A New Competitor in 2D Modeling: Complex Comparison of AdH and HEC-RAS 5.0



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EVOLUTION OF HYDRAULIC MODELING



EVOLUTION OF HYDRAULIC MODELING



WHAT DRIVES CHANGE?



TECHNOLOGY



HEC-RAS 5.0



Why are we doing this presentation?

- Unprecedented Case Study Opportunity
- Extensive calibration to a physical model
- It is rare that we have the ability to compare two models side by side with the same level of scrutiny
- Is HEC-RAS 5.0 all that it claims to be?
 - Is the build and calibration process faster than other 2D models?
 - Is the runtime faster than other 2D models?
 - Do we have confidence in the model results?
 - Are the post processing tools robust enough?
- When do I need a 2D model?

2D Case Study







Site Location





Purpose of Project

Provide aquatic and
hydraulic connectivity of
Maple River across the
Diversion channel while
reducing flooding on the
East side of the Diversion
channel.

 Numeric and Physical modeling was conducted to verify assumptions made during feasibility design and refine the final design.





Project Components

- Aqueduct
- Spillway
- **Relocated Maple River** Channel
- **Bypass Channel**



550

600



Alternatives Evaluation





Analysis

- Hydraulic modeling
 - Physical model
 - 1-D model
 - 2-D model
 - 3-D model



- 1-D unsteady provides flow and boundary conditions
- Physical model used to calibrate the numeric models
- 2-D model focused on the Maple River flow split
- 3-D model focused on the Diversion flow through the conduits



AdH Numeric Model Extents

Full Domain – 5.2 sq. mi.

TruncatedDomain– 0.2 sq. mi.









Test: M4

Tributary Inflow: 8000cfs Diversion Inflow: 5000cfs

Date: January 11, 2015



Why 2D?

Optimization for Complex Flow Patterns

- Aqueduct
- Spillway
- Relocated Maple River Channel
- Bypass Channel





Aqueduct

- Contractions / Expansions
- Recirculation
- Velocity Direction & Magnitude



Spillway





Relocated Channel

- Complex flow patterns
- Recirculation
- Velocity direction & magnitude
- Variable WSEL









Lessons Learned – 2D Case Study

- Challenging to get 1-D, 2-D, 3-D, and Physical models to have good correlation between models
- Your model is only as good as your data
- 2D modeling is very useful for design optimization when complex flow patterns are expected
- Before selecting a 2D model, verify the model capabilities and limitations

CALIBRATION IS CRITICAL !!!

Start Simple...Start Simple...Start Simple



How Does HEC-RAS 5.0 Compare







What's New in HEC-RAS

- 2D St. Venants Shallow Water Equation
 - Momentum additions for turbulence and Coriolis Effect
- Diffusion Wave
 - Faster (More Forgiving Numerically)
 - Greater Stability
 - Inappropriate for Rapid Velocity Change
- Volume Conservation
 - Implicit Finite Volume Solution
 - Implicit = Larger Computation Timestep

Full Saint Venant Equations:

		-	
	<i>C</i> =	$\frac{V * \Delta 7}{\Delta X}$	$- \leq 1.0$ (with a max $C = 3.0$)
Where:C	=	Cour	ant Number
	v	=	Velocity of the Flood Wave (ft/s)
	ΔT	=	Computational Time Step (seconds)
	ΔX	=	The average Cell size (ft)

Diffusion Wave Equations:

$$C = \frac{V * \Delta T}{\Delta X} \le 2.0 \quad (with \ a \max \ C = 5.0)$$

Familiar Platform



Still Looks and Feels Like RAS

- Additional Menus, but familiar setting
- RAS Mapper
- AdH

HEC-RAS 5.0.0

- Learning curve
- BC files, Flux files, .dat files
- SMS makes it easier

لمر Unsteady Flow Analysis	×
File Options Help	
Plan : 2D_LowFlow_5x5_Aq_0.5x0.5 Short ID 5x5_Aq0.5x0.5	
Geometry File : Fargo 2D Validation_5x5_Aq_0.5x0.5	•
Unsteady Flow File : Fargo Trunc Validation_LowFlow	•
Plan Description :	
Programs to Run Iv Geometry Preprocessor Iv Unsteady Flow Simulation Sediment Iv Post Processor Iv Floodplain Mapping	
Simulation Time Window	
Starting Date: 22SEP2008 Starting Time: 0:00	
Computation Settings Computation Interval: 0.5 Second 💌 Hydrograph Output Interval: 5 Minute	•
Mapping Output Interval: 1 Minute 💌 Detailed Output Interval: 5 Minute	•
Computation Level Output	
DSS Output Filename: S:\Water Resources Tech Group\RAS Test Files\Fargo HEC 5.0 2D	Ē
✓ Mixed Flow Regime (see menu: "Options/Mixed Flow Options")	

		,
File Edit Ru	n View Options GISTools Help	Compute
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Project:	Fargo 2D Validation	S:\\Presentation Runs\100YR_5x5 Mesh 0.5x0.5 Aq\Fargo2DValidation.prj
Plan:	2D_LowFlow_5x5_Aq_0.5x0.5	S:\\Presentation Runs\100YR_5x5 Mesh 0.5x0.5 Aq\Fargo2DValidation.p06
Geometry:	Fargo 2D Validation_5x5_Aq_0.5x0.5	S:\\Presentation Runs\100YR_5x5 Mesh 0.5x0.5 Aq\Fargo2DValidation.g05
Steady Flow:		
Unsteady Flow:	Fargo Trunc Validation_LowFlow	S:\\Presentation Runs\100YR_5x5 Mesh 0.5x0.5 Aq\Fargo2DValidation.u02
Description :		HEC-RAS 5.0.0 US Customary Units

AdH Interface

Dayle All	XY1 18 2 3 0 "Flux_Aqueduct_US"	DB LID 33 16 "Flux_Spillway"	Time 8.63047852e+004 Flux-Dt 9.52148438e+001
100	0 0	DB LID 35 17 "Flux_GAP"	String 32 Flux 4.6562e+003 WSE 8.9300e+002 WSEMin 8
10	10 0	DB LID 36 19 "US_Aqueduct_Weir_Ref"	String 34 Flux 0.0000e+000 WSE 0.0000e+000 WSEMin 9
20		NB DIS 37 / Diversion_DS_Aqueduct	String 3/ Flux 5.0011e+003 WSE 8.83/5e+002 WSEMin 8
No	XY1 19 2 3 0 "US_Aqueduct_Weir_Ref"	NB DIS 38 9 Aqueduct weir US	String 39 Flux -1.3840e-003 WSE 8.9051e+002 WSEMIN
A	0 0	NB DIS 39 10 Adueduct Weir DS	String 40 Flux 3.3707e+003 WSE 8.9634e+002 WSEMIN 6
1 1	10 0	DB LID 41 15 Flux_Aqueduct_DS	String 42 Flux 5.00000000 WSE 8.90020+002 WSEMIN a
5.438 cfs		DB LID 43 18 Flux_Adueduct_US	String 45 Elux 3 3694e+003 WSE 8 9560e+002 WSEMin 8
0.100	XX1 20 2 3 0 "comparison Physical Extents DS Diversion"	NB OTW 44 14 Diversion_US_Aqueduct	String 47 Flux 6 2362e+003 WSE 8 9895e+002 WSEMin 8
		DB LID 46 21 Comparison_Physical_Extents_DS_Maple	String 49 Flux 9.6341e+003 WSE 8.8323e+002 WSEMin 8
dawa60	10.0	DB LID 48 22 Comparison_Physical_Extents_OS_Maple	String 51 Flux 0.0000e+000 WSE 0.0000e+000 WSEMin 8
A State	10 0	UB DIG 10 20 Comparison_Physical_extends_bs_biversion	String 52 Flux 0.0000e+000 WSE 0.0000e+000 WSEMin 8
S	VV/L 21 2 2 0 "companies physical sytemate ps Maple"	NB DIS SI 2 DIV_SC-27 (RUSH SASO LO SASA)	String 53 Flux 0.0000e+000 WSE 0.0000e+000 WSEMin 8
	XTI ZI Z S O Compartson_Physical_Extends_bs_Mapre	NB DIS 52 I RUSH_SC-I20 (RUSH SA30 to SA43)	String 54 Flux 0.0000e+000 WSE 0.0000e+000 WSEMin 8
the officer of	00	NB DIS 33 II RUSH_ES-2//IZ	String 55 Flux 6.4000e+003 WSE 9.0256e+002 WSEMin 9
The state of	10 0	NB DIS 34 3 KUSH SC-34 & KUSH SC-100 (KUSH SA-13)	String 56 Flux 1.5003e+003 WSE 9.0104e+002 WSEMin 9
		NB DIS 554 Mapre_05_X5-55955	String 57 Flux 1.0000e+002 WSE 9.0110e+002 WSEMin 9
	XY1 22 2 3 0 "Comparison_Physical_Extents_US_Maple"	NB DIS 30 3 MpSSC-341 + MpSSC-329	String 58 Flux 5.0000e+003 WSE 8.8405e+002 WSEMin 8
	0 0	NB DIS 37 0 MPSSC-330 NB DIS 58 8 "Diversion US demain"	String 59 Flux -3.3689e+003 WSE 8.9410e+002 WSEMin
	10 0	NB DIS 56 6 Diversion_05_domain	String 60 Flux -9.6322e+003 WSE 8.8212e+002 WSEMINI
		NB OTW 59 12 "Diversion DS demain"	Time 8.64000000e+004 Flux-Dt 9.52148438e+001
	XY1 23 2 3 0 "Time Step Sizes"		string 32 Flux 4.03090+003 WSE 0.95000+002 WSEMIN a
	0.0 300.0	ELX 32 "Elux spillway"	String 37 Elux 5.0009e+003 WSE 8.8375e+002 WSEMin 8
	24.0 300.0	ELX 34 "Elux GAP"	String 39 Flux -4 6288e-004 WSE 8 9659e+002 WSEMin
		ELX 37 "Diversion DS Aqueduct"	String 40 Flux 3.3705e+003 WSE 8.9634e+002 WSEMin 8
	05 24 1 0	FLX 39 "Aqueduct Weir DS"	String 42 Flux 3.3706e+003 WSE 8.9682e+002 WSEMin 8
	0 0 24 0 1 2	FLX 40 "Flux Aqueduct DS"	String 44 Flux -5.0000e+003 WSE 8.8350e+002 WSEMin
		FLX 42 "Flux Aqueduct US"	String 45 Flux 3.3694e+003 WSE 8.9560e+002 WSEMin 8
	ER MNG 1 0 025 "channel"	FLX 44 "Diversion US Aqueduct"	String 47 Flux 6.2413e+003 WSE 8.9895e+002 WSEMin 8
	FR MMG 1 0.025 "Concrete Spillway Crost"	FLX 45 "Comparison Physical Extents DS Maple"	String 49 Flux 9.6351e+003 WSE 8.8323e+002 WSEMin 8
	FR MMG 2 0.030 Concrete Sprinway Crest	FLX 47 "Comparison Physical Extents US Maple"	String 51 Flux 0.0000e+000 WSE 0.0000e+000 WSEMin 8
	FR MNG 5 0.045 Channel_vegetation	FLX 49 "Comparison_Physical_Extents_D5_Diversion"	String 52 Flux 0.0000e+000 WSE 0.0000e+000 WSEMin 8
	FR MNG 4 0.03 EMB	FLX 51 "DIV_SC-27 (Rush SA36 to SA34)"	String 53 Flux 0.0000e+000 WSE 0.0000e+000 WSEMin a
	FR MNG 5 0.015 DS_wingwall	FLX 52 "Rush_SC-120 (Rush SA50 to SA45)"	string 54 Flux 6.4000e+000 WSE 0.0000e+000 WSEMIN a
	FR MNG 6 0.03 Diversion Channel	FLX 53 "Rush_LS-27712"	string 55 Flux 0.4000e+005 WSE 9.0250e+002 WSEMIN 9
	FR MNG / 0.03 "LowFlowChannel"	FLX 54 "Rush SC-34 & Rush SC-106 (Rush SA-15)"	String 57 Flux 0.000201001 WSE 0.010404002 WSEMin 0
	FR MNG 8 0.03 "Spillway"	FLX 55 "Maple_US_XS-35955"	String 58 Flux 5.0000e+003 WSE 8.8405e+002 WSEMin 8
	FR MNG 9 0.03 "Grass"	FLX 56 "MpSSC-541 + MpSSC-529"	String 59 Flux -3.3689e+003 WSE 8.9410e+002 WSEMin
	FR MNG 10 0.015 "US_Wingwall"	FLX 57 "MpSSC-530"	String 60 Flux -9.6320e+003 WSE 8.8212e+002 WSEMin
	FR MNG 11 0.04 "Aqueduct"	FLX 58 "Diversion_US_domain"	
	FR MNG 12 0.04 "Ditch"	FLX 59 "Maple_DS_BR-14481"	
	co wie 12 0 015 "comik privak"	FLX 60 "Diversion_D5_domain"	
		TC TO 0.0.0 "01/15/2014 10:42:24 AM"	
		TC TDT 23	
		TC TE 24.0 2	

VERSTON	#/ 2
VERSION	#4.5

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HYD HYD HYD	-	1.20000 1.20000 1.20000	000e+003 000e+003 000e+003	3.000000e+002 %1 3.000000e+002 %1 3.000000e+002 %1	.39 .39 .39	1 0 2 0 3 0	2.2780e+006 3.3785e+005 2.0689e+005	38655 36996 36198	2.85167004e+006 2.85164239e+006 2.85164459e+006	4.80615665e+005 4.80627534e+005 4.80632788e+005	8.9428e+002 8.9596e+002 8.9567e+002	2.5553e+001 1.9340e+001 1.2123e+001	38655 36996 37812

Mesh Generation





Boundary Conditions



Starting Conditions

- Initial WSEL (Hot Start)
 - AdH
 - Critical to model stability
 - Must start WET
 - HEC-RAS
 - Optional (Additional Tool to Increase Stability)
 - Can start DRY
 - May need warm up period





Which Build is Faster? Dependent on Familiarity With Model

AdH

- Mesh Generation Requires More Detail at Startup
- Regional Mesh Density

HEC-RAS

- Draw a Polygon and Run
 - Refine Through Break Lines
- Both use GIS to expedite process





Computational Time

- Preliminary Runs 6 hours
- Final Refined Product 1-2 hours
- Timestep = 300 sec(average timestep = 1sec)
- 16 Core processor
- Mesh Density = 1ft to 40 ft

HEC-RAS

AdH

- Final Product 24 hours
- Timestep = 0.2 sec
- 16 Core processor
- Mesh Density = 1ft to 5 ft





Mesh Density - Number of Elements

Affects Computation Time!!

AdH Truncated Model 239,338 HEC-RAS Truncated Model 399,616 AdH Full Domain Model 437,338



Mesh Quality Affects Stability and Results !

- What are we looking for?
 - Mesh error (i.e. area change, angle, connecting elements)
 - Density
 - Boundary Sensitivity
 - Land Use
- Iterative Process!
- Both Make Identifying Mesh Errors Simple
- MbA 📓
 - Terrain Errors Slip Through
 - Often aren't caught until a model is completed
 - Export data while running
- HEC-RAS
 - Wait until it's done







Results Comparison



Viewing Results-AdH

- Observation
 Lines & Nodes
- Data Calculator
 - WSEL is calculated
 - Data Filter
- Output Flux





Viewing Results – RAS Mapper

- Observation Line Hiccups
 - Discharge Internal Flux Observation
- Output is currently limited





WSEL Results Comparison Which one is correct?

896.00

2D Model Calibration WSEL Comparison

HEC-RAS 5.0 (Beta) Water Surface Profiles







Results Comparison Which one is correct?

HEC-RAS 5.0 (Beta) Velocity Magnitude & Distribution



Size Matters! WSEL





Size Matters! Velocity



HEC-RAS 5.0







HEC-RAS 5.0

AdH





2-D Results – Aqueduct Velocity





HEC-RAS 5.0





HEC-RAS 5.0



AdH





Sensitivity Analysis



HEC-RAS Variable Sensitivity - WSEL

2D Model Calibration Bank Full WSEL Sensitivity Comparison





2

Variable Sensitivity - Velocity Base Model



Wall Roughness (Weir Boundary)





AdH Flow Split Sensitivity Analysis

2D M4 Tailwater and Manning's "n" Sensitivity Analysis							
	Plot Title	M4 HTW H"n" (WSEL)	M4 HTW L"n" (WSEL)	M4 LTW H"n" (WSEL)	M4 LTW L"n"(WSEL)	M4 LTW Physical "n"(WSEL)	
	TW Curve	Unsteady HEC-RAS	Unsteady HEC-RAS	Steady HEC-RAS	Steady HEC-RAS	Steady HEC-RAS	
	DS Maple WSEL (ft)	891.56	895.04	891.19	894.10	894.57	
	Spillway Control Elevation	894.00	894.00	894.00	894.00	894.00	
Sensitivity Variables	LS 22940 Overbank Elevation	899.00	899.00	899.00	899.00	899.00	
variables	Aqueduct "n"	0.08	0.040	0.08	0.040	0.015	
	US Aqueduct Approach "n"	0.08	0.040	0.08	0.040	0.015	
	DS Aqueduct Exit "n"	0.08	0.040	0.08	0.040	0.015	
	Engineered Channel "n"	0.045	0.045	0.045	0.045	0.029	
	US Maple Flow (cfs)	8000.00	8000.00	8000.00	8000.00	8000.00	
	Spillway Flow (cfs)	6369.00	4850.00	6368.00	4651.00	4194.00	
	Total DIVSA40 Outflow	3167.24	3033.16	3165.97	3013.35	2703.63	
Boundary Flux	Total DIVSA40 Inflow From Maple	1479.72	1377.35	1480.11	1364.38	1103.00	
Output	LS Discharge to Relocated Channel(cfs)	1806.59	1649.72	1803.37	1634.95	1597.73	
	Discharge to Risk Reduction Area (cfs)	1633.00	3160.00	1643.00	3369.00	3830.00	



Roughness Sensitivity



Significant Impact on Overbank and Spillway flows





Lessons Learned / Modeling Limitations



AdH - Hydraulic Structures



10.5 17.5 24.5 31.5 38.5 45.5 52.5 59.5 66.5

73.5 80.5

87.5

94.5

101.5

108.5

115.5

122.

129.5

136.5

143.5

150.5

157. 164.

171.5

178.5

185.5 192.5

199.5

206.5

213.5

220.5

227.5

234.5

241.5

HEC-RAS – Hydraulic Structures





Culvert Data Editor						
Add Copy	Delete Culvert ID	Culvert #1				
Solution Criteria:	Highest U.S. EG 🔹	Rename 🖡 🕇				
Shape: Circular	▼ Span:	Diameter:				

Chart 1 - Concrete Pipe Culvert					
Scale #: 1 - Square edg	e entrance wit	h headwall 🗾			
		Upstream Invert Elev:			
Culvert Length:		Downstream Invert			
Entrance Loss Coeff:	2	# identical barrels : 0			
Exit Loss Coeff:	1	Centerline Stations			
Manning's n for Top:	2	Upstream Downstream			
Manning's n for Bottom:		1			
Depth to use Bottom n:	0	3			
Depth Blocked:	0	4			
	O	K Cancel Help			
Select culvert to edit					

• Connect	tion Data Editor - Combine	d				_ 🗆 ×
File View	Help					
Connection:	Spillway_US	→ ↓ ↑	Apply Data			
Description				Breach (plan	data)	
Connection	IS			-		
From:	2D flow area: Maple		Set SA/2D	Weir Length:	485.06	
To:	2D flow area: Spillway		Set SA/2D	Centerline Length:	484.44	
-						
				Centerline GIS	Coords	
Structure Typ	pe: Weir 💌	Compute flow each	time step 🛛 💌	Terrain Pro	file	
Weir / Embaikment			Spillway US			-
HTab						
Param.	900 T				1	Legend
						Spillway
	899					Centerline Terrain
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atic .	897					
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	894	0 200	300	0 400	50	00
			Station (ft)			v
4						Þ
Belect conne	ction to Edit					

Connections	I					
From:	2D flow area: Diversion	Set SA/2D				
To:	2D flow area: Diversion	Set SA/2D				
Overflow Computation Method Normal 2D Equation Domain Use Weir Equation						
Structure Type:						





HEC-RAS 5.0



Tools Data Calculator -Data Sets Time Steps - Math Compare datasets - Mesh Data Calculator Z d1. elevation Angle convention DD15_T9_Con12_Full_M4 - Spatial 123 d2. Depth_Filtered Geometry 123 d3. M4 WSEL Grid Spacing 123 d4. ITL Depth Difference - Temporal Sample time steps 123 d5. ITL Velocity Difference Compute derivative 123 d6. x location Merge datasets 123 d7. y location - Conversion Scalar to Vector - Coastal Wave Length and Celerity Gravity Waves Use all time steps - Modification Map activity Calculator Filter min 1 (* In x^y max log sqrt ave Add to Expression Data Set Info... + 1/x abs trunc Update Available Tools Output dataset name: new dataset Compute

AdH

$$\tau = \rho g n^2 \frac{v^2}{R^{1/3}}$$





Summary

- Time!
- HEC-RAS 5.0 is still BETA HERE!



- Verification of model capabilities and limitations
- What could we have done differently
- What are we looking for in the future
- Still wondering how to choose Manning's 'n' and Eddy Viscosity parameters?
- Calibration is critical model parameters vary



Eddy Viscosity and Manning's "n"





Would I recommend HEC-RAS 5.0 (in its current form) for a project of this complexity?





Press Release... HEC-RAS 5.0 Released



Questions

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Flow Arrows Showing Flow Over Weir



	Required Weir Cre Edge	st Length to Eliminate Jets (M4)	Spillway Invert V	Width (At Weir Base)	Required Weir to Spillway Base Ratio to Eliminate Edge Jets (M4)
Weirs	Model Scale (ft)	Prototype Scale (ft)	Model Scale (ft)	Prototype Scale (ft)	
Control	5.68	284			1.29
Middle	5.41	270.5	4.4	220	1.23
Lower	4.98	249			1.13