

# EVALUATING GEOMORPHIC EVOLUTION IN CONSTRUCTED TWO-STAGE DITCHES



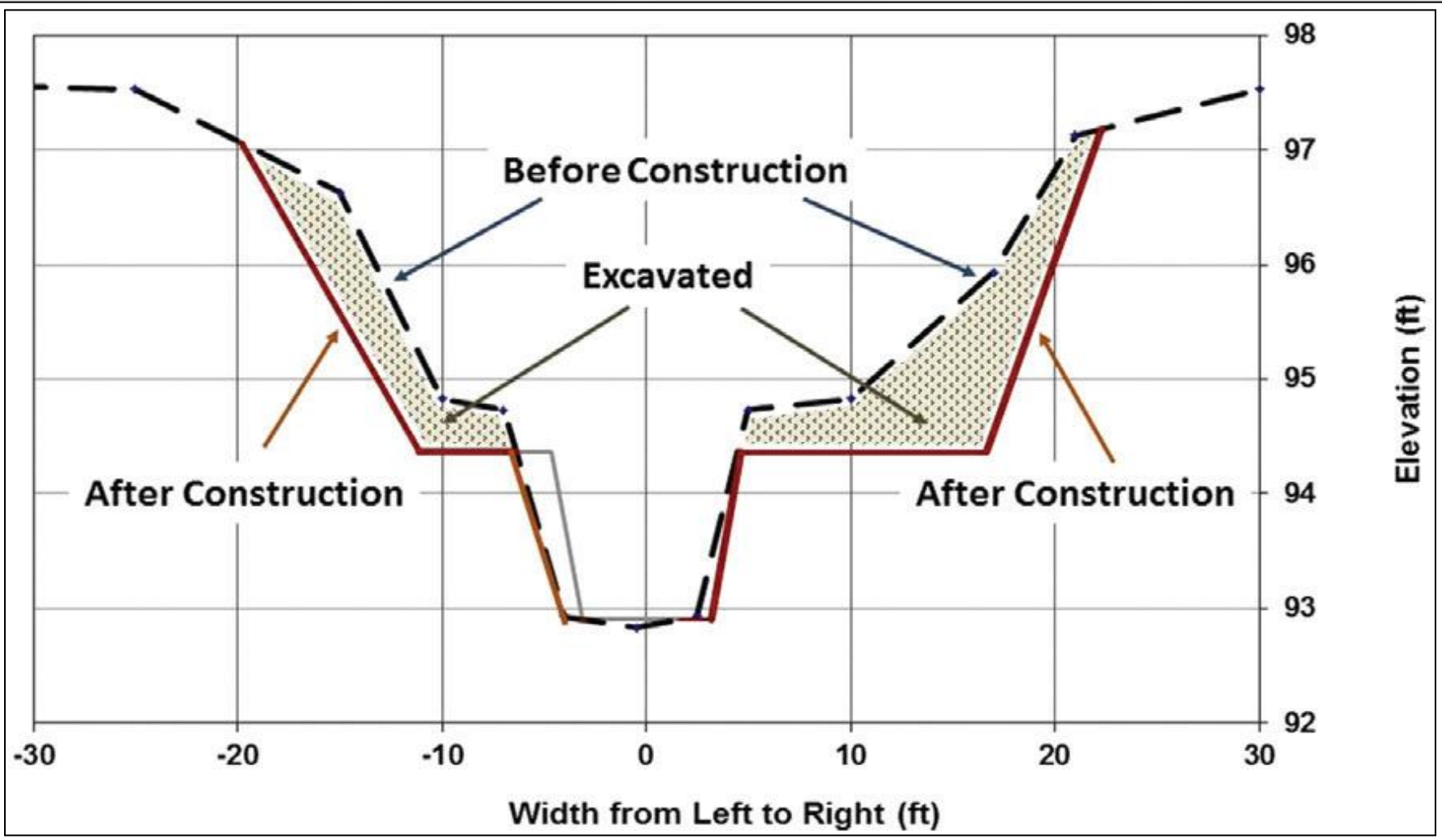
**JESSICA D'AMBROSIO**  
**JONATHAN WITTER, ANDY WARD**

# TWO-STAGE CHANNEL DESIGN



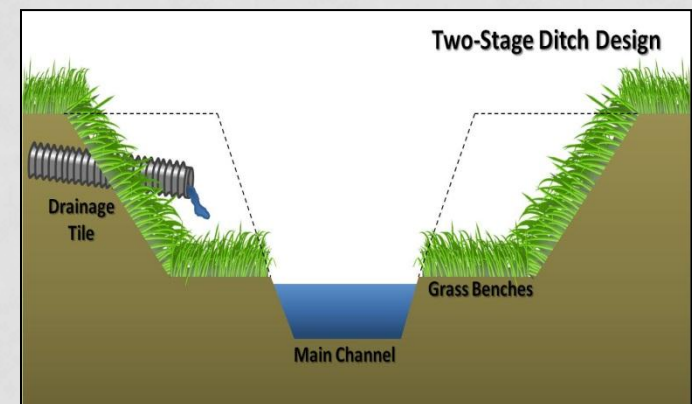
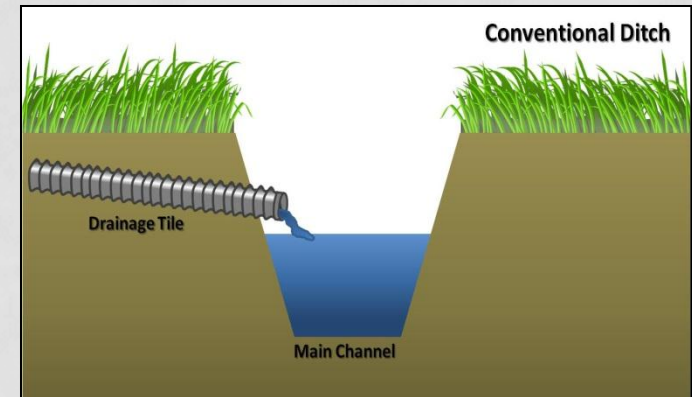


# TWO-STAGE CHANNEL DESIGN



# THEORY SAYS... *IN CONDITIONS WHERE THE TWO-STAGE DITCH PRACTICE APPLIES*

- ✓ Stabilizes ditch banks.
- ✓ Increases or maintains drainage capacity for subsurface tile flows.
- ✓ Lowers the water surface elevation/stage of peak flows.
- ✓ Creates a self-flushing system by maintaining an inset channel that effectively transports sediment.
- ✓ Provides detention by creating valley storage.
- ✓ Reduces need for maintenance or clean-out.
- ✓ Reestablishes some habitat and watershed functions including pollutant assimilation.



# NRCS RESOURCE CONCERNS

- **Soil Erosion**
- Soil Condition
- **Water Quality**
- Air Quality
- **Plant Condition**
- **Fish and Wildlife**
- Domestic Animals
- **Water Quantity**
- Energy



## EVALUATION OF EVOLUTION AND WATER QUALITY BENEFITS OF TWO-STAGE DITCHES IN A TRI-STATE REGION OF THE USA

- Determine the evolution and stability of two-stage channels in the tri-state region (*Research Objective*).
- Ascertain the enhanced nitrate removal benefits of two-stage channels in the tri-state region (*Research Objective*).
- Demonstrate the water quality or drainage benefits of alternative land management and channel system practices to rural and urban stakeholders using a suite of modeling and management tools (*Education and Extension Objective*).

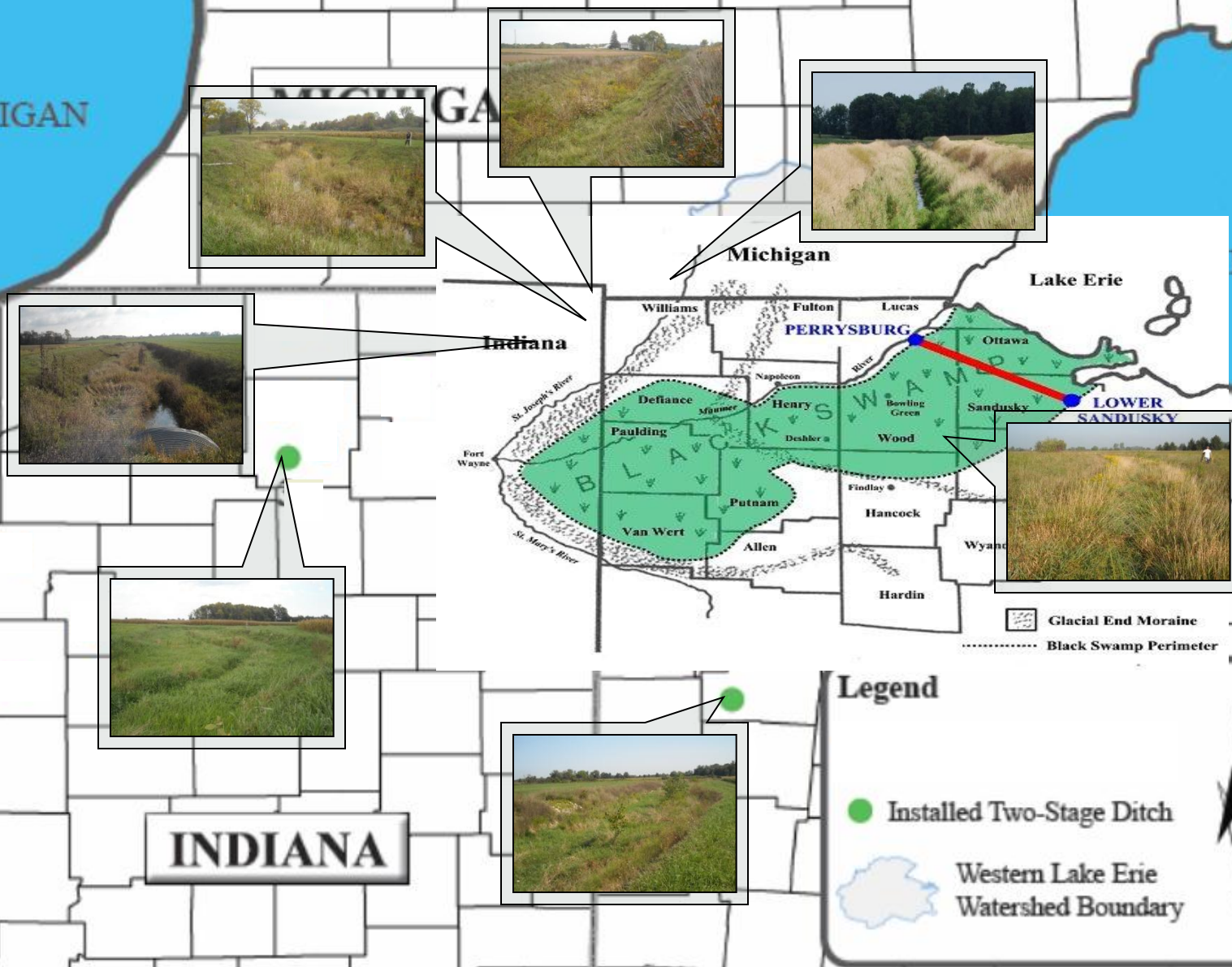


# RESEARCH QUESTIONS

1. Where are significant geomorphic changes occurring within the ditch?
2. Do two-stage ditches maintain their drainage capacity over time?
3. Has the two-stage ditch maintained an inset channel and reached a quasi-equilibrium state?
4. Did the two-stage ditch meet the goals of the project for which it was designed?

# TWO-STAGE DITCHES IN TRI-STATE REGION

LAKE MICHIGAN





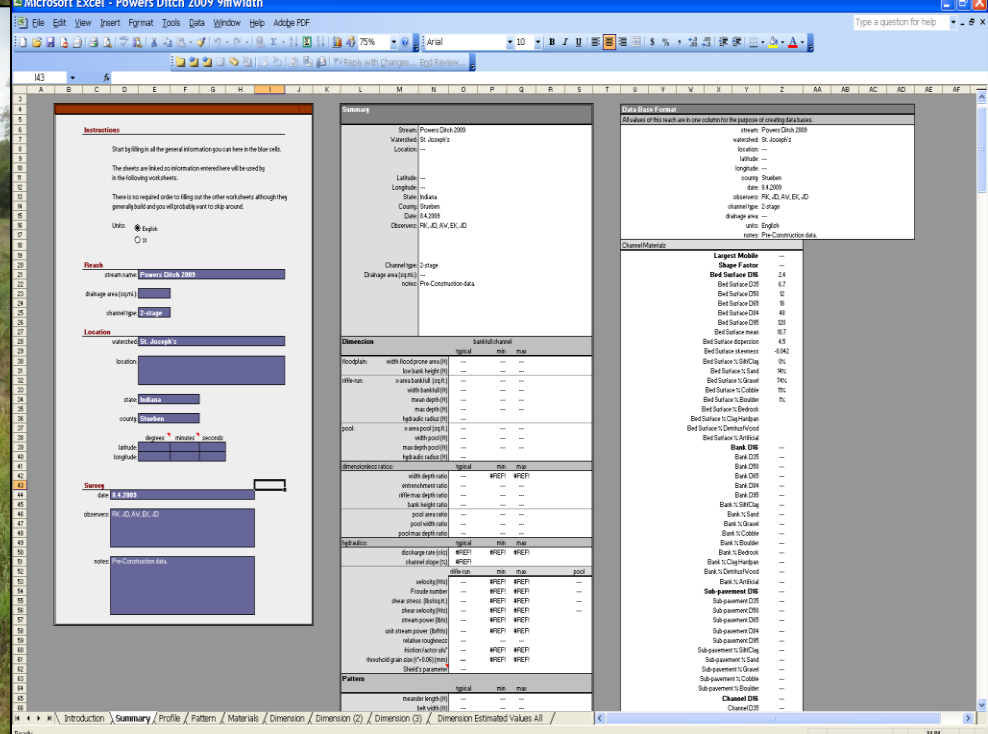


2007 google map

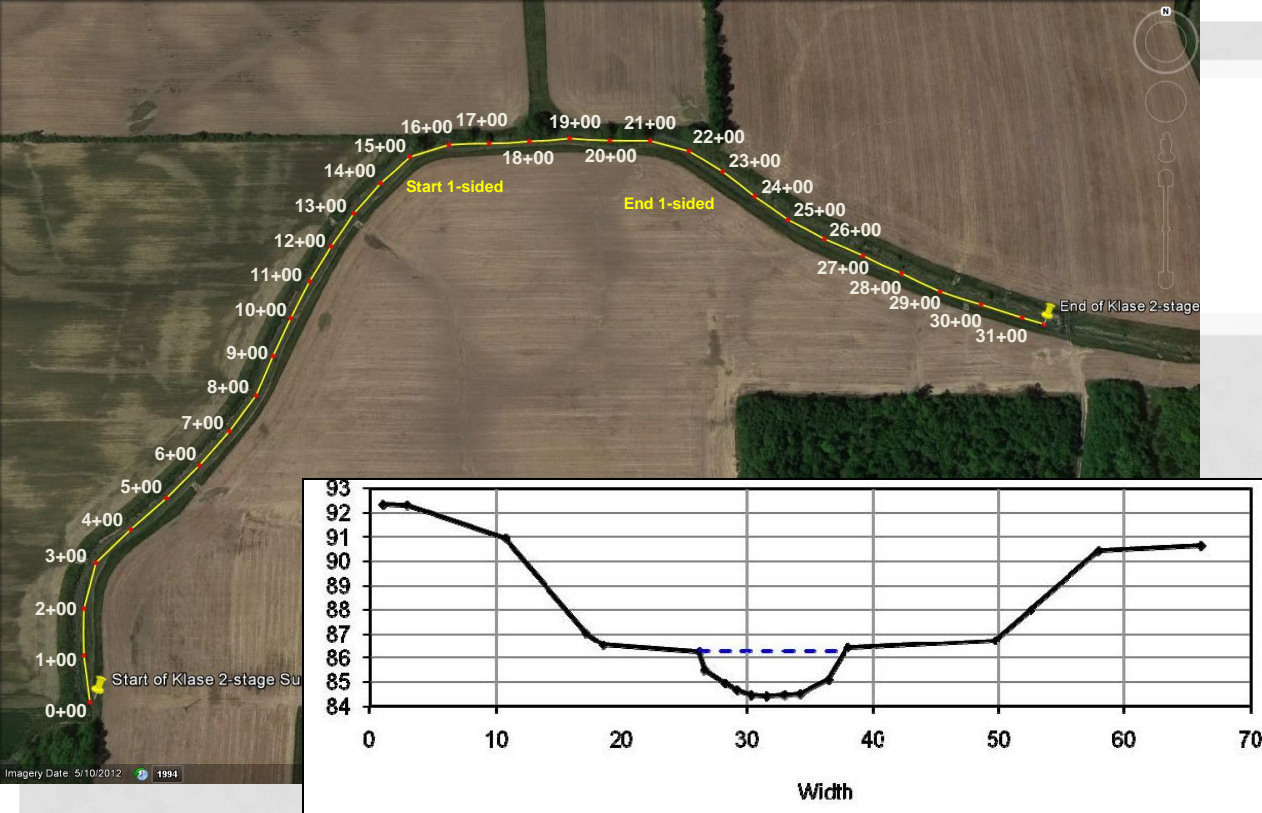
# EXPERIMENTAL DESIGN

- Before After Control Impact (BACI).
- 1 year of pre-construction data collection.
- 2+ years of post-construction data collection.

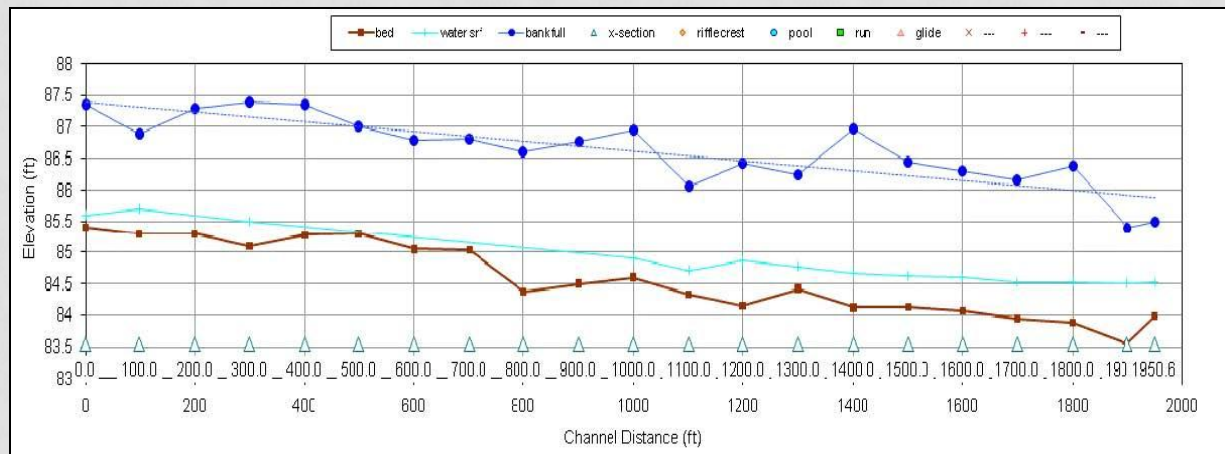






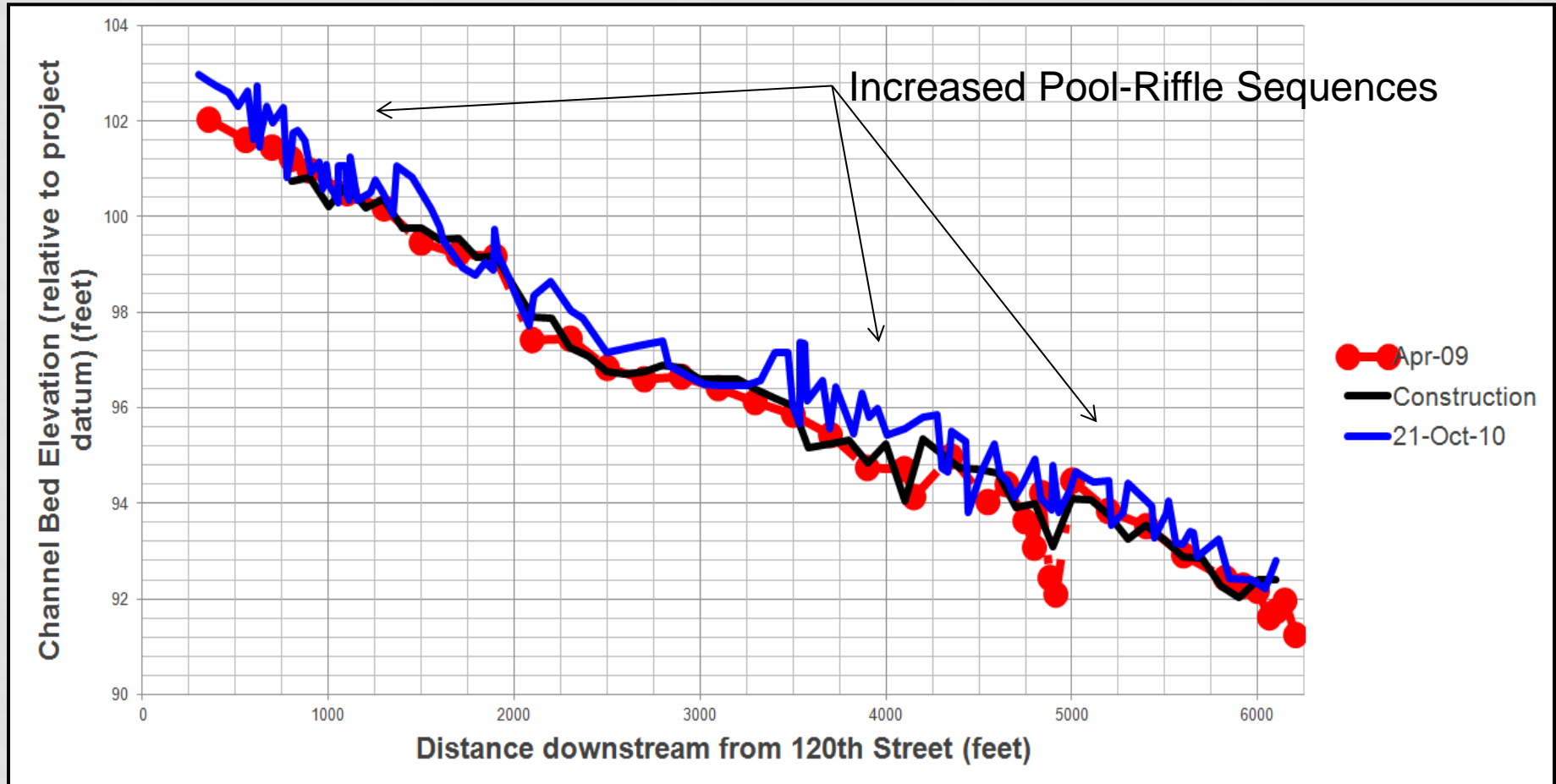


Station	Width			
	2001	2004	2009	2012
0	20.1		53.0	35.0
100			37.3	35.8
200	25.8		30.2	27.7
300	25.5		46.5	36.0
400			55.1	35.4
500	33.6		34.1	30.1
600	50.8		31.7	35.1
700	29.1		32.3	34.6
800	21.3		34.9	34.1
900		35.2	51.0	29.3
1000	63.2	43.6	43.6	54.5
1100		43.3	35.1	44.6
1200		58.9	44.0	44.1
1300		32.9	53.0	37.1
1400		55.7	33.5	37.2
1500		34.2	31.1	32.7
1600		32.1	32.2	33.0
1700		39.9	30.3	42.1
1800		51.0	33.8	30.9
1900		30.5	47.2	44.7
2000				48.0
2100				38.7

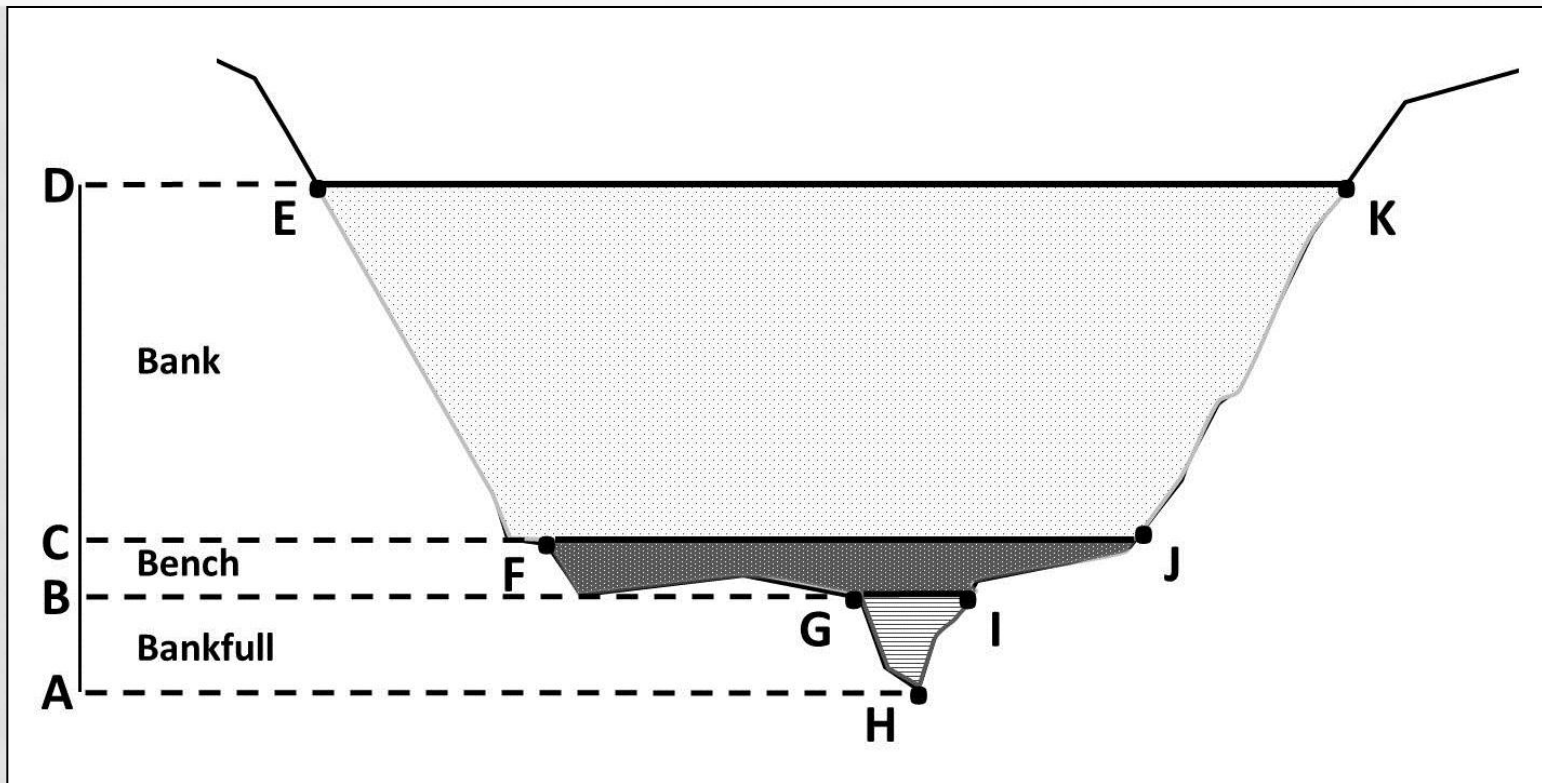




# EVALUATING GEOMORPHIC CHANGE: INSTABILITY OR NATURAL ADJUSTMENTS?



# Evaluating Geomorphic Change



**FIXED WIDTH/DEPTH  
APPROACH**

Benches  
Inset Channel

- Inset Channel (GHI) 2009
- Benches (FGIJ) 2012
- Banks (EFJK)
- Top of Ditch (EK)

# BULL CREEK TRIBUTARY, WOOD COUNTY, OH (BUILT 2002)

**Results: No significant changes to inset channel dimensions; scour on benches.**





# CROMMER DITCH, HILLSDALE COUNTY, MI (BUILT 2003)

**Results: No significant changes to dimensions.**



**PRE- CONSTRUCTION**



**FLOOD EVENT DURING CONSTRUCTION**



**1 MONTH AFTER CONSTRUCTION**



**5 YEARS POST- CONSTRUCTION**



# KLASE DITCH, SHELBY COUNTY, OH (BUILT 2005)

**Results: No significant changes to dimensions.**



**PRE-CONSTRUCTION (2004)**



**2 YEARS POST-CONSTRUCTION**



**4 YEARS POST-CONSTRUCTION**



**7 YEARS POST-CONSTRUCTION**



# SHATTO DITCH, KOSCKIUSKO COUNTY, IN (BUILT 2007)

**Results: Inset channel significantly smaller after construction.**



**PRE-CONSTRUCTION (2007)**



**FLOOD EVENT DURING CONSTRUCTION**



**1 YEAR POST-CONSTRUCTION**



**5 YEARS POST-CONSTRUCTION**



# CREEL DITCH, STEUBEN COUNTY, IN (BUILT 2008)

**Results: No significant changes in inset channel dimensions; minor scour on benches.**





# POWERS DITCH, STEUBEN COUNTY, IN (BUILT 2009)

**Results: No significant changes in dimensions; issues with 1-sided construction.**



**PRE-CONSTRUCTION (2009)**



**1 YEAR POST-CONSTRUCTION**



**3 YEARS POST-CONSTRUCTION, 2-SIDED**



**3 YEARS POST-CONSTRUCTION, 1-SIDED**



# RIDENOUR DITCH, STEUBEN COUNTY, IN (BUILT 2009)

**Results: Inset channel wider and deeper post-construction.**



**1 YEAR POST-CONSTRUCTION (2010)**



**3 YEARS POST-CONSTRUCTION**



**3 YEARS POST-CONSTRUCTION**



**3 YEARS POST-CONSTRUCTION, 1-SIDED**

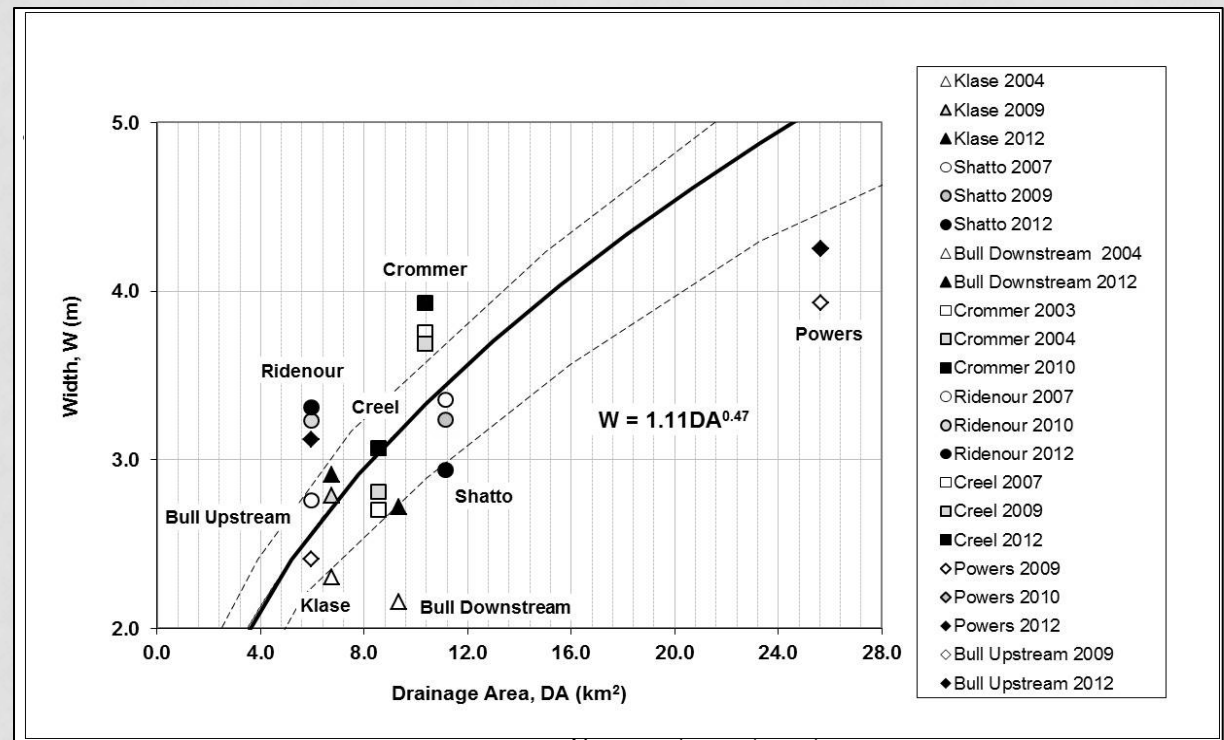


## RESEARCH QUESTIONS

HAS THE TWO-STAGE DITCH MAINTAINED AN INSET CHANNEL AND REACHED A QUASI-EQUILIBRIUM STATE?

# Findings:

- Inset channel maintained based on regional curve predicted design
  - Inset channel changes reflected natural adjustments, but not all ditches had reached their quasi-equilibrium state.
  - Nearly all of the sites fell within the expected range for the inset channel width.



## RESEARCH QUESTIONS

HAS THE TWO-STAGE DITCH MAINTAINED AN INSET CHANNEL AND REACHED A QUASI-EQUILIBRIUM STATE?

# Findings:

- Minor changes detected in the inset channel and on the benches. Few exhibited scour on the side slopes.
  - Benches inundated 75-175 times/yr (wet year); 5-125 times/yr (dry year)\*
  - Ditches had experienced both degradation and aggradation on the benches at a rate of 0.5-13 mm/yr (Ave. rates of change along 400 m to 1200 m reaches).



\*Data from Notre Dame (Tank et al.)



## RESEARCH QUESTIONS

DO TWO-STAGE DITCHES MAINTAIN THEIR DRAINAGE CAPACITY OVER TIME?

WHERE ARE SIGNIFICANT GEOMORPHIC CHANGES OCCURRING WITHIN THE DITCH?

# Findings:

- Two-stage ditches did not lose drainage capacity (i.e., fill in) 3-10 years after construction.
  - Aggradation on the benches was not likely to threaten tile drain outlets.
  - Localized scour was observed on the banks at some sites, but at all but one site changes were not statistically significant.





## RESEARCH QUESTIONS

DID THE TWO-STAGE DITCH MEET THE GOALS OF THE PROJECT FOR WHICH IT WAS DESIGNED?

# Findings:

- All ditches designed to reduce ditch bank instability, excessive aggradation, and flooding have achieved their goals.
- None have needed traditional maintenance since construction.





# **BANK STABILITY: LOWERING SHEAR STRESSES ON THE BENCHES?**



# BANK STABILITY: BSTEM MODE



Microsoft Excel - BSTEM-5.2 class.xls

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Input bank geometry and flow conditions

Work through all 4 sections then hit the "Run Bank Geometry Macro" button

1) Select EITHER Option A or Option B for Bank Profile and enter the data in the relevant box cells in the alternative option are ignored in the simulation and may be left blank if desired.

2) Enter bank material layer thicknesses (if bank is all one material it helps to divide it into several layers).

3) If bank is submerged then select the appropriate channel flow duration to include confining pressures and calculate erosion amount, otherwise set to 0 in duration below the bank toe.

4) To enter bank profile as correct you can view it by clicking the "View Bank Geometry" button.

Option A - Draw a detailed bank profile using the boxes below

Point	Station (m)	Elevation (m)	Top of toe?
A	0.00	4.00	
B	4.00	4.00	
C	4.14	3.73	
D	4.25	3.47	
E	4.43	3.20	
F	4.57	2.93	
G	4.71	2.67	
H	4.85	2.40	
I	4.93	2.13	
J	5.13	1.87	
K	5.28	1.60	
L	5.42	1.33	
M	5.56	1.07	
N	5.70	0.80	
O	5.84	0.53	
P	5.99	0.27	
Q	6.13	0.00	
R	6.19	0.00	
S	6.25	0.00	
T	6.38	0.00	
U	6.50	0.00	
V	6.63	0.00	
W	7.13	0.00	

Option B - Enter a bank height and angle, the model will generate a bank profile

Option B

a) Input bank height (m) 4.0

b) Input bank angle (°) 62.0

c) Input bank toe length (m) 0.0

d) Input bank toe angle (°) 0.0

Input shear surface angle

Bank layer thickness (m)

Layer	Thickness (m)	Number of layers
Layer 1	0.70	3.30
Layer 2	0.80	2.50
Layer 3	1.00	1.50
Layer 4	0.90	0.60
Layer 5	0.60	0.00

Bank material

Bank profile

Bank edge

Shear surface emergence

Top of bank toe

Break of slope on bank toe

Base of bank toe

End point (usually mid point of channel)

Notes:

Bank profile may overhang

If the bank profile is fully populated, the shear surface emergence point should be anywhere between points B and Q.

The shear surface emergence point must not be on a horizontal section - the elevation of this point must be unique or an error message will display.

Channel and flow parameters

Microsoft Excel - BSTEM-5.2 class.xls

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worksheets. Once you are satisfied that you have completed all necessary inputs, hit the "Run Bank-Stability Model" button.

Bank Material Properties

Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
Silt	Angular Sand	Soft Clay	Stiff Clay	Stiff Clay

ELEVATION (M)

STATION (M)

bank profile

base of layer 1

base of layer 2

base of layer 3

base of layer 4

base of layer 5

failure plane

water surface

water table

Water table depth (m) below bank top

Use water table

Input own pore pressures (kPa)

Own Pore Pressures

Pore Pressure From Water Table

Layer	Pore Pressure (kPa)
Layer 1	1.47
Layer 2	8.83
Layer 3	17.65
Layer 4	26.97
Layer 5	34.32

Factor of Safety

1.23

Conditionally stable

Run Bank-Stability Model

Tech Background Model use and FAQ Input Geometry Bank Material Bank Vegetation and Protection Bank Model Output Toe I

Draw AutoShapes

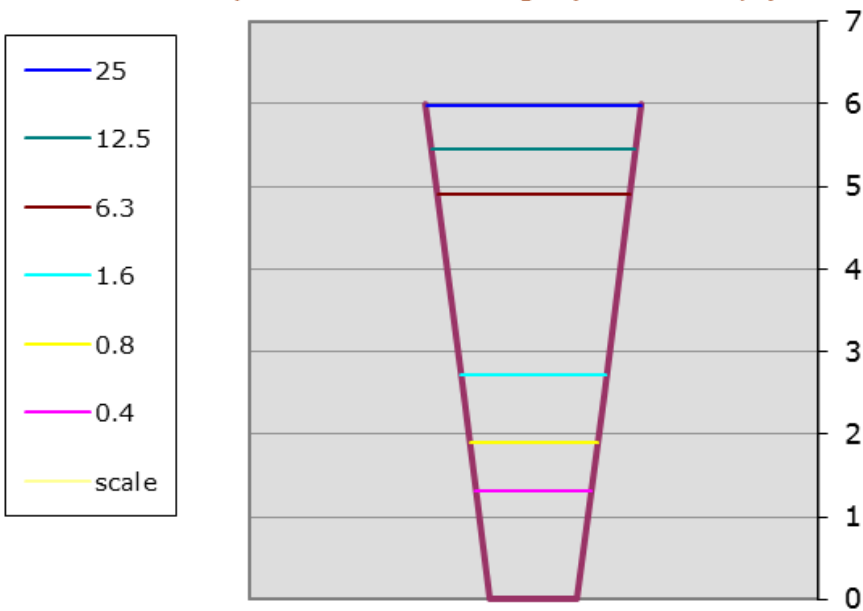
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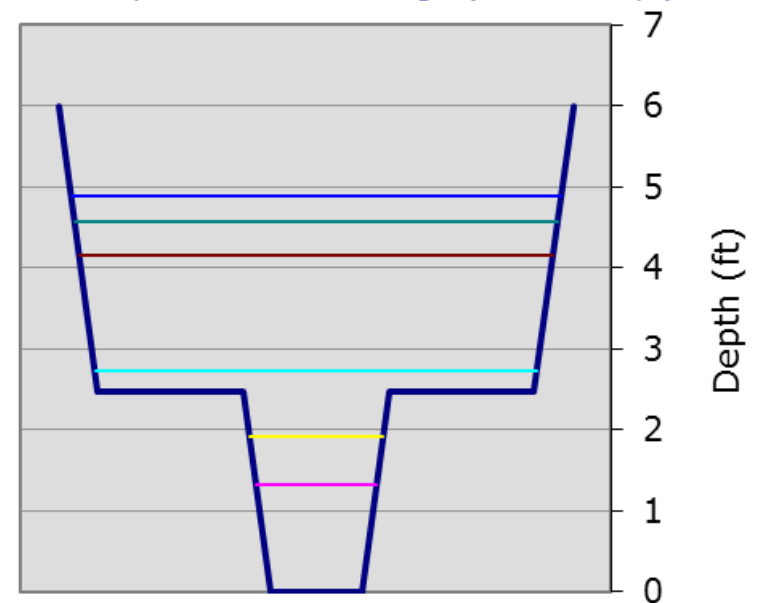


# FLOOD STAGE REDUCTION: CONTRASTING CHANNELS TOOL

A - Depth of Peak Discharge (RI 0.2-100yr)



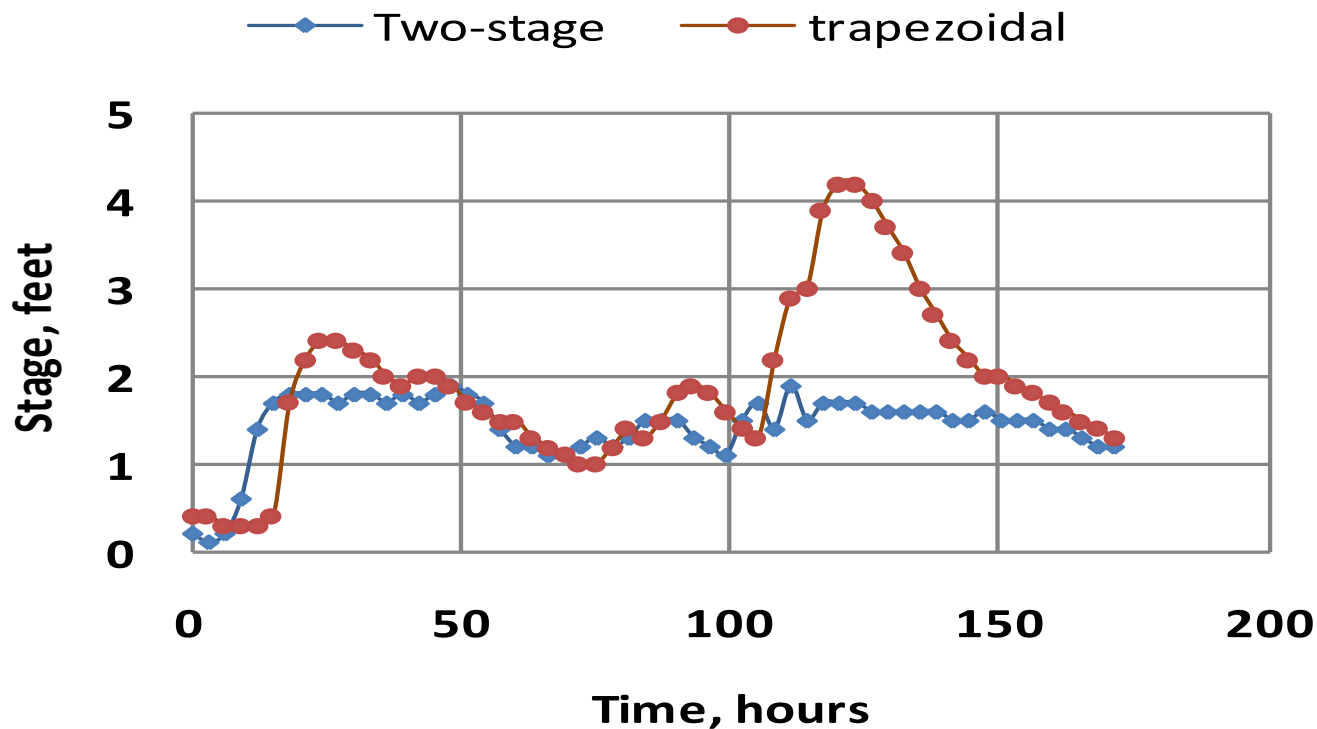
B - Depth of Peak Discharge (RI 0.2-100yr)



**BANKFULL DISCHARGES MAINTAINED,  
PEAK DISCHARGE STAGES LOWERED**

# PEAK FLOW STAGE REDUCTION: MEASURED DATA

## Creel Ditch February 7-14, 2009

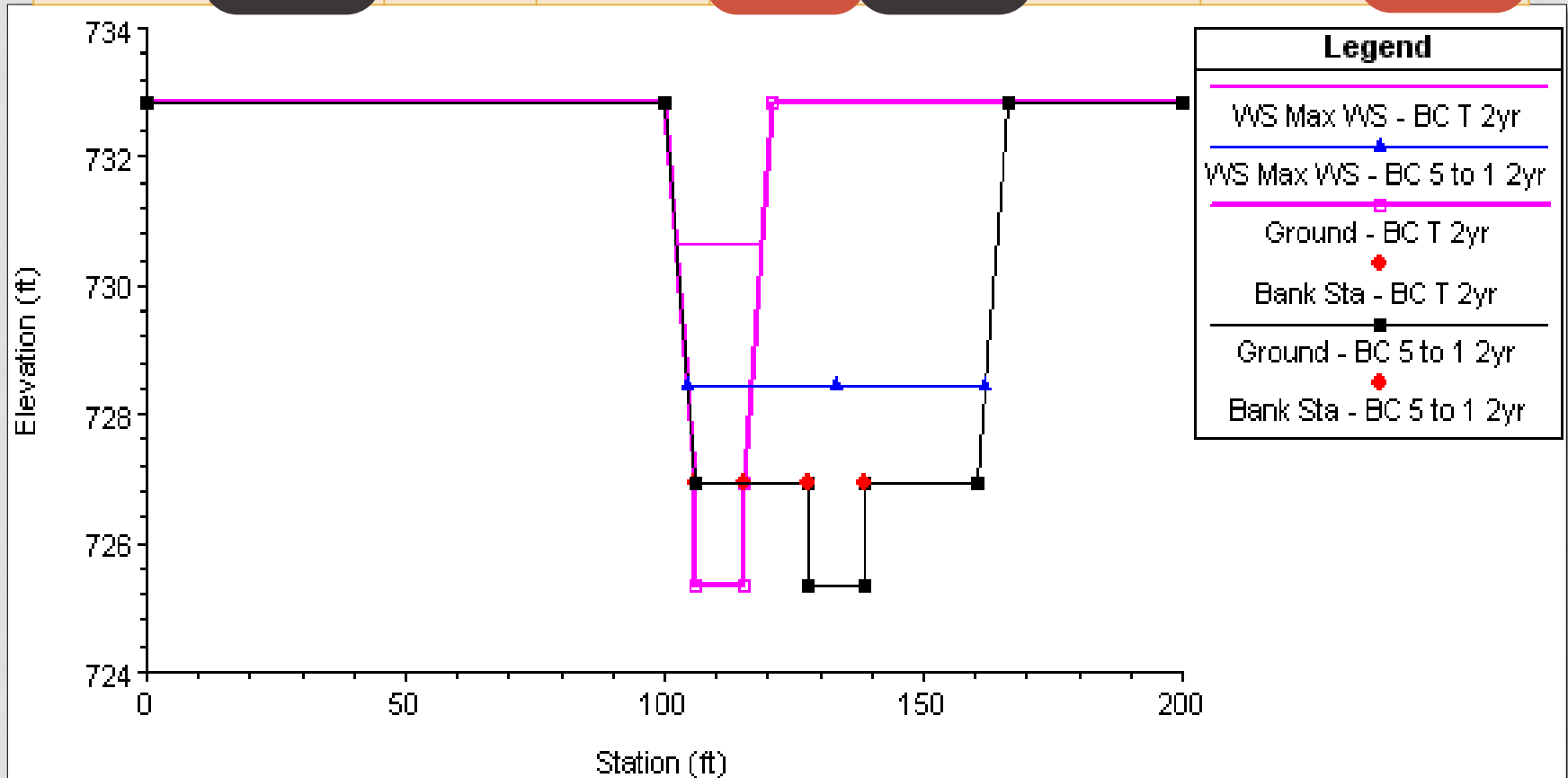


Comparison of stage depths for trapezoidal and two-stage ditch cross-sections at Creel Ditch, IN.

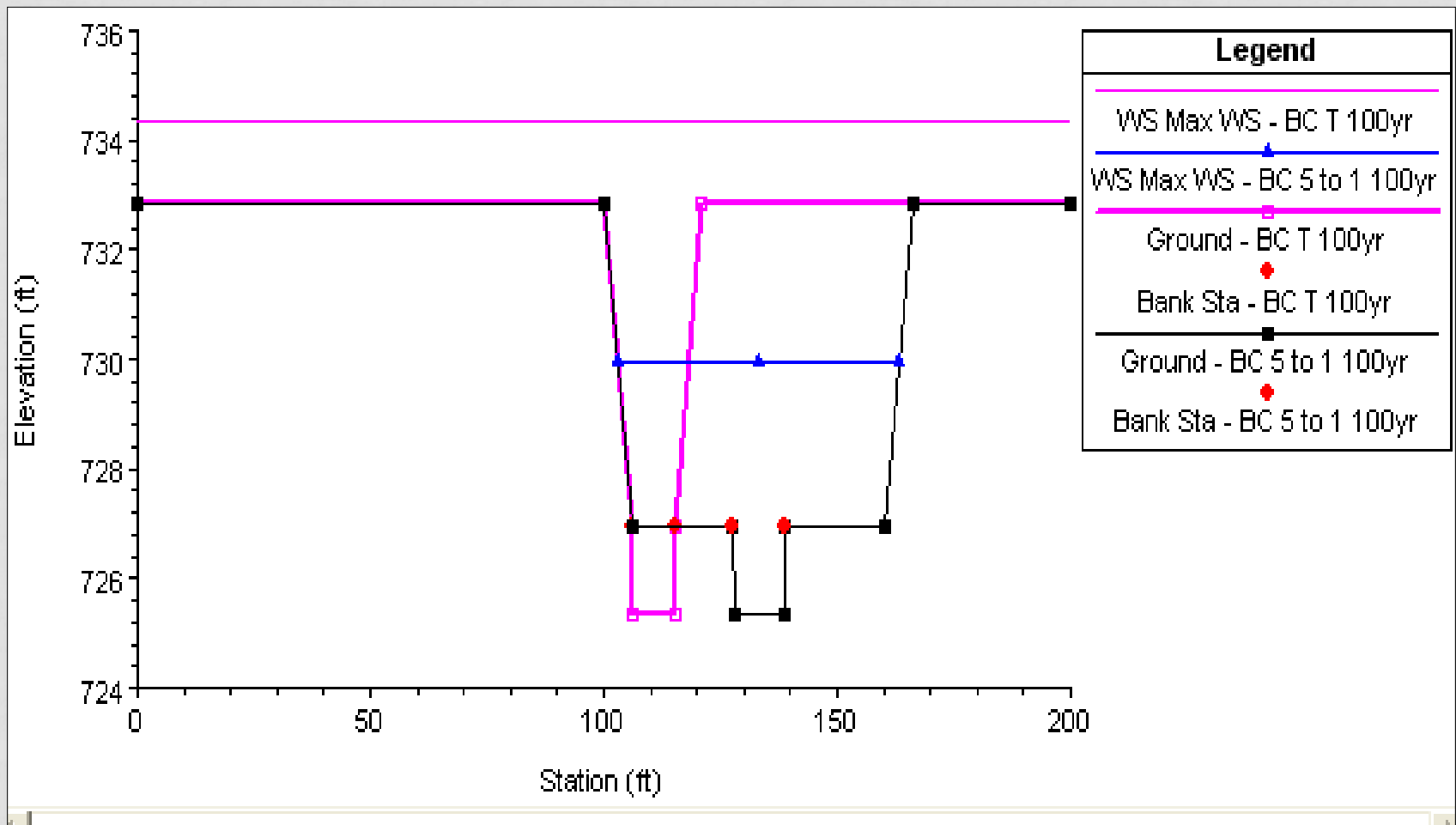


# FLOOD STAGE REDUCTION: HEC-RAS

	Trapezoidal				5 to 1 Two-Stage			
RI	Velocity (m/s)	Area (sq. m)	Discharge (cms)	Stage (m)	Velocity (m/s)	Area (sq. m)	Discharge (cms)	Stage (m)
2	0.7	5.8	4.1	1.6	0.5	9.3	4.2	0.9

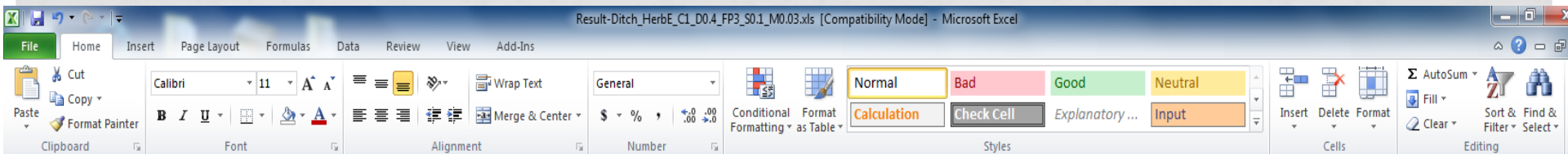


	Trapezoidal				5 to 1 Two-Stage			
RI	Velocity (m/s)	Area (sq. m)	Discharge (cms)	Stage (m)	Velocity (m/s)	Area (sq. m)	Discharge (cms)	Stage (m)
100	0.3	37.2	11.3	2.7	0.6	17.5	11.4	1.4



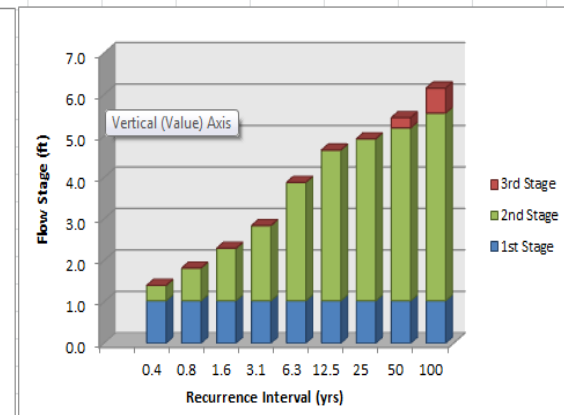
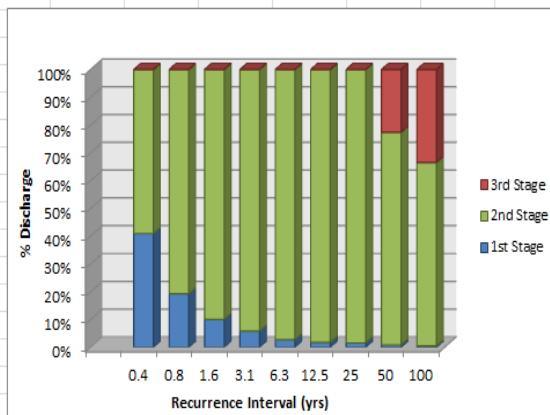
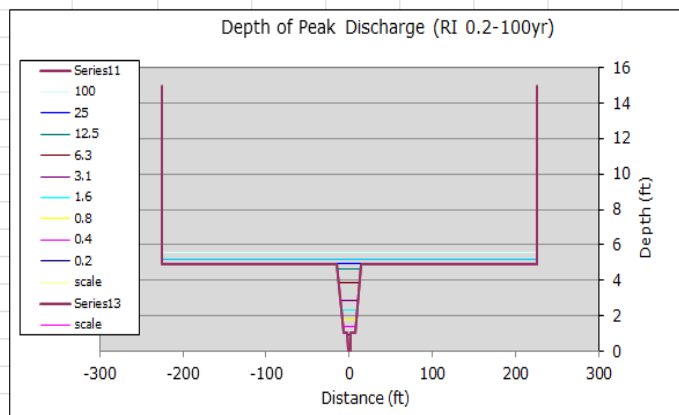


# PREDICTING STABILITY AND FLOODING

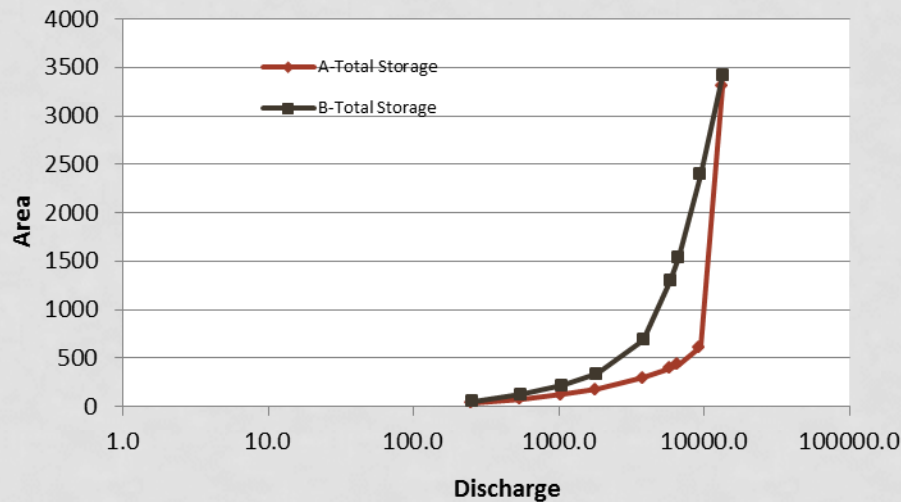
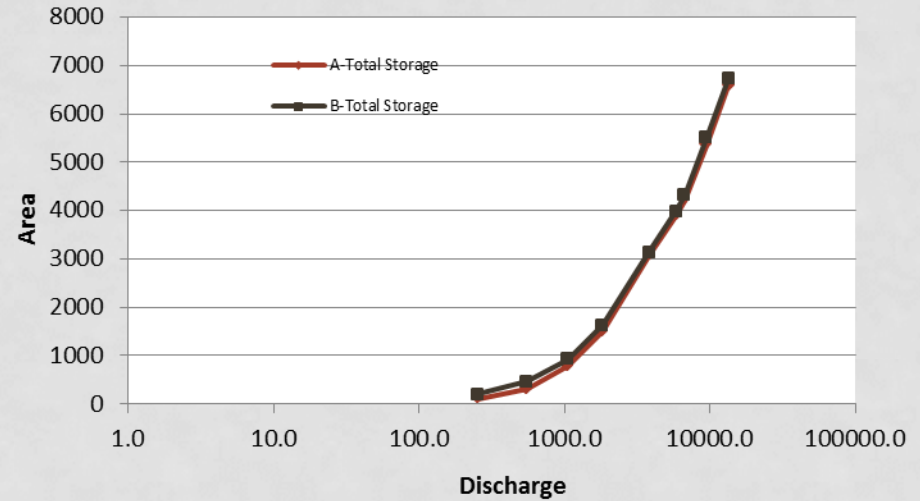
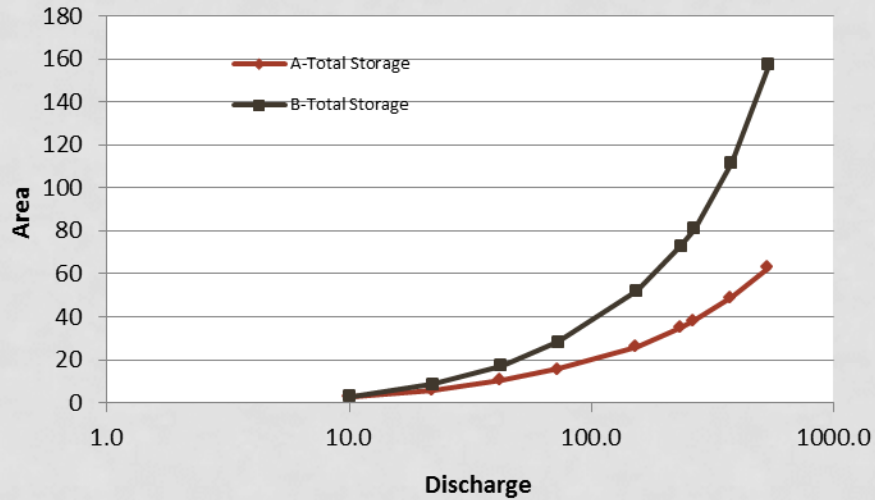


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	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI							
2																																
3	Discharge (cfs)														Stage (ft)															Flow		
4	1st Stage	2nd Stage	0.4		0.8	1.6	3.1	6.3	12.5	25	50	100	Second S	Third Stage	0.4		0.8	1.6	3.1	6.3	12.5	25	50	100	1st Stag							
5	4.26	268.95	10.40		22.10	42.32	73.03	153.70	234.37	266.52	379.54	540.49	1.02	4.95	1.40		1.81	2.29	2.84	3.88	4.66	4.93	5.20	5.55	3.							
6																																
7	n	RI	0.4		0.8	1.6	3.1	6.3	12.5	25	50	100			0.4		0.8	1.6	3.1	6.3	12.5	25	50	100								
8	0.03	1st Stage	4.3		4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	1st Stage		1.0		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0								
9	0.03	2nd Stage	6.1		17.8	38.1	68.8	149.4	230.1	262.3	375.3	536.2	2nd Stage		0.4		0.8	1.3	1.8	2.9	3.6	3.9	4.2	4.5								
10	0.06	3rd Stage	0.0		0.0	0.0	0.0	0.0	0.0	0.0	110.6	271.5	3rd Stage		0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6								
11																																

The bankfull discharge corresponds to less than a 0.4 year recurrence interval event. All flows up to and including the 25 year event are contained in the 1st and 2nd stages. The 50 and 100 year events are in the 3rd Stage. Depth of flow for the 100 year discharge is 0.6 ft. The inset channel (1st stage) has a discharge velocity of 1.2 f/s (4.3 cfs/3.6 ft<sup>2</sup>). Having benches 3 times the bankfull channel width, the 2nd stage ty of 1.5 f/s (536 cfs/355 ft<sup>2</sup>). Velocity of the 100 year discharge is 1.0 f/s (272 cfs/271 ft<sup>2</sup>).

[illegible]

# PREDICTING CHANNEL AND WATERSHED CONDITIONS THAT MAXIMIZE FLOODPLAIN STORAGE





# CONCLUSIONS (TO DATE)

- ✓ **Constructed two-stage ditches ages 3-10yrs are stable and are progressing towards quasi-equilibrium.**
- ✓ **Two-stage channels with at least 3:1 bench width to bankfull width ratio reduce flood stage and provide storage benefits.**
- ✓ **Banks are stable under a variety of modeled conditions. Watch out for overbank runoff, design/construction errors, poorly established vegetation, and 1-sided construction.**
- ✓ **Stable constructed Two-stage Channels have potential ecological benefits that may improve over time.**

# ACKNOWLEDGEMENTS

- Landowners
- USDA-NIFA
- USDA-NRCS
- The Nature Conservancy
- North Central Region Water Network
- The Joyce Foundation
- Ohio Water Development Authority
- Great Lakes Protection Fund
- Indiana DEM
- Ohio DNR
- Ohio EPA
- County Ditch Managers





# TO BUILD A BETTER DITCH...

(<http://vimeo.com/7901535>)

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