Buffers, Filters, and Wetlands to Expand Sustainable Cultivation

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The Challenge of Reducing Nutrient Transport to Improve Water Quality:

1. Nature - Contrasting Behavior of Nitrogen and Phosphorus

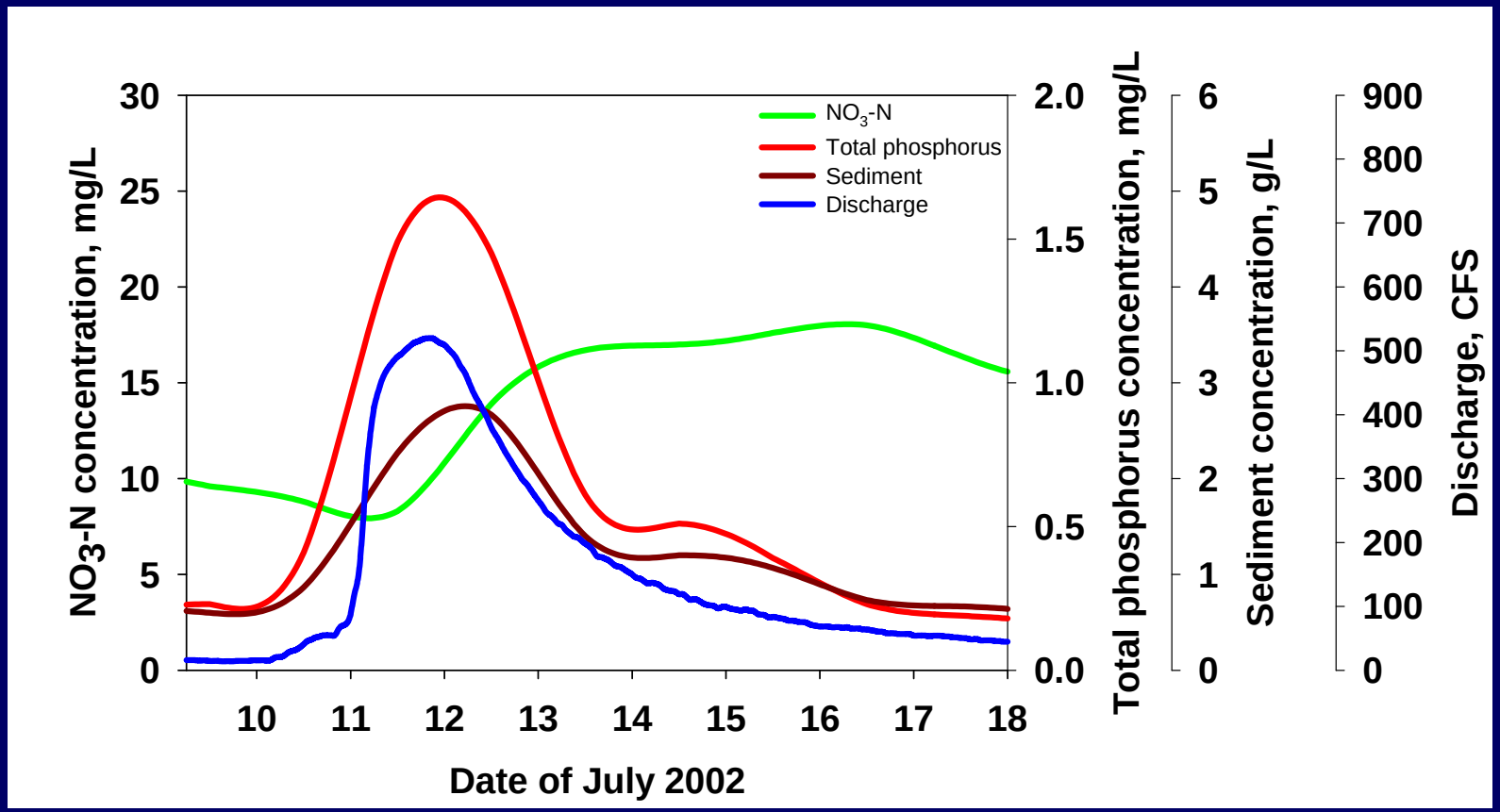
Nitrogen:

- Biologically complex
- Dominant form is a gas
- Easily leached from well-drained soils
- Subsurface transport
- Seasonally dynamic
- Released from saturated soils as a gas
- Ecological impacts are distant (Gulf of Mexico)

Phosphorus:

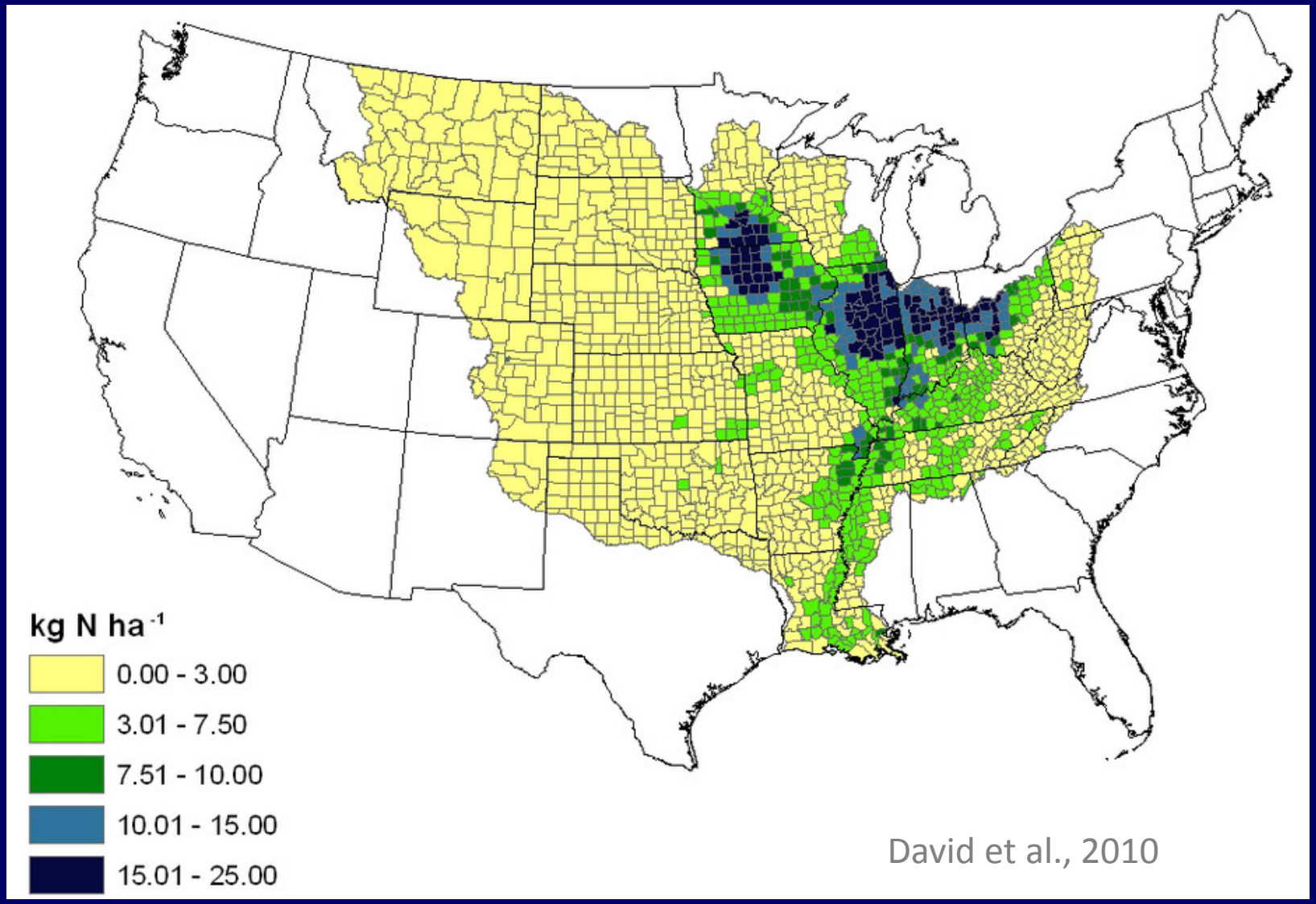
- Chemically complex
- No gaseous form
- Strongly adsorbed in well-drained soils
- Surface transport
- Episodically dynamic
- Released from saturated soils as a solute
- Ecological impacts are local (Eutrophication)

Contrasting changes in NO_3-N and total P concentrations during a runoff event



2. History - Agricultural legacies as challenges for the management of riparian corridors

3. Scale - Nitrate Sources to the Mississippi River Contributing to Gulf of Mexico Hypoxia



David et al., 2010

Managing Agricultural Water Quality – What we are dealing with:

- Complex natural systems
- Legacies of agricultural history
- Wide scale of major drainage basins

To be successful, we need an approach to water quality planning that is flexible, scalable, non-prescriptive, updateable, and ensures continued agricultural productivity while improving its sustainability.

Iowa Nutrient Reduction Strategy Practice Review Process

Iowa St. Univ., Iowa Dept. of Agric. & Land Stewardship

- Established a list of potential practices that can reduce nutrient losses.
- Identify those with greatest potential and research results (Emerging practices may be added in future).
- Review literature from Iowa and surrounding states where soils and climate are similar to Iowa.
- Compile measured practice effects on nitrogen & phosphorus concentrations / loads, and crop yield.
- Summarize and rank expected practice performance.

Nitrogen Reduction Practices

	Practice	% Nitrate-N Reduction [Average (Std. Dev.)]
Nitrogen Management	Timing (Fall to spring)	6 (25)
	Source (Liquid swine compared to commercial)	4 (11)
	Nitrogen Application Rate	Depends on starting point
	Nitrification Inhibitor	9 (19)
	Cover Crops (Rye)	31 (29)
Land Use	Perennial – Land retirement	85 (9)
	Living Mulches	41 (16)
	Extended Rotations	42 (12)
Edge-of-Field	Drainage Water Mgmt.	33 (32)*
	Shallow Drainage	32 (15)*
	Wetlands	52
	Bioreactors	43 (21)
	Buffers	91 (20)**

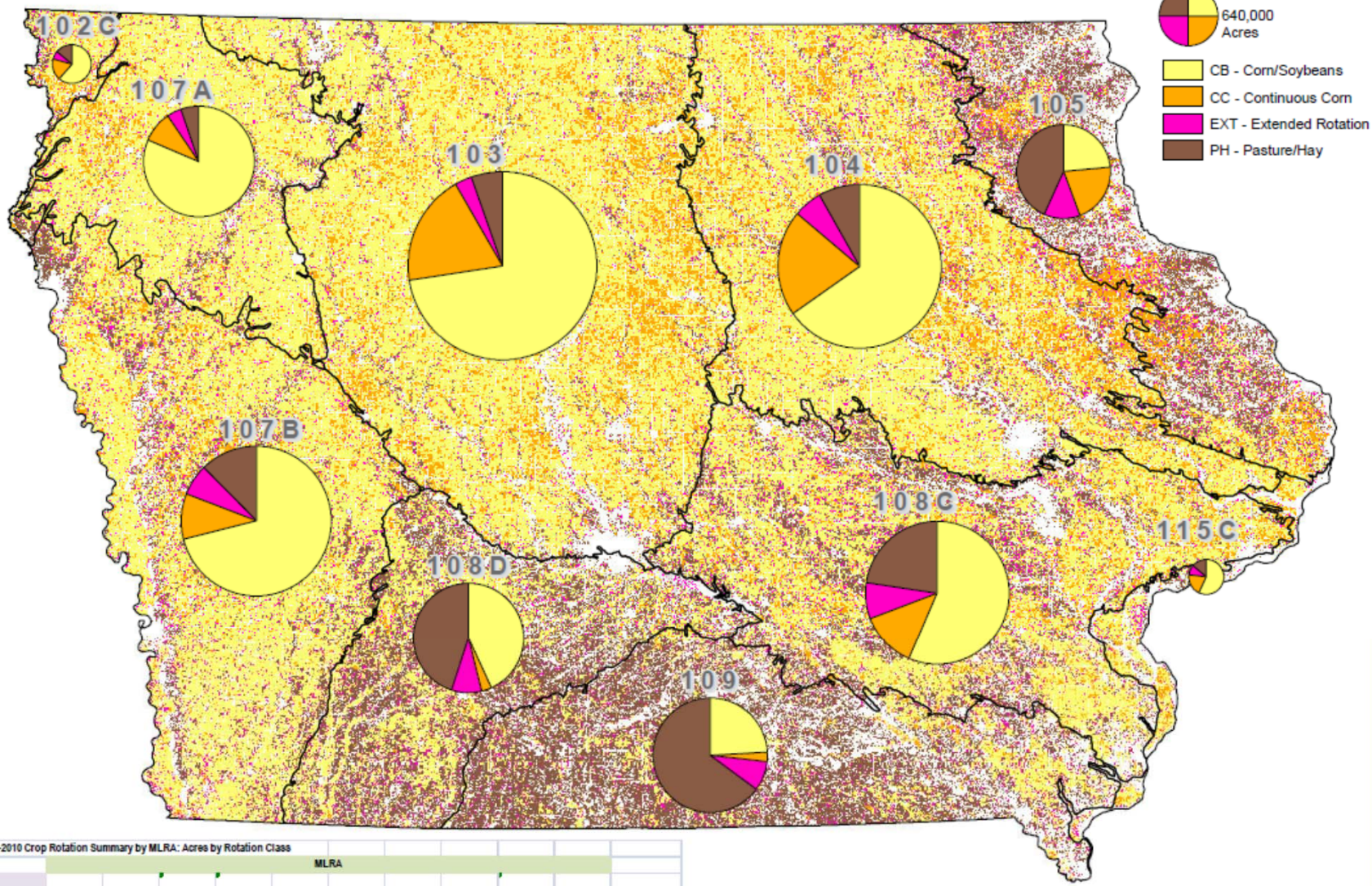
*Load reduction not concentration reduction

**Concentration reduction of that water interacts with active zone below the buffer

Phosphorus Reduction Practices

	Practice	% Phosphorus-P Reduction [Average (Std. Dev.)]
Phosphorus Management	Producer does not apply phosphorus until STP drops to optimal level	17 (40)
	Source (Liquid swine compared to commercial)	46 (45)
	Incorporation	36 (27)
	No-till (70% residue) vs. conventional tillage (30% residue)	90 (17)
	Cover Crops (Rye)	29 (37)
Land Use	Perennial – Land retirement	75 (-)
	Pasture	59 (42)
Edge-of-Field	Buffers	58 (32)

Crop Rotations by MLRA 2006-2010



2006-2010 Crop Rotation Summary by MLRA: Acres by Rotation Class

	MLRA										
Rotation Class	102C	103	104	105	107A	107B	108C	108D	109	115C	Class Total
CB	170,150	4,737,173	3,196,747	381,385	1,833,614	2,938,063	2,137,446	960,322	582,198	127,776	17,064,874
CC	50,077	1,252,578	1,031,193	339,917	208,446	408,404	479,205	65,003	63,872	44,997	3,943,694
EXT	18,180	190,573	275,015	201,089	95,205	280,602	310,546	199,601	201,817	20,183	1,792,811
PH	38,865	351,362	402,027	705,143	118,910	510,586	855,005	999,998	1,564,762	31,536	5,578,193
MLRA Total	281,365	6,598,812	4,970,105	1,657,127	2,283,620	4,185,568	3,830,637	2,253,206	2,436,344	229,875	

Source: USDA NASS

Implementation of Nutrient Reduction Strategy

- Strategies identified for Iowa MLRAs.
- Need techniques to be able to promulgate strategy from the MLRA down to the small watershed scale.
- The next slide illustrates a possible process by which this could be done.

A process for conservation planning in agricultural watersheds using precision technologies

1 Input: Field boundary data
Soils, Land use, LiDAR-based DEM

2 **All fields:**
Encourage practices that:
a) Protect soil (e.g., no tillage);
b) Limit excess nutrients (e.g., NMPs);
c) Build soil (e.g., cover crops)

Fields that are tile drained

3

Fields that are not tile drained

All fields

4

Runoff/Risk Assessment:
Prioritize fields where multiple erosion control practices are most needed

Close to stream?

Slope steepness	Yes		No
H	A	B	C
M	B	C	
L	C		

Practices implemented in fields

7 Controlled drainage where flat

8 Surface intake filters or Restored wetlands where depressions occur

5 Contour filter strips, Terraces, Conservation cover where slopes are steep

6 Grassed waterways where gullies may form

Practices implemented at field edges

9 Bioreactors

10 Perennial crops, & novel practices to intercept flows where soils stay wet

11 Water detention using impoundments of varying designs

Nutrient removal wetlands

Sediment detention basins
Farm ponds

Practices implemented in riparian zones

14 Re-saturated buffers

Ditch design: Two-stage ditches; novel practices for detention / diversion of tile drainage **15**

13 Emphasis for Buffer Design:

i. High water & nutrient uptake
ii. Diversified vegetation
iii. Increased infiltration (stiff-stemmed grasses)
iv. Deep rooted vegetation
v. Shade stream, stabilize banks

12

Riparian Assessment:
Identify riparian function by stream reach

Shallow water table?

Runoff delivery	Yes		No
H	i	ii	iii
M	ii	ii	iii
L	iv	iv	v

16 Downstream :
river restoration (re-meandering, oxbow rehabilitation)

17 Scenario Development/ stakeholder feedback/ implement/ monitor/ adapt

A process for conservation planning in agricultural watersheds using precision technologies

INRS practices
Novel practices

1 Input: Field boundary data
Soils, Land use, LiDAR-based DEM

2 All fields:
Encourage practices that:
a) Protect soil (e.g., no tillage);
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c) Build soil (e.g., cover crops)

Fields that are tile drained → **3** → Fields that are not tile drained → All fields

Practices implemented in fields

- **7** Controlled drainage where flat
- **8** Surface intake filters or Restored wetlands where depressions occur
- **5** Contour filter strips, Terraces, Conservation cover where slopes are steep
- **6** Grassed waterways where gullies may form

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Runoff/Risk Assessment: Prioritize fields where multiple erosion control practices are most needed

Slope steepness	Close to stream? Yes		No
H	A	B	C
M	B	C	
L	C		

Practices implemented at field edges

- **9** Bioreactors
- **10** Perennial crops, & novel practices to intercept flows where soils stay wet
- **11** Water detention using impoundments of varying designs
  - Nutrient removal wetlands
  - Sediment detention basins
  - Farm ponds

Practices implemented in riparian zones

- **14** Re-saturated buffers
- **15** Ditch design: Two-stage ditches; novel practices for detention / diversion of tile drainage
- **13** Focus for Riparian Buffer Design:
  - i. High water & nutrient uptake
  - ii. Diversified vegetation
  - iii. Increased infiltration (stiff-stemmed grasses)
  - iv. Deep rooted vegetation
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Riparian Assessment: Identify riparian function by stream reach

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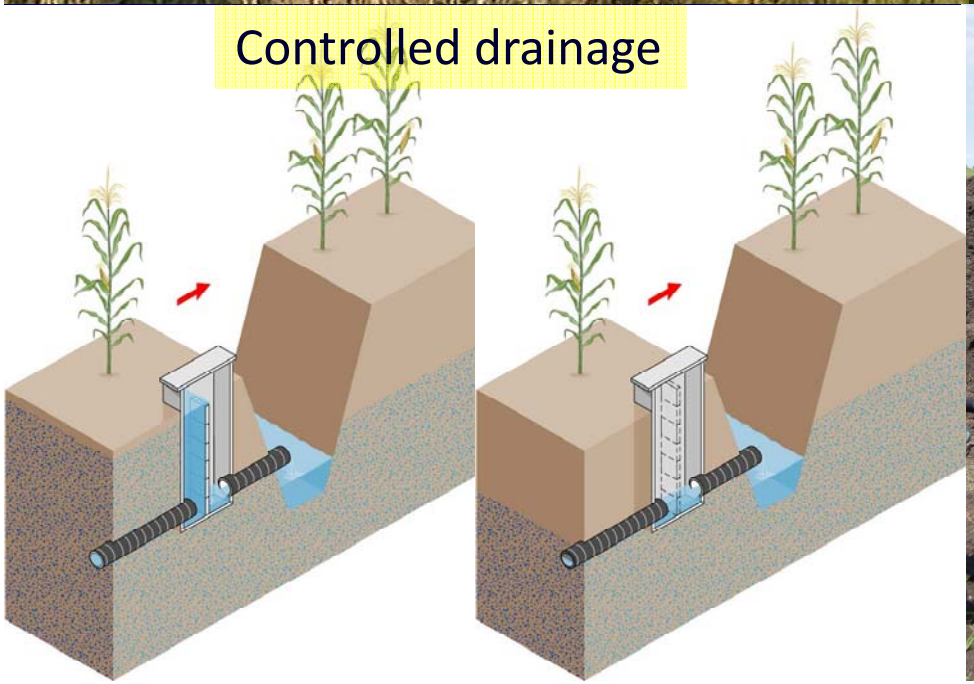
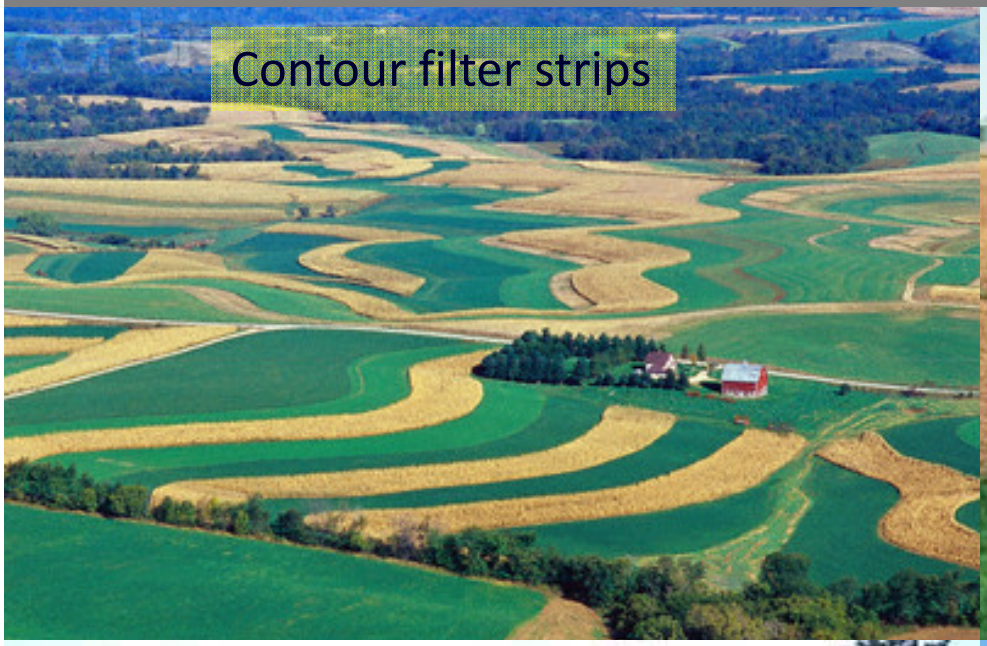
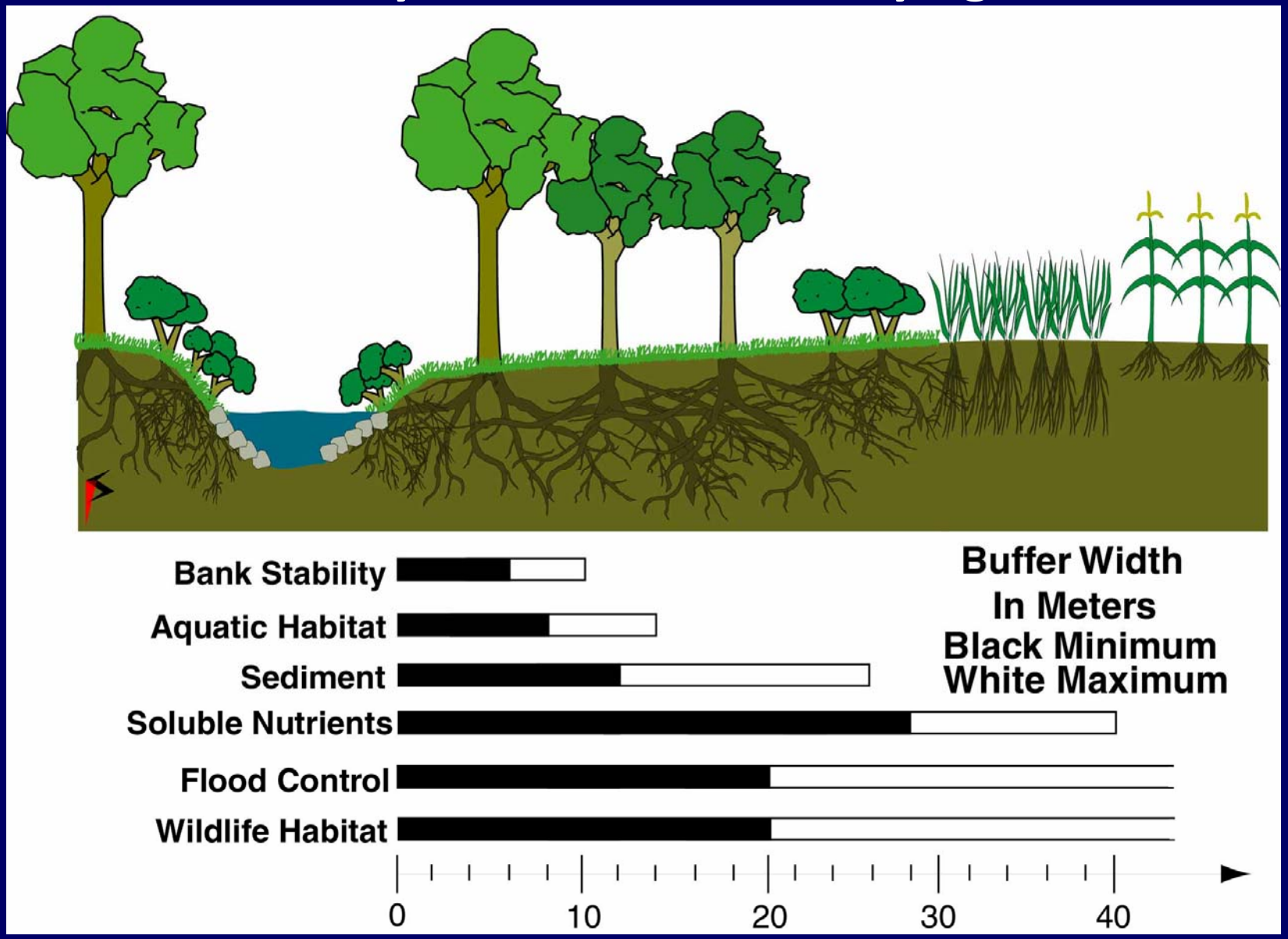
Practices for Managing Tile Drainage & Water Quality

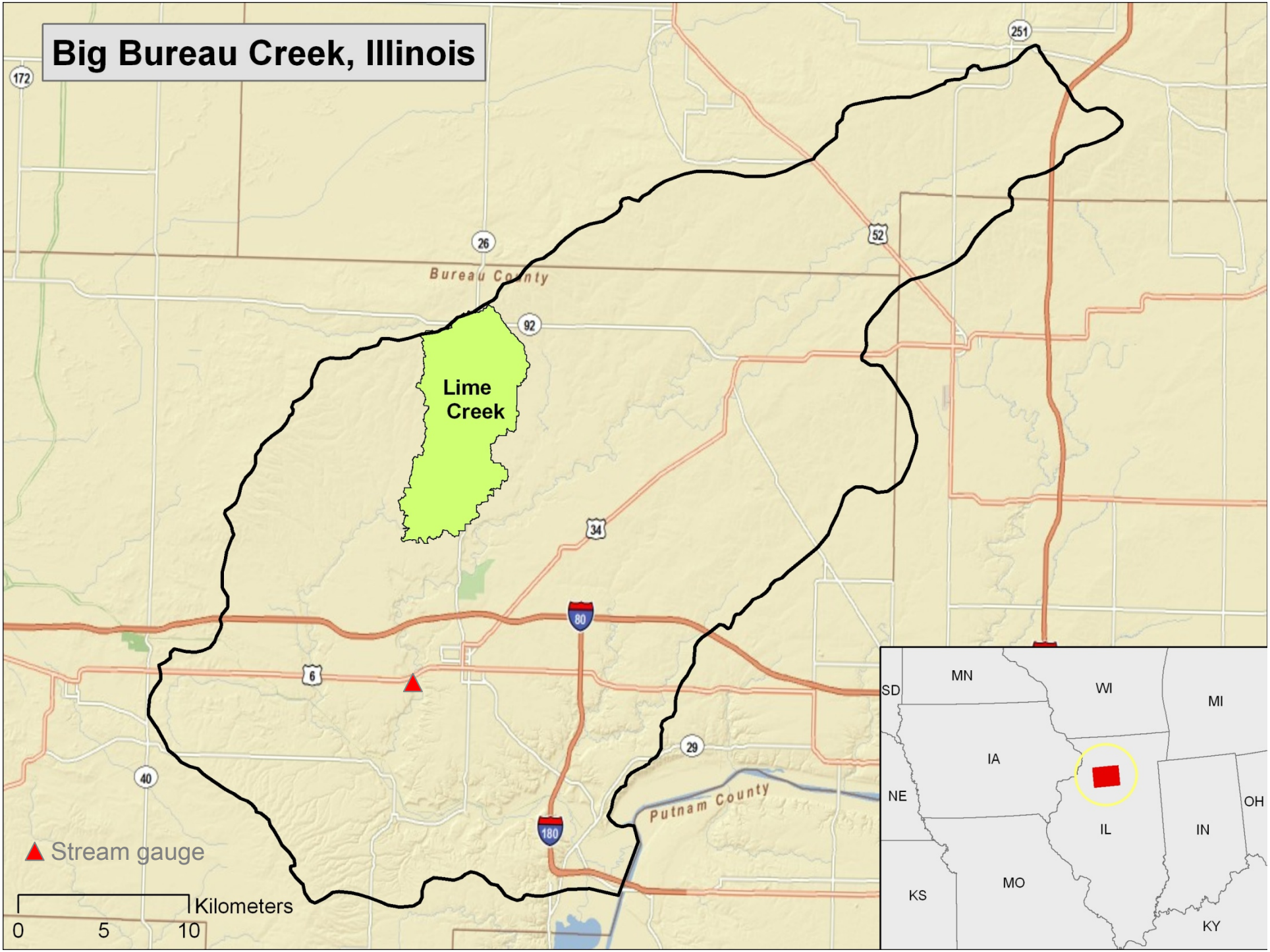


Practices for Managing Runoff & Water Quality

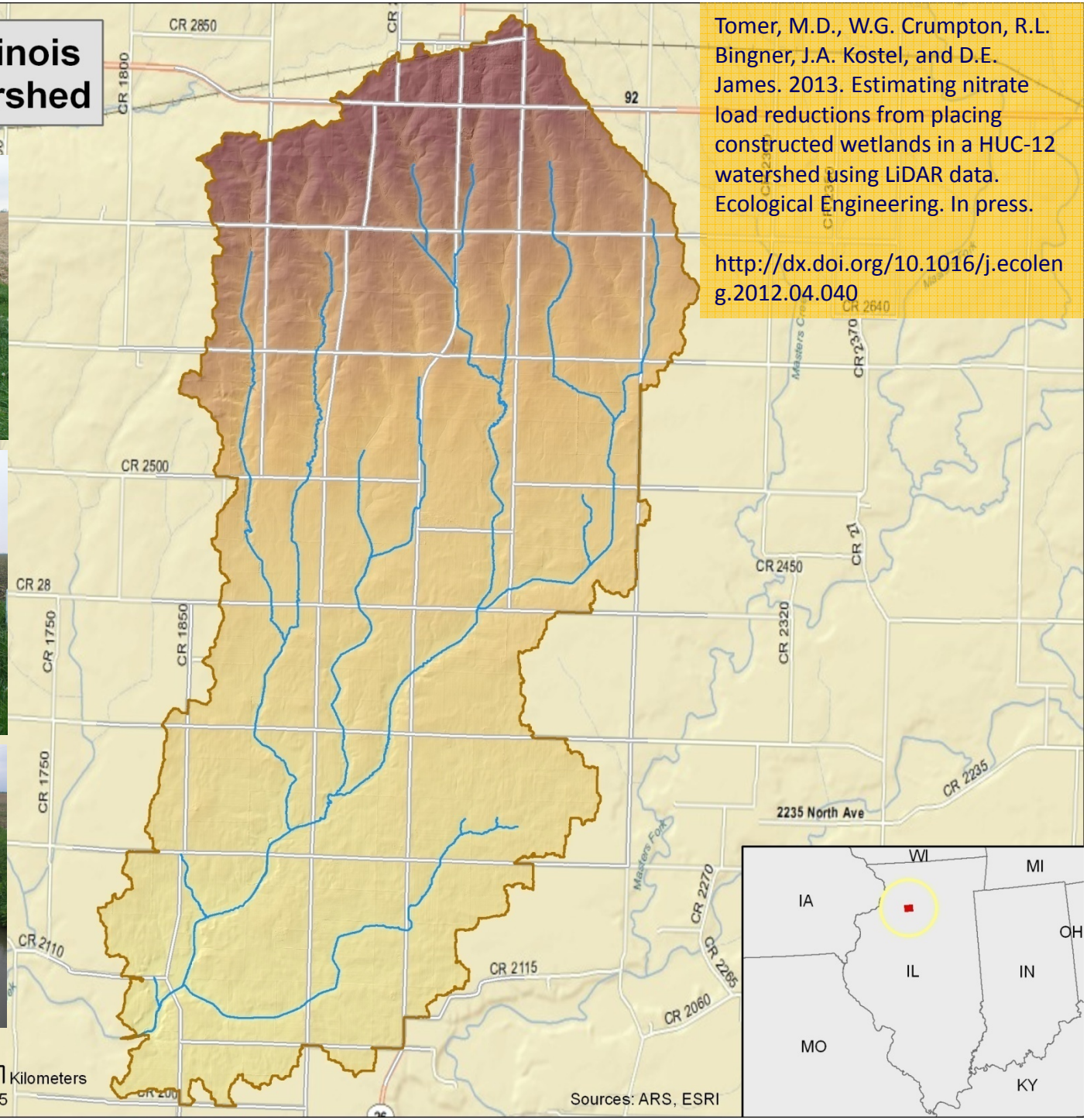


Potential Riparian Functions Depend on Landscape Attributes and May Be Achieved at Varying Buffer Widths




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

Big Bureau Creek, Illinois
Lime Creek subwatershed



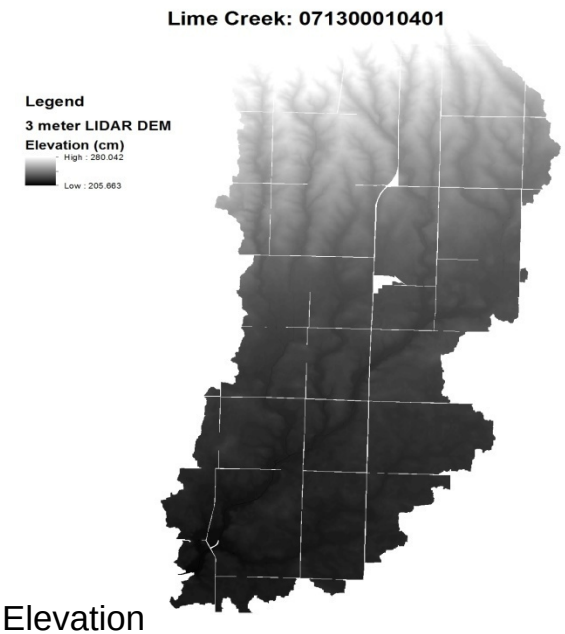
Tomer, M.D., W.G. Crumpton, R.L. Bingner, J.A. Kostel, and D.E. James. 2013. Estimating nitrate load reductions from placing constructed wetlands in a HUC-12 watershed using LiDAR data. Ecological Engineering. In press.

http://dx.doi.org/10.1016/j.ecoleng.2012.04.040

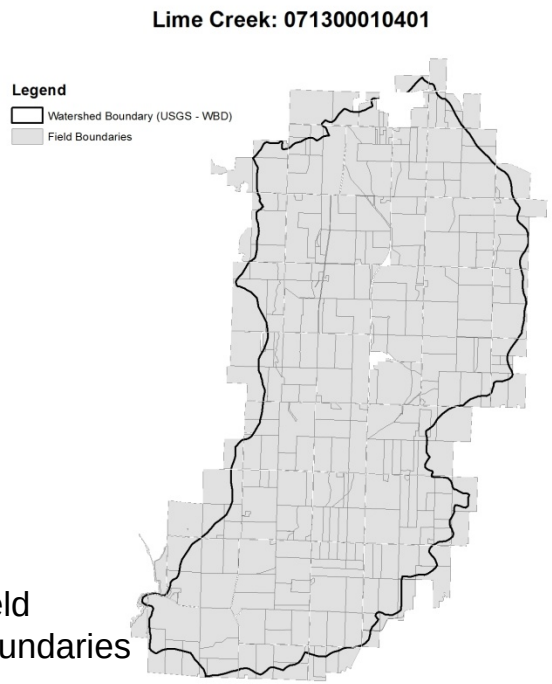
1. INPUT DATA

Input Data:

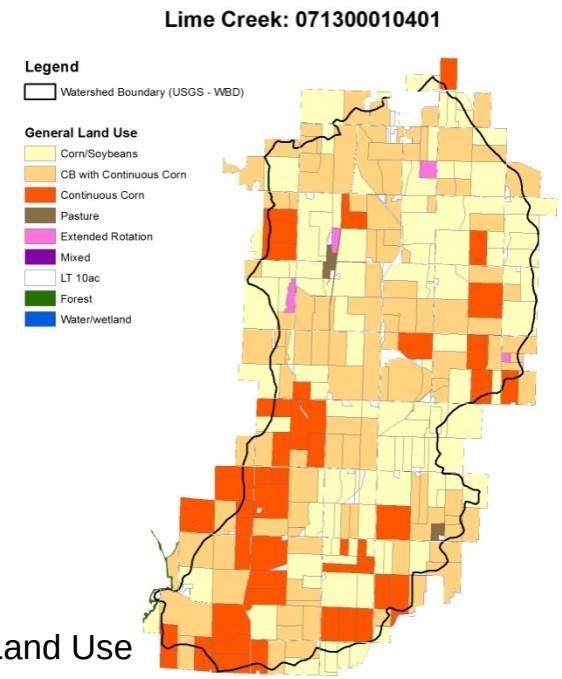
- Soils data
- Land Use data (compiled from NASS CDL data for years 2007 - 2011
- Field Boundaries (edited to 2009 from 2005 CLU's)
- 3 meter LIDAR DEM (processed for hydrologic analysis)



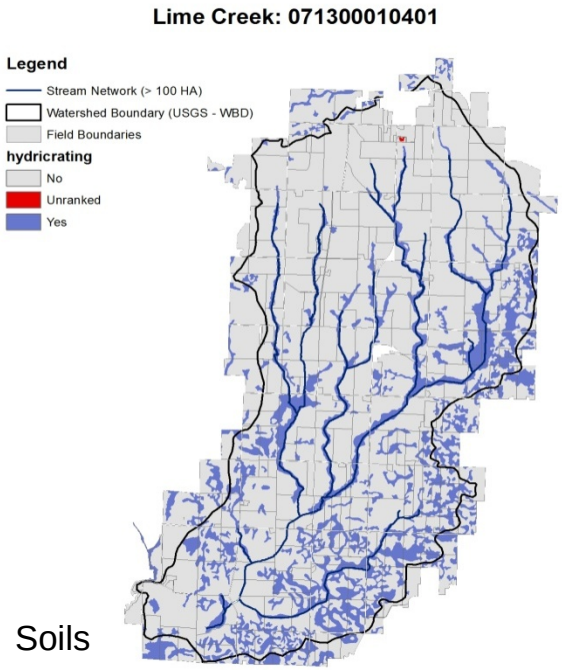
Elevation



Field Boundaries



Land Use



Soils

2. ENCOURAGE PRACTICES ON ALL FIELDS

NOT ALL CONSERVATION PRACTICES SHOULD BE PRIORITIZED FOR SOME FIELDS OVER OTHERS. RATHER, THERE ARE SOME CONSERVATION PRACTICES THAT SHOULD BE PART OF STANDARD PRACTICE FOR AGRICULTURAL PRODUCTION.

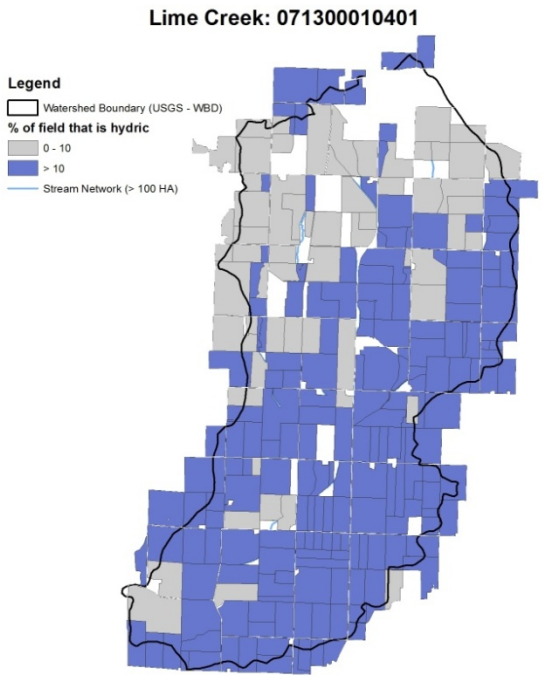
OUR SUGGESTION IS THAT PRACTICES TO

A. PROTECT SOIL (e.g., no-tillage, strip tillage),
B. BUILD SOIL (e.g., cover crops, living mulches), and
C. LIMIT EXCESS NUTRIENTS (e.g., NMPs, MMPs)

SHOULD BE CONSIDERED GERMANE TO SOIL AND LAND STEWARDSHIP AND A SUSTAINABLE AGRICULTURAL PRODUCTION SYSTEM.

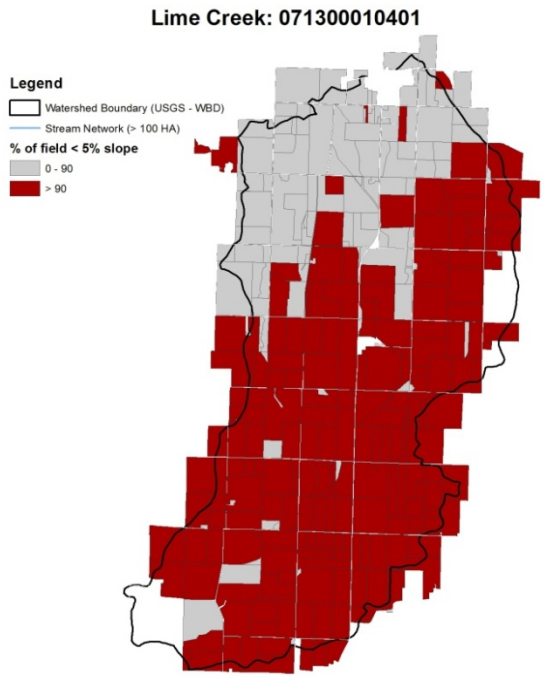
3. DISTINGUISH TILE DRAINED FIELDS

- Distinguish tile-drained from non tile-drained fields.
- If 10% or more of a field is hydric soils, or > 90% of the field is less than 5% slopes, consider it tile-drained.

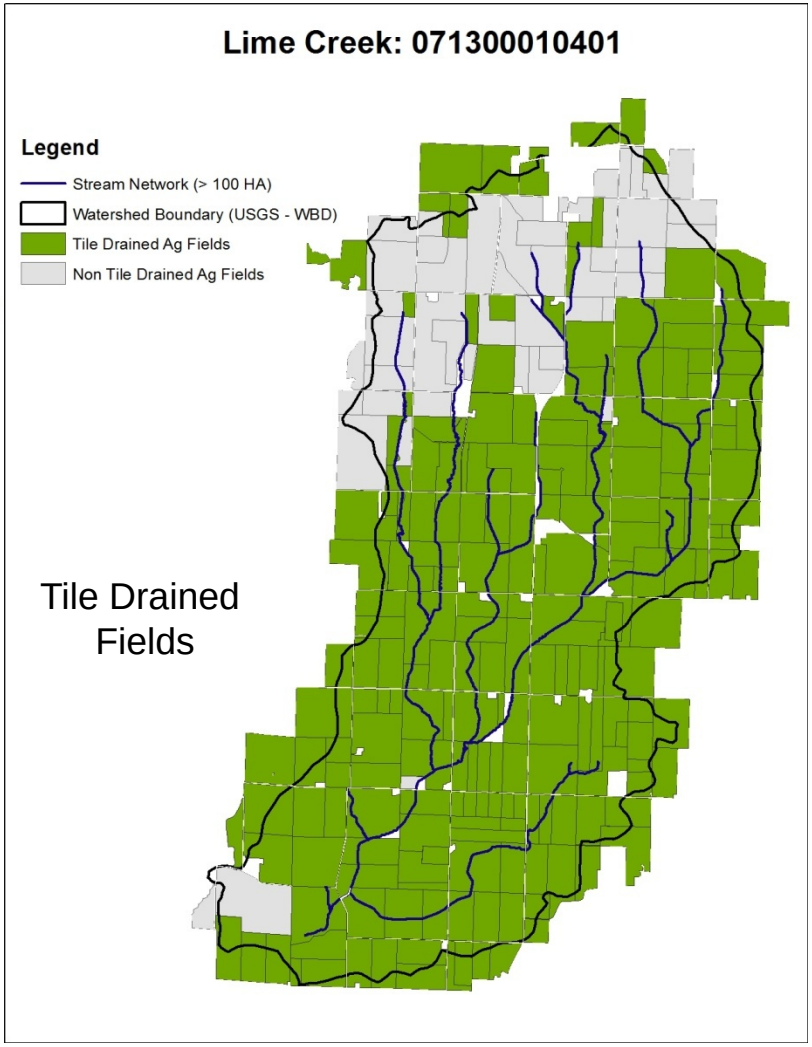


% Hydric

+



% Less than 5% slope



Tile Drained Fields

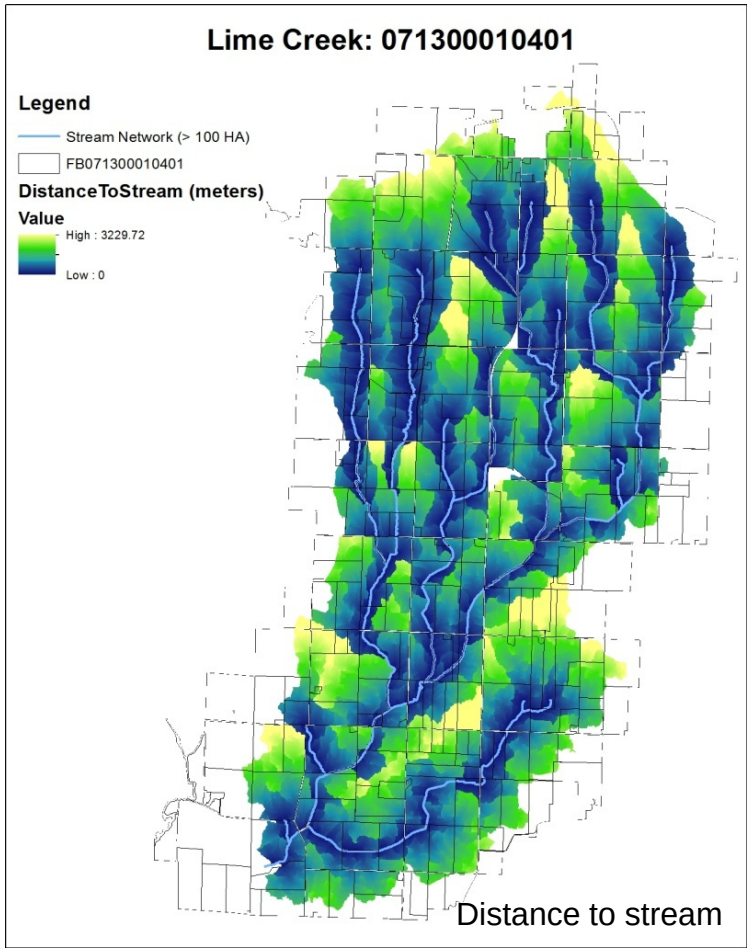
4. RUNOFF/RISK ASSESSMENT

- Analysis of field-scale data

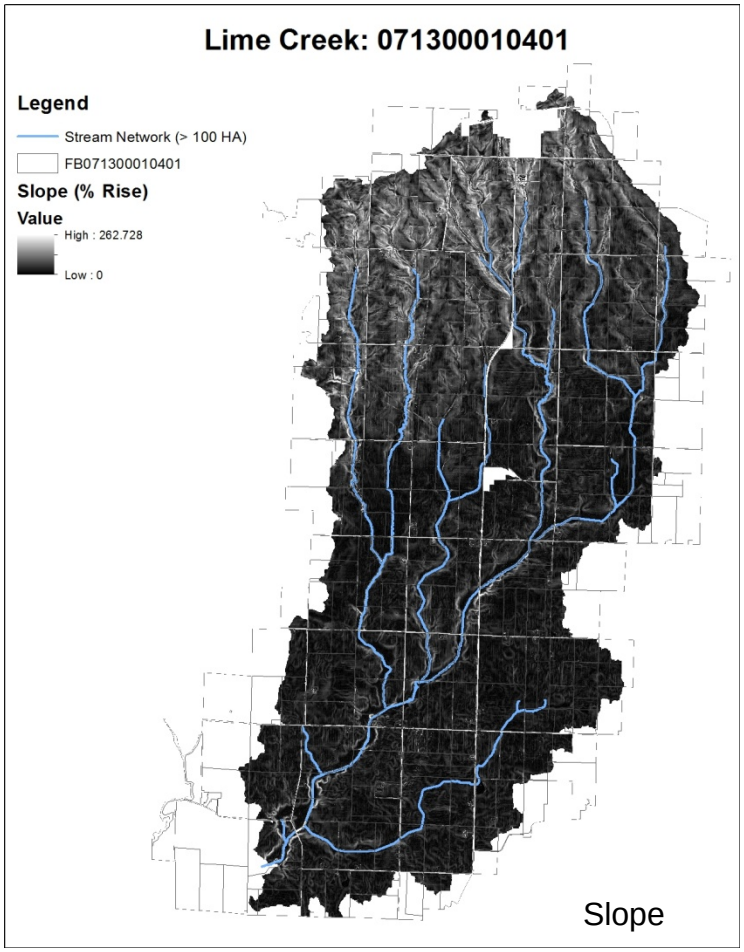
BASED ON RELATIONSHIP BETWEEN 2 FACTORS:

1. Distance to Stream (via overland flow)
2. Slope steepness

RUNOFF RISK CALCULATION		Stream Proximity		
		H (80 – 100%)	M(40 - 80%)	L(0 -40%)
Slope Steepness	H (80 – 100%)	A	B	C
	M (40 - 80%)	B	C	-
	L (0 - 40%)	C	-	-



Distance to stream



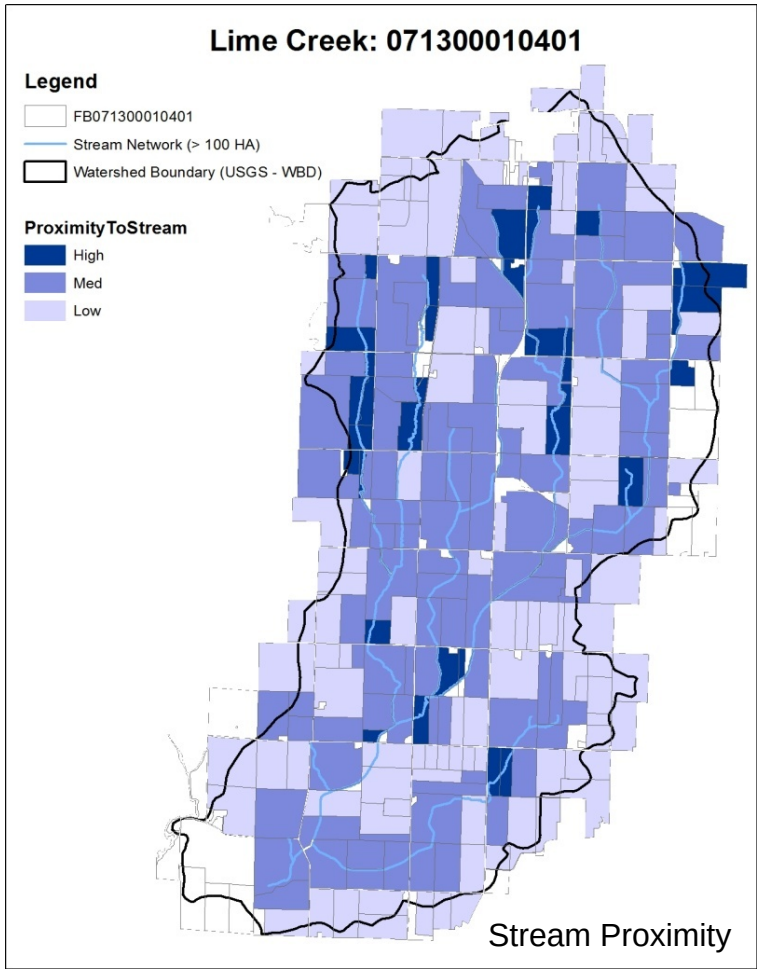
Slope

4. RUNOFF/RISK ASSESSMENT

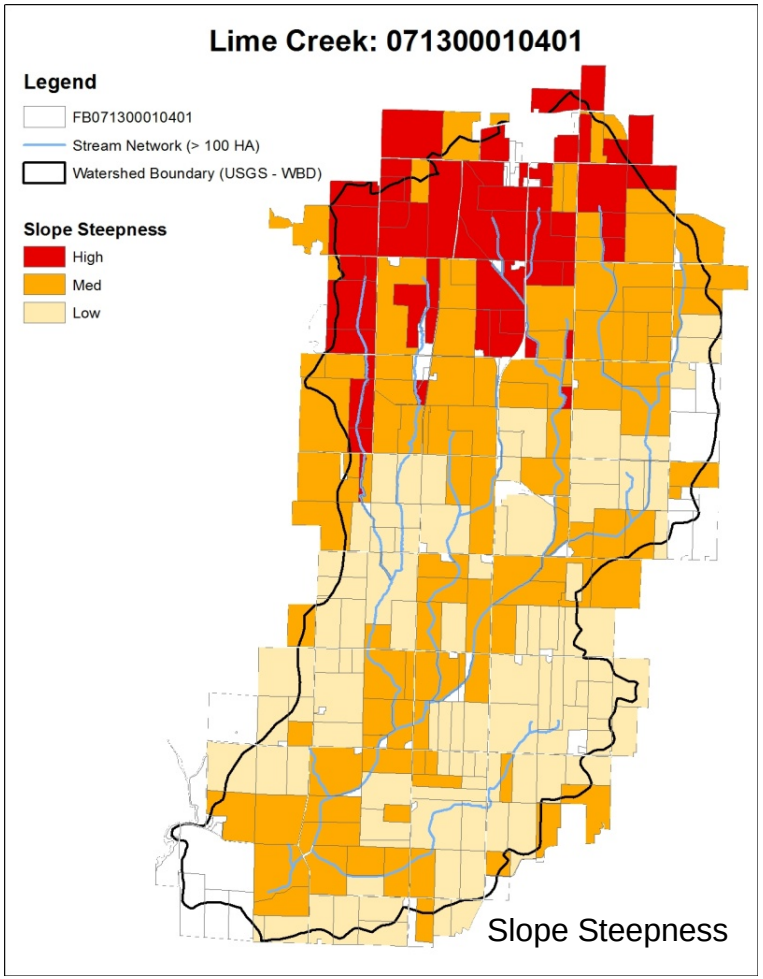
Extract information to each field

1. Distance to stream
   - Median distance to stream within each field
2. Slope steepness
   - 3rq quartile slope values within field

RUNOFF RISK ASSESSMENT		Stream Proximity		
		H (80 – 100%)	M(40 - 80%)	L(0 -40%)
Slope Steepness	H (80 – 100%)	A	B	C
	M (40 - 80%)	B	C	-
	L (0 - 40%)	C	-	-



Stream Proximity

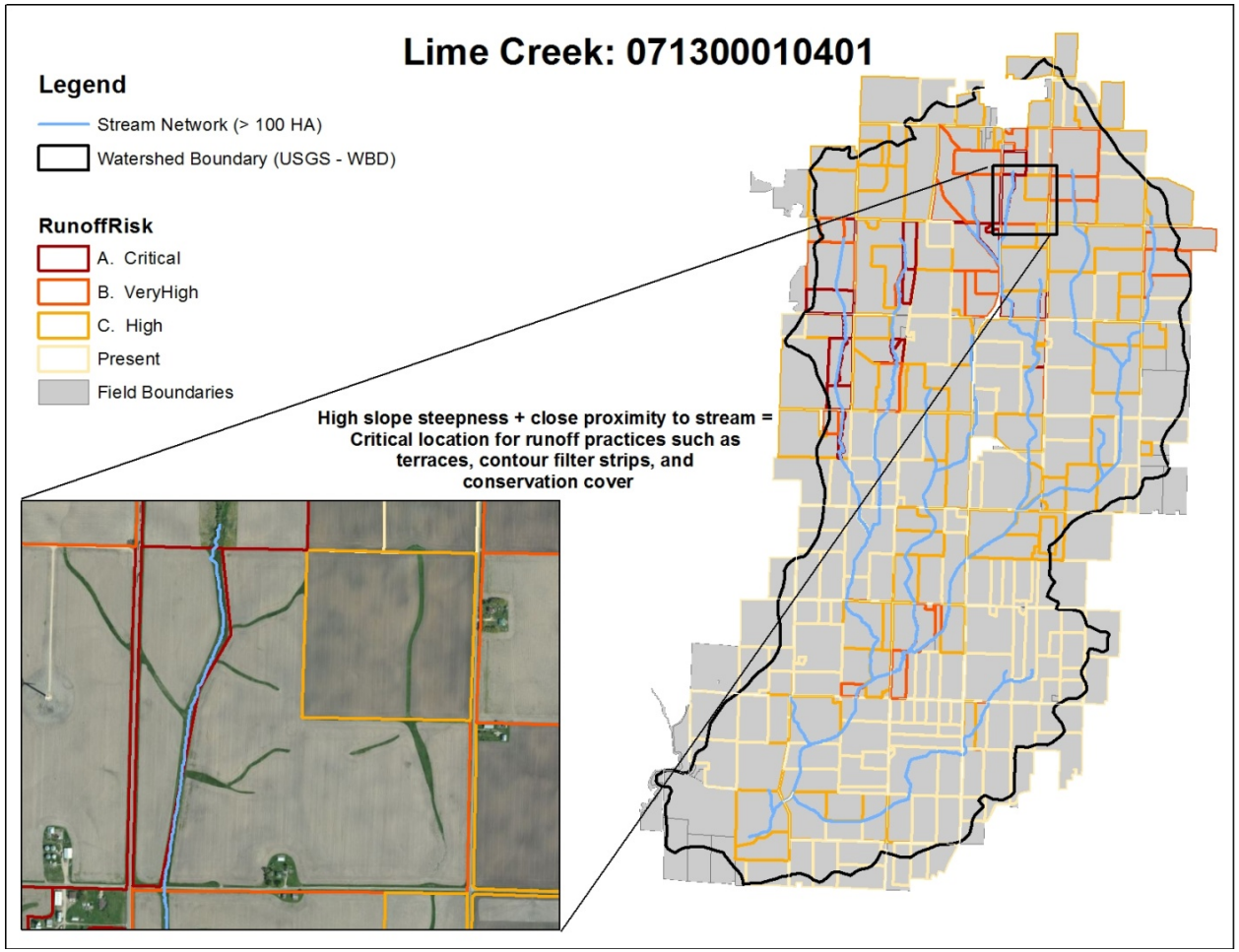


Slope Steepness

5 CONTOUR FILTER STRIPS, TERRACES, CONSERVATION COVER

- Output of runoff/risk assessment identifies the critical fields for runoff control BMP's to protect water quality.
- In these fields, filter strips, terraces, and conservation cover should be considered on steep slopes; grassed waterways where convergent runoff occurs.
- These practices may be considered wherever else they address landowner concerns for soil conservation.

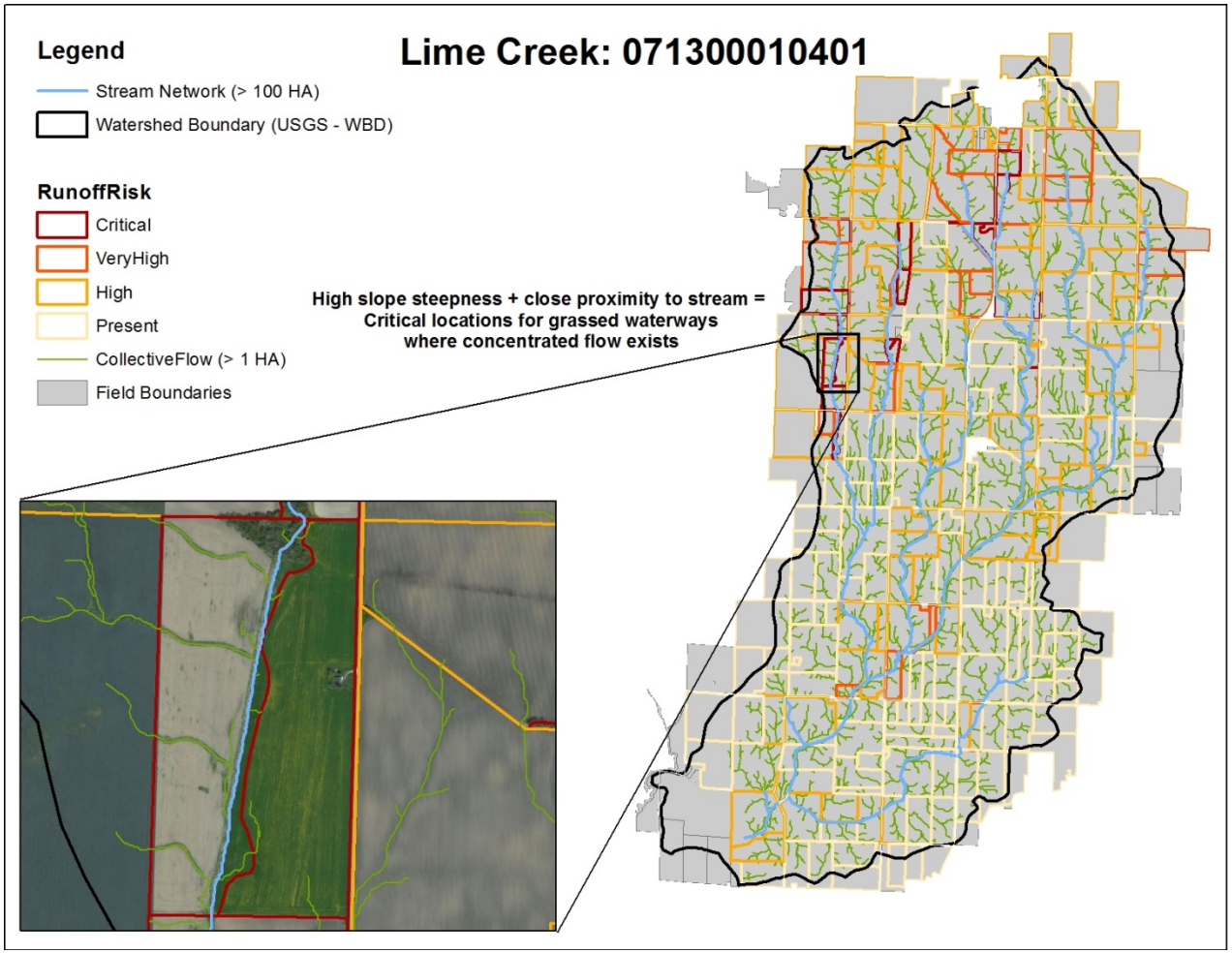
RUNOFF RISK CALCULATION		Stream Proximity		
		H (80 – 100%)	M(40 - 80%)	L(0 -40%)
Slope Steepness	H (80 – 100%)	A	B	C
	M (40 - 80%)	B	C	-
	L (0 - 40%)	C	-	-



6 GRASSED WATERWAYS WHERE GULLIES MAY FORM

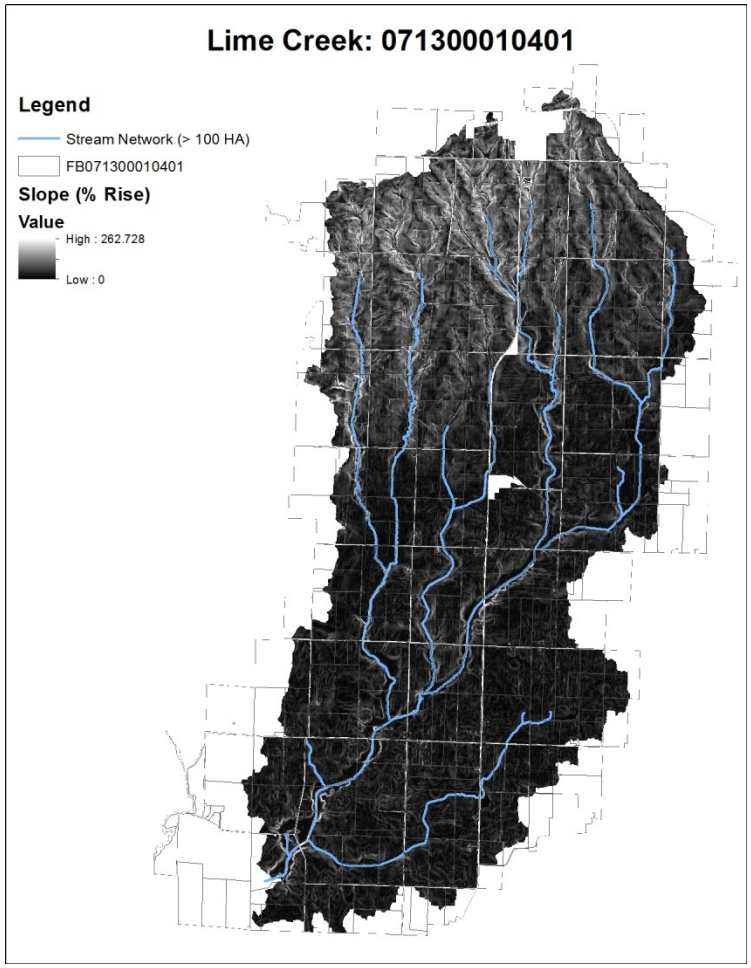
- Output of runoff/risk assessment identifies the critical fields for runoff control BMP's
- Within these fields, grassed waterways should be implemented where concentrated flow exists (shown here as > .5 HA of drainage area)

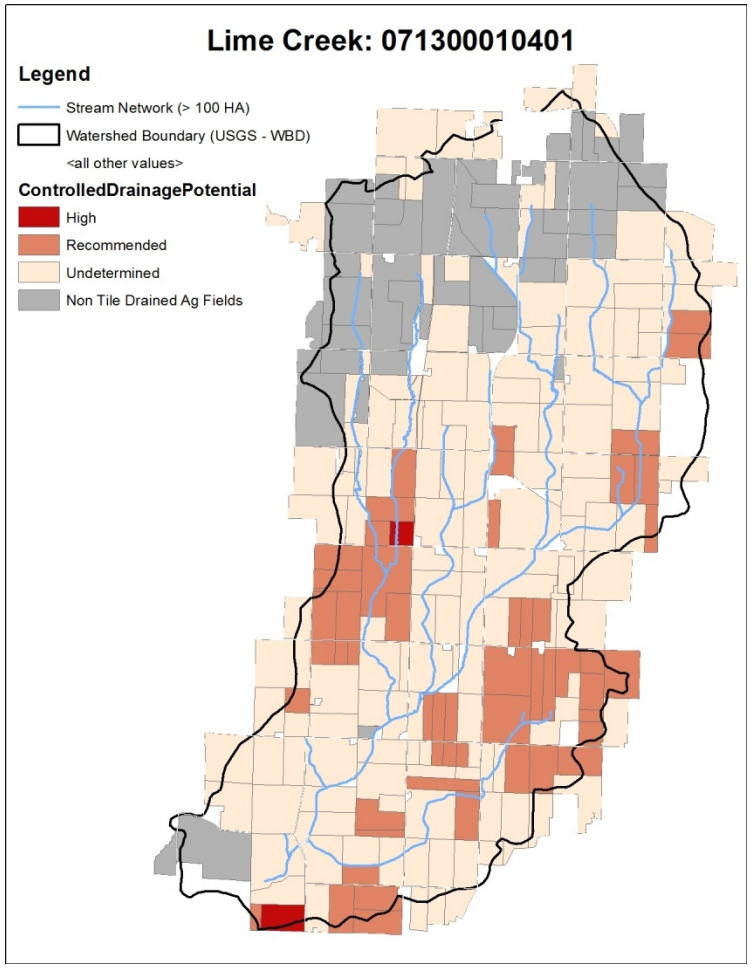
RUNOFF RISK CALCULATION		Stream Proximity		
		H (80 – 100%)	M(40 - 80%)	L(0 -40%)
Slope Steepness	H (80 – 100%)	A	B	C
	M (40 - 80%)	B	C	-
	L (0 - 40%)	C	-	-



7 CONTROLLED DRAINAGE

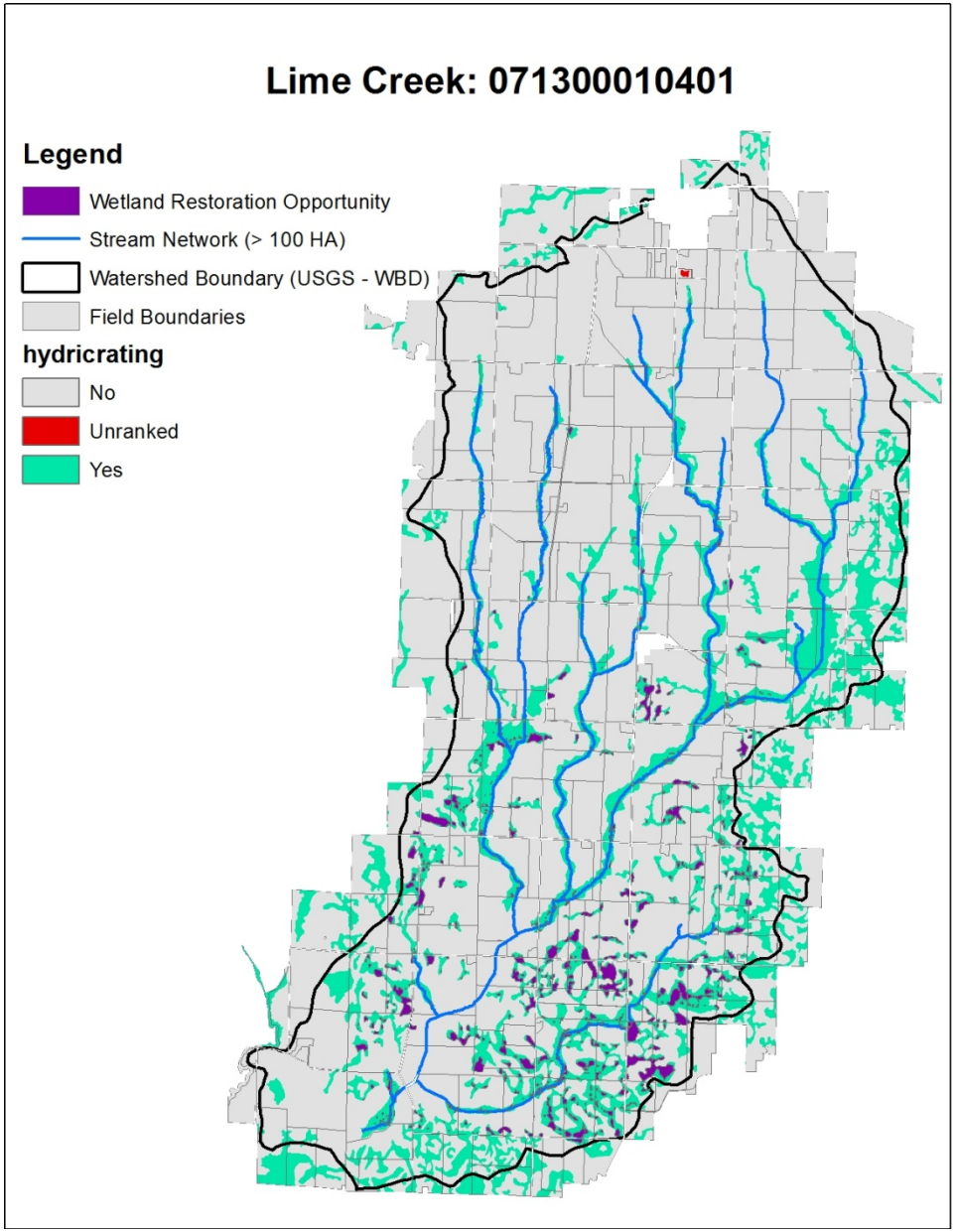
- Identify **tile-drained fields** that are suitable for controlled drainage
- Rank potential by % of field that is less than 1% slope:
  - 80 – 100% of field: High potential
  - 60 – 80% of field: Recommended
  - < 60% of field: Undetermined





8 SURFACE INTAKE FILTERS OR RESTORED WETLANDS

- Find “sinks” or depressions (common in many glacial landscapes)
- Opportunities for wetland restoration exist where depressions coincide with hydric soils and do not already exist as wetlands on the landscape.
- Eliminate regions smaller than 100 m^2



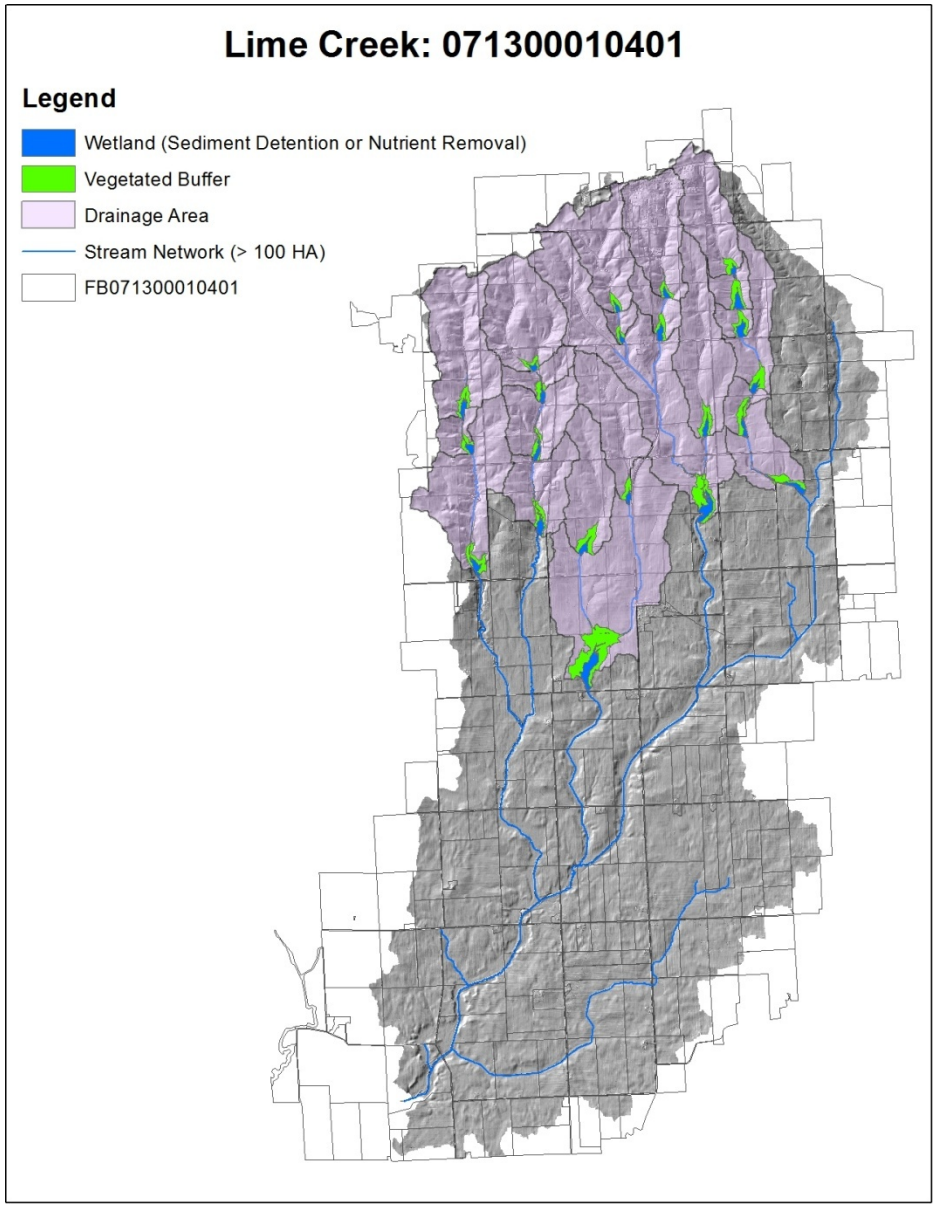
11 WATER DETENTION USING IMPOUNDMENTS OF VARYING DESIGN

Nutrient removal wetlands

- Designed to treat tile-drained water
- Important factors for wetland efficiency:
  - Timing and magnitude of nutrient and hydrologic loads
  - Extent of subsurface tile drainage

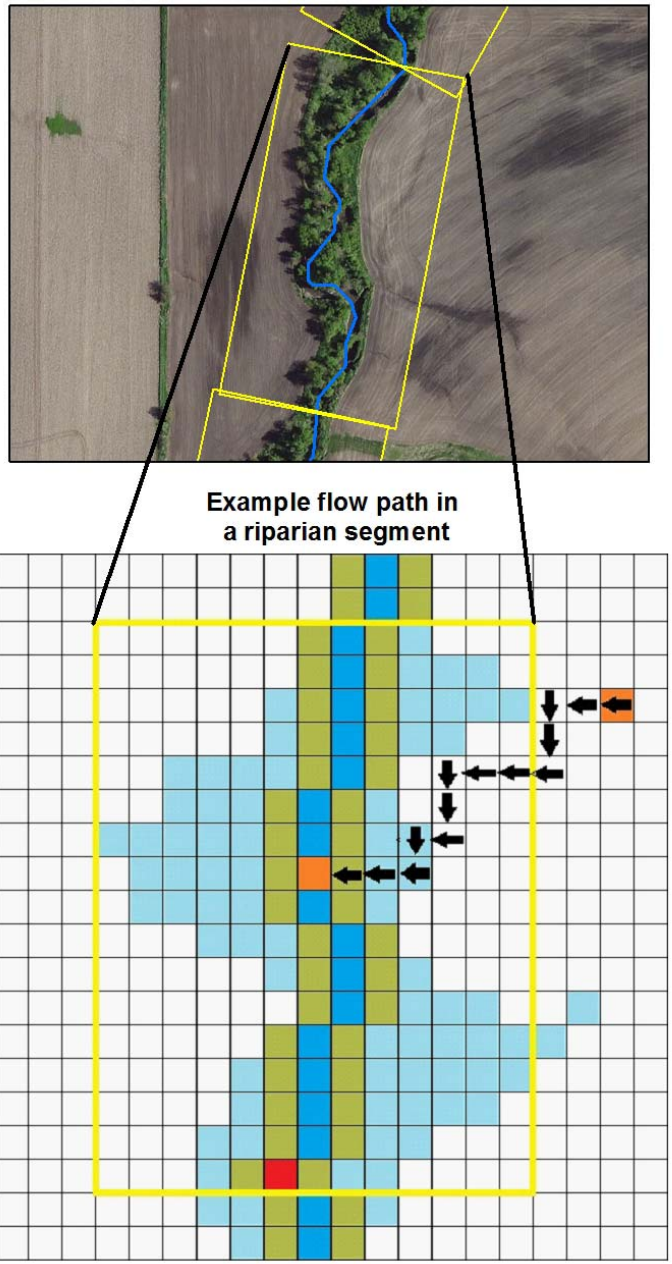
Process

- All sites along the stream network are tested where:
  - Height of drainage ditch is less than 4 meters
- Downstream sites sampled first
- Wetland/buffer constructed, then tested for suitability
- Design specifications:
  - Wetlands (ponded area) defined as .9 meter above the depth of the drainage ditch
  - Buffer (surrounding vegetation to account for impedance of tile drainage) defined as 2.4 meters above depth of the drainage ditch
- Suitable if:
  - Wetland to Drainage Area ratio is between .5 and 2%
  - Wetland or buffer does not intersect a roadway
  - Wetland to Buffer ratio is greater than 1:4
- If suitable: the next upstream site is sampled that does not fall within the just delineated wetland/buffer
- If not suitable: the next upstream site is sampled that is > 200 meters away than the just sampled site



12 RIPARIAN ASSESSMENT

This assessment of potential riparian function is conducted on each 200 m reach of stream, demarked as rectangles. Average width of shallow water table and contributing areas are tabulated.



- 3 meter grid cell
- Channel grid cell
- Bank grid cell
- Shallow water table grid cell (< 1.5 meters)
- Origin and termination grid cells of flow path
- Most downstream grid cell in riparian segment (highest accumulation)
- Riparian segment; framework for determining function

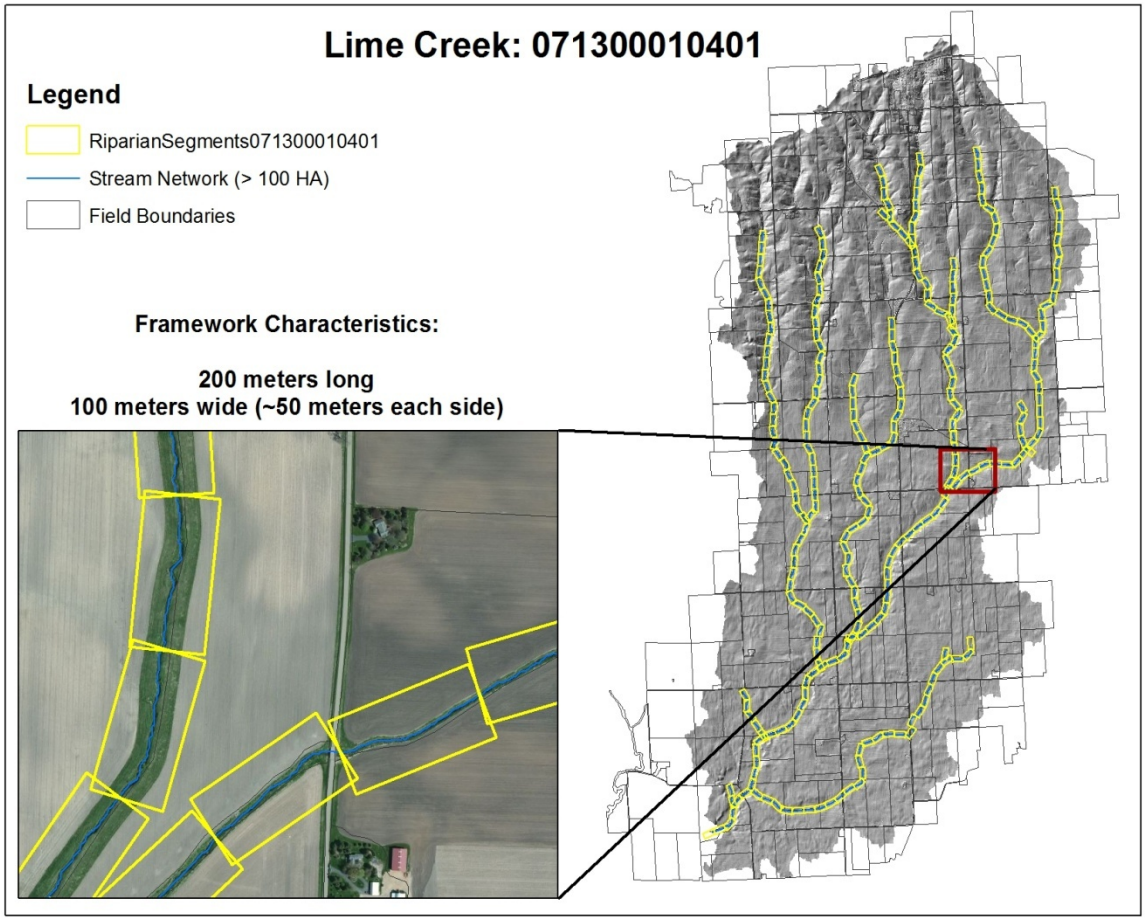
12 RIPARIAN ASSESSMENT

- Analysis applied at a scale of stream reaches ~ 200 meters wide

BASED ON RELATIONSHIP BETWEEN 2 FACTORS:

1. Water table interaction potential
   - Create depth to water table raster
   - Calculate average width of shallow water table zone (< 1.5 meters above channel) along each stream reach
2. Local Runoff delivery
   - Amount of local runoff passing through the riparian zone of each stream reach

RIPARIAN COVER FUNCTION ASSESSMENT		Water Table Interaction		
		H (80 – 100%)	M(40 - 80%)	L(0 -40%)
Runoff Delivery	H (80 – 100%)	i	ii	iii
	M (40 - 80%)	ii	ii	iii
	L (0 - 40%)	iv	iv	V



12 RIPARIAN ASSESSMENT

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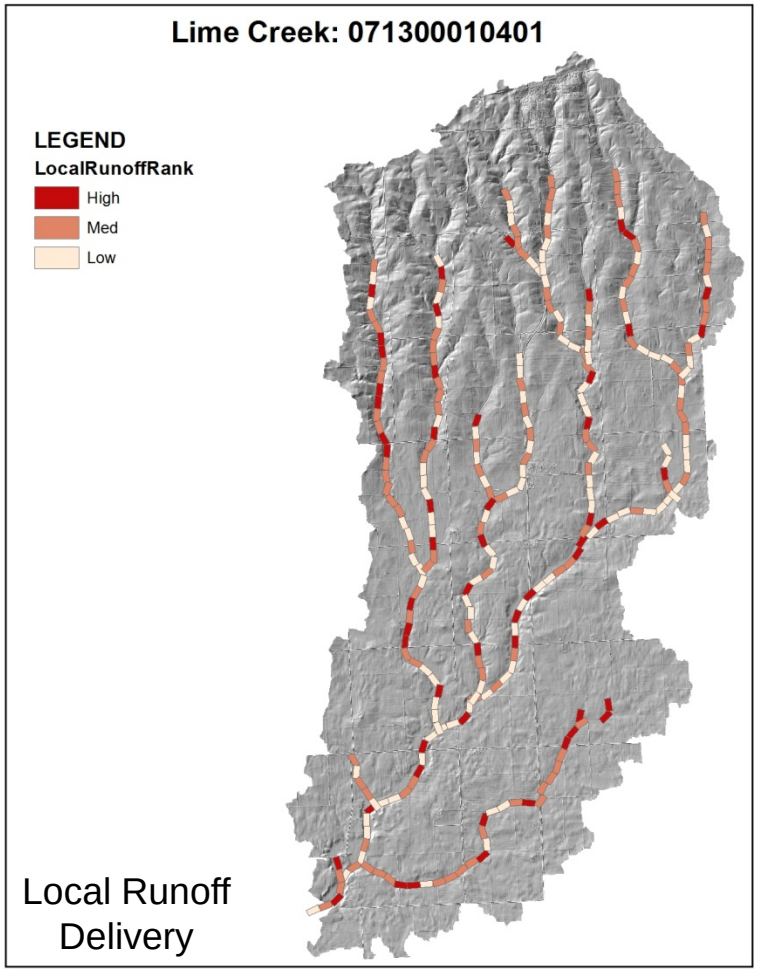
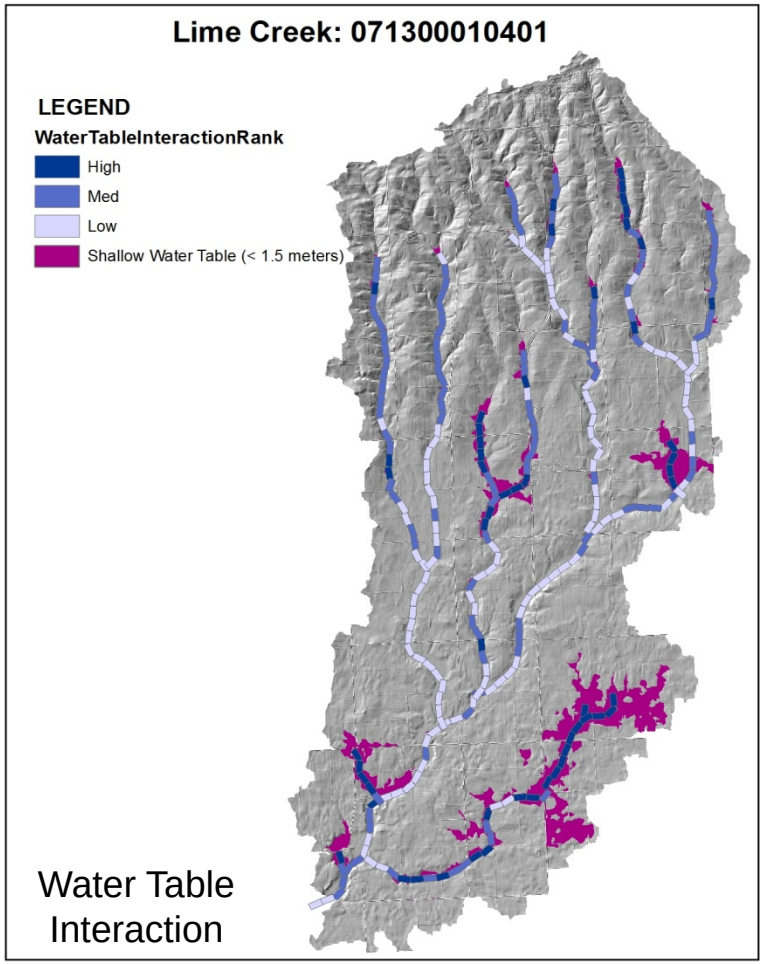
Runoff Delivery	H (80 – 100%)	i	ii	iii
	M (40 - 80%)	ii	ii	iii
	L (0 - 40%)	iv	iv	V



Local Runoff Delivery



Water Table Interaction

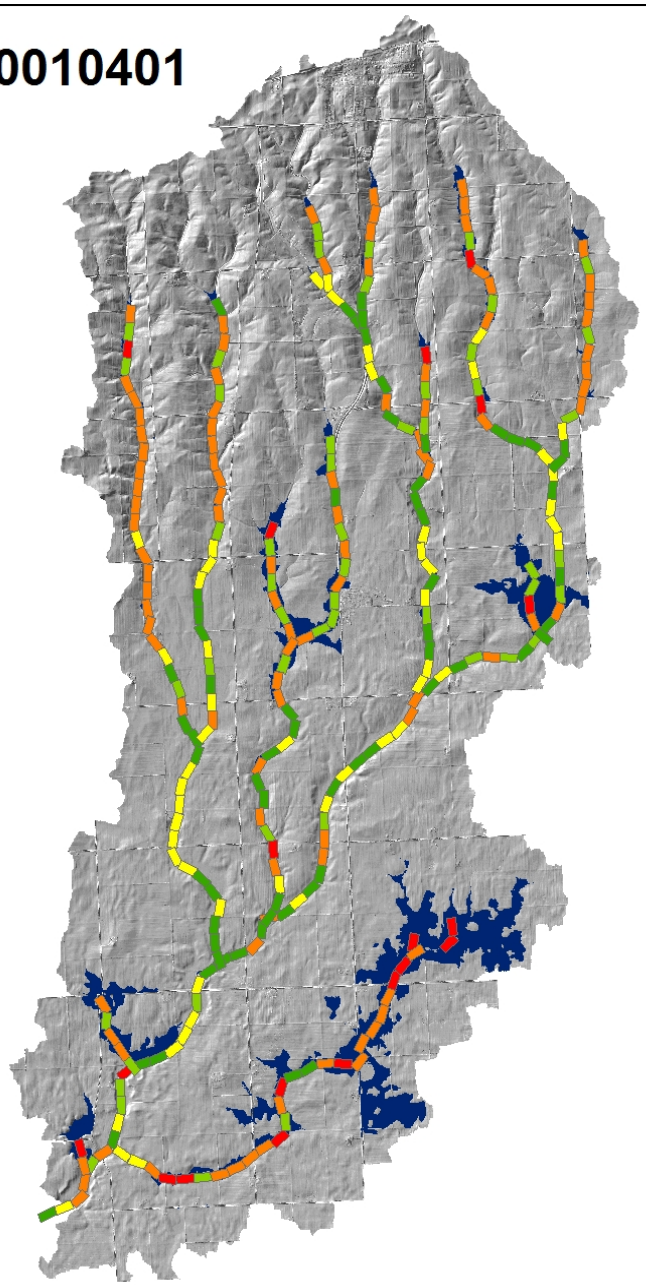
12 RIPARIAN ASSESSMENT

Lime Creek: 071300010401

LEGEND

RiparianFunction

- IntensifiedNutrientUptake (i)
- DiversifiedVegetation (ii)
- IncreasedInfiltration (iii)
- DeepRootedVegetation (iv)
- StreamShading/BankStabilization (v)
- Shallow Water Table (< 1.5 meters)



RIPARIAN COVER FUNCTION ASSESSMENT		Water Table Interaction		
		H (80 – 100%)	M(40 - 80%)	L(0 -40%)
Runoff Delivery	H (80 – 100%)	i	ii	iii
	M (40 - 80%)	ii	ii	iii
	L (0 - 40%)	iv	iv	V

A process for conservation planning in agricultural watersheds using precision technologies

1 Input: Field boundary data
Soils, Land use, LiDAR-based DEM

2 **All fields:**
Encourage practices that:
a) Protect soil (e.g., no tillage);
b) Limit excess nutrients (e.g., NMPs);
c) Build soil (e.g., cover crops)

Fields that are tile drained

3

Fields that are not tile drained

All fields

4

Runoff/Risk Assessment:
Prioritize fields where multiple erosion control practices are most needed

Close to stream?

Slope steepness	Yes		No
H	A	B	C
M	B	C	
L	C		

Practices implemented in fields

7 Controlled drainage where flat

8 Surface intake filters or Restored wetlands where depressions occur

5 Contour filter strips, Terraces, Conservation cover where slopes are steep

6 Grassed waterways where gullies may form

Practices implemented at field edges

9 Bioreactors

10 Perennial crops, & novel practices to intercept flows where soils stay wet

11 Water detention using impoundments of varying designs

Nutrient removal wetlands

Sediment detention basins
Farm ponds

Practices implemented in riparian zones

14 Re-saturated buffers

15 Ditch design: Two-stage ditches; novel practices for detention / diversion of tile drainage

13 Emphasis for Buffer Design:

i. High water & nutrient uptake
ii. Diversified vegetation
iii. Increased infiltration (stiff-stemmed grasses)
iv. Deep rooted vegetation
v. Shade stream, stabilize banks

12

Riparian Assessment:
Identify riparian function by stream reach

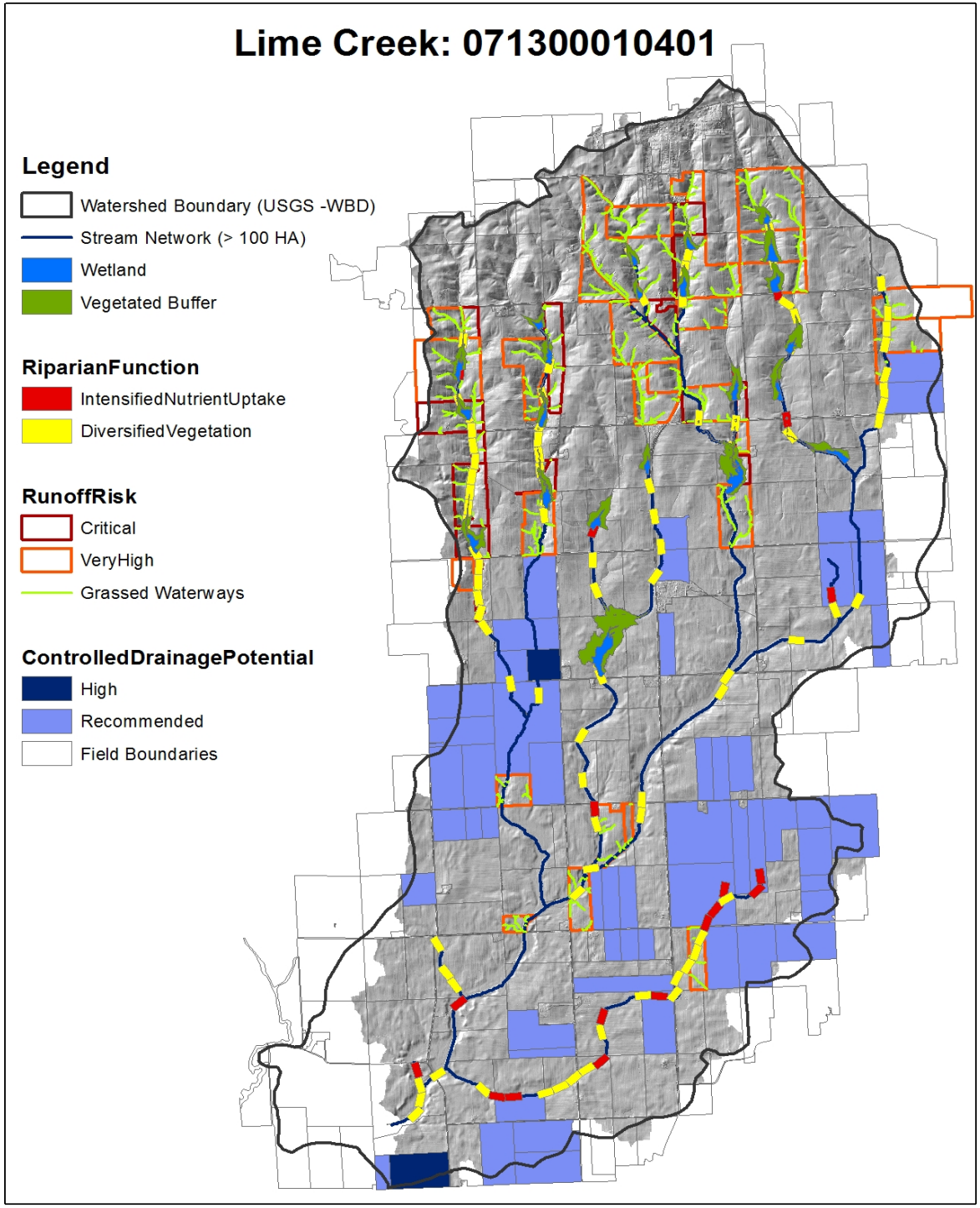
Shallow water table?

Runoff delivery	Yes		No
H	i	ii	iii
M	ii	ii	iii
L	iv	iv	v

16 Downstream :
river restoration (re-meandering, oxbow rehabilitation)

17 Scenario Development/ stakeholder feedback/ implement/ monitor/ adapt

17 CONSERVATION SCENARIO DEVELOPMENT



A process for conservation planning in agricultural watersheds using precision technologies

1 Input: Field boundary data
Soils, Land use, LiDAR-based DEM

2 **All fields:**
Encourage practices that:
a) Protect soil (e.g., no tillage); RP
b) Limit excess nutrients (e.g., NMPs); PN
c) Build soil (e.g., cover crops) RPN

Practices that attenuate:
R - Runoff
P - Phosphorus, sediment
N - Nitrate-N

Fields that are tile drained → **3** → Fields that are not tile drained → All fields

Practices implemented in fields

- **7** Controlled drainage where flat N
- **8** Surface intake filters or Restored wetlands where depressions occur RP
- **5** Contour filter strips, Terraces, Conservation cover where slopes are steep RP
- **6** Grassed waterways where gullies may form RP

4

Runoff/Risk Assessment: Prioritize fields where multiple erosion control practices are most needed

Slope steepness	Close to stream? Yes		No
H	A	B	C
M	B	C	
L	C		

Practices implemented at field edges

- **9** Bioreactors N
- **10** Perennial crops, & novel practices to intercept flows where soils stay wet RPN
- **11** Water detention using impoundments of varying designs
  - Nutrient removal wetlands RN
  - Sediment detention basins Farm ponds RP

Practices implemented in riparian zones

- **14** Re-saturated buffers N
- **15** Ditch design: Two-stage ditches; novel practices for detention / diversion of tile drainage N
- **13** Emphasis for Buffer Design:
  - i. High water & nutrient uptake RPN
  - ii. Diversified vegetation
  - iii. Increased infiltration (stiff-stemmed grasses) RP
  - iv. Deep rooted vegetation N
  - v. Shade stream, stabilize banks P

12

Riparian Assessment: Identify riparian function by stream reach

Runoff delivery	Shallow water table? Yes		No
H	i	ii	iii
M	ii	ii	iii
L	iv	iv	v

16 Downstream : river restoration (re-meandering, oxbow rehabilitation) RPN

17 Scenario Development/ stakeholder feedback/ implement/ monitor/ adapt

Conclusions

- Complexity of water quality management challenges requires new technologies in order to be addressed effectively. A small watershed planning framework allows issues of water quality management to become tractable at the local level.
- We developed a framework using a broad set of precision conservation tools, based on practices that have been shown effective in improving water quality by research and that provides flexibility to trial new and innovative practices. Input data are available across broad areas, but not yet everywhere.
- The output, demonstrated on a small Illinois watershed with both tile drained and sloping fields, provides an array of alternatives from which watershed-scale conservation plans can be developed.
- We recommend trial and refinement of this framework in a local conservation planning context with involvement of local planners, landowners, and other stakeholders.
- Development of modeling capability to be able to rank the suitability of conservation planning scenarios is an important next step.

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