September 11, 2025

LOMR Modeling Requirements

Breaking Down the Hydraulic Analysis

Indiana Department of Natural Resources

Paul Brayton
Hydraulic Engineer
Division of Water

Introduction

Indiana DNR LOMR Review Partners Team

Danielle Bowman – Hydraulic Engineer
Paul Brayton - Hydraulic Engineer
Aung Htut – Hydraulic Engineer
Morgan Lucas – Hydraulic Engineer

- Adam Bales – Program Manager
- Deidre Hansen – Project Manager

DNR Indiana Department of Natural Resources | DIVISION OF WATER

Introduction

- In 2019, FEMA opened the LOMR Review Partners Program to new partners.
- In 2022, DNR began processing LOMRs and CLOMRs as part of this program.

- We do not review:
  - LOMAs/MT-1 Requests
  - MT-2 Requests with levees, floodwalls, or multi-state cases.
    - We still must give State Concurrence!

Inventory

MT-2 Form 2

B. HYDRAULICS

1. Reach to be Revised

	Description	Cross Section	Water-Surface Elevation (ft.) Effective	Water-Surface Elevation (ft.) Proposed/Revised
Downstream Limit*				
Upstream Limit*				

*Proposed/Revised elevations must tie-into the Effective elevations within 0.5 foot at the downstream and upstream limits of revision.

2. Hydraulic Method/Model Used: _____

☐ Steady State ☐ Unsteady State ☐ One-Dimensional ☐ Two-Dimentional

3. Pre-Submittal Review of Hydraulic Models*

DHS-FEMA has developed two review programs, CHECK-2 and CHECK-RAS, to aid in the review of HEC-2 and HEC-RAS hydraulic models, respectively. We recommend that you review your HEC-2 and HEC-RAS models with CHECK-2 and CHECK-RAS.

4. HEC-RAS File Description**:

Models Submitted	Natural Run		Floodway Run		Datum
Duplicate Effective Model*	File Name:	Plan Name:	File Name:	Plan Name:	
Corrected Effective Model*	File Name:	Plan Name:	File Name:	Plan Name:	
Existing or Pre-Project Conditions Model	File Name:	Plan Name:	File Name:	Plan Name:	
Revised or Post-Project Conditions Model	File Name:	Plan Name:	File Name:	Plan Name:	
Other - (attach description)	File Name:	Plan Name:	File Name:	Plan Name:	

* For details, refer to the corresponding section of the instructions.
**See instructions for information about modeling other then HEC-RAS. ☐ Digital Models Submitted? (Required)

(FEMA, 2023), (FEMA, 2025)

DNR Indiana Department of Natural Resources | DIVISION OF WATER

Inventory

Acceptable Software

- HEC-RAS v3.1.1*
- HEC-RAS v4.1.0
- HEC-RAS v5
- HEC-RAS v6.2.1*
- Check-RAS
- RAS-Plot v3.0
- HY-8 v4.1 and newer
- Others

No Longer Accepted

- HEC-2
- ICPR
- FLOW2D
- WSP2
- Others

(FEMA, 2025)

Inventory

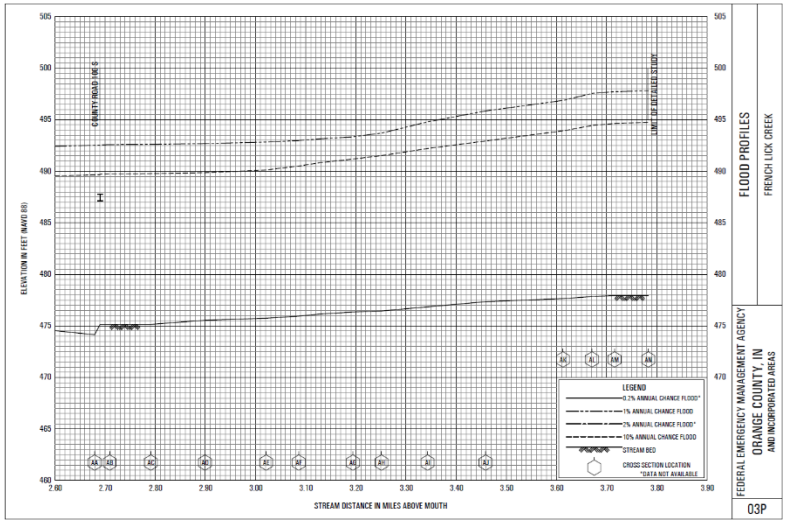
Effective Recurrence Intervals

Table 10. Summary of Discharges

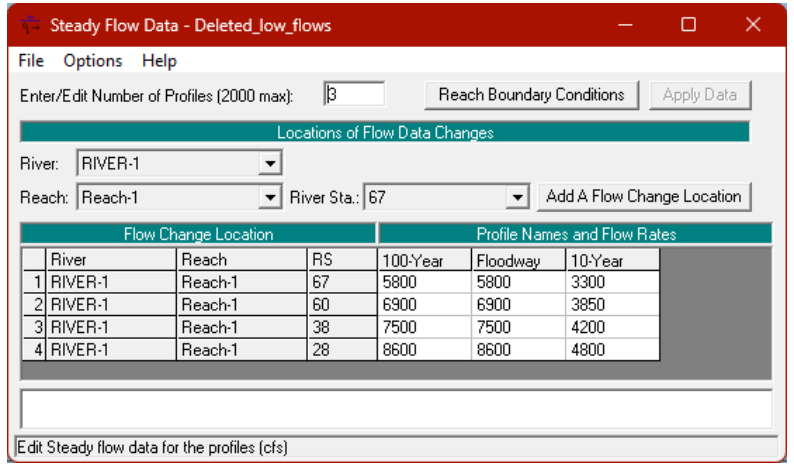
Flooding Source And Location	Drainage Area (Square Miles)	Peak Discharge (CFS) 10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
French Lick Creek					
1700' Downstream of SR 53	35	4,800	*	8,600	*
700' Downstream of College St	29	4,200	*	7,500	*
2700' Upstream of CR 100S	25.5	3,850	*	6,900	*
1.1 miles Upstream of CR 100S	20	3,300	*	5,800	*
Lick Creek					
1300' Downstream of Willowcreek Dr	25	4600	*	8700	*
Willowcreek Dr	22.5	4400	*	8200	*
1.2 miles Upstream of Gospel St	20	4200	*	7800	*
2300' Upstream of Belle Ford Rd	13	3400	*	6300	*

*Discharge was not calculated

FIS Summary of Discharges Table



FIS Flood Profile



Effective Model Flow File

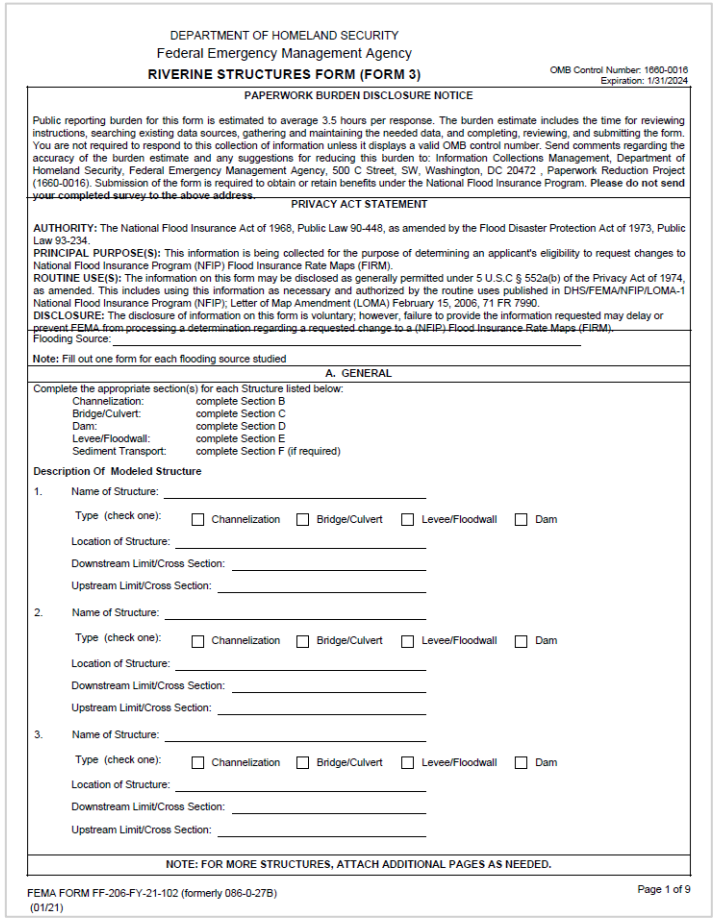
(FEMA, 2024), (FEMA,2014)

DNR Indiana Department of Natural Resources | DIVISION OF WATER

Inventory

Riverine Structures

- General
  - Proposed/New
  - Not in Effective Model
- Channelization
  - Reason for Analysis
  - PLANS
  - Sediment transport
- Bridge/Culvert
  - Reason for Analysis
  - PLANS
  - Input Parameters



DEPARTMENT OF HOMELAND SECURITY
Federal Emergency Management Agency
RIVERINE STRUCTURES FORM (FORM 3)
OMB Control Number: 1660-0016
Expiration: 1/31/2024

PAPERWORK BURDEN DISCLOSURE NOTICE

Public reporting burden for this form is estimated to average 3.5 hours per response. The burden estimate includes the time for reviewing instructions, searching existing data sources, gathering and maintaining the needed data, and completing, reviewing, and submitting the form. You are not required to respond to this collection of information unless it displays a valid OMB control number. Send comments regarding the accuracy of the burden estimate and any suggestions for reducing this burden to: Information Collections Management, Department of Homeland Security, Federal Emergency Management Agency, 500 C Street, SW, Washington, DC 20472 , Paperwork Reduction Project (1660-0016). Submission of the form is required to obtain or retain benefits under the National Flood Insurance Program. **Please do not send your completed survey to the above address.**

PRIVACY ACT STATEMENT

AUTHORITY: The National Flood Insurance Act of 1968, Public Law 90-448, as amended by the Flood Disaster Protection Act of 1973, Public Law 93-234.
PRINCIPAL PURPOSE(S): This information is being collected for the purpose of determining an applicant's eligibility to request changes to National Flood Insurance Program (NFIP) Flood Insurance Rate Maps (FIRM).
ROUTINE USE(S): The information on this form may be disclosed as generally permitted under 5 U.S.C § 552a(b) of the Privacy Act of 1974, as amended. This includes using this information as necessary and authorized by the routine uses published in DHS/FEMA/NFIP/LOMA-1 National Flood Insurance Program (NFIP); Letter of Map Amendment (LOMA) February 15, 2006, 71 FR 7990.
DISCLOSURE: The disclosure of information on this form is voluntary; however, failure to provide the information requested may delay or prevent FEMA from processing a determination regarding a requested change to a (NFIP) Flood Insurance Rate Maps (FIRM).

Flooding Source: _____

Note: Fill out one form for each flooding source studied

A. GENERAL

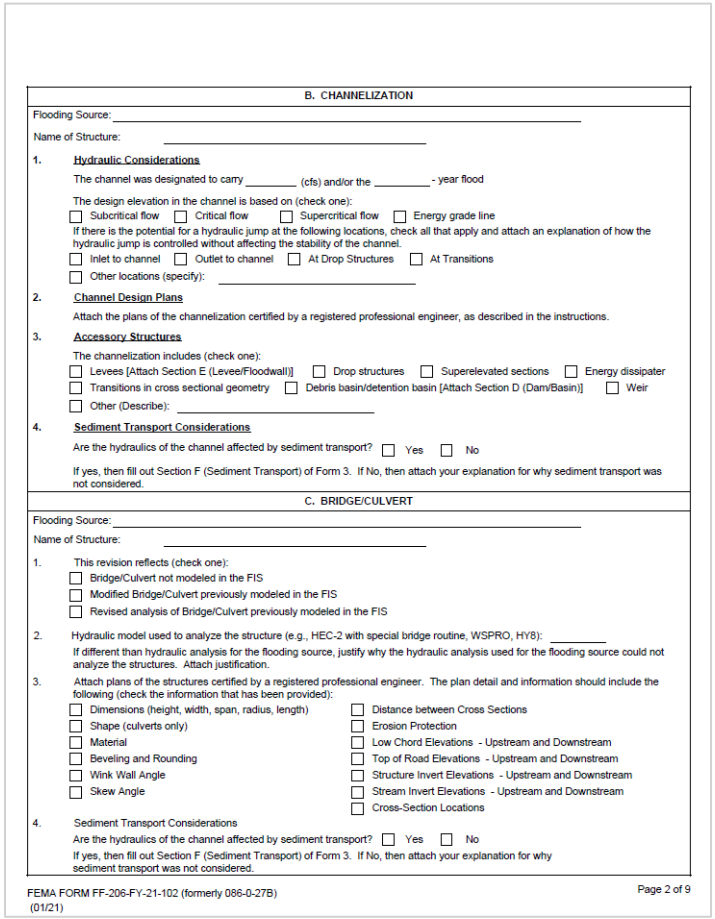
Complete the appropriate section(s) for each Structure listed below:
Channelization: complete Section B
Bridge/Culvert: complete Section C
Dam: complete Section D
Levee/Floodwall: complete Section E
Sediment Transport: complete Section F (if required)

Description Of Modeled Structure

1. Name of Structure: _____
   Type (check one): ☐ Channelization ☐ Bridge/Culvert ☐ Levee/Floodwall ☐ Dam
   Location of Structure: _____
   Downstream Limit/Cross Section: _____
   Upstream Limit/Cross Section: _____
2. Name of Structure: _____
   Type (check one): ☐ Channelization ☐ Bridge/Culvert ☐ Levee/Floodwall ☐ Dam
   Location of Structure: _____
   Downstream Limit/Cross Section: _____
   Upstream Limit/Cross Section: _____
3. Name of Structure: _____
   Type (check one): ☐ Channelization ☐ Bridge/Culvert ☐ Levee/Floodwall ☐ Dam
   Location of Structure: _____
   Downstream Limit/Cross Section: _____
   Upstream Limit/Cross Section: _____

NOTE: FOR MORE STRUCTURES, ATTACH ADDITIONAL PAGES AS NEEDED.

FEMA FORM FF-206-FY-21-102 (formerly 086-0-27B)
(01/21)
Page 1 of 9



B. CHANNELIZATION

Flooding Source: _____
Name of Structure: _____

1. **Hydraulic Considerations**
   The channel was designated to carry _____ (cfs) and/or the _____ - year flood
   The design elevation in the channel is based on (check one):
   ☐ Subcritical flow ☐ Critical flow ☐ Supercritical flow ☐ Energy grade line
   If there is the potential for a hydraulic jump at the following locations, check all that apply and attach an explanation of how the hydraulic jump is controlled without affecting the stability of the channel.
   ☐ Inlet to channel ☐ Outlet to channel ☐ At Drop Structures ☐ At Transitions
   ☐ Other locations (specify): _____
2. **Channel Design Plans**
   Attach the plans of the channelization certified by a registered professional engineer, as described in the instructions.
3. **Accessory Structures**
   The channelization includes (check one):
   ☐ Levees [Attach Section E (Levee/Floodwall)] ☐ Drop structures ☐ Superelevated sections ☐ Energy dissipater
   ☐ Transitions in cross sectional geometry ☐ Debris basin/detention basin [Attach Section D (Dam/Basin)] ☐ Weir
   ☐ Other (Describe): _____
4. **Sediment Transport Considerations**
   Are the hydraulics of the channel affected by sediment transport? ☐ Yes ☐ No
   If yes, then fill out Section F (Sediment Transport) of Form 3. If No, then attach your explanation for why sediment transport was not considered.

C. BRIDGE/CULVERT

Flooding Source: _____
Name of Structure: _____

1. This revision reflects (check one):
   ☐ Bridge/Culvert not modeled in the FIS
   ☐ Modified Bridge/Culvert previously modeled in the FIS
   ☐ Revised analysis of Bridge/Culvert previously modeled in the FIS
2. Hydraulic model used to analyze the structure (e.g., HEC-2 with special bridge routine, WSPRO, HY8): _____
   If different than hydraulic analysis for the flooding source, justify why the hydraulic analysis used for the flooding source could not analyze the structures. Attach justification.
3. Attach plans of the structures certified by a registered professional engineer. The plan detail and information should include the following (check the information that has been provided):
   ☐ Dimensions (height, width, span, radius, length)
   ☐ Shape (culverts only)
   ☐ Material
   ☐ Beveling and Rounding
   ☐ Wink Wall Angle
   ☐ Skew Angle
   ☐ Distance between Cross Sections
   ☐ Erosion Protection
   ☐ Low Chord Elevations - Upstream and Downstream
   ☐ Top of Road Elevations - Upstream and Downstream
   ☐ Structure Invert Elevations - Upstream and Downstream
   ☐ Stream Invert Elevations - Upstream and Downstream
   ☐ Cross-Section Locations
4. Sediment Transport Considerations
   Are the hydraulics of the channel affected by sediment transport? ☐ Yes ☐ No
   If yes, then fill out Section F (Sediment Transport) of Form 3. If No, then attach your explanation for why sediment transport was not considered.

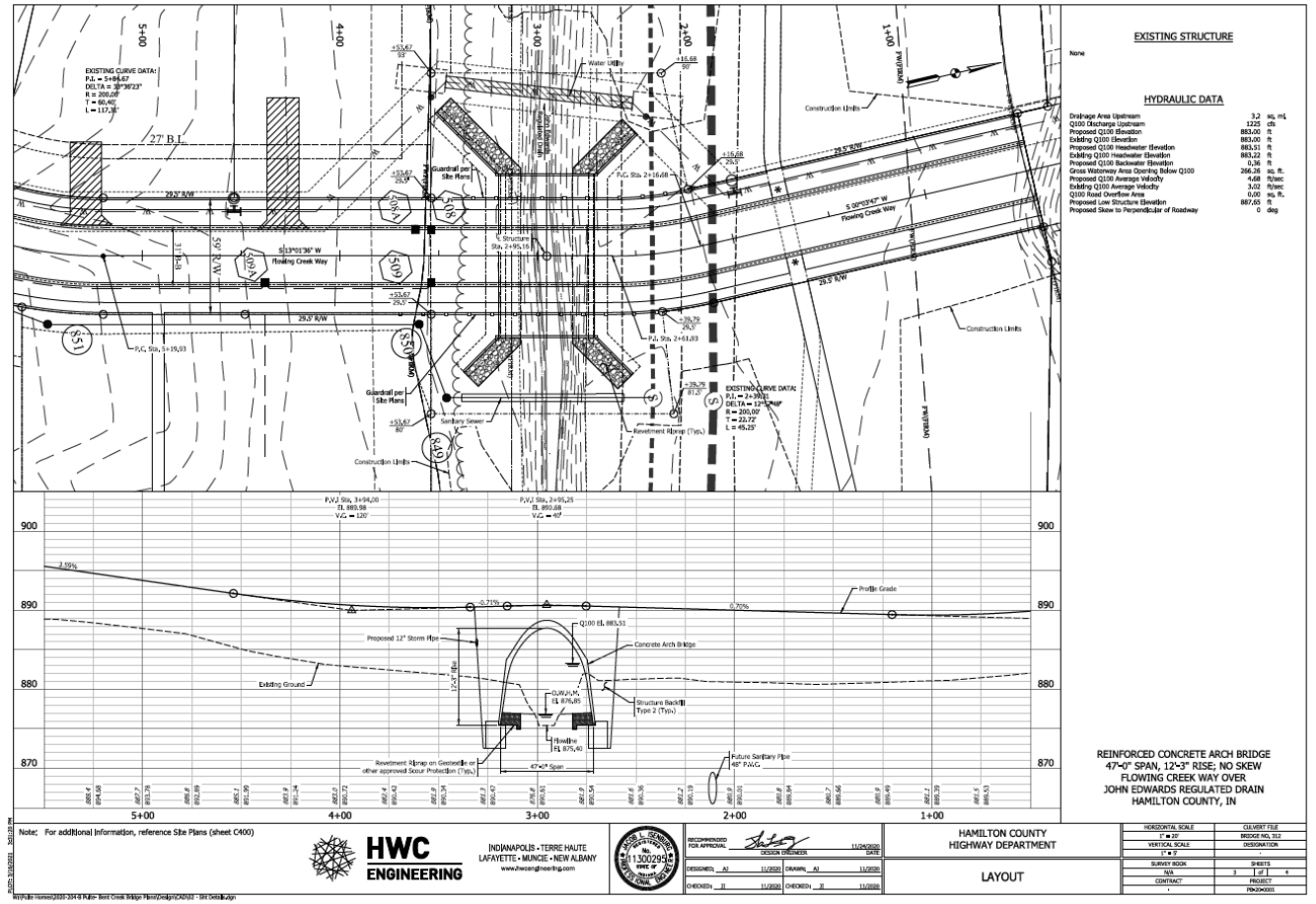
FEMA FORM FF-206-FY-21-102 (formerly 086-0-27B)
(01/21)
Page 2 of 9

DNR Indiana Department of Natural Resources | DIVISION OF WATER

Inventory

Plans

- CLOMR
  - Not Certified
- LOMR
  - Must be Certified
- Used to Verify Input Geometry
- Meet Data Capture and Elevation Guidance



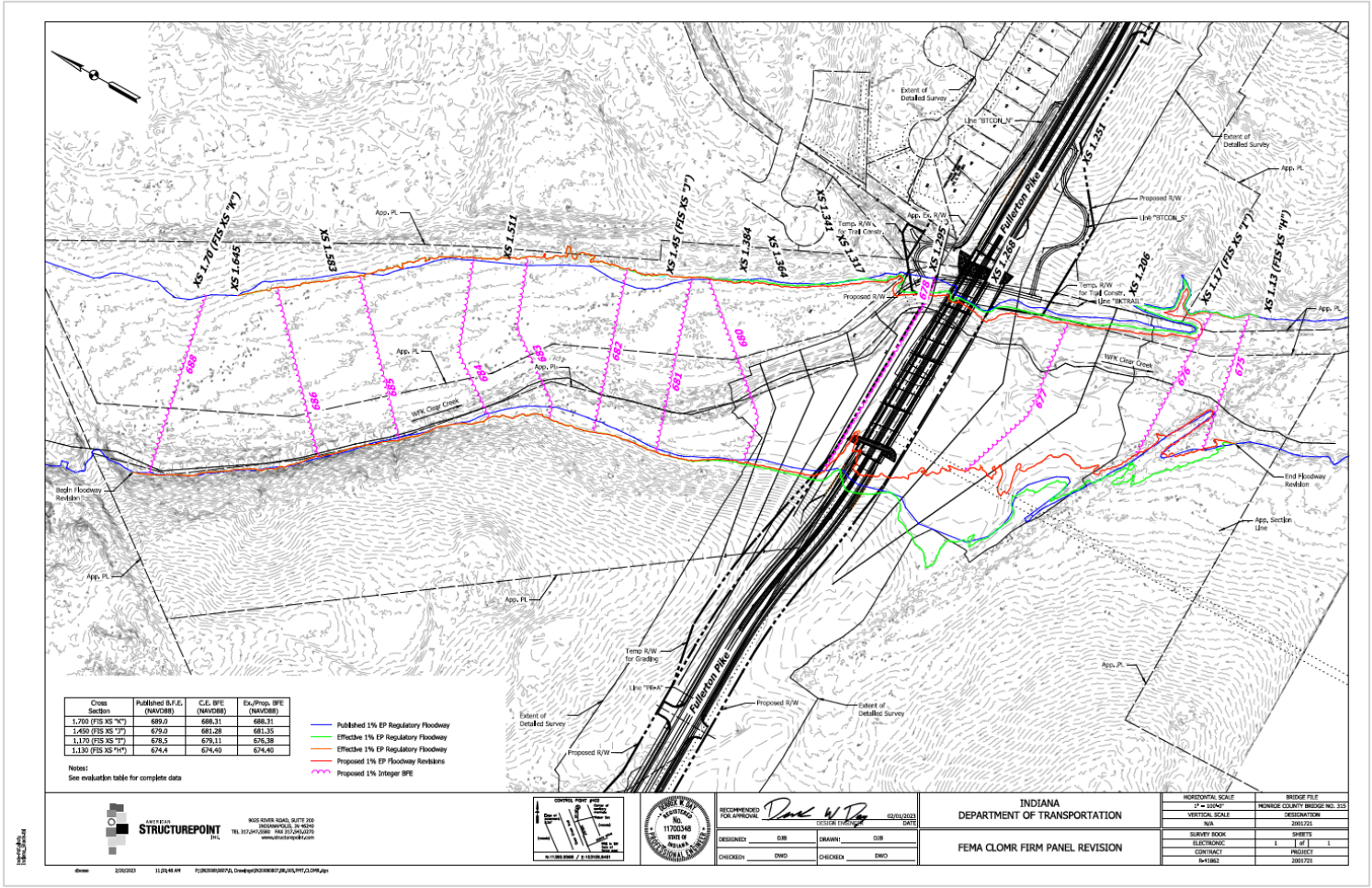
(FEMA, 2024)

DNR Indiana Department of Natural Resources | DIVISION OF WATER

Inventory

Topographic Work map

- Revised Delineation
- Effective Delineation
- Graphical Tie In of Delineations
- Topographic Contours w/ Labels
- Vertical Datum and North Arrow
- Locations and Alignment of Cross Sections
- Flow Line used in Model
- Engineer's Certification
  - Also for CLOMRs
  - For Data Submitted not Post Project Conditions



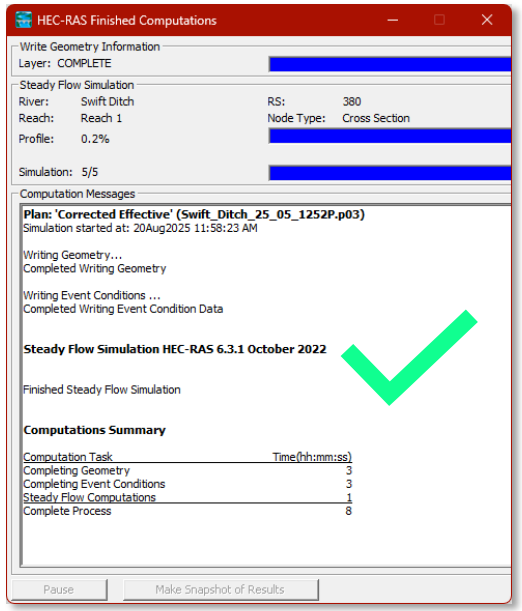
(FEMA, 2023)

DNR Indiana Department of Natural Resources | DIVISION OF WATER

Review

Questions to ask:

- Do all the Plans Run?
- Are the Flows Placed in the Correct Place per the Software User's Manual?



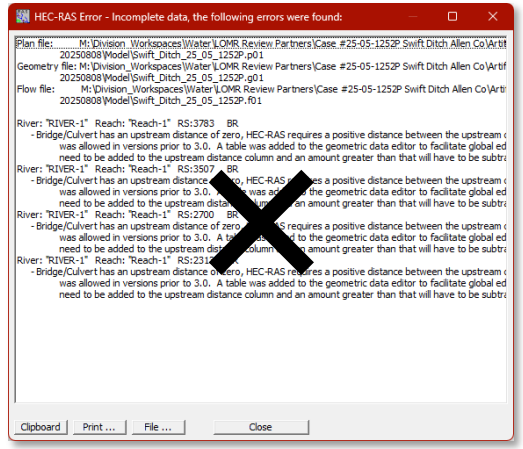
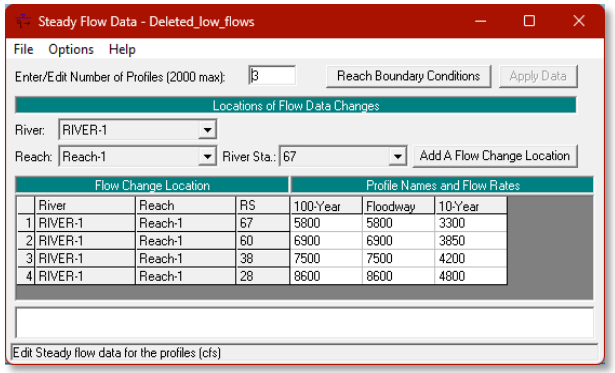


Table 10. Summary of Discharges

Flooding Source And Location	Drainage Area (Square Miles)	Peak Discharge (CFS) 10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
French Lick Creek					
1700' Downstream of SR 53	35	4,800	*	8,600	*
700' Downstream of College St	29	4,200	*	7,500	*
2700' Upstream of CR 100S	25.5	3,850	*	6,900	*
1.1 miles Upstream of CR 100S	20	3,300	*	5,800	*
Lick Creek					
1300' Downstream of Willowcreek Dr	25	4600	*	8700	*
Willowcreek Dr	22.5	4400	*	8200	*
1.2 miles Upstream of Gospel St	20	4200	*	7800	*
2300' Upstream of Belle Ford Rd	13	3400	*	6300	*

*Discharge was not calculated



DNR Indiana Department of Natural Resources | DIVISION OF WATER

Review

Duplicate Effective

- Confirmation that Effective Data has been Imported onto Applicant's Computer.
- No Changes to the Effective Data.

Corrected Effective

- Corrects Errors in Effective Model.
- Updates Natural Conditions.
  - Not Man-Made
- Add Evaluation Cross Sections.
- Incorporates More Detailed Topography at the Time of the Effective FIRM.
- Permitted Changes not in Effective Model.

Pre-Project Conditions

- Is a Modified Corrected Effective Model.
- Man-Made Changes to the Effective Data Occurring Since the Date of the Effective Model.
  - Potential Violations
- Used to Determine True Impacts of the Project.

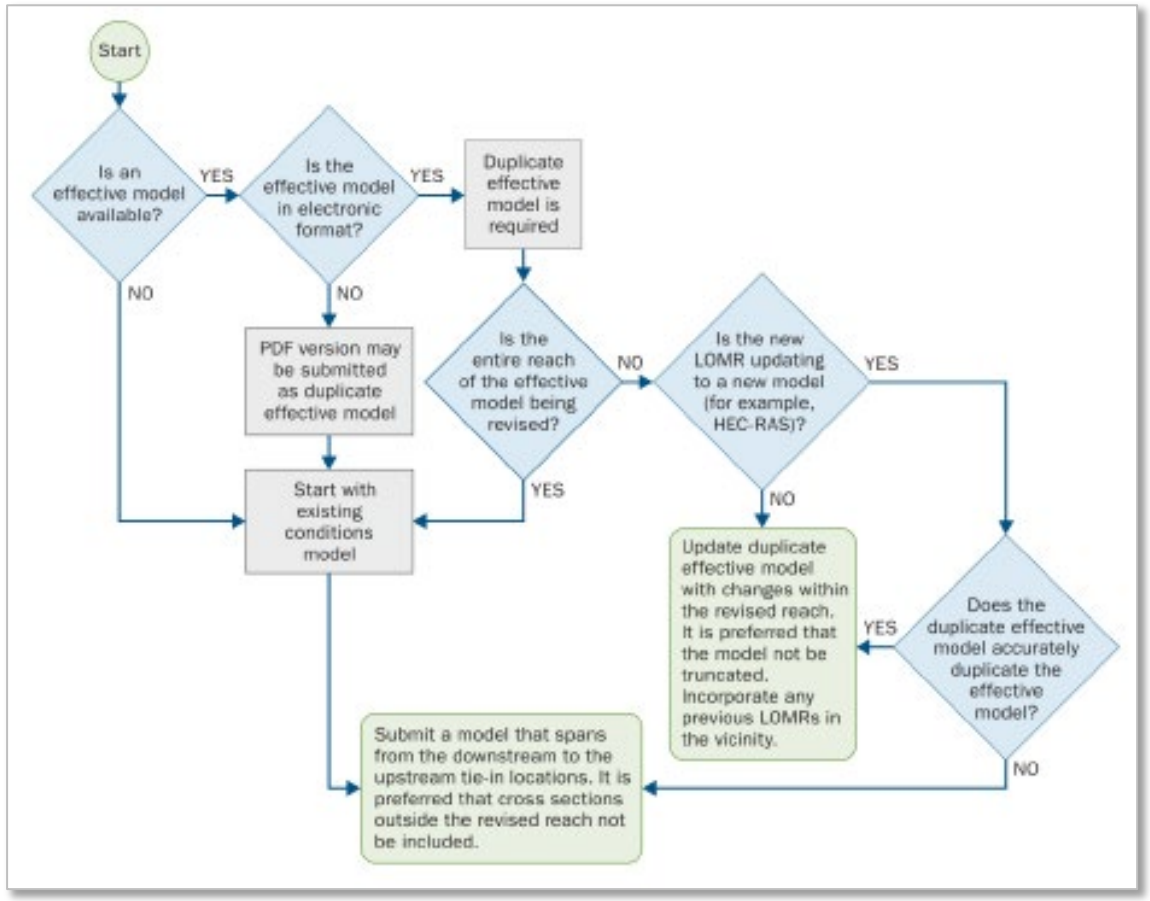
Post-Project

- Is a Modified Pre-Project Model.
- Must Reflect any Physical Changes to the Floodplain AND the Project.

(FEMA, 2023)

Review

Duplicate Effective Model



(FEMA, 2025)

Review

Correct Model Format

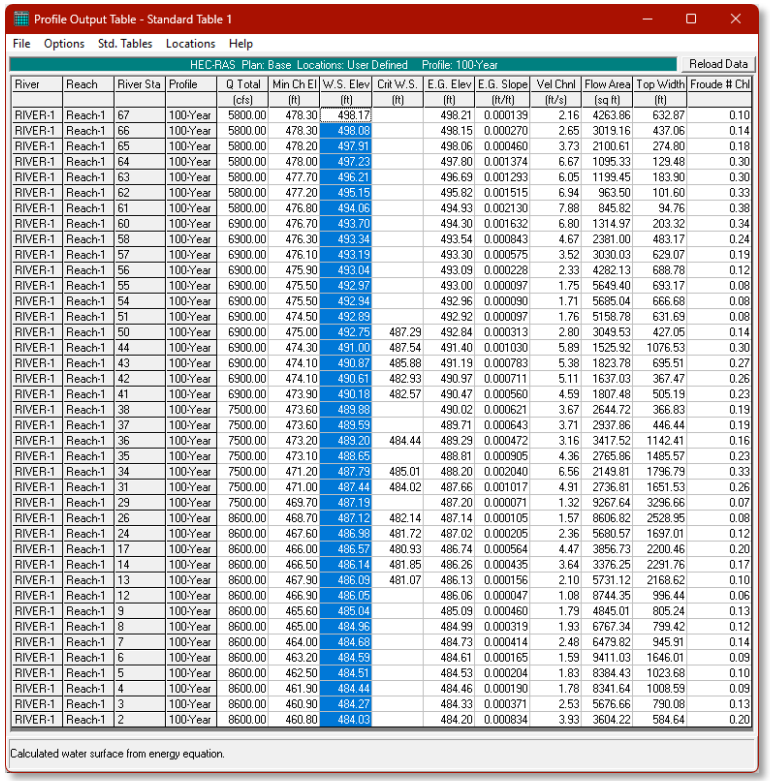
Does the Duplicate Effective Model Calibrate with the Effective Data?

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET/ SECOND)	REGULATORY (FEET, NAVD)	WITHOUT FLOODWAY (FEET, NAVD)	WITH FLOODWAY (FEET, NAVD)	INCREASE (FEET)
FRENCH LICK CREEK								
A	0.12	533	4128	2.5	489.4	483.7 [2]	483.8	0.1
B	0.16	667	5334	1.6	489.4	483.9 [2]	484.0	0.1
C	0.27	964	8209	1.1	489.4	484.1 [2]	484.2	0.1
D	0.35	972	8247	1.0	489.4	484.2 [2]	484.3	0.1
E	0.43	1090	9352	0.9	489.4	484.3 [2]	484.4	0.1
F	0.50	881	6313	1.4	489.4	484.4 [2]	484.5	0.1
G	0.62	769	6621	1.3	489.4	484.6 [2]	484.7	0.1
H	0.66	792	4831	1.8	489.4	484.7 [2]	484.8	0.1
I	0.72	906	8507	1.0	489.4	485.7 [2]	485.7	0.0
J	0.82	757	5439	1.6	489.4	485.8 [2]	485.8	0.0
K	0.91	450	3223	2.7	489.4	485.8 [2]	485.9	0.1
L	0.95	555	3620	2.4	489.4	486.2 [2]	486.2	0.0
M	1.04	800	5341	1.7	489.4	486.6 [2]	486.6	0.0
N	1.20	1105	7359	1.4	489.4	486.8 [2]	486.9	0.1
O	1.31	1240	8589	1.1	489.4	486.8 [2]	486.9	0.1
P	1.51	705	2964	3.1	489.4	487.1 [2]	487.2	0.1
Q	1.55	638	2470	3.8	489.4	487.4 [2]	487.5	0.1
R	1.65	550	3241	2.6	489.4	488.3 [2]	488.4	0.1
S	1.79	435	3277	2.3	489.4	488.9 [2]	489.0	0.1
T	1.93	388	2836	2.6	489.4	489.2 [2]	489.3	0.1
U	2.02	342	2612	2.9	489.5	489.5	489.6	0.1
V	2.21	221	1787	3.9	489.9	489.9	490.0	0.1
W	2.35	232	1623	4.3	490.3	490.3	490.4	0.1
X	2.41	232	1663	4.2	490.5	490.5	490.6	0.1
Y	2.45	251	1619	4.5	490.7	490.7	490.8	0.1
Z	2.58	377	2994	2.3	492.4	492.4	492.5	0.1
AA	2.68	593	5101	1.4	492.6	492.6	492.7	0.1
AB	2.71	628	5625	1.2	492.6	492.6	492.7	0.1
AC	2.79	647	5567	1.2	492.7	492.7	492.8	0.1
AD	2.90	602	4138	1.7	492.7	492.7	492.8	0.1
AE	3.02	595	2995	2.3	492.8	492.8	492.9	0.1
AF	3.09	456	2360	2.9	493.0	493.0	493.1	0.1

[1] MILES ABOVE MOUTH
[2] ELEVATION WITHOUT CONSIDERING BACKWATER EFFECTS FROM LOST RIVER

TABLE 12

FEDERAL EMERGENCY MANAGEMENT AGENCY	FLOODWAY DATA
ORANGE COUNTY, IN (AND INCORPORATED AREAS)	FRENCH LICK CREEK



River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
RIVER-1	Reach-1	67	100-Year	5800.00	478.30	498.17		498.21	0.000139	2.16	4263.86	632.87	0.10
RIVER-1	Reach-1	66	100-Year	5800.00	478.30	498.08		498.15	0.000270	2.65	3019.16	437.06	0.14
RIVER-1	Reach-1	65	100-Year	5800.00	478.20	497.91		498.06	0.000460	3.73	2100.61	274.80	0.18
RIVER-1	Reach-1	64	100-Year	5800.00	478.00	497.23		497.80	0.001374	6.67	1095.33	129.49	0.30
RIVER-1	Reach-1	63	100-Year	5800.00	477.70	496.21		496.69	0.001293	6.05	1199.45	183.90	0.30
RIVER-1	Reach-1	62	100-Year	5800.00	477.20	495.15		495.82	0.001515	6.94	963.50	101.60	0.33
RIVER-1	Reach-1	61	100-Year	5800.00	476.80	494.06		494.93	0.002130	7.88	845.82	94.76	0.38
RIVER-1	Reach-1	60	100-Year	6900.00	476.70	493.70		494.30	0.001632	6.80	1314.97	203.32	0.34
RIVER-1	Reach-1	58	100-Year	6900.00	476.30	493.34		493.54	0.000843	4.67	2381.00	483.17	0.24
RIVER-1	Reach-1	57	100-Year	6900.00	476.10	493.19		493.30	0.000575	3.52	3030.03	629.07	0.19
RIVER-1	Reach-1	56	100-Year	6900.00	475.90	493.04		493.09	0.000228	2.33	4282.13	688.78	0.12
RIVER-1	Reach-1	55	100-Year	6900.00	475.50	492.97		493.00	0.000097	1.75	5649.40	693.17	0.08
RIVER-1	Reach-1	54	100-Year	6900.00	475.50	492.94		492.96	0.000090	1.71	5685.04	666.68	0.08
RIVER-1	Reach-1	51	100-Year	6900.00	474.50	492.89		492.92	0.000097	1.76	5158.78	631.69	0.08
RIVER-1	Reach-1	50	100-Year	6900.00	475.00	492.75	487.29	492.84	0.000313	2.80	3049.53	427.05	0.14
RIVER-1	Reach-1	44	100-Year	6900.00	474.30	491.00	487.54	491.40	0.001030	5.89	1525.92	1076.53	0.30
RIVER-1	Reach-1	43	100-Year	6900.00	474.10	490.87	485.88	491.19	0.000783	5.38	1823.78	695.51	0.27
RIVER-1	Reach-1	42	100-Year	6900.00	474.10	490.61	482.93	490.97	0.000711	5.11	1637.03	367.47	0.26
RIVER-1	Reach-1	41	100-Year	6900.00	473.90	490.18	482.57	490.47	0.000560	4.59	1807.48	505.19	0.23
RIVER-1	Reach-1	38	100-Year	7500.00	473.60	489.88		490.02	0.000621	3.67	2644.72	366.83	0.19
RIVER-1	Reach-1	37	100-Year	7500.00	473.60	489.59		489.71	0.000643	3.71	2937.86	446.44	0.19
RIVER-1	Reach-1	36	100-Year	7500.00	473.20	489.20	484.44	489.29	0.000472	3.16	3417.52	1142.41	0.16
RIVER-1	Reach-1	35	100-Year	7500.00	473.10	488.65		488.81	0.000905	4.36	2765.86	1485.57	0.23
RIVER-1	Reach-1	34	100-Year	7500.00	471.20	487.79	485.01	488.20	0.002040	6.56	2149.81	1796.79	0.33
RIVER-1	Reach-1	31	100-Year	7500.00	471.00	487.44	484.02	487.66	0.001017	4.91	2736.81	1651.53	0.26
RIVER-1	Reach-1	29	100-Year	7500.00	469.70	487.19		487.20	0.000071	1.32	9267.64	3296.66	0.07
RIVER-1	Reach-1	26	100-Year	8600.00	468.70	487.12	482.14	487.14	0.000105	1.57	8606.82	2528.95	0.08
RIVER-1	Reach-1	24	100-Year	8600.00	467.60	486.98	481.72	487.02	0.000205	2.36	5680.57	1697.01	0.12
RIVER-1	Reach-1	17	100-Year	8600.00	466.00	486.57	480.93	486.74	0.000564	4.47	3856.73	2200.46	0.20
RIVER-1	Reach-1	14	100-Year	8600.00	466.50	486.14	481.85	486.26	0.000435	3.64	3376.25	2291.76	0.17
RIVER-1	Reach-1	13	100-Year	8600.00	467.90	486.09	481.07	486.13	0.000156	2.10	5731.12	2168.62	0.10
RIVER-1	Reach-1	12	100-Year	8600.00	466.90	486.05		486.06	0.000047	1.08	8744.35	996.44	0.06
RIVER-1	Reach-1	9	100-Year	8600.00	465.60	485.04		485.09	0.000460	1.79	4845.01	805.24	0.13
RIVER-1	Reach-1	8	100-Year	8600.00	465.00	484.96		484.99	0.000319	1.93	6767.34	799.42	0.12
RIVER-1	Reach-1	7	100-Year	8600.00	464.00	484.68		484.73	0.000414	2.48	6479.82	945.91	0.14
RIVER-1	Reach-1	6	100-Year	8600.00	463.20	484.59		484.61	0.000165	1.59	9411.03	1646.01	0.09
RIVER-1	Reach-1	5	100-Year	8600.00	462.50	484.51		484.53	0.000204	1.83	8384.43	1023.68	0.10
RIVER-1	Reach-1	4	100-Year	8600.00	461.90	484.44		484.46	0.000190	1.78	8341.64	1008.59	0.09
RIVER-1	Reach-1	3	100-Year	8600.00	460.90	484.27		484.33	0.000371	2.53	5676.66	790.08	0.13
RIVER-1	Reach-1	2	100-Year	8600.00	460.80	484.03		484.20	0.000834	3.93	3604.22	584.64	0.20

(FEMA, 2024)

Review

Correct Model Format

Corrected Effective Model

- Is the study reach long enough to properly tie in at the limit of the revision area?
- Can the missed calibration from the Duplicate Effective Model be fixed?
- Only contain natural changes?
- Are the evaluation cross sections added?

Does it:

- Match the BFE **AND** delineation.
- Correct the errors that are present.
- Represent the natural floodplain and the real flood risks.
- Use the needed cross sections to properly evaluate the hydraulics without energy or flow errors.

FEMA Region 5 State-Specific Considerations for Indiana allow for the incorporation of properly permitted RIK bridges and culverts, the most efficient hydraulic structure, to be incorporated in the base model. Even CIF crossings with 0.14-foot surcharge still need a C/LOMR. The absence of FEMA “permitting” is considered man-made and a potential violation.

(FEMA, 2024), (FEMA, 2025), (FEMA, 2025)

Review

Correct Model Format

Pre-Project Conditions Include Man-Made Changes

- Fill
- Excavation
- Any Construction

Post-Project Conditions Include Man-Made Changes

- Changes made by the project
- Any changes from the Effective Conditions
- This will become the new Effective Model

Separate Floodway Analysis is Allowed

- Match the Post-Project Exactly
  - No Exceptions

(FEMA, 2024)

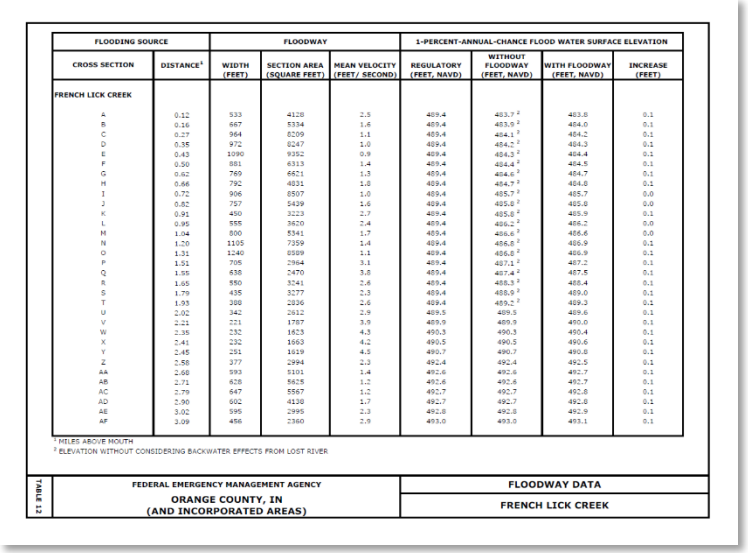
DNR Indiana Department of Natural Resources | DIVISION OF WATER

Review

Starting Water Surface Boundary Condition

Known Water Surface
- Effective Cross Section
  - Lettered
  - Unlettered
- Middle or End of Stream

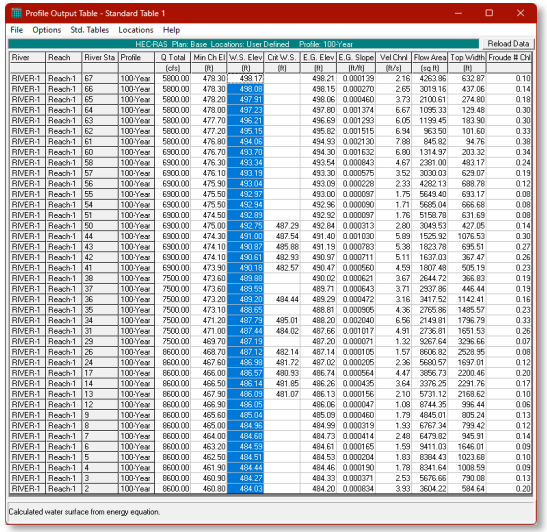
Energy Grade Slope
- Whole Stream Study
- Includes Mouth of Stream
- HEC-RAS needs time to Stabilize



FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET / SECOND)	REGULATORY (FEET, NAVD)	WITHOUT FLOODWAY (FEET, NAVD)	WITH FLOODWAY (FEET, NAVD)	INCREASE (FEET)
FRENCH LICK CREEK								
A	0.12	533	4128	2.5	469.4	483.7[2]	483.8	0.1
B	0.16	667	5334	1.6	469.4	483.9[2]	484.0	0.1
C	0.27	964	8299	1.1	469.4	484.1[2]	484.2	0.1
D	0.35	972	8247	1.0	469.4	484.2[2]	484.3	0.1
E	0.43	1090	9352	0.9	469.4	484.3[2]	484.4	0.1
F	0.50	881	6313	1.4	469.4	484.4[2]	484.5	0.1
G	0.62	769	6621	1.3	469.4	484.6[2]	484.7	0.1
H	0.66	792	4031	1.8	469.4	484.7[2]	484.8	0.1
I	0.72	906	6807	1.0	469.4	485.7[2]	485.7	0.0
J	0.82	757	5439	1.6	469.4	485.8[2]	485.8	0.0
K	0.91	450	3223	2.7	469.4	485.8[2]	485.9	0.1
L	0.95	555	3620	2.4	469.4	486.2[2]	486.2	0.0
M	1.04	800	5341	1.7	469.4	486.6[2]	486.6	0.0
N	1.20	1105	7359	1.4	469.4	486.8[2]	486.9	0.1
O	1.31	1240	8889	1.1	469.4	486.8[2]	486.9	0.1
P	1.51	795	2964	3.1	469.4	487.1[2]	487.2	0.1
Q	1.55	638	2470	3.8	469.4	487.4[2]	487.5	0.1
R	1.65	550	3241	2.6	469.4	488.3[2]	488.4	0.1
S	1.79	435	3277	2.3	469.4	488.9[2]	489.0	0.1
T	1.93	388	2836	2.6	469.4	489.2[2]	489.3	0.1
U	2.02	342	2612	2.9	469.5	489.5	489.6	0.1
V	2.21	221	1787	3.9	469.9	489.9	490.0	0.1
W	2.35	232	1623	4.3	490.3	490.3	490.4	0.1
X	2.41	232	1663	4.2	490.5	490.5	490.6	0.1
Y	2.45	251	1819	4.5	490.7	490.7	490.8	0.1
Z	2.58	377	2994	2.3	492.4	492.4	492.5	0.1
AA	2.68	593	5101	1.4	492.6	492.6	492.7	0.1
AB	2.71	628	5625	1.2	492.6	492.6	492.7	0.1
AC	2.79	647	5567	1.2	492.7	492.7	492.8	0.1
AD	2.90	602	4138	1.7	492.7	492.7	492.8	0.1
AE	3.02	595	2995	2.3	492.8	492.8	492.9	0.1
AF	3.09	456	2360	2.9	493.0	493.0	493.1	0.1

[1] MILES ABOVE MOUTH
[2] ELEVATION WITHOUT CONSIDERING BACKWATER EFFECTS FROM LOST RIVER

TABLE 12 — FEDERAL EMERGENCY MANAGEMENT AGENCY — ORANGE COUNTY, IN (AND INCORPORATED AREAS) — FLOODWAY DATA — FRENCH LICK CREEK



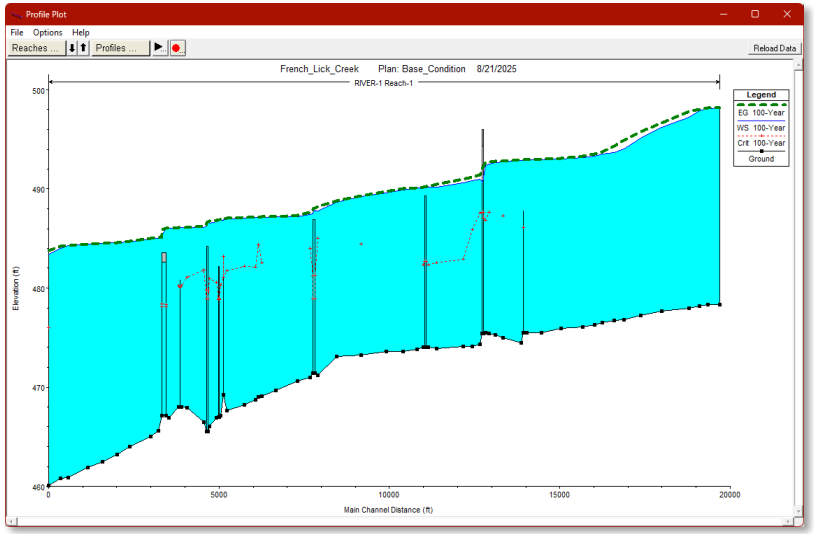
Profile Output Table - Standard Table 1

File Options Std. Tables Locations Help

HEC-RAS Plan: Base_Locations: User Defined Profile: 100Year — Reload Data

River	Reach	River Sta	Profile	Q Total [cfs]	Min Ch El [ft]	W.S. Elev [ft]	Crit W.S. [ft]	E.G. Elev [ft]	E.G. Slope [ft/ft]	Vel Chnl [ft/s]	Flow Area [sq ft]	Top Width [ft]	Froude # Chl
RIVER-1	Reach-1	67	100-Year	5800.00	478.30	498.17		498.21	0.000139	2.16	4263.96	632.87	0.10
RIVER-1	Reach-1	66	100-Year	5800.00	478.30	498.08		498.15	0.000270	2.65	3019.16	437.06	0.14
RIVER-1	Reach-1	65	100-Year	5800.00	479.20	497.91		498.06	0.000460	3.73	2100.61	274.80	0.19
RIVER-1	Reach-1	64	100-Year	5800.00	478.00	497.23		497.80	0.001374	6.67	1095.33	123.48	0.30
RIVER-1	Reach-1	63	100-Year	5800.00	477.70	496.21		496.69	0.001293	6.05	1139.45	183.90	0.30
RIVER-1	Reach-1	62	100-Year	5800.00	477.20	495.15		495.82	0.001515	6.94	963.50	101.60	0.33
RIVER-1	Reach-1	61	100-Year	5800.00	476.80	494.06		494.93	0.002130	7.88	945.82	94.76	0.38
RIVER-1	Reach-1	60	100-Year	6900.00	476.70	493.70		494.30	0.001632	6.80	1314.97	203.32	0.34
RIVER-1	Reach-1	58	100-Year	6900.00	476.30	493.34		493.54	0.000843	4.67	2381.00	483.17	0.24
RIVER-1	Reach-1	57	100-Year	6900.00	476.10	493.13		493.30	0.000575	3.52	3030.03	629.07	0.19
RIVER-1	Reach-1	56	100-Year	6900.00	475.90	493.04		493.09	0.000226	2.33	4282.13	689.78	0.12
RIVER-1	Reach-1	55	100-Year	6900.00	475.50	492.92		493.00	0.000097	1.75	5649.40	693.17	0.08
RIVER-1	Reach-1	54	100-Year	6900.00	475.50	492.94		492.96	0.000090	1.71	5685.04	666.68	0.08
RIVER-1	Reach-1	51	100-Year	6900.00	474.50	492.88		492.92	0.000097	1.76	5158.78	631.69	0.08
RIVER-1	Reach-1	50	100-Year	6900.00	475.00	492.79	487.29	492.84	0.000313	2.80	3049.53	427.05	0.14
RIVER-1	Reach-1	44	100-Year	6900.00	474.30	491.00	487.54	491.40	0.001030	5.89	1525.92	1076.53	0.30
RIVER-1	Reach-1	43	100-Year	6900.00	474.10	490.82	485.88	491.19	0.000783	5.38	1823.78	695.51	0.27
RIVER-1	Reach-1	42	100-Year	6900.00	474.10	490.61	482.93	490.97	0.000711	5.11	1637.03	367.47	0.26
RIVER-1	Reach-1	41	100-Year	6900.00	473.90	490.10	482.57	490.47	0.000560	4.59	1807.48	505.19	0.23
RIVER-1	Reach-1	38	100-Year	7500.00	473.60	489.88		490.02	0.000621	3.67	2644.72	366.83	0.19
RIVER-1	Reach-1	37	100-Year	7500.00	473.60	489.53		489.71	0.000643	3.71	2937.86	446.44	0.19
RIVER-1	Reach-1	36	100-Year	7500.00	473.20	489.20	484.44	489.29	0.000472	3.16	3417.52	1142.41	0.16
RIVER-1	Reach-1	35	100-Year	7500.00	473.10	488.93		488.81	0.000905	4.36	2765.86	1495.57	0.23
RIVER-1	Reach-1	34	100-Year	7500.00	471.20	487.73	485.01	488.20	0.002040	6.56	2149.81	1796.79	0.33
RIVER-1	Reach-1	31	100-Year	7500.00	471.00	487.44	484.02	487.66	0.001017	4.91	2736.81	1651.53	0.26
RIVER-1	Reach-1	29	100-Year	7500.00	469.70	487.15		487.20	0.000071	1.32	9267.64	3296.66	0.07
RIVER-1	Reach-1	26	100-Year	8600.00	468.70	487.13	482.14	487.14	0.000105	1.57	8606.82	2528.95	0.08
RIVER-1	Reach-1	24	100-Year	8600.00	467.60	486.96	481.72	487.02	0.000205	2.36	5690.57	1697.01	0.12
RIVER-1	Reach-1	17	100-Year	8600.00	466.00	486.57	480.93	486.74	0.000564	4.47	3856.73	2200.46	0.20
RIVER-1	Reach-1	14	100-Year	8600.00	466.50	486.14	481.85	486.26	0.000435	3.64	3376.25	2291.76	0.17
RIVER-1	Reach-1	13	100-Year	8600.00	467.90	486.05	481.07	486.13	0.000156	2.10	5731.12	2168.62	0.10
RIVER-1	Reach-1	12	100-Year	8600.00	466.90	485.95		486.06	0.000047	1.08	8744.25	596.44	0.06
RIVER-1	Reach-1	9	100-Year	8600.00	465.60	485.04		485.09	0.000460	1.79	4845.01	805.24	0.13
RIVER-1	Reach-1	8	100-Year	8600.00	465.00	484.96		484.99	0.000319	1.93	6767.34	799.42	0.12
RIVER-1	Reach-1	7	100-Year	8600.00	464.00	484.68		484.73	0.000414	2.48	6479.82	345.91	0.14
RIVER-1	Reach-1	6	100-Year	8600.00	463.20	484.59		484.61	0.000165	1.59	9411.03	1646.01	0.09
RIVER-1	Reach-1	5	100-Year	8600.00	462.50	484.51		484.53	0.000204	1.83	8384.43	1023.68	0.10
RIVER-1	Reach-1	4	100-Year	8600.00	461.90	484.44		484.46	0.000190	1.78	8341.64	1008.59	0.09
RIVER-1	Reach-1	3	100-Year	8600.00	460.90	484.27		484.33	0.000371	2.53	5676.66	790.08	0.13
RIVER-1	Reach-1	2	100-Year	8600.00	460.80	484.03		484.20	0.000834	3.93	3604.22	594.64	0.20

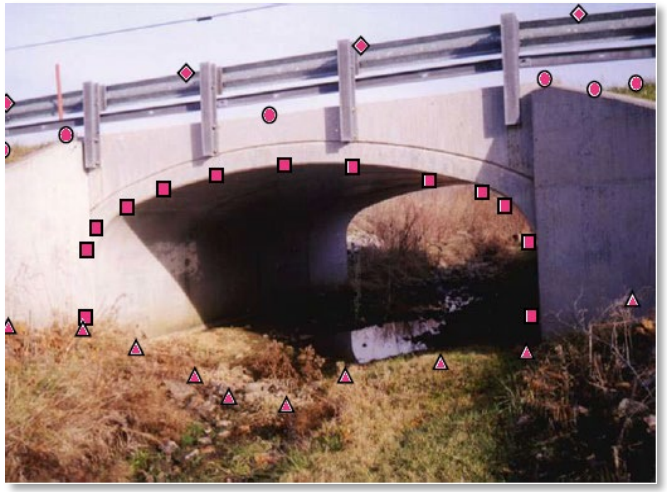
Calculated water surface from energy equation.



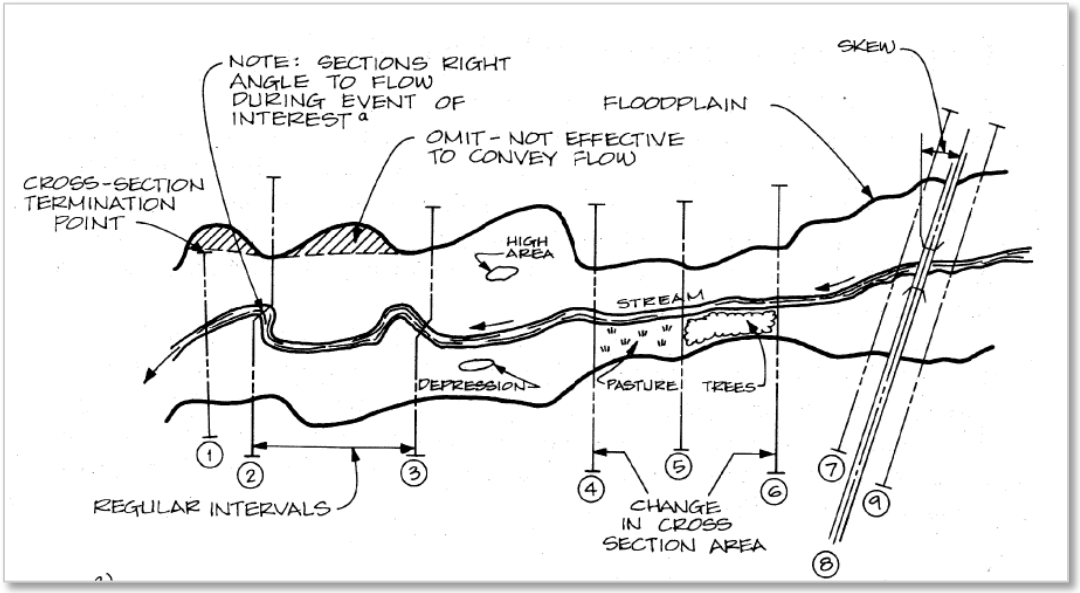
(FEMA, 2020), (USACE, 1993)

Review

Cross Sections



- NAVD88 Vertical Datum is Preferred
- Verify the source of the topography
  - LiDAR
  - Survey
  - Follow the Data Capture Technical Guidelines
- The Cross Sections
  - Best Practice Placement
  - Skew
  - Spacing
  - Matching the Topo Workmap
  - Span the extent of the water surface



(FEMA, 2024), (FEMA, 2024), (INNRC, 2014)

Review

Profile Baseline - River Stationing

- For most streams this is the distance, measured in feet or miles, above the mouth of the stream or above its confluence (SID #278)
  - Distances in 1D models must be referenced to the Profile Baseline
    - Follows all bends and curves of the stream
    - For streets, use the center of the street when measuring distances.

- Stream distances reported in the Floodway Data Tables, Flood Profiles and FIRM database must be measured along the Profile Baseline. (SID #280)
  - Should be consistent across all documents
  - Must match within 1/20th of an inch on the Flood Profile or 5% on the FIRM when compared to the Hydraulic Model. (SID #273 and 335)

Review

Geometry

Bridge

- Geometry must match submitted plans
- Source and method documented
  - As-built plans
    - State Department of Transportation
    - Field Survey Data
      - ❑ PS or PE
  - LiDAR data
  - Proposed plans

- High/Low flow modeling method explained

- Contraction and expansion coefficients
- Overtopping/weir flow
  - Ineffective limits

- FEMA recommends FHWA published Hydraulic Design Series

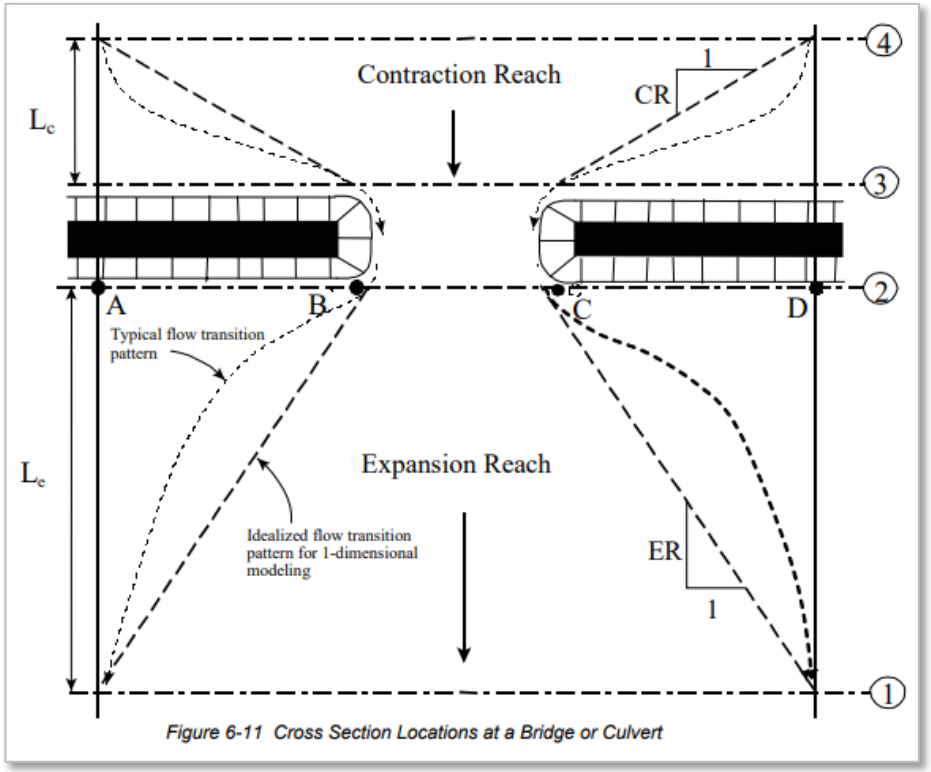


Figure 6-11 Cross Section Locations at a Bridge or Culvert

HEC-RAS User Manual

Review

Geometry

Channelization
- Must match plans
- Lined or natural
- Government agreement to maintain channel

- Split flow justified and documented properly

- Manning's n
- Ineffective/blocked flow

Table 1. Base values of Manning's *n*

[Modified from Aldridge and Garrett, 1973, table 1; —, no data]

Bed material	Median size of bed material (in millimeters)	Base *n* value: Straight uniform channel[1]	Base *n* value: Smooth channel[2]
Sand channels			
Sand[3]	0.2	0.012	—
	.3	.017	—
	.4	.020	—
	.5	.022	—
	.6	.023	—
	.8	.025	—
	1.0	.026	—
Stable channels and flood plains			
Concrete	—	0.012–0.018	0.011
Rock cut	—	—	.025
Firm soil	—	0.025–0.032	.020
Coarse sand	1–2	0.026–0.035	—
Fine gravel	—	—	.024
Gravel	2–64	0.028–0.035	—
Coarse gravel	—	—	.026
Cobble	64–256	0.030–0.050	—
Boulder	>256	0.040–0.070	—

[1] Benson and Dalrymple (1967).
[2] For indicated material; Chow (1959).
[3] Only for upper regime flow where grain roughness is predominant.

Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains, USGS Water Supply Paper 2339

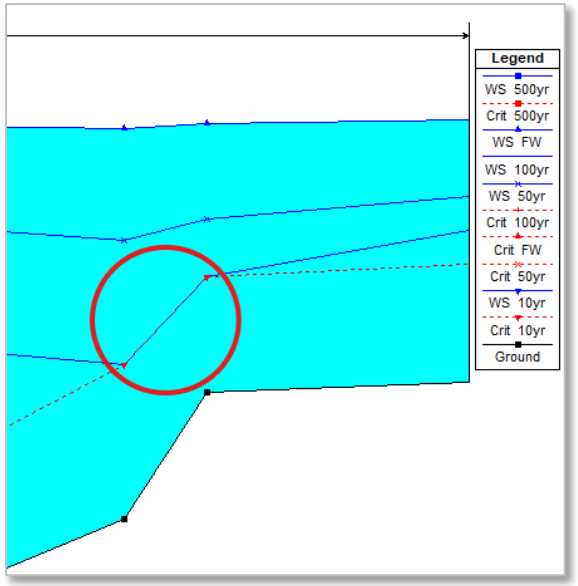
Review

Errors

Critical Depth Flow Errors

- Is it justified?

Location:	River: RS: 18713.14 Profile: 50YR-FIS Downstream
Warning:	The energy equation could not be balanced within the specified number of iterations. The program used critical depth for the water surface and continued on with the calculations.
Warning:	The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than 0.7 or greater than 1.4. This may indicate the need for additional cross sections.
Warning:	The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross section. This may indicate the need for additional cross sections.
Warning:	During the standard step iterations, when the assumed water surface was set equal to critical depth, the calculated water surface came back below critical depth. This indicates that there is not a valid subcritical answer. The program defaulted to critical depth
Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid, water surface was used.



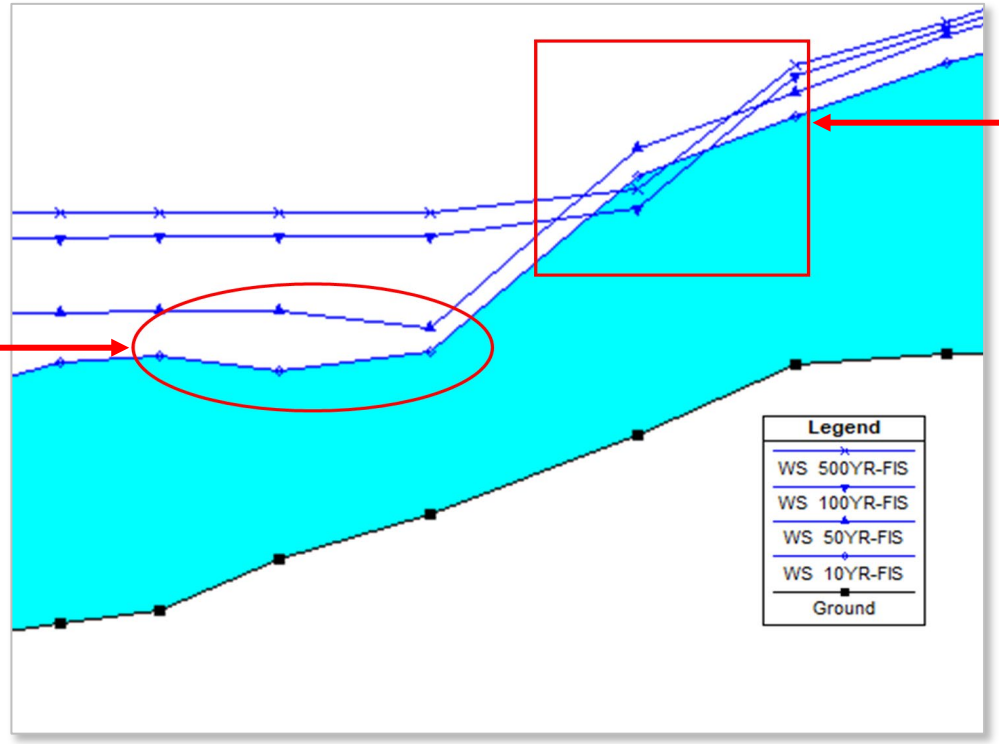
- cHECk-RAS errors
- HEC-RAS errors

(Knipe, 2003)

Review

Errors

Drawdowns •



• Profile lines crossing

Review

Floodway Run

- Equal encroachments
- Acceptable surcharge
  - 0.00’ to 0.14’
  - No negative values

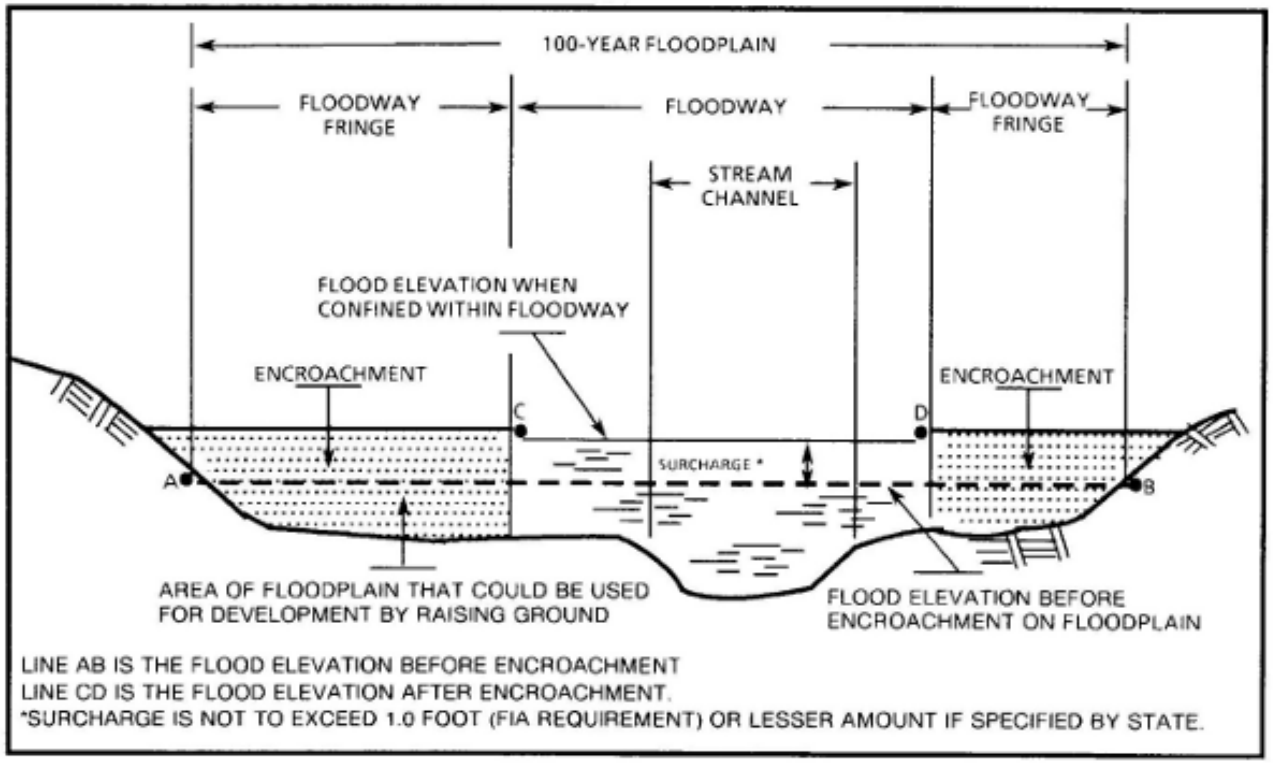


Figure 7. Cross section of the floodplain showing the floodway, floodway fringe and surcharge. The model assumes that the entire floodplain outside of the floodway is filled or otherwise obstructed.

DNR Indiana Department of Natural Resources | DIVISION OF WATER

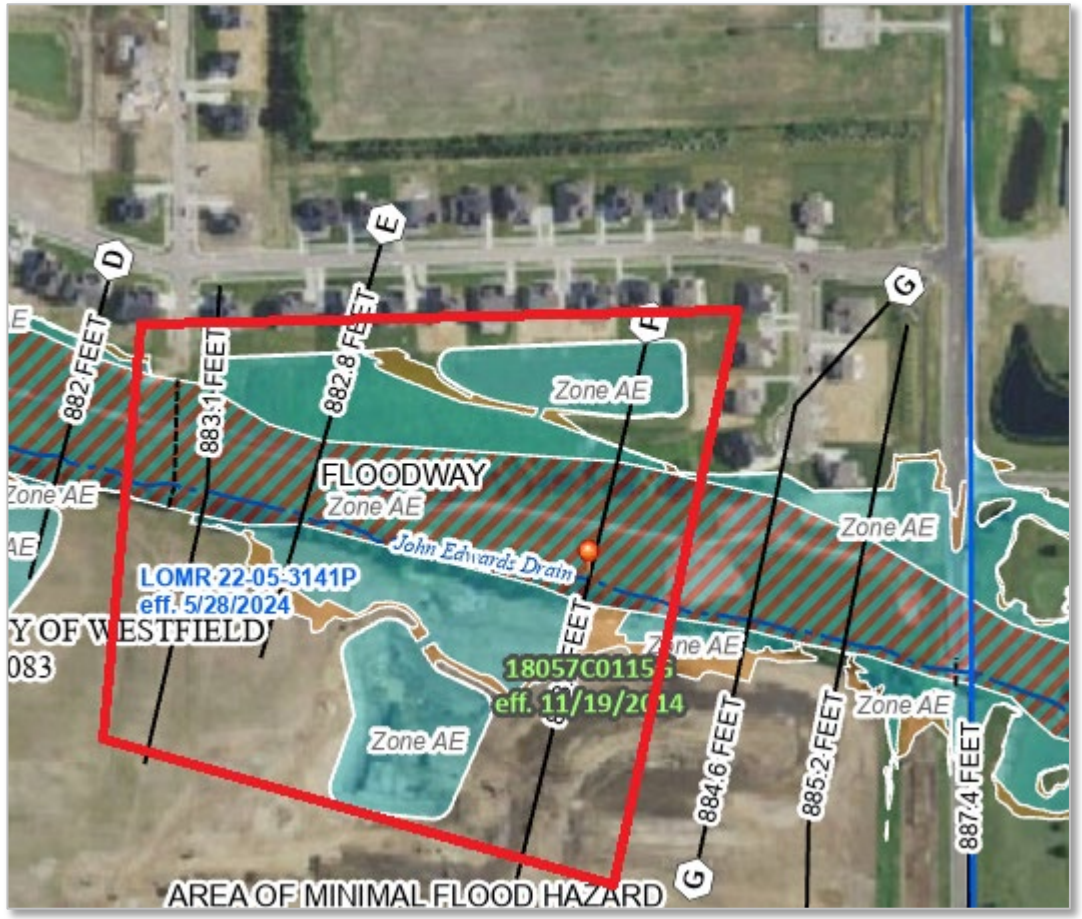
Review

BFE Tie-in

Project Area Limits:

- The Corrected Effective BFE when compared to the Effective BFE
  - +/- 0.1 feet
- The same difference in BFE when the Post-Project BFE is compared to the Effective BFE.

- Project Area may not be the same as mapping revision area.



DNR Indiana Department of Natural Resources | DIVISION OF WATER

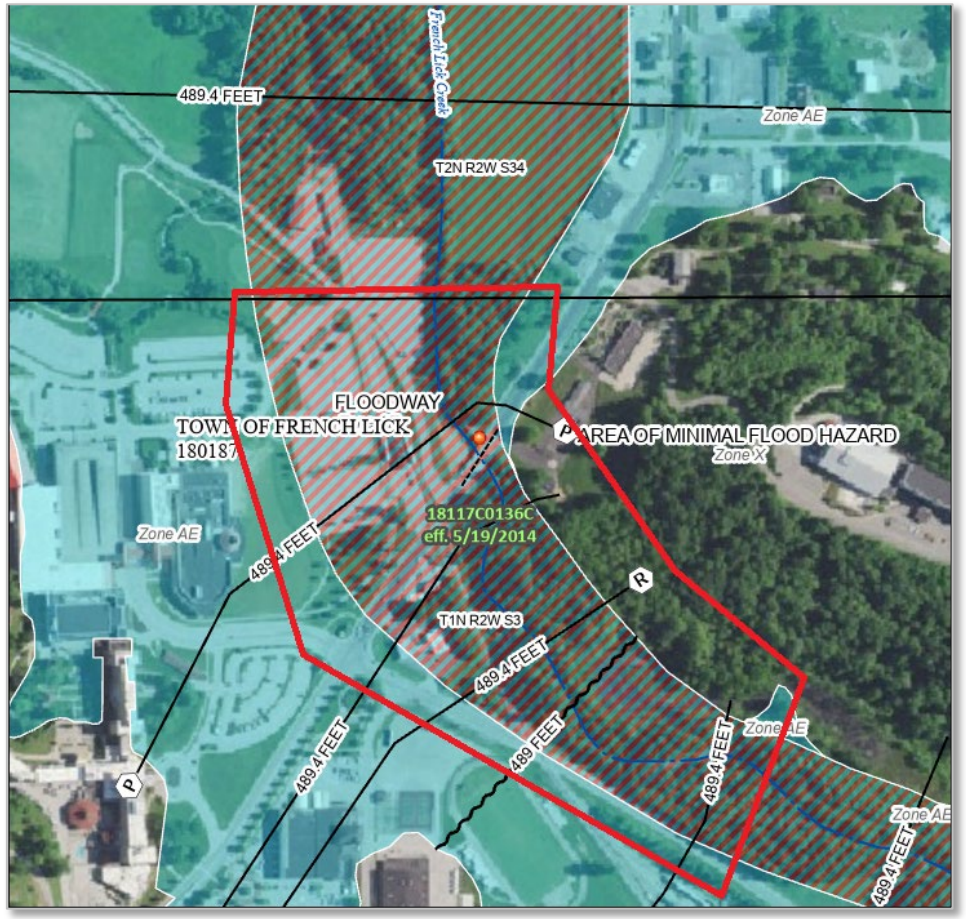
Review

BFE Tie-in

Revision Area Limits:

- The Corrected Effective BFE when compared to the Effective BFE.
- Must agree with other contiguous studies +/- 0.5 feet from Pre-Project to Post-Project
  - Provides for mapping tie in.

XS	R/S	FIS	DE	Δ	CE	Δ	EX	Δ	PR	Δ
M	1.04	489.4	489.4	0.0	489.9	0.5	489.9	0.5	489.9	0.5
N	1.20	489.4	489.3	-0.1	489.8	0.4	489.8	0.4	489.4	0.4
O	1.31	489.4	489.4	0.0	489.5	0.1	489.5	0.1	489.5	0.1
P	1.51	489.4	489.5	0.1	489.6	0.2	489.6	0.2	489.6	0.2
	1.53	IN-56								
Q	1.55	489.4	489.4	0.0	489.5	0.1	489.5	0.1	489.6	0.2
R	1.65	489.4	498.3	-0.1	489.5	0.1	489.5	0.1	489.6	0.2
S	1.79	489.4	489.4	0.0	489.5	0.1	489.5	0.1	489.5	0.1
T	1.93	489.4	489.4	0.0	489.9	0.5	489.9	0.5	489.9	0.5



Review

Model Comparison

CE/DE vs. Existing
- Potential Violations?

Existing vs Revised/Proposed/Post-Project/As-built
- Evaluate true project impacts
- CLOMR: if increases, then 44 CFR 65.12 compliance required

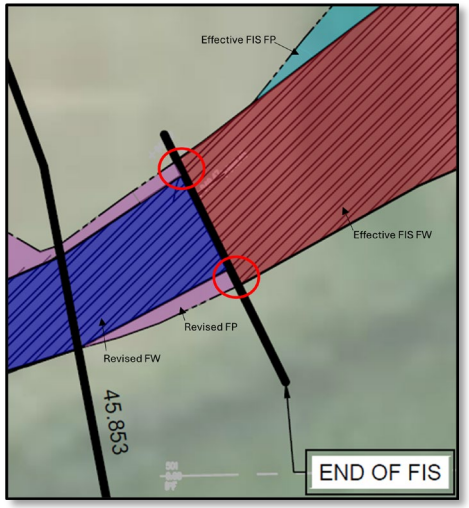
Effective vs Revised/Proposed/Post-Project/As-built
- No-rise?
- If increases, adverse impacts notifications required

Adjacent Checks

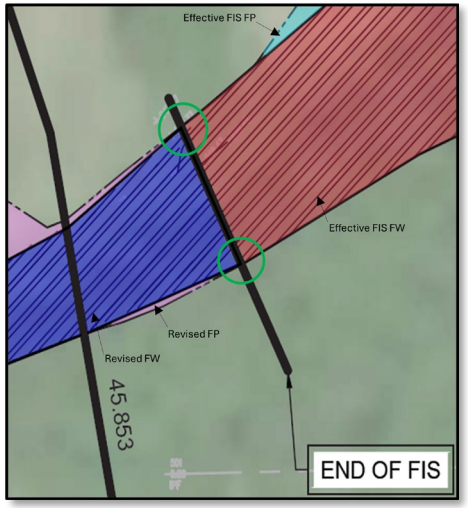
Mapping

Boundary Tie-in

- Floodplain and Floodway widths at the upstream and downstream ends of the studies reach must match those shown on the effective FIRM (Doc no. 52)



Bad Tie In



Good Tie In

- Top-width discrepancies from model to mapping have a tolerance of 5% (SID #335)

- Revised/Post-Project/As-built model match workmaps for distance between cross sections, structures, water surface elevations, top-widths, and surcharges.

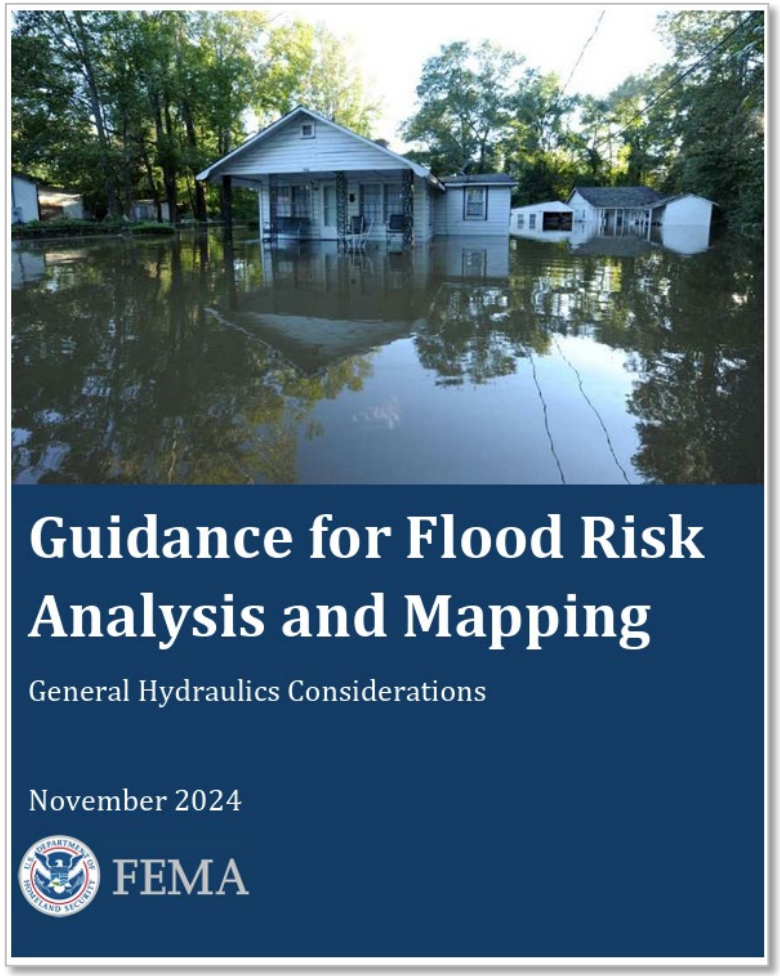
DNR Indiana Department of Natural Resources | DIVISION OF WATER

FEMA General Hydraulic Considerations

Guidance for Flood Risk Analysis and Mapping

- Contains the standards and methods to be applied by Mapping Partners in the performance, analysis, and presentation of results for riverine flooding analyses.

- Objectives of a Hydraulic Studies:
  - Identify areas subject to flooding and define the flood-frequency relation at those areas
  - Depict data and analyses results to support flood insurance decisions and floodplain management
  - Document data and analyses to enable results to be checked, reproduced, and updated.
  - Maintain consistency and continuity within national inventory of FIRMs and FIS reports

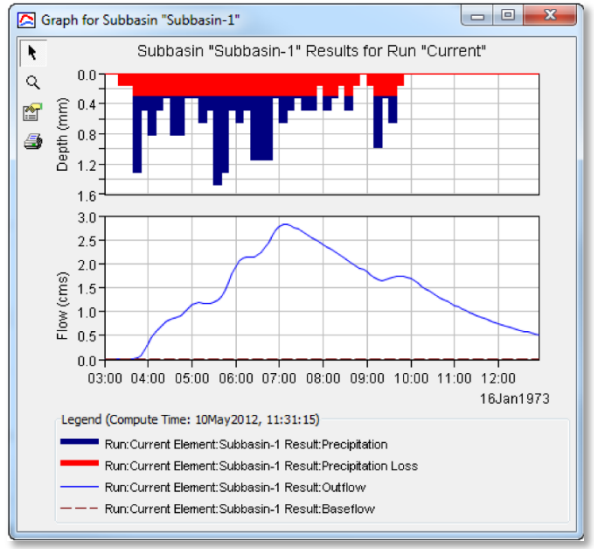


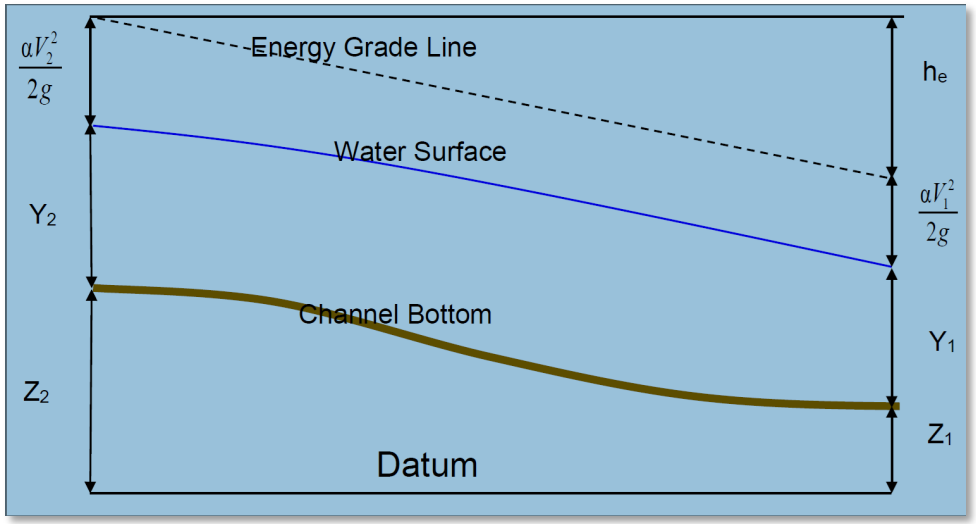
(FEMA, 2023)

FEMA General Hydraulic Considerations

Procedures - 1D Steady Flow

- Computes the energy of the water passing through a cross section as equal to the energy of the water passing through the cross section immediately downstream plus the energy lost to friction and turbulence in the reach between cross sections.
- Requires the following:
  - Cross Section Geometry (including hydraulic structures)
  - Loss Coefficients
  - Water Surface Elevation at the most Downstream Cross Section
  - Peak Flow Discharge
- Applicable to streams with well-defined open channels with gradually varied flows



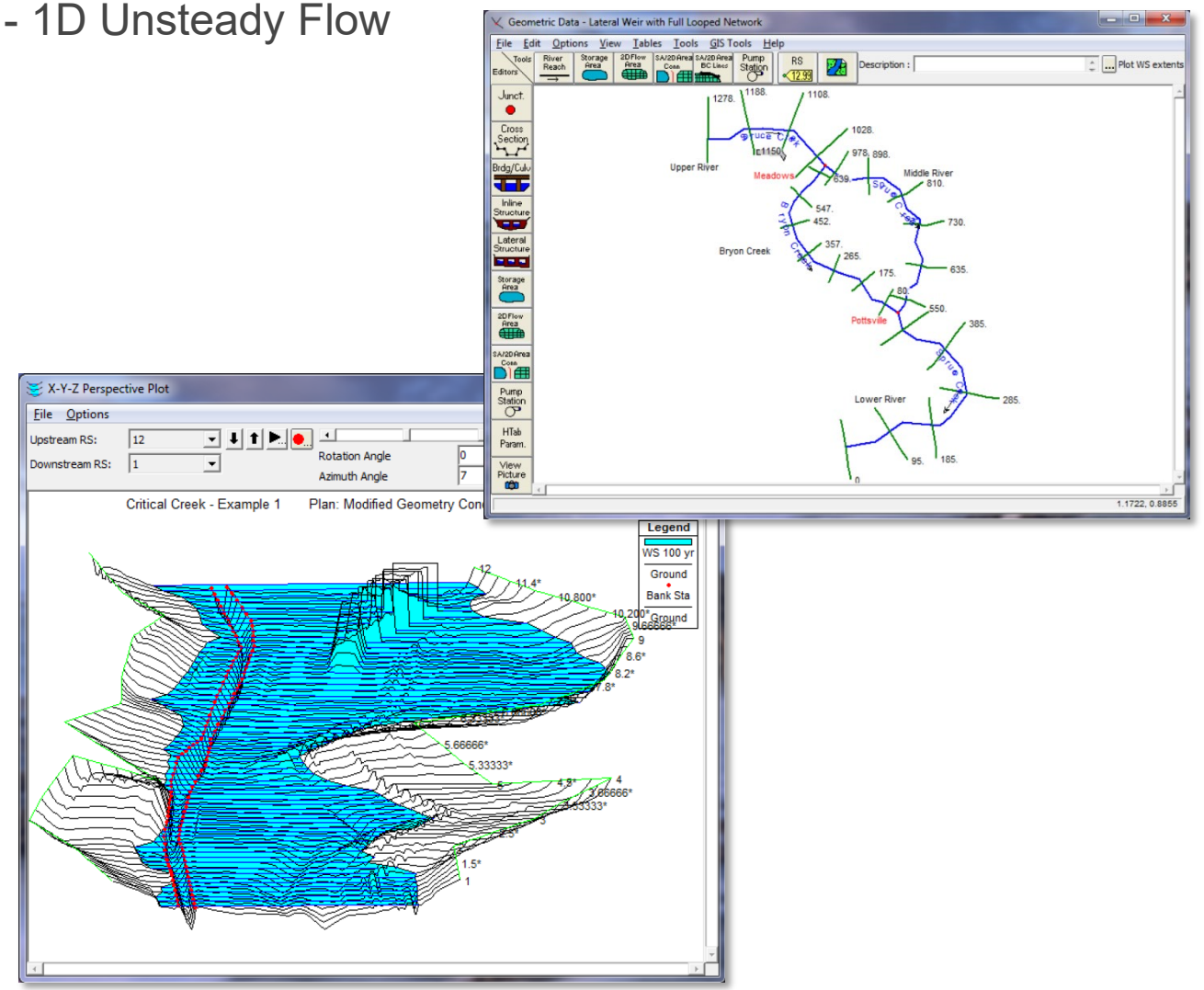


(USACE, 2015)

FEMA General Hydraulic Considerations

Procedures - 1D Unsteady Flow

- Computes using steady flow analysis methods for the range of discharges the structure is likely to experience
- Includes the following:
  - Unsteady State Channel Routing Models, which utilize inflow hydrographs produced by separate hydrologic analysis
  - Hydrodynamic Models, which include rainfall-runoff modeling component to simulate both watershed hydrographs and channel routing
- Applicable to larger rivers where open channel flow is the predominant source of flooding
- Unlike Steady State Models, these compute storage along with conveyance within the floodplain



(USACE, 2015)

DNR Indiana Department of Natural Resources | DIVISION OF WATER

FEMA General Hydraulic Considerations

Procedures - Calibration of Hydraulic Models

- Historic Flood Data
- Document the Calibration Process
  - Dates, Data, Location of measurements
  - Parameters revised and rationale for revising
  - Calibration model input and output data
- Calibration Parameter Adjustments must be inline with measurable conditions.
- Aerial photos can be helpful to compare reasonableness of the simulation

(WBIW, 2025)

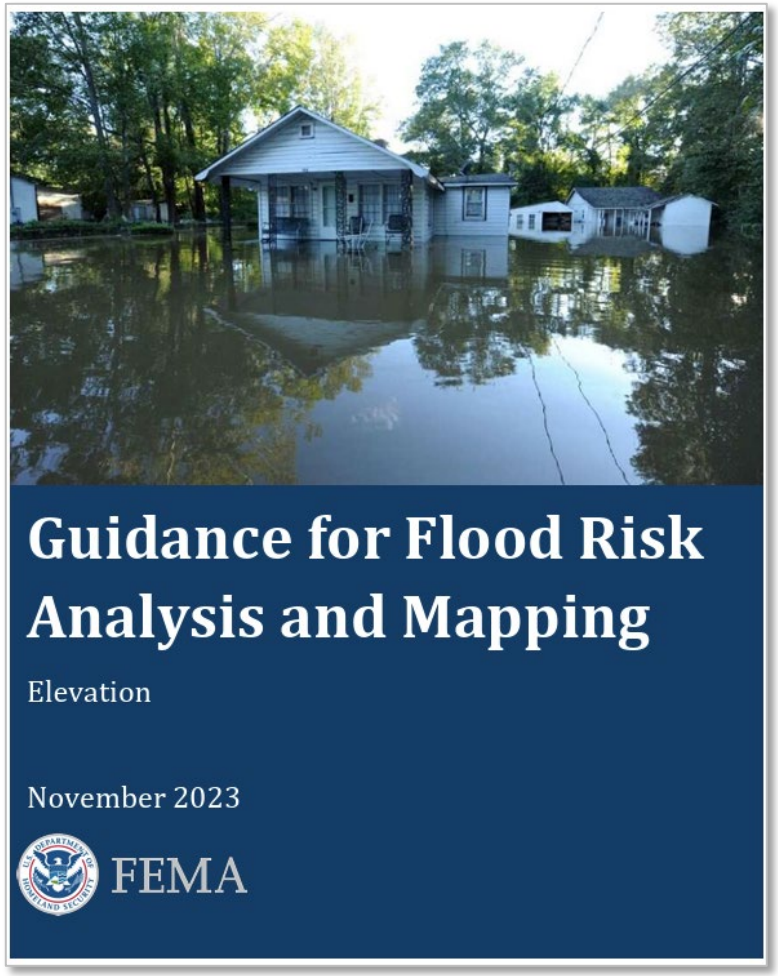
DNR Indiana Department of Natural Resources | DIVISION OF WATER

FEMA General Hydraulic Considerations

Data Requirements

Elevation - Guidance Document #47

Provides basic information on elevation data terminology, data formats used in Risk MAP program, references for accuracy and other lidar topics, as well as guides for procurement of either leveraged or newly acquired elevation data



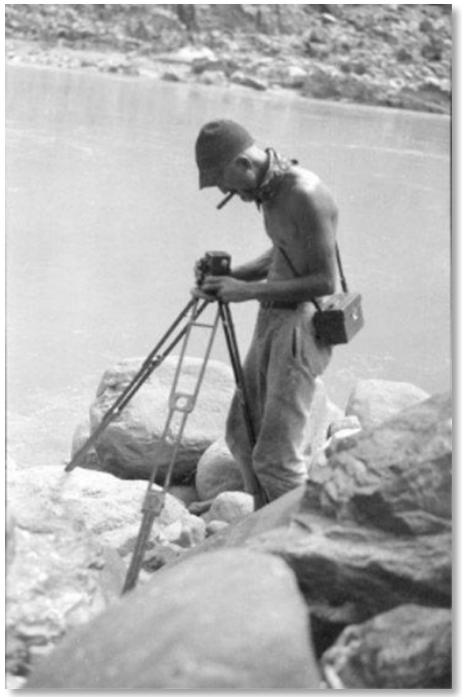
(FEMA, 2024)

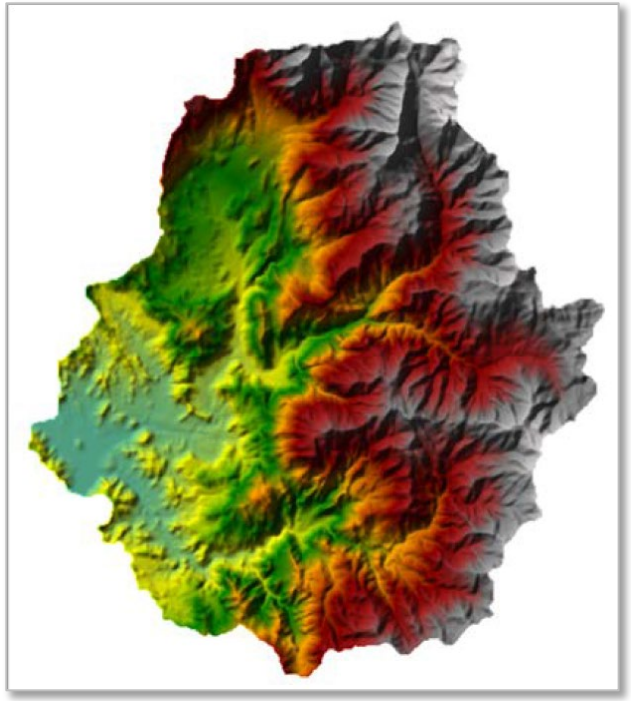
FEMA General Hydraulic Considerations

Data Requirements

Topography

- Factors for Suitability of Topographic Data
  - 4ft or less Contours intervals in Steep Terrain
  - 2ft or less Contours intervals in Flat Terrain
  - Currency of Data: Whether significant changes have occurred since data was developed





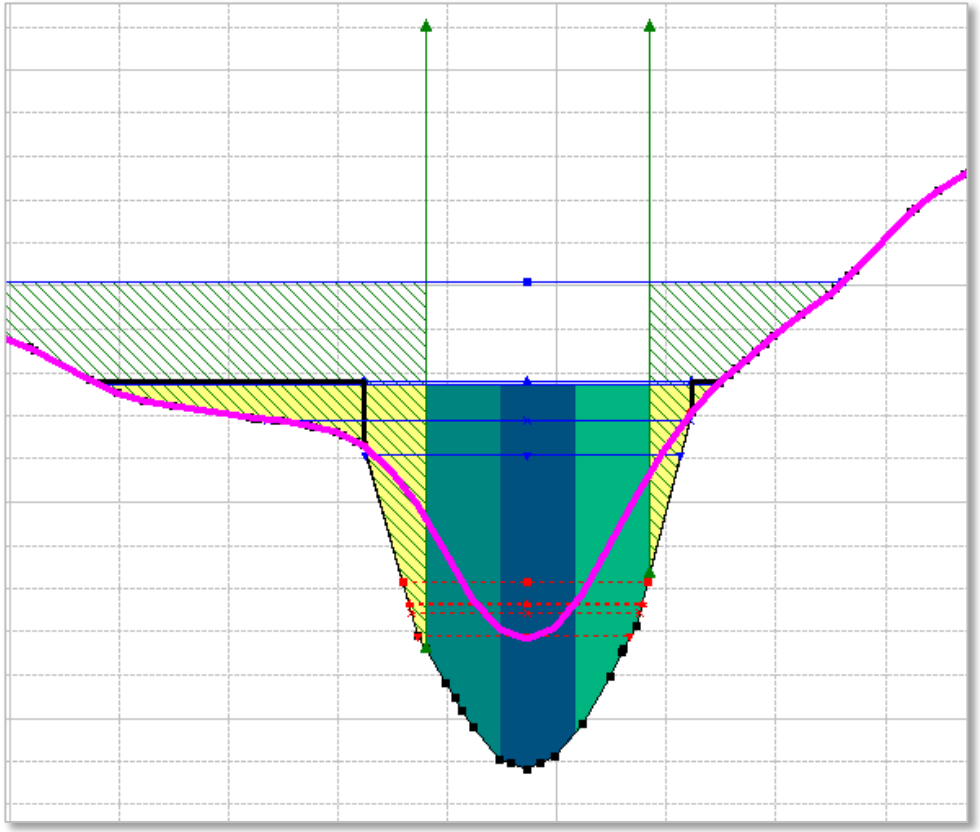
(USGS, 1923)

FEMA General Hydraulic Considerations

Data Requirements

Bathymetry

- Channel data is typically used to support an enhanced level of study.
- The Mapping Partner should consider the following:
  - Currency of Data
  - Density of Cross Sections
- Sometimes requiring interpolation to be used in between surveyed areas.
- Information necessary to adequately represent hydraulic structures, cross sections, or bathymetry should be determined by the engineer:
  - Requirements may differ between locations along the same reach depending on characteristics and availability of existing information

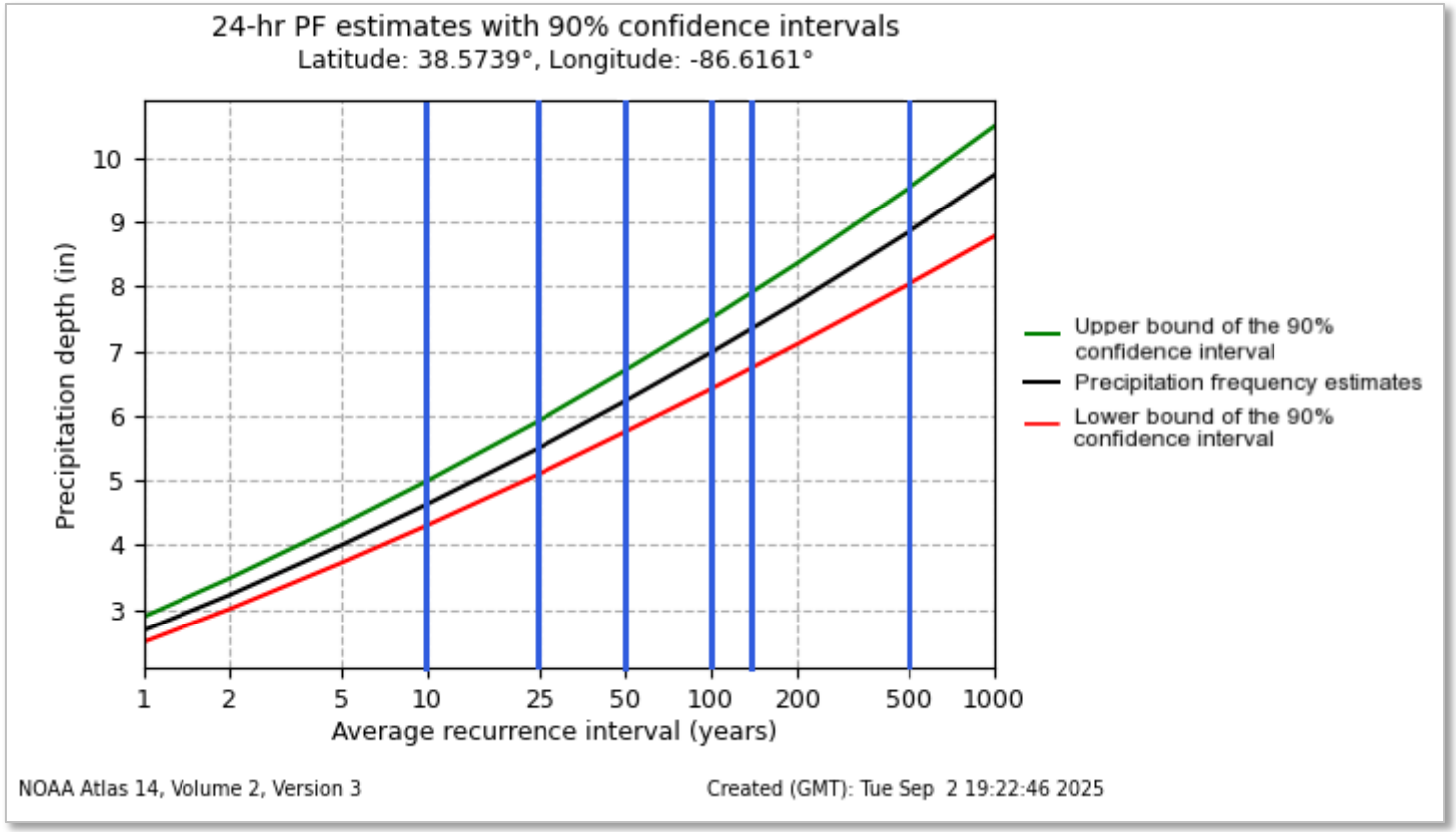


FEMA General Hydraulic Considerations

Data Requirements

Hydrology

- In order to perform hydraulic analysis, hydrologic or flow data must be available for each of the five flood frequency events and the 1-percent plus flood event. (New Studies)
- Significant changes to the hydrology of the watershed can be cause for the peak flow not reflecting existing conditions



FEMA General Hydraulic Considerations

Model Development

Narrative detailing the process and considerations made while building the models

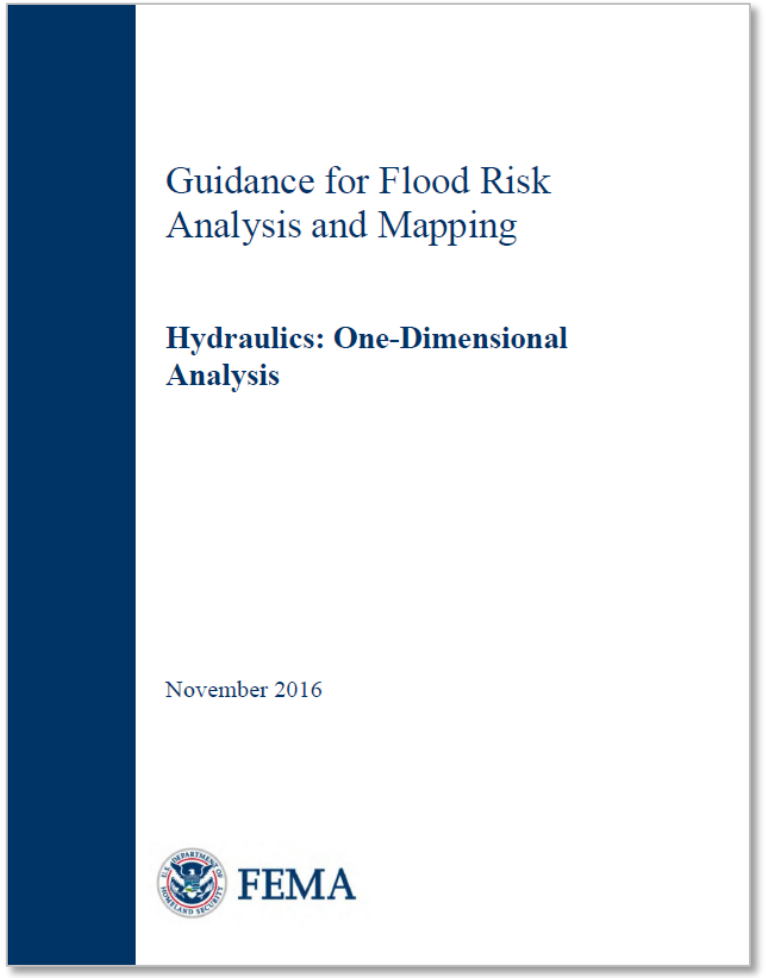
- Deviations from recommended values of inputs
- Calibration data and use
- Highlights of major changes to the effective data

DNR Indiana Department of Natural Resources | DIVISION OF WATER

FEMA Hydraulics: 1D Analysis

Guidance for Flood Risk Analysis and Mapping

- Hydraulic analysis is most performed using a one-dimensional, steady flow, step backwater model for subcritical flow.
- Following to Guidance for Flood Risk Analysis and Mapping Hydraulics published in November 2016.

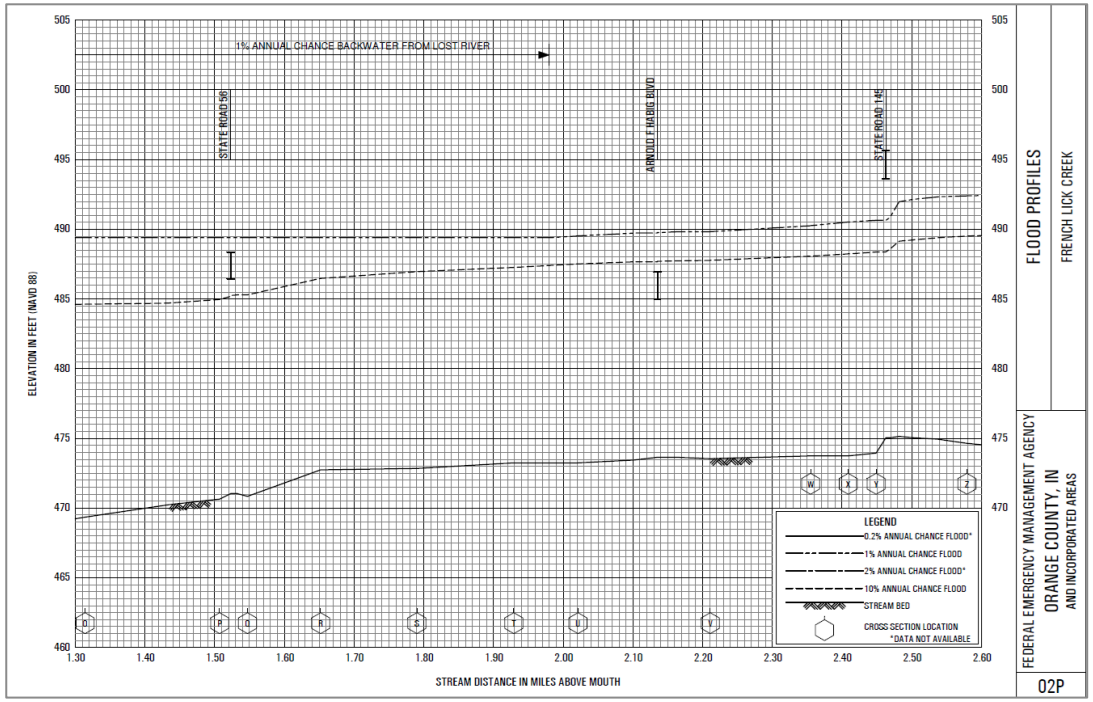


DNR Indiana Department of Natural Resources | DIVISION OF WATER

FEMA Hydraulics: 1D Analysis

Profile Baseline

- Horizontal distance along the Flood Profile as represented on the FIRM and shown in the Floodway Data Table can be the distance between cross sections or nodes in a one-dimensional model.

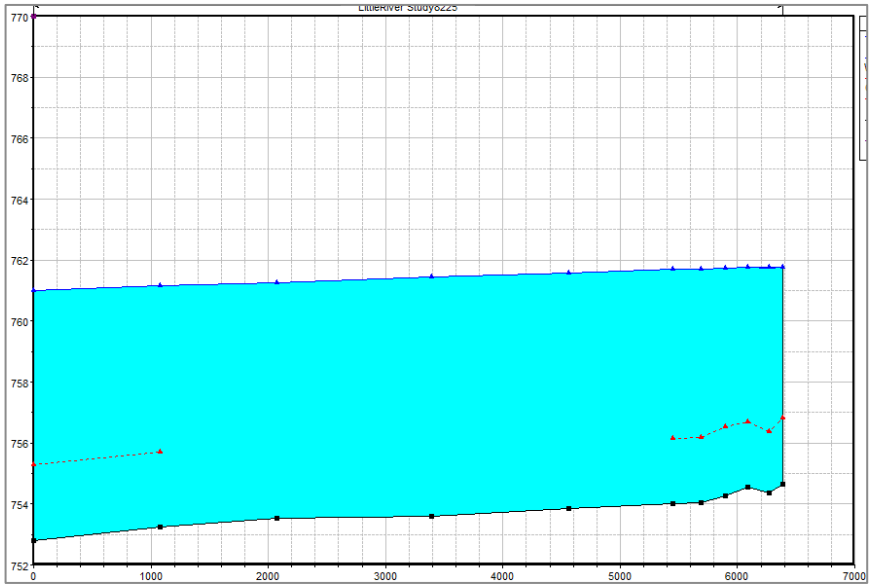


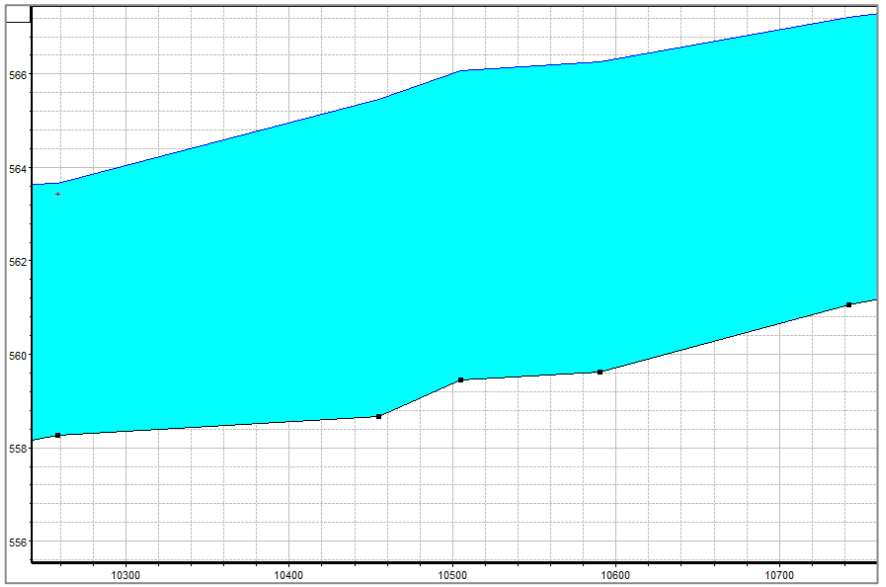
DNR Indiana Department of Natural Resources | DIVISION OF WATER

FEMA Hydraulics: 1D Analysis

Cross Sections

- Must be placed perpendicular to flood flow and extend beyond the most extreme event modeled.
- Must be spaced related to the geometry and hydraulic roughness of the reach between adjacent cross sections varies gradually to be as Linear.
- General slope of the flow path between adjacent cross sections should be approximately constant.
- Cross sections of underwater/above water portions should be surveyed by Conventional surveying techniques.



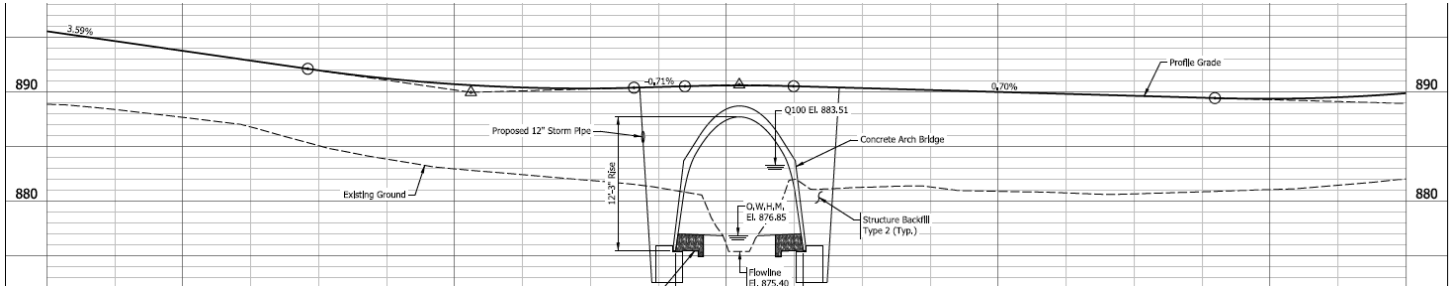


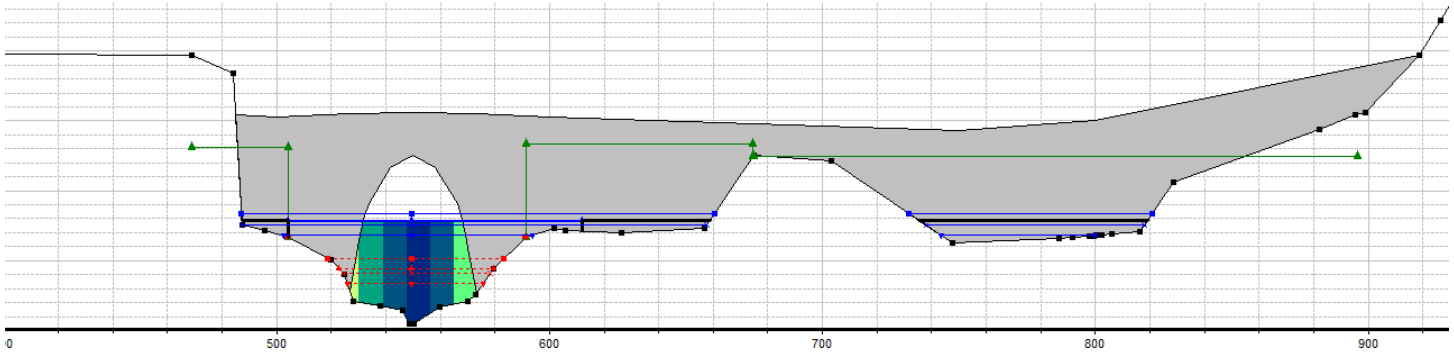
DNR Indiana Department of Natural Resources | DIVISION OF WATER

FEMA Hydraulics: 1D Analysis

Hydraulic Structures

- Dimensions of hydraulic structures (flood gates/diversion channels) crossing the stream should be surveyed in the field where a BFE to be published/ estimated appropriate dimensions with using direct measurement or from as-built plans.
- Bridge Skews are the most common hydraulic structure crossing a stream and may significantly affect water-surface profiles (FEWA Hydraulic Design Series No.1, HSD1, 1978 & HEC-18, 2001).
- Noted that bridge scouring may result in significant changes in cross sections.

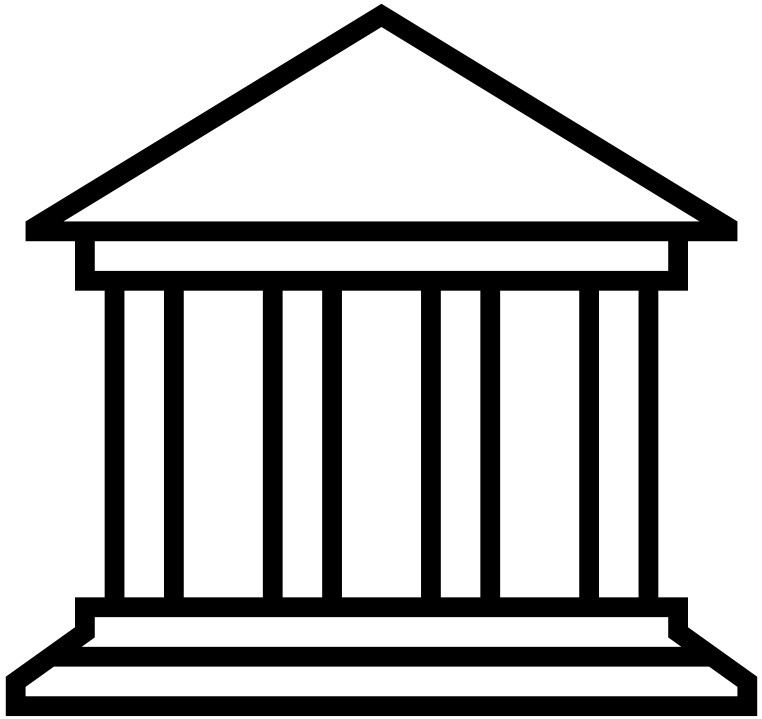




DNR Indiana Department of Natural Resources | DIVISION OF WATER

Regulatory Requirements

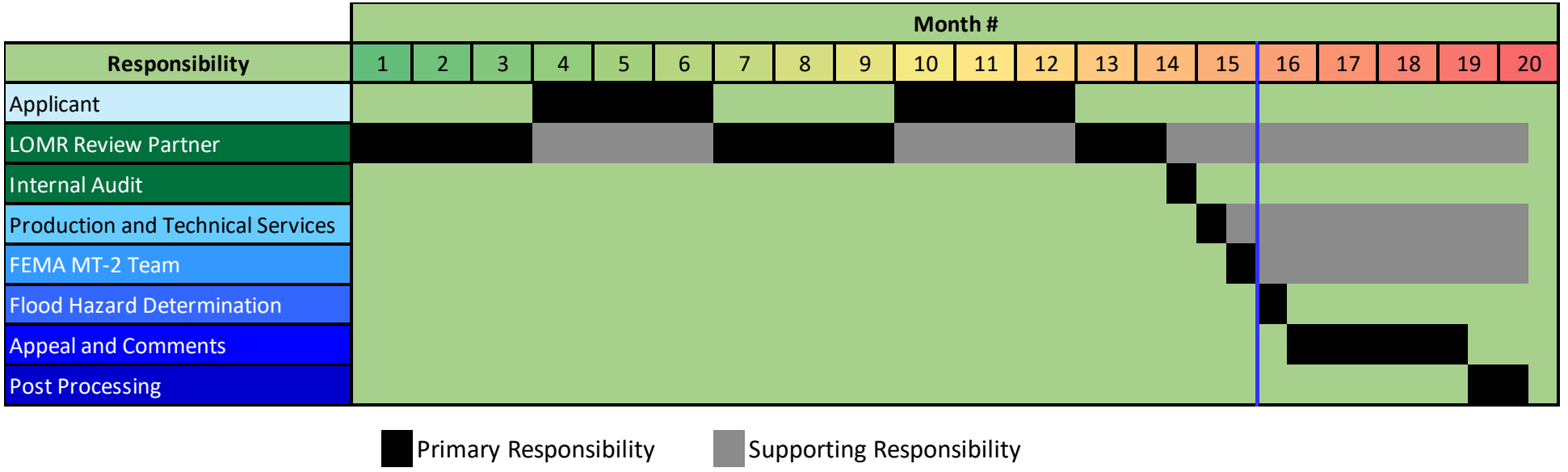
- Same model as the effective
  - Except HEC-2
  - Appropriate Justification
- 44 CFR 65.5(a)(8)
  - Zone AE must have all of the effective return intervals
- 44 CFR 65.5 Changes Based on Fill (No-Rise)
  - Potential Violation.
- 44 CFR 65.6(a)(9)
  - Zone A to Zone AE only needs 1% recurrence interval
- 44 CFR 65.6 Change in BFE
- 44 CFR 65.7 Change in Floodway
- 44 CFR 65.8 Proposed Projects
- 44 CFR 65.10 Levee Projects
- 44 CFR 65.12 LOMC due to Proposed Encroachments



DNR Indiana Department of Natural Resources | DIVISION OF WATER

Does it Matter?

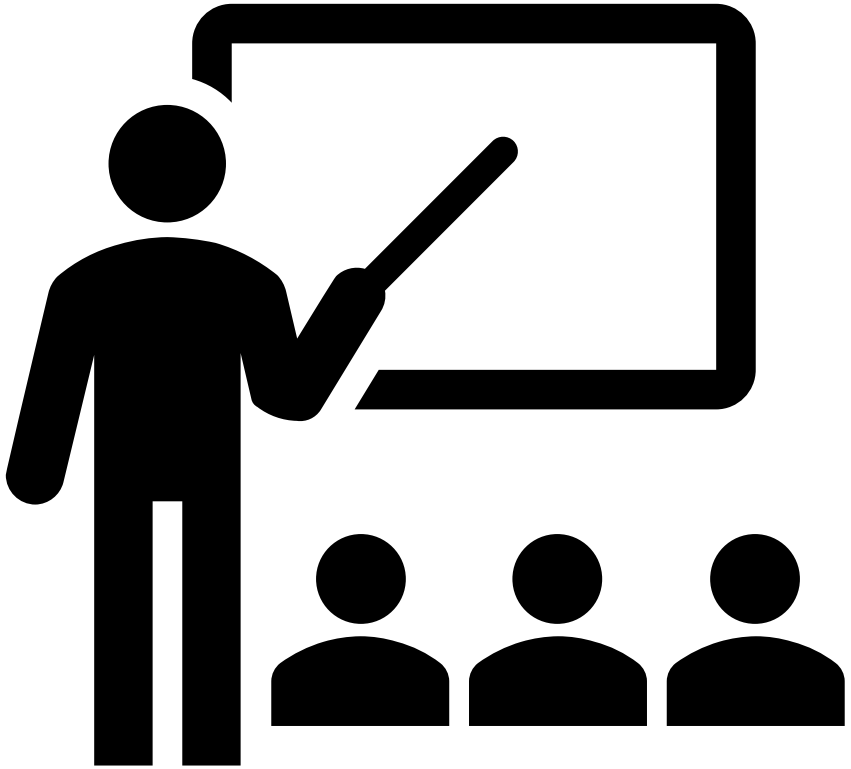
- 44 CFR 67.5
  - Right of appeal
- 44 CFR 67.6
  - Basis: modeling or input parameter errors.
- Repeatable
  - The next engineer must use your data.
- Reduce Processing Time



QUESTIONS?

Conclusion

HOMEWORK



DNR Indiana Department of Natural Resources | DIVISION OF WATER

References

1. FEMA. (2023, December 13). MT-2 Application Forms and Instructions. Retrieved from FEMA: https://www.fema.gov/sites/default/files/documents/fema_rm-mt-2-forms-instructions.pdf
2. FEMA. (2025, August 18). Guidance for FEMA's Risk Mapping, Assessment and Planning. Retrieved from FEMA: https://www.fema.gov/sites/default/files/documents/fema_rm-mt-2_requests_guidance_nov_2023.pdf
3. FEMA. (2025, July). Hydraulic Numerical Models Meeting the Minimum Requirement of National Flood Insurance Program. Retrieved from FEMA: https://www.fema.gov/flood-maps/products-tools/numerical-models/hydraulic#national
4. FEMA. (2024, December 5). Guidance for FEMA's Risk Mapping, Assessment and Planning. Retrieved from FEMA: https://www.fema.gov/sites/default/files/documents/fema_guidance_general_hydraulics_considerations_nov2024.pdf
5. FEMA. (2014, May 19). FEMA Flood Map Service Center. Retrieved from FEMA: https://msc.fema.gov/portal/downloadProduct?productTypeID=FINAL_PRODUCT&productSubTypeID=FIS_REPORT&productID=18117CV000A
6. FEMA. (2024, November 18). Guidance for FEMA's Risk Mapping, Assessment and Planning. Retrieved from FEMA: https://www.fema.gov/sites/default/files/documents/fema_guidance_elevation_nov_2024_0.pdf
7. FEMA. (2025, June). State-Specific Preferences. Guidance for Flood Risk Analysis and Mapping: State-Specific Preferences. Washington, D.C.: U.S. Government Printing Office.
8. FEMA. (2020, December 1). Guidance for FEMA's Risk Mapping, Assessment and Planning. Retrieved from FEMA: https://www.fema.gov/sites/default/files/documents/fema_contiguous-community-matching-guidance.pdf
9. USACE. (1993, October 15). Engineer Manuals. Retrieved from USACE Publications: https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1416.pdf
10. Indiana Natural Resource Commission. (2014, June). General Guidelines for the Hydrologic-Hydraulic Assessment. Retrieved from Indiana Department of Natural Resources: https://www.in.gov/dnr/water/files/wa-GGHHA-chapter_5.pdf
11. FEMA. (2020, December 1). Guidance for FEMA's Risk Mapping, Assessment and Planning. Retrieved from FEMA: https://www.fema.gov/sites/default/files/documents/fema_archived-bfe-mapping-guidance.pdf
12. FEMA. (2021, November). Guidance for FEMA's Risk Mapping, Assessment and Planning. Retrieved from FEMA: https://www.fema.gov/sites/default/files/documents/fema_guidance_data_capture%25E2%2580%2593workflow_details_nov2024.pdf
13. FEMA. (2023, December 13). FEMA Policy Standards for Flood Analysis and Mapping Policy (Rev. 14). Retrieved from: https://www.fema.gov/sites/default/files/documents/fema_rm-flood-risk-analysis-mapping-policy-rev14.pdf
14. USGS. (1989). Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains. Retrieved from USGS: https://pubs.usgs.gov/wsp/2339/report.pdf
15. Bradley, J. N. (1978, March 1). Hydraulics of Bridge Waterways, Hydraulic Design Series (HDS) No. 1. Retrieved from National Transportation Library: https://rosap.ntl.bts.gov/view/dot/75187/dot_75187_DS1.pdf
16. USACE. (1995, September). Hydrologic Engineering Center. Retrieved from Institute for Water Resources: https://iwrlibrary.sec.usace.army.mil/resource?title=Flow%20Transitions%20in%20Bridge%20Backwater%20Analysis&documentId=e07d7c22-9737-4892-9a99-feaaf2dfc10b
17. USACE. (2016, February). Hydrologic Engineering Center. Retrieved from Institute for Water Resources Library: https://iwrlibrary.sec.usace.army.mil/resource?title=HEC-RAS%20River%20Analysis%20System%20User%27s%20Manual&documentId=8686025d-dac5-41a9-f388-a2dc94abe6e4
18. USACE. (2016, February). Hydrologic Engineering Center. Retrieved from Institute for Water Resources Library: https://iwrlibrary.sec.usace.army.mil/resource?title=HEC-RAS%20River%20Analysis%20System%20Hydraulic%20Reference%20Manual&documentId=c3941546-35b0-4257-ec8b-a6a23a4ede11
19. Knipe, D. (2003, February). State Engineering Resources. Retrieved from Indiana Department of Natural Resources: https://www.in.gov/dnr/water/surface-water/indiana-floodplain mapping/state-engineering-resources/#Notes_on_Critical_Depth_Messages