Watershed Health to In-Field and Edge-of-Field Water Management

Convening Event
January 23 – January 24, 2020 | Morgantown, WV
Erickson Alumni Center, West Virginia University

Chesapeake Bay Program
Science. Restoration. Partnership.

Current Research Challenges in Drainage Management

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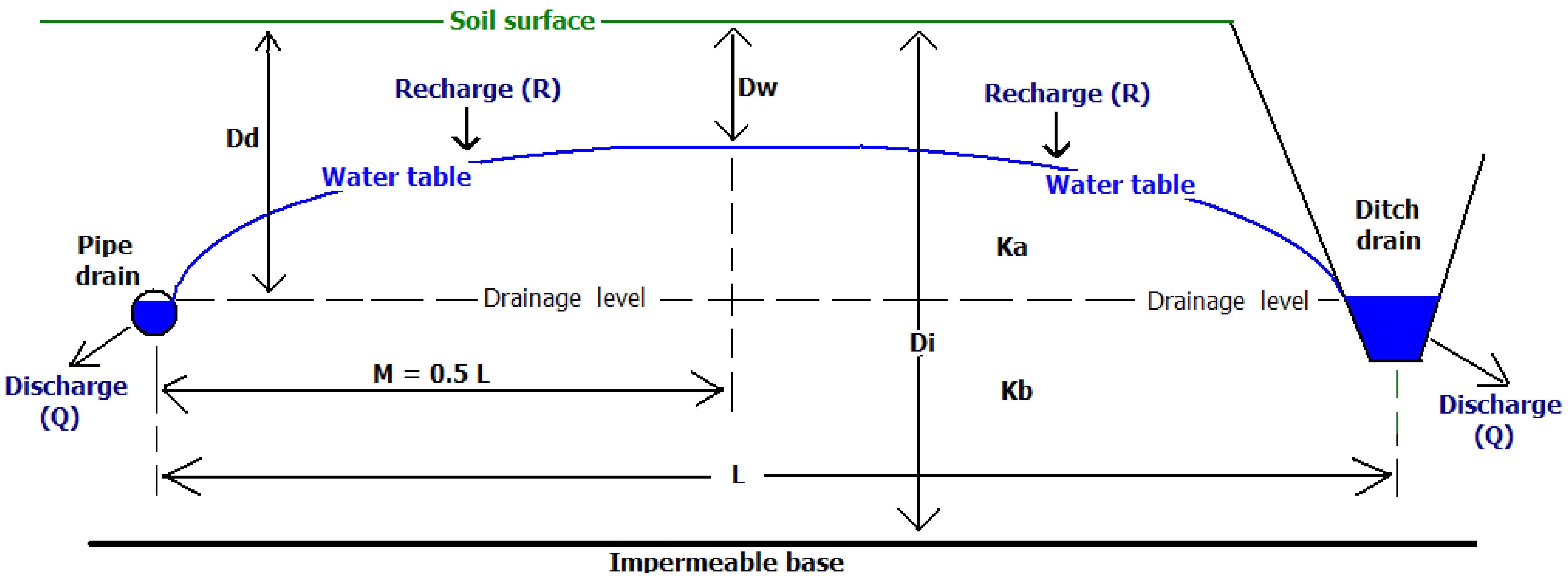
Focus has historically been on drainage improvements for:

1. Removal of excess soil water in the spring
2. Planting earlier to take advantage of the shorter growing season
3. Improved field machine trafficability during the growing season
4. Improved soil aeration
5. Higher crop yields

High precipitation in the summer growing season

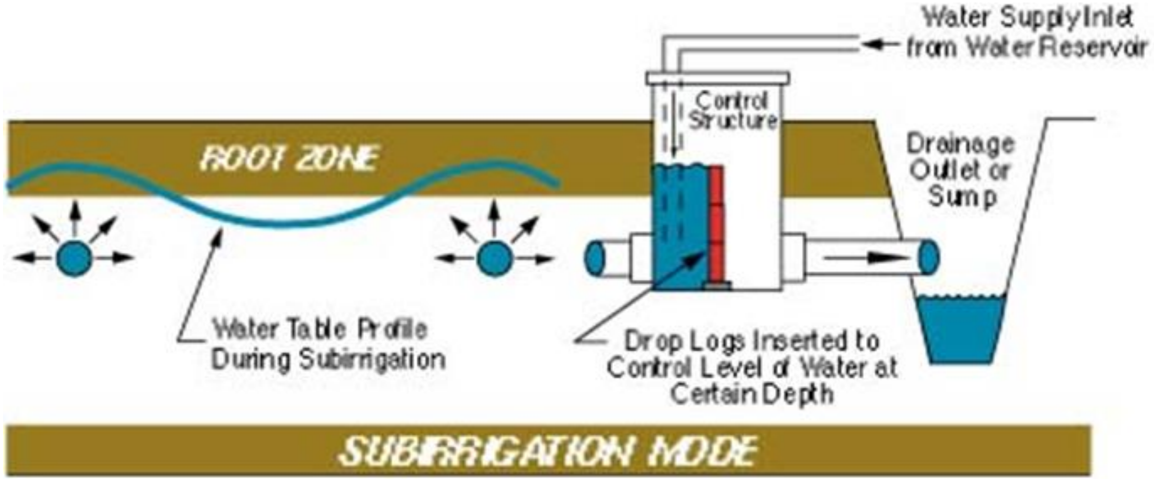


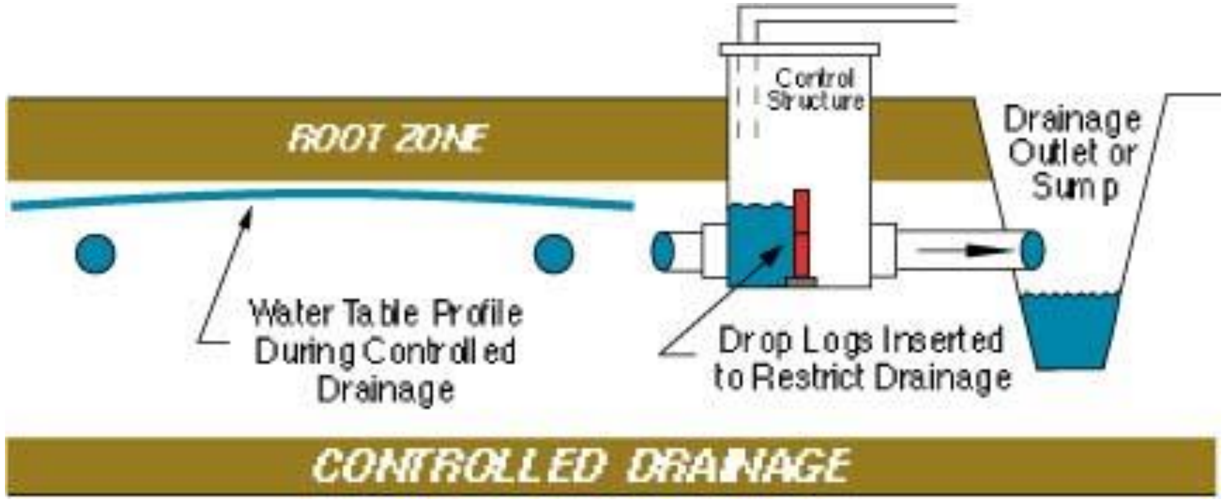
Geometry subsurface drainage system by pipes or ditches

D = depth K = hydraulic conductivity L = Drain spacing

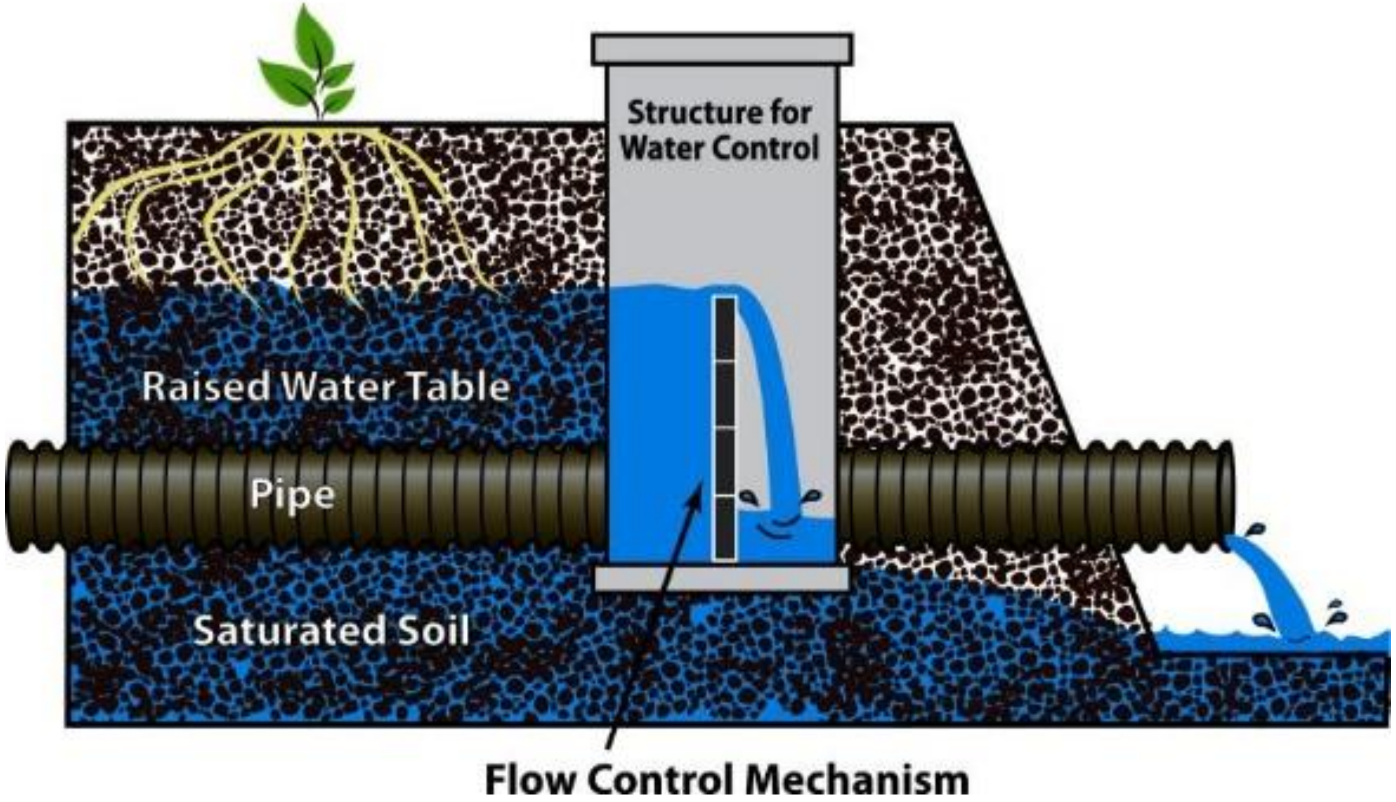
Drainage water quantity and water quality

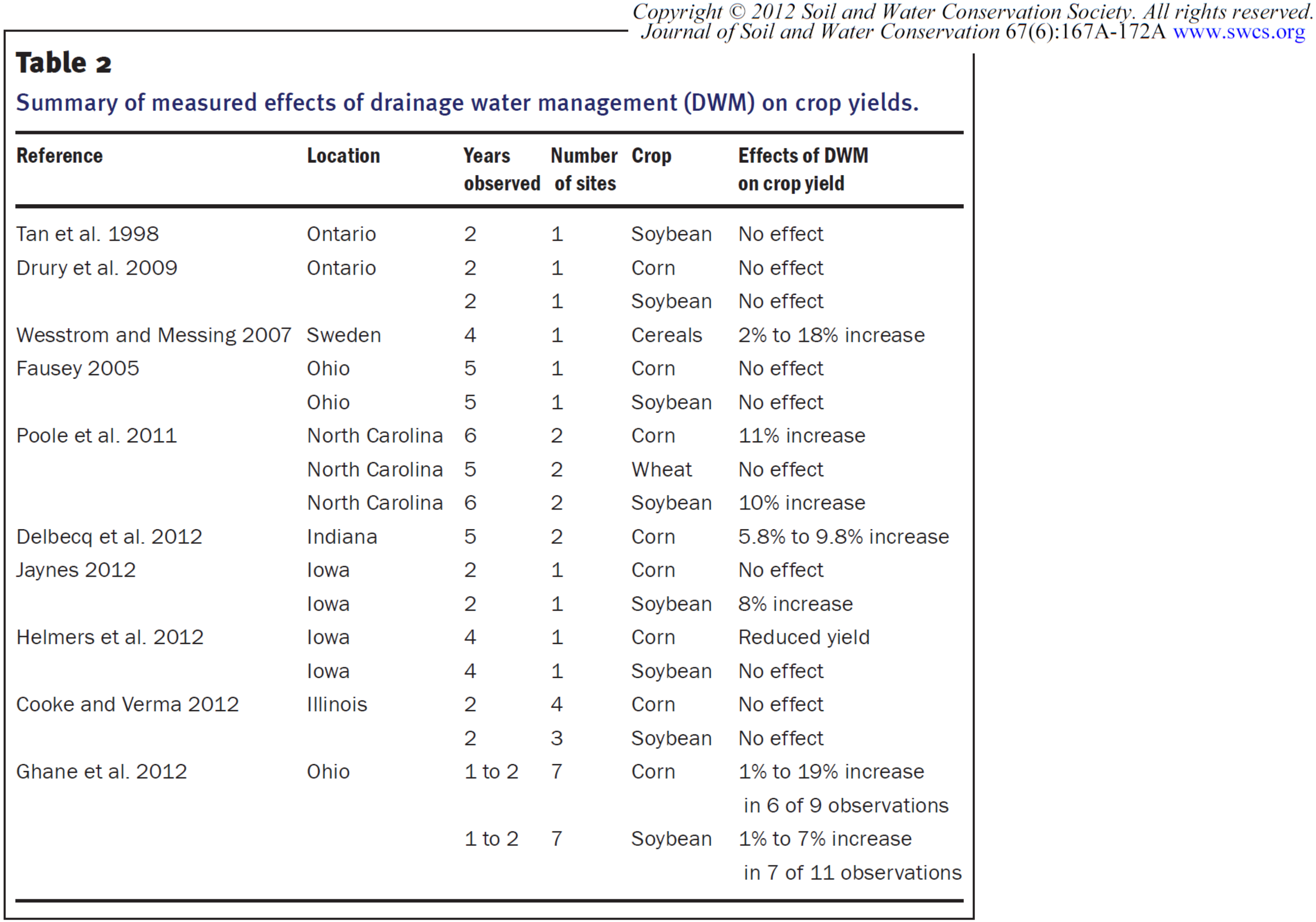
Water Table Control





- **Reduce water inputs for irrigation and therefore conserve water usage**
- **Reduce drainage outflows**
- **Lower amounts of N and P in the drainage water**
- **Increased crop yield**


Structure for Water Control
Raised Water Table
Pipe
Saturated Soil
Flow Control Mechanism



Journal of Soil and Water Conservation 67(6):167A-172A www.swcs.org

Table 2

Summary of measured effects of drainage water management (DWM) on crop yields.

Reference	Location	Years observed	Number of sites	Crop	Effects of DWM on crop yield
Tan et al. 1998	Ontario	2	1	Soybean	No effect
Drury et al. 2009	Ontario	2	1	Corn	No effect
		2	1	Soybean	No effect
Wesstrom and Messing 2007	Sweden	4	1	Cereals	2% to 18% increase
Fausey 2005	Ohio	5	1	Corn	No effect
	Ohio	5	1	Soybean	No effect
Poole et al. 2011	North Carolina	6	2	Corn	11% increase
	North Carolina	5	2	Wheat	No effect
	North Carolina	6	2	Soybean	10% increase
Delbecq et al. 2012	Indiana	5	2	Corn	5.8% to 9.8% increase
Jaynes 2012	Iowa	2	1	Corn	No effect
	Iowa	2	1	Soybean	8% increase
Helmers et al. 2012	Iowa	4	1	Corn	Reduced yield
	Iowa	4	1	Soybean	No effect
Cooke and Verma 2012	Illinois	2	4	Corn	No effect
		2	3	Soybean	No effect
Ghane et al. 2012	Ohio	1 to 2	7	Corn	1% to 19% increase in 6 of 9 observations
		1 to 2	7	Soybean	1% to 7% increase in 7 of 11 observations

Table 7. Comparisons of grain corn yields in FD and CD-SI scenarios.

Year	Precipitation[a] (mm)	Yield (Mg ha^{-1})[b] FD	Yield (Mg ha^{-1})[b] CD-SI	Higher Yield	Difference in Yields (%)	References
1993	482.4	8.0	8.2	CD-SI	2.5	Zhou et al. (2000)
1994	443.9	8.9	9.4	CD-SI	5.6	
1995	479.3	11.1	11.4	CD-SI	2.8	Mejia et al. (2000)
1996	500.9	6.8	7.3	CD-SI	6.9	
1998	618.2	8.8	6.6	FD	25.0	Madramootoo et al. (2001
1999	482.0	9.7	9.5	FD	1.7	
2001	365.4	6.9	9.4	CD-SI	36.2	Stampfli and Madramooto (2006)
2002	476.2	7.6	10.1	CD-SI	32.9	
2008	431.9	12.5	12.3	FD	2.2	This study
2009	461.7	11.3	10.4	FD	8.0	

[a] Precipitation from May to September; 30-year average precipitation of the growing season at the site was 474.4 mm.

[b] FD = free or conventional drainage plots; CD-SI = controlled drainage plots with subirrigation.

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Table 1

Summary of results of field studies of effectiveness of drainage water management in reducing drainage volumes and nitrogen loads (modified from Skaggs et al. 2010).

Reference	Location	Soil	Years observed	Area (ha)	Drain spacing (m)	Drain depth (m)	Control depth* (m)	Percent drainage	Reduction nitrogen loss
Gilliam et al. 1979	North Carolina	Portsmouth sandy loam	3	5 to 16	30 and 80	1.2	0.3 to 0.5	50	50
	North Carolina	Goldsboro sandy loam	3	3	30	1	0.3	85	85
Evans et al. 1989	North Carolina	Ballanhack sandy loam	2	4	18	1	0.6	56	56
	North Carolina	Wasda muck	2	4	100	1.2	0.6	51	56
	North Carolina	Wasda muck	2	4	18	1	0.6	17	18
Lalonde et al. 1996	Ontario	Bainesville silty loam	2	0.63	18.3	1	0.75	49	69
							0.5	80	82
Breve et al. 1997†	North Carolina	Portsmouth	1.2	1.8	22	1.2	0.4 to 0.5	16	20
Tan et al. 1998	Ontario	Brookston clay loam	2	2.2	9.3	0.65	0.3	20	19
Gaynor et al. 2002‡	Ontario	Brookston clay loam	2	0.1	7.5	0.6	0.3	16	
Drury et al. 2009§	Ontario	Brookston clay loam	4	0.1	7.5	0.6	0.3	29	31 to 44||
Wesstrom and Messing 2007	Sweden	Loamy sand	4	0.2	10	1	0.2 to 0.4	80	80
Fausey 2005	Ohio	Hoytville silty clay	5	0.07	6	0.8	0.3	41	46
Jaynes 2012	Iowa	Kossuth/Ottosen	4	0.46	36	1.2	0.6	18	21
Helmers et al. 2012	Iowa	Taintor/Kalona	4	1.2 to 2.4	18	1.2	0.3	37	36
Adeuya et al. 2012	Indiana	Rensselaer	2	3	21	1	0.15 to 0.6	19	23
	Indiana	Rensselaer	2	6 to 9	43				18
Cooke and Verma 2012	Illinois	Drummer	2	15	30	1.15	0.15	44	51
		Drummer/Dana	1 to 2#	8.1	15	1.15	0.15	44	52
		Orion Haymond	1 to 2#	5.7	18 to 21	1.15	0.15	89	79
		Patton/Montgomery	1 to 2#	16.2	12	0.85	0.15	38	73

* Control typically removed during seedbed preparation, planting, and harvesting periods.

† Controlled drainage (CD) during the growing season only. CD reduced subsurface drainage volume by 16%; Nitrogen loss from subsurface drain + runoff by 20%.

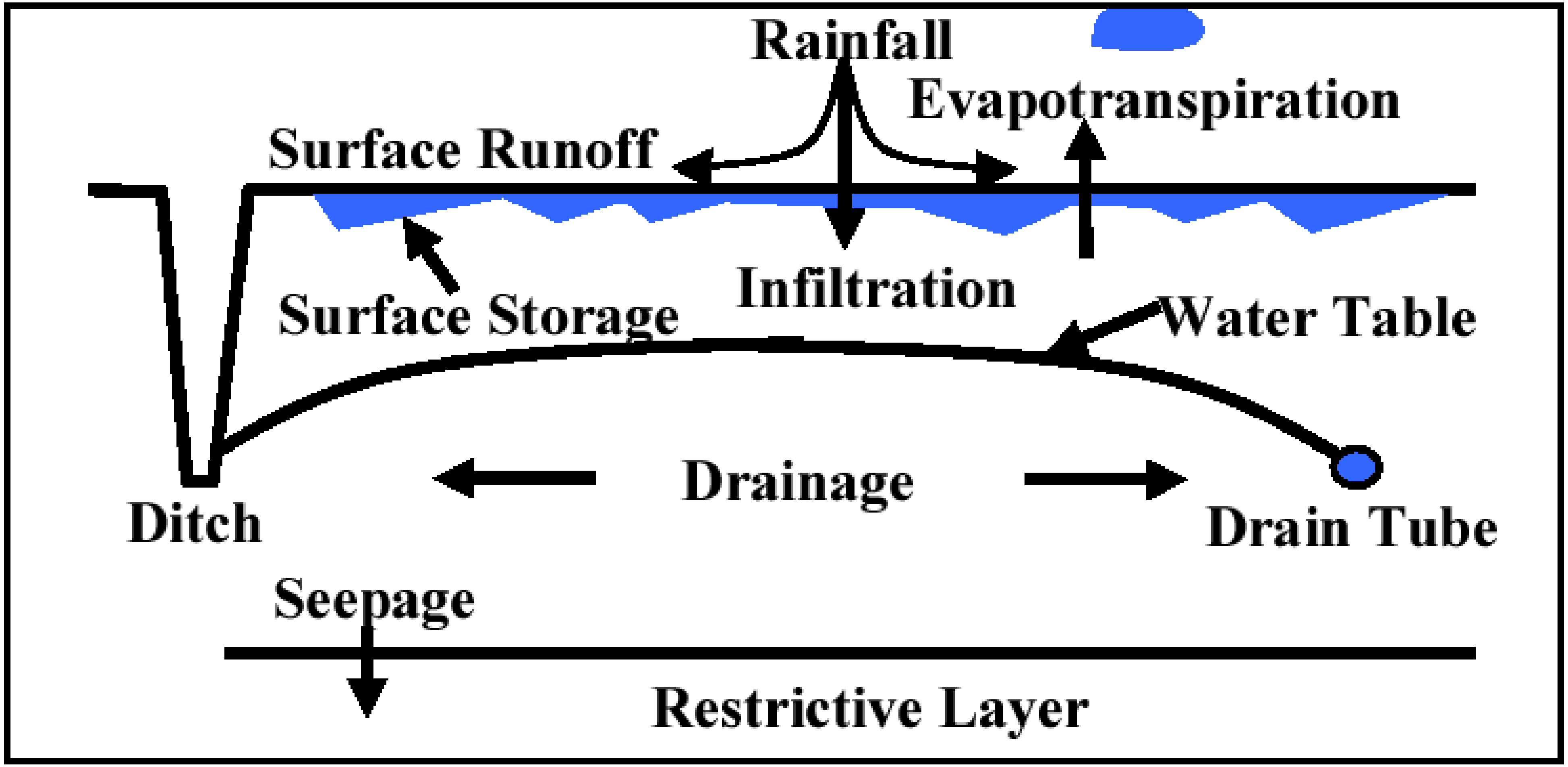
‡ CD reduced subsurface drainage by 35%, increased surface runoff by 28%, and reduced total outflow by 16%. Nitrogen results were not reported and effects on pesticide loss were reported.

§ CD reduced subsurface drainage by 29%, increased surface runoff by 38%, and reduced total outflow by 11%.

||CD reduced nitrogen loss by 44% for recommended nitrogen application rates and by 31% for elevated nitrogen rates.

Drainage volume measured for two years and nitrogen losses measured for one year for these locations.

- Where does the N go?
- What happens with the retained water?



Nitrogen Cycle

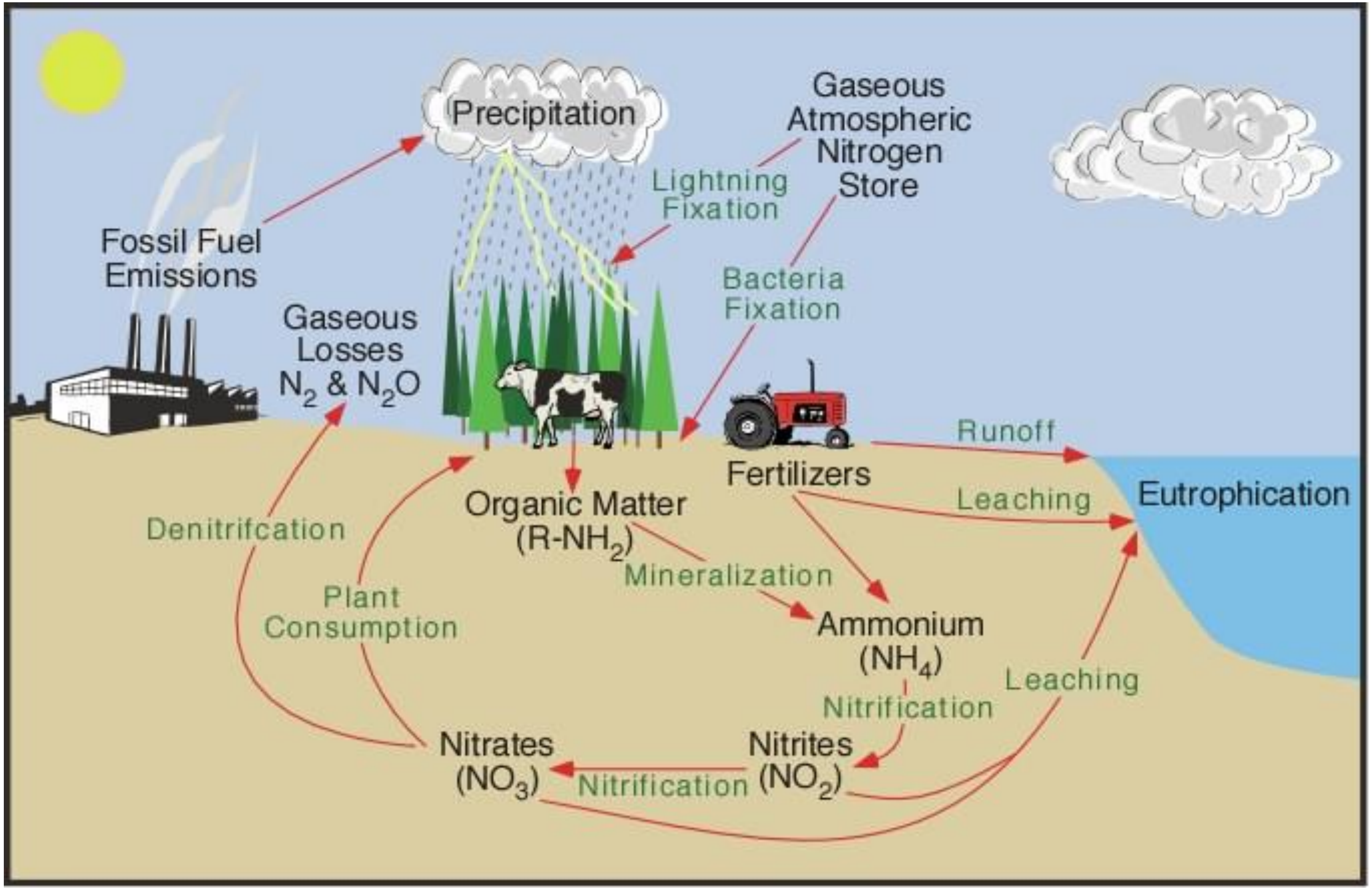


Table 3. Soil inorganic N contents in the 0- to 50-cm depths at harvest with cover crop and water-table management treatments.

Cover crop†	Water-table management‡	2000	2001	2003	2004	2005	5-yr§ avg.
		Soil inorganic N					
		kg N ha^{-1}					
NCC	UTD	41.6 (4.1)¶	25.8 (1.7)	33.2 (2.7)	43.7 (5.3)	64.5 (6.6)	41.8 (2.0)
	CDS	42.4 (2.7)	28.2 (1.6)	35.8 (2.3)	41.7 (4.0)	47.4 (6.3)	38.8 (3.7)
CC	UTD	47.2 (3.6)	29.8 (1.1)	39.0 (1.0)	48.8 (6.3)	63.0 (2.9)	45.6 (0.7)
	CDS	43.3 (5.3)	26.8 (0.1)	37.3 (2.0)	42.1 (1.0)	66.9 (13.4)	43.3 (1.5)
		Soil inorganic N ($P > F$)					
CC		ns#	ns	ns	ns	ns	ns
WTM		ns	ns	ns	ns	ns	ns
CC × WTM		ns	*	ns	ns	ns	ns

* Significant at the 0.05 probability level.

† CC, cover crop; NCC, no cover crop; WTM, water-table management.

‡ CDS, controlled drainage–subirrigation; UTD, unrestricted tile drainage.

§ Data not available for 2002.

¶ Numbers in parentheses are SE.

Not significant at the $p = 0.05$ probability level.

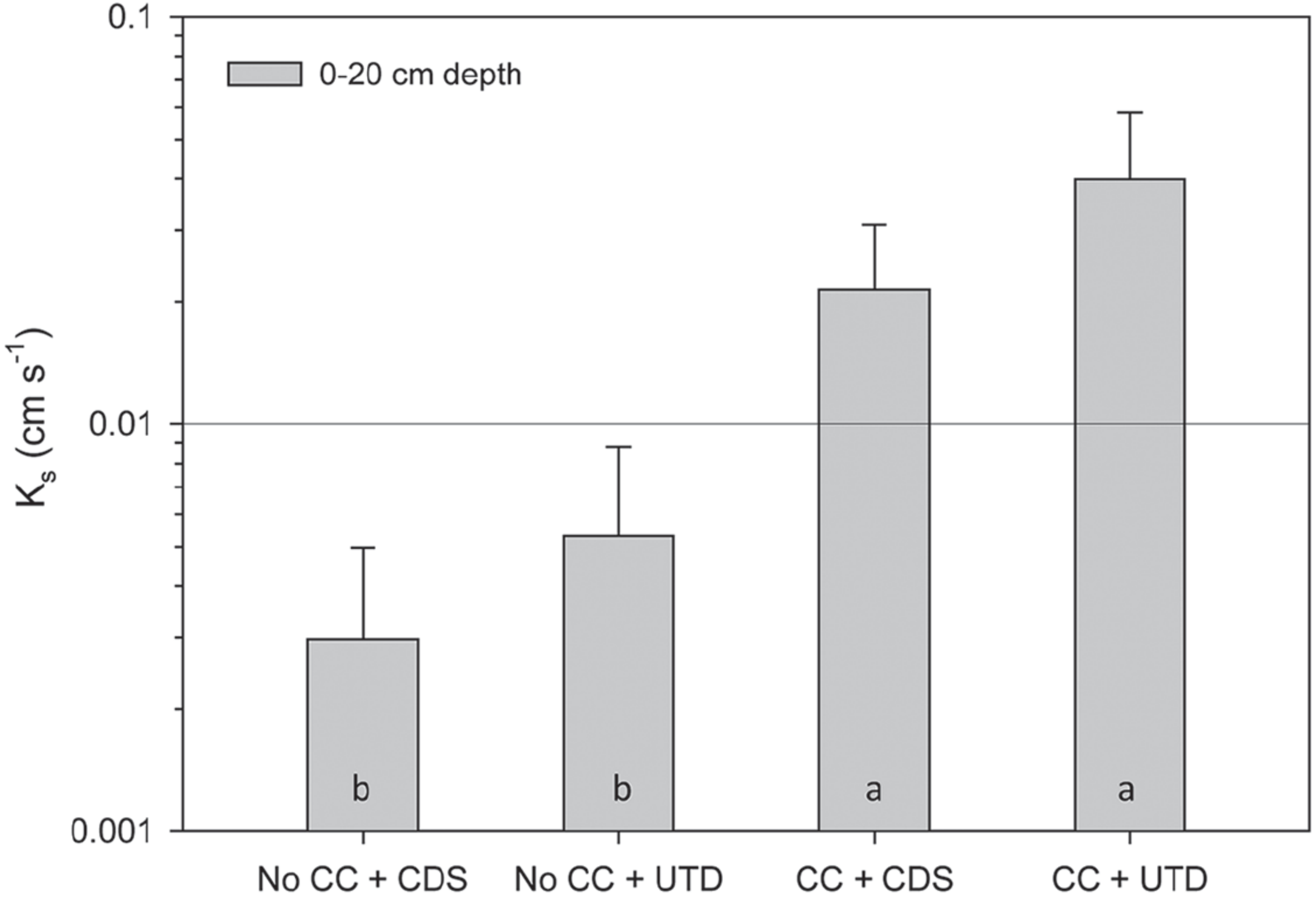
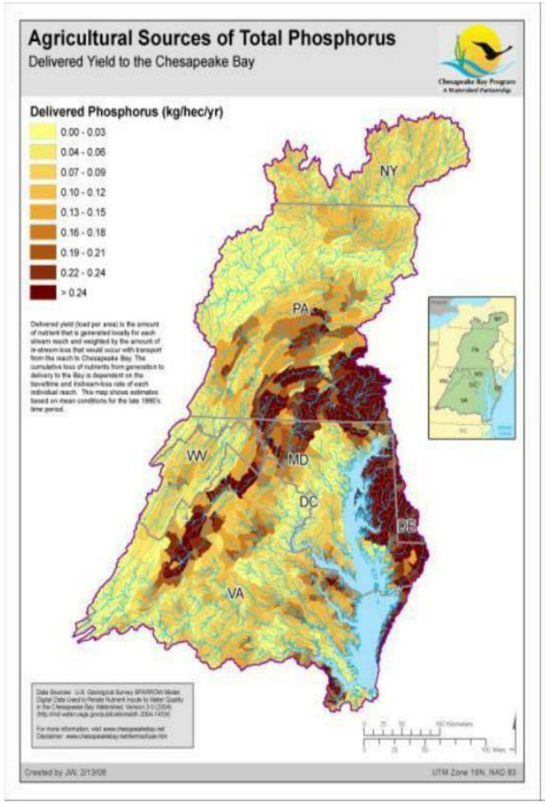


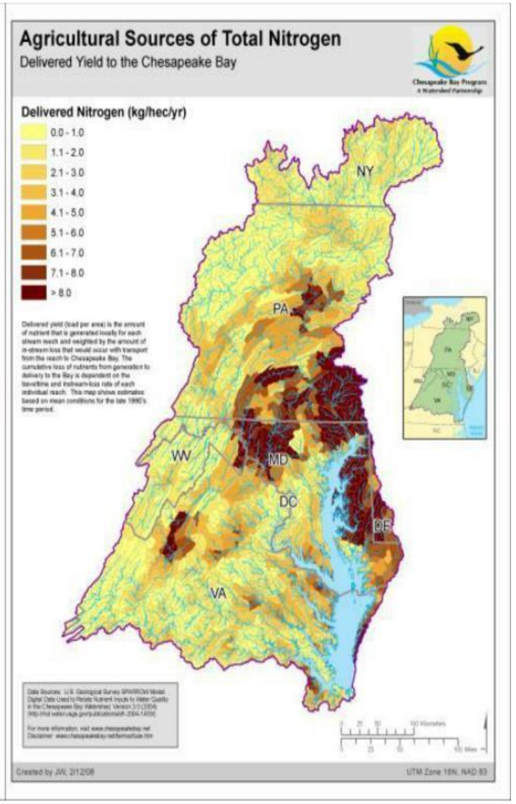
Fig. 2. Near-surface (0- to 20-cm depth) saturated soil hydraulic conductivity (K_s) for factorial combination of winter wheat cover crop (CC) versus no winter wheat cover crop (NCC) and controlled tile drainage with subsurface irrigation (CDS) versus traditional unrestricted tile drainage (UTD). Bars (means) labeled with the same lowercase letter are not significantly different according to the Tukey's HSD test ($P < 0.05$). The vertical T-bars are SE ($n = 20$).

J. Environ. Qual. 43:587–598 (2014)

C. F. Drury,* C. S. Tan, T. W. Welacky, W. D. Reynolds, T. Q. Zhang, T. O. Oloya, N. B. McLaughlin, and J. D. Gaynor



Delivered yield (load per area) is the amount of nutrient that is generated locally for each stream reach and weighted by the amount of in-stream loss that would occur with transport from the reach to Chesapeake Bay. The cumulative loss of nutrients from generation to delivery to the Bay is dependent on the traveltime and instream-loss rate of each individual reach. This map shows estimates based on mean conditions for the late 1990's time period.



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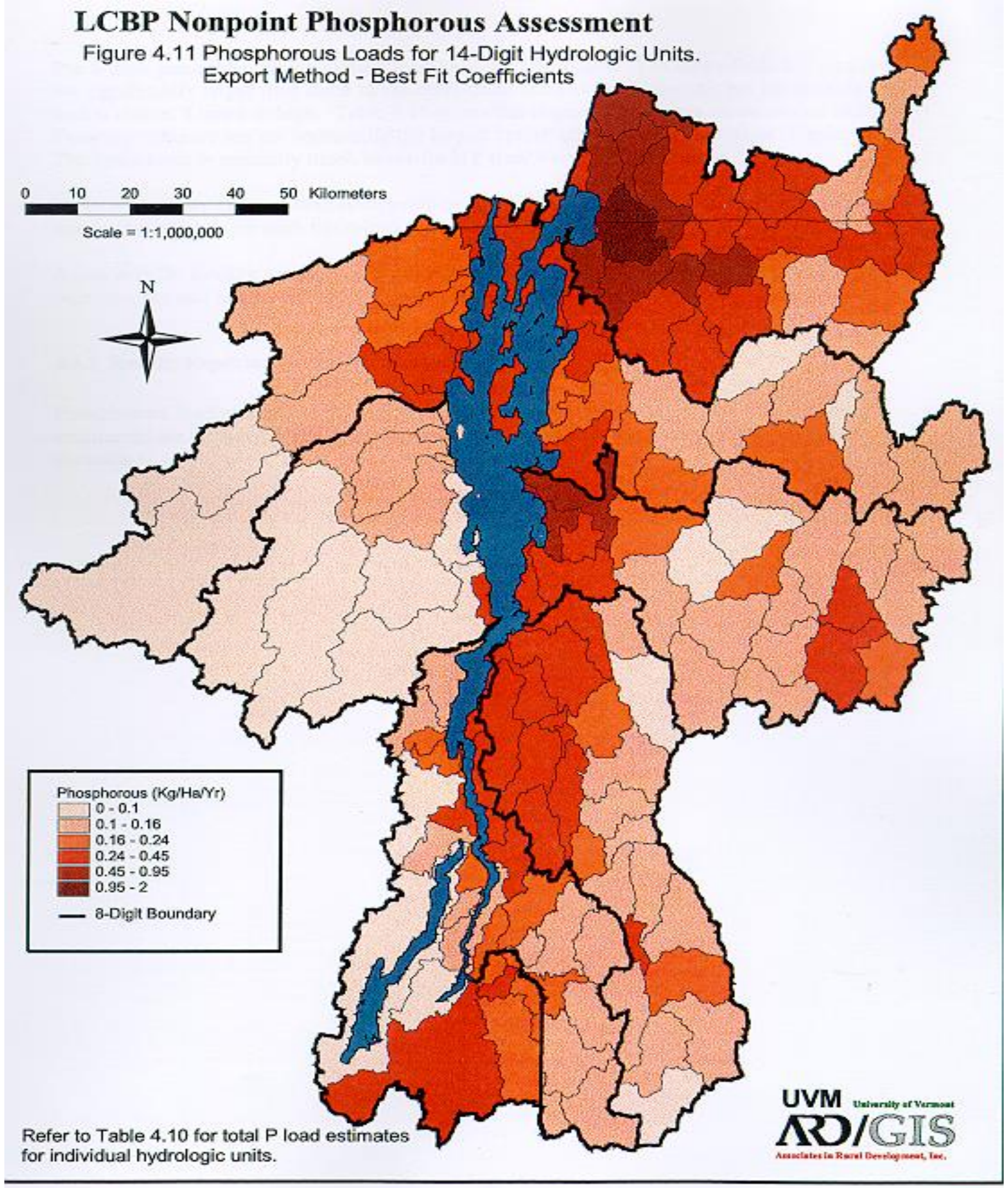


Refer to Table 4.10 for total P load estimates for individual hydrologic units.

- Inorganic Fertilizers contain nutrients, primarily phosphorous and nitrogen.
- Since many tributaries flow near actively farmed land, inorganic fertilizer runoff tends to be present in the streams and eventually the bay.
- These fertilizers, once in the waters, also favor algae growth and can cause algae blooms.
- The danger of inorganic fertilizers in the bay are magnified by the Bay’s shallow waters

Site Description

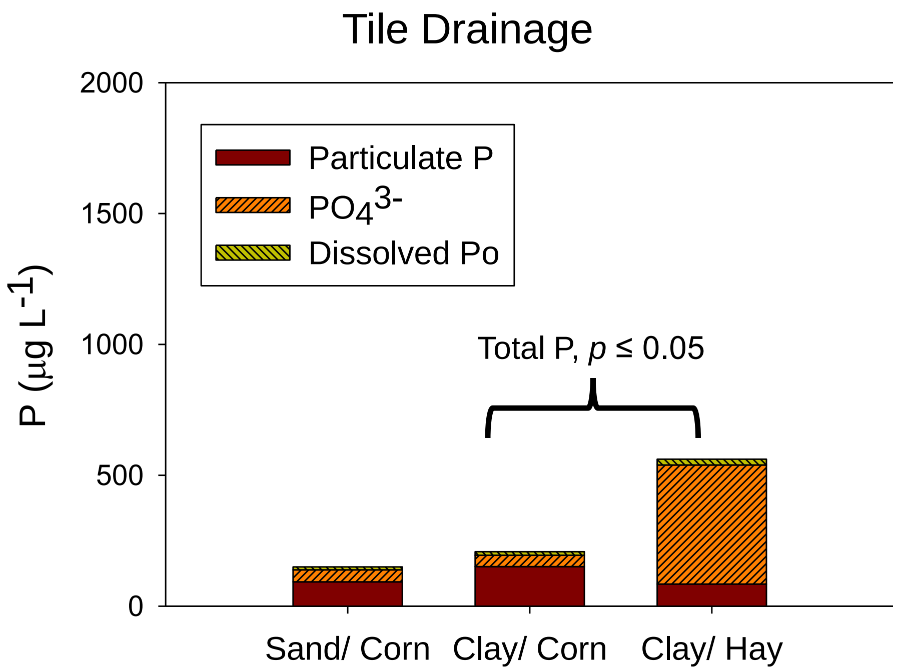
Field	Area	Soil Type
1	7 ha	Sandy Clay Loam
2	6 ha	Sandy Loam
3	2 ha	Clay Loam
4	3 ha	Sandy Clay Loam

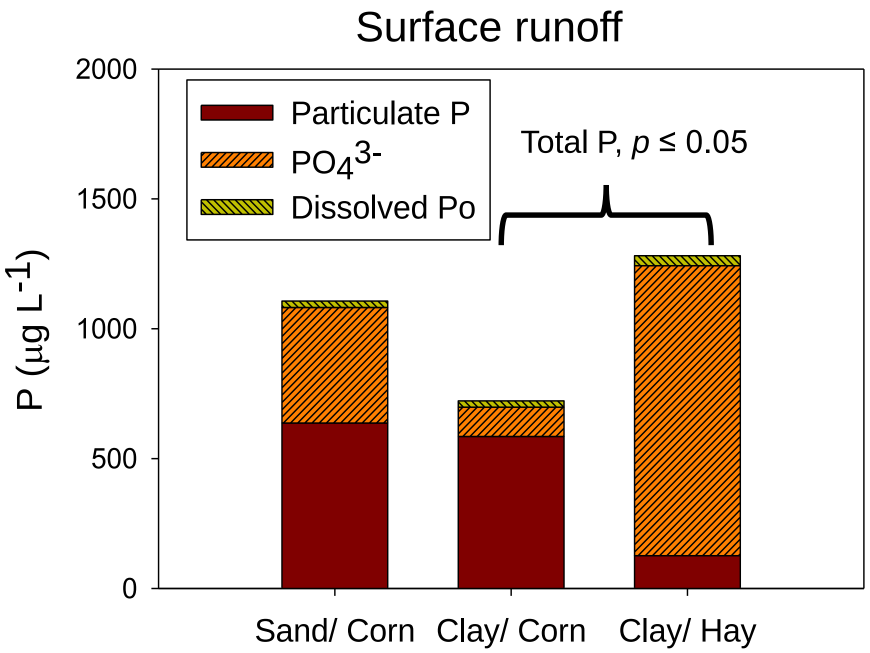
Field	Drainage	Crops
1	Surface + Tile	Corn, Soybeans
2	Surface + Tile	Alfalfa, Corn
3	Only Surface	Corn, Cereals
4	Only Surface	Hay, Pasture

Site Description

Field	Soil Test P (kg/ha)	% P sat
1	114	5.3
2	373	22.0
3	38	1.6
4	72	4.0

Hypothesis: Soil texture has an influence on the P speciation



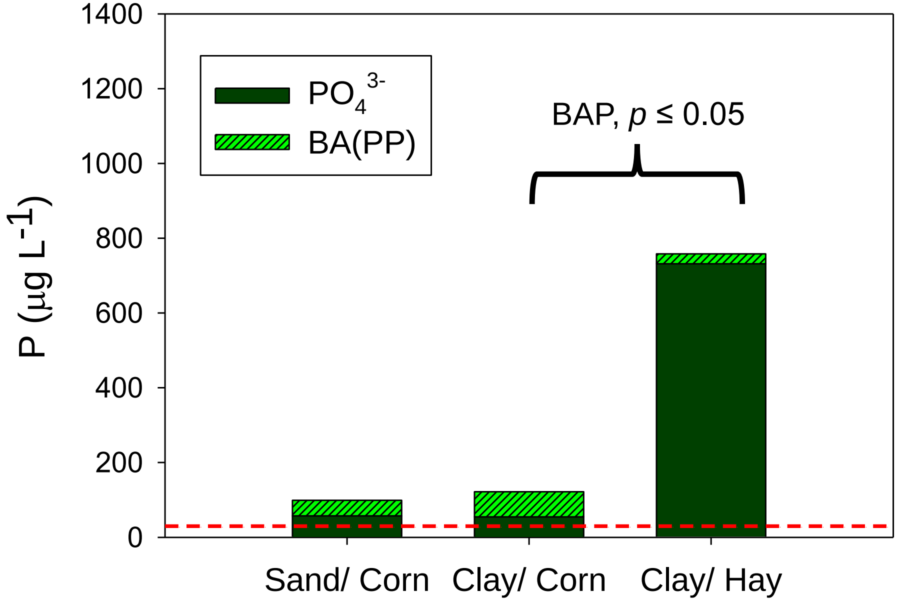


No soil texture effect.

But cultural practices effect => Effect of topsoil management

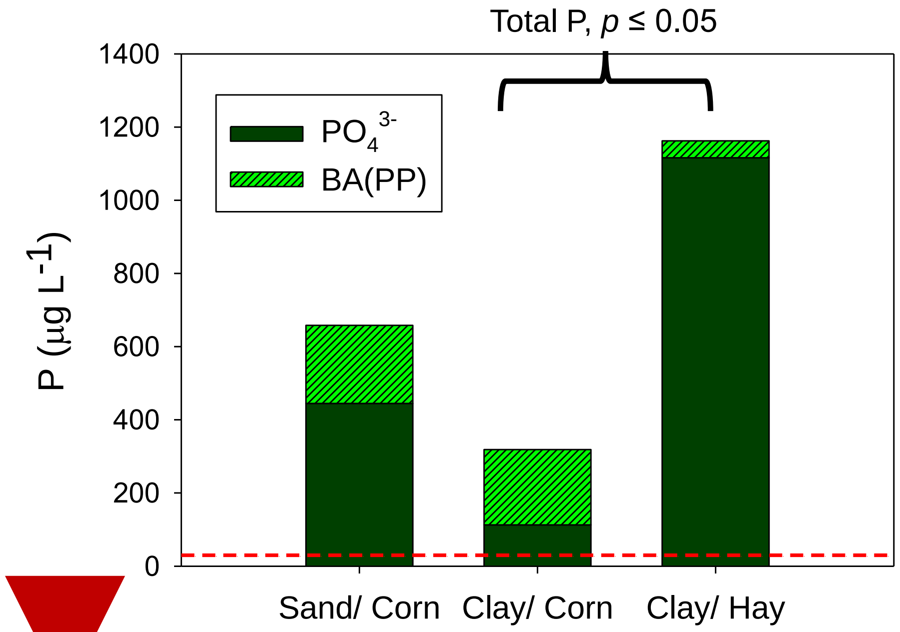
Tile Drain

n=19



Surface

n=9



Lake
Eutrophication
Threshold
(30 µg L^{-1})

Site/Year	Avgerage Subsurface TP conc. (mg/L)	Average Surface runoff TP conc. (mg/L)	Ratio SS:SRO
Site 1 – 00/01	0.060	0.312	5.2
Site 1 – 01/02	0.063	2.146	34.3
Site 1 – 02/03	0.073	0.780	10.4
Site 2 – 00/01	0.104	0.196	1.9
Site 2 – 01/02	0.365	1.681	4.6
Site 1 – 02/03	0.213	1.758	8.8
			Average = 10.8

Site/Year	*TP Load (kg/ha)*	*SS drains (% of load)*	*SS drains (% of H20)*	*Total drainage (mm)*
Site 1 – 01/02	0.81	29%	93%	398 mm
Site 1 – 02/03	0.77	34%	84%	415 mm
Site 2 – 00/01	0.27	37%	52%	184 mm
Site 2 – 01/02	1.95	63%	89%	381 mm
Site 2 – 02/03	1.79	38%	84%	352 mm
AVERAGE	**1.12**	**40%**	**80%**	

Average Annual P load

Site	Annual P loss (kg/ha)	Soil Test P (% P sat) Kg/ha
Site #1	**0.79 kg/ha**	**360 (23%)**
Site #2	**1.34 kg/ha**	**140 (7%)**

See following references for complete results:

Gombault, C., C.A. Madramootoo, A.R. Michaud, I. Beaudin, M.F. Sottile, M. Chikhaoui, F.F. Ngwa. 2015. Impacts of climate change on nutrient losses from the Pike River watershed of southern Québec. Canadian Journal of Soil Science, 95(4):337-358.

Gombault, C., M-F. Sottile, F.F Ngwa, C.A. Madramootoo, A.R Michaud, I. Beaudin and M. Chikhaoui, 2014. Modelling climate change impacts on the hydrology of an agricultural watershed in southern Québec. Canadian Water Resources Journal. Doi.org/10.1080/07011784.2014.985509.

Eastman, M., A. Gollamudi, N. Stampfli, C.A. Madramootoo and A. Sarangi. 2010. Comparative evaluation of phosphorus losses from subsurface and naturally drained agricultural fields in the Pike River watershed of Quebec, Canada. Agricultural Water Management, 97(5):596-604.

Gollamudi, A., C.A. Madramootoo and P. Enright. 2007. Water quality modeling of two agricultural fields in Southern Quebec using SWAT. Transactions of the American Society of Agricultural and Biological Engineers, 50(6): 1973-1980.

Michaud, A.R., Beaudin, I., Deslandes, J., Bonn, F. and C.A. Madramootoo. 2007. SWAT-predicted influence of different landscape and cropping system alterations on phosphorus mobility within the Pike River watershed of south-western Quebec. Can. J. Soil Sci. 87:329-344.

Deslandes, J., I. Beaudin, A. Michaud, F. Bonn and C. A. Madramootoo. 2007. Influence of Landscape and Cropping System on Phosphorus Mobility within the Pike River Watershed of Southwestern Quebec: Model Parametrization and Validation. Canadian Water Resources Journal, 32(1):21-42.

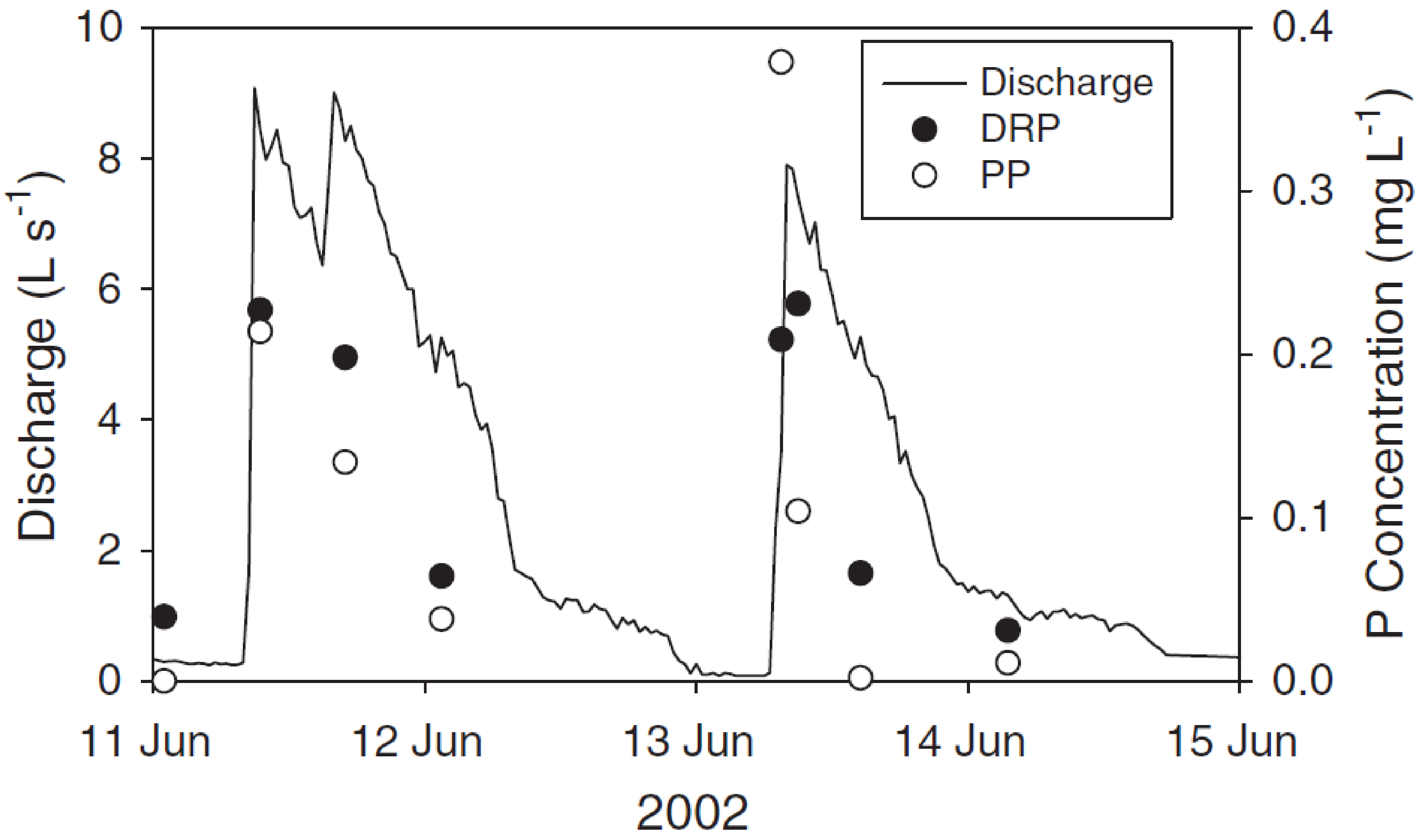
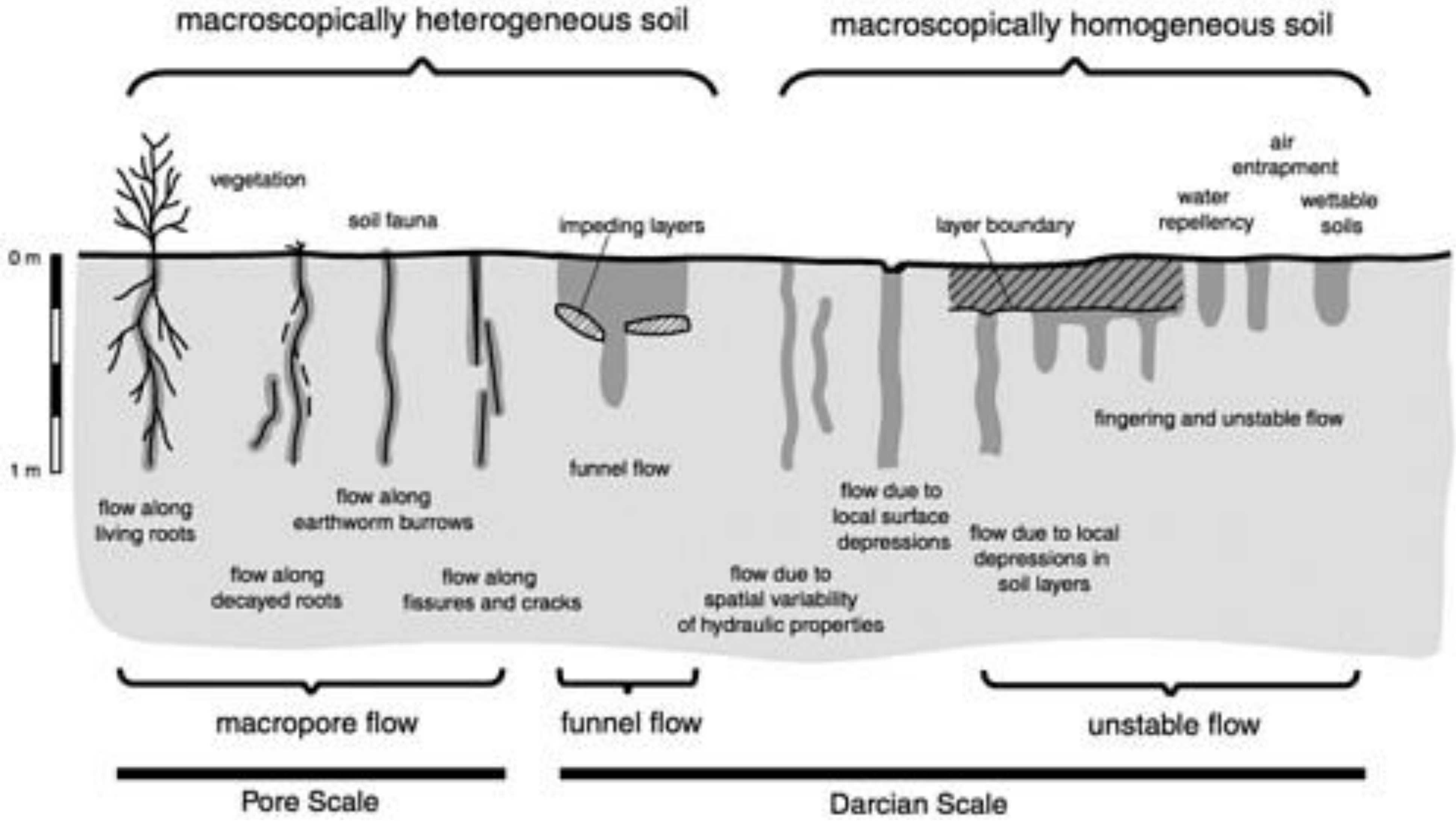
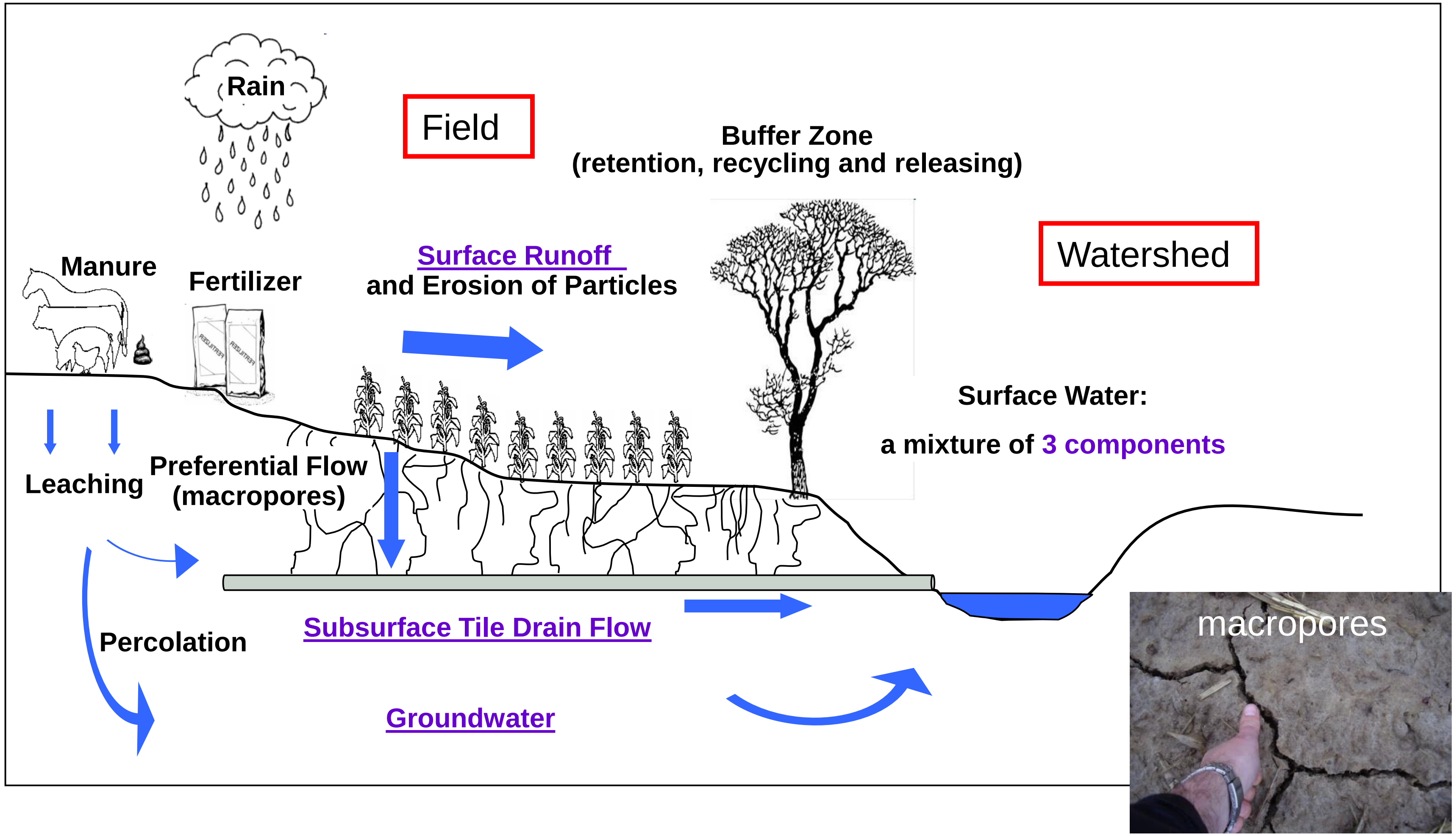


Fig. 7. Discharge, particulate phosphorus (PP), and dissolved reactive phosphorus (DRP) concentration from an agricultural tile drain in the Big Ditch watershed showing two successive rain events during June 2002.

L. E. Gentry,* M. B. David, T. V. Royer, C. A. Mitchell, and K. M. Starks J. Environ. Qual. 36:408–415 (2007).

Hydraulic and Chemical Pathways in the soil Matrix





Rain

Field

Buffer Zone
(retention, recycling and releasing)

Manure

Fertilizer

Surface Runoff
and Erosion of Particles

Watershed

Surface Water:

a mixture of 3 components

Leaching

Preferential Flow
(macropores)

Percolation

Subsurface Tile Drain Flow

Groundwater

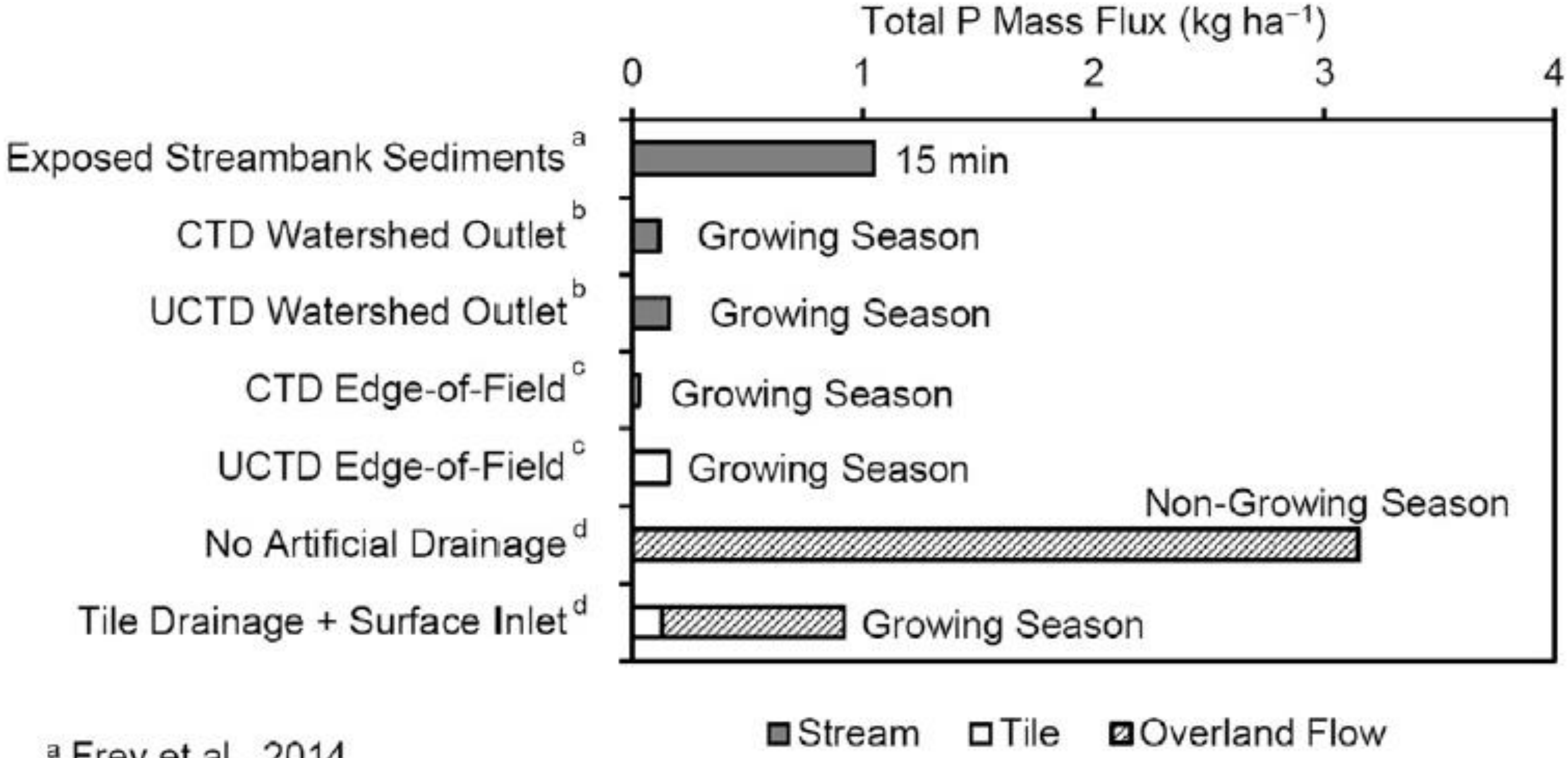
macropores

How the transport pathway influences the bioavailable P?

Is there some methods to differentiate surface from subsurface contribution at the watershed outlet?

Mark D. Sunohara[a], Natalie Gottschall[a], Emilia Craiovan[a], Graham Wilkes[a], Edward Topp[b], Steven K. Frey[a,c], David R. Lapen[a,*]

Agricultural Water Management 178 (2016) 159–170

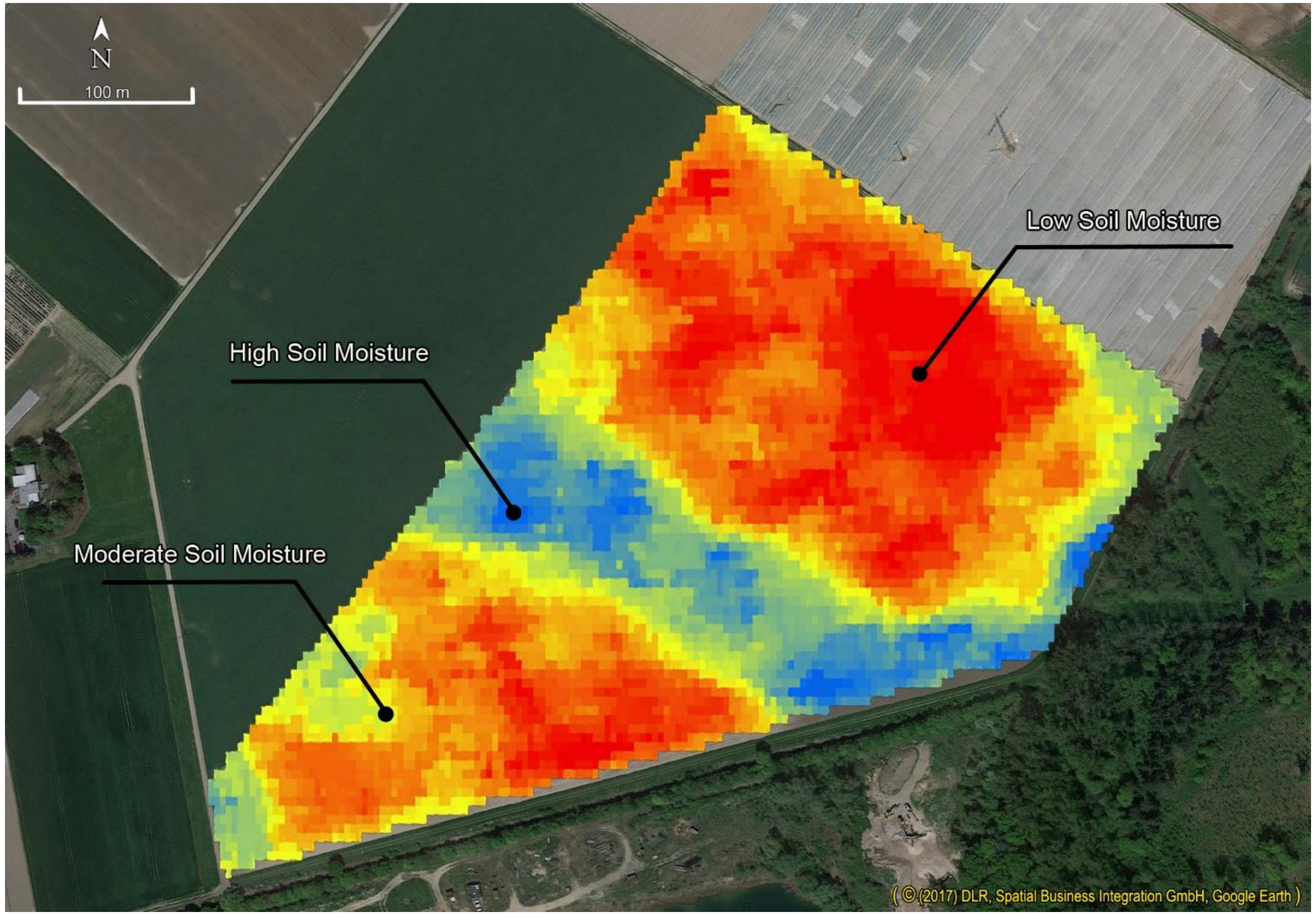


[a] Frey et al., 2014
[b] Sunohara et al., 2015
[c] Sunohara et al., 2014; current article
[d] Ball Coelho et al., 2012

What are the Challenges?

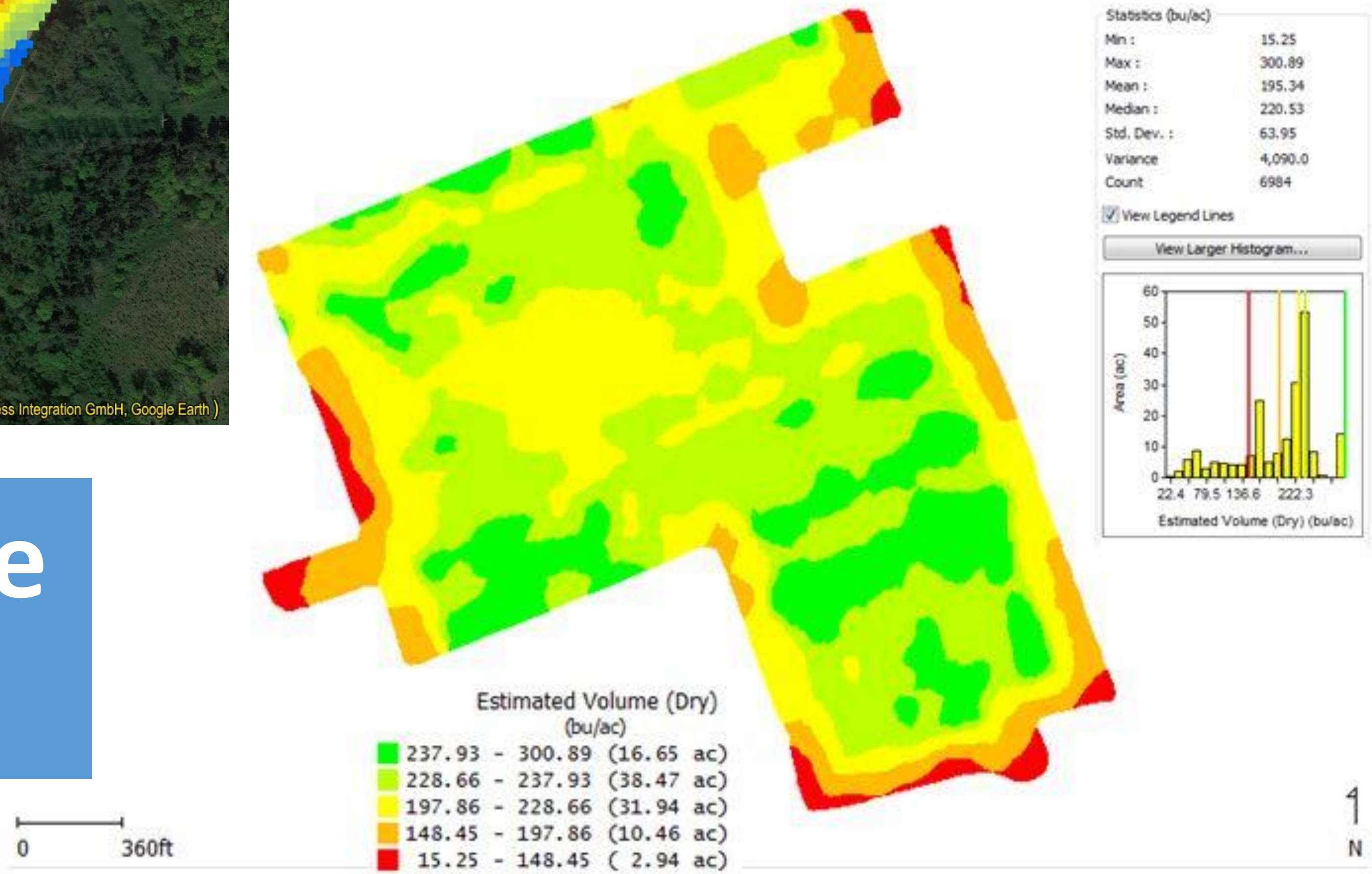
1. How to take soil variability into account, both chemical properties?
2. Can field results be extrapolated to the watershed scale?
3. How to incorporate drainage into soil health indicators?

Moisture, soils and crop yield variability



(© (2017) DLR, Spatial Business Integration GmbH, Google Earth)

Site specific drainage management?



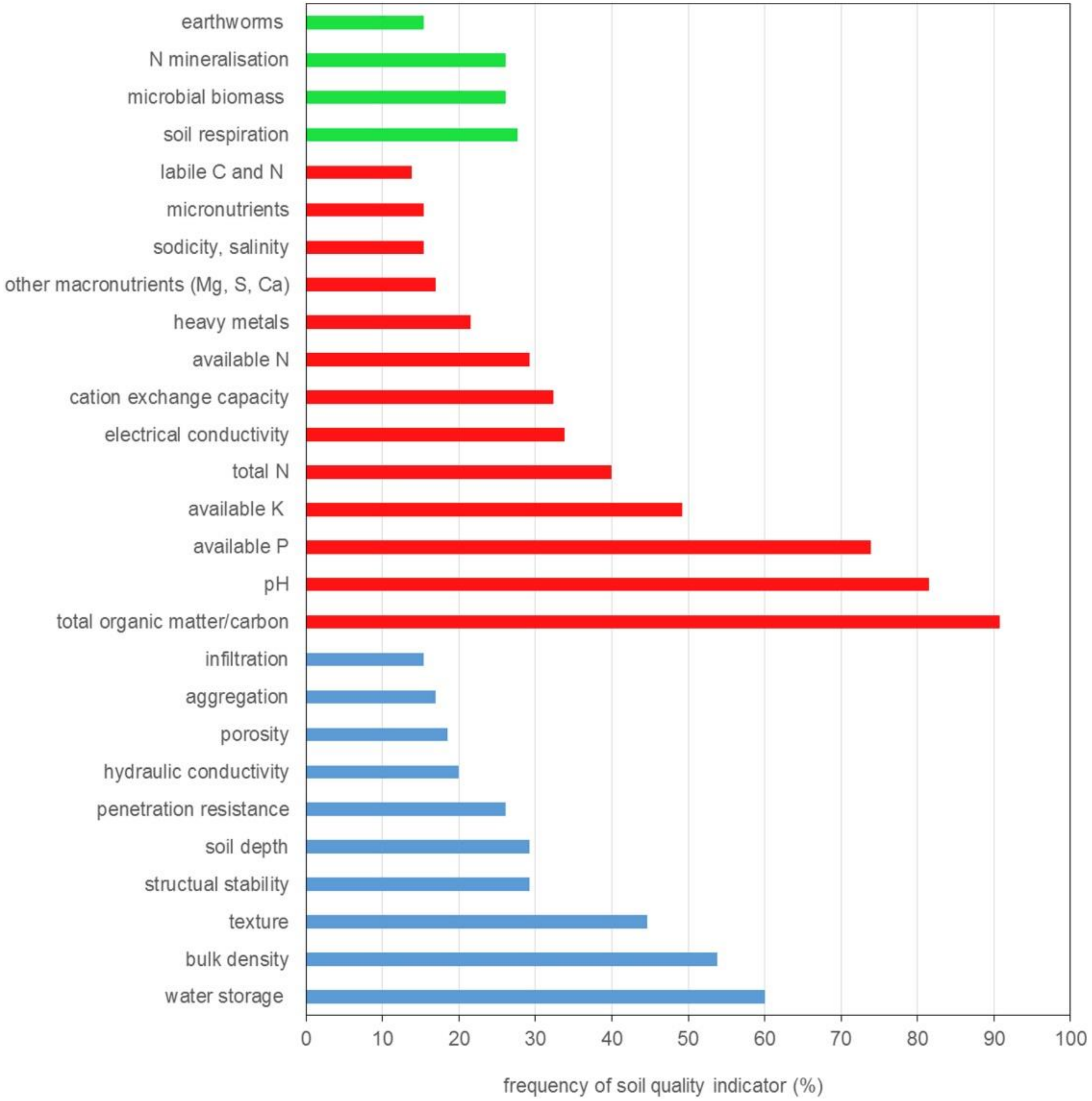
Statistics (bu/ac)

Min :	15.25
Max :	300.89
Mean :	195.34
Median :	220.53
Std. Dev. :	63.95
Variance	4,090.0
Count	6984

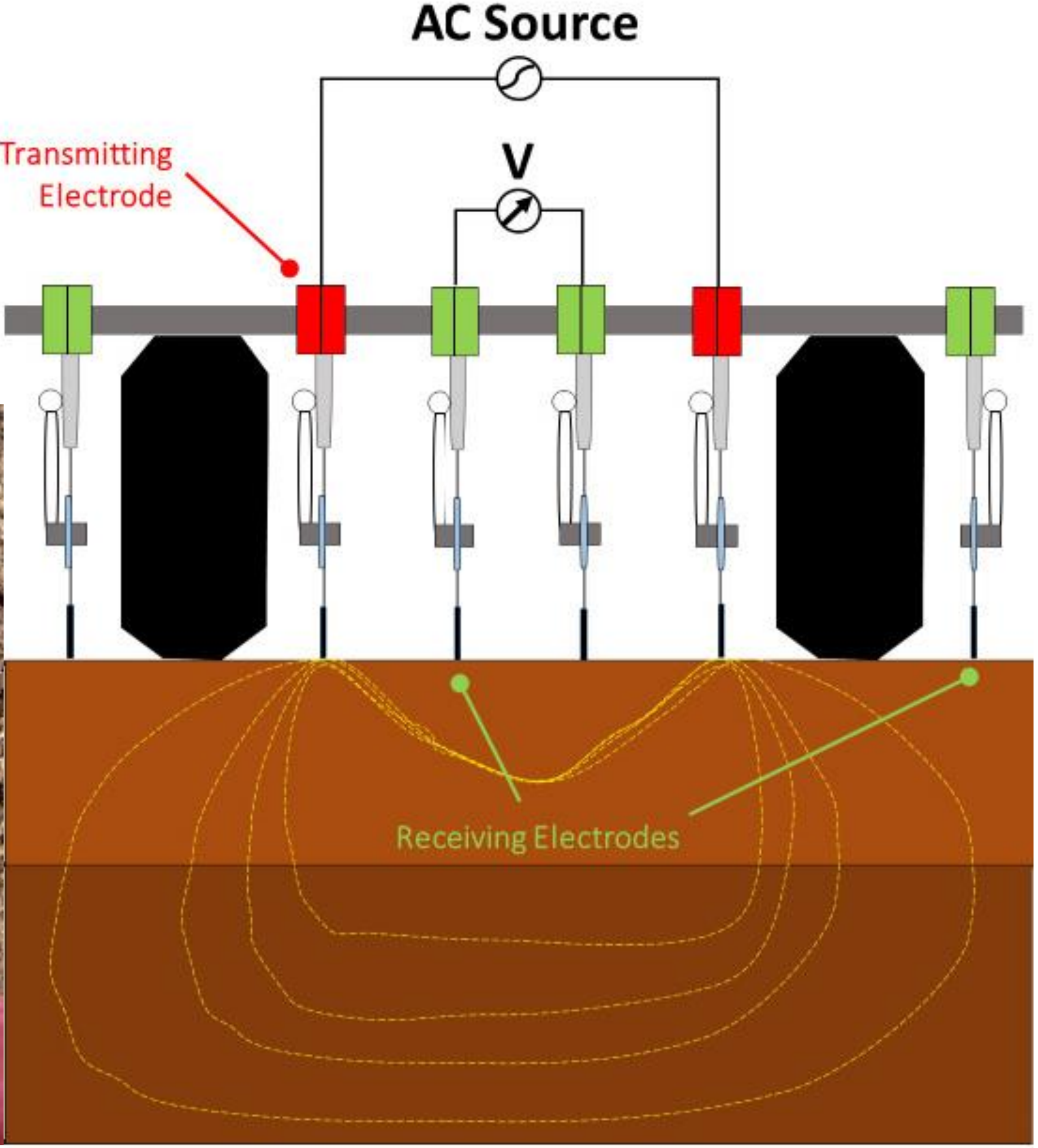
☑ View Legend Lines

Estimated Volume (Dry)
(bu/ac)

🟩	237.93 - 300.89 (16.65 ac)
🟩	228.66 - 237.93 (38.47 ac)
🟨	197.86 - 228.66 (31.94 ac)
🟧	148.45 - 197.86 (10.46 ac)
🟥	15.25 - 148.45 (2.94 ac)



Soil Health Indicators


AC Source
V
Transmitting Electrode
Receiving Electrodes

Thank You!