Knickpoint Migration in Western Iowa Streams

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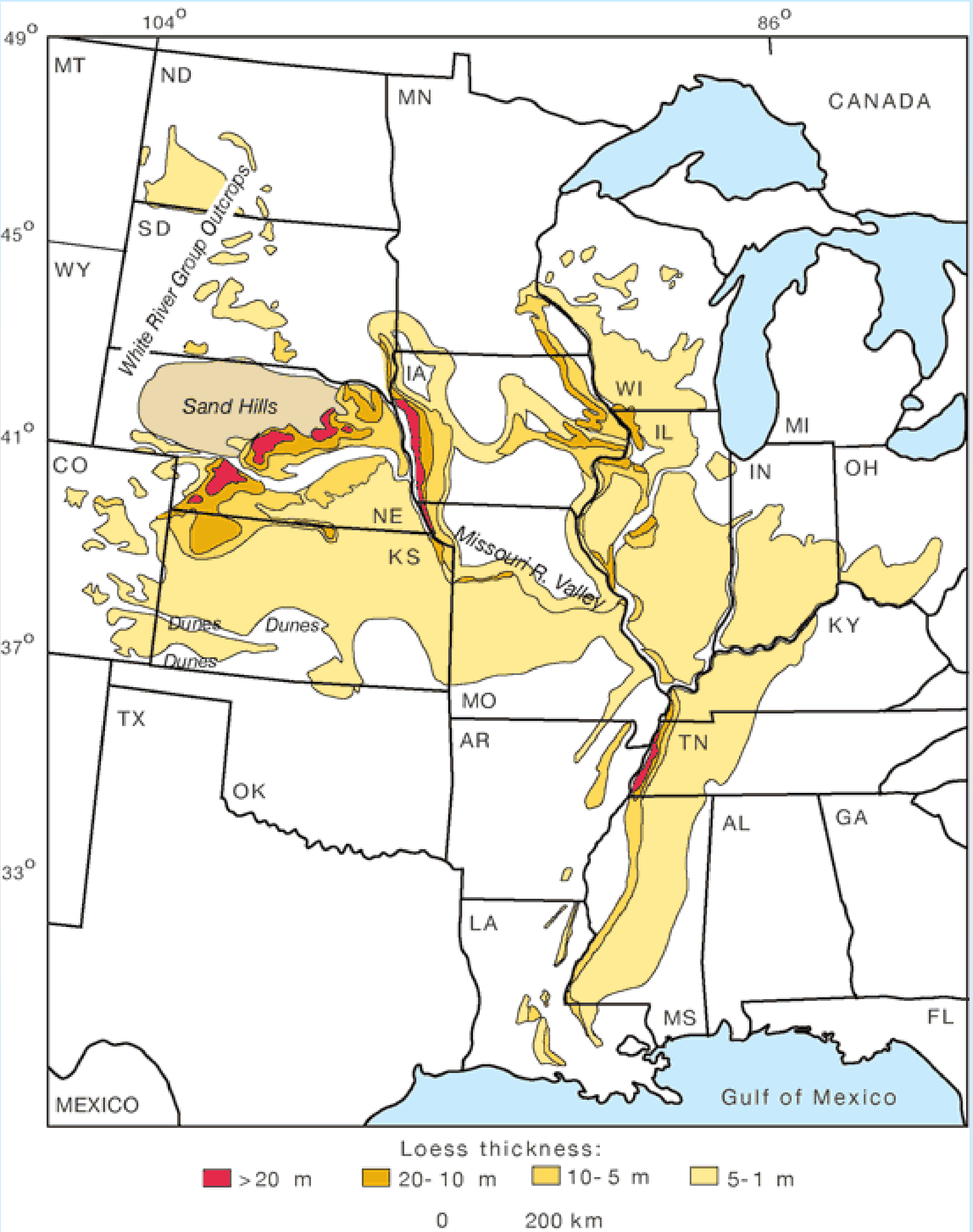
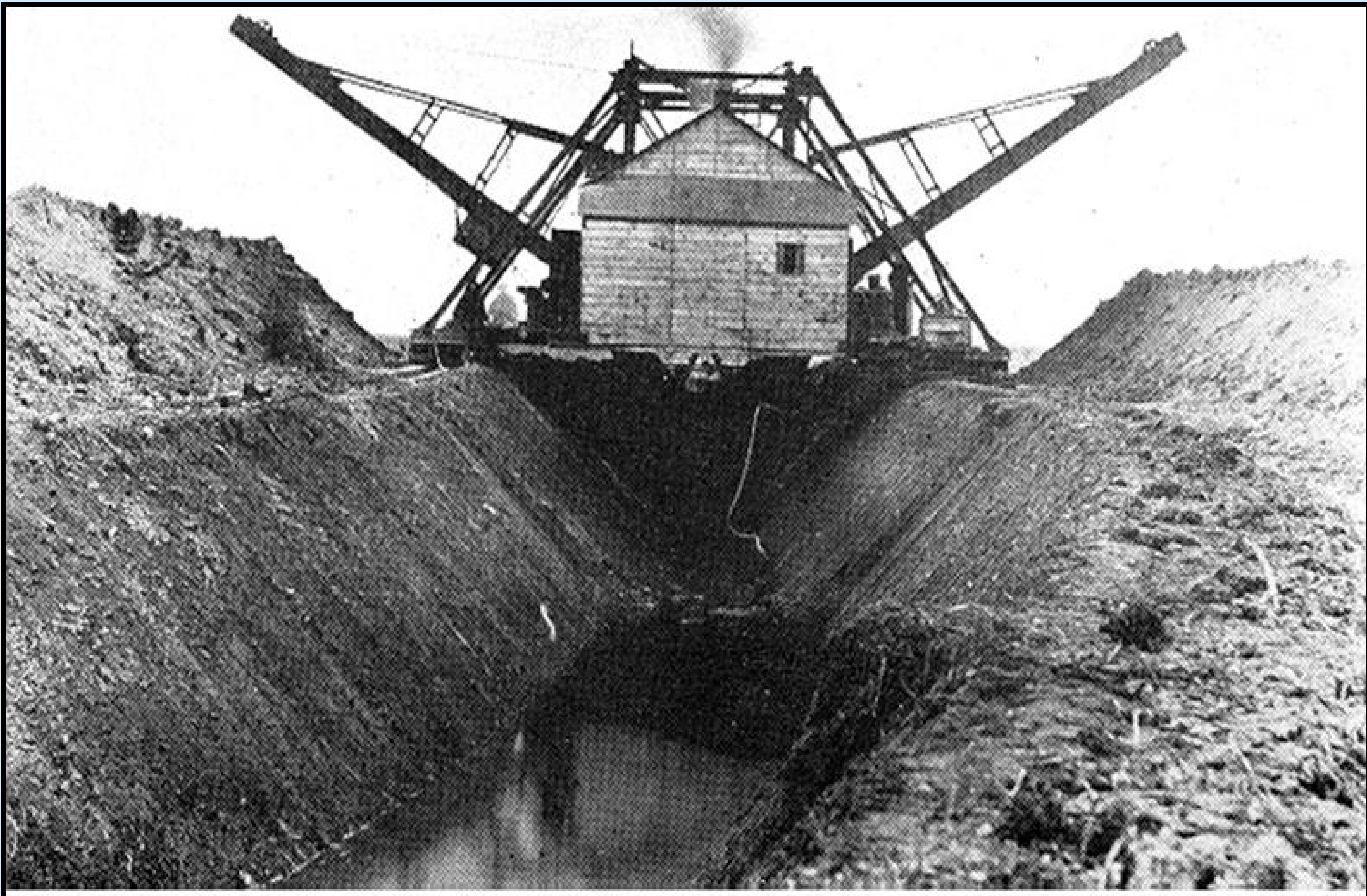
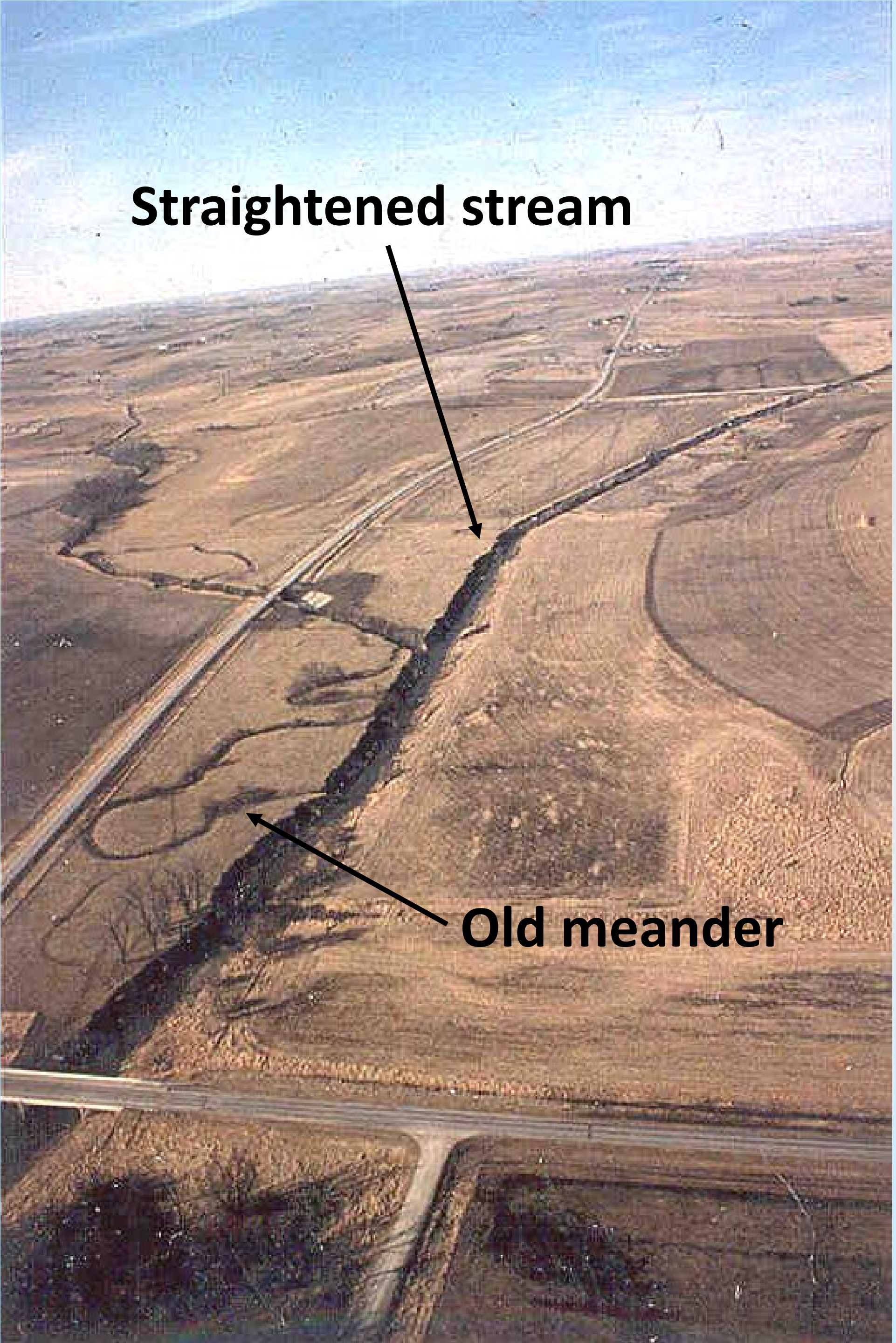


- Loess is a wind blown silt deposit often formed near large rivers.
- Loess is a very erosive streambed material
- Thicker loess deposits = ↑ potential erosion
- MRV loess deposits reach great enough depth (> 5 m) to cause widespread stream channel downcutting and erosion



Excavating a large ditch using steam power, circa 1910.



Highly erodible loess soils

+

Stream straightening and land use changes

=

Higher water velocities

=

Channel downcutting

=

Increased channel erosion

Higher sediment loads

Altered flow regimes

Lost fish habitat

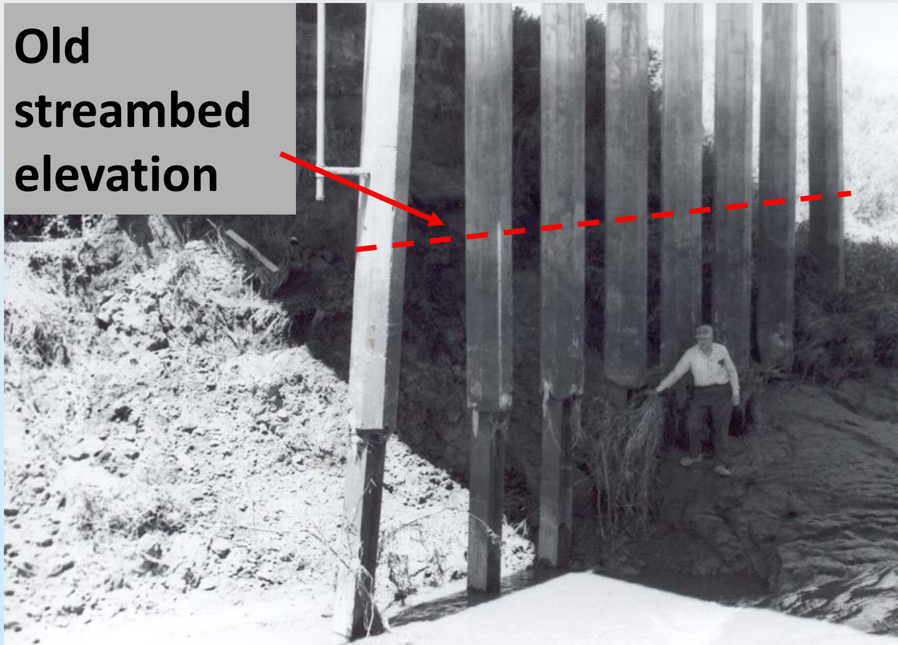
No pool-riffle sequences

Lost lateral connectivity w/ floodplain

Decreased biodiversity

Examples of Knickpoints in Western Iowa

Consequences of knickpoint passage

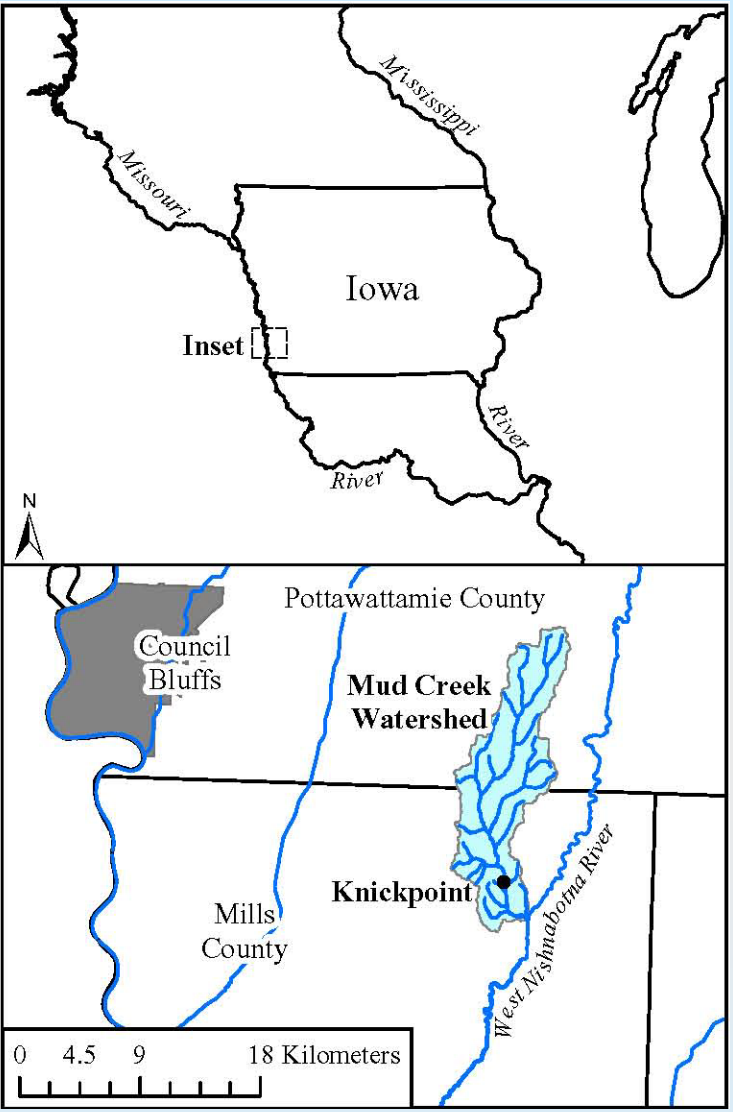


1,200+ Grade Control Structures in Western Iowa

Purpose

- Field measurement of migration rate of a knickpoint and compare this rate to rates of knickpoint migration in other studies
- Results of this field study:
  - better understanding of principal factors causing knickpoint propagation
  - give a range for migration rates of other knickpoints around western Iowa
  - estimate needed response time to control propagation of other knickpoints

Knickpoint Study Site



Mud Creek DA – 97.5 km^2

Rural agricultural landscape

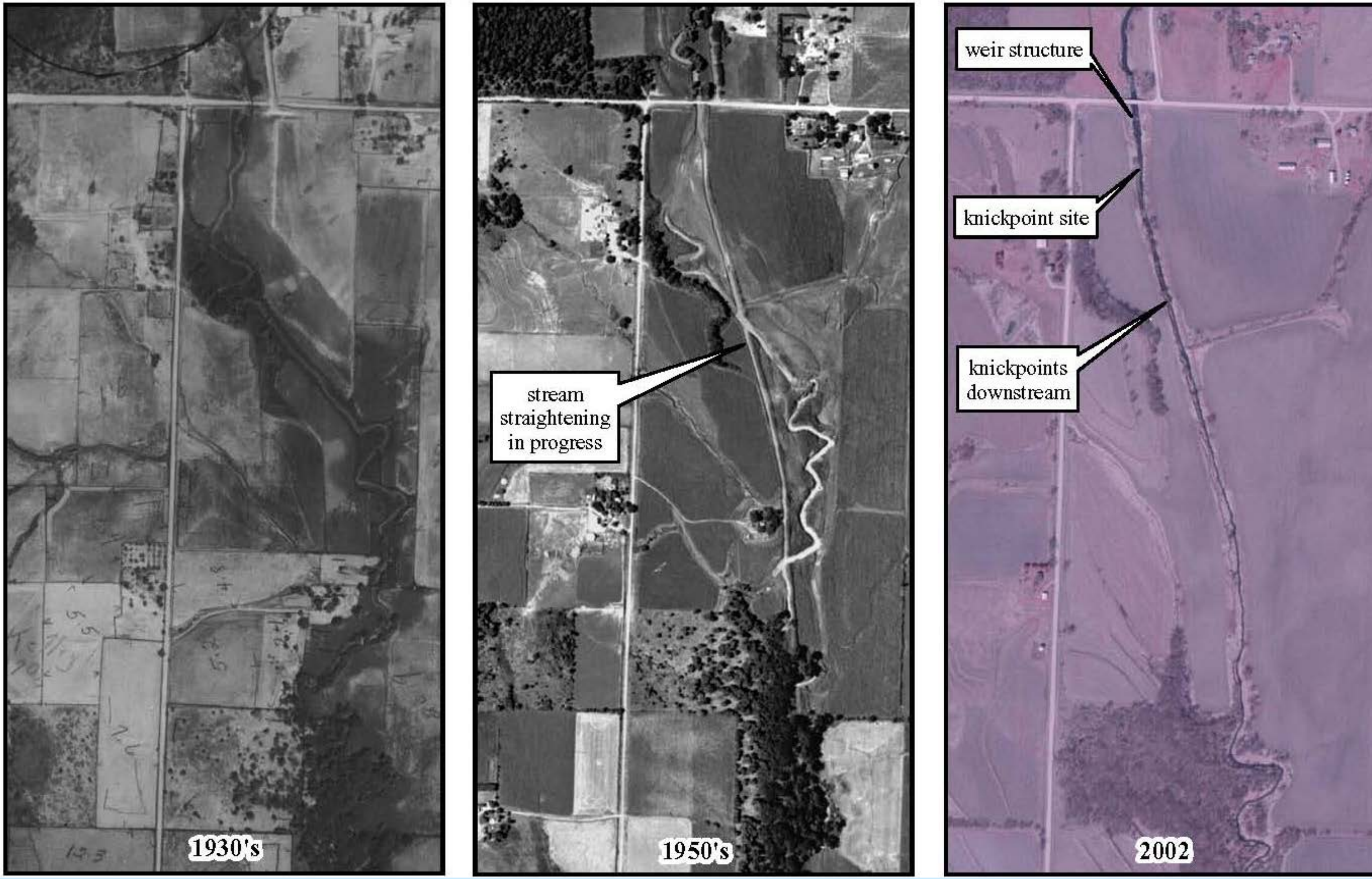
Channel 4-5 m deep

Knickpoint DA – 85.5 km^2

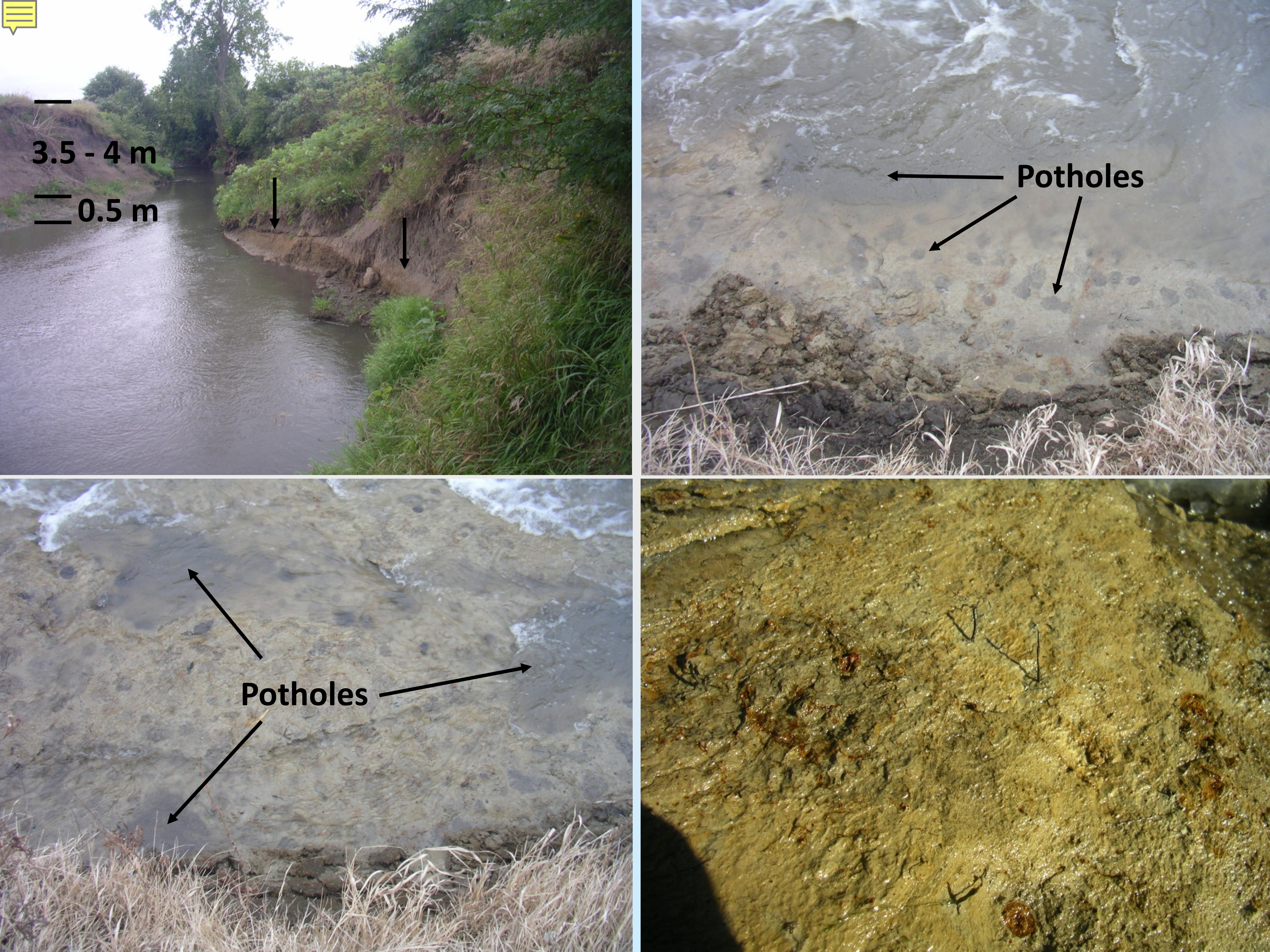
Weir and bridge upstream

In knickzone

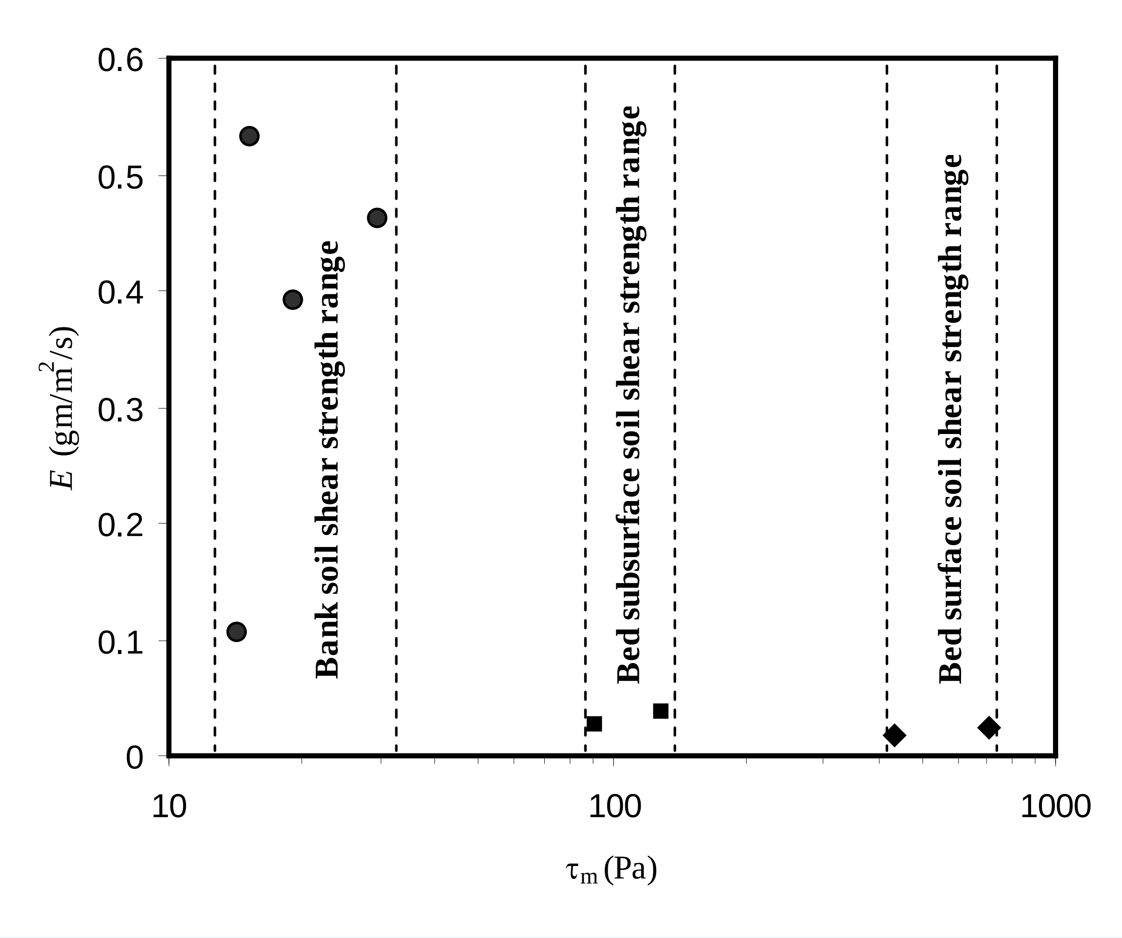
Baseflow - knickpoint - 5 m wide and average flow depth 10 cm


stream
straightening
in progress
weir structure
knickpoint site
knickpoints
downstream
1930's
1950's
2002

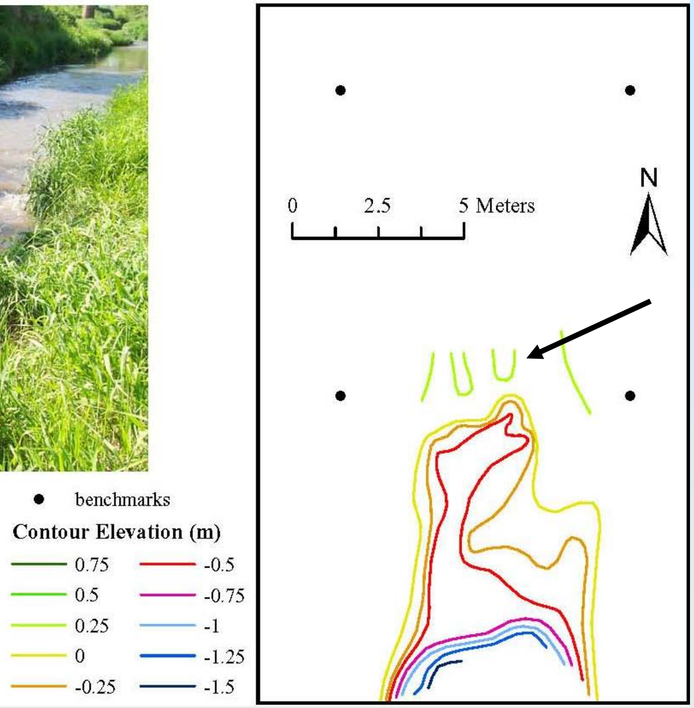

Stage recorded once every hour


3.5 - 4 m
0.5 m
Potholes
Potholes

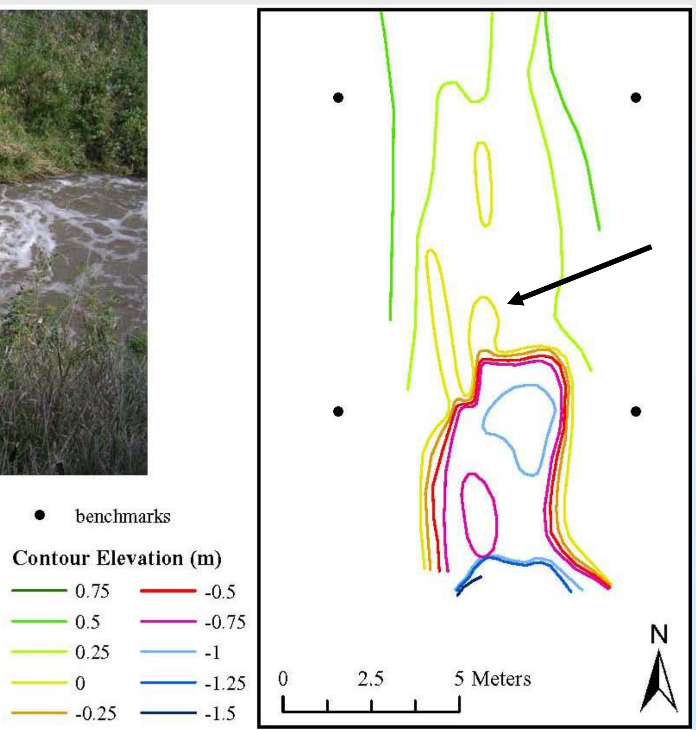
Erosion Rate vs. Critical Shear Strength



- Erosion jet test experiments conducted to estimate mechanical shear strength of bank and knickpoint soils
- Three distinct ranges of critical shear strength separated by an order of magnitude:
  - bank soil weakest
  - subsurface of knickpoint bed moderate strength
  - knickpoint surface strongest

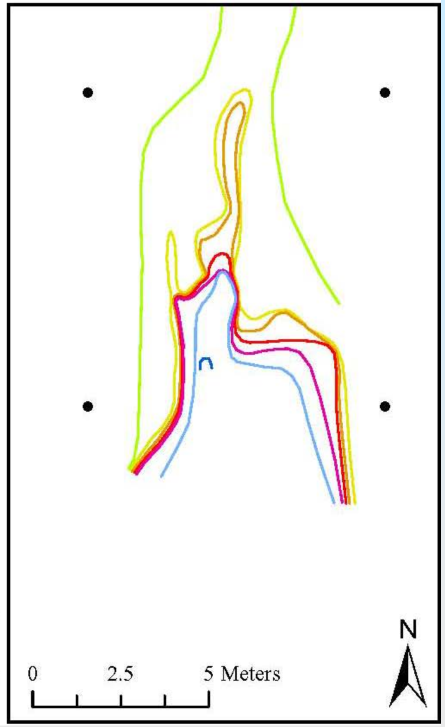


Knickpoint on
May 21, 2006

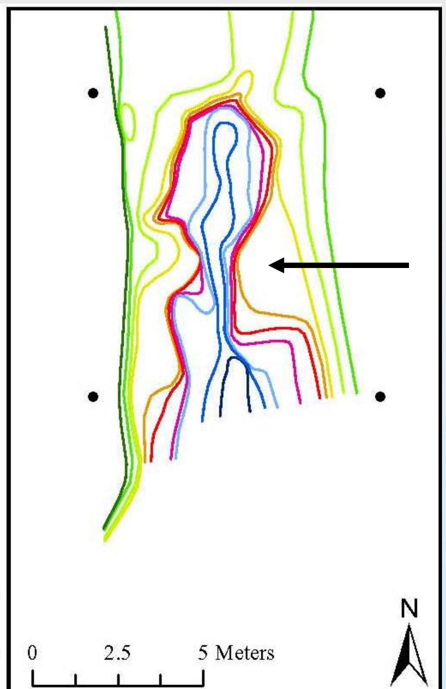


Knickpoint on
September 25, 2007

- 2006 knickpoint
  - 0.7 m drop from knickpoint lip to scour hole base
  - Another 0.6 m drop in elevation underwater 6 m downstream
- 2007 knickpoint
  - retreated 1.8 m
  - scour hole had expanded in width and depth
- Linear channels upstream from the knickpoint lip
  - Possibly caused by passage of past knickpoints leaving a scar on channel bed



Knickpoint on July 23, 2008



Knickpoint on March 3, 2009

- 2008 knickpoint
  - Finger-like projection extended upstream, funneling majority of water going over knickpoint
- 2008 knickpoint
  - Retreated 3.6 m between February 11 and March 3, 2009 along path of finger-like projection
  - Deep narrow channel bypassed knickpoint ledge sediment on either side and scour hole created US
  - Only baseflow during this period

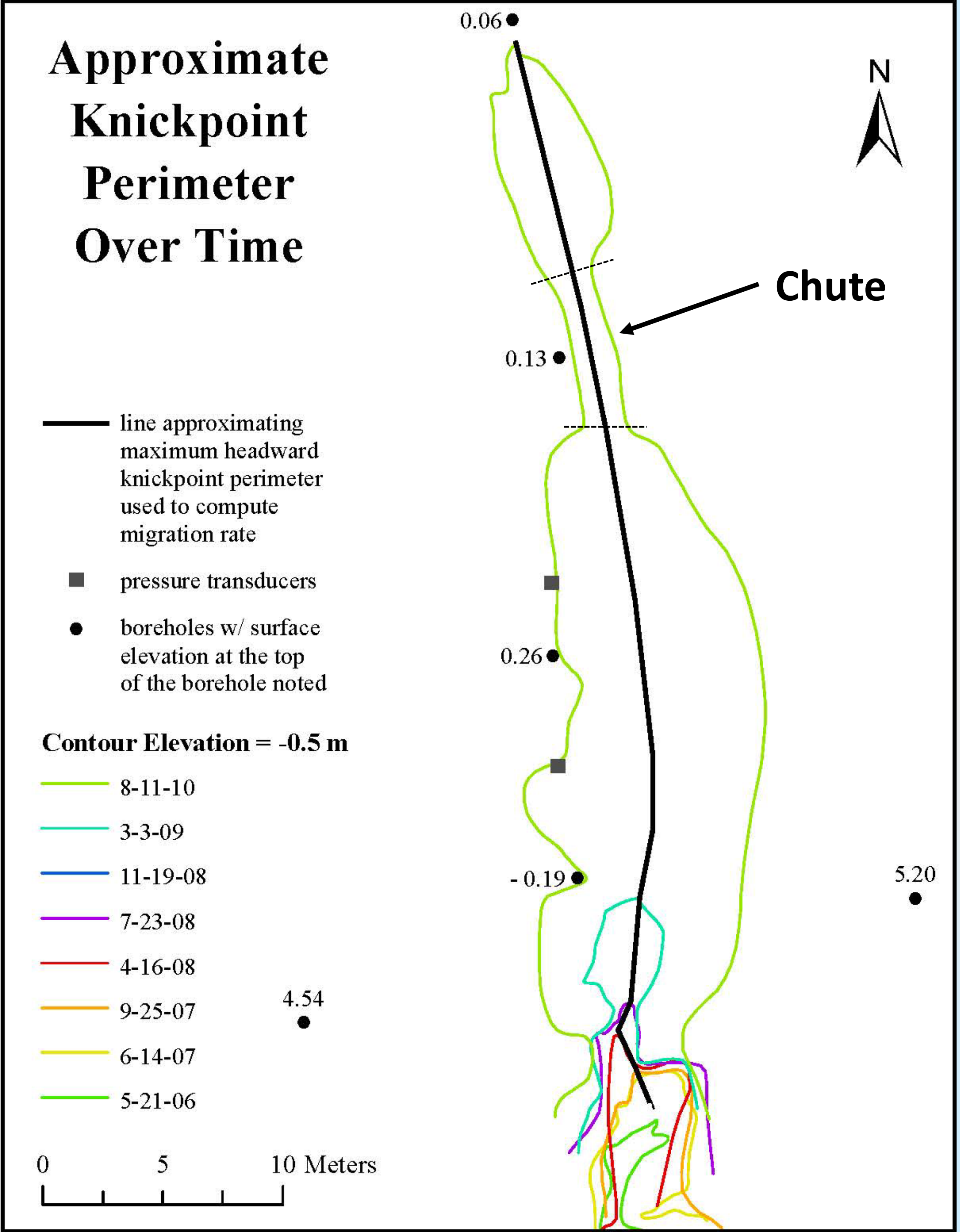
Fluvial Erosion or Other Cause?

- Knickpoint retreat by fluvial erosion can occur when:
  - $\tau_0 \geq \tau_m$ (400 Pa minimum)
  - Average bed shear stress approximatey by: $\tau_0 = \gamma S y$
    - $\gamma = 9810\ N/m^3$, $S = 0.05\ m/m$, $y = 0.815\ m$
  - Flow depth only exceeded 0.815 m five times during study
    - once in October 2007 and four times in June 2008
  - But surveys showed knickpoint migrated outside these events also
- Elevation of knickpoint does not decrease or incline over time but areas of focused flow do appear to erode faster
- Discrepancy between available hydraulic shear stress and shear strength and erodibility of knickpoint indicate fluvial erosion not responsible for some or all of observed knickpoint migration
- However bed shear stress alone could easily erode knickpoints formed in the bank material

Knickpoint Migration Rates Reported in Previous Studies

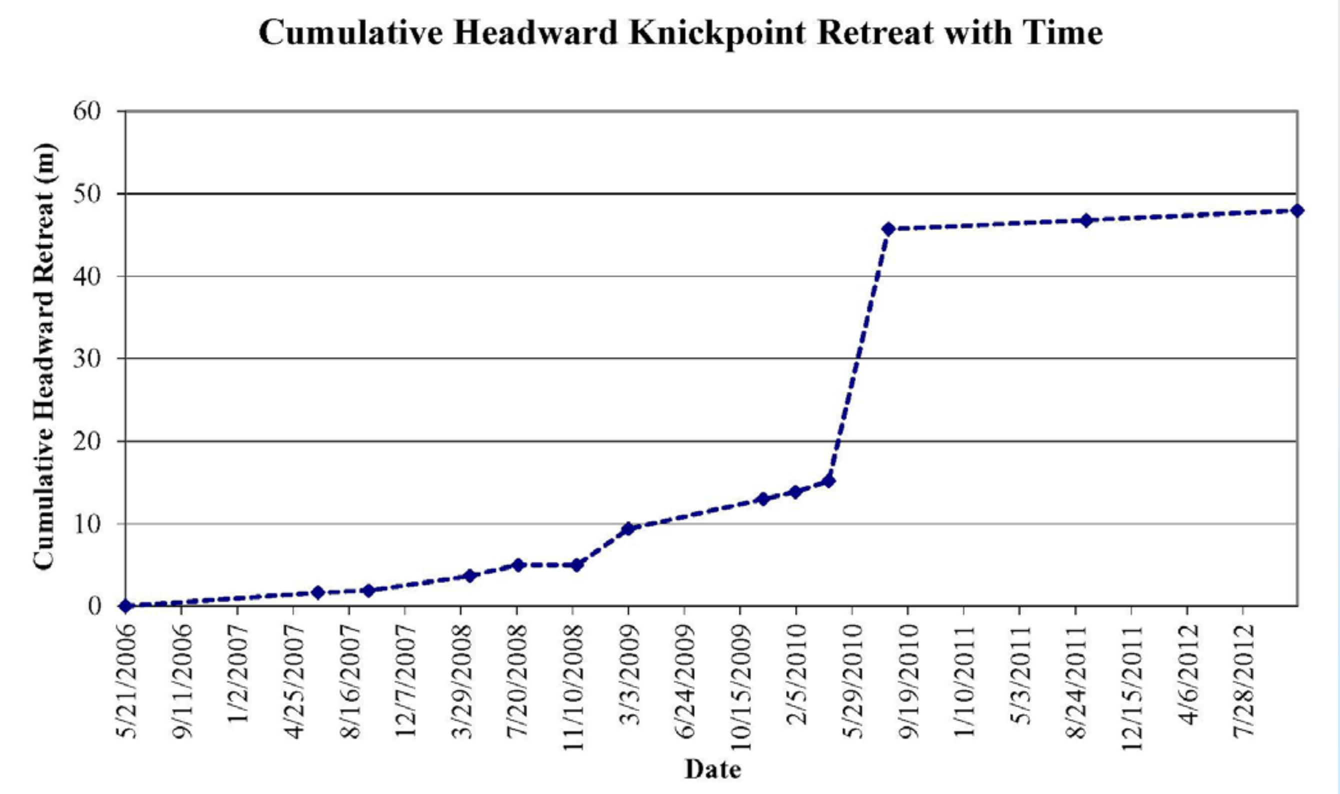
Type	Authors and Year	Bed Material	Knickpoint Erosion Rates (m/yr)			Comments
			Max.	Min.	Avg.	
Bedrock	Crosby, Whipple, 2005	mudstone bedrock	100	0.04		236 knickpoints in New Zealand watershed
	Tinkler, Pengelly, Parkins, Asselin, 1994	limestone bedrock			1.57	Niagara Falls
	Anthony, Granger, 2007	limestone bedrock	4.0	0.01	0.66	Appalachian Plateau fluviokarst bedrock
	Hayakawa, Matsukura, 2003	mudstone bedrock	0.27	0.0013	0.087	Seismically uplifted bedrock in Japan
Unlithified Sediment	Robbins, Simon, 1983	alluvium			2,600	South Fork Forked Deer River, Tennessee
	Simon, Darby, 2002	alluvium	> 1,000			Streams in northern Mississippi
	Robbins, Simon, 1983	sand, gravel, bedrock	517	10.6	130	North Indian Creek, Tennessee
	Rus, Dietsch, Simon, 2003	loess alluvium			8	Kezan Creek, Nebraska
	Simon, Bennett, Griffith, 2000; Thomas, Collison, Simon, 2001; Simon, Thomas, Collison, Dickerson,	firm silty-clay	16	0.4	7.2 - 1.0	Yalobusha River Watershed, N. Mississippi
Unlithified Sediment in western Iowa	Daniels, 1960	loess alluvium	16,687	0.0	568	Willow Creek, Harrison County, western Iowa
	Bettis, 1990	loess alluvium	25,031	57.3	85.4	Keg Creek, Pottawattamie County, western Iowa
	Pottawattamie Co. Sec. Rd. Dept., 1952	loess alluvium	2090	1543	1780	Silver Creek, Pottawattamie County, western Iowa
	Page Co. Sec. Rd. Dept., 2007	loess alluvium	1,115.7	82.8	181.1	Mill Creek Tributary, Page County, western Iowa
	This study	firm silty-clay	92.06	0.00	7.39	Mud Creek - 6-28-2007 to 11-15-2012
	This study	firm silty-clay			0.67	Walnut Creek - 10-21-2004 to 5-21-2006

Local longtime resident – channel in 1950’s less incised, larger drop in KP elevation, and KP “there one summer and gone the next” (indicating migration rates > 1,000 m/yr). Stream likely eroding through weaker bank material at that time. Past authors also likely observed KP eroding through bank material.

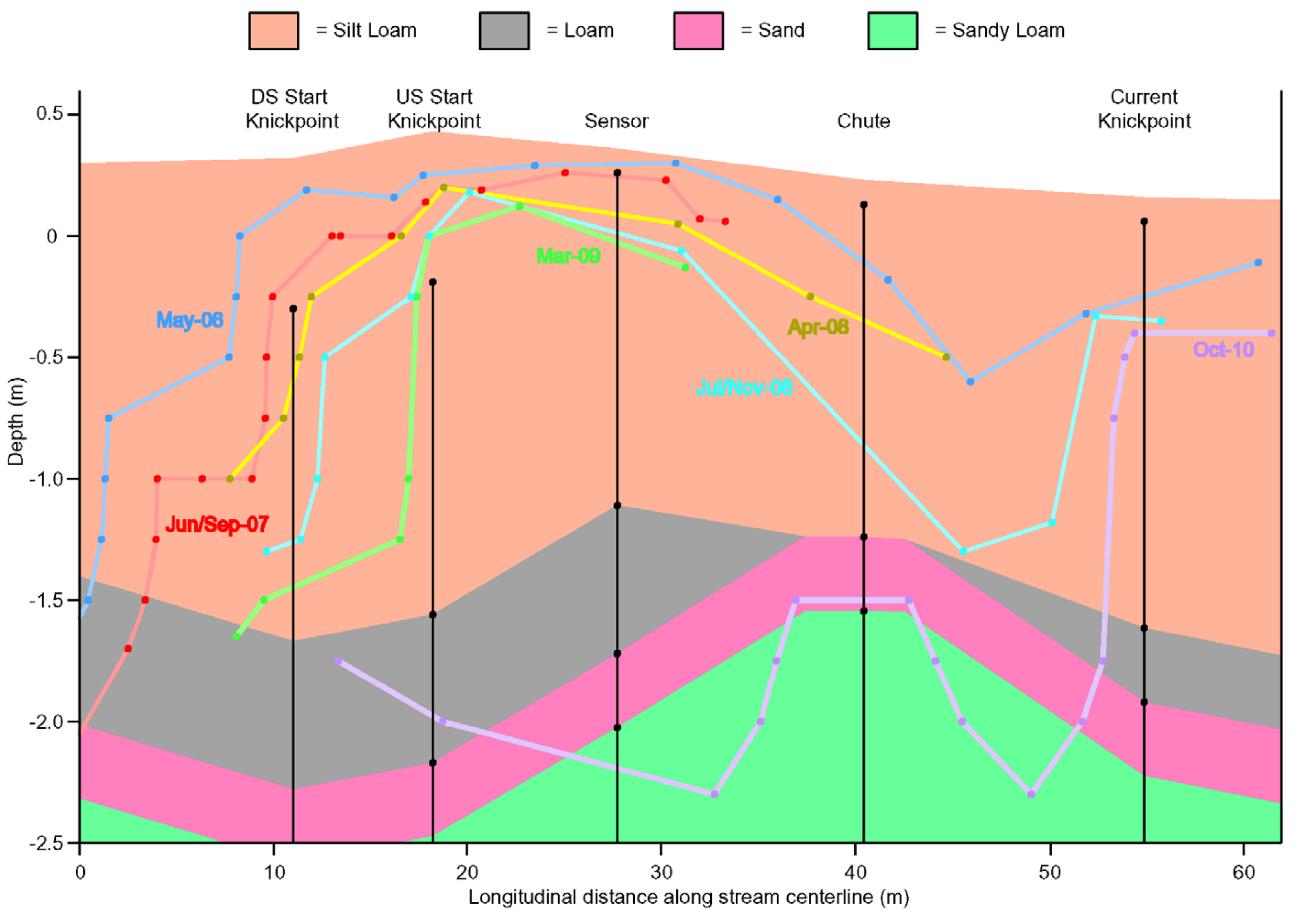


- Between April and August 2010 knickpoint retreated 30.5 m
  - No significant snowmelt or rain events
  - Another example of little change in driving stresses (flow) but had rapid retreat
- Look closer at stratigraphy
  - Boreholes into streambed
  - Stratigraphic diagram shown later extrapolates stratigraphy using these boreholes, deep boreholes on banks, and photographs

Date	Julian Day	Time Diff. (days)	Time (yr)	Cumulative Time (yr)	Migration (m)	Cumulative Migration (m)	Migration Rate (m/yr)	Method
5/21/2006	38858	0	0	0	0	0	0	survey
6/14/2007	39247	389	1.07	1.07	1.61	1.61	1.51	survey
9/25/2007	39350	103	0.28	1.35	0.26	1.87	0.92	survey
4/16/2008	39554	204	0.56	1.91	1.78	3.65	3.18	survey
7/23/2008	39652	98	0.27	2.18	1.32	4.97	4.92	survey
11/19/2008	39771	119	0.33	2.50	0.00	4.97	0.00	survey
3/3/2009	39875	104	0.28	2.79	4.38	9.35	15.37	survey
12/1/2009	40148	273	0.75	3.53	3.60	12.95	4.81	estimate
2/4/2010	40213	65	0.18	3.71	0.90	13.85	5.05	estimate
4/12/2010	40280	67	0.18	3.90	1.30	15.15	7.08	estimate
8/11/2010	40401	121	0.33	4.23	30.52	45.67	92.06	survey
9/15/2011	40801	400	1.10	5.32	1.10	46.77	1.00	estimate
11/15/2012	41228	427	1.17	6.49	1.20	47.97	1.03	estimate
		2370	6.49		47.97		7.39	



Channel Bed Erodibility/Lithology and Knickpoint Profiles



Erosional Topography

- Caused by presence and propagation of multiple knickpoints in series
  - Current streambed and knickpoint surface is scar of passage of past knickpoints
- rapid knickpoint migration – little channel bed scour – become exposed ledges through which future knickpoints migrate
- slow knickpoint migration – high channel bed scour and deep, large scour holes – remain pools between future knickpoints

Other Factors in Knickpoint Migration

- Abrasive scour of krotovina potholes may be areas of weakness through which knickpoint advances
- Areas of unfocused flow exposed to weathering may become more erodible and probable area of focused flow in future
- Pipe-flow during ice-over conditions and plucking




- Ice froze to knickpoint bed surface during extended cold spell
- Large snow melt event
  - Temperatures warmed more than 40°F in one day

- Several large blocks of sediment plucked and moved due to buoyancy of ice
- Segregation ice observed on detached block
- Block likely plucked along similar segregation ice layer

Conclusions

- Knickpoint migrated a total of 48 m, at rate of 7.4 m/yr
- No correlation between knickpoint retreat and increased flow
- Discrepancy between available hydraulic shear stress and shear strength and erodibility of knickpoint
- 30.5 m of retreat occurred in a four-month period when knickpoint finally eroded through a resistant ledge and into weaker layer below and stopped when highly erodible layers again dipped below the a critical depth threshold
- Higher knickpoint migration rates observed locally in past
    1. Eroded through weaker stream bank material
    2. Lower mechanical shear strength allowed fluvial erosion
    3. Steeper stream gradient in past – higher erosion rates

Conclusions

- Presence and propagation of multiple knickpoints in series cause erosional topography
  - Current knickpoint is bed scar of past knickpoints
- Other factors in knickpoint erosion
  - Not direct causes of knickpoint retreat
  - Abrasive scour of krotovina potholes may be areas of weakness through which knickpoint advances
  - Areas of unfocused flow exposed to weathering may become more erodible and probable area of focused flow in future
  - Formation of ice over knickpoint
    - Pipe-like flow under the ice – fluvial erosion of surface
    - Plucking and removal of large sediment blocks

Research Partners and Future Paper

- Hungry Canyons Alliance
- IIHR–Hydroscience and Engineering Department at the University of Iowa
- Iowa Department of Transportation Highway Research Board
- USDA-NRCS
- Iowa Department of Natural Resources

Paper in preparation –
Earth Surface Processes and Landforms in 2014 or 2015

Thank You

Any Questions?