolerance
- **Restart Iteration (Only FGMRES-SOR)**
  - Reduces run time and memory requirements
- **Relaxation Factor**
  - Used for both SOR solver and preconditioner
- **SOR Preconditioner Iterations (Only FGMRES-SOR)**
  - In-lieu of checking convergence which would be slower

Parameter	Range
Convergence Tolerance	0.001 – 0.000001
Minimum Iterations	3 – 6
Maximum Iterations	5 – 30
Restart Iteration (FGMRES Only)	8 – 12
Relaxation Factor	1.1 – 1.5
SOR Preconditioner Iterations (FGMRES Only)	5 – 20

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# Iterative Solvers: Stopping Criteria



• Error Estimate

$$E^m = \frac{\|D^{-1}(Ax^m - b)\|_2}{\sqrt{N}}$$

- D**: Diagonal of **A**
- A**: Coefficient matrix
- x**: Solution
- b**: Right-hand-side
- N**: Number of rows

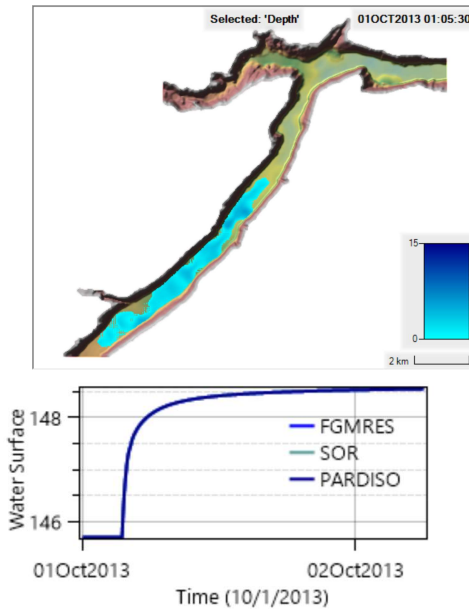
Iterative Solver Status	Criteria	Description
Iterating	$N_{min} < m < N_{max}$ and $E^m > T_C$ and $\frac{E^{m-1} - E^m}{E^1 - E^m} > T_S$ and $E^m < E^1$	Iterative solver is converging and will continue to iterate. $N_{min}$ : Minimum number of iterations $N_{max}$ : Maximum number of iterations $T_C$ : Convergence tolerance $T_S = 0.1T_C$ : Stalling tolerance
Converged	$E^m \leq T_C$	Convergence criteria met. Solution accepted.
Stalled	$\frac{E^{m-1} - E^m}{E^1 - E^m} \leq T_S$	Convergence rate has decreased to an insignificant level without satisfying the converged criteria. The current solution is accepted and the iteration loop is exited.
Max Iterations	$m = N_{max}$	Maximum number of iterations reached without reaching the converged criteria. The current solution is accepted and the iteration loop is exited.
Divergent	$E^m > E^1$	Iterative solution is divergent. Either the normalized residuals are getting larger, or a Not a Number (NaN) has been detected.

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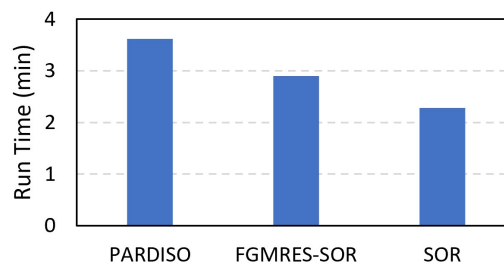
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# Example: EA Test 5 (Dam Failure)





Setting	FGMRES-SOR	SOR
Convergence Tolerance	0.0001	0.0001
Minimum Iterations	3	5
Maximum Iterations	20	30
Restart Iteration	10	
Relaxation Factor	1.3	1.3
SOR Preconditioner Iterations	10	



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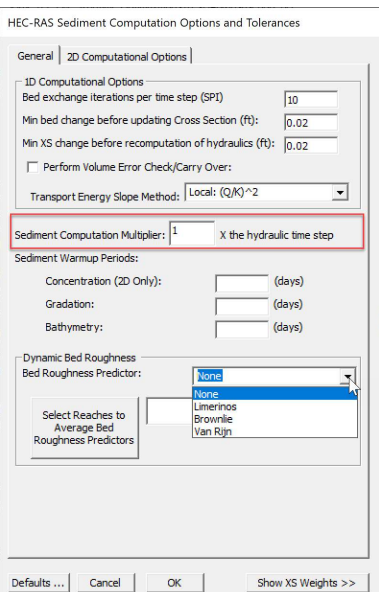
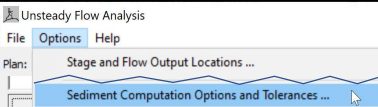
## Optimizing Sediment

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## Sediment Computation Multiplier

- Number of hydraulic time steps within a sediment time step
 
$$\Delta t_{Sed} = m \Delta t_{Hyd}$$
- Multiplier used in adaptive time stepping
- Uses time-average (conservative) fluxes and instantaneous hydraulics
- Output Mapping Interval enforced
- Reduces computational time
- Maximum value
  - Depends on application
  - Typically ranges from 2 to 20
  - Needs validation
- Adaptive scheme coming

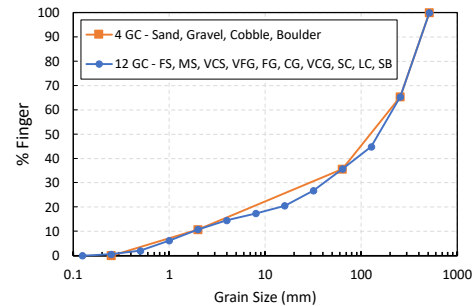
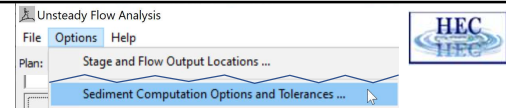
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## Number of Grain Classes

- Sediment Computational approximately proportional to number of grain classes
- However, grain classes are coupled together and solved iteratively
- Number of grain classes can affect convergence and number of iterations
- Reducing number of classes can have a huge impact on computational time
- Start with one grain class and slowly increase number of grain classes



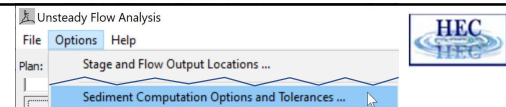
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## Number of Grain Classes

- Default Grain Classes
  - Wentworth (1992) scale
  - Logarithmic with base 2
  - More resolution in the finer particles
  - However, not based on actual particle physics or site-specific bed gradations
- Modeling considerations
  - Cohesive particles erode and often deposit at equal rates due to aggregates and flocs so no need for 5 cohesive grain classes
  - Grain class limits can be better defined using actual bed gradation curves



Define Grain Classes and Sediment Properties									
Sediment Diameters (mm)									
Class	Label	Min	Max	Mean	SG	n	UW	Coh?	De
1	Clay	0.002	0.004	0.003	2.65	0.82	30	1	1
2	VFM	0.004	0.008	0.006	2.65	0.61	65	1	1
3	FM	0.008	0.016	0.011	2.65	0.61	65	1	1
4	MM	0.016	0.032	0.023	2.65	0.61	65	1	1
5	CM	0.032	0.0625	0.045	2.65	0.61	65	1	1
6	VFS	0.0625	0.125	0.088	2.65	0.3	93	0	1
7	FS	0.125	0.25	0.177	2.65	0.3	93	0	0.4
8	MS	0.25	0.5	0.354	2.65	0.3	93	0	0.09
9	CS	0.5	1	0.707	2.65	0.3	93	0	0.09
10	VCS	1	2	1.41	2.65	0.3	93	0	0.09
11	VFG	2	4	2.83	2.65	0.3	93	0	0.09
12	FG	4	8	5.66	2.65	0.3	93	0	0.09
13	MG	8	16	11.3	2.65	0.3	93	0	0.09
14	CG	16	32	22.6	2.65	0.3	93	0	0.09
15	VCG	32	64	45.3	2.65	0.3	93	0	0.09
16	SC	64	128	90.5	2.65	0.3	93	0	0.09
17	LC	128	256	181	2.65	0.3	93	0	0.09
18	SB	256	512	362	2.65	0.3	93	0	0.09
19	MB	512	1024	724	2.65	0.3	93	0	0.09
20	LB	1024	2048	1448	2.65	0.3	93	0	0.09

Currently Default

Density Method: Unit Weight (All Classes)

Enforce Adjacent-Non-Overlapping Grain Classes and Geometric Mean

OK Cancel

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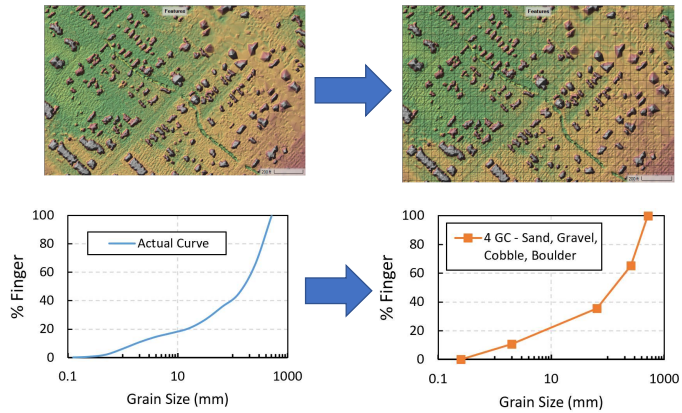
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## Grain Size Distribution



- The **Terrain** is to the **Grid Resolution** as the **Grain Size Distribution** is to the **Grain Classes**
- In other words, the grain classes are analogous to the grid resolution for the grain size distribution



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## Matrix Solver Best Practices





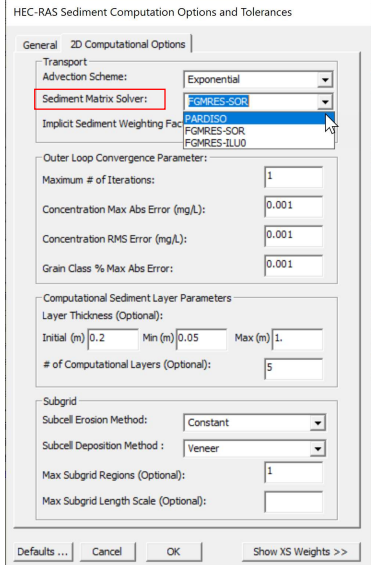
- Start with PARDISO
- Ensure model is stable and not going to max iterations every time step or reporting large water surface or volume errors
- Try FGMRES and SOR solvers
- Start with conservative parameters
- Compare with PARDISO
- Adjust parameters to optimize run time
- Iteration parameters left empty or set to zero are assigned a default value based on mesh size

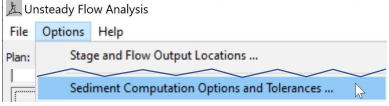
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# Matrix Solver Options







**PARDISO** More Accurate and Stable  
**PFGMRES-SOR** Faster  
**PFGMRES-ILUO**

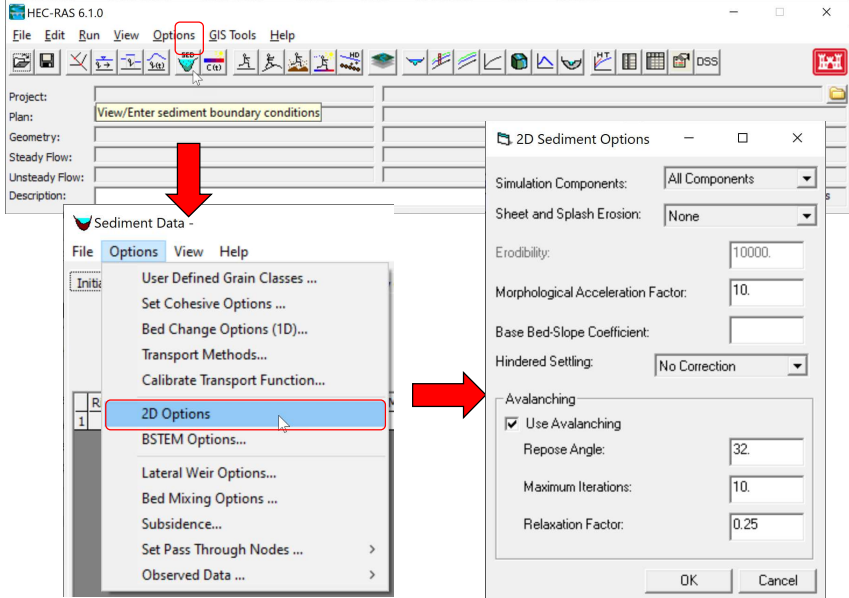
- PFGMRES - Preconditioned Flexible Generalized Minimal RESidual method
- FMRES - Flexible Generalized Minimal RESidual matrix solver
- SOR – Success Over-Relaxation used as the preconditioner (can also be a solver)
- ILUO – Incomplete Lower Upper with Zero Fill-in
- Start with PARDISO and quickly switch to one of the other solvers for speed

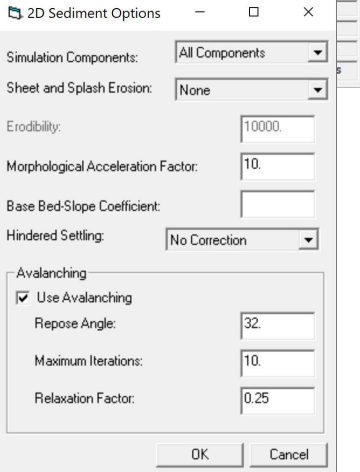
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# 2D Options





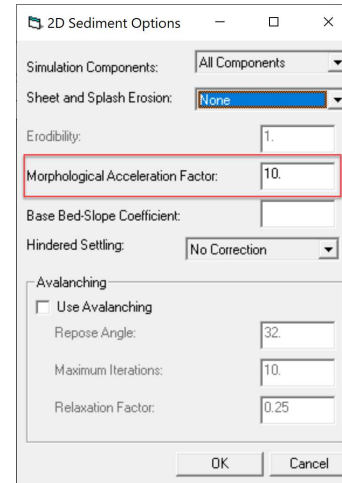
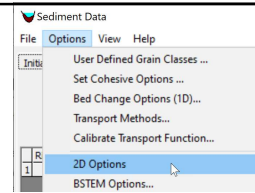
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## Morphologic Acceleration Factor

- Approaches/Uses
  - Turn off bed change
  - Scale bed change
    - Simulation time window and boundary conditions unchanged
    - Modeled bed change represents a factor longer simulated window
    - Best used for periodic boundary conditions
  - Scale time
    - Simulation time window and boundary condition time series scaled
    - Modeled bed change represents unscaled time window results
    - Best used for simulating events



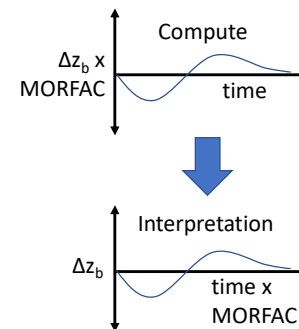
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## MORFAC: Scaling Bed Change

- A period is simulated with real time, but the bed change is representative or scaled time period
- Often used in coastal applications
- For example, a 5-year simulation can be run with MORFAC of 20 to simulate 100 years of change
- Changes the order of events which can have a negative impact on the accuracy of the approach



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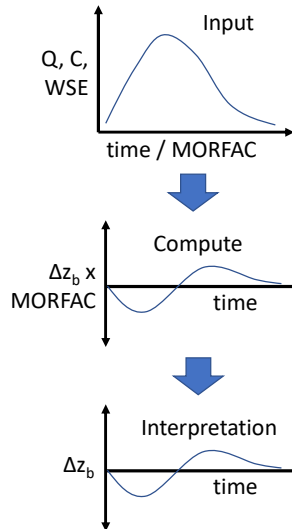
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## MORFAC: Scaling Time



- Simulation time is scaled to speed-up the simulation
- Time in all BC's needs be divided by MORFAC
- For example:  
A 12-month period is scaled to 1 month by dividing time by 12. The bed change is multiplied by 12 in the simulation and represents a year of bed change



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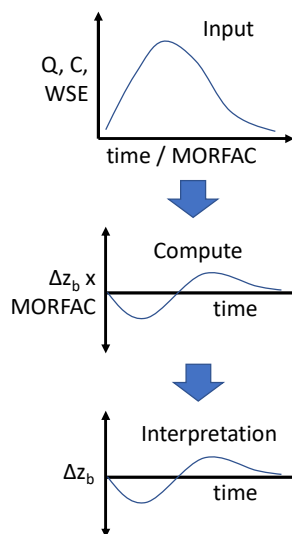
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## MORFAC: Scaling Time

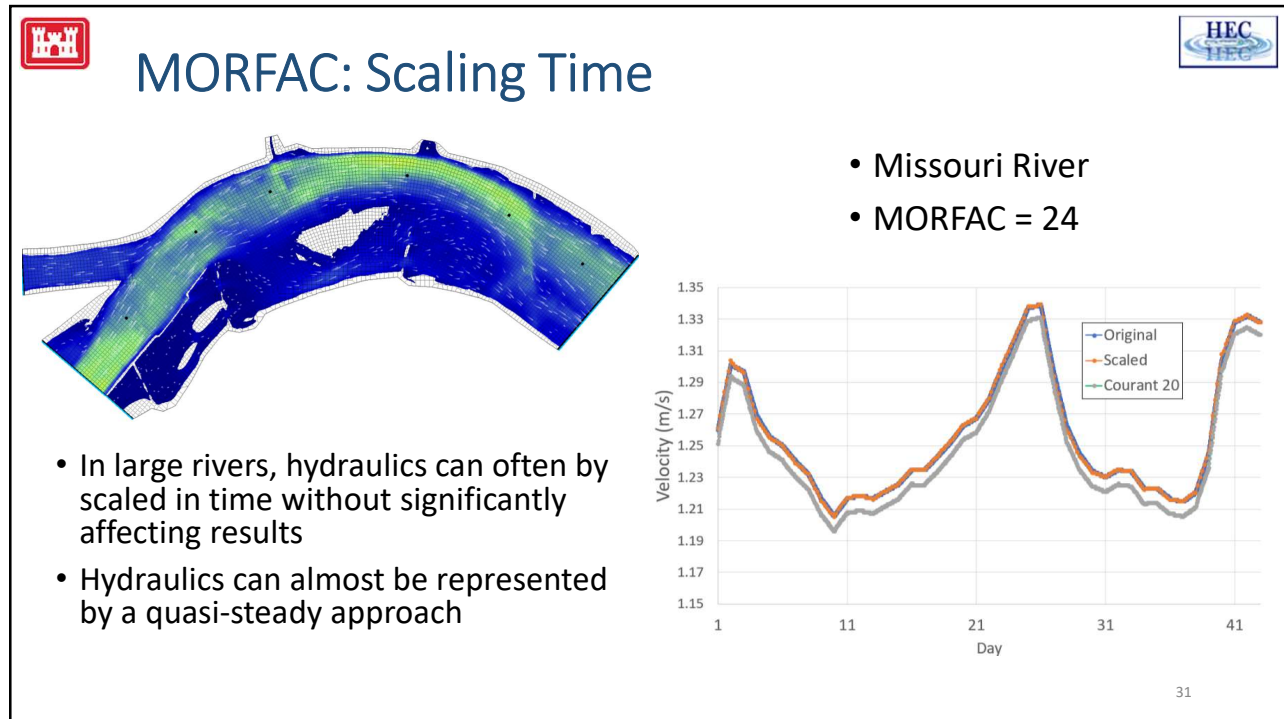


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# Thank You!

HEC-RAS Website:

<https://www.hec.usace.army.mil/software/hecras/>

Online Documentation:

<https://www.hec.usace.army.mil/confluence/rasdocs>



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