Estimating Nitrate-N Removal by Wetlands Placed using LiDAR Topographic Data: A Watershed-Scale Modeling Exercise

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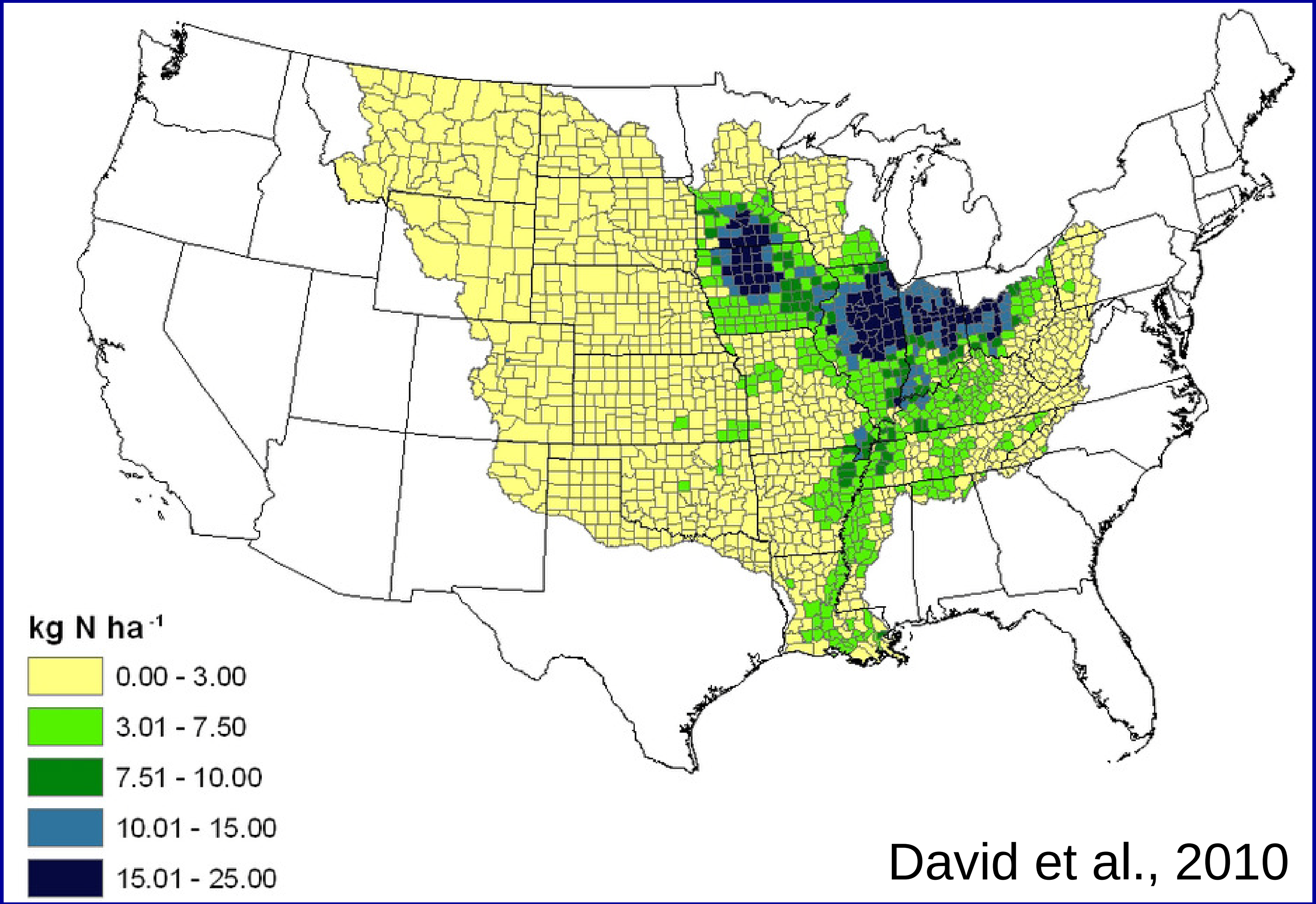
Rationale

- There are approximately 20×10^6 ha of subsurface (tile) drained cropland in the US Midwest.
- Nutrient losses from tile drained cropland in the Midwest are significant, particularly for nitrate, and are contributing to Gulf of Mexico hypoxia.
- A range of practices can help mitigate nitrate losses, but nutrient removal wetlands have been shown particularly effective.
- We need the ability to locate sites suitable for installation of wetlands, to develop water quality management approaches for watersheds and implementation schemes such as nutrient trading.
- We not only need to understand how wetlands can help meet nutrient reduction goals, but must also implement alternative practices to intercept nutrients where wetlands are not feasible.

Artificial Drainage & Nitrate Loads in the Mississippi River Basin



What placement strategy?

- Few large wetlands, large contributing areas
  - Design, construction, & maintenance more complex
  - Nitrate loads and removal rates more consistent
  - Site acquisition complex, involves many parties

- Many small wetlands, small contributing areas
  - Simpler design, construction, & maintenance
  - Variable loads and N removal performance
  - Simpler agreements but with many landowners

What is the balance of ecosystem services from each strategy?

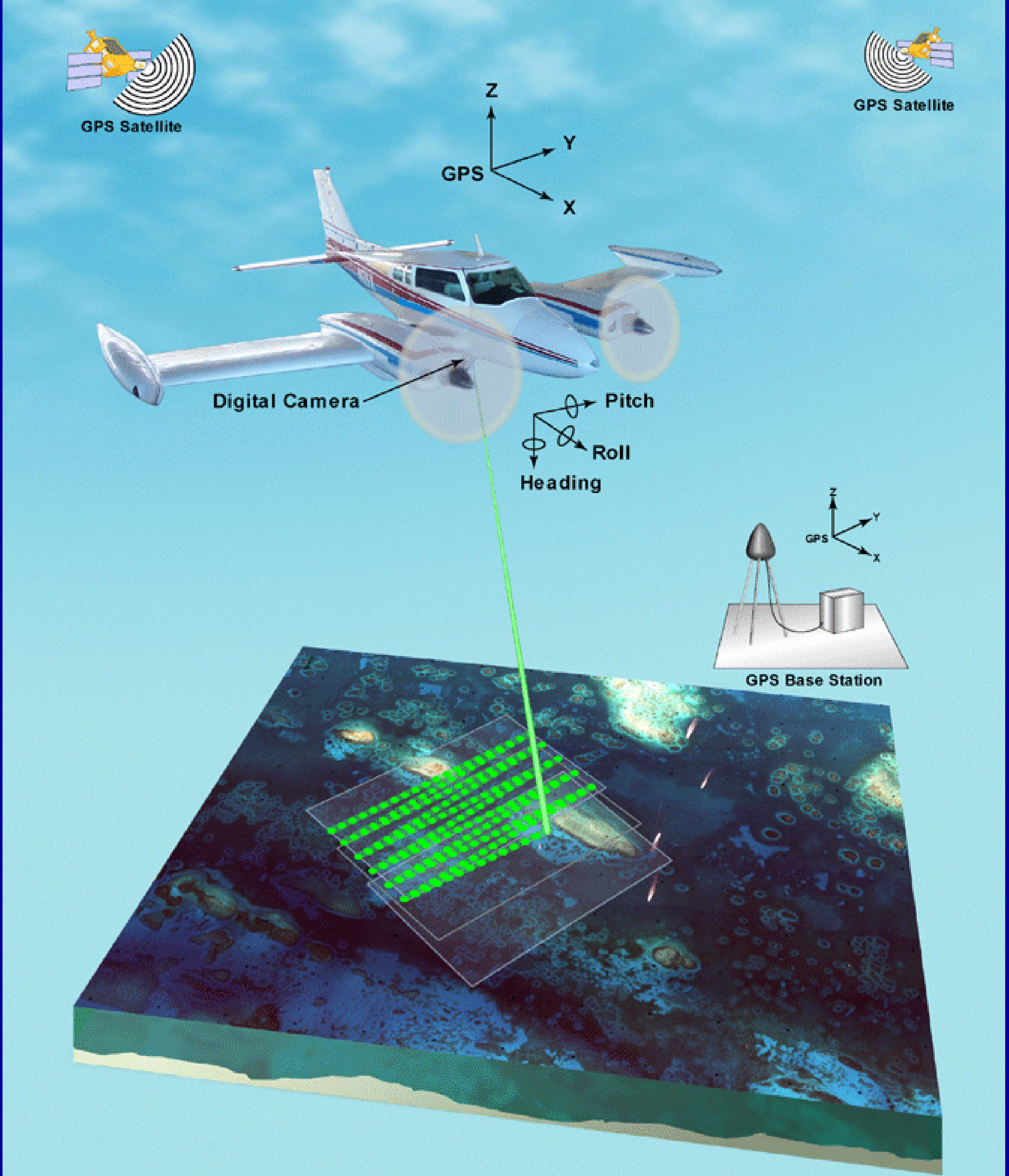
Objectives

To demonstrate that sites for nutrient removal wetlands can be identified using LiDAR topographic data.

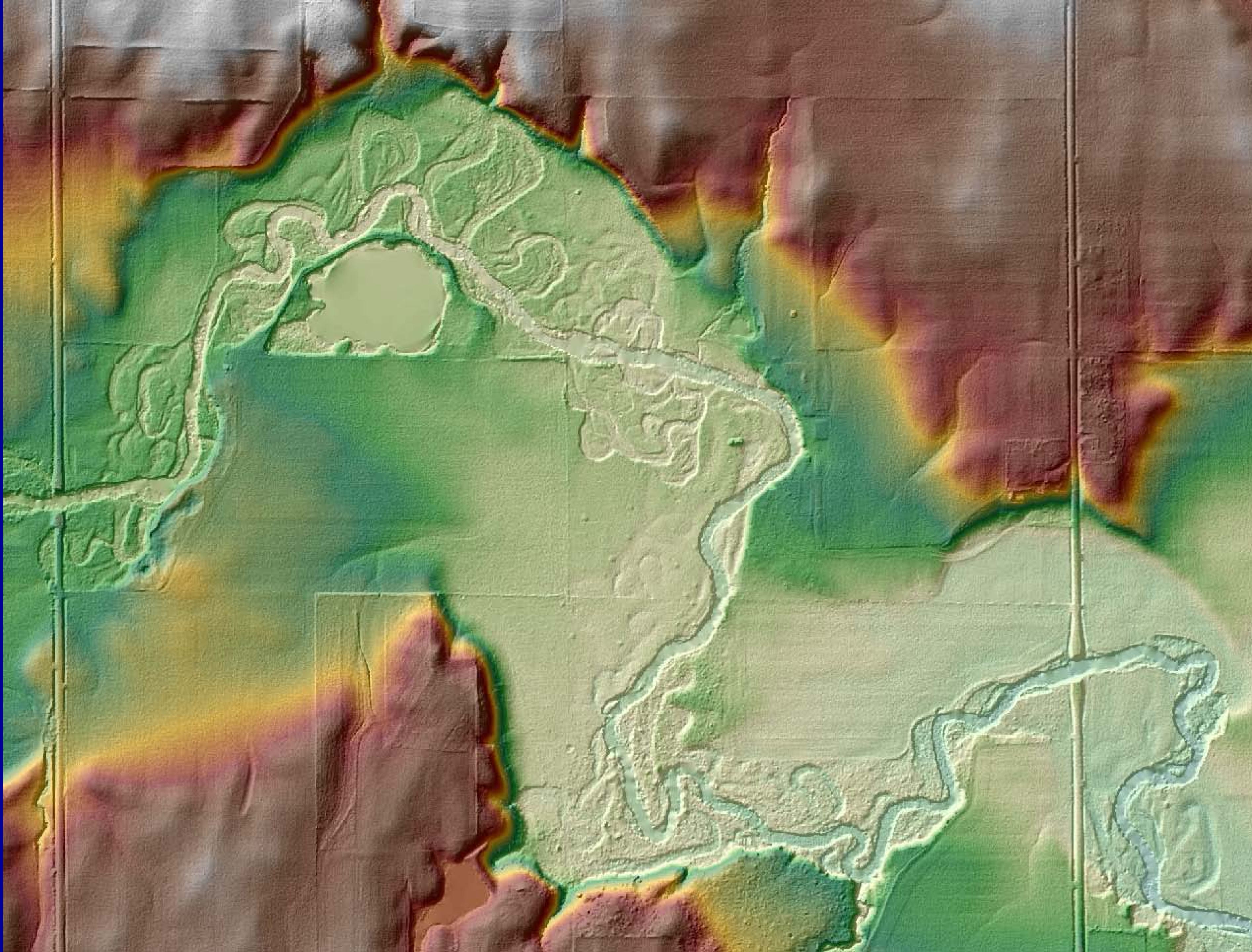
Illustrate factors impacting N removal performance of wetlands through a modeling exercise.

Aerial "LiDAR" data acquisition

Light
Detection
And
Ranging



Source: USGS

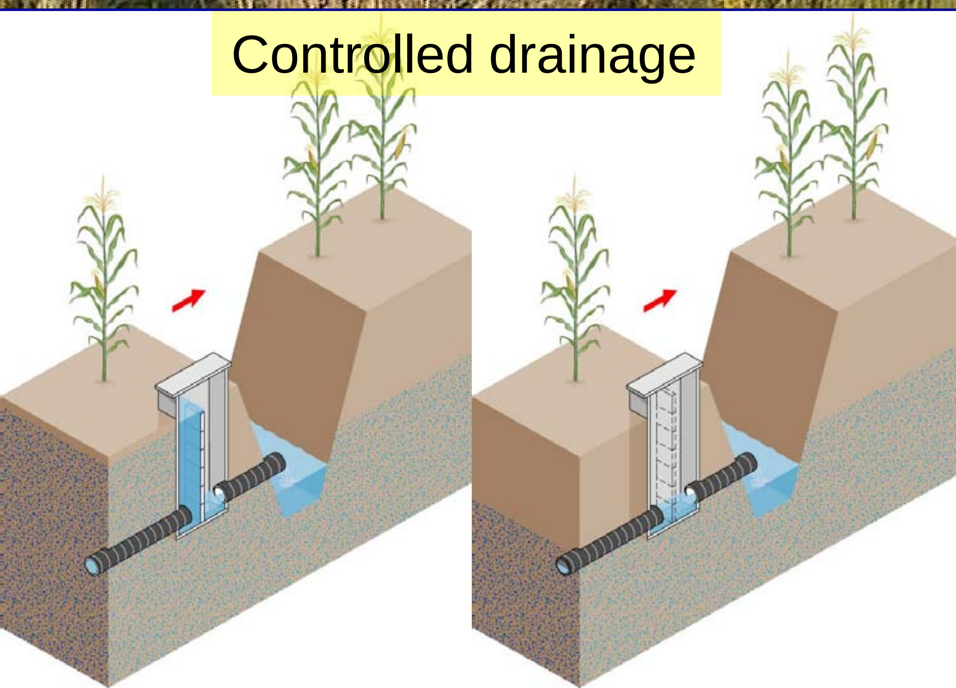


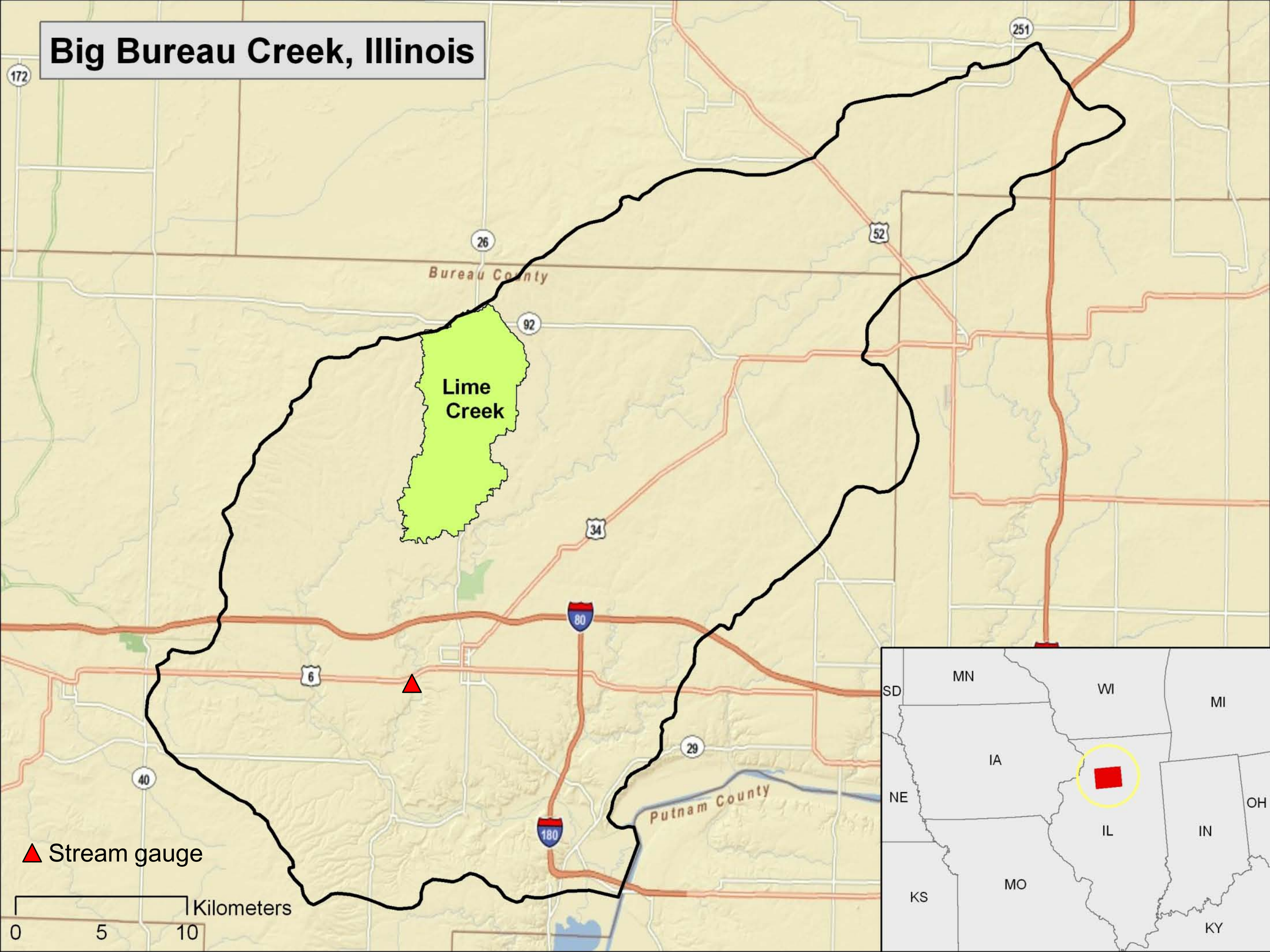
Learning to use LiDAR terrain data for conservation planning

- Applications that can use LiDAR data to plan in-field erosion-control practices (reduced tillage, terraces, etc.) are being developed.

- We are exploring use of LiDAR data to plan edge-of-field, riparian zone, wetland, and stream restoration conservation practices.

Practices for Managing Tile Drainage Water Quality



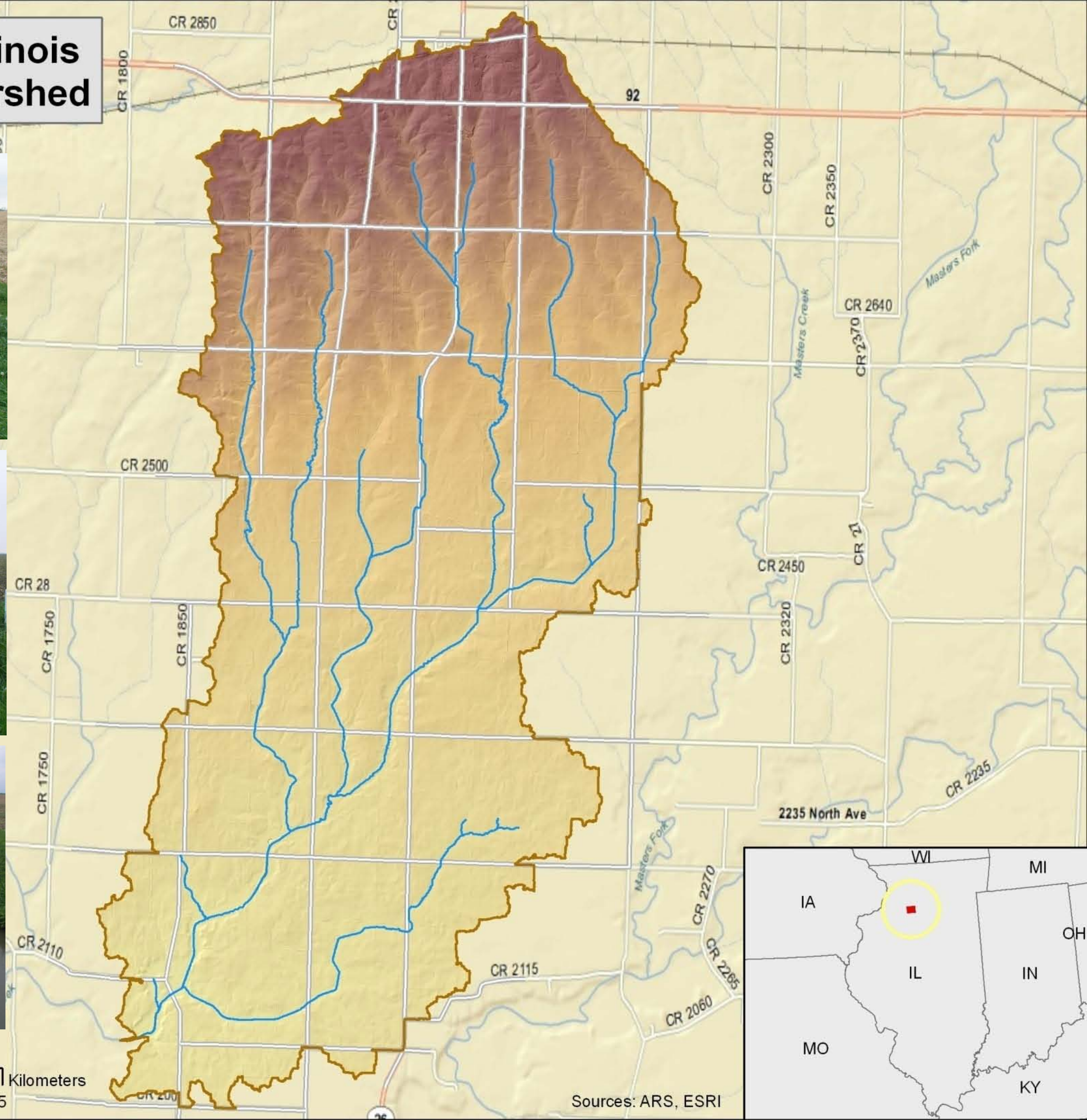

Big Bureau Creek, Illinois
Lime Creek
Bureau County
Putnam County
172
251
26
52
92
34
80
6
29
40
180
Stream gauge
Kilometers
0
5
10
MN
WI
MI
SD
IA
NE
IL
IN
OH
KS
MO
KY

Big Bureau Creek, Illinois
Lime Creek subwatershed

Upper Watershed

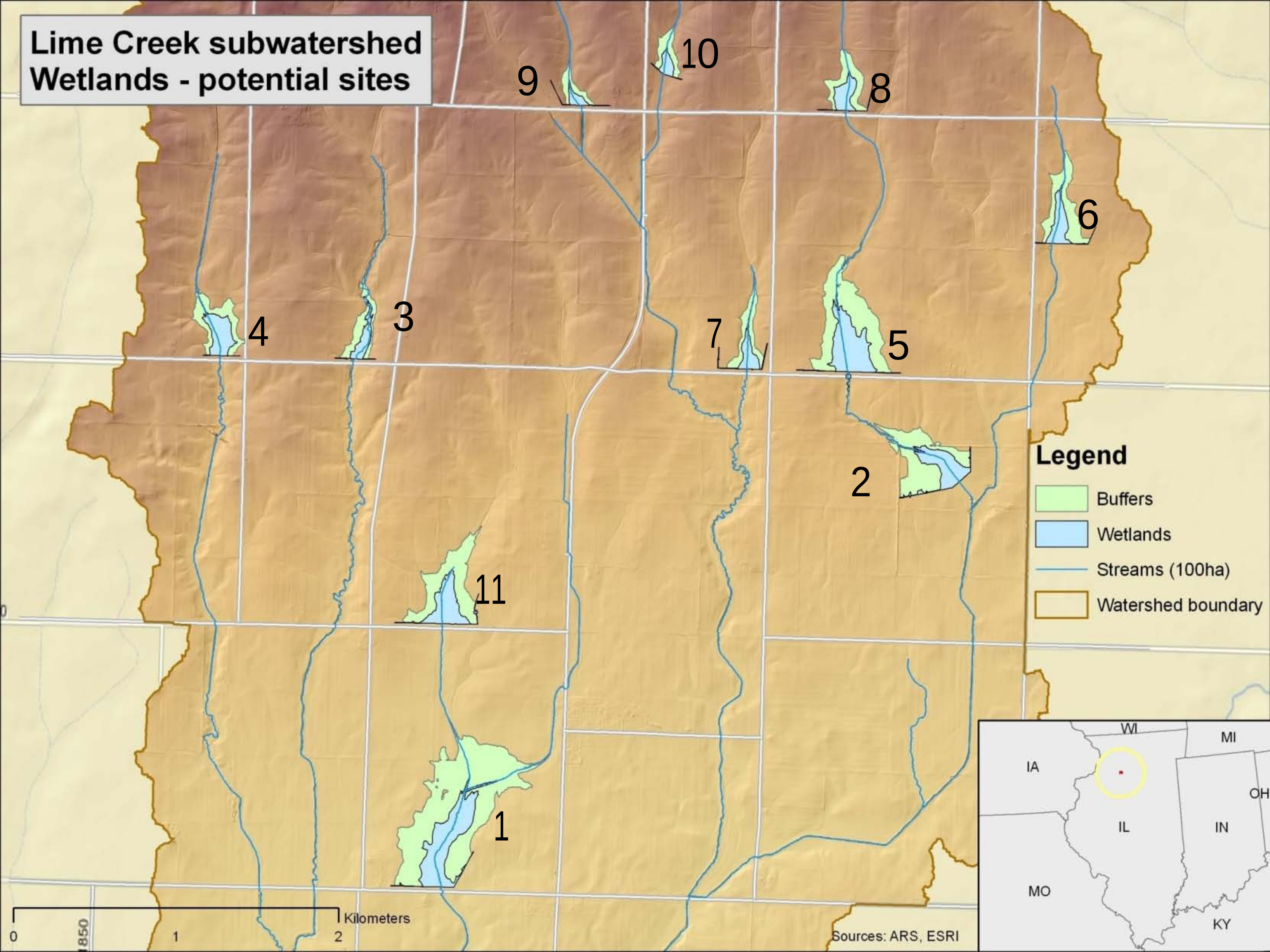
Middle Watershed

Lower Watershed



Wetland site criteria

- Minimum contributing area (CA) of 100 ha.
- Depth criteria of 0.9 m wetland depth, plus a 1.5 m vertical buffer where the wetland could impede drainage (from Iowa CREP program).
- Neither a wetland nor its buffer can impede drainage along roads or within farmsteads.
- Tested sites immediately above road crossings to minimize chance of inundating the next up-gradient road crossing.
- Conducted field review of sites meeting criteria.
- Sorted sites into a preliminary ranking to favor large contributing areas (CA), wetland areas <2% of CA, and small buffer areas.


Lime Creek subwatershed
Wetlands - potential sites
1
2
3
4
5
6
7
8
9
10
11
Legend
Buffers
Wetlands
Streams (100ha)
Watershed boundary
0
1
2
Kilometers
Sources: ARS, ESRI
WI
MI
IA
IL
IN
OH
MO
KY

Wetland siting – results following field review

- Eleven potential wetland sites could intercept 30% of the watershed area (1976 ha).
- Wetlands occupy 39 ha (25 ha if only lowest wetland per tributary is selected).
- Buffer plus wetlands occupy 6.2% of CA (4.2% if lowest per tributary).

Wetland Site ID	Contributing area ha	Wetland area ha	Wetland plus buffer area ha
1	518	9.40	40.04
2	334	4.42	13.66
3	266	1.73	4.83
4	237	3.36	7.59
5	260	7.26	19.71
6	171	2.54	7.95
7	152	1.81	4.91
8	152	2.14	5.58
9	148	0.85	2.39
10	152	0.97	2.95
11	118	4.38	12.72

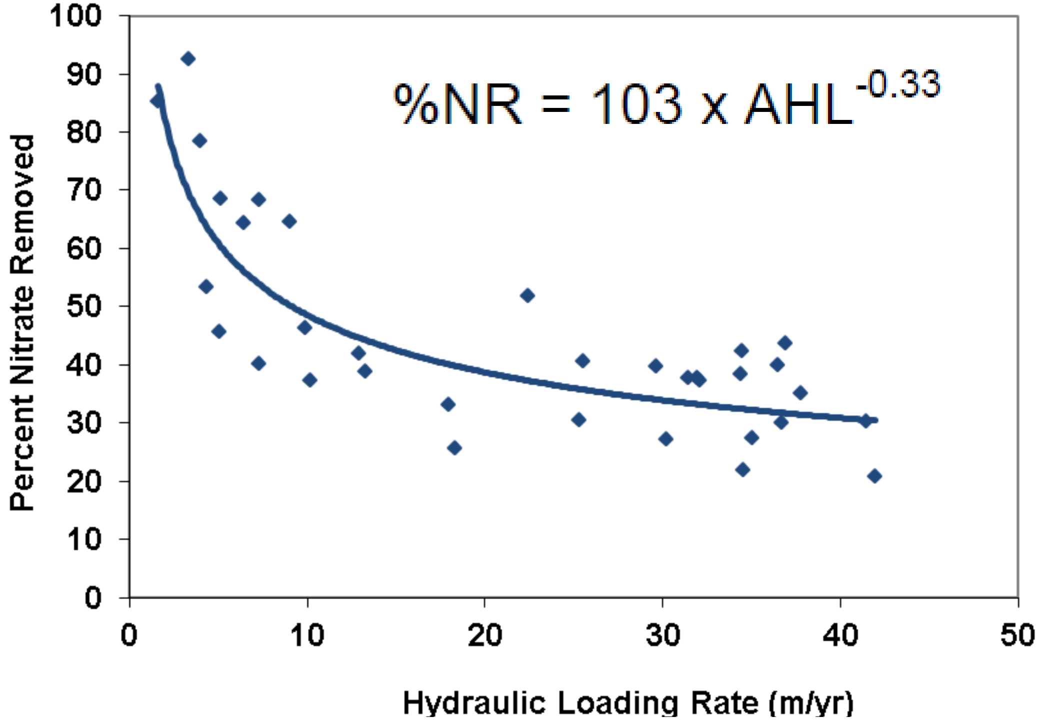
What Contribution to Nitrate Reduction?
AnnAGNPS model

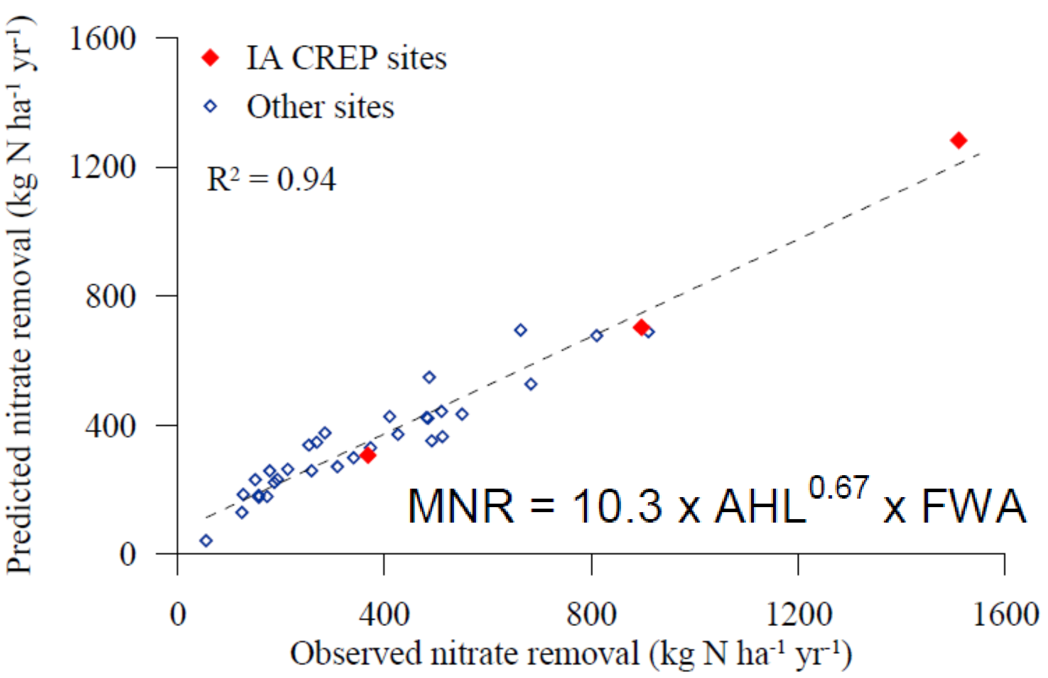
- Raster-based watershed simulation model
- Simulates crop growth and agricultural management practices
- Incorporates tile drainage
- Used 30 yr simulated weather record as input
- 30 year record of hydrologic and nutrient load discharge simulated.

AnnAGNPS Results: Hydraulic and Nitrate-N Loads to Wetland Sites

	Contributing Area		Wetland		
Wetland Site ID	Q (s.d.) $mm\ yr^{-1}$	N loss (s.d.) $kg\ ha^{-1}$	AHL (s.d.) $M\ yr^{-1}$	N load (s.d.) $kg\ ha^{-1}$	FWA (s.d.) $mg\ L^{-1}$
1	293 (106)	31.5 (8.5)	16.4 (5.9)	1757 (474)	11.4 (2.9)
2	279 (105)	24.7 (6.4)	21.7 (8.1)	1923 (501)	9.4 (2.6)
3	267 (101)	28.9 (9.4)	44.9 (16.9)	4843 (1586)	11.4 (3.2)
4	302 (108)	44.4 (19.4)	21.0 (7.5)	3084 (1345)	15.5 (5.7)
5	272 (104)	21.2 (5.6)	10.9 (4.2)	849 (222)	8.4 (2.4)
6	270 (106)	13.3 (3.1)	19.2 (7.5)	952 (225)	5.4 (1.6)
7	303 (108)	30.9 (8.9)	25.3 (9.1)	2588 (742)	10.8 (2.8)
8	231 (100)	5.5 (1.6)	17.4 (7.5)	410 (121)	2.6 (0.9)
9	299 (108)	35.5 (10.9)	55.1 (20.0)	6535 (2015)	12.5 (3.6)
10	261 (103)	17.9 (5.1)	42.4 (16.7)	2898 (823)	7.4 (2.4)
11	314 (108)	39.1 (11.3)	8.5 (3.0)	1062 (308)	13.0 (3.3)
Outlet	279 (103)	28.6 (7.1)			

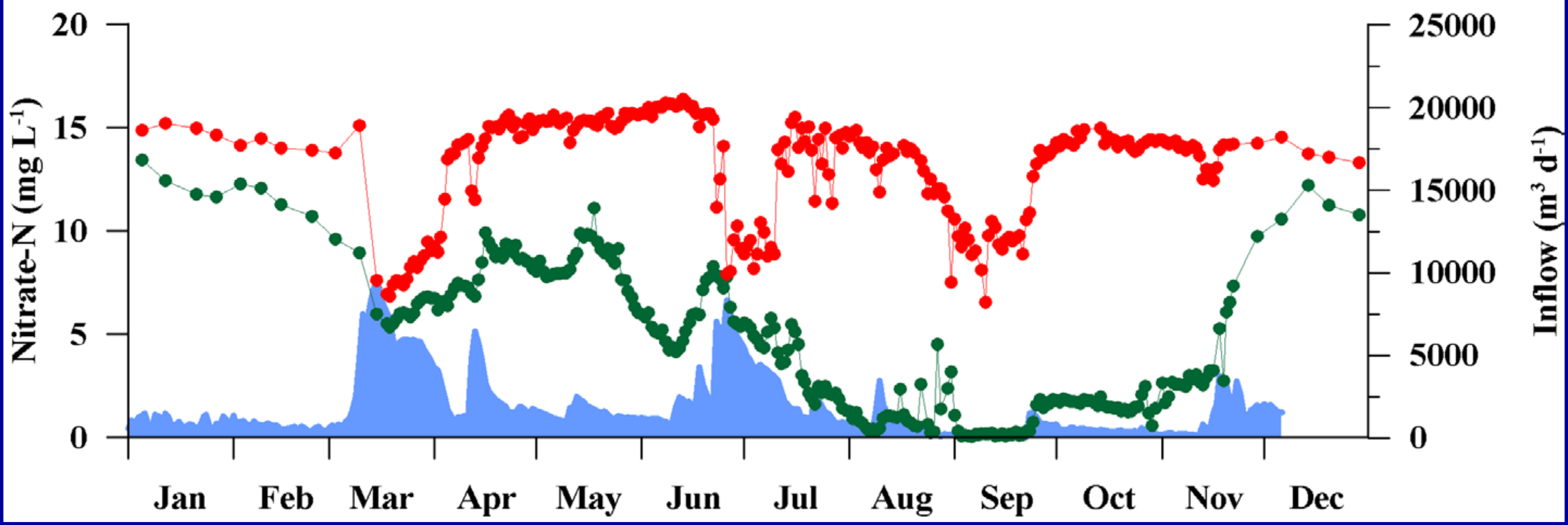
Nitrate Removal in Wetlands





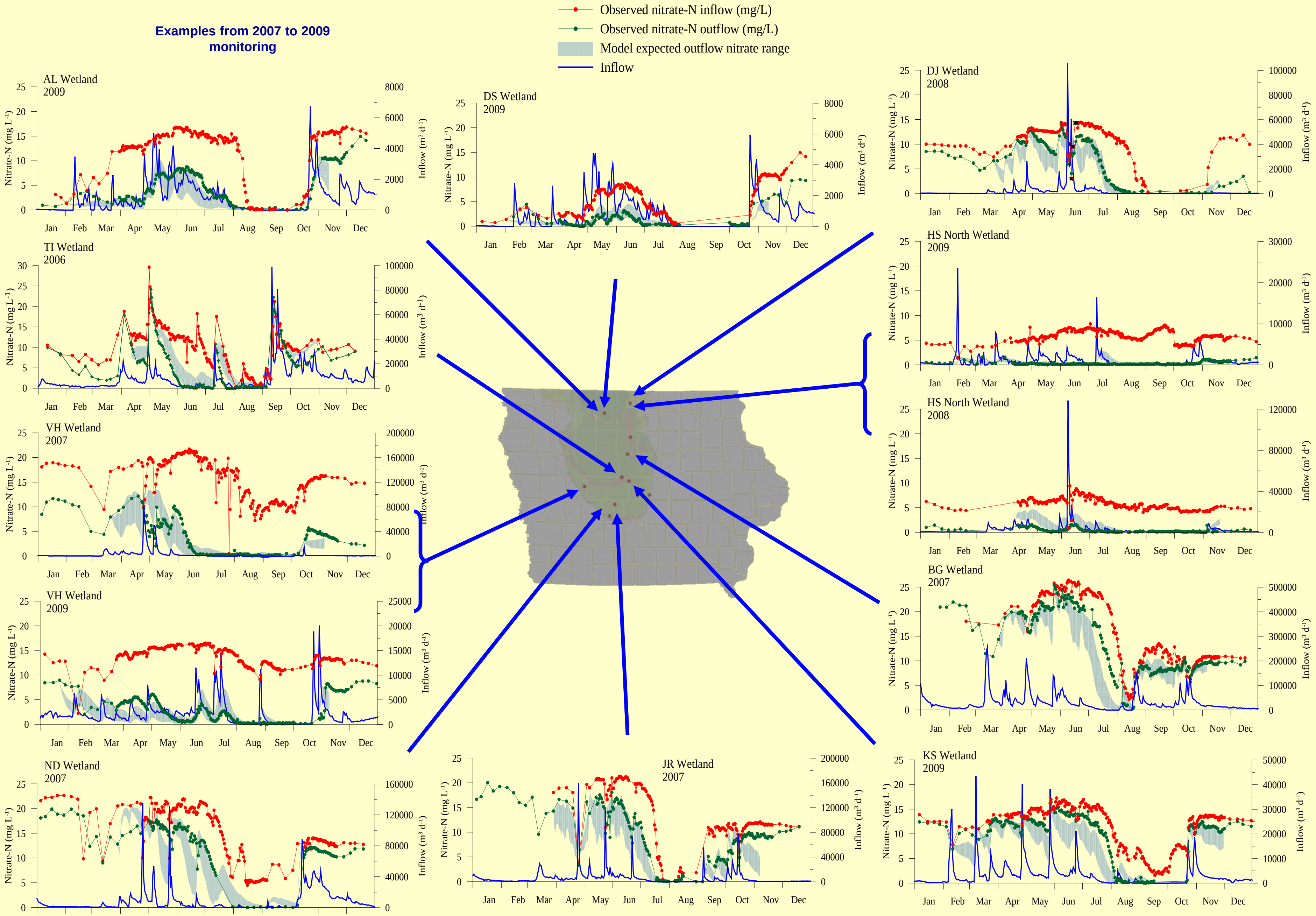
Dale et al., 2010

Wetland monitoring in Iowa



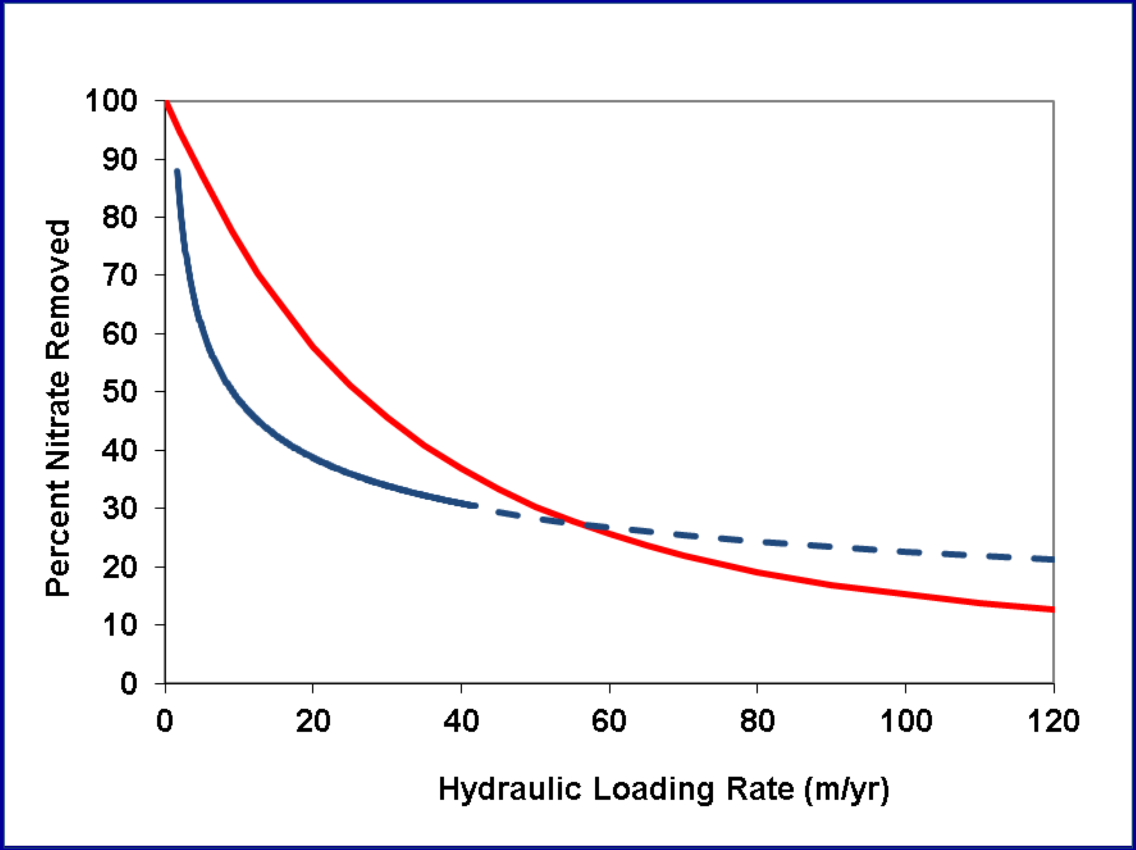
Patterns in NPS Nitrate Loading and Nitrate Loss in Wetlands

Examples from 2007 to 2009 monitoring



W.G. Crumpton, Iowa State University

Old (blue) and new (red) expected nitrate loss with expanded HLR range.
New line based on 23 annual mass balances from 11 separate wetlands in Iowa.

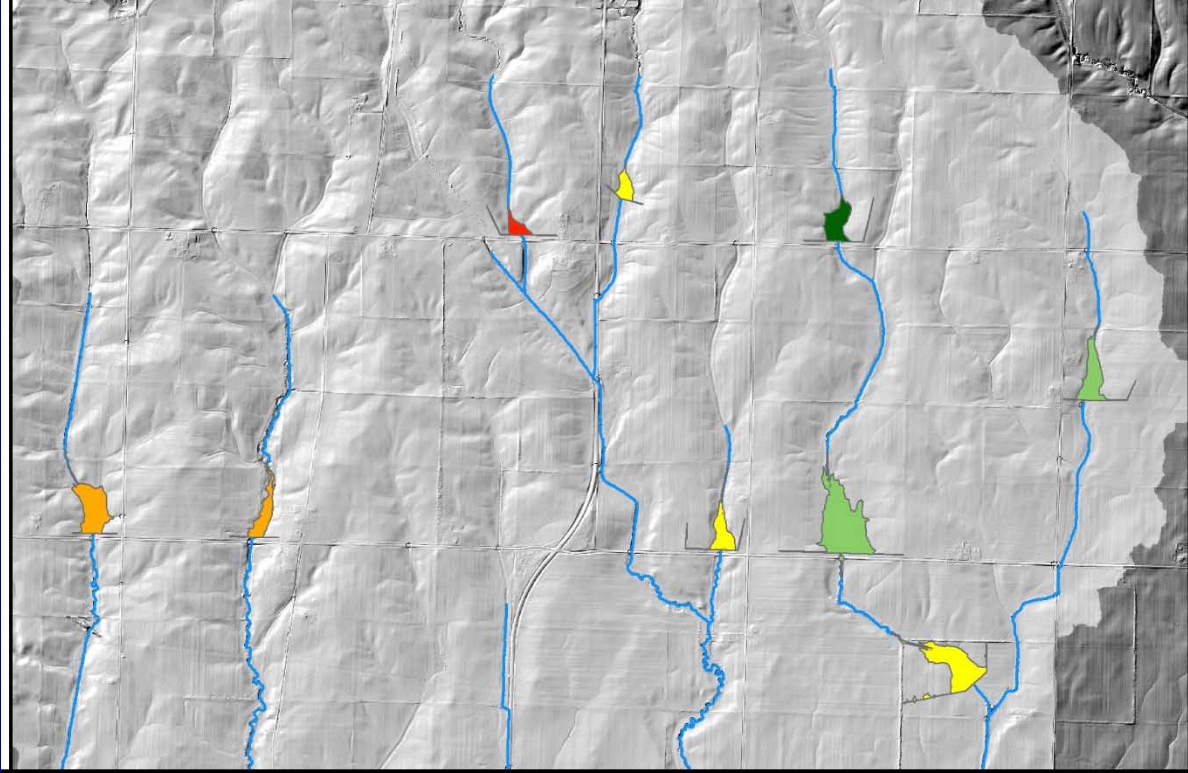


W.G. Crumpton, Iowa State University

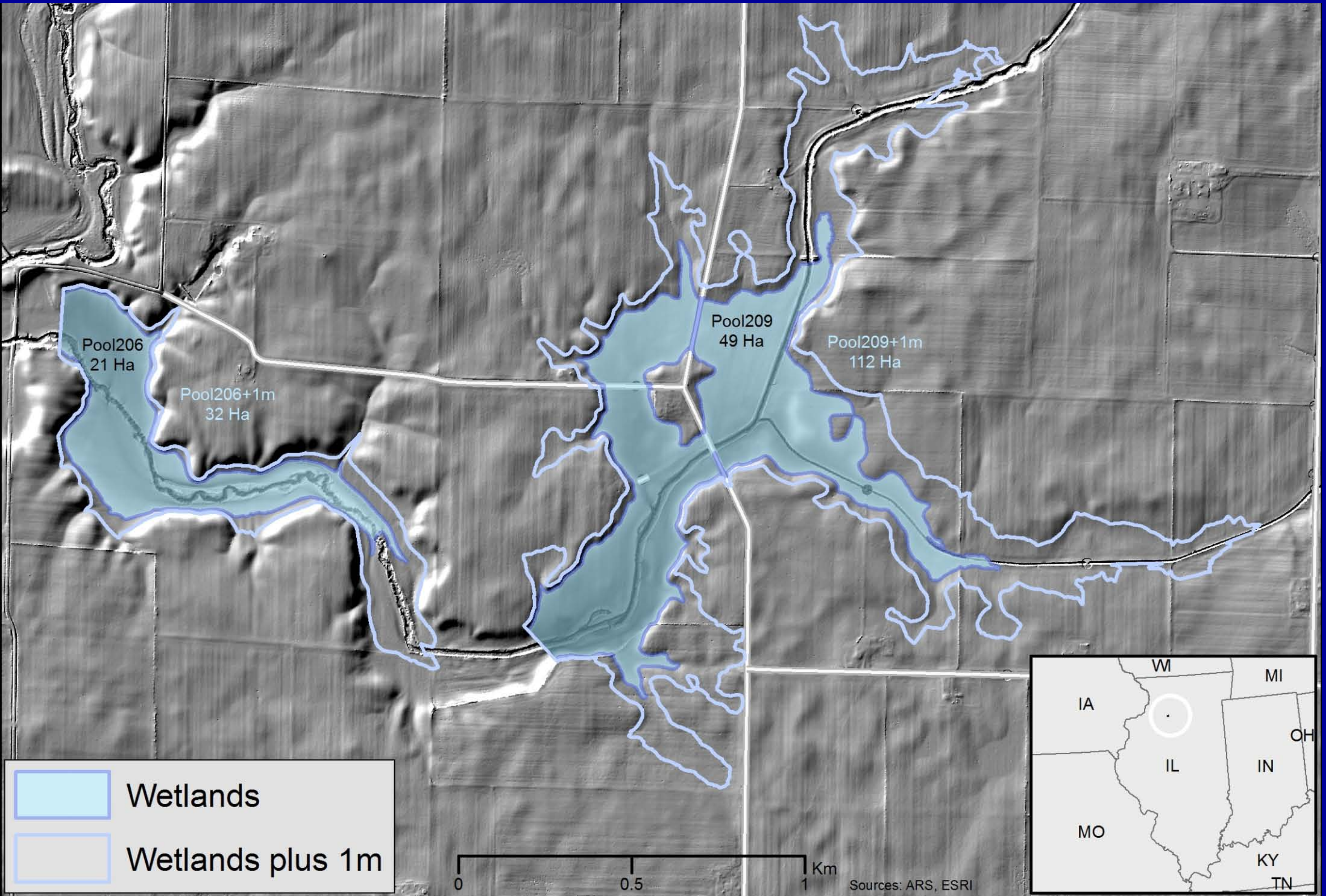
Estimated Mass Nitrate-N Removals

Wetland Site ID	AHL m	N load kg ha^{-1} yr^{-1}	MNR* kg ha^{-1} yr^{-1}	%NR	Rank
1	16.4	1757	722 (130)	41%	6
2	21.7	1923	721 (128)	37%	7
3	44.9	4843	1423 (324)	29%	2
4	21.0	3084	1164 (409)	37%	3
5	10.9	849	400 (74)	47%	9
6	19.2	952	373 (59)	39%	10
7	25.3	2588	919 (180)	35%	4
8	17.4	410	167 (43)	40%	11
9	55.1	6535	1795 (404)	27%	1
10	42.4	2898	873 (185)	30%	5
11	8.5	1062	540 (108)	51%	8

Simulation: Average Annual N Removal Rates Varied Widely



Placing wetland at outlet (relaxed criteria)



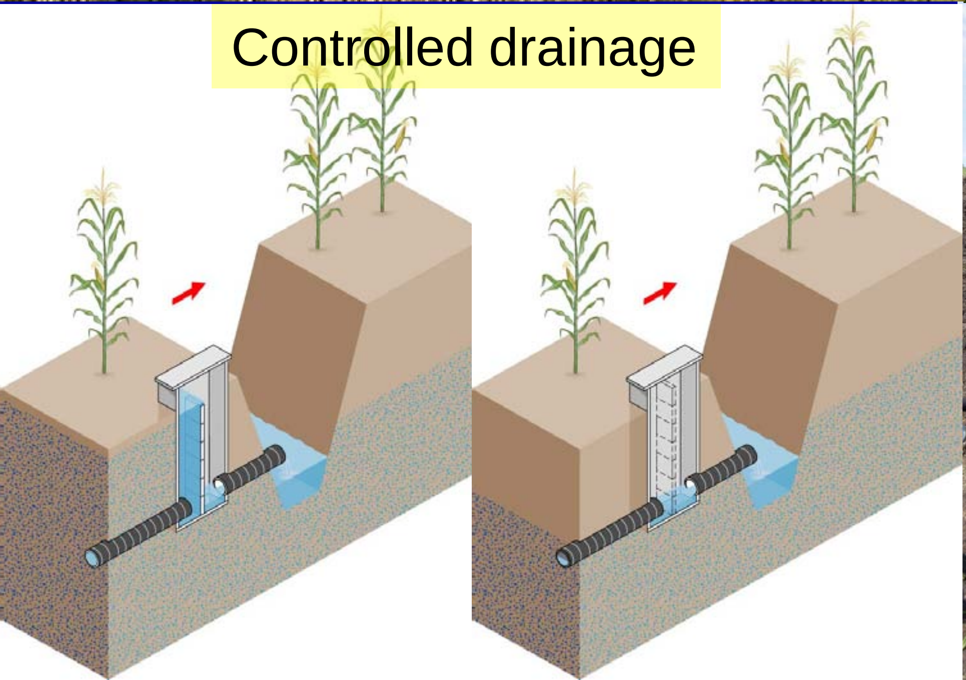
Conclusions

- LiDAR data helped to identify potential sites for wetlands in a 6500 ha watershed. A field review was critical to confirm site suitability.
- Wetlands could intercept drainage from 30% of the watershed and occupy only 1.3% of the contributing area (4.2% incl. buffers).
- These wetlands could reduce nitrate-N load from the watershed by 11-16%, based on model estimates.
- A large, two-pool wetland near the watershed outlet could reduce the watershed nitrate N load by 35%, but planning, design and implementation would be more complicated.
- Additional practices would be required to meet a targeted nitrate N load reduction of 45%.

Factors Impacting Performance

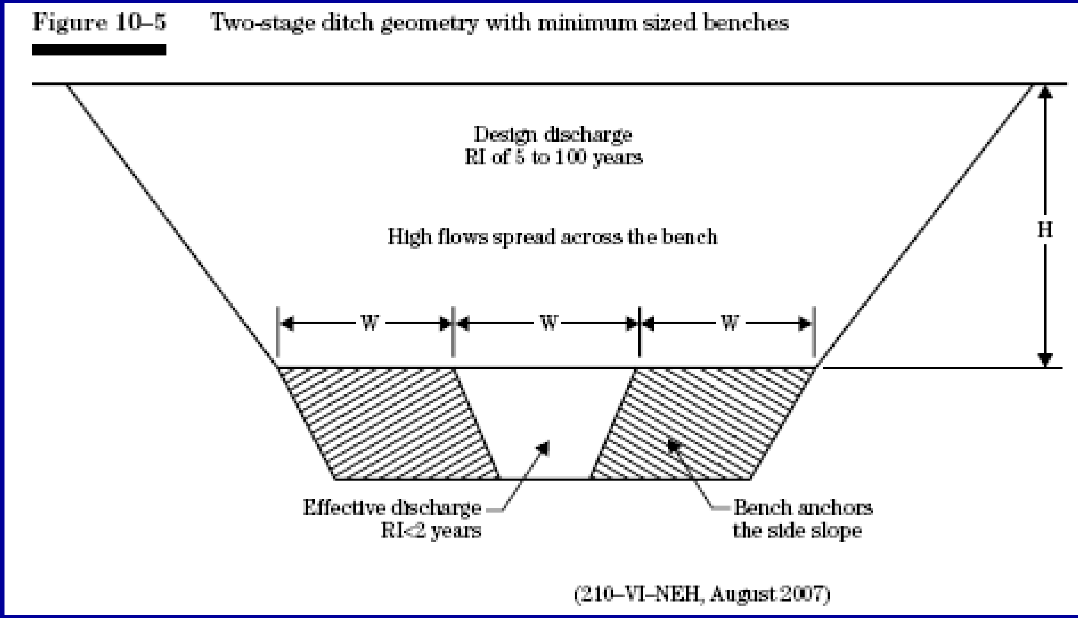
- Hydraulic loading
  (contributing:wetland area ratio)
- Nitrate concentration in tile drainage
  (row cropping, nutrient management practices, soil type)
- Regional and year to year variation in climate that impact amounts and timing of loads.
- Wetland characteristics (flow routing, vegetation, organic substrates)

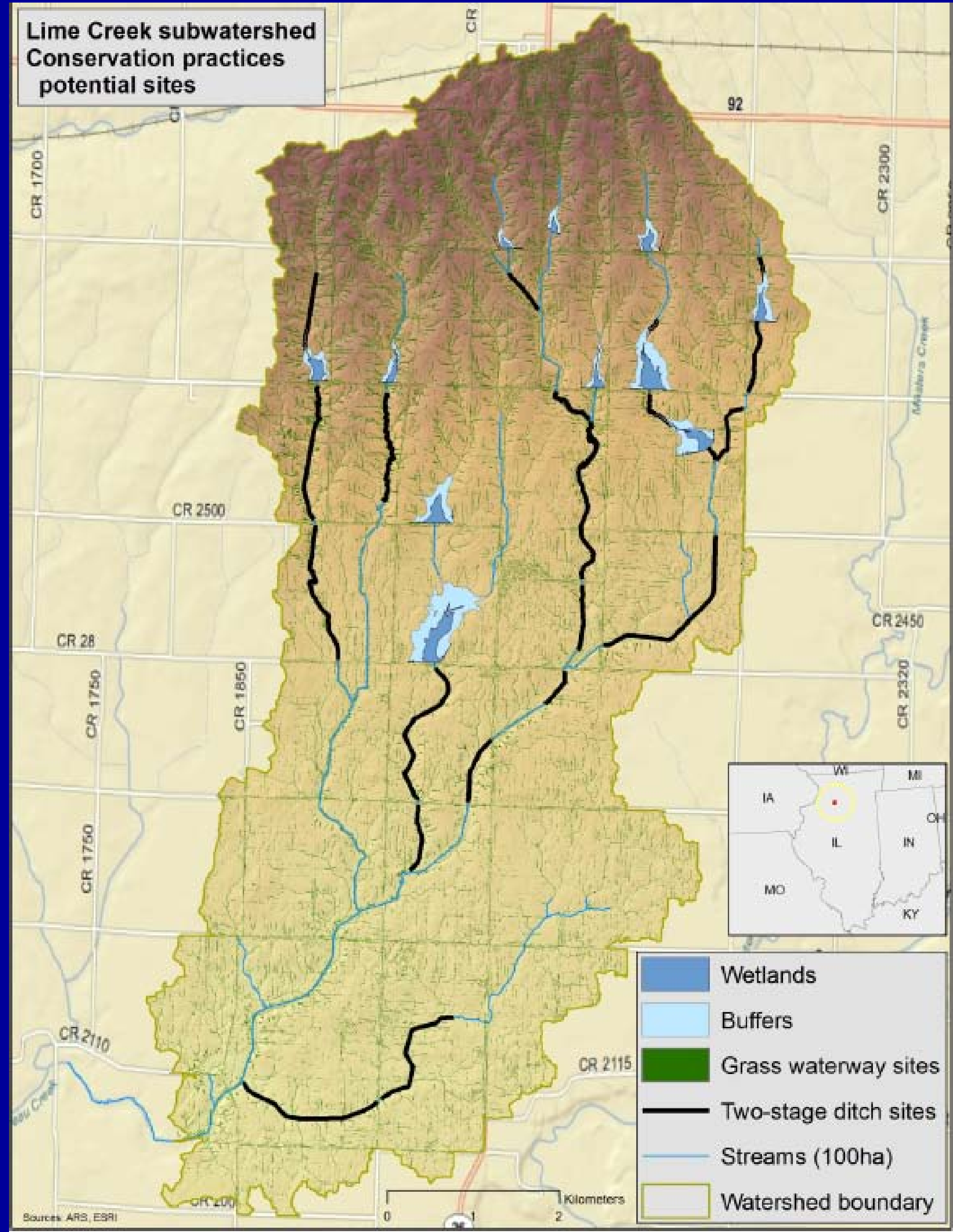
Practices for Managing Tile Drainage Water Quality



Two-stage ditches

- General assessment only, based on ditch depth. Assume 1-2 m depths most feasible.
- Need depth and width for final design (LiDAR can estimate depth, but not width).
- NRCS, 2007:





Lime Creek subwatershed
Conservation practices
potential sites
92
CR 1700
CR 2300
CR 2500
CR 28
CR 2450
CR 1750
CR 1850
CR 2320
CR 1750
CR 2110
CR 2115
WI
MI
IA
OH
IL
IN
MO
KY
Wetlands
Buffers
Grass waterway sites
Two-stage ditch sites
Streams (100ha)
Watershed boundary
Kilometers
0
1
2
Sources: ARS, ESRI

Acknowledgments:

The Wetlands Initiative
(www.wetlands-initiative.org)
provided research funding

under a grant from the
US EPA’s Targeted Watershed Program